OCS Study
BOEMRE 2010-052

Long-Term Monitoring at the East and West Flower Garden Banks, 2004-2008

Volume I: Technical Report

U.S. Department of the Interior
Bureau of Ocean Energy Management, Regulation and Enforcement
Gulf of Mexico OCS Region

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Prepared under BOEMRE Contract
1435-01-04-CT-33137 (M04PC00033)
by
PBS&J
2001 NW 107th Avenue
Miami, Florida 33172

Published by

U.S. Department of the Interior
Bureau of Ocean Energy Management, Regulation and Enforcement
Gulf of Mexico OCS Region

New Orleans
December 2010

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CITATION

Suggested citation:

Zimmer, B., L. Duncan, R.B. Aronson, K.J.P. Deslarzes, D. Deis, M.L. Robbart, W.F. Precht, L. Kaufman, B. Shank, E. Weil, J. Field, D.J. Evans, and L. Whaylen. 2010. Long-term monitoring at the East and West Flower Garden Banks, 2004-2008. Volume I: Technical report. U.S. Dept. of the Interior, Bureau of Ocean Energy Management, Regulation, and Enforcement, Gulf of Mexico OCS Region, New Orleans, Louisiana. OCS Study BOEMRE 2010-052. 310 pp.

ABOUT THE COVER

Montage of photographs from the Flower Garden Banks National Marine Sanctuary created by Beth Zimmer, PBS&J. Photographs by Walt Stearns.

ACKNOWLEDGMENTS

We thank the many individuals, listed below, who contributed their time and expertise to make this long-term monitoring effort successful. We are grateful to BOEMRE and NOAA for their invaluable institutional knowledge. In particular we acknowledge James Sinclair, the BOEMRE Contracting Officer's Technical Representative, for his ongoing support and enthusiasm.

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TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

Page

EXECUTIVE SUMMARY

The Flower Garden Banks are remotely located topographic features on the continental shelf in the Gulf of Mexico that are capped with a diverse assemblage of reef-building corals. These reefs are afforded a certain measure of natural protection due to their geographic distance from land. Problems that affect coral reefs throughout the region, including land-based sources of pollution, overfishing, and coral disease have, to date, not had a measurable effect at the Flower Garden Banks. In addition to their relative isolation, the depth of these reefs, 18-48 m (59-157 ft), has protected the corals from most of the severe bleaching events that have had devastating effects on most western Atlantic reefs over the past two decades. Although coral bleaching events and disease outbreaks have been identified at the Flower Garden Banks, the incidence and prevalence have been low compared to other sites within the western Atlantic reef-building province.

The results of the 2004-2008 monitoring efforts, conducted in September and November 2004 (East Flower Garden Bank and West Flower Garden Bank, respectively), June 2005, June 2006, June 2007, August and September 2007 (East Flower Garden Bank and West Flower Garden Bank, respectively), and November 2008 demonstrated the continued stability of the coral reef community and its associated fish populations. Random transect results revealed high coral cover at both Banks from 2004-2008, with coral cover ranging from 49.55 ± 3.01% to 64.13 ± 2.70% at the East Flower Garden Bank and from 54.41 ± 3.13% to 60.41 ± 2.94% at the West Flower Garden Bank. These results are consistent with previous monitoring efforts (Dokken et al. 2001; Dokken et al. 1999; CSA 1996; Gittings et al. 1992; Aronson et al. 2005), highlighting the stability of the coral assemblage over time. The *Montastraea annularis* species complex was the predominant component of coral cover at both Banks from 2004-2008. Cover at the East Flower Garden Bank ranged from 26.80 ± 4.09% to 33.58 ± 4.52%. At the West Flower Garden Bank cover ranged from 31.70 ± 2.70% to 40.13 ± 3.29%. *Diploria strigosa* was the next most abundant species from 2004-2008, ranging at the East Flower Garden Bank from 5.82 ± 1.11% to 12.13 ± 2.82%. The West Flower Garden Bank estimates ranged from 6.68 ± 1.29% to 13.41 ± 1.74%.

From 2004-2008, macroalgae were typically less abundant than crustose coralline algae, fine turf algae, and bare rock (CTB), ranging from ~12-34%. The most abundant macroalgal taxa in terms of substratum cover were *Dictyota* spp. and *Lobophora variegata*. Overall, macroalgal cover was higher at the East Flower Garden Bank than the West Flower Garden Bank from 2004-2008. A two-way ANOVA revealed significant effects of Bank and Year, and a significant Bank x Year interaction. The data for the East Flower Garden Bank showed a significant effect of year ($F=10.59$, $df=4,72$, $P<0.001$) and Tukey–Kramer *a posteriori* comparisons showed that macroalgal cover was significantly higher at the East Flower Garden Bank in 2005 than in all other years. The data for the West Flower Garden Bank showed a significant effect of year ($F=2.99$, $df=4,75$, $P<0.024$) and Tukey–Kramer *a posteriori* comparisons did not reveal any significant difference between pairs of years, but again 2005 stood out as the year of highest macroalgal cover.

In general, CTB was the most abundant non-coral category of substratum cover, ranging from ~12-27% from 2004-2008. The exception was the East Flower Garden Bank in June 2005 (macroalgal value of 34% and CTB value of 12%) and November 2008 (macroalgal value of 24% and CTB value of 18%), when macroalgae values were higher than CTB. Overall, CTB cover was higher at the West Flower Garden Bank than the East Flower Garden Bank from 2004-2008, the inverse of the pattern for macroalgal cover. A two-way ANOVA showed significant effects of Bank and Year, whereas the Bank x Year interaction was not significant. Tukey–Kramer *a posteriori* comparisons showed that CTB cover was significantly lower in 2005 than in any other year, and that the other years were not significantly different from each other.

The Shannon-Wiener diversity index, H', was calculated from the species-specific coral cover data from each transect from 2004-2008. The three species of the *Montastraea annularis* species complex were combined for the calculation. Mean H' ranged from a low of 0.916 ± 0.076 SE at the West Flower Garden Bank in 2006 to a high of 1.245 ± 0.103 SE at the East Flower Garden Bank in 2004. A two-way ANOVA showed no significant effects of Bank or Year, and the Bank x Year interaction was also not significant. The low values of H' overall reflect the strong dominance of the coral assemblage by the *M. annularis* species complex.

Sclerochronology was used to measure the accretionary growth rates of *Montastraea faveolata*. Cores collected at both Banks in 2005 and 2007 revealed annual growth bands spanning 1992-2005 and 2000-2007, respectively. In the 2005 cores, estimated annual growth ranged from 2.24 mm to 14.54 mm between Banks. These results differed slightly from the growth rates reported by Precht et al. (2006) but agreed with past work by Dokken et al. (2003), who reported a wider range of growth rates at the East and West Flower Garden Banks. Interestingly, a disruption in accretion was seen in three quarters of the 2005 samples from both Banks. In all cases, the colonies had subsequently recovered. In the 2007 cores, estimated annual growth ranged from 4.9 mm to 8.8 mm between Banks. When compared to the past two coring events (2003 and 2005), the 2007 core data did not appear substantially different with respect to mean growth rates. However, the range of annual growth from the 2007 samples does not show the same magnitude as the 2003 and 2005 samples. In addition, a reduction in mean annual coral growth rates was observed in the 2007 cores at both the East and West Flower Garden Banks, which was likely related to the large-scale bleaching event that occurred in the late summer and fall of 2005.

Lateral growth stations were monitored from 2003-2007 to measure changes in *Diploria strigosa* colonies. *Diploria strigosa* is important at the Flower Garden Banks because it is the second largest contributor to coral cover. Although growth showed some significant variations and interactions, net growth was positive over the period 2003-2007.

Repetitive quadrats were photographed from 2004-2008 to monitor changes in coral reef community structure over time. The repetitive quadrat data showed that coral cover was consistently high during the period 2004-2008, ~64% for both banks in all years. Macroalgae and CTB cover showed reciprocal patterns and the incidences of bleaching, paling, and fish biting were low (ranging from 0.00-4.73% of coral points assessed), with the exception of November 2005 (Precht et al. 2008a). In November 2005, Precht et al. (2008a) conducted a post-hurricane assessment and reported that approximately 10% of coral points assessed in repetitive quadrat stations at the East Flower Garden Bank were bleached. This was the highest level of bleaching reported for the Flower Garden Banks since the bleaching event of 1990, when coral bleaching levels of ~5% were reported at the East Flower Garden Bank (Precht et al.

2008a). There was no evidence of coral disease in any of the repetitive quadrats analyzed from 2004-2008. 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*. Colonies of *M. annularis* species complex in repetitive quadrats (planimetry) showed overall positive growth from 2003-2008.

Deep repetitive quadrats (32-40 m or 105-131 ft) were established on the East Flower Garden Bank in April 2003 (Precht et al. 2005) and photographed in September 2004, June 2005, June 2006, August 2007, and November 2008. Coral cover was high, averaging ~77% between 2004 and 2008. The *Montastraea annularis* species complex and *M. cavernosa* were the dominant species in these 8-m^2 quadrats. CTB averaged ~12% at the deep stations from 2004 to 2008, while macroalgae averaged ~9% during the same time period.

During the August 2007 cruise, in addition to the film photography, subsamples of the lateral growth and repetitive quadrat stations were re-photographed at both Banks using digital camera setups. This data collection served as a pilot effort to evaluate the possibility of switching from film to digital photography for the lateral growth and repetitive quadrat components of the monitoring effort. Statistical comparisons between film and digital photographs taken at lateral growth stations demonstrated that the methodology used for digital photography needed to be further refined before meaningful comparisons could be made between digital and film photographs. Statistical comparisons between film and digital photographs at repetitive quadrat stations yielded no significant difference. Thus, it was concluded that digital repetitive quadrat photographs could be directly compared to film repetitive quadrat photographs of the same repetitive quadrat station from the previous year, and that switching to digital photography was feasible.

The review of the 2004-2008 perimeter videos suggests that, in general, the coral condition and fish population levels along the perimeter lines at the East and West Flower Garden Bank study sites were comparable to those observed in past perimeter videos. The coral communities displayed low levels of stress and high coral cover. Most distressed corals were affected by fish biting and there were few incidences of paling and bleaching, with the exception of November 2005 (Precht et al. 2008a). Precht et al. (2008a) reported that most distressed corals were affected by bleaching (6.4%), with slightly fewer incidences of fish biting (1.2%) along perimeter lines at the East Flower Garden Bank in November 2005. The low levels of paling and bleaching observed at the Flower Garden Banks from 2004-2008 were comparable to random transect and repetitive quadrat data, although no statistical comparisons were made. Furthermore, no evidence of coral disease was observed in the perimeter video.

Coral disease was not observed during the long-term monitoring tasks at either Bank from 2004 through 2008. However, the Flower Garden Banks National Marine Sanctuary reported winter, white plague-like disease symptoms at the Flower Garden Banks for four consecutive years from 2005-2008.

On September 23, 2005 Hurricane Rita (Category 3, Saffir-Simpson Index) passed ~93 km (58 mi) from the East Flower Garden Bank on its route north to the mainland United States. At approximately 5 p.m. on September 12, 2008, Hurricane Ike (Category 3, Saffir-Simpson Index) passed directly over the EFGB, with the storm track ~0.7 km (0.4 mi) from mooring buoy number 2 at the EFGB study site. To monitor changes in coral reef community structure due to the passage of Hurricanes Rita and Ike, repetitive 8-m^2 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. 2008a). An estimated total area of ~2.3 m^2 of coral was missing from the study-site repetitive quadrat stations between June 2007 and November 2008 at the East and West Flower Garden Banks, 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 East Flower Garden Bank. *Diploria strigosa* was the only coral species missing from repetitive quadrat stations at both Banks. Of the 41 missing colonies, 39% were *D. strigosa.* Despite depths of 32 m (105 ft) to 40 m (131 ft), three coral colonies were removed from the East Flower Garden Bank deep stations, totaling 0.10 m^2 of coral cover loss. Hurricane impacts (i.e., one dislodged colony of *Diploria strigosa*) were only observed in perimeter video at the East Flower Garden Bank. No obvious hurricane impacts were observed along perimeter lines at the West Flower Garden Bank. 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 shifting corner locations and line placement and 2) the 2008 perimeter video was recorded at an angle of 90º to the substrate (rather than at 45º as in previous surveys), providing a smaller area of view and fewer coral colonies for comparison.

Qualitative coral health assessments were conducted at the FGB from 2004-2008. In addition, dedicated quantitative coral health surveys were conducted during the June 2007 cruise to assess the presence, types, and prevalence of coral diseases and other coral health issues at the East and West Flower Garden Banks. The vast majority of colonies surveyed were healthy. The prevalence of all coral health issues (including predation, bleaching, ciliate infections, growth anomalies, and other miscellaneous health issues) was higher at the West Flower Garden Bank (9.96%) than at the East Flower Garden Bank (3.20%). The overall prevalence of all coral health issues at the community-wide level (East and West Flower Garden Banks combined) was 6.78%. When predation and bleaching are excluded, the prevalence of “disease” (ciliate infections, growth anomalies, and other coral maladies) at the community-wide level was 1.72%.

In addition to the annual data collection protocol, notable biological and oceanographic events, such as sponge spawning, *Acropora* discoveries, coral disease, and exotic/invasive species were qualitatively assessed and documented. Coral biodiversity and taxonomy at the Flower Garden Banks were also evaluated.

Water quality parameters, including photosynthetically active radiation (PAR), turbidity, temperature, salinity, pH, and dissolved oxygen were recorded at the East and West Flower Garden Banks using YSI datasondes from 2004-2008. HoboTemp thermographs were attached to each of the YSI instruments as backup records of water temperature. Chlorophyll *a* and nutrients were recorded using water samples. Despite increased YSI datasonde change-outs (quarterly basis), numerous problems continued to occur with YSI datasondes and probes failing, creating uncertainty in the quality of data. Substantial amounts of YSI data could not be used from 2004-2008, only temperature, salinity, and pH could be reported with sufficient confidence. In an effort to improve the accuracy of the water quality data, two SBE 37-SMP MicroCATs (high-accuracy conductivity and temperature recorders designed for long-term oceanographic deployment) were deployed at the East and West Flower Garden Banks in February 2008.

Fish surveys were conducted using the Bohnsack and Bannerot (1986) method from 2004-2007. Fish surveys showed robust fish assemblages that were dominated by herbivorous fish and included healthy piscivore populations. From 2004 to 2007, the Pomacentridae, Labridae, and Serranidae were the dominant fish taxa at the Flower Garden Banks. Herbivores were the dominant fish guild, with Pomacentridae (damselfish) and Labridae: Scarinae (parrotfish) representing the largest portion of these. The size-frequency distributions of herbivores at the Flower Garden Banks were normally distributed with the majority of individuals in the medium-sized category and few individuals in the small and large size categories. These bell-shaped curves suggest that herbivore populations are healthy. Piscivorous fish were represented by fewer families than herbivores and most of these individuals were in the Serranidae and Lutjanidae families. The size-frequency distributions of piscivores at the Flower Garden Banks were generally non-normal. Interannual comparisons of fish statistics indicated generally stable assemblages; however, diversity and evenness values did fluctuate among years from 2004-2007. Following the pattern of coral species present at the Flower Garden Banks (low diversity compared to Caribbean reefs, but high coral cover), the fish assemblages appear to be following a similar trend of low diversity and high abundance (Pattengill-Semmens and Gittings 2003).

Sea urchin surveys documented low densities of *Diadema antillarum* at both Banks from 2004-2008, except at the West Flower Garden Bank in 2004 (0.11 individuals/m^2), 2007 (0.068 individuals/m^2), and 2008 (0.075 individuals/m^2). These populations still have not recovered to pre-1984 levels, which ranged from 0.54-1.63 individuals/m^2 between 1970 and 1983 (Bright and Pequegnat 1974; CSA 1984). Two *Panulirus argus* (spiny lobster) were recorded along transects at the West Flower Garden Bank in 2004 and one at the East Flower Garden Bank in 2005. *Panulirus guttatus* and *Scyllarides aequinoctialis* were also observed in low numbers.

The Flower Garden Banks support healthy coral and fish assemblages compared to reefs elsewhere in the region. Continued monitoring will document their long-term condition and will be useful for studies focused on the dynamics of the robust benthic communities and fish populations they support.

1.0 INTRODUCTION

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

The biotic assemblages of the Flower Garden Banks (FGB) 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). Although coral species richness is lower at the FGB than on Caribbean reefs, 31 species of scleractinian corals have been documented at the FGB (Schmahl et al. 2008). No significant long-term changes have been detected in coral cover or diversity at the FGB from 1988 to 2008. In more than 20 years of continuous monitoring, the coral reefs of the FGB have maintained high levels of coral cover, suffered minimally from hurricanes, coral bleaching and disease outbreaks, and supported diverse and abundant fish populations as well as other vertebrate and invertebrate species. While the rest of the Caribbean has experienced declines in scleractinian coral cover and subsequent increases in macroalgal cover, the FGB remains a stable coral reef system in the western Gulf of Mexico. These reefs, therefore, represent a natural laboratory for understanding the causes of stability and change in reef systems. The importance of the FGB, in terms of the entire Atlantic coral reef system as a whole, has been substantially elevated by the regional decline of corals. Consequently, the risk of loss (or estimated loss value) is elevated for the FGB in the event of a severe industrial accident or expansion of the zone of influence of the Mississippi River.

Gittings et al. (1992) established one, 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 metrics 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 ~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, discharged mud and drill cuttings from oil and gas operations, seismic activity due to oil and gas exploration, and platform accidents to be the greatest localized threats to these reefs.

No long-term changes in coral community structure using similar parameters 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. Coral bleaching was documented in 1990, 1992, 1994, and 1995, coinciding with water 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 ~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 predominant functional group of algae, whereas macroalgae accounted for less than 10% cover (Pattengill-Semmens and Gittings 2003).

Continued monitoring of the study sites in 2002-2003 by Precht et al. (2006) highlighted the long-term stability of the coral reef communities. Coral cover was ~50% at both Banks during those years, and neither significant bleaching nor disease was detected. The relative dominance of coral species also remained consistent with past findings. *Diploria strigosa* margins grew overall from 2001-2002, whereas a low sample size for 2002-2003 (due to replacement of monitoring stations in 2003) prevented firm conclusions from being drawn. 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 where conclusions could not be made, particularly regarding turbidity and PAR. Fish populations continued to be robust; however, *Diadema antillarum* and *Panulirus argus* abundance remained low.

1.2. Flower Garden Banks National Marine Sanctuary in the Gulf of Mexico

1.2.1. Habitat Description

The FGB is located in the northwestern Gulf of Mexico and forms part of a discontinuous arc of reef environments along the outer continental shelf (Rezak et al. 1985; Figure 1.2.1). These coral reef banks are the largest charted calcareous banks in the northwestern Gulf of Mexico (Bright et al. 1985) and are 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.

The large-scale topographic features of the FGB were created by salt diapirs of the Jurassic Louann Formation and consequent loading and uplifting of sedimentary rocks (Rezak 1981). The caps of many of these salt domes 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. Although coral species richness is lower at the FGB than on Caribbean reefs, 31 species of scleractinian corals have been documented at the FGB (Schmahl et al. 2008) and 177 species of tropical Atlantic fish have been reported at the Banks (Pattengill-Semmens and Gittings 2003). It should be noted that three additional coral species (*Agaricia humilis, Madracis pharensis*, and *Mycetophyllia ferox*) were identified during the June 2007 coral biodiversity surveys. Oceanic salinity conditions prevail at the FGB and range from 34 to 36 PSU, with water temperatures ranging from 18°C (in mid-February) to ~30°C (in August). Water clarity at the Banks is excellent - commonly 30 m or more - providing ample light to photosynthesizing organisms.

1.2.2. East and West Flower Garden Banks

The EFGB (27º54.5' N, 93º36.0' W) is located approximately ~193 km (120 mi) southeast of Galveston, Texas. The EFGB encompasses 67 km^2 (26 mi^2), sloping from its shallowest point at 18 m (59 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 1.2.2). The WFGB (27º52.4' N, 93º48.8' W) is located 20 km (12 mi) west of the EFGB and ~172 km (107 mi) southeast of Galveston and is more than twice as large (137 km^2 or 53 mi^2) as the EFGB (Figure 1.2.3). 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 acroporids were not found in the past. However, one colony of *Acropora palmata* was discovered in 2003 at the WFGB and was still present and growing at the time of this writing. Another living colony of *A. palmata* was discovered at the EFGB, southeast of the study site, by Beth Zimmer in June 2005 (Zimmer et al. 2006).

There are four major biological zones at the FGB: the coral reef zone, the coral community zone, the coralline algae zone, and the deep coral zone (Hickerson et al. 2008). The zones previously described by Rezak et al. (1985), including the *Diploria-Montastraea-Porites* zone, the *Madracis* and Leafy Algae zone, and the *Stephanocoenia-Millepora* zone, are considered subcomponents of the coral reef zone and have recently been renamed as follows. The coral reef zone is now divided into four habitat types, including the *Montastraea* habitat (previously referred to as the *Diploria-Montastraea-Porites* zone), the *Madracis* habitat (previously described as the *Madracis* and Leafy Algae zone), the *Stephanocoenia* habitat (formerly known as the *Stephanocoenia-Millepora* zone), and the coral sand habitat (Hickerson et al. 2008). The *Montastraea* habitat is the primary reef community at the FGB and includes at least 23 species of stony corals (Hickerson et al. 2008). This habitat is interspersed by sand channels with sediments comprised of coral sand. The *Madracis* habitat is located at the periphery of the primary reef structure in depths from 28-44 m (Hickerson et al. 2008). The *Stephanocoenia* habitat, dominated by *Stephanocoenia intersepta*, is a lower diversity coral community occurring in water depths primarily below 36 m (Hickerson et al. 2008). All monitoring at the EFGB and WFGB was conducted within the *Montastraea* habitat, except for the deep stations at the EFGB (32-40 m or 105-131 ft), which were established in 2003 (Precht et al. 2005). Contradicting previous descriptions of species dominance in the *Stephanocoenia* habitat, the deep stations were dominated by the *Montastraea annularis* species complex (*M. annularis, M. faveolata*, and *M. franksi*) and *M. cavernosa*. The difference in coral dominance between the deep sites and previous descriptions illustrates the spatial variability in the composition of benthic assemblages (Precht et al. 2005). The coral community zone, coralline algae zone, and deep coral zone were not encountered during the annual monitoring events. The coral community zone is not considered a true coral reef but does contain hermatypic coral species at low densities and is characterized by other coral reef associated organisms (Hickerson et al. 2008). This zone was formerly identified as the *Millepora*-Sponge zone by Rezak et al. (1985). The coralline algae zone is characterized by crustose coralline algae that actively produce carbonate substrate (Hickerson et al. 2008). This is the largest reef-building zone at the FGB, extending from 45 m to > 90 m (Hickerson et al. 2008). Finally, the deep coral zone is located at water depths below that which support active photosynthesis by coralline algae (i.e., greater than 90 m; Hickerson et al. 2008). This zone is characterized by a diverse assemblage of antipatharians, gorgonians, crinoids, bryozoans, sponges, azooxanthellate corals, and small solitary hard corals (Hickerson et al. 2008).

1.3. BOEMRE AND FGBNMS PROTECTIVE MEASURES

Oil and gas activity in the vicinity of the FGB has been ongoing since the 1970s. The Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE), under the U.S. Department of the Interior (USDOI), has regulated the development of the oil and gas industry within the Gulf of Mexico outer continental shelf. The first coral reef assessment of the FGB took place at the WFGB in 1972 (Bright and Pequegnat 1974). In 1973, the BOEMRE (then 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 (NWGOM) such as the FGB, 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, as well as potential toxic and smothering effects from drilling muds and cuttings discharges (USDOI, MMS 2002). The Stipulation defines a No Activity Zone (NAZ) around the 100-m isobath at each of the Banks based on the ¼, ¼, ¼ system (USDOI, MMS 1998). The boundary of the NAZ overlaps the 100- to 120-m isobaths (328- to 394-ft) at the WFGB and the 100- to 130-m isobaths (328- to 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.

In addition to the protections provided by BOEMRE, the FGB was designated a United States National Marine Sanctuary in 1992 (Code of Federal Regulations, 15 CFR Part 992, Subpart L, Section 922.120). The Flower Garden Banks National Marine Sanctuary (FGBNMS) regulates, restricts and/or 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;

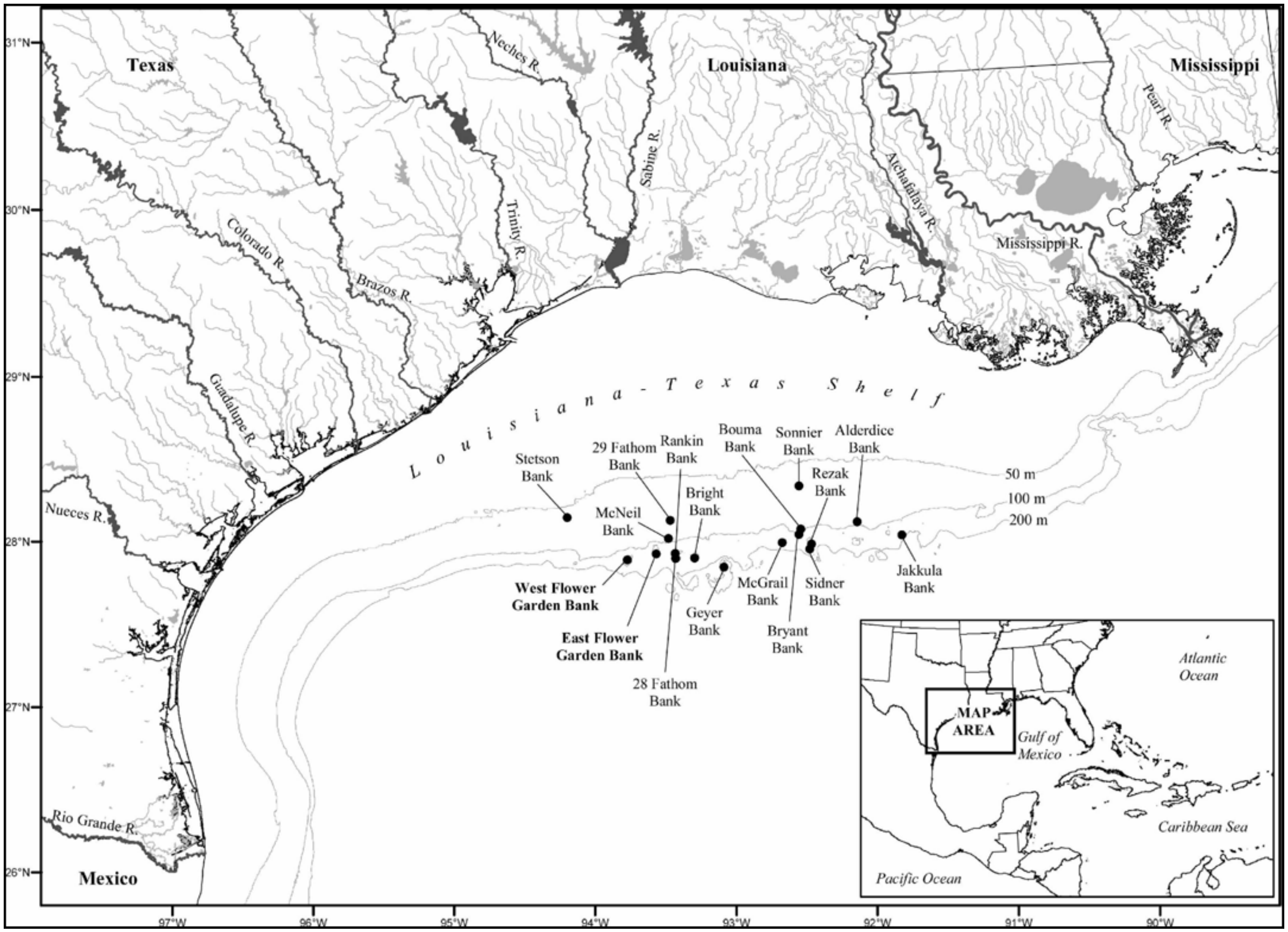


Figure 1.2.1. Location map of the EFGB and WFGB in relation to the Texas-Louisiana continental shelf and other topographic features of the northwestern Gulf of Mexico (map created by K.J.P Deslarzes).

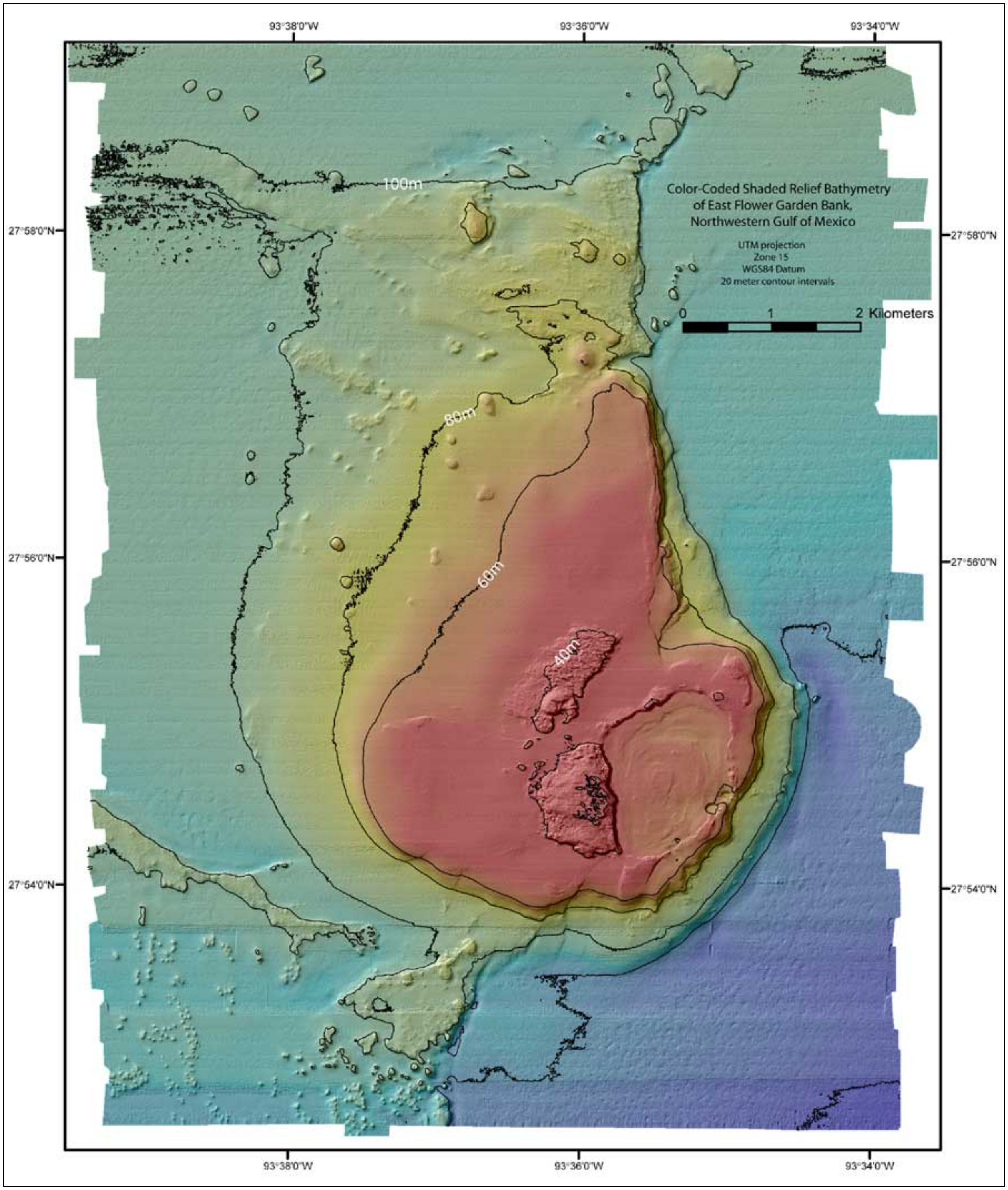


Figure 1.2.2. Topographic contour map of the EFGB (Gardner et al. 1998).

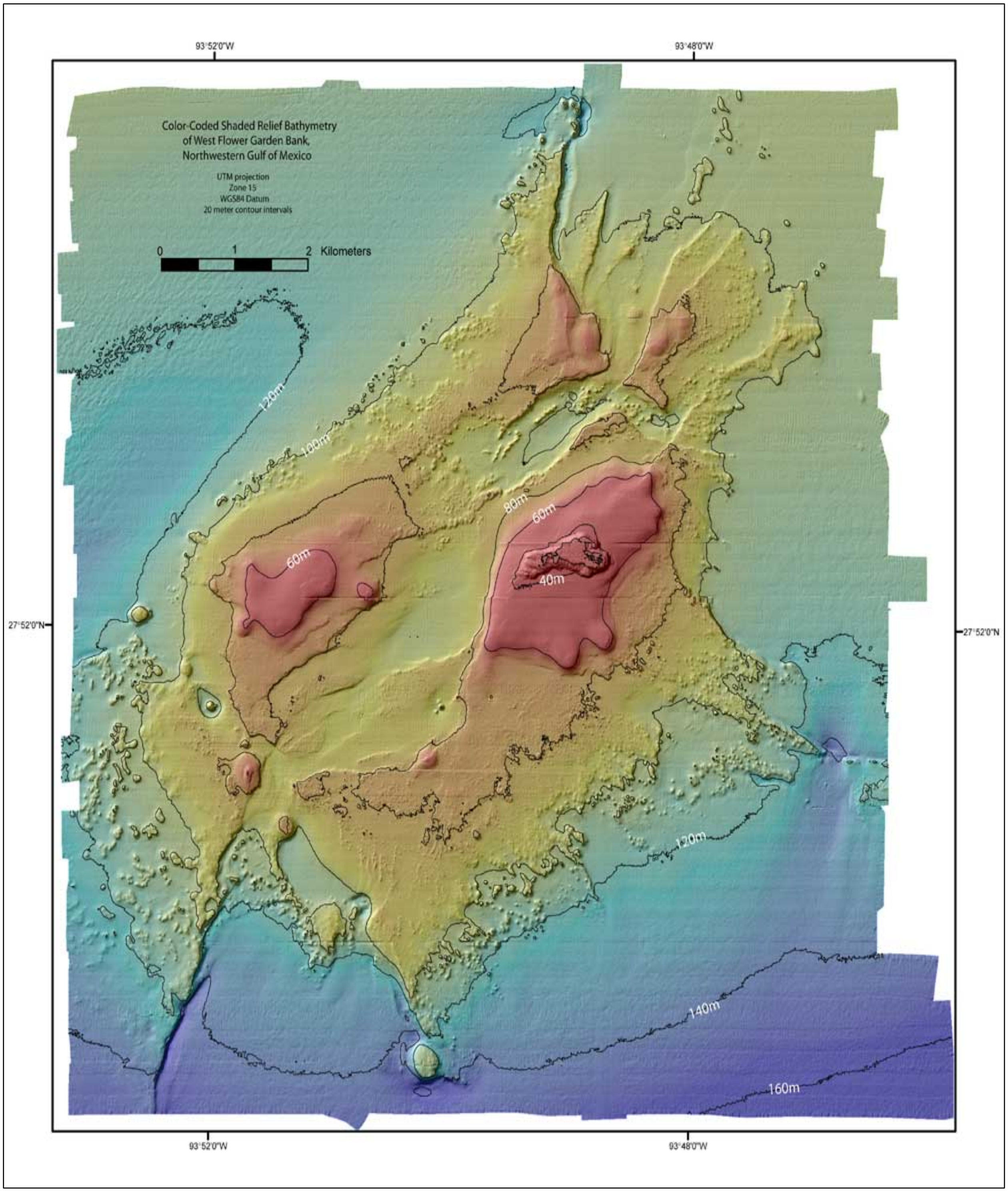


Figure 1.2.3. Topographic contour map of the WFGB (Gardner et al. 1998).

(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.

From 1988 to 1995, the BOEMRE monitored the FGB coral reefs to detect any incipient changes that may be caused by oil and gas activities, as well as by any other disturbances (Gittings et al. 1992; Gittings 1998). Since 1996, the FGBNMS and the BOEMRE have partnered to continue the long-term monitoring of the FGB.

1.4. Coral Disease at the Flower Garden Banks

As previously mentioned, the FGB has suffered minimally from disease outbreaks during the past 20 years of continuous monitoring. However, winter, white plague-like disease symptoms were reported for four consecutive years at the EFGB and WFGB from 2005-2008 (Hickerson 2005; Hickerson and Schmahl 2005a; Hickerson 2006a; Hickerson 2008a; Hickerson 2009). In April 2005, 41 colonies were observed with white plague-like symptoms at the EFGB and WFGB (Hickerson 2005). Affected species included *Montastraea franksii*, *M. faveolata*, *Diploria strigosa*, *Porites astreoides*, *M. annularis*, *Stephanocoenia intersepta*, and *Colpophyllia natans* (Hickerson 2005). A majority of the affected colonies were observed at the EFGB (34 colonies) compared to the WFGB (7 colonies), with ~85% of all affected colonies belonging to the *Montastraea annularis* species complex (Hickerson 2005). Seven colonies exhibiting active, white plague-like symptoms were identified and tagged at the EFGB and WFGB. These tagged colonies were revisited in May 2005 and numerous, active disease lesions continued to be observed (Hickerson and Schmahl 2005a). Coral disease surveys were also performed in January 2006, March 2006, May 2006, March 2007, and February 2008. In January 2006, there was an increased occurrence of white plague-like symptoms, with approximately 2% of coral colonies within the transect displaying disease symptoms (Hickerson 2006a). The most severe coral disease outbreak ever recorded at the FGB was observed in March 2006. At least 8.34% of colonies at the EFGB and at least 3.33% of colonies at the WFGB exhibited symptoms similar to white plague (Hickerson 2006a). In May 2006, the disease event appeared to have slowed down with very low incidence of active lesions (Hickerson 2006a). Plague-like disease was documented for the third consecutive winter in March 2007; however, the outbreak did not appear to be as widespread as the previous winter in 2006 (Hickerson 2008a). Lastly, plague-like coral disease was affecting multiple colonies and species in February 2008 (Hickerson 2009). This was the fourth consecutive year where winter-time disease events were documented.

1.5. Recent Hurricanes at the Flower Garden Banks

On September 23, 2005 Hurricane Rita (Category 3, Saffir-Simpson Index) passed ~93 km (58 mi) from the EFGB on its route north to the mainland United States (Figure 1.4.1; Robbart et al. 2009). Hurricane Rita's winds were up to 222 kph (138 mph or 120 kn) and the closest weather buoy, Buoy #42019, located 230 km (143 mi) west, recorded waves close to 6-m (20-ft) high. An October cruise, conducted by the National Oceanic and Atmospheric Administration (NOAA), revealed physical damage, including massive overturned and dislodged coral colonies, broken corals of smaller sizes, gouged coral colonies damaged by projectiles, and the displacement of large quantities of sand. Following Hurricane Rita, four to six inches of rainfall was recorded along the Mississippi and Atchafalaya Rivers on September 24, 2005 (Precht et al. 2008a). Other areas along the Louisiana coast experienced up to 12 inches of rainfall on September 24th. Satellite imagery of total suspended matter in the northwestern Gulf of Mexico showed that nearshore water associated with the high levels of precipitation was driven across the shelf onto the shelf edge, including the area of the FGB (Precht et al. 2008a). The discolored water that reached the FGB may have contained pollutants from industrial sites. In addition to the hurricane impacts, the summer of 2005 was unusually warm and sea surface temperatures in the Eastern Caribbean, as well as at the FGB, were high for an extended period of time. Corals that were bleached during the October cruise, mainly *Montastraea cavernosa, Millepora alcicornis*, and the *M. annularis* species complex were noted. As a result of the hurricane, a post-hurricane cruise was conducted at the EFGB in November 2005. Although some recovery was evident on the November cruise, *M. cavernosa* and *M. alcicornis* continued to be bleached. Study site repetitive quadrats, deep station repetitive quadrats, videography of two perimeter lines, and water quality data were collected and analyzed. The results of the post-hurricane cruise were reported as a separate report (Precht et al. 2008a).

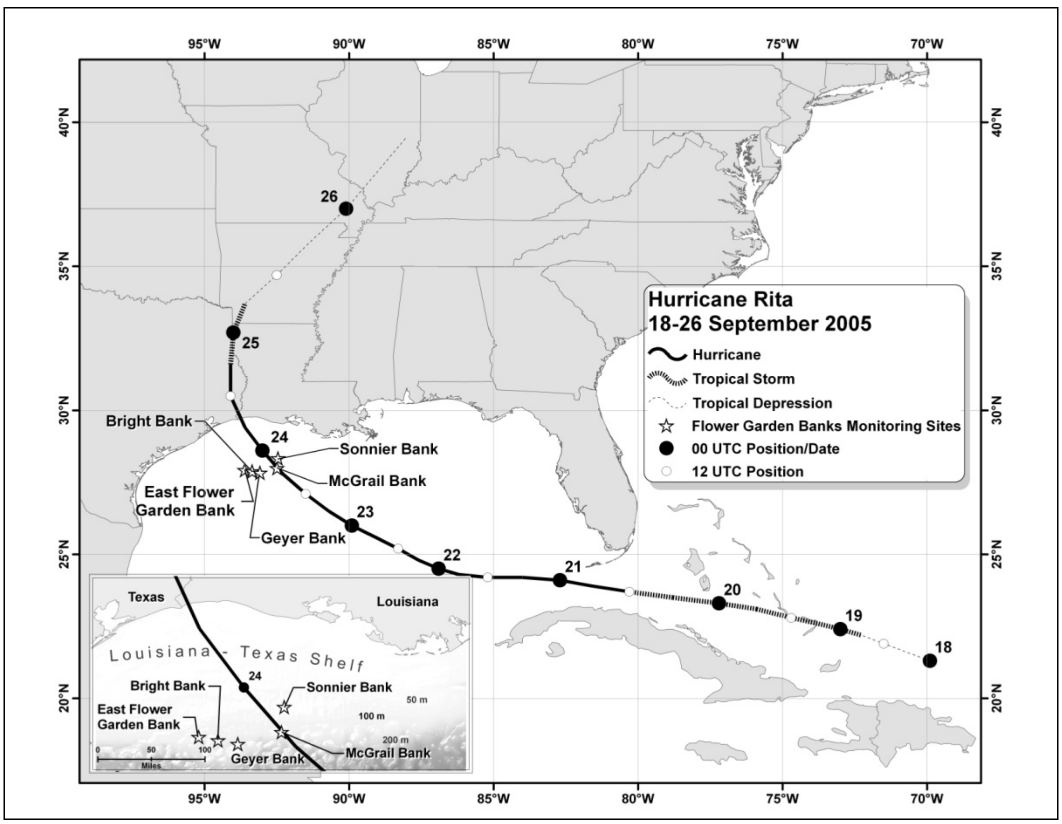


Figure 1.4.1. Track of Hurricane Rita, September 18-26, 2005 (USDOC, NOAA, National Hurricane Center 2006).

At approximately 5 p.m. on September 12, 2008, Hurricane Ike (Category 3, Saffir-Simpson Index) passed directly over the EFGB with the storm track ~0.7 km (0.4 mi) from mooring buoy number 2 at the EFGB study site (Figure 1.4.2). At the time of passage, Hurricane Ike's winds were ~169 kph (105 mph or 91 kn) and the atmospheric pressure was ~955 mb (Hickerson 2008b). The highest winds recorded by TABS Buoy V (located near the EFGB) were 97 kph (60 mph or 52 kn) and the maximum wave height recorded during the storm was 8 m (26 ft; Hickerson 2008b). On October 9, 2008, FGBNMS staff and volunteers travelled to the FGB to preliminarily document hurricane impacts. Their assessments included 1) dislodged boulder colonies, leaving large craters and paths of impact; 2) sheared *Xestospongia muta*; 3) sediment-scoured corals bordering sand flats; 4) significant breakage of the *Madracis auretenra* field at the EFGB; 5) branch loss on the *Acropora palmata* colony at the EFGB and observed coral malady on the *A. palmata* colony at the WFGB (Hickerson 2008b). No coral bleaching was observed and very little plague-like disease was encountered (Hickerson 2008b). Long-term monitoring stations at the EFGB were found (some pins dislodged or bent) and the YSI/Seabird equipment was partially buried (Hickerson 2008b). The WFGB study site was not visited during the assessment.

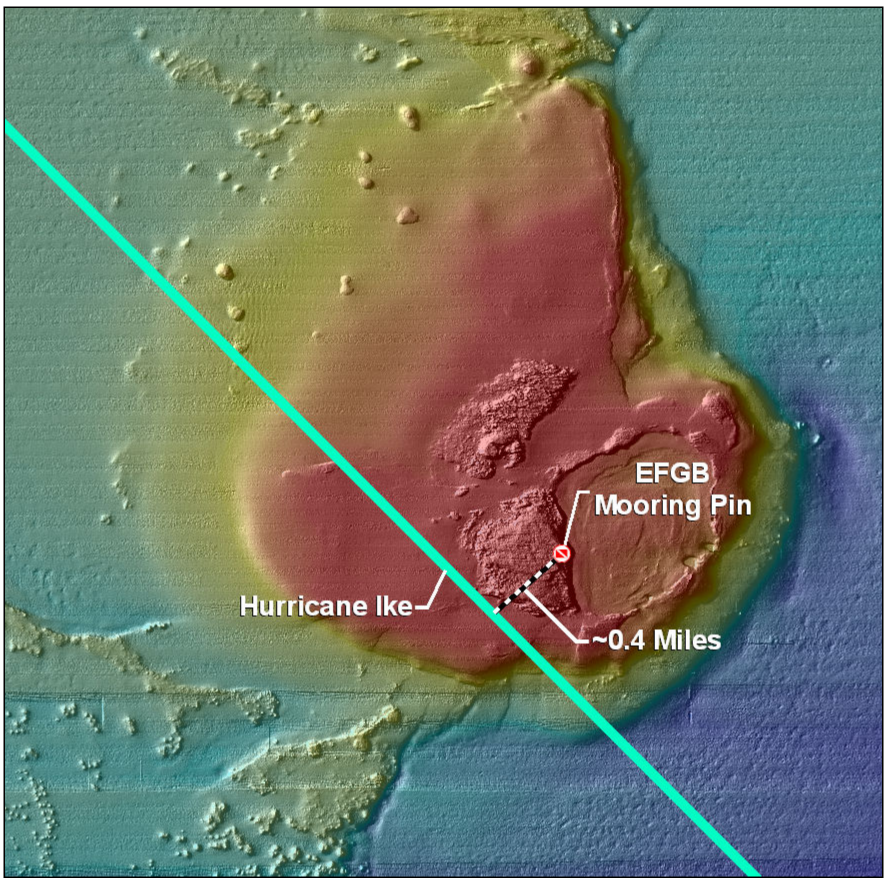


Figure 1.4.2. The track of Hurricane Ike passed within 0.7 km (0.4 mi) of mooring buoy number 2 at the EFGB study site on September 12, 2008.

2.0 METHODS

The FGB are located roughly 190 km (118 mi) offshore and are submerged in more than 18 m (59 ft) of water; therefore, the monitoring effort was conducted from a dive vessel that remained at each Bank for approximately two days per year. The benthos (with an emphasis on corals) was examined along videographic transects and in stationary repetitive photoquadrats. Sclerochronology was used to document the accretionary growth rate of corals, and photography was used at permanent stations to monitor the lateral growth of corals. General aspects of coral condition and fish populations were documented along perimeter lines at the EFGB and WFGB. Coral health surveys were conducted during the June 2007 annual monitoring cruise to assess the presence, types, and prevalence of coral diseases and other coral health issues at the FGB. 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 FGB. Fish surveys were conducted at haphazardly located stations and sea urchin and lobster surveys were conducted on the study site perimeter lines.

2.1. STUDY SITES

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 from 2004-2008 (Table 2.1.1). The general locations of the study sites were marked by permanent mooring buoys: FGBNMS permanent mooring No. 2 at the EFGB (27°54'31.9" N, 93°35'49.0" W) and mooring No. 5 at the WFGB (27°52'30.6" N, 93°48'54.1" 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. Subsurface buoys were installed at the corners of each study site to facilitate underwater relocation. Geographical Positioning System (GPS) coordinates taken at the site corners in 2002 allowed for quick site relocation and initial mapping of the corners (Table 2.1.2). For each survey, divers were transported and dropped at the exact corner locations using a dinghy and Garmin GPS unit. Divers installed polypropylene lines to temporarily mark the perimeters of the study sites and 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. Additionally, 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 2.1.3 and 2.1.4).

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) 8-m^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.

Table 2.1.1.

Cruise dates at the EFGB and WFGB from 2004-2008.

EFGB	WFGB
September 20-21, 2004	November 19-20, 2004
June 8-9, 2005	June 6-7, 2005
June 12-13, 2006	June 14-15, 2006
June 11-12, 2007	June 12-15, 2007
August 13-14, 2007	August 14-15, 2007
	September 4-6, 2007
November 3-4, 2008	November 4-6, 2008

Table 2.1.2.

GPS coordinates for the EFGB and WFGB study-site corner markers and mooring pins.

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
Mooring Pin #2	27°54'31.9	93°35'49.0	Mooring Pin #5	27°52'30.6	93°48'54.1

2.1.2. EFGB Deep Repetitive Quadrat Stations

There are nine deep repetitive quadrat stations located outside the 100- x 100-m study site at the EFGB. These deep stations were established in April 2003 by BOEMRE and NOAA (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 2.1.5 and 2.1.6; Precht et al. 2005).

2.1.3. Study Site Rehabilitation

Study site rehabilitation was necessary during the course of the long-term monitoring from 2004-2008 because of storm damage from Hurricane Rita (September 2005) and Hurricane Ike (September 2008). Rehabilitation activities were performed for damaged stations on the EFGB during the August 2007 cruise and on the WFGB during the November 2008 cruise. Rehabilitation activities included replacement of bent or missing rods at lateral growth and repetitive quadrat stations, replacement of missing station tags, reinstallation of loose rods with epoxy, and the installation of missing corner markers. During the November 2008 rehabilitation activities, lateral growth stations were not rehabilitated at the WFGB due to time constraints and in an effort to reduce boat costs. It should be noted that the identification of both repetitive quadrat and lateral growth stations at the WFGB in November 2008 was difficult because a majority of the stations were missing tags and/or etchings on the pins were no longer visible.

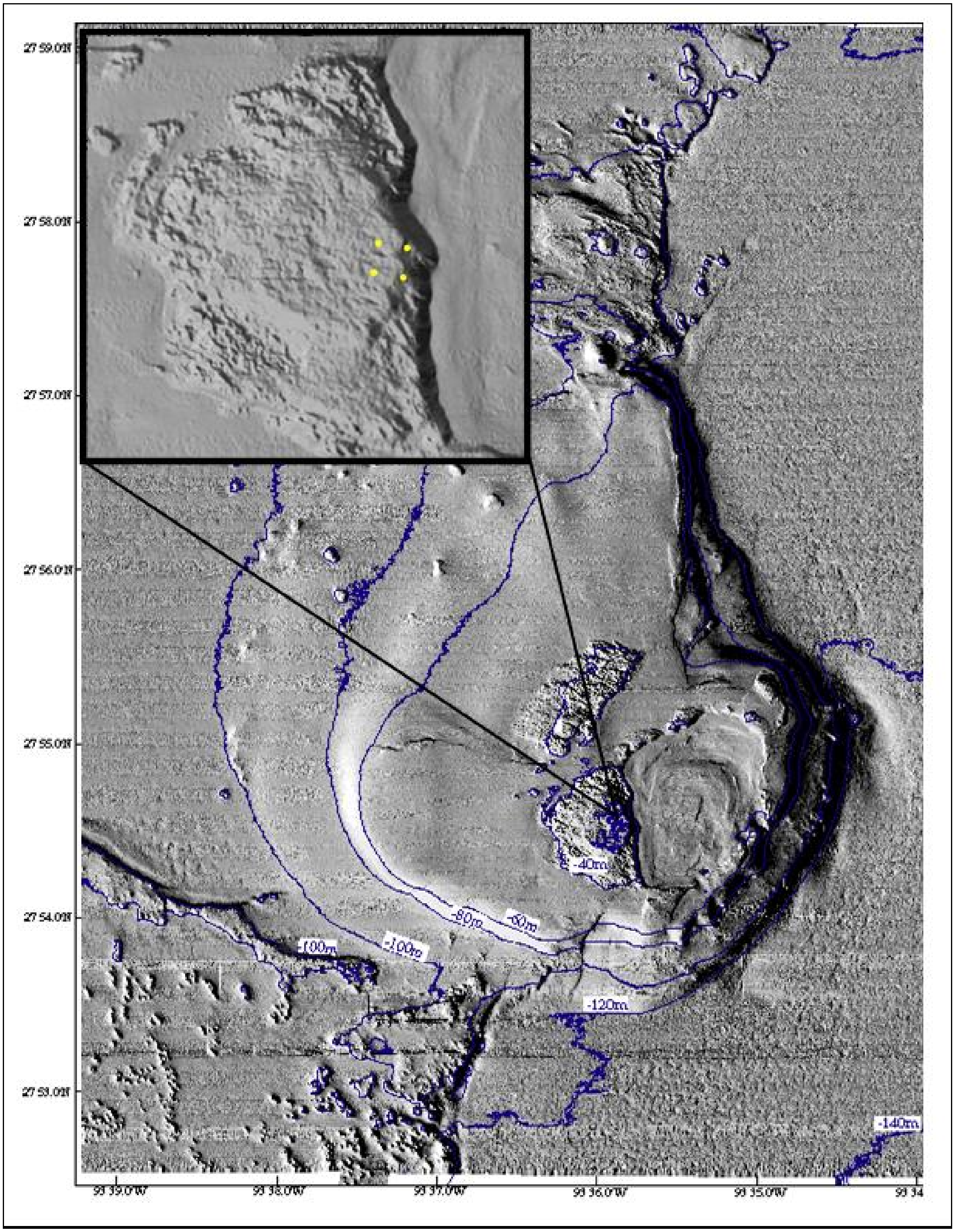


Figure 2.1.1. Topographic map of the EFGB (USDOI, GS 2001). Inset shows the locations of the corners of the study site.

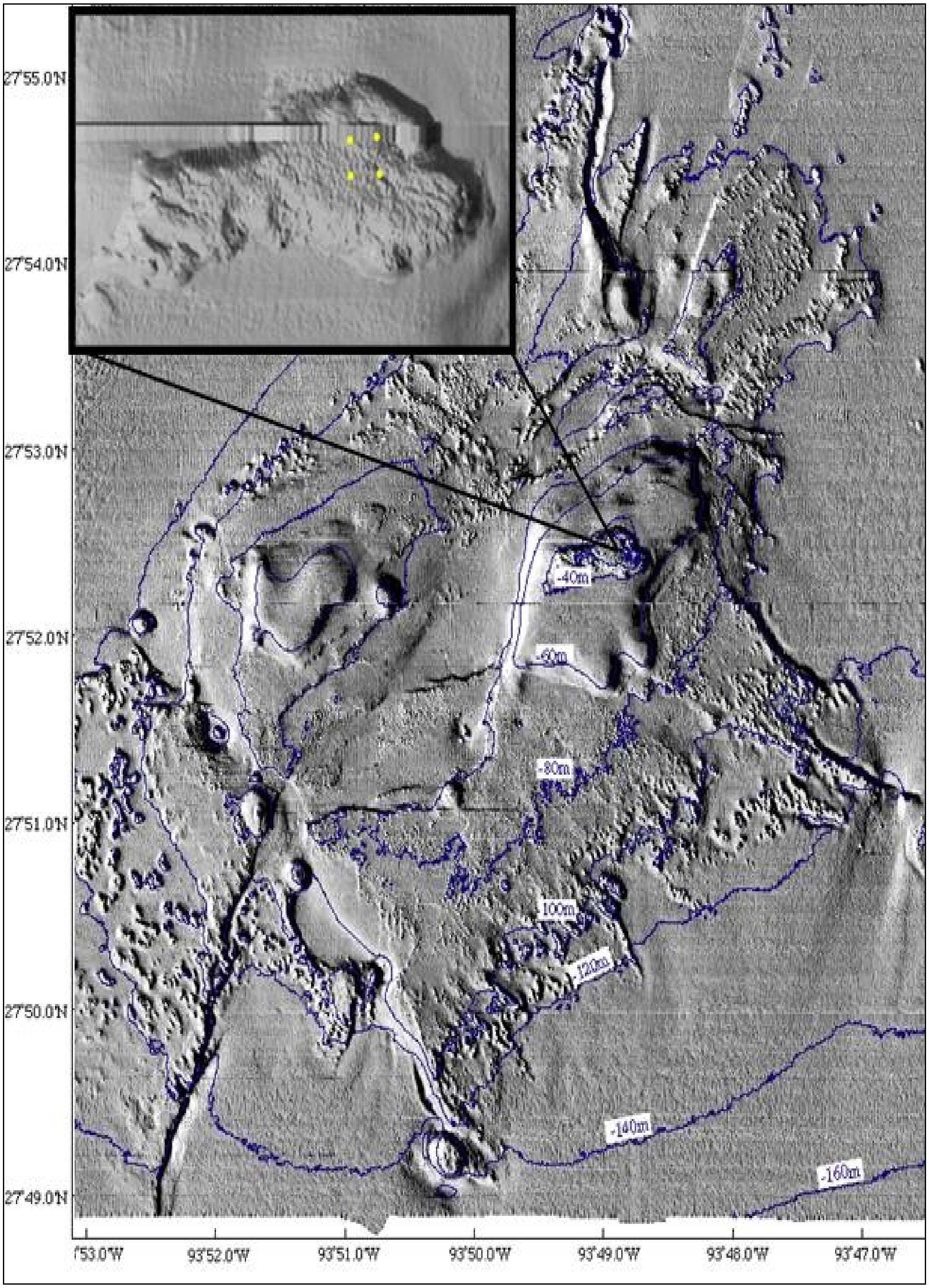


Figure 2.1.2. Topographic map of the WFGB (USDOI, GS 2001). Inset shows the locations of the corners of the study site.

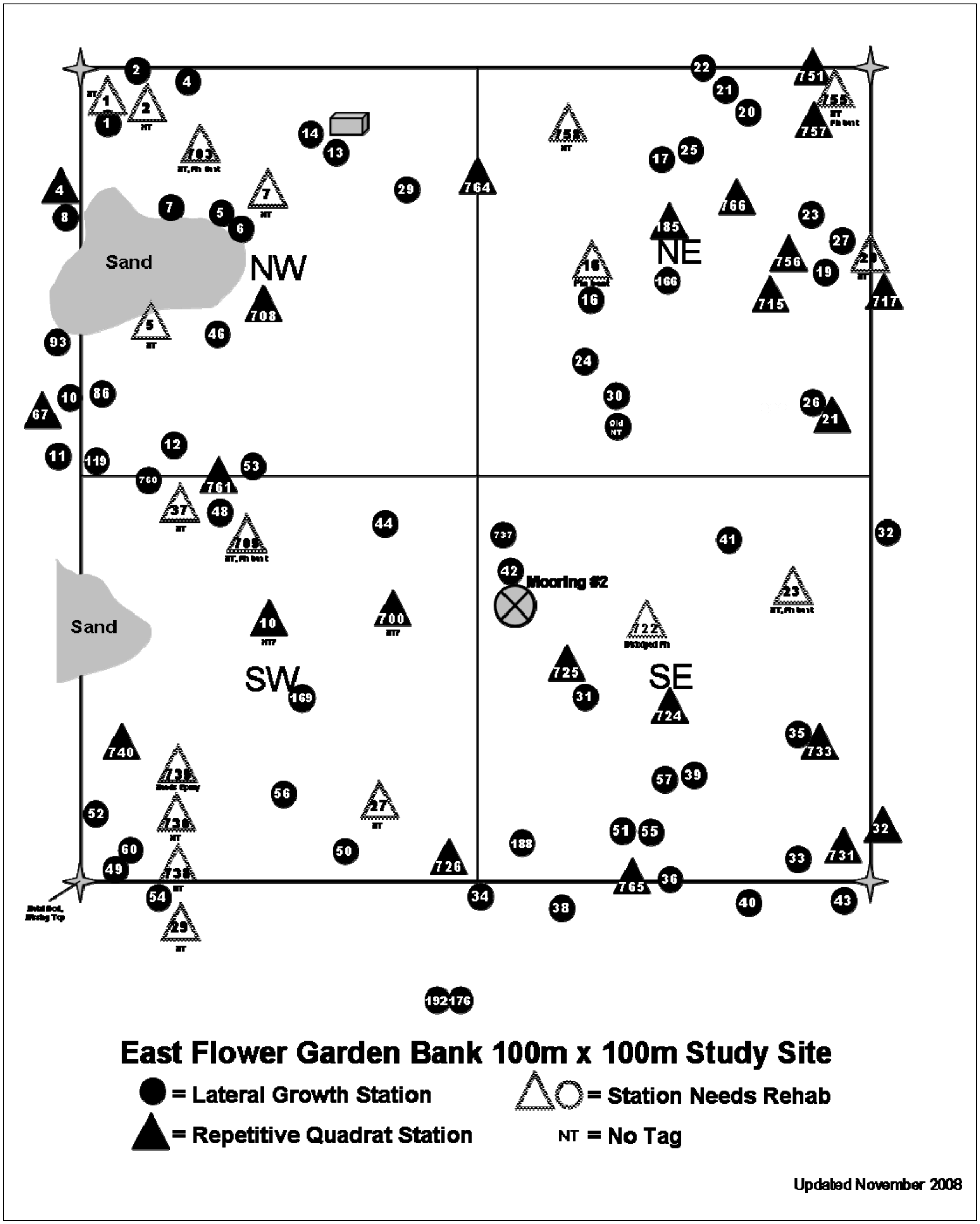


Figure 2.1.3. Locations of monitoring stations at the EFGB, 2008.

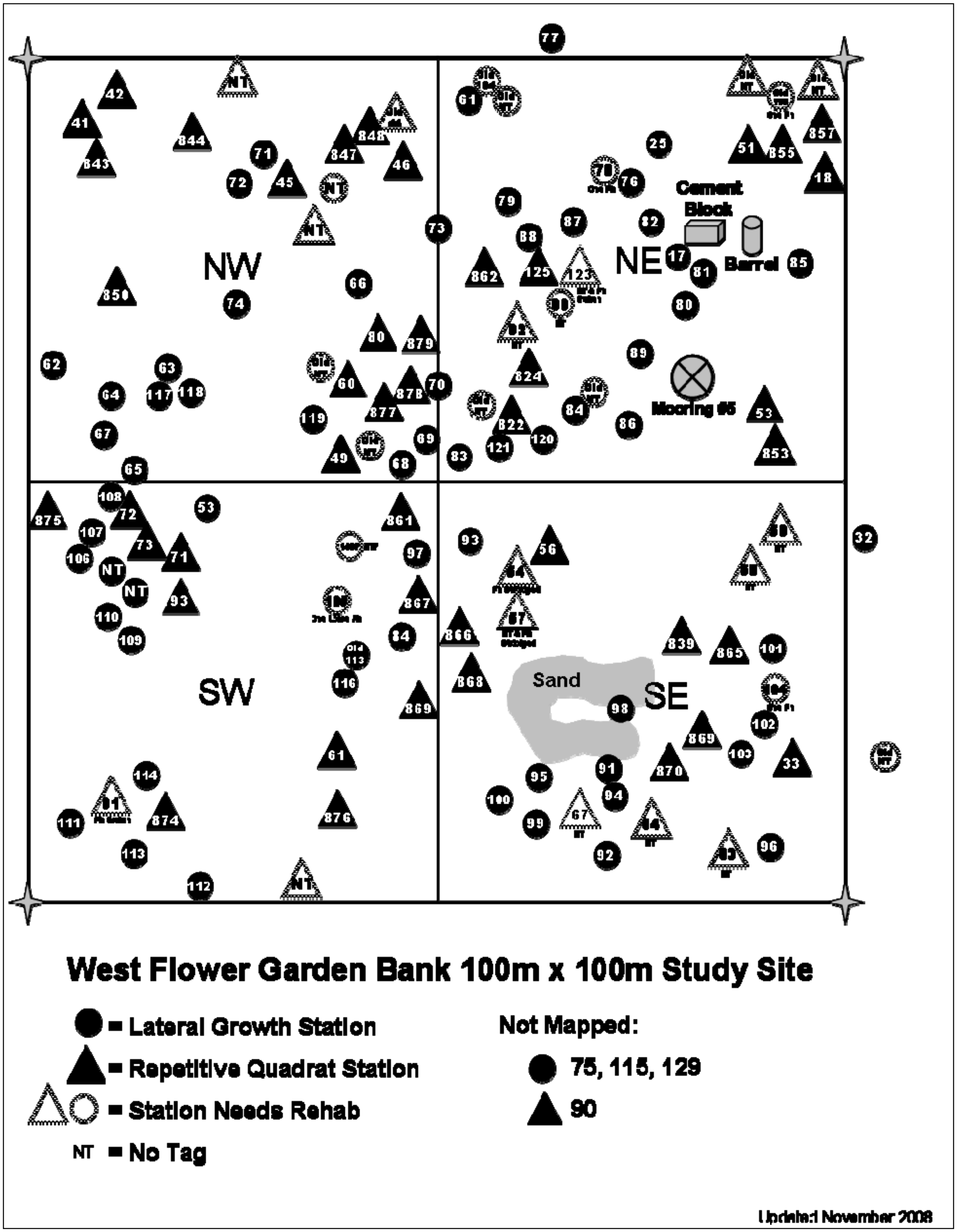


Figure 2.1.4. Locations of monitoring stations at the WFGB, 2008.

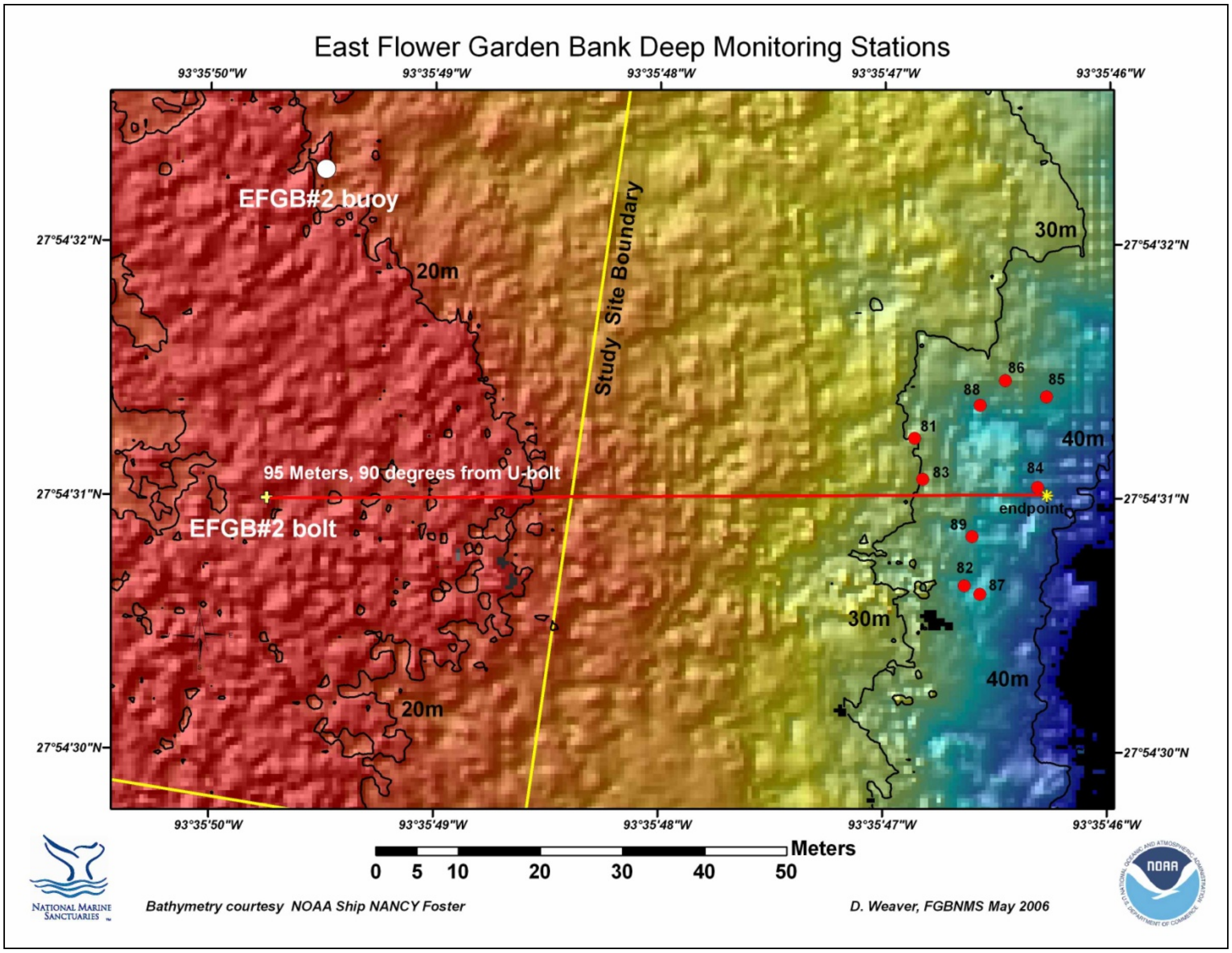


Figure 2.1.5. Bathymetric map with the deep repetitive quadrat stations in relation to the permanent study site at the EFGB (32-40 m or 105-131 ft), established in April 2003. Contour lines at 20, 30, and 40 m. Image courtesy of Doug Weaver, NOAA/FGBNMS.

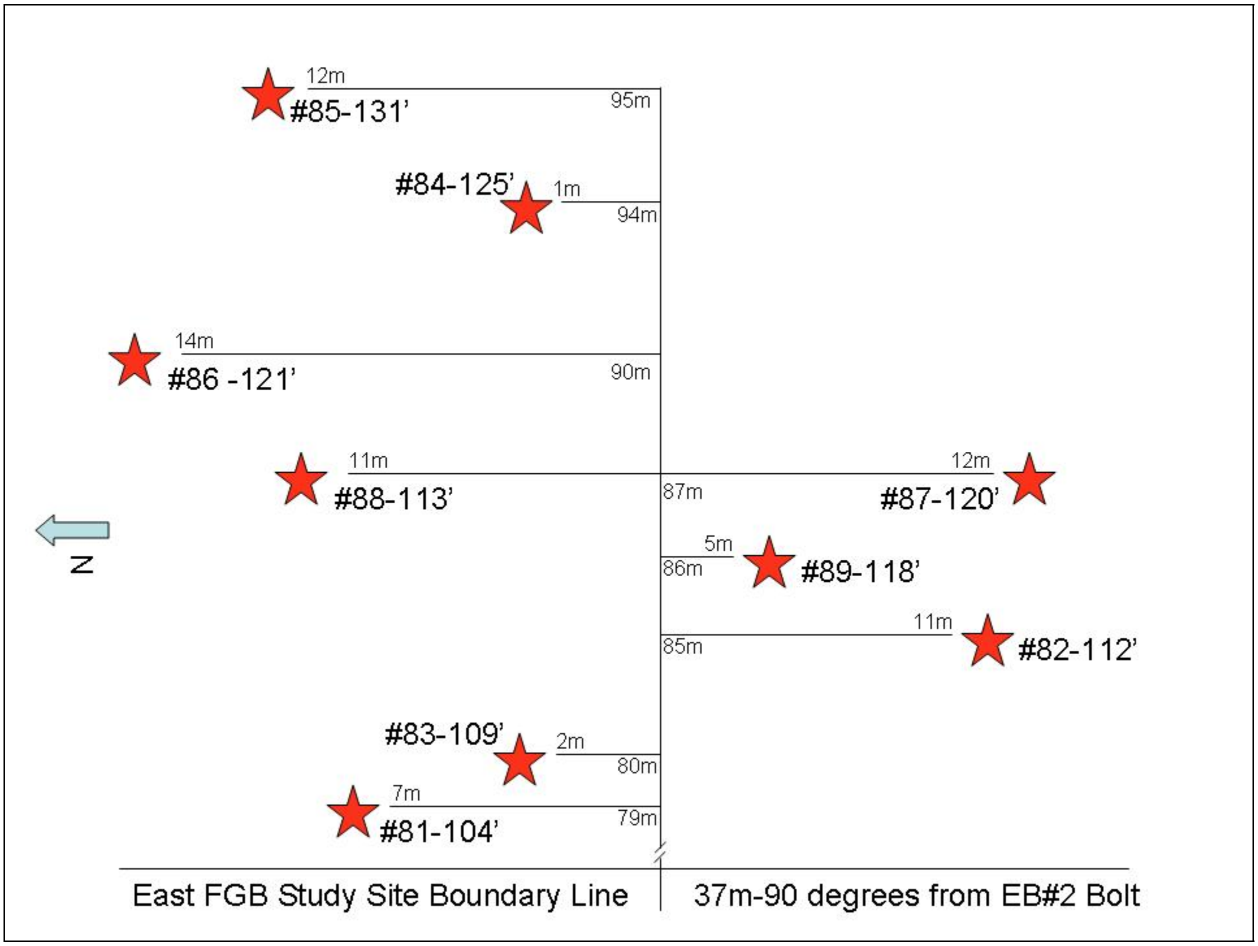


Figure 2.1.6. Map showing depth and relative locations of the nine deep repetitive quadrat stations at the EFGB.

During rehabilitation activities, the station numbering system was slightly modified to avoid the repetition of pre-existing station numbers. In 2004-2006, the repetitive quadrat stations were numbered 1-40 at the EFGB and 41-80 at the WFGB, while the lateral growth stations were numbered 1-60 at the EFGB and 61-120 at the WFGB. Stations that required new tags at the EFGB received new station numbers ranging from 700-799, while new tags at the WFGB ranged from 800-899 (Table 2.1.3). In most cases, divers matched the last two digits of the new tag number to the station number (number etched on metal rod). For example, at the EFGB, station #3 was replaced with new tag #703. However, at times, divers were not equipped with proper tag numbers. In order to save time and maintain productivity, a random tag was assigned to a station and recorded (e.g., repetitive quadrat station #12 replaced with new tag #755). As previously mentioned, the identification of repetitive quadrat stations was difficult at the WFGB in November 2008 because a majority of the stations were missing tags and/or etchings on the pins were no longer visible. In these instances, divers attempted to identify the unmarked station using underwater maps of the study sites (Figures 2.1.3 and 2.1.4).

Table 2.1.3.

New station tag numbers assigned at the EFGB and WFGB during rehabilitation activities. Abbreviations: RQ= repetitive quadrat station and LG= lateral growth station.

EFGB			WFGB		
Station Type	**Former Station #**	**Current Station #**	**Station Type**	**Former Station #**	**Current Station #**
RQ	No Tag	700	RQ	122	822
RQ	3	703	RQ	124	824
RQ	8	708	RQ	No Tag	839
RQ	9	709	RQ	43	843
RQ	15	715	RQ	44	844
RQ	17	717	RQ	47	847
RQ	22	722	RQ	48	848
RQ	24	724	RQ	50	850
RQ	25	725	RQ	52	853
RQ	26	726	RQ	55	855
RQ	30	730	RQ	57	857
RQ	31	731	RQ	61	861
RQ	35	733	RQ	62	862
RQ	38	738	RQ	65	865
RQ	39	739	RQ	66	866
RQ	40	740	RQ	No Tag	867
RQ	11	751	RQ	68	868
RQ	12	755	RQ	69	869
RQ	14	756	RQ	70	870
RQ	18	757	RQ	74	874
RQ	19	758	RQ	75	875
RQ	37	761	RQ	76	876
RQ	6	764	RQ	77	877
RQ	34	765	RQ	78	878
RQ	13	766	RQ	79	879
LG	37	737			
LG	47	760			
LG	Old 184	784			

At the EFGB in August 2007, a total of 28 repetitive quadrat stations were rehabilitated: 20 stations received new tags only, five stations received new tags and new metal rods were installed, and three stations with loose metal rods were secured with epoxy. A total of eight lateral growth stations were rehabilitated at the EFGB in August 2007. Three stations received new tags and new short rods/bolts were installed at five stations. Three of the four corner markers needed rehabilitation at the EFGB in August 2007. Two corner markers were loose and secured with epoxy and a new northeast corner marker was installed. In November 2008, only a new northwest corner marker was installed at the EFGB.

At the WFGB in November 2008, a total of 25 repetitive quadrat stations were rehabilitated. These stations received new tags only. Rehabilitation activities were also performed on all of the corner markers at the WFGB. New corner markers were installed at the southwest and northwest corners and loose markers were secured with epoxy at the northeast and southeast corners. Due to time constraints and in an effort to reduce boat costs, lateral growth stations were not rehabilitated at the WFGB.

2.2. RANDOM TRANSECTS

2.2.1. 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 within each study site. Each transect originated at a random location and laid out in a random direction according to a set of randomly generated numbers.

The Scope of Work in the 2002-2003 contract for this study expressed a well-founded desire to move away from still photography for recording the random transect data at each site. Therefore, the 2002-2003 data collection included an assessment of the utility of videography for surveying transects at the FGB and the comparability of video to still photography (Precht et al. 2006). Coverage was estimated from 14 transects at both the EFGB and WFGB in 2002 and 2003 in three ways: (1) still photography, (2) videography, and (3) the linear-point intercept (LPI) method. The LPI method was used to ascertain whether data recorded in situ were different than data derived from either of the photographic methods (still photography or videography). Based on the results of this assessment (presented in Precht et al. 2006), coverage using videography was shown to be equal in power and accuracy to those of still photography.

2.2.2. 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. In two cases, contingencies prevented the full set of 16 transects from being collected at the EFGB, but a minimum of 14 transects were sampled per study site in each monitoring year (Table 2.2.2). Upon arrival in the quadrant, a diver would swim a number of kicks determined by a randomly generated number and secure the transect at its starting point. Another randomly generated number would be used to denote a heading in one of eight directions. The beginning of the next transect was positioned a random number of kicks in the same direction as the first transect and a random heading was used to lay the second transect. The third transect was laid in the same manner relative to the second, and so on. This design was considered more desirable than the clustered sampling of areas that can occur when transects are positioned at random within the study site as a whole. If a transect reached the border of the study site, it was reflected off the border and continued as a “bent” line. If it appeared that the transect would encounter a sand patch, the path of the transect line was slightly and randomly altered to avoid the sand patch.

Table 2.2.2.

Number of random transects completed at the EFGB and WFGB from 2004 through 2008.

Year	EFGB	WFGB
2004	14	16
2005	15	16
2006	16	16
2007	16	16
2008	16	16

To collect digital videography, a diver swam slowly along each transect, videotaping at a height of 40 cm (16 in) from the substratum, using a digital video camera in an underwater housing fitted with a wide-angle lens and underwater video lights (Figure 2.2.1). A depth gauge and scaling bar were attached to an aluminum bar that projected forward from the video housing. The gauge and scaling bar ensured that the camera remained a constant distance from the bottom. By holding the video camera perpendicular to the substratum and swimming slowly along the transect it was possible to produce clear stop-action images for analysis (Aronson et al. 1994; Murdoch and Aronson 1999).

Figure 2.2.1. A scientific diver collects random transect data using a digital video camera at the FGB.

The video frames covered a 40-cm (16-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 ~56 m^2 (600 ft^2) videotaped per study site per year. Each video frame was 40 cm x 27 cm (16 in x 11 in), or 1080 cm^2 (167 in^2). Non-overlapping video frames were captured from each of the 16 video transects using ULead® VideoStudio® 9. Digital filters were applied using the ULead® software in order to enhance image quality. The original videotape of a transect was used to gain more detail on an object or a different perspective on a specific still image. Substrate cover was assessed from all captured images.

After image capture and enhancement, randomly placed dots were added to each frame using Coral Point Count® (CPCe), for a total of 500 dots per transect (see Kohler and Gill 2006). Organisms positioned beneath each random dot were identified as follows: corals and macroalgae were identified to lowest possible taxonomic group (macroalgae included algae longer than ~3 mm and included thick algal turfs); sponges were combined into a single group in 2004 and 2005 and were identified to lowest possible taxonomic group in 2006-2008; and crustose coralline algae, fine turfs, and bare rock were grouped as "CTB." CTB components are difficult to distinguish visually in still photographs and video transects. All three connote high levels of physical disturbance and/or herbivory, and so it is reasonable to combine them (Aronson and Precht 2000). The remaining categories included "other" live components (ascidians, fish, serpulids, etc), sand, rubble, and unknown. Beginning in 2006, cyanobacteria (*Schizothrix* sp.) was more frequently observed within the random transect videography; thus, a new category, Cyanobacteria, was created to include data under this classification. 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. This approach to data analysis was a refinement of past methods at the FGB and has been used successfully in a separate, NOAA-funded study comparing no-take zones and reference sites within the Florida Keys National Marine Sanctuary (Aronson et al. 2005).

Quality assurance/quality control (QA/QC) for the video method consisted of multiple, trained individuals diving together on the study sites and identifying corals and other taxa. These individuals then viewed captured video frames to ensure that (1) they agreed on species identifications (which was particularly an issue with respect to the *Montastraea annularis* species complex; Aronson et al. 2005) and that (2) the taxa were recognizable on the frames.

2.2.3. Statistical Analyses of the Transect Data

Each transect was treated as a replicate at the scale of the study site, yielding an estimate of coral cover and the cover of other benthic categories. Percent coverage was calculated for each transect from the 500 analyzed points for each of the taxa and benthic categories discussed in section 2.2.2. Factor plots were produced 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 accurate and precise estimates of the coverage of benthic components, regardless of the transect length (Aronson et al. 1994; Carleton and Done 1995).

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. Tests for normality and homogeneity of variances were followed by transformation as necessary. ANOVAs were calculated for each substratum variable with the statistical software Minitab® 14.12.

The random sampling approach to videography provided sufficient statistical power to test hypotheses of change in community composition in previous studies in Florida and the Caribbean. Differences on the order of 3-5% in univariate coral cover were detectable at the 5% level (i.e., at $P<0.05$) with 80% power (Aronson et al. 1994; Murdoch and Aronson 1999). The technique also performed well in multivariate analyses (Aronson and Swanson 1997). For the FGB, analysis of the monitoring data collected in 2002-2003 showed that differences on the order of 7.5% coral cover were detectable at an alpha of 0.05 with a power of 0.80 (Aronson et al. 2005).

2.3. SCLEROCHRONOLOGY

2.3.1. Methodological Rationale

Sclerochronology is the determination of annual growth rates through the measurement of accretionary growth bands in coral core samples taken perpendicular to coral growth. The most commonly measured growth parameter in corals is linear extension. Thus, skeletal growth rate can be estimated by measuring the length of a corallite within a given band. Such growth rates are known to vary with corallite orientation, which can be determined by measuring the corallite growth angle (Graus and Macintyre 1982). Growth is determined directly by identifying high- and low-density bands found in the coral skeletons (Figure 2.3.1). The area between two sequential high-density growth bands is considered an annual growth increment. This method has the advantage of recording growth in the same colony on a decadal scale so that comparisons (linear extension) can be made to current rates. Skeletal density and mass growth are additional parameters which may be obtained using image analysis densitometry (Dodge and Kohler 1984).

Although the method of counting seasonal density bands within the skeleton has been used for some time (Buddemeier et al. 1974; Knutson et al. 1972), there still remains considerable controversy as to the exact cause of density variations in coral skeleton. It is generally believed (Highsmith 1979) that low-density bands are produced under optimal growth conditions (fall/winter) and that high density bands accrete during suboptimal growth conditions (spring/summer). Physical environmental factors which are known to influence coral skeletal density are: (1) light (Macintyre and Smith 1974; Knutson et al. 1972; Wellington and Glynn 1983); (2) temperature (Highsmith 1979; Hudson et al. 1976); and (3) suspended sediment (Dodge et al. 1974; Brown and Howard 1985). Salinity and water agitation may also exert some control. Other factors, which 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 the symbiotic zooxanthellae in influencing calcification, and endolithic algae in modifying density patterns, as well as the effects of boring organisms, are further complications.

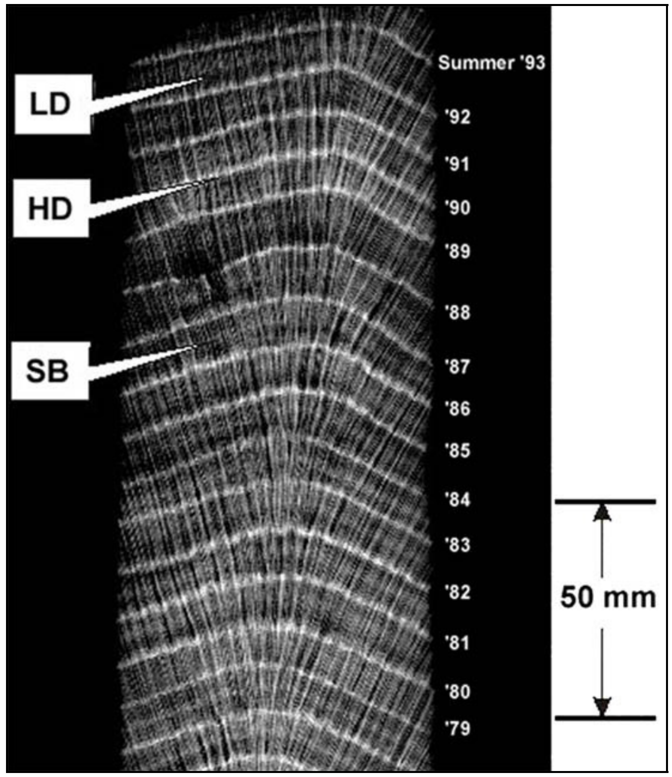


Figure 2.3.1. X-ray of *Montastraea faveolata* showing skeletal banding. Abbreviations: LD= low-density growth band, HD= high-density growth band, and SB= stress band.

Skipped or stressed bands are commonly observed during years of significant coral bleaching or other stresses, including cold-air outbreaks, freshwater pulses, concentrated parrotfish biting, and damselfish territories (Wells 1963; Kaufman 1977; Buddemeier et al. 1974; Dodge 1975; Hudson et al. 1976; Highsmith 1979; Dodge 1980; Hudson 1981a, b; Hudson et al. 1989; Smith et al. 1989; Leder et al. 1991; Fitt et al. 1993; Heiss and Dullo 1995; Insalco 1996). Finally, care must be taken to differentiate between normal, annual bands and other bands produced by non-cyclic environmental fluctuations (Graus and Macintyre 1982; Leder et al.1991).

2.3.2. Field Methods

Core samples were collected for sclerochronology analysis during the June 2005 and June 2007 monitoring cruises. At each collection period, four cores were extracted from *Montastraea faveolata* colonies at both Banks for a total of eight cores. A pneumatic drill, fitted with a diamond tipped 7.62-cm (3.00-in) lapidary bit, was used to extract cores from the center ridge of large *M. faveolata* colonies. Corals were sampled at their apex and cores were drilled down the main growth axis. Cores were 30 mm (1.18 in) in diameter and 50- to 80-mm (1.97- to 3.15-in) long, spanning several years of growth. Short cores spanning ten or more years of growth can be collected quickly and easily. The hole left from core extraction was filled with a pre-formed limestone plug inscribed with the date of core extraction to prevent subsequent mortality and bioerosion of the sampled colony (Figure 2.3.2).

Figure 2.3.2. Scientists use a pneumatic drill at the FGB in June 2007 to extract a coral core from a colony of *Montastraea faveolata*. The core measures 30 mm in diameter and at least 50 mm in length.

2.3.3. Laboratory Methods

Cores from the field were stored in coolers and shipped to Florida for analysis. In the laboratory, cores were longitudinally sectioned into 3- to 4-mm (0.12- to 0.16-in) thick slabs to reveal accretionary growth bands. Cores were sectioned using a single-blade diamond impregnated lapidary saw. Coral slabs were arranged on Kodak brand Industrix 400 X-ray film and exposed to X-rays (70-kV, 15-ma with an exposure time of 7-sec) to reveal annual density bands.

Growth rates of the *Montastraea faveolata* colonies were determined directly by measuring distances between consecutive high-density bands. Three measurements were made along each growth band and averaged for an estimate of growth rate per year. 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 Region Office in Key Largo, Florida.

2.3.4. Data Presentation and Statistical Analysis of Growth Rates

The two sampling periods (June 2005 and June 2007) resulted in the collection of 16 cores (eight cores per sampling period). Mean growth rates and standard errors or standard deviations were calculated for each Bank and year (1992-2007). A Student's t-test assuming equal variances compared values between the EFGB and WFGB.

2.4. LATERAL GROWTH

2.4.1. 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; CSA 1996; Dokken et al. 2003; Gittings et al. 1992; Precht et al. 2006; Precht et al. 2008b). The margins of *D. strigosa* colonies were monitored to detect any incipient changes over time and space.

2.4.2. Field Methods

Sixty lateral growth stations, located on the margins of *Diploria strigosa* colonies, were maintained at each Bank. Sixty-two and 64 colonies of *D. strigosa* were photographed on the EFGB and WFGB, respectively, to assess coral margin growth rates in 2003. In 2004, 36 and 27 lateral growth stations were photographed at the EFGB and WFGB, respectively. The low sample sizes in 2004 resulted from poor weather conditions. Sixty colonies of *D. strigosa* on the EFGB and 58 colonies on the WFGB were photographed in June 2005. In 2006, 52 colonies were photographed on the EFGB and 60 colonies were photographed on the WFGB, and in 2007 the sample sizes were 58 and 18, respectively. The low sample size at the WFGB in 2007 was again a result of diving interruptions due to poor weather conditions. Lateral growth data were not collected during the 2008 annual monitoring cruise due to constraints of weather.

These photographs permitted comparisons of a total of 45 stations between 2003 and 2004 (24 from the EFGB and 21 from the WFGB), 55 stations between 2004 and 2005 (30 from the EFGB and 25 from the WFGB), 85 stations between 2005 and 2006 (35 from the EFGB and 50 from the WFGB), and 54 stations between 2006 and 2007 (39 from the EFGB and 15 from the WFGB). Table 2.4.1 shows the number of lateral growth photographs collected and the number of photographs comparable at the EFGB and WFGB from 2003 to 2007. 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 or photographer error 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 totalled 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 (e.g., 2005 and 2006), there were fewer than 60 photo comparisons possible for the reasons listed above.

2.4.2.1. 2004-2007 Film Photography

Divers were equipped with a Nikonos V camera with a 28-mm lens, Nikonos close-up kit (close-up lens and framer), and strobe (Figure 2.4.1). The camera was set at f22 and a distance of infinity, and the strobe set to TTL. This produced 13.3- x 19.7-cm (262.01-cm^2) photographic images (Figure 2.4.2). The framer was placed on corner pins at each station, ensuring a repeated image of the station. Many 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* colonies.

Table 2.4.1.

Number of lateral growth photographs collected and number of photographs comparable to the previous year at the EFGB and WFGB from 2003 to 2007.

Year	EFGB		WFGB	
	Number of Photos Collected	**Number of Photos Comparable to Previous Year**	**Number of Photos Collected**	**Number of Photos Comparable to Previous Year**
2003	62	Refer to Precht et al. (2006)	64	Refer to Precht et al. (2006)
2004	36	24	27	21
2005	60	30	58	25
2006	52	35	60	50
2007	58	39	18	15

Figure 2.4.1. Scientist photographing a lateral growth station on a *Diploria strigosa* colony at the FGB in June 2007.

Figure 2.4.2. Image for analysis of *Diploria strigosa* lateral growth at the EFGB, showing 2004 (yellow line) and 2005 (orange line) comparison, using Adobe Photoshop®.

2.4.2.2. 2007 Digital Photography

During the August 2007 cruise, in addition to the film photography, subsamples of the lateral growth stations at both Banks were re-photographed with digital camera setups. This data collection served as a trial run to evaluate the possibility of switching from film to digital photography in the lateral growth component of the monitoring effort. Seventeen lateral growth stations were re-photographed with an Olympus digital camera setup, and an additional 13 stations were re-photographed with a Sea&Sea digital camera setup.

The Olympus setup included an Olympus C4000 digital camera (4 megapixels; Super High Quality setting), a Light & Motion Tetra 3030 housing equipped with a flat lens port (Tetra 854-0055), two Nikonos SB 105 strobes (M 1/16 setting), and a camera frame. The camera frame was built with a plate of lexan (highly durable polycarbonate resin thermoplastic), aluminum angle, and stainless steel nuts and bolts. The lexan plate steadied the base of the underwater housing and two pieces of aluminum angle that set the underwater housing lens port at a 26.7-cm (10.51-in) distance from the coral substrate. The two pieces of aluminum angle were attached to the lexan plate and were 24.7 cm (9.72 in) apart such that the dimensions of the digital image would include the length of the living coral margin found between the two permanent station pins (image dimensions were 24.3 cm by 16.6 cm or 9.57 in by 6.54 in). The aluminum angle was painted with mat black paint to prevent interference with the artificial lighting of the strobes.

The Sea&Sea setup consisted of a 5.1 megapixel Sea&Sea 5000G digital camera, underwater housing (Sea&Sea DX 5000G), Sea&Sea YS-15 strobe, and framer kit. The zoom function on the digital camera was set to wide angle and the strobe was set to 1. The close-up frame was attached to the camera by a 35.5-cm (14-inch) metal bar. The framer was positioned on corner pins at each station.

2.4.3. Image Analysis for Lateral Growth

Images corresponding to a specific lateral growth station were compared between consecutive years (2003-2004, 2004-2005; 2005-2006; 2006-2007), and between film and digital images taken in 2007 (Figure 2.4.2). Lateral differences in the margins of the *Diploria strigosa* colonies were evaluated by overlaying the pairs of photographs and calculating the area of advance or retreat laterally, using Sigma Scan Pro 5®. Successive photographs of a given colony were lined up using the colony's ridge patterns.

2.4.4. Data Presentation and Statistical Analysis for Lateral Growth

The data were examined for conformity to the normality and homogeneity-of-variances assumptions of parametric statistics, and were transformed as necessary. Proportional annual changes in the area of individual *Diploria* colonies, whether positive or negative, were examined by site (EFGB and WFGB) and by interval (2003-2004, 2004-2005, 2005-2006, and 2006-2007). A repeated-measures ANOVA design was employed to compare lateral changes through time, as described in section 3.3. Statistical analyses were performed using Minitab® 14.12. Film and digital photographs taken at the same stations in 2007 were compared informally using descriptive statistics (means and standard errors).

2.5. Repetitive Quadrats

2.5.1. Methodological Rationale

Permanent quadrats, each covering 8 m^2, were repeatedly photographed to monitor changes in the composition of benthic assemblages on the FGB. The 8-m^2 repetitive quadrats were located within the EFGB and WFGB study sites, as well as at the deep stations on the EFGB. The photographs were analyzed in two ways. The first method measured the percent cover of benthic components in 2004 through 2008 using random-dot analysis. Second, selected corals within the repetitive quadrats were analyzed using planimetry to measure growth or loss of tissue. Colonies of the most prevalent coral species (*Montastraea annularis* species complex, *M. cavernosa*, *Porites astreoides*, *Diploria strigosa*, and *Colpophyllia natans*) were matched between years based on their visible margins. These corals tended to be near the centers of the photographs. A subsidiary methodological question was whether and how to make the transition to digital photography from film photography, which had been used in previous monitoring of the repetitive quadrats.

2.5.2. Field Methods

In 2004 through 2008, the number of 8-m^2 repetitive quadrats photographed at the EFGB study site ranged from 38 to 41 and the number photographed at the WFGB study site ranged from 23 to 44 (Table 2.5.2). All nine EFGB deep station quadrats were photographed in 2004, 2005, 2007, and 2008. In 2006, only seven of the nine deep repetitive quadrats were photographed. In 2003, eight deep stations were photographed (Precht et al. 2005).

Table 2.5.2.

Number of repetitive quadrats photographed each year at the EFGB and WFGB study sites, as well as the EFGB deep stations.

Number of Repetitive Quadrats Photographed			
Year	**EFGB**	**WFGB**	**Deep Stations**
2003	41	44	8
2004	39	23	9
2005	41	38	9
2006	39	41	7
2007	39	36	9
2008	38	37	9

2.5.2.1. 2004-2007 Film Photography

In 2004 through 2007, stations were photographed using a Nikonos V camera and 15-mm lens (Figure 2.5.2). The camera was loaded with Kodak Ektachrome or EliteChrome 200 ASA, 36-exposure slide film and standard settings were applied (distance = 2 m, f8). The camera was mounted in the center of a T-bar camera frame, with a distance of 2 m (6.56 ft) from the substrate and 1.2 m (3.94 ft) between strobes. Two Ikelite 75 watt-second strobes were mounted on the ends of the T-bar and set on TTL and slave (Gittings et al. 1992). The camera was positioned in a north-facing direction to ensure repetitive photographs from year to year. The consistent orientation of the camera was achieved with a compass and a bubble level.

2.5.2.2. 2007 Digital Photography

During the August 2007 rehabilitation cruise, in addition to the film photography, a subsample of the repetitive quadrat stations at the EFGB study site was re-photographed with a digital camera set-up. This data collection served as a trial run to evaluate the possibility of switching from film to digital photography in the repetitive quadrat component of the monitoring effort. Ten repetitive quadrats at the EFGB were photographed with a digital setup (only eight of these stations were photographed with both the digital and film set-ups) that consisted of an Olympus C4000 set on the super-high-quality, 4-megapixel setting. The camera was housed in a Light & Motion Tetra 3030 housing equipped with a wide angle lens (Tetra Wide Angle Lens 854-0048), providing an angle of coverage of ~75°. Two synchronized Nikonos SB-105 strobes, set to M-full (the camera does not work on TTL), were affixed at the ends of articulated Ultralight strobe arms. The housing was attached to a frame placing the camera lens at a height of 2.7 m (8.86 ft) above the reef. The camera frame consisted of a plate of lexan, aluminum angle, and stainless steel nuts and bolts. The lexan plate steadied the base of the underwater housing and the aluminum angle established the camera altitude above the reef. The aluminum angle was painted with mat-black paint to prevent any light reflection. A bubble level affixed to the back plate of the camera housing allowed for the positioning of the housing perpendicular to the reef as the digital images were captured. At a height of 2.7 m (8.86 ft) above the reef, the camera captured an area measuring 2.43 m by 3.29 m (7.97 ft by 10.79 ft), or 8 m^2 (86 ft^2).

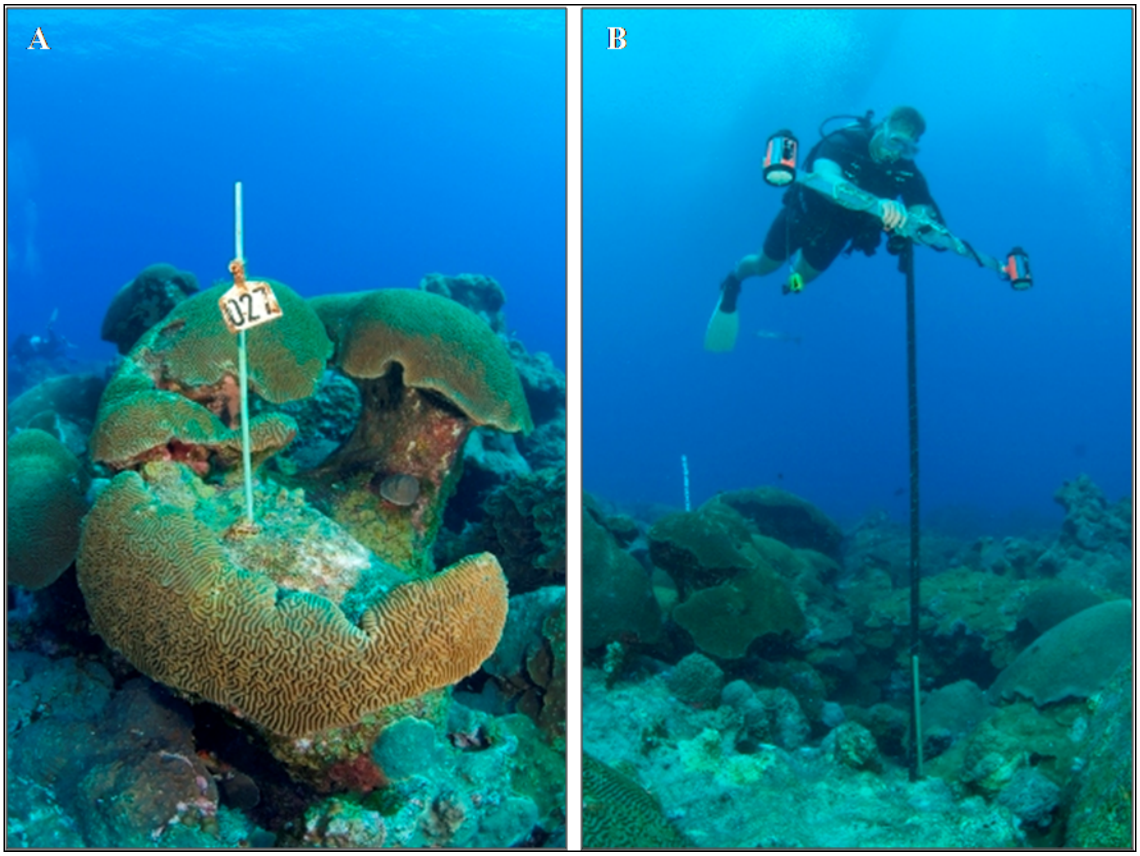


Figure 2.5.2. (A) A repetitive quadrat station at the EFGB. (B) A scientist collects repetitive quadrat data using the Nikonos V camera setup.

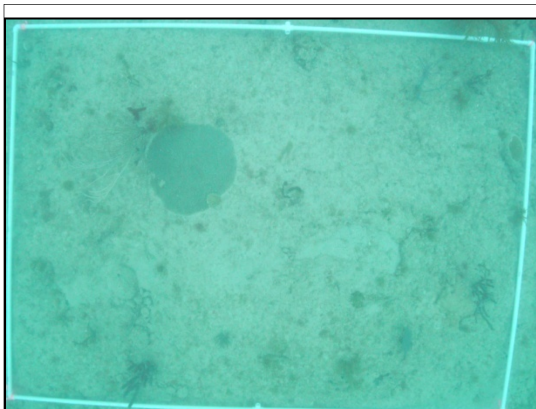
2.5.2.3. 2008 Digital Photography

Sea&Sea DX-1G Digital Camera Set-up and Field Test

The Olympus C4000 digital images collected at the repetitive quadrat stations in August 2007 provided enough resolution to conduct a statistical comparison of the 2007 film and digital photographs. However, the Olympus C4000 did not have the necessary resolution to analyze benthic components to lowest possible taxonomic group. In order to produce high-resolution photographs at a distance of > 2.0 m (6.56 ft) from the substrate, an appropriate digital camera would need the following qualities: 1) At least 6-megapixel resolution, 2) the ability to store high-resolution images in the RAW format, 3) an affordable price, and 4) a compact underwater housing. A new digital camera and underwater housing package was purchased on May 13, 2008, which consisted of a Sea&Sea DX-1G digital camera and underwater housing, two Inon D-2000S strobes, and a Sea&Sea Wide Angle Lens.

The new digital camera setup was field-tested on May 23, 2008 and June 1, 2008. The purpose of these dives was twofold: 1) to determine the necessary height off of the seafloor to capture an 8-m^2 (86-ft^2) area (same area captured by Nikonos V set-up at the repetitive quadrat stations) and 2) to determine the camera settings needed to produce a high quality image, allowing the analyzer to identify benthic components to lowest, possible taxonomic group. Prior to the dives, a 2.43-m by 3.29-m (7.97-ft by 10.79-ft) PVC rectangle was constructed to represent the 8-m^2 (86-ft^2) area of substrate captured by the Nikonos V camera setup. A PVC pole was also constructed with holes drilled at 0.1-m (0.33-ft) increments from 1.8 m (5.9 ft) to 3.0 m (9.8 ft) from the base of the pole. These increments were used to determine the appropriate height from the substrate at which to mount the camera. The first dive was conducted near Haulover Inlet in Miami, Florida. The PVC rectangle was assembled on the boat and then dropped overboard into sand. Once the PVC rectangle was positioned on the sand, the center-point of the rectangle was determined by using two transect tapes. The PVC pole was then placed at the center-point. First, the Nikonos V was attached to the PVC pole at the 1.8-m (5.9-ft) mark and two pictures were taken. Divers then moved the Nikonos V up the PVC pole at 0.1-m (0.33-ft) increments and took two pictures at each distance. Because the viewfinder is difficult to use underwater, we were unable to analyze the shots until after the film was developed. This exercise was performed in order to verify that the Nikonos V captured the entire PVC rectangle, or 8-m^2 (86-ft^2) area, at 2.0 m (6.6 ft). The second exercise involved hovering in the center of the PVC rectangle with the Sea&Sea DX-1G digital camera set-up, increasing and decreasing buoyancy as needed, until the entire PVC rectangle was visible in the viewfinder. The distance between the screw, located on the mounting tray of the Sea&Sea DX-1G set-up, and the seafloor was measured with a transect tape. Observed height above seafloor was determined to be 2.2 m (7.2 ft).

Divers moved the PVC rectangle to a hardbottom area in order to ensure that the selected camera settings would produce a high-quality picture for benthic analysis. Appropriate camera settings are required in order to ensure that the subject (2.2-m or 7.2-ft away) would be in focus and illuminated. Due to bad weather, divers were only able to take a few pictures. After analyzing the photographs, it was determined that the picture quality was poor and camera settings needed to be modified (Figure 2.5.3).

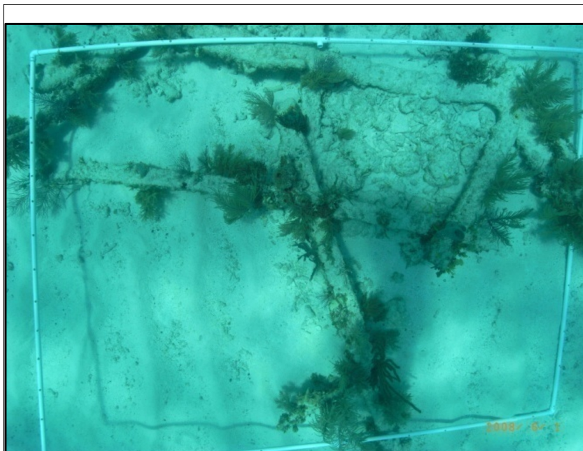


Camera Settings
Picture Quality Mode/Image Size: Raw 10 MB
Focus Setting: Multi AF
Light Metering (AE Metering): Multi
Shooting with Multi-Shot (Cont. Mode): Off
Picture Quality (IMG set): Hard
Auto Bracket: Off
Exposure Setting: 0.0
White Balance: Auto
ISO Sensitivity: Auto
Camera Shake Correction: On

Figure 2.5.3. Photograph taken with Sea&Sea DX-1G on May 23, 2008.

The next two dives were completed on June 1, 2008 in Key Largo, Florida. The purpose of this dive was to confirm the height of 2.2 m (7.2 ft) and to fine-tune the camera settings. During the field test, divers placed the 8-m^2 (86-ft^2) PVC rectangle on sandy substrate. Divers attached the camera to the PVC pole at a distance of 1.8 m (5.9 ft) from the bottom of the pole. The center of the rectangle was determined using transect tapes. The PVC pole (with mounted Sea&Sea DX-1G camera) was placed in the center of the rectangle. A diver took a photo at the closest setting

(1.8 m or 5.9 ft) and then moved the camera to the next increment on the pole and took a photograph. The diver continued to increase the distance from the substrate (in 0.1 m or 0.33 ft increments) until the entire PVC rectangle was visible in the viewfinder and corresponding photograph. The distance between the screw (attaching the Sea&Sea DX-1G to the PVC pole) and the seafloor was measured with a transect tape. The measured height necessary to capture the 8-m^2 (86-ft^2) area was between 2.1 m (6.89 ft) and 2.2 m (7.22 ft). Thus, the mounting height used for the repetitive quadrat set-up for the 2008 annual monitoring cruise was 2.15 m (7.05 ft; average between 2.1 m and 2.2 m). This mounting height put the camera lens at 2.0 m (6.56 ft) above the seafloor. Camera settings were adjusted to ensure that the photographed area was in focus and properly illuminated (Figure 2.5.4).



Camera Settings
Picture Quality Mode/Image Size: Raw 10 MB
Focus Setting: Multi AF
Light Metering (AE Metering): Spot
Shooting with Multi-Shot (Cont. Mode): Off
Picture Quality (IMG set): Normal
Auto Bracket: Off
Exposure Setting: 0.0
White Balance: Auto
ISO Sensitivity: ISO 100
Camera Shake Correction: On

Figure 2.5.4. Photograph taken with Sea&Sea DX-1G on June 1, 2008.

2008 Annual Monitoring Cruise
The results of the statistical comparison of the 2007 film and digital photographs (see section 3.4.2) indicated that the digital photographs can be directly compared to film photographs of the same repetitive quadrat station from the previous year. Thus, only digital photographs were collected at the repetitive quadrat stations in November 2008. The Sea&Sea DX-1G camera was mounted in the center of a T-bar camera frame, at a distance of 2.15 m (7.05 ft) from the substrate. Two Inon D-2000S strobes were mounted 1.2 m (3.9 ft) apart on the ends of the T-bar and set to TTL. The camera settings were adjusted to ensure that the photographed area was in focus and properly illuminated (see discussion of camera settings above), and the camera was positioned in a north-facing direction to ensure consistency from year to year. The consistent orientation of the camera was achieved with a compass and a bubble level.

2.5.3. Image Analysis for Repetitive Quadrats

2.5.3.1. Percent Cover of Benthic Components

The percent cover of coral species; the cover of sponges, macroalgae, and CTB; and the cover of coral bleaching, paling, concentrated and isolated fish biting, and disease were determined by overlaying different sets of 300 random dots on each photograph using CPCe® point-count software with Excel extensions. Percent cover was calculated for the 2004-2008 images. Table 2.5.3 presents the number of repetitive quadrats analyzed for percent cover per year at the EFGB and WFGB. Note that only 38 of the 39 repetitive quadrat stations and eight of the nine deep repetitive quadrat stations photographed at the EFGB in 2004 were analyzed.

Table 2.5.3.

Number of repetitive quadrats analyzed each year for the EFGB and WFGB study sites, as well as the EFGB deep stations.Only photographs of the same repetitive quadrat station taken at the WFGB between 2004 and 2005 (matching photographs for planimetry analysis) were analyzed using random dots.

Number of Repetitive Quadrat Stations Analyzed			
Year	**EFGB**	**WFGB**	**Deep Stations**
2004	38	20	8
2005	41	20	9
2006	39	41	7
2007	39	36	9
2008	38	37	9

Percent cover estimates of major benthic categories (coral, sponges, macroalgae, other live, CTB, and sand, rubble, shell matrix) were determined for each of the eight quadrats that were photographed with both film and digital cameras in 2007. The cover estimates were derived using the random-dot method for both photograph types, as described above. The cover estimates from the digital photographs were subtracted from the corresponding cover estimates from the film photographs. To determine how much of the variability between the film and digital assessments was due to the placement of the random dots, a second assessment of the film photographs was conducted, with a new and different set of random dots generated for each photograph.

2.5.3.2. Planimetry Analysis

Planimetry was used to measure tissue change of select coral colonies (i.e., *Montastraea annularis* species complex, *Diploria strigosa*, *Colpophyllia natans, Montastraea cavernosa*, and *Porites astreoides)* at repetitive quadrat stations in successive years (2003-2004; 2004-2005; 2005-2006; 2006-2007; 2007-2008). To calculate coral colony areas from the 2004-2007 Nikonos V photographs, the image was first calibrated to an image size of 25.2 cm by 37.9 cm (9.92 in by 14.92 in) in Sigma Scan Pro 5®. Once calibrated, the analyzer used the tracing tool to trace the boundary of select coral colonies, with the same colonies traced each year. Upon completion of the trace, the program then output the individual coral colony area in cm^2. At the EFGB study site, it was possible to compare 38 quadrats for the 2003-2004 interval; 36 quadrats for the 2004-2005 interval; 37 quadrats for the 2005-2006 interval; 35 quadrats for the 2006-2007 interval; and 32 quadrats for the 2007-2008 interval. At the WFGB study site, it was possible to compare 23 quadrats for the 2003-2004 interval; 20 quadrats for the 2004-2005 interval; 38 quadrats for 2005-2006 interval; 35 quadrats for 2006-2007 interval; and 34 quadrats for the 2007-2008 interval. For the EFGB deep stations, eight quadrats were compared for the 2003-2004 interval; nine quadrats were compared for the 2004-2005 interval; seven quadrats were compared for the interval 2005-2006 interval; seven quadrats were compared for the interval 2006-2007; and nine quadrats were compared for the 2007-2008 interval (Table 2.5.4). Note that these numbers represent all quadrats/stations analyzed during planimetry analysis and not the number of quadrats statistically analyzed for the *Montastraea annularis* species complex. The *M. annularis* species complex was not measured at all repetitive quadrat stations.

Table 2.5.4.

Number of quadrats compared during planimetry analysis at the EFGB, WFGB, and EFGB deep stations over the time intervals 2003-2004, 2004-2005, 2005-2006, 2006-2007, and 2007-2008.

Interval	EFGB	WFGB	EFGB Deep Stations
2003-2004	38	23	8
2004-2005	36	20	9
2005-2006	37	38	7
2006-2007	35	35	7
2007-2008	32	34	9

Area of Capture for the Nikonos V Camera and the Sea&Sea DX-1G Digital Camera

Planimetry measurements of coral colonies photographed from 2003 to 2007 (with the Nikonos V) were based on a calibration to image size rather than the actual, 8-m^2 (86-ft^2) area. In order to conduct planimetry analyses on the 2008 digital photographs, the exact dimensions of the 8-m^2 (86-ft^2) area needed to be determined for both the Nikonos V and the Sea&Sea DX-1G. Divers laid two transect tapes at 90º angles to one another in the bottom of a swimming pool. Divers then photographed the transect tapes with the Nikonos V camera set-up (Nikonos V camera and 15-mm lens; distance = 2.0 m; f8; camera mounting height of 2.0 m) and the Sea&Sea DX-1G camera set-up (Raw; Multi AF, Spot Metering; ISO 100; Camera Shake Correction; mounting height of 2.15 m; Figure 2.5.5). Bubble levels were used to ensure the appropriate orientation of the cameras perpendicular to the pool bottom.

For the Nikonos V, the height and width measurements of the actual area captured were 2.2-m (7.2-ft) high by 3.5-m (11.5-ft) wide (7.7 m^2 or 82.9 ft^2). For the Sea&Sea DX-1G, the height and width measurements were 2.4 m (7.9 ft) by 3.4 m (11.2 ft), respectively (8.2 m^2 or 88.3 ft^2). To calculate coral colony areas from the 2008 digital photographs, each image was calibrated to the actual area captured by the Sea&Sea DX-1G, 2.4 m by 3.4 m (7.9 ft by 11.2 ft). As described above, select coral colonies were traced and areas were determined.

In order to compare the 2007 and 2008 coral colony areas for planimetry analysis, the 2007 colony areas were first converted so that they were relative to the actual area photographed rather than the image size. The conversion factor was determined by dividing the actual area captured with the Nikonos V (7.7 m^2 or 77,000 cm^2) by the image area (955.08 cm^2) previously used during planimetry analysis. This resulted in a conversion factor of 80.62. The 2007 coral colony areas (cm^2) were multipled by 80.62 and then converted to m^2.

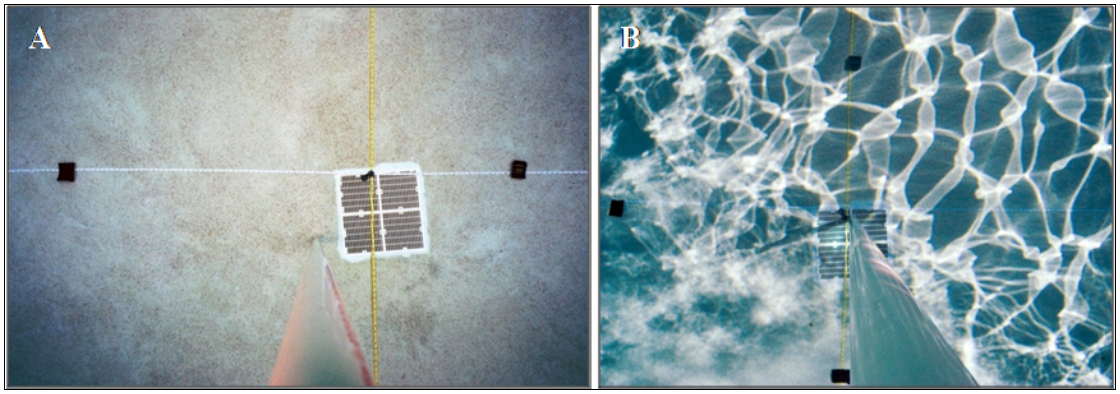


Figure 2.5.5. Images used to estimate the dimensions captured by (A) the Nikonos V camera and (B) the Sea&Sea DX-1G digital camera.

2.5.4. Data Presentation and Statistical Analysis for Repetitive Quadrats

2.5.4.1. Percent Cover of Benthic Components

Mean percent cover of corals, sponges, macroalgae, CTB, bleaching, fish biting, and disease were calculated using random-dot analysis with CPCe® software. Results of this analysis are presented in section 3.4.1.1.

2.5.4.2. Film vs. Digital Comparison

The percent cover estimates generated from the digital photographs were subtracted from the corresponding cover estimates from the film photographs. The absolute values of these differences were compiled and basic statistics were calculated. The estimates were compared using a repeated-measures ANOVA design.

2.5.4.3. Planimetry Analysis

Planimetry results were calculated by taking areal measurements of dominant, frame-building corals (i.e., *Montastraea annularis* species complex, *Diploria strigosa*, *Colpophyllia natans, Montastraea cavernosa*, and *Porites astreoides)* from 2003-2008. The change in area was calculated by subtracting the areal value of Year 1 from the areal value of Year 2. The change (either positive=growth, or negative=tissue loss) in cm^2 was divided by the areal value (cm^2) from Year 1 to determine proportional growth or loss of tissue.

The proportional changes of several coral taxa were calculated; however, only the *Montastraea annularis* species complex was statistically analyzed, comparing proportional change between Banks and over time. The low samples sizes of the other coral taxa were inadequate for statistical analysis.

2.6. PERIMETER VIDEOGRAPHY

2.6.1. Methodological Rationale

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

2.6.2. Field Methods

Divers videotaped two 100-m (328-ft) segments of the perimeter lines at the EFGB (north and east margins) and WFGB (south and west margins) in 2004, 2005, 2006, 2007, and 2008. At the EFGB, divers began at the northwest corner of the 100- 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 (6.6-ft) distance above the benthos using a weighted line attached to the video housing. In the 2004-2007 video, the camera was aimed down at a 45° angle to capture the substratum. In 2008, the camera was aimed at a 90° angle to the reef. In all years, except at the WFGB in 2008, a 360° panoramic view of the reef was videotaped at those corners documented during the perimeter video.

2.6.3. Laboratory Methods

The video footage was reviewed to record the general condition of coral health and fish populations 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: bleaching, paling, healthy colony, concentrated fish biting, isolated fish biting, growth infilling (tissue regrowth), new incidence of fish biting, surface replaced by turf algae, and unchanged. Concentrated fish biting (CFB) represents the concentrated biting which 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 on an annual basis for 2004-2005, 2005-2006, 2006-2007, and 2007-2008. Changes in coral colony condition were recorded. Note that the same coral colonies were not compared during each time interval. In the 2004-2005 analysis, those corals observed in one year and not found in the other were designated NP (not photographed). In all other years, comparisons were only made between coral colonies that were present in both videos. In addition to comparisons of coral colony condition, fish counts were also conducted. Note that it is not possible to determine fish sizes from perimeter video lines or panoramic views because there is no scale reference. Thus, the perimeter video data may not accurately reflect the status of the FGB fish populations. The perimeter surveys are intended to provide a general overview of ecosystem health.

These analyses were qualitative; therefore, no statistical analyses were conducted on these data.

2.7. Hurricane Ike Impacts

2.7.1. Methodological Rationale

To monitor changes in coral reef community structure due to Hurricane Ike, 8-m^2 repetitive quadrats and perimeter video collected in November 2008 were assessed for hurricane damage.

2.7.2. Field Methods

Refer to sections 2.5.2 and 2.6.2 for repetitive quadrat and perimeter videography field methods.

2.7.3. Laboratory Methods

Repetitive quadrat photographs were collected in both June 2007 and November 2008 at the EFGB and WFGB and compared (32 and 34 matching repetitive quadrat stations compared at the EFGB and WFGB, respectively). Coral colonies present in 2007 repetitive quadrat photographs and missing in 2008 photographs were documented. Measurements of all missing corals were made from June 2007 photographs using Sigma Scan Pro 5® planimetry software to obtain a total area of living coral that had been lost.

To calculate coral colony areas from the June 2007 Nikonos V photographs, the image was first calibrated to an image size of 25.2 cm by 37.9 cm (9.92 in by 14.92 in) in Sigma Scan Pro 5®. Once calibrated, the analyzer used the tracing tool to trace the boundary of coral colonies that were later missing in November 2008 photographs. Upon completion of the trace, the program then output the individual coral colony area in cm^2. Because these coral colony areas were based on a calibration to image size and not the actual 8-m^2 area, all areas were converted by multiplying the 2007 areal value by 80.62. This conversion factor of 80.62 was calculated by dividing the actual area of the 8-m^2 repetitive quadrat station using the Nikonos V (77,000 cm^2 or 11,935 in^2) by the image area used during planimetry analysis (955.08 cm^2 or 148.04 in^2).

Perimeter video footage collected in November 2008 at the EFGB and WFGB was reviewed and compared to June 2007 video to determine possible hurricane impacts along perimeter lines. Possible hurricane impact categories included dislodgement, loss or deposition of entire coral colonies, breaking of corals, and abrasion on the reef.

2.8. Coral Health Surveys

2.8.1. Methodological Rationale

During the 2007 cruise, quantitative coral health surveys were conducted to assess the presence, types, and prevalence of coral diseases and other coral health issues at the EFGB and WFGB. In addition, qualitative observations of coral health were made during dives to cover a wider area of the reef.

2.8.2. Field Methods

Seven 20-m^2 (10-m x 2-m) band transects were haphazardly placed within the 100- x 100-m study sites at both the EFGB and WFGB. All colonies within the each of the band transects were counted and assessed for signs of disease, predation, and any other damage or identifiable health problem.

2.8.3. Data Presentation and Statistical Analyses of Coral Health Data

The prevalence of coral health issues was calculated for the EFGB and WFGB in June 2007. The proportion of healthy colonies, diseased colonies (ciliates, bleaching, and growth anomalies), and colonies exhibiting signs of predation was calculated for each coral species at each Bank.

2.9. QUALITATIVE FIELD OBSERVATIONS

2.9.1. Methodological Rationale

In addition to the annual data collection protocol, it is necessary to document other biologically relevant information observed on the reefs of the FGB. During each annual monitoring cruise, observations of general coral reef health, as well as notable biological and oceanographic events (e.g., sponge spawning) were qualitatively assessed and documented.

2.9.2. Field Methods

As divers traversed the EFGB and WFGB study sites during the 2004-2008 annual monitoring cruises, they noted and photographically documented any biologically relevant observations and/or events. In addition, samples of interest (i.e., sub-fossil corals and coral fragments) were occasionally collected for further analysis.

Sponge spawning. Qualitative field observations of *Agelas clathrodes* and *Xestospongia muta* spawning were made during dives on the EFGB and WFGB during the June 2007 annual monitoring cruise.

Acropora discoveries. The first living colonies of *Acropora palmata* were discovered on the FGB in 2003 and 2005 (Zimmer et al. 2006). Those discoveries, coupled with a known history of bank flooding since the last glacial maximum, led a member of our team (W.F. Precht) to predict that *Acropora*-dominated reefs underlie and form the structural foundation of the living reef community at the EFGB and WFGB. Surveys conducted in June 2006 and June 2007 investigating this hypothesis resulted in the first discoveries of sub-fossil *A. palmata* and *A. cervicornis*.

Coral disease. During the 2004-2008 annual monitoring cruises, scientific divers made qualitative observations of coral colonies exhibiting signs of disease or other coral health issues.

Exotic/invasive species. During the 2004-2008 annual monitoring cruises, scientific divers made qualitative observations of any exotic species occurring on the reefs of the EFGB and WFGB.

Coral biodiversity and taxonomy. Qualitative field observations regarding scleractinian coral diversity and taxonomy were made during dedicated dives on the June 2007 annual monitoring cruise.

2.10. Water Quality

2.10.1. Methodological Rationale

Hereafter, 'water quality' will refer to the physical (temperature, turbidity, photosynthetically active radiation [PAR]), biological (chlorophyll *a* [chl *a*]), and chemical (salinity, dissolved oxygen [DO], hydrogen ion concentration [pH], and nutrients) characteristics of the water overlying the FGB. This report presents the results of the water quality monitoring at the EFGB and WFGB conducted from March 2004 to November 2008.

During the 2004 to 2008 reporting period, YSI sensors and HoboTemp thermistors deployed at the EFGB and WFGB recorded variations of water depth, temperature, salinity, DO, pH, turbidity, and PAR (Figure 2.10.1). On September 12-13, 2001, two semi-permanent platforms (Ocean Sentinel Platforms or OSPs) were installed at the EFGB and WFGB to provide secure attachment points for the YSI and HoboTemp thermistors (Dokken et al. 2003). The design for the OSPs includes eight angle-iron struts welded to a galvanized train wheel (Dokken et al. 2003). The stainless steel YSI frame, with anti-fouling collars to protect the sensors from bioaccumulation, was mounted between two of the angle-iron struts. The distance between the mounting holes on the angle-iron struts is ~0.8 m.

Figure 2.10.1. Photograph of YSI/Hobo set-up at the FGB in February 2003.

In 2008, temperature and salinity data were also recorded using an additional instrument, the SBE 37-SMP MicroCAT, manufactured by Sea-Bird Electronics, Inc. Starting in June 2005, vertical profiles of temperature and salinity were constructed for the FGB reef cap. A backup

YSI instrument was also deployed during onsite work for quality assurance purposes. Water samples collected from the sea surface to the reef cap at the EFGB and WFGB from March 2004 to November 2008 were analyzed for chl *a* and nutrients (ammonia, nitrate, nitrite, soluble reactive phosphorous, and total Kjeldahl nitrogen [TKN]).

2.10.2. YSI Datasondes

The YSI 6600 Series datasonde used in this study was a multiparameter, deployable monitoring system capable of measuring and recording temperature, depth, pH, DO, specific conductance, turbidity, and PAR. The datasondes typically had up to a 75-day battery life (at 15-min sampling intervals) and stored 150,000 individual parameter readings. The datasondes were 51.8-cm (20.4-in) long and had an 8.9-cm (3.5-in) diameter. The units were internally powered by eight size-C, alkaline batteries. Measurement methods were as follows:

Specific Conductance. Datasondes utilized 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).

Temperature. The datasondes utilized 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.

pH. A field-replaceable pH electrode was used to determine hydrogen ion concentration. The probe was a combination electrode consisting of a proton selective glass reservoir filled with a buffer at approximately pH 7 and an Ag/AgCl reference electrode that utilized a gelled electrolyte. A silver wire coated with AgCl was immersed in the buffer reservoir. Protons (H+ ions) on both sides of the glass (media and buffer reservoir) selectively interacted with the glass, setting up a potential gradient across the glass membrane.

Depth. Depth was estimated with a differential strain gauge transducer that measured pressure with one side of the transducer exposed to the water and the other side to a vacuum.

Dissolved Oxygen (DO). The datasondes employed a proprietary YSI Rapid Pulse system to estimate DO. The system utilized a Clark-type sensor similar to other membrane-covered steady-state dissolved oxygen probes. The system measured the current associated with the reduction of oxygen diffusing through a Teflon membrane. This current was still proportional to the partial pressure (not the concentration) of oxygen in the solution being evaluated. The membrane isolated the electrodes necessary for this reduction from the external media, enclosed in a thin layer of electrolyte required for current flow, and prevented other non-gaseous, electrochemically active species from interfering with the measurement.

Turbidity. Turbidity describes the content of suspended solids (cloudiness) in water and is typically determined by shining a light beam into a sample solution and measuring light scatter. For turbidity systems capable of field deployment (including YSI), the usual light source is a light emitting diode (LED) which produces radiation in the near infrared region of the spectrum. The YSI turbidity system datasondes consisted of a probe which conformed to International Organization for Standardization (ISO) recommendations. The output of the datasonde turbidity sensor was processed via the datasonde software to provide readings in nephelometric turbidity units or NTUs.

Photosynthetically Active Radiation (PAR). PAR is the portion of the light spectrum used by primary producers to perform photosynthesis (400-700 nanometers). Because primary producers (phytoplankton, turf algae, macroalgae, and algal symbionts living within sessile invertebrates) are critical to the reef community and form the basis of the food web, it is critical to measure this component of light on the reef cap.

One YSI datasonde was deployed at the EFGB (23-m or 75-ft water depth) and one at the WFGB (27-m or 89-ft water depth). Sand flats were used as deployment locations to accommodate the secure attachment of the datasondes to galvanized train wheels (Figure 2.10.2). Water quality data were recorded every 30 minutes. Available and missing YSI datasets are shown in Tables 2.10.2 and 2.10.3, respectively.

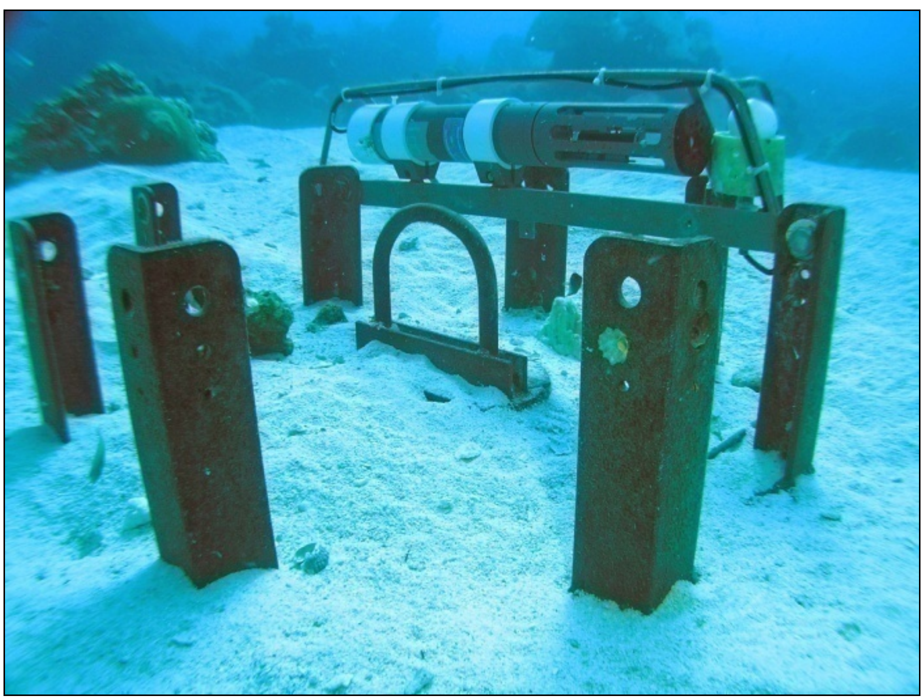


Figure 2.10.2. An image of the YSI datasonde deployed at the FGB. Photograph courtesy of FGBNMS.

Table 2.10.2.

Available YSI datasets at the EFGB and WFGB from March 2004 to November 2008.

	EFGB	WFGB
1	03/11/04 to 04/15/04	03/11/04 to 07/15/04
2	07/15/04 to 12/03/04	07/15/04 to 11/19/04
3	05/11/05 to 06/08/05	11/19/04 to 02/23/05
4	06/08/05 to 08/27/05	05/09/05 to 06/07/05
5	08/27/05 to 10/12/05	06/07/05 to 08/25/05
6	10/12/05 to 11/14/05	10/11/05 to 12/15/05
7	11/14/05 to 05/13/06	05/13/06 to 06/14/06
8	05/13/06 to 06/13/06	06/14/06 to 02/19/07
9	06/12/06 to 11/27/06	03/06/07 to 05/19/07
10	03/07/07 to 05/19/07	05/19/07 to 06/12/07
11	05/19/07 to 06/12/07	06/14/07 to 08/14/07
12	06/12/07 to 08/13/07	10/14/07 to 02/02/08
13	08/14/07 to 10/13/07	02/02/08 to 07/02/08
14	10/13/07 to 02/02/08	07/02/08 to 09/17/08
15	02/02/08 to 07/03/08	
16	07/03/08 to 11/03/08	

Table 2.10.3.

Time periods of missing or irretrievable YSI data at the FGB from 2004-2008.

Bank	Time Period	Reason for Data Loss
EFGB	04/15/04 to 07/15/04	Data recovery impossible
	12/03/04 to 05/11/05	Data recovery impossible
	11/27/06 to 03/07/07	Data lost due to battery failure
WFGB	02/23/05 to 05/09/05	YSI hardware failure
	08/25/05 to 10/11/05	YSI data not recovered due to hurricane damage
	12/15/05 to 05/13/06	YSI hardware failure
	02/19/07 to 03/06/07	Data lost due to battery failure
	08/14/07 to 10/14/07	Data encrypted and recovery impossible
	09/17/08 to 11/04/08	Data recovery impossible

2.10.3. HoboTemp Thermographs

HoboTemp recorders have an accuracy of ±0.2°C and resolution is 0.02°C at 25°C. HoboTemp thermographs were attached to each of the YSI instruments as backup records of water temperature. The data loggers were deployed in a water depth of 23 m (75 ft) at the EFGB and in a 27-m (89-ft) water depth at the WFGB. Temperature was recorded every 30 minutes, concurrently with the YSI estimates. Some HoboTemp data were gathered outside of the YSI deployment schedule. Available and missing HoboTemp datasets are shown in Tables 2.10.4 and 2.10.5, respectively.

Table 2.10.4.

Available HoboTemp thermograph datasets at the EFGB and WFGB from March 2004 to July 2008.

	EFGB	WFGB
1	03/11/04 to 07/15/04	03/11/04 to 07/15/04
2	05/11/05 to 06/08/05	07/15/04 to 11/19/04
3	06/08/05 to 08/27/05	05/09/05 to 06/07/05
4	10/12/05 to 11/14/05	06/07/05 to 08/25/05
5	11/14/05 to 05/13/06	08/25/05 to 10/12/05
6	05/13/06 to 06/12/06	05/13/06 to 06/14/06
7	06/12/06 to 03/06/07	06/14/06 to 03/06/07
8	03/07/07 to 05/19/07	03/06/07 to 05/19/07
9	05/19/07 to 06/12/07	05/19/07 to 06/12/07
10	06/12/07 to 08/13/07	06/14/07 to 08/14/07
11	08/14/07 to 10/13/07	08/14/07 to 10/14/07
12	10/13/07 to 02/02/08	10/14/07 to 02/02/08
13	02/02/08 to 07/03/08	

Table 2.10.5.

Time periods of missing or irretrievable HoboTemp data at the FGB from 2004-2008.

Bank	Time Period	Reason for Data Loss
EFGB	07/15/04 to 05/11/05	HoboTemp lost from the YSI datasonde
	08/27/05 to 10/12/05	HoboTemp lost from the YSI datasonde due to hurricane damage
	07/03/08 to 11/03/08	Data recovery impossible
WFGB	11/19/04 to 05/09/05	HoboTemp lost from the YSI datasonde
	10/12/05 to 05/13/06	Data recovery impossible
	02/02/08 to 07/02/08	Data recovery impossible
	07/02/08 to 11/04/08	Data recovery impossible

2.10.4. Sea-Bird Conductivity and Temperature Recorder

The Sea-Bird Electronics, Inc. (SBE) 37-SMP MicroCAT is a high-accuracy conductivity and temperature recorder designed for long-term oceanographic deployment. The MicroCATs used at the FGB included pressure and sound velocity sensors. The sound velocity sensor measures the time (flight time) required for a sound pulse to travel over a fixed length, using a high-speed clock to measure time. The sound velocity data may be coupled with an Acoustic Doppler Current Profiler (ADCP) to calculate currents or it could also be used as baseline data for future projects. 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 2.10.4 shows the MicroCAT deployment apparatus. The available MicroCAT datasets at the EFGB and WFGB are presented in Table 2.10.6.

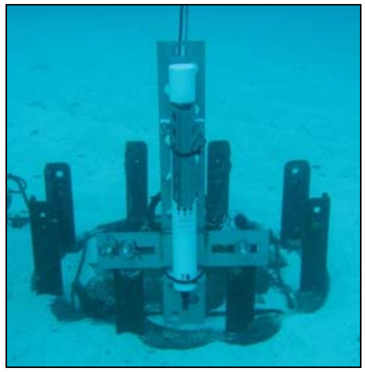


Figure 2.10.4. An image of the Sea-Bird MicroCAT deployed at the EFGB.

Table 2.10.6.

Available Sea-Bird Electronics, Inc. 37-SMP MicroCAT datasets at the EFGB and WFGB.

	EFGB	WFGB
1	02/02/08 to 07/03/08	02/02/08 to 07/02/08
2	11/03/08 - Ongoing	07/02/08 to 11/04/08
3		11/05/08 - Ongoing

During the November 2008 annual monitoring cruise, there was a problem with the connection between the computer and the EFGB Seabird MicroCAT during data download. As a result, data from 07/03/08 to 11/03/08 were not retrieved. Plans were made to recover the dataset during the January 2009 water quality cruise. Unfortunately the data could not be recovered.

2.10.5. Chlorophyll a and Nutrients

Surface (<1 m or <3 ft), midwater (~9 m or 30 ft), and near bottom (~18 m or 59 ft) water samples were acquired at 17 different times on the EFGB and WFGB from March 2004-November 2008 (Table 2.10.7). During each sampling event, water was collected twice at each depth using a vertical sampling bottle (Wildco). Samples were taken off the bow of the dive vessel while the vessel was moored over the monitoring site. The line of the vertical sampling bottle was marked every five feet for the first 30 ft and marked every 10 ft thereafter in order to collect water samples at the depths previously mentioned. During high currents or to compensate for boat swing, weights were added and additional line was deployed to reach the desired depth. The near bottom depth of 18 m or 59 ft was selected in order to avoid contact between the vertical sampling bottle and the reef cap. Water samples were immediately transferred into pre-cleaned polyethylene containers (tested monthly using nanopure water) provided by an independent, EPA-certified analytical laboratory (Anacon, Inc.). 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 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 during each sampling event. 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 an independent laboratory for analysis using standard United States Environmental Protection Agency (USEPA) methods (Table 2.10.8) to assess concentrations of chl *a* and nutrients (ammonia, nitrate and nitrite, TKN, soluble reactive phosphorous).

2.11. FISH SURVEYS

2.11.1. Methodological Rationale

Surveys of fish assemblages have been conducted at the FGB since the early 1980s (Boland et al. 1983; Rezak et al. 1985; Dennis and Bright 1988; Pattengill 1998). Generally, the fish assemblages of the coral reef zone at the EFGB and WFGB are composed of Caribbean reef species; however, the total number of species is reduced in comparison. Certain families such as the snappers (Lutjanidae) and grunts (Haemulidae) are underrepresented or completely absent 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 FGB has been under continuous investigation (Rooker et al. 1997). Therefore, continued monitoring of the FGB 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.

2.11.2. Field Methods

Stationary visual fish surveys were conducted on the reef cap at the EFGB and WFGB in 2004, 2005, 2006, and 2007 (Table 2.11.2). Fish surveys were not collected during the 2008 annual monitoring cruise based on limited dive staff and impending inclement weather. 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 and height of 7.5 m (25 ft) from the diver. All fish species observed within the first five minutes of the survey were recorded. Immediately following this five-minute observation period, additional time was used to record abundance (number of individuals per species) and total length (in centimeters: minimum, maximum, and average) of those fish species noted in the original five-minute period. Unlike previous years, the mode was recorded in 2007 rather than the mean. In 2007, divers also noted maturation phase of certain fish species in the families Labridae, Labridae: Scarinae (parrotfishes; Kaufman and Liem 1982), Acanthuridae, and Pomacentridae. Each survey lasted for a total of 10 to 15 minutes. When necessary, species identifications were verified using Humann (1994) and Humann and DeLoach (2002).

Table 2.10.7.

Water sampling schedule, depth, and number of samples taken at the EFGB and WFGB from 2004-2008.

EFGB			WFGB		
Sampling Date	**Depth**	**Samples**	**Sampling Date**	**Depth**	**Samples**
03-11-04	Surface	4	03-11-04	Surface	4
03-11-04	Midwater	4	03-11-04	Midwater	4
03-11-04	Reef cap	4	03-11-04	Reef cap	4
07-16-04	Surface	4	07-15-04	Surface	4
07-16-04	Midwater	4	07-15-04	Midwater	4
07-16-04	Reef cap	4	07-15-04	Reef cap	4
09-21-04	Surface	4	No sample	-	-
09-21-04	Midwater	4	No sample	-	-
09-21-04	Reef cap	4	No sample	-	-
No sample	-	-	11-19-04	Surface	4
No sample	-	-	11-19-04	Midwater	4
No sample	-	-	11-19-04	Reef cap	4
02-23-05	Surface	4	02-23-05	Surface	4
02-23-05	Midwater	4	02-23-05	Midwater	4
02-23-05	Reef cap	4	02-23-05	Reef cap	4
05-11-05	Surface	4	05-10-05	Surface	4
05-11-05	Midwater	4	05-10-05	Midwater	4
05-11-05	Reef cap	4	05-10-05	Reef cap	4
06-08-05	Surface	4	06-07-05	Surface	4
06-08-05	Midwater	4	06-07-05	Midwater	4
06-08-05	Reef cap	4	06-07-05	Reef cap	4
08-26-05	Surface	4	08-25-05	Surface	4
08-26-05	Midwater	4	08-25-05	Midwater	4
08-26-05	Reef cap	4	08-25-05	Reef cap	4
10-12-05	Surface	4	10-11-05	Surface	4
10-12-05	Midwater	4	10-11-05	Midwater	4
10-12-05	Reef cap	4	10-11-05	Reef cap	4
05-13-06	Surface	4	05-13-06	Surface	4
05-13-06	Midwater	4	05-13-06	Midwater	4
05-13-06	Reef cap	4	05-13-06	Reef cap	4
06-13-06	Surface	4	06-15-06	Surface	4
06-13-06	Midwater	4	06-15-06	Midwater	4
06-13-06	Reef cap	4	06-15-06	Reef cap	4
05-20-07	Surface	9	05-19-07	Surface	9
05-20-07	Midwater	9	05-19-07	Midwater	9
05-20-07	Reef cap	9	05-19-07	Reef cap	9
08-14-07	Surface	6	08-15-07	Surface	6
08-14-07	Midwater	6	08-15-07	Midwater	6
08-14-07	Reef cap	6	08-15-07	Reef cap	6
10-14-07	Surface	5	10-13-07	Surface	5

Table 2.10.7. Water sampling schedule, depth, and number of samples taken at the EFGB and WFGB from 2004-2008 (continued).

EFGB			WFGB		
Sampling Date	**Depth**	**Samples**	**Sampling Date**	**Depth**	**Samples**
10-14-07	Midwater	5	10-13-07	Midwater	5
10-14-07	Reef cap	5	10-13-07	Reef cap	5
02-02-08	Surface	4	02-02-08	Surface	4
02-02-08	Midwater	4	02-02-08	Midwater	4
02-02-08	Reef cap	4	02-02-08	Reef cap	4
07-03-08	Surface	4	07-02-08	Surface	4
07-03-08	Midwater	4	07-02-08	Midwater	4
07-03-08	Reef cap	4	07-02-08	Reef cap	4
11-04-08	Surface	3	11-05-08	Surface	3
11-04-08	Midwater	3	11-05-08	Midwater	3
11-04-08	Reef cap	3	11-05-08	Reef cap	3

Table 2.10.8.

Standard USEPA methods used to analyze water samples taken at the FGB [mg/m^3 = milligrams per cubic meter; mg/l = milligrams per liter].

Parameter	Method	Detection Limit
Chlorophyll *a*	10200HPLC	1-mg/m^3
Ammonia	E350.3	0.03-mg/l
Nitrate	E353.3	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

Table 2.11.2.

Number of fish surveys conducted each year at the EFGB and WFGB from 2004-2007.

	Number of Fish Surveys Conducted	
Year	**EFGB**	**WFGB**
2004	12	27
2005	24	23
2006	24	24
2007	24	24

Fish survey dives began in the early morning (generally between 0700 and 0900), before commencement of other dive activities, and were repeated by two to three divers throughout the day until dusk. One or two days were spent conducting surveys on each Bank and individual survey locations were spread randomly within the 100- x 100-m study site to achieve maximum coverage of the reef habitat while excluding sand patches. Survey depths ranged from 15-23 m (49-75 ft) at the EFGB and 16-25 m (52-82 ft) at the WFGB.

In 2004, 2005, and 2007, individual fish survey locations were determined by using a table of random numbers (Rohlf and Sokal 1969). This table presents random numbers up to ten thousand digits and is generally useful for a variety of sampling operations. The table was entered at random by choosing a random page. The row and column were determined by "blindly pointing to it," yielding a random number. Additional random numbers were acquired by proceeding in some predetermined fashion, either horizontally or vertically, across the table.

In 2006, fish survey locations were selected using a random point generation script in Environmental Systems Research Institute's (ESRI) ArcView 3.3 GIS software application. The script was programmed to position 24 random points within a 100- x 100-m polygon divided into four, 50- x 50-m quadrants. Point placement was subject to restrictions such that the distance between points had to be greater than 15 m (49 ft) and that there had to be six points per quadrant. The script was run twice, one for each Bank. Points were plotted on each of the two study site maps, and labeled with Cartesian coordinates representing distance in meters from the center of the study site.

A fish species list was maintained for each Bank and included species observed during the diver surveys, as well as any other additional species noted during the dives (mostly during transit from one diver survey location to another).

2.11.3. 2004 and 2005 Data Presentation and Statistical Analysis

Fish densities are expressed as the number of fish per 100-m^2 horizontal area. For each Bank and year, densities were calculated by dividing the mean number of individuals recorded per survey by the horizontal area of the survey cylinder (176.7 m^2). This value was then multiplied by 100 to provide fish densities per 100 m^2.

Relative abundance 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).

Size-frequency distributions for two trophic guilds, herbivores and piscivores, were calculated for each Bank and year by dividing the number of herbivores or piscivores in each size class by the total number of herbivores or piscivores observed. Size classes included 0-5 cm, 6-10 cm, 11-20 cm, 21-30 cm, 31-40 cm, and >40 cm. Size was based on average fish lengths recorded during the surveys. The herbivore guild is comprised of parrotfishes (Labridae: Scarinae), surgeonfishes (Acanthuridae), and yellowtail damselfish (*Microspathodon chrysurus*), while the demersal piscivore guild is comprised of snappers (Lutjanidae) and select groupers (Serranidae). The select groupers in the piscivore guild included yellowmouth grouper (*Mycteroperca interstitialis*), tiger grouper (*M. tigris*), graysby (*Cephalopholis cruentata*), and coney (*C. fulvus*; Claro and Cantelar Ramos 2003; Pattengill-Semmens and Gittings 2003).

Weighted means for fish lengths were calculated as follows (Zar 1984):

$$\bar{x} = \frac{\sum_{i=1}^{n} w_i \cdot x_i}{\sum_{i=1}^{n} w_i}$$

where n is the number of surveys, ω is the non-negative weight or the number of individuals used to compute mean fish length for each survey, and χ is the mean fish length for each survey.

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

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

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 the densities and species-richness values by Bank and year.

2.11.4. 2006 Data Presentation and Statistical Analysis

Fish densities, diversity, and evenness were calculated as described in section 2.11.3. Relative abundance 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 expression of the total number of species for 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 herbivore and piscivore guilds were as described in the previous section. However, in 2006, the select groupers in the piscivore guild included black grouper (*Mycteroperca bonaci*) and marbled grouper (*Dermatolepis inermis*), in addition to yellowmouth grouper (*M. interstitialis*), tiger grouper (*M. tigris*), and graysby (*Cephalopholis cruentata*; Claro and Cantelar Ramos 2003; Pattengill-Semmens and Gittings 2003).

Fish biomass, an important component of coral reef ecology, was added to the analyses of the 2006 monitoring data. Biomass 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). Since lengths for every individual fish are not recorded, mean lengths for each species 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 or 1901.9 ft^2). Coupling both biomass and abundance was useful in assessing the fish communities at the EFGB and WFGB.

2.11.5. 2007 Data Presentation and Statistical Analysis

Fish densities, diversity, and evenness were calculated as described in section 2.11.3. Fish biomasses were computed using the recorded mean species length in each survey and following the protocol described in the section 2.11.4.

All comparisons of density or biomass were conducted using parametric models on log+1 transformed means (either ANOVAs or two-tailed t-tests, unless otherwise stated). Species prevalence was calculated based on 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. Species occurring in less than seven surveys in 2007 were excluded from the 2007 analyses, as their prevalence was too low to achieve statistical significance at α=0.05.

In 2007, the two trophic guilds evaluated were the herbivores and piscivores. The herbivore species list included all surgeonfishes (Acanthuridae), yellowtail damselfish (*Microspathodon chrysurus*), and all parrotfishes (Labridae: Scarinae) to allow comparability to the 2006 data. The piscivore species analyzed within 2007 data were constrained to the snappers (Lutjanidae), the groupers and sea basses (Serranidae, excluding hamlets and basslets), the jacks and pompanos (Carangidae), and the great barracuda (*Sphyraena barracuda*).

Long-term piscivore biomass was analyzed for the 2002-2007 time series (2002-2003 data from Precht et al. 2006) to detect changes in biomass of sportfishes over time and differences between EFGB and WFGB. A subset of piscivore species was extracted from the survey dataset and divided into two groups: pelagics (all Carangidae and great barracuda) and large members of the demersal snapper/grouper complex. Members of the demersal snapper/grouper complex included dog snapper (*Lutjanus jocu*), gray snapper (*L. griseus*), rock hind (*Epinephelus adscensionis*), red hind (*E. guttatus*), red grouper (*E. morio*), Nassau grouper (*E. striatus*), black grouper (*Mycteroperca bonaci*), yellowmouth grouper (*M. interstitialis*), scamp (*M. phenax*), tiger grouper (*M. tigris*), and yellowfin grouper (*M. venenosa*). These species were selected due to their desirability as sportfishes, susceptibility to fishing, and position near the top of the food web. Biomasses for each survey were summed within the two groups and log-transformed before analysis. Each group was subjected to a factorial ANOVA using year (2002-2007) and Bank (EFGB and WFGB) as factors.

To detect long-term patterns in fish community structure from 2002-2007 (2002-2003 data from Precht et al. 2006), the species abundances were pooled into functional groups. The most prevalent fish species (those recorded on >20% of the visual censuses) were pooled into trophic functional groups related to diet, adult size, and trophic subguild (i.e., functional syndromes, such as hard grazers vs. browsers within the herbivores). These data, spanning 2002 to 2007, were ordinated using principal components analysis on covariances, yielding four axes with eigenvalues >1.0, accounting for a cumulative total of 62.5% explained variance. Factor rotation did not further condense information content or enhance explained variance and so was abandoned.

2.12. Sea Urchin and Lobster Surveys

2.12.1. Methodological Rationale

The long-spined sea urchin, *Diadema antillarum*, was an important herbivore on coral reefs throughout the Caribbean until 1983-1984. At that time, an unknown pathogen decimated populations throughout the region, including the FGB. Since then, patchy recovery has been documented (Edmunds and Carpenter 2001). *Diadema antillarum* populations at the FGB pre-1984 were near 1 individual/m^2 (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*) at the FGB are not well understood.

2.12.2. 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 2004-2008, belt transects (2 m by 100 m or 7 ft by 328 ft) were surveyed along the northern and eastern boundaries of the EFGB study site and along the southern and western boundaries at the WFGB study site, for a total of 400 m^2 (4,306 ft^2) surveyed at each Bank during each year. Surveys began with the northeast corner at the EFGB and with the southeast corner at the WFGB. All observed species of sea urchin and lobster were recorded.

2.12.3. Data Presentation and Statistical Analysis

Due to low sample abundance, only qualitative analyses were possible for the lobster surveys. Sea urchin abundance data were imported into PRIMER® Version 6.1.6. A Bray-Curtis similarity matrix was constructed using square-root transformed data. Cluster analyses were performed on the Bray-Curtis matrices, using the group-averages clustering algorithm, and dendrograms were plotted. Multidimensional scaling (MDS) plots were created using 25 restarts and a 0.01 minimum stress level with a Kruskal fit scheme 1 in PRIMER®. The MDS analyses were used to evaluate the effect of Bank (EFGB and WFGB) and year (2004-2008) on sea urchin abundance. A similarity percentage (SIMPER) analysis was also conducted on the urchin abundance data to determine which taxa were responsible for the observed differences within and among groups.

3.0 RESULTS

3.1. RANDOM TRANSECTS

Data collected from 2004 through 2008 showed persistence of the *Montastraea annularis* species complex as the dominant coral species at the EFGB and WFGB (Tables 3.1.1 and 3.1.2). Likewise, *Diploria strigosa* remained the second most prevalent coral species during this time period, and *Porites astreoides* and *M. cavernosa* were consistently the third and fourth most dominant corals (Figures 3.1.1 and 3.1.2). Macroalgal cover, which had increased dramatically at the EFGB from 2004 to 2005, declined in 2006 and then held steady from 2006 to 2008 (Figure 3.1.3). These changes in macroalgal cover were due in large part to changes in the cover of *Lobophora*; however, *Dictyota* also increased substantially at both the EFGB and WFGB after 2005. At the WFGB, macroalgal cover had increased from 2004 to 2005, declined from 2005 to 2006, increased again from 2006 to 2007, and then decreased again from 2007 to 2008 (Figure 3.1.3). Appendix 1 contains the random transect data from 2004-2008 at the FGB.

In the 2004-2008 random transects, the incidences of bleaching, paling, and fish biting were low at both Banks and coral disease was absent (Tables 3.1.1 and 3.1.2). The percentage of corals impacted by isolated/concentrated fish biting at the EFGB and WFGB ranged from 0.08-1.71% (Tables 3.1.1 and 3.1.2). Fish biting occurred primarily on the *Montastraea annularis* species complex and was highest on both the EFGB and WFGB in 2007 (Tables 3.1.1-3.1.4). When combined, isolated and concentrated fish biting appeared to be higher at the WFGB than the EFGB from 2005-2008 and was approximately the same at both Banks in 2004 (Tables 3.1.1- and 3.1.4).

In the 2004-2008 random transects, paling and bleaching were low at both Banks and ranged from 0.00-0.91% (Tables 3.1.1 and 3.1.2). Bleaching levels were highest at the EFGB and WFGB in 2005, at 0.91% and 0.90%, respectively (Tables 3.1.1 and 3.1.2). From 2004 to 2006, *Millepora alcicornis* was the most frequently bleached species at the EFGB, with bleaching rates ranging from 0.20-0.86% (Table 3.1.3). At the EFGB in 2007 and 2008, bleaching was only observed on a single colony of *Diploria strigosa* (0.05%) and *Agaricia* sp. (0.08%), respectively (Table 3.1.3). At the WFGB, *M. alcicornis* was the most bleached coral (0.25-0.69%) in all years except 2006, when the *Montastraea annularis* species complex showed the highest bleaching (0.11%) and 2008, when bleaching was not observed (Table 3.1.4). Paling was more frequent at the EFGB, mainly occurring on the *Montastraea annularis* species complex (Tables 3.1.3 and 3.1.4).

The point counts from the video transects were grouped into major functional categories and expressed as percent covers (Figure 3.1.3). The univariate data were expressed as proportions and analyzed by two-way analysis of variance (ANOVA), with site (EFGB and WFGB) and year (2004, 2005, 2006, 2007, and 2008) as fixed factors. Prior to analysis, the data were tested for conformity to the parametric assumptions of normality and homogeneity of variances. The Anderson-Darling test was used to test normality, and Bartlett's test (for normally distributed data) and Levene's test (for non-normal data) were used to test for homogeneity of variances.

Table 3.1.1.

Cover of benthic categories in random transect video at the EFGB from 2004 to 2008. Values are expressed as percent cover ± SE. n/a= benthic categories not used during random transect analysis.

Cover Category	EFGB 2004	EFGB 2005	EFGB 2006	EFGB 2007	EFGB 2008
Coral					
Agaricia spp.	0.3 ± 0.11	0.11 ± 0.07	0.08 ± 0.03	0.10 ± 0.08	0.38 ± 0.12
Colpophyllia natans	2.81 ± 1.28	1.77 ± 1.08	1.73 ± 1.06	1.56 ± 0.85	1.65 ± 0.58
Unidentifiable coral	0.09 ± 0.04	0.32 ± 0.15	0.16 ± 0.05	0.09 ± 0.06	0.64 ± 0.17
Diploria strigosa	12.13 ± 2.82	5.95 ± 1.26	10.25 ± 1.52	5.82 ± 1.11	7.69 ± 2.00
Madracis spp.	0.7 ± 0.32	0.88 ± 0.38	0.18 ± 0.08	0.29 ± 0.13	0.89 ± 0.30
Millepora alcicornis	1.41 ± 0.49	1.63 ± 0.59	0.46 ± 0.20	0.08 ± 0.06	0.14 ± 0.08
Montastraea annularis species complex	30.14 ± 4.76	26.8 ± 4.09	31.45 ± 4.09	32.44 ± 4.62	33.58 ± 4.52
Montastraea cavernosa	7.73 ± 1.94	3.4 ± 1.14	2.48 ± 0.67	3.74 ± 0.94	2.84 ± 0.92
Mussa angulosa	0.03 ± 0.02	0.07 ± 0.05	0.05 ± 0.04	0.00	0.23 ± 0.12
Porites astreoides	8.19 ± 0.99	7.55 ± 1.19	4.91 ± 0.83	5.81 ± 0.88	7.27 ± 1.19
Scolymia cubensis	0.00	0.01 ± 0.01	0.00	0.00	0.02 ± 0.01
Siderastrea siderea	0.27 ± 0.27	0.6 ± 0.38	0.20 ± 0.13	1.64 ± 1.38	0.05 ± 0.05
Stephanocoenia intersepta	0.33 ± 0.24	0.47 ± 0.47	0.31 ± 0.16	0.35 ± 0.13	0.99 ± 0.49
Total Coral	**64.13 ± 2.70**	**49.55 ± 3.01**	**52.26 ± 3.50**	**51.93 ± 4.46**	**56.37 ± 3.62**
Sponge					
Agelas clathrodes	n/a	n/a	0.11 ± 0.05	0.14 ± 0.11	0.14 ± 0.09
Pseudoceratina crassa	n/a	n/a	0.00	0.24 ± 0.16	0.00
Unidentifiable sponge	0.26 ± 0.24	0.23 ± 0.08	0.45 ± 0.17	0.15 ± 0.05	0.26 ± 0.11
Xestospongia sp.	0.06 ± 0.06	0.25 ± 0.25	0.26 ± 0.26	0.03 ± 0.03	0.00
Total Sponge	**0.31 ± 0.24**	**0.48 ± 0.26**	**0.83 ± 0.33**	**0.56 ± 0.22**	**0.40 ± 0.15**

Table 3.1.1. Cover of benthic categories in random transect video at the EFGB from 2004-2008 (continued).

Cover Category	EFGB 2004	EFGB 2005	EFGB 2006	EFGB 2007	EFGB 2008
CTB					
Crustose coralline algae, fine turfs, and bare rock (CTB)	20.87 ± 3.08	8.68 ± 1.17	20.33 ± 1.95	23.30 ± 2.14	13.34 ± 1.25
Crustose coralline algae	0.01 ± 0.01	3.28 ± 0.82	2.83 ± 0.53	1.13 ± 0.25	4.29 ± 0.78
Total CTB	**20.89 ± 3.08**	**11.96 ± 1.49**	**23.15 ± 1.94**	**24.43 ± 2.11**	**17.64 ± 1.77**
Macroalgae					
Dictyota spp.	0.00	0.23 ± 0.14	13.05 ± 2.24	5.74 ± 1.08	12.90 ± 1.46
Lobophora variegata	1.86 ± 0.27	22.59 ± 2.11	6.15 ± 1.07	14.40 ± 1.87	0.40 ± 0.10
Unidentifiable macroalgae	0.3 ± 0.15	0.07 ± 0.04	0.11 ± 0.05	0.08 ± 0.05	1.74 ± 0.23
Thick turf algae	9.87 ± 2.73	11.15 ± 1.55	1.79 ± 0.67	1.51 ± 0.37	9.02 ± 1.03
Total Macroalgae	**12.03 ± 2.77**	**34.03 ± 2.58**	**21.10 ± 2.32**	**21.73 ± 2.28**	**24.06 ± 2.16**
Cyanobacteria					
Schizothrix sp.	n/a	n/a	0.26 ± 0.12	0.23 ± 0.09	0.03 ± 0.02
Other					
Ascidian	0.00	0.01 ± 0.01	0.00	0.00	0.00
Other	0.03 ± 0.02	0.05 ± 0.02	0.13 ± 0.05	0.00	0.03 ± 0.02
Serpulidae	0.17 ± 0.08	0.09 ± 0.04	0.19 ± 0.11	0.15 ± 0.07	0.20 ± 0.05
Rubble	0.04 ± 0.04	0.00	0.05 ± 0.02	0.14 ± 0.12	0.38 ± 0.32
Sand	0.13 ± 0.11	0.51 ± 0.25	0.33 ± 0.15	0.74 ± 0.37	0.31 ± 0.16
Unknown	2.27 ± 0.57	3.32 ± 0.41	1.71 ± 0.23	0.08 ± 0.03	0.60 ± 0.13
Coral Condition (occurrences in coral)					
Bleaching	0.27 ± 0.08	0.91 ± 0.50	0.57 ± 0.24	0.05 ± 0.07	0.08 ± 0.15
Paling	0.02 ± 0.01	0.00	0.05 ± 0.03	0.12 ± 0.06	0.05 ± 0.03
Concentrated fish biting	0.13 ± 0.05	0.30 ± 0.12	0.22 ± 0.07	0.54 ± 0.14	0.08 ± 0.04
Isolated fish biting	0.25 ± 0.06	0.54 ± 0.17	1.08 ± 0.22	1.21 ± 0.22	0.16 ± 0.06

Table 3.1.2.

Cover of benthic categories in random transect video at the WFGB from 2004 to 2008.Values are expressed as percent cover ± SE. n/a= benthic categories not used during random transect analysis.

Cover Category	WFGB 2004	WFGB 2005	WFGB 2006	WFGB 2007	WFGB 2008
Coral					
Agaricia spp.	0.29 ± 0.11	0.24 ± 0.07	0.13 ± 0.06	0.16 ± 0.07	0.22 ± 0.10
Colpophyllia natans	3.48 ± 1.56	1.4 ± 0.54	0.55 ± 0.28	3.35 ± 1.24	1.14 ± 0.45
Unidentifiable coral	0.3 ± 0.11	0.45 ± 0.12	0.21 ± 0.05	0.44 ± 0.08	0.67 ± 0.14
Diploria strigosa	13.41 ± 1.74	6.68 ± 1.29	10.14 ± 1.64	9.56 ± 1.85	8.98 ± 2.43
Madracis spp.	0.54 ± 0.42	0.08 ± 0.04	0.15 ± 0.10	0.08 ± 0.04	0.21 ± 0.15
Millepora alcicornis	1.05 ± 0.51	1.68 ± 0.47	0.65 ± 0.20	0.81 ± 0.27	0.28 ± 0.14
Montastraea annularis species complex	31.70 ± 2.70	36.20 ± 3.50	40.13 ± 3.29	35.50 ± 3.81	37.01 ± 4.65
Montastraea cavernosa	3.7 ± 1.02	2.43 ± 0.69	2.25 ± 0.84	1.84 ± 0.53	2.81 ± 1.05
Mussa angulosa	0.16 ± 0.07	0.13 ± 0.08	0.24 ± 0.16	0.08 ± 0.05	0.06 ± 0.05
Porites astreoides	5.19 ± 0.62	4.04 ± 0.46	3.39 ± 0.57	3.61 ± 0.44	3.62 ± 0.64
Scolymia cubensis	0.00	0.01 ± 0.01	0.01 ± 0.01	0.03 ± 0.02	0.00
Siderastrea siderea	0.00	1.1 ± 0.73	0.00	0.03 ± 0.03	3.78 ± 1.59
Stephanocoenia intersepta	0.59 ± 0.27	0.00	0.44 ± 0.21	1.11 ± 0.33	0.48 ± 0.20
Total Coral	**60.41 ± 2.94**	**54.41 ± 3.13**	**58.28 ± 2.88**	**56.58 ± 3.28**	**59.27± 3.40**
Sponge					
Agelas clathrodes	n/a	n/a	0.29 ± 0.10	0.05 ± 0.05	0.25 ± 0.11
Pseudoceratina crassa	n/a	n/a	0.00	0.09 ± 0.06	0.03 ± 0.02
Unidentifiable sponge	0.24 ± 0.08	0.25 ± 0.11	0.18 ± 0.04	0.18 ± 0.08	0.22 ± 0.08
Xestospongia sp.	0.16 ± 0.15	0.00	0.00	0.03 ± 0.03	0.49 ± 0.43

Table 3.1.2. Cover of benthic categories in random transect video at the WFGB from 2004 to 2008 (continued).

Total Sponge	**0.4 ± 0.15**	**0.25 ± 0.11**	**0.46 ± 0.12**	**0.35 ± 0.10**	**1.00 ± 0.47**
CTB					
Crustose coralline algae, fine turfs, and bare rock (CTB)	17.50 ± 1.34	15.31 ± 1.79	22.06 ± 1.98	21.78 ± 1.88	22.42 ± 1.87
Crustose coralline algae	3.35 ±1.16	2.96 ± 0.65	3.58 ± 0.47	2.50 ± 0.34	4.32 ± 1.00
Total CTB	**20.85 ± 2.11**	**18.27 ± 1.67**	**25.64 ± 2.06**	**24.27 ± 1.89**	**26.74 ± 2.41**
Macroalgae					
Dictyota spp.	0.00	0.00	2.93 ± 0.51	0.58 ± 0.15	0.01 ± 0.02
Lobophora variegata	1.13 ± 0.41	13.53 ± 1.64	6.99 ± 1.20	13.36 ± 2.49	2.30 ± 0.64
Unidentifiable macroalgae	0.03 ±0.02	0.06 ± 0.03	0.00	0.43 ± 0.15	0.42 ± 0.13
Thick turf algae	13.6 ± 1.34	4.76 ± 1.16	2.46 ± 0.35	3.27 ± 0.37	9.33 ± 1.01
Total Macroalgae	**14.75 ± 1.50**	**18.35 ± 1.44**	**12.38 ± 1.34**	**17.64 ± 2.44**	**12.06 ± 1.31**
Cyanobacteria					
Schizothrix sp.	n/a	n/a	0.13 ± 0.05	0.18 ± 0.08	0.06 ± 0.03
Other					
Ascidian	0.00	0.01 ± 0.01	0.00	0.00	0.00
Other	0.00	0.03 ± 0.02	0.03 ± 0.02	0.06 ± 0.02	0.03 ± 0.02
Serpulidae	0.04 ± 0.03	0.08 ± 0.04	0.26 ± 0.07	0.08 ± 0.04	0.16 ± 0.04
Rubble	0.06 ± 0.05	0.4 ± 0.4	0.26 ± 0.21	0.00	0.00
Sand	1.66 ± 0.61	0.75 ± 0.49	0.66 ± 0.21	0.61 ± 0.20	0.06 ± 0.06
Unknown	1.83 ± 0.40	7.45 ± 0.9	1.91 ± 0.22	0.23 ± 0.06	0.61 ± 0.15
Coral Condition (occurrences in coral)					
Bleaching	0.52 ± 0.19	0.90 ± 0.31	0.30 ± 0.10	0.34 ± 0.11	0.00
Paling	0.00	0.00	0.00	0.30 ± 0.09	0.05 ± 0.04
Concentrated fish biting	0.12 ± 0.05	0.48 ± 0.16	0.43 ± 0.11	0.53 ± 0.18	0.25 ± 0.09
Isolated fish biting	0.25 ± 0.07	1.49 ± 0.26	1.12 ± 0.20	1.71 ± 0.22	0.28 ± 0.09

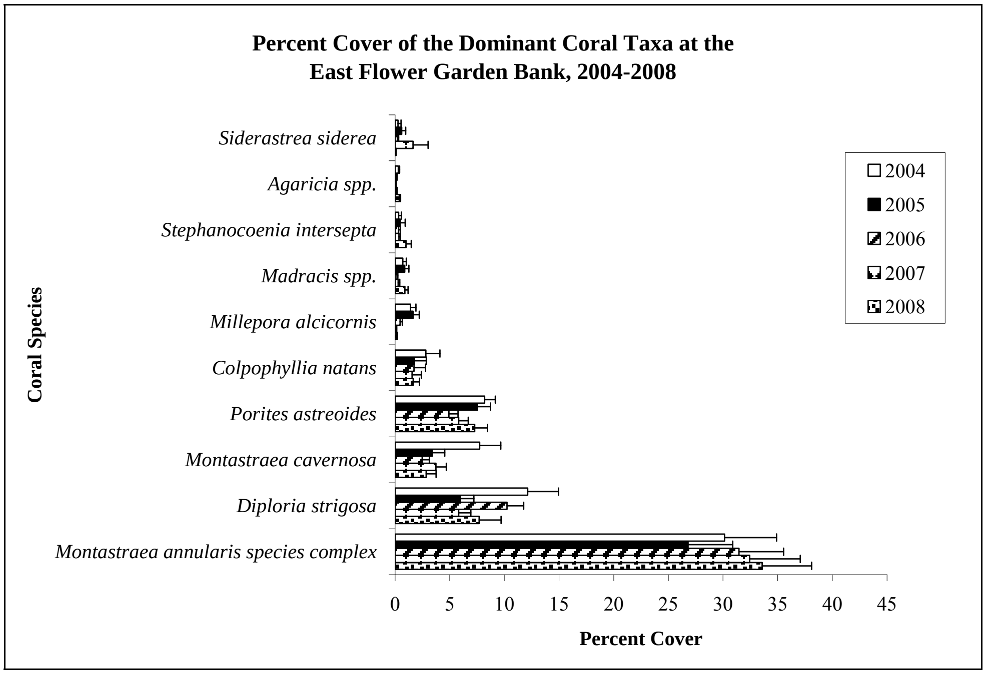


Figure 3.1.1. Percent cover (+ SE) of the dominant coral taxa at the EFGB, 2004-2008. Values are calculated from random transect videography.

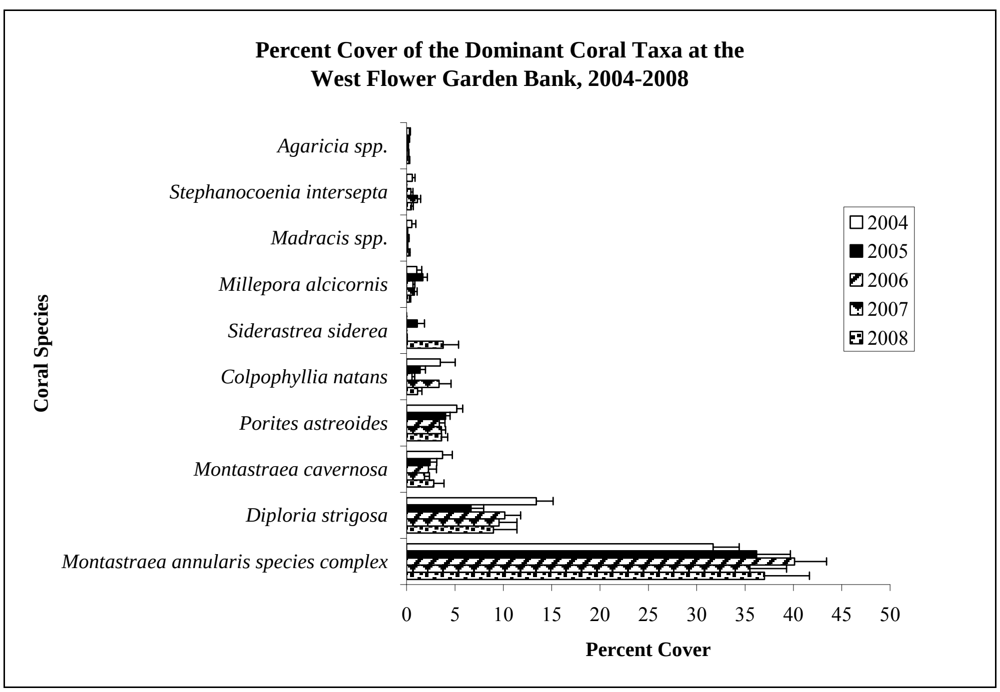


Figure 3.1.2. Percent cover (+ SE) of the dominant coral taxa at the WFGB, 2004-2008. Values are calculated from random transect videography.

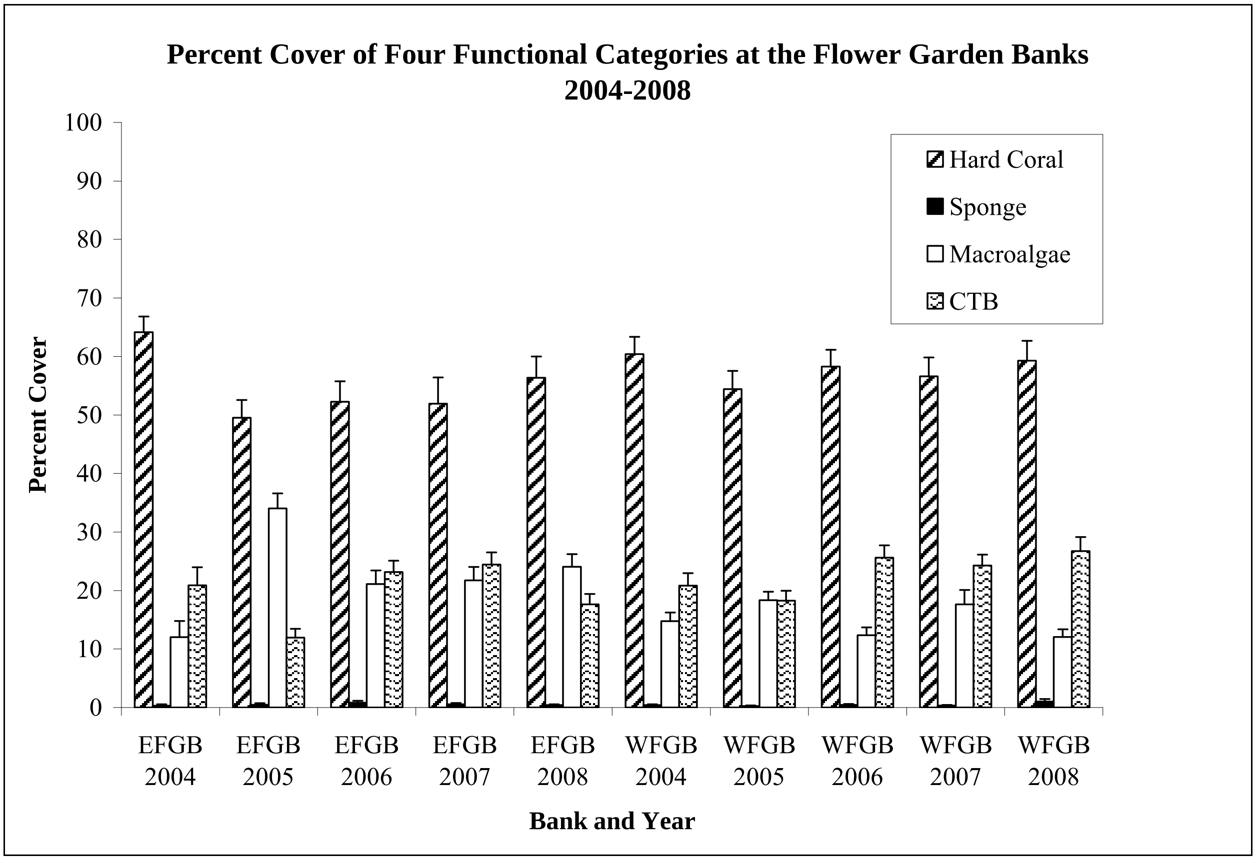


Figure 3.1.3. Percent cover (+ SE) of four functional categories of sessile benthos at the FGB from 2004 to 2008. Abbreviation: CTB, crustose coralline algae, fine turf algae, and bare rock. The "macroalgae" category includes thick turfs as well as fleshy macroalgal species. Values are calculated from the random transect videography.

Table 3.1.3.

Percent cover of isolated and concentrated fish biting, paling, and bleaching in random transects at the EFGB 2004-2008. IFB= isolated fish biting, CFB= concentrated fish biting, P= paling, BL= bleaching. The *Montastraea annularis* species complex includes *M. annularis*, *M. faveolata* and *M. franksi*. EFGB 2004 (n=4489; 14 transects), 2005 (n= 3716; 15 transects), 2006 (n=4181; 16 transects), 2007 (n=4051; 16 transects) and 2008 (n= 3688; 16 transects). n = number of coral points within random transects.

	2004				**2005**				**2006**			
Coral Species	**IFB**	**CFB**	**P**	**BL**	**IFB**	**CFB**	**P**	**BL**	**IFB**	**CFB**	**P**	**BL**
Agaricia sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diploria strigosa	0.02	0.00	0.02	0.02	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
Millepora alcicornis	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.86	0.00	0.00	0.00	0.55
Montastraea annularis species complex	0.20	0.13	0.00	0.00	0.51	0.27	0.00	0.00	1.00	0.22	0.05	0.02
Montastraea cavernosa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Porites astreoides	0.02	0.00	0.00	0.04	0.03	0.03	0.00	0.05	0.02	0.00	0.00	0.00
Total	**0.25**	**0.13**	**0.02**	**0.27**	**0.54**	**0.30**	**0.00**	**0.91**	**1.08**	**0.22**	**0.05**	**0.57**

Table 3.1.3. Percent cover of isolated and concentrated fish biting, paling, and bleaching in random transects at the EFGB, 2004 through 2008 (continued).

	2007				2008			
Coral Species	**IFB**	**CFB**	**P**	**BL**	**IFB**	**CFB**	**P**	**BL**
Agaricia sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08
Diploria strigosa	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00
Millepora alcicornis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Montastraea annularis species complex	1.16	0.52	0.12	0.00	0.16	0.05	0.05	0.00
Montastraea cavernosa	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00
Porites astreoides	0.02	0.00	0.00	0.00	0.00	0.03	0.00	0.00
Total	**1.21**	**0.54**	**0.12**	**0.05**	**0.16**	**0.08**	**0.05**	**0.08**

Table 3.1.4.

Percent cover of isolated and concentrated fish biting, paling, and bleaching in random transects at the WFGB 2004-2008. IFB= isolated fish biting, CFB= concentrated fish biting, P= paling, BL= bleaching. The *Montastraea annularis* species complex includes *M. annularis*, *M. faveolata* and *M. franksi*. WFGB 2004 (n=4833; 16 transects), 2005 (n= 4353; 16 transects), 2006 (n=4662; 16 transects), 2007 (n=4375; 16 transects) and 2008 (n= 3965; 16 transects). n = number of coral points within random transects.

	2004				**2005**				**2006**			
Coral Species	**IFB**	**CFB**	**P**	**BL**	**IFB**	**CFB**	**P**	**BL**	**IFB**	**CFB**	**P**	**BL**
Agaricia sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Colpophyllia natans	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diploria strigosa	0.00	0.02	0.00	0.04	0.02	0.00	0.00	0.14	0.00	0.00	0.00	0.09
Madracis decactis	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00
Millepora alcicornis	0.00	0.00	0.00	0.46	0.00	0.00	0.00	0.69	0.00	0.00	0.00	0.09
Montastraea annularis species complex	0.23	0.10	0.00	0.00	1.40	0.39	0.00	0.00	1.09	0.41	0.00	0.11
Montastraea cavernosa	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.05	0.00	0.00	0.00	0.02
Porites astreoides	0.02	0.00	0.00	0.02	0.02	0.02	0.00	0.02	0.00	0.00	0.00	0.00
Stephanocoenia intersepta	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.00
Unidentifiable coral	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00
Total	**0.25**	**0.12**	**0.00**	**0.52**	**1.49**	**0.48**	**0.00**	**0.90**	**1.12**	**0.43**	**0.00**	**0.30**

Table 3.1.4. Percent cover of isolated and concentrated fish biting, paling, and bleaching in random transects at the WFGB 2004-2008 (continued).

	2007				2008			
Coral Species	**IFB**	**CFB**	**P**	**BL**	**IFB**	**CFB**	**P**	**BL**
Agaricia sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Colpophyllia natans	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diploria strigosa	0.02	0.00	0.00	0.05	0.00	0.00	0.00	0.00
Madracis decactis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Millepora alcicornis	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00
Montastraea annularis species complex	1.65	0.50	0.25	0.05	0.28	0.18	0.05	0.00
Montastraea cavernosa	0.00	0.00	0.02	0.00	0.00	0.03	0.00	0.00
Porites astreoides	0.05	0.02	0.00	0.00	0.00	0.00	0.00	0.00
Stephanocoenia intersepta	0.00	0.00	0.02	0.00	0.00	0.05	0.00	0.00
Unidentifiable coral	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**1.71**	**0.53**	**0.30**	**0.34**	**0.28**	**0.25**	**0.05**	**0.00**

Seven parameters were analyzed by two-way ANOVA. To control experiment-wise error, the Type I error rate was adjusted using the Bonferroni correction to $\alpha_{adj} = 0.05/7 = 0.0071$.

The data on proportional cover of all living hard corals (Scleractinia and Milleporina) conformed to the normality and equal-variances assumptions of parametric statistics (Anderson-Darling tests, P>0.119; Bartlett's test, P=0.705); therefore, the data were not transformed. A two-way ANOVA showed no significant effect of Year or Bank, and the Bank x Year interaction was also not significant (Table 3.1.5A). ANOVA using arcsine-transformed data yielded similar results.

The *Montastraea annularis* species complex was the most abundant coral taxon, accounting for nearly 60% of hard coral cover. The data on proportional cover of *M. annularis* species complex were normally distributed, with the exception of non-normal data from the EFGB in 2005 (Anderson–Darling test, P<0.001). The data conformed to the assumption of homogeneity of variances (Levene's test, P=0.614). Logarithmic transformation corrected that normality problem but resulted in unequal variances. Because ANOVA is more robust to violations of the normality requirement than the equal-variances requirement, the data were analyzed without transformation. As for total coral cover, a two-way ANOVA showed no significant effect of either Bank or Year, and the Bank x Year interaction was not significant (Table 3.1.5B). ANOVA on the log-transformed data yielded similar results.

The data on proportional cover of sponges were non-normal (Anderson-Darling test, P<0.005 for each Bank-Year combination). In addition, the variances were marginally heterogeneous (Levene's test, P=0.0578). Arcsine transformation homogenized the variances (Levene's test, P=0.464) and slightly improved the normality of the data, although all but the WFGB in 2006 remained significantly non-normal. A two-way ANOVA on the arcsine-transformed data showed no significant effects of Bank or Year, and the Bank x Year interaction was also not significant (Table 3.1.5C). ANOVA on the untransformed data yielded similar results.

The most abundant macroalgal taxa in terms of substratum cover were *Dictyota* spp. and *Lobophora variegata* (Tables 3.1.1 and 3.1.2). The data on proportional cover of macroalgae were non-normal for the WFGB in 2004 (Anderson–Darling test, P=0.035) and marginally non-normal for the WFGB in 2007 (P=0.094). The variances were homogeneous (Levene's test, P=0.267). The arcsine transformation did not correct the normality problem. A two-way ANOVA on the untransformed data revealed significant effects of Bank and Year, and a significant Bank x Year interaction (Table 3.1.5D). Overall, macroalgal cover was higher at the EFGB than the WFGB during the study period. Because the Bank x Year interaction was significant, one-way ANOVAs were performed on the macroalgal data for each Bank separately to examine year-to-year variations. The data for the EFGB showed a significant effect of year (F=10.59, df=4,72, P<0.001). Tukey–Kramer *a posteriori* comparisons showed that macroalgal cover was significantly higher at the EFGB in 2005 than in all other years. Macroalgal cover in 2008 was significantly higher than in 2004, and in 2005 and 2006 macroalgal cover was not significantly different from either 2004 or 2008. The data for the WFGB also showed a significant effect of year (F=2.99, df=4, 75, P<0.024). Tukey–Kramer *a posteriori* comparisons did not reveal any significant difference between pairs of years, but again 2005 stood out as the year of highest macroalgal cover (Table 3.1.2). ANOVA on the arcsine-transformed data yielded similar results.

The fourth cover category combined crustose coralline algae, fine algal turfs and bare rock (abbreviated CTB). These components were difficult to distinguish visually in the field, and they were equally if not more problematic in still photographs and video transects. All three connote high levels of physical disturbance and/or herbivory, and so it was reasonable to combine them (Aronson and Precht 2000). The data from the WFGB in 2004 and 2006 were non-normally distributed (Anderson–Darling test, P=0.027 and 0.028, respectively), although the variances were homogeneous (Levene's test, P=0.441). The arcsine transformation improved normality for WFGB in 2004 (P=0.097) and 2006 (P=0.045), but no transformation corrected the problem entirely. A two-way ANOVA on the arcsine-transformed data showed significant effects of Bank and Year, whereas the Bank x Year interaction was not significant (Table 3.1.5E). Overall, CTB cover was higher at the WFGB than the EFGB during the study period, the inverse of the pattern for macroalgal cover. Tukey–Kramer *a posteriori* comparisons showed that CTB cover was significantly lower in 2005 than in any other year, and that the other years were not significantly different from each other. ANOVA on the untransformed data yielded essentially the same results.

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. Mean H' ranged from a low of 0.916 ± 0.076 SE at the WFGB in 2006 to a high of 1.245 ± 0.103 SE at the EFGB in 2004 (Table 3.1.6 and Figure 3.1.4). The data conformed to the assumption normality (Anderson–Darling test, P>0.160 in all cases), and the variances were homogeneous (Levene's test, P=0.940). A two-way ANOVA on the untransformed data showed no significant effects of Bank or Year, and the Bank x Year interaction was also not significant (Table 3.1.5F). The low values of H' overall reflect the strong dominance of the coral assemblage by the *M. annularis* species complex.

In summary, mean coral cover exceeded 49% at both the EFGB and WFGB in 2004 through 2008. These values were consistent with measurements of coral cover 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). The cover of sponges remained extremely low. CTB was the next most abundant category in terms of cover, indicating high levels of herbivory and a generally healthy reef ecosystem. Macroalgal cover and the cover of CTB fluctuated in a reciprocal fashion, spatially between the two Banks and temporally through the years, with macroalgal cover highest and CTB cover lowest in 2005. This pattern was consistent with earlier results from the EFGB and WFGB (Aronson et al. 2005; Precht et al. 2006) and previous work in the Caribbean (Aronson and Precht 2000).

Table 3.1.5.

Results of two-way ANOVAs on proportional cover estimates and H' from random transects.

A. Hard Corals (untransformed)					
Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**	***P* value**
Site	0.0398	1	0.0398	2.27	0.134
Year	0.1958	4	0.0490	2.79	0.029
Site*Year	0.0499	4	0.0125	0.71	0.585
Error	2.5784	147	0.0175		
Total	2.8602	156			
B. *Montastraea annularis* species complex (untransformed)					
Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**	***P* value**
Site	0.1137	1	0.1137	4.46	0.036
Year	0.0564	4	0.1410	0.55	0.697
Site*Year	0.0369	4	0.0092	0.36	0.836
Error	0.0369	147	0.0255		
Total	3.7513	156			
C. Sponges (arcsine transformed)					
Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**	***P* value**
Site	0.0003	1	0.0003	0.11	0.737
Year	0.0184	4	0.0046	1.64	0.167
Site*Year	0.0100	4	0.0025	0.89	0.472
Error	0.4121	147	0.0028		
Total	0.4403	156			
D. Macroalgae (untransformed)					
Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**	***P* value**
Site	0.2159	1	0.2159	32.76	<0.001
Year	0.2728	4	0.0682	10.35	<0.001
Site*Year	0.1602	4	0.0401	6.08	<0.001
Error	0.9687	147	0.0066		
Total	1.6176	156			
E. CTB (arcsine transformed)					
Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**	***P* value**
Site	0.0950	1	0.0950	9.24	0.003
Year	0.3013	4	0.0753	7.33	<0.001
Site*Year	0.0764	4	0.0191	1.86	0.121
Error	1.5113	147	0.0103		
Total	1.9781	156			
F. Shannon-Wiener Diversity, H' (untransformed)					
Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**	***P* value**
Site	0.3997	1	0.3997	3.59	0.060
Year	1.0808	4	0.2669	2.40	0.053
Site*Year	0.0936	4	0.0234	0.21	0.932
Error	16.3595	147	0.1113		
Total	17.9038	156			

Table 3.1.6.

Shannon-Wiener diversity values for the EFGB and WFGB, 2004-2008.

Year	EFGB	WFGB
2004	1.24	1.20
2005	1.22	1.05
2006	1.06	0.92
2007	1.09	1.03
2008	1.07	0.98

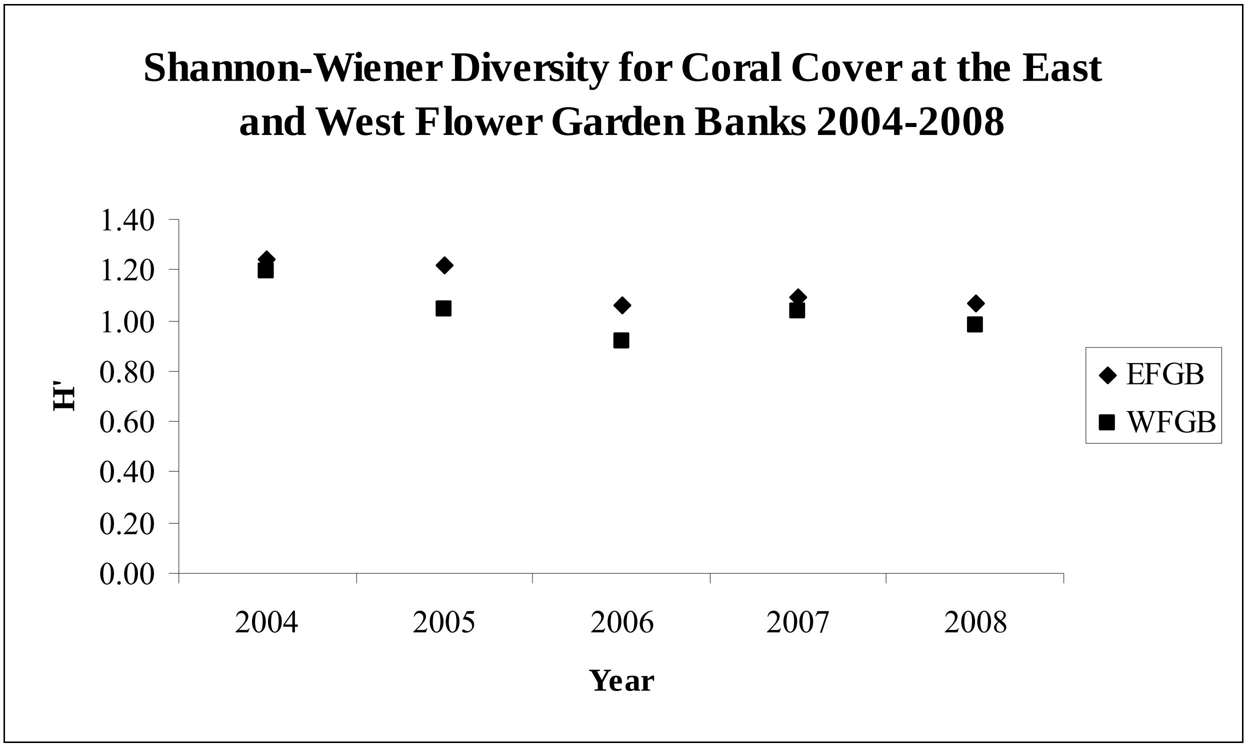


Figure 3.1.4. Graph depicting Shannon-Wiener diversity for coral cover at the EFGB and WFGB, 2004-2008.

3.2. SCLEROCHRONOLOGY

Eight cores were collected from separate *Montastraea faveolata* colonies at both the EFGB (four cores) and the WFGB (four cores) in both June 2005 and June 2007, resulting in a total of 16 cores. Each core was longitudinally sectioned to reveal accretionary growth bands. Mean growth rates and standard errors or standard deviations were calculated for each Bank and year. For the June 2005 cores, mean growth rates were determined for the years 1997-2005 at the EFGB and from 1992-2005 at the WFGB. For the June 2007 cores, mean growth rates were calculated for the years 2000-2007 at both the EFGB and WFGB. Appendix 2 contains 2005 and 2007 coral core growth measurements for the EFGB and WFGB.

3.2.1. June 2005 Cores

Based on the coral cores collected in June 2005, the estimated annual growth from 1997-2005 at the EFGB ranged from 3.19 mm to 14.54 mm, with an overall mean of 6.06 ± 1.2 SE mm. The highest mean growth (8.26 mm) occurred in 2004 (Table 3.2.1) and the lowest (3.19 mm) in 1999. Numerous cores showed mortality scars around 1998-1999 and re-growth thereafter (Figure 3.2.1). It is important to note that the black cells in Table 3.2.1 represent disconformities in accretionary growth.

Table 3.2.1.

Mean annual growth (mm) of *Montastraea faveolata* colonies collected at the EFGB and WFGB in June 2005. The black cells represent disconformities in accretionary growth. C1= Core 1, C2= Core 2, C3= Core 3, C4= Core 4, and SE= standard error.

	East Flower Garden Bank						West Flower Garden Bank					
Year	**C1**	**C2**	**C3**	**C4**	**Mean**	**SE**	**C1**	**C2**	**C3**	**C4**	**Mean**	**SE**
2005	5.94	3.36	6.54	8.69	**6.13**	**1.10**	7.31	2.75	4.13	5.43	**4.91**	**0.97**
2004	7.31	3.78	7.39	14.54	**8.26**	**2.26**	8.78	3.18	6.63	6.11	**6.18**	**1.15**
2003	7.05	3.62	8.25		**6.31**	**1.39**	6.79	5.24	6.02	4.99	**5.76**	**0.41**
2002	7.83	5.42			**6.63**	**1.21**	6.97	6.11	5.85	6.98	**6.48**	**0.29**
2001	8.94	6.11			**7.53**	**1.42**		5.84	6.46	2.84	**5.05**	**1.12**
2000		5.16			**5.16**			4.99	5.33	3.53	**4.62**	**0.55**
1999		3.19			**3.19**			3.78	5.00	3.96	**4.25**	**0.38**
1998		6.97			**6.97**			6.20	6.19	2.24	**4.88**	**1.32**
1997		4.39			**4.39**			6.11		7.75	**6.93**	**0.82**
1996								6.45		6.89	**6.67**	**0.22**
1995								5.94		6.29	**6.12**	**0.18**
1994								6.02		3.10	**4.56**	**1.46**
1993										3.70		
1992										7.66		
Overall Mean Growth Rate					**6.06**	**1.2**					**5.53**	**1.3**

The estimated annual growth of *Montastraea faveolata* at the WFGB from 1992-2005 ranged from 2.24 mm to 8.78 mm, with an overall mean of 5.53 ± 1.3 SE mm. The highest mean growth (6.93 mm) occurred in 1997 and the lowest (4.25 mm) in 1999 (Table 3.2.1). As at the EFGB, some cores showed partial mortality in 1999 and subsequent recovery in later years (Figure 3.2.1). Figure 3.2.2 presents the mean annual growth shown by cores collected from the EFGB and WFGB in June 2005.

Using the June 2005 coral core data, mean growth rates were calculated for each core and a Student's t-test was performed to compare growth between the EFGB and WFGB from 1992-2005. The mean growth rates were not significantly different between the EFGB and the WFGB ($t=0.96$, $df=19$, $P=0.35$).

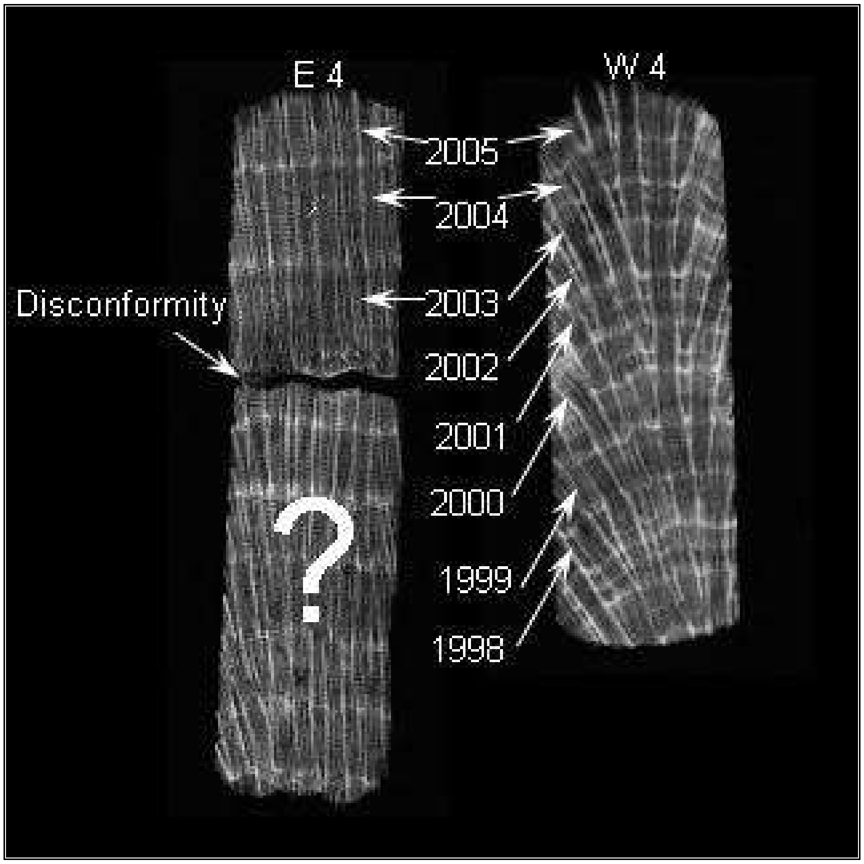


Figure 3.2.1. X-ray images of *Montastraea faveolata* cores from EFGB (left) and WFGB (right) showing a disconformity in accretionary growth. Growth resumed sometime within the 2002-2003 time period. The "?" indicates that years cannot be ascribed for bands below the disconformity.

3.2.2. June 2007 Cores

Based on the coral cores collected in June 2007, the estimated annual growth of *Montastraea faveolata* at the EFGB ranged from 4.9 mm to 8.8 mm from 2000-2007. The overall mean growth from cores on the EFGB was 7.5 ± 0.9 SD mm (Table 3.2.2). The highest mean growth (8.3 mm) occurred in 2003 and the lowest (5.4 mm) in 2006 (Table 3.2.2).

Estimated annual growth of *Montastraea faveolata* at the WFGB varied from 5.4 mm to 8.8 mm from 2000-2007. The overall mean growth from cores on the WFGB was 7.5 ± 0.8 SD mm (Table 3.2.2), which is similar to results from the 2007 EFGB cores. The highest mean growth (8.4 mm) occurred in 2000 and the lowest (5.8 mm) in 2006 (Table 3.2.2). Figure 3.2.3 presents the mean annual growth shown by cores collected from the EFGB and WFGB in June 2007.

Using the June 2007 coral core data, mean growth rates were calculated for each core and a Student's t-test was performed to compare growth rates between the EFGB and WFGB from

2000-2007. The mean growth rates were not significantly different between the EFGB and the WFGB (t=-0.09, df=14, P=0.93).

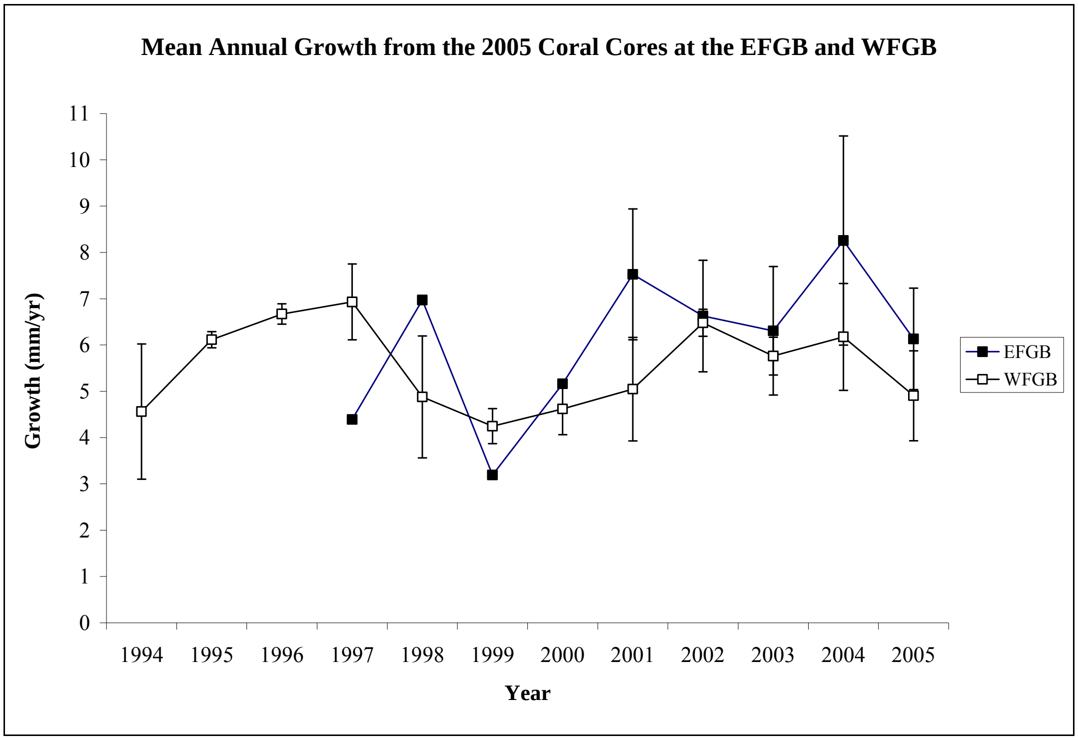


Figure 3.2.2. Estimated mean annual coral growth calculated from cores collected during the June 2005 long-term monitoring cruise. Errors bars represent standard error.

Table 3.2.2.

Mean annual growth (mm) of *Montastraea faveolata* colonies collected at the EFGB and WFGB in June 2007. C1= Core 1, C2= Core 2, C3= Core 3, C4= Core 4, and SD= standard deviation.

	EFGB						WFGB					
Year	**C1**	**C2**	**C3**	**C4**	**Mean**	**SD**	**C1**	**C2**	**C3**	**C4**	**Mean**	**SD**
2007	7.4	7.8	7.9	8.2	**7.8**	**0.33**	7.1	7.3	7.6	7.0	**7.3**	**0.26**
2006	5.8	5.3	5.5	4.9	**5.4**	**0.38**	6.0	6.1	5.7	5.4	**5.8**	**0.32**
2005	7.6	7.7	7.3	7.2	**7.5**	**0.24**	7.4	7.5	7.2	7.5	**7.4**	**0.14**
2004	8.4	7.9	8.0	8.6	**8.2**	**0.33**	8.2	8.4	8.5	8.2	**8.3**	**0.15**
2003	8.1	8.0	8.4	8.8	**8.3**	**0.36**	7.9	8.2	7.9	8.3	**8.1**	**0.21**
2002	7.6	7.5	7.8	7.9	**7.7**	**0.18**	7.9	7.7	7.4	7.4	**7.6**	**0.24**
2001	7.2	7.4	7.3	7.5	**7.4**	**0.13**	7.0	7.5	7.7	7.0	**7.3**	**0.36**
2000	8.0	7.6	7.4	7.5	**7.6**	**0.26**	8.2	8.4	8.8	8.1	**8.4**	**0.31**
Overall Mean Growth Rate					**7.5**	**0.9**					**7.5**	**0.8**

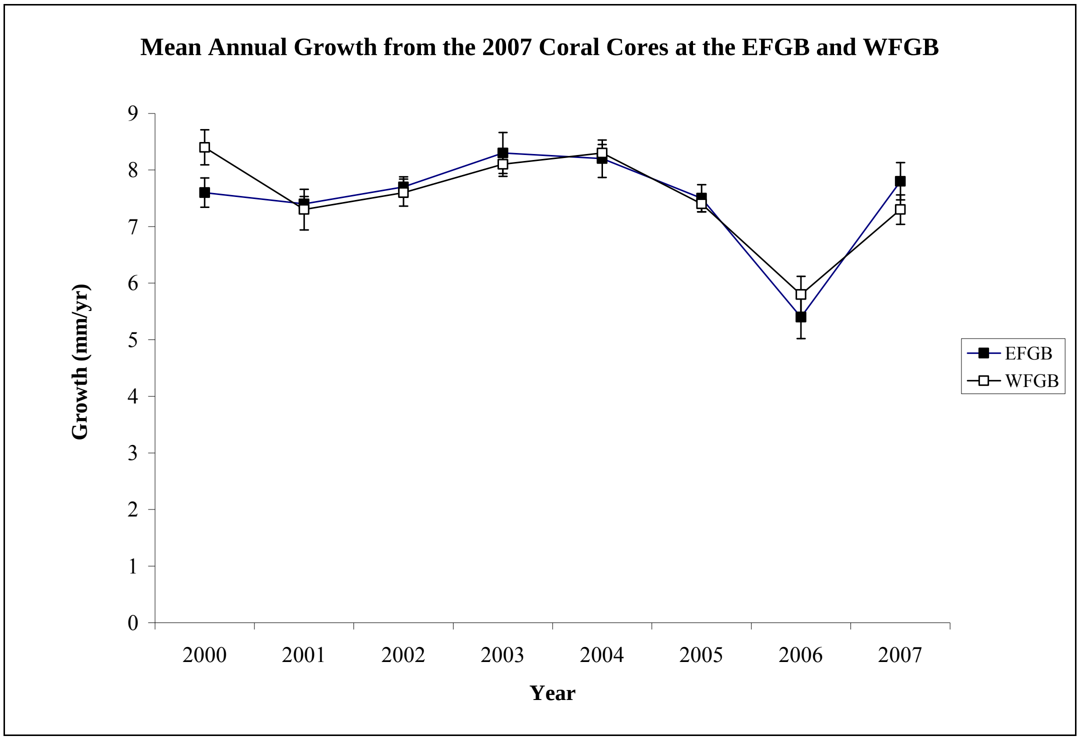


Figure 3.2.3. Estimated mean annual coral growth rates calculated from cores collected during the June 2007 long-term monitoring cruise. Note the reduction in coral growth in 2005 which was likely related to the large-scale bleaching event of that year. Error bars represent standard deviation.

3.3. Lateral Growth

3.3.1. Variability between Banks and Through Time

Examination of the data on lateral growth revealed high variability among time Intervals, as well as high variability between Banks and within some Bank-Interval combinations (Figure 3.3.1). Poor-weather conditions and other logistical constraints made it impossible to re-photograph each station in each year. The result was an unbalanced design, which is to say that sample sizes were low for certain Banks in certain years and, therefore, in the Intervals to which those years belonged. Two approaches were considered to analyze the lateral-growth data for the entire monitoring period, 2003-2007 (i.e., to compare proportional change in colony areas among the Intervals 2003-2004, 2004-2005, 2005-2006, and 2006-2007). The first was a repeated-measures design that used only the stations that were photographed in every year.

In total, 22 stations were photographed each year from 2003 through 2007: 18 at the EFGB and 4 at the WFGB. The variances were heterogeneous (Anderson-Darling test, $P=0.005$). The data were normally distributed with the exception of the WFGB data in 2006-2007 (Levene's test, $P<0.005$). Some of the proportional changes were greater than 1, excluding use of the arcsine transformation. The only transformation that conformed the data reasonably well to the assumptions of parametric statistics was $\{y = 1/(x+1)\}$. Transforming the data rendered the variances homogeneous (Anderson-Darling test on the transformed data, P=0.713) but did not normalize the WFGB data in 2006-2007 (Levene's test on the transformed data, P<0.005). Because ANOVA is robust to departures from normality, the non-normality of one cell was not considered a serious impediment to the analysis. A two-way repeated-measures ANOVA, with Bank and Interval as fixed factors and Station nested within Bank, showed no significant effects of Interval, Bank or Station, and the interaction between Bank and Interval was not significant (Table 3.3.1).

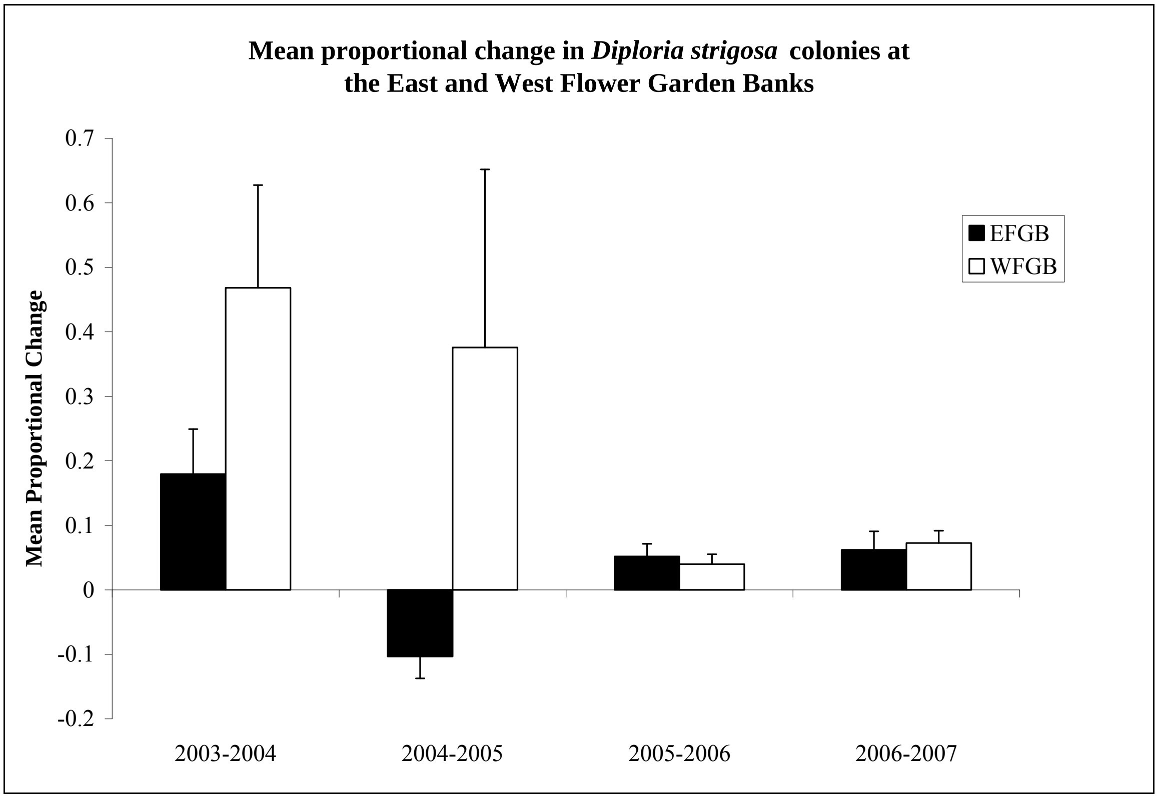


Figure 3.3.1. Mean proportional change in area of *Diploria strigosa* colonies, comparing the EFGB and WFGB during the intervals 2003-2004, 2004-2005, 2005-2006, and 2006-2007. Error bars represent standard errors. Figure is based on untransformed data.

The second design considered was a two-way Analysis of Covariance (ANCOVA), in which the factors were Bank and Interval and the datum for each station consisted of the first growth estimate for that station (i.e., growth during the first interval for which growth was measured). Because the *Diploria strigosa* growth stations were established in haphazard (essentially random) positions, and because only the first datum from each station was considered, the design would have been fully factorial. Unfortunately, the data departed severely from normality and homogeneity of variances, and these conditions could not be corrected by transformation. The condition of the data excluded this analysis.

Table 3.3.1.

Results of repeated-measures ANOVA on proportional change in areas of *Diploria strigosa* colonies, comparing the EFGB and WFGB during the intervals 2003-2004 through 2006-2007.
Data were transformed to 1/(x+1).

Source	df	SS	MS	F	P
Bank	1	0.2098	0.2098	1.83	0.192
Station(Bank)	19	2.1735	0.1144	1.08	0.390
Interval	3	0.1406	0.0469	0.44	0.722
Bank*Interval	3	0.0865	0.0288	0.27	0.844
Error	57	6.0114	0.1055		
Total	83	8.9165			

A nested ANCOVA approach to Table 3.3.1 would have been desirable in order to assess the effect of the initial area of living *Diploria strigosa* tissue on the proportional change in sequential years. Such a test was not possible due to the highly unbalanced sample sizes. Instead, a series of supplementary ANCOVAs were performed (Table 3.3.2), in which sequential one-year intervals were compared. The covariate was initial area of living tissue in the interval in question; for example, in comparing 2003-2004 with 2004-2005, the covariate for each datum from 2003-2004 was the area in 2003, and for each datum from 2004-2005 the covariate was the area in 2004. The ANCOVA assumption of equality of slopes was tested by examining the interactions between Bank and the covariate Initial Area, and, separately Interval and Initial Area; there were no significant deviations for any of the ANCOVAs in Table 3.3.2. To control experiment-wise error in Table 3.3.2, the Type I error rate was adjusted using the Bonferroni correction to $\alpha_{adj} = 0.05/6 = 0.0083$.

To compare 2003-2004 with 2004-2005, the data were first examined for conformity to the normality and homogeneity-of-variances assumptions of parametric statistics. The data violated the assumption of normality for all combinations of Bank and Interval except the 2004-2005 data for the EFGB (for which the Anderson-Darling test gave P=0.89; P<0.05 in all other cases). The variances were homogeneous (Levene's test, P=0.262). The data were transformed to {y = 1/(x+1)}. Even so, Anderson-Darling tests revealed that the transformed 2004-2005 data from the WFGB were not normally distributed (P=0.008). The data sets representing the three other combinations of Bank and Interval were normally distributed (P>0.19 in all cases). Levene's test showed that the variances of the four Bank-Interval combinations were homogeneous for the transformed data (P=0.25).

Comparing growth from 2003-2004 to growth in 2004-2005, the ANCOVA (Table 3.3.2A) yielded a significant covariate effect (i.e., a significant effect of initial area photographed). Bank and the Bank x Interval interaction were significant, whereas there was no significant effect of Interval. The Station effect was non-significant in light of the number of tests performed for Table 3.3.2. Ignoring the covariate rendered the interaction non-significant but did not change conclusions regarding the other sources of variance (Table 3.3.2B).

Table 3.3.2.

Results of repeated-measures analyses on proportional change in areas of *Diploria strigosa* colonies, comparing the EFGB and WFGB from 2003-2004 through 2006-2007 by pairs of sequential intervals. Data transformations as noted.

A. 2003-2004 compared to 2004-2005: ANCOVA; 1/(x+1) transformation

Source	df	SS	MS	F	P
Bank	1	1.1098	1.1098	16.06	<0.001
Station (Bank)	42	4.1772	0.0995	1.9	0.021
Interval	1	0.0403	0.0403	0.77	0.386
Bank*Interval	1	0.4057	0.4057	7.73	0.008
Initial Area	1	3.1969	3.1969	60.93	<0.001
Error	41	2.1512	0.0525		
Total	87	8.4614			

B. 2003-2004 compared to 2004-2005: ANOVA; 1/(x+1) transformation

Source	df	SS	MS	F	P
Bank	1	0.4826	0.4826	10.12	0.003
Station (Bank)	42	1.9655	0.0468	0.37	0.999
Interval	1	0.5326	0.5326	4.26	0.045
Bank*Interval	1	0.1043	0.1043	0.83	0.366
Error	44	5.5007	0.1250		
Total	89	8.6322			

C. 2004-2005 compared to 2005-2006: ANCOVA, untransformed data

Source	df	SS	MS	F	P
Bank	1	0.7002	0.7002	1.47	0.231
Station (Bank)	40	18.9047	0.4726	0.89	0.638
Interval	1	1.5505	1.5505	2.93	0.095
Bank*Interval	1	0.0457	0.0457	0.09	0.770
Initial Area	1	1.8694	1.8694	3.53	0.068
Error	39	20.6356	0.5291		
Total	83	49.3606			

D. 2004-2005 compared to 2005-2006: ANOVA, untransformed data

Source	df	SS	MS	F	P
Bank	1	1.6102	1.6102	2.79	0.103
Station (Bank)	40	23.1238	0.5781	1.03	0.466
Interval	1	0.4102	0.4102	0.73	0.398
Bank*Interval	1	1.7114	1.7114	3.04	0.089
Error	40	22.5050	0.5626		
Total	83	49.3606			

Table 3.3.2. Results of repeated-measures analyses on proportional change in areas of *Diploria strigosa* colonies, comparing the EFGB and WFGB from 2003-2004 through 2006-2007 by pairs of sequential intervals (continued).

E. 2005-2006 compared to 2006-2007: ANCOVA, untransformed data

Source	df	SS	MS	F	P
Bank	1	0.0336	0.0336	0.47	0.495
Station (Bank)	42	2.9721	0.0708	1.07	0.418
Interval	1	0.0040	0.0040	0.06	0.807
Bank*Interval	1	0.0157	0.0157	0.24	0.629
Initial Area	1	0.0056	0.0056	0.08	0.773
Error	41	2.7192	0.0663		
Total	87	5.8851			

F. 2005-2006 compared to 2006-2007: ANOVA, untransformed data

Source	df	SS	MS	F	P
Bank	1	0.0368	0.0368	0.50	0.483
Station (Bank)	42	3.0842	0.0734	1.13	0.345
Interval	1	0.0090	0.0090	0.14	0.712
Bank*Interval	1	0.0144	0.0144	0.22	0.640
Error	42	2.7248	0.0649		
Total	87	5.8851			

The 2004-2005 and 2005-2006 data were normally distributed, except for the WFGB in 2004-2005 (Anderson-Darling test, P<0.005), and the variances were homogeneous (Levene's test, P=0.290). Transformation did not correct the normality problem, and the analyses were performed on the untransformed data. The ANCOVA yielded no significant effect of the covariate, Bank, Interval, Station, or the Bank x Interval interaction (Table 3.3.2C). Removing the covariate did not qualitatively alter the results (Table 3.3.2D).

The 2005-2006 and 2006-2007 data were normally distributed, except for the EFGB in 2005-2006 (Anderson-Darling test, P<0.005), and the variances were homogeneous (Levene's test, P=0.250). Transformation did not correct the normality problem, and the analyses were performed on the untransformed data. The ANCOVA yielded no significant effect of the covariate, Bank, Interval, Station, or the Bank x Interval interaction (Table 3.3.2E). Removing the covariate did not qualitatively alter the results (Table 3.3.2F). (Note that the data for the EFGB in 2005-2006 were normally distributed in the 2004-2005/2005-2006 comparison, but they were not normally distributed in the 2005-2006/2006-2007 comparison. The reason for this apparent inconsistency is that the data sets are slightly different in the two comparisons. There were differences in which stations were repetitively photographed in different years.)

In summary, the area of living *Diploria strigosa* tissue in the initial photograph exerted an important influence on the outcome of one of the analyses. Although growth showed some significant variations and interactions and no consistent trend that was statistically significant, net growth was positive over the period 2003-2007 (Figure 3.3.1). Uncontrollable disruptions of data collection caused by foul weather will always be an issue in monitoring studies in the FGB; nevertheless, future monitoring efforts should strive for more balanced sample sizes to make the ANCOVA approach analytically more feasible. See Appendix 3 for 2003-2007 lateral growth data.

3.3.2. Comparison of Film and Digital Lateral Growth Photographs

The collection of digital photography in 2007 served as a trial run to evaluate the possibility of switching from film to digital photography in the lateral growth component of the monitoring effort. Using the digital photographs taken in 2007, it was possible to compare the film and digital results for that year with sample sizes of 10 for the Olympus digital setup and nine for the Sea&Sea digital setup. In addition, comparisons were made between the 2006-2007 results using film for both years and the 2006-2007 results using film in 2006 and digital photography in 2007; sample sizes for this comparison were nine each for the Olympus and Sea&Sea digital setups.

Comparing the 10 stations photographed with both film and the Olympus setup in 2007, the absolute value of the mean proportional difference between the two overlaid images was 0.056 ± 0.015 SE. The difference was >0.05 in four cases, or 40% of the sample. For the nine stations photographed with both film and the Sea&Sea setup, the absolute value of the mean proportional difference between the two overlaid images was 0.050 ± 0.007 SE. The difference was >0.05 in four cases, or 56% of the sample.

Estimates of proportional change in the lateral margins of colonies from 2006 to 2007 differed depending on whether film or digital photographs from 2007 were compared to film photographs from 2006. The proportional annual change in the area of individual coral colonies was calculated by subtracting the proportional change between the 2006 film image and the 2007 digital image from the proportional change between the 2006 film image and the 2007 film image. The mean difference in the estimates of annual change in the area of individual coral colonies from 2006-2007 averaged 0.121 ± 0.025 SE (n=18).

Each lateral growth station was then analyzed separately depending on whether the Olympus or Sea&Sea setup was used in 2007. The difference between the estimates of proportional annual change in the area of individual coral colonies using film in 2006 and digital in 2007 and the estimates of proportional change using film in both years averaged. The mean proportional difference was 0.130 ± 0.027 SE (n=9) for the stations in which the Olympus setup was used in 2007 and 0.111 ± 0.023 SE (n=9) for stations in which the Sea&Sea setup was used in 2007.

The two digital photography setups performed equivalently in terms of data quality. These comparisons demonstrate that the methodology used for digital photography must be further refined before meaningful comparisons can be made between digital and film photographs of the growth margins of *D. strigosa* colonies. Switching from film to digital photography for the lateral growth stations is not recommended until the two photographic methods (film and digital) consistently give results within 2-3% of each other.

3.4. REPETITIVE QUADRATS

3.4.1. Repetitive Quadrat Analysis

3.4.1.1. Percent Cover

For percent cover data in the 100- x 100-m study sites at the EFGB and WFGB, a total of 58 quadrats were analyzed for 2004 (38 EFGB and 20 WFGB), 61 quadrats in 2005 (41 EFGB and 20 WFGB), 80 quadrats in 2006 (39 EFGB and 41 WFGB quadrats), 75 quadrats in 2007 (39 EFGB and 36 WFGB), and 75 quadrats in 2008 (38 EFGB and 37 WFGB). Coral cover was consistently high during the period 2004-2008 (Figure 3.4.1 and Figure 3.4.2). Macroalgae and CTB showed reciprocal patterns: for example, macroalgae increased at the EFGB from 2004 to 2005, while CTB decreased at the EFGB during the same period. The incidences of bleaching, paling, and fish biting were low (Tables 3.4.1 and 3.4.2). The coral assemblages remained stable at both Banks during the study period, with the dominant corals being the *Montastraea annularis* species complex, *Diploria strigosa*, *Porites astreoides*, and *M. cavernosa* (Figures 3.4.3 and 3.4.4). Appendix 4 contains all repetitive quadrat percent cover data for the EFGB and WFGB from 2004 to 2008.

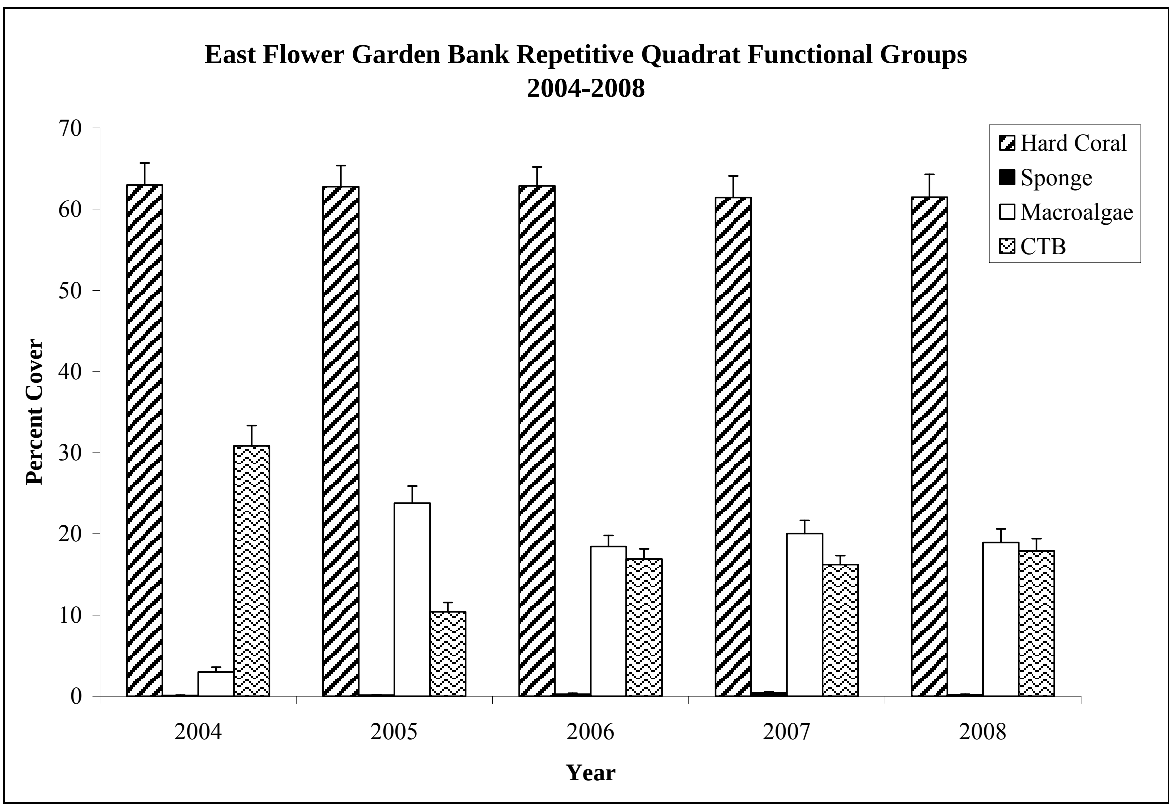


Figure 3.4.1. Percent cover (+ SE) of four functional groups in the EFGB repetitive quadrats from 2004 to 2008. Abbreviation: CTB- crustose coralline algae, fine turf algae, and bare rock. Macroalgae includes thick turfs as well as fleshy macroalgae.

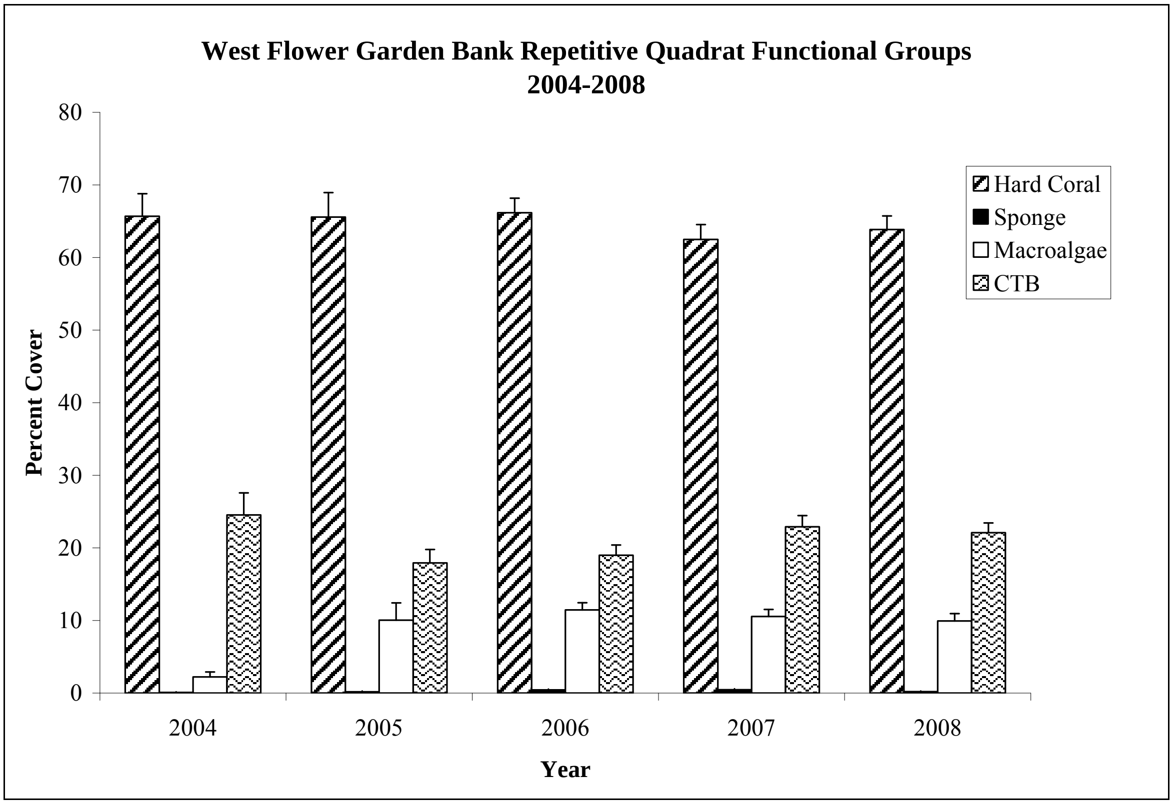


Figure 3.4.2. Percent cover (+ SE) of four functional groups in the WFGB repetitive quadrats from 2004 to 2008. Abbreviation: CTB - crustose coralline algae, fine turf algae, and bare rock. Macroalgae includes thick turfs as well as fleshy macroalgae.

Table 3.4.1.

Percent paling, bleaching, concentrated fish biting, isolated fish biting, and disease (± SE) observed in 8-m^2 repetitive quadrats at the EFGB from 2004 through 2008.

Observation	2004	2005	2006	2007	2008
Paling	0.2 ± 0.07	0.18 ± 0.06	0.02 ± 0.01	0.07 ± 0.06	0.03 ± 0.03
Bleaching	0.32 ± 0.08	0.57 ± 0.18	0.62 ± 0.24	0.03 ± 0.03	0.03 ± 0.03
Concentrated Fish Biting	0.30 ± 0.12	0.31 ± 0.10	0.21 ± 0.07	0.45 ± 0.14	0.37 ± 0.09
Isolated Fish Biting	2.72 ± 1.09	4.73 ± 1.40	2.10 ± 0.30	1.02 ± 0.18	1.41 ± 0.20
Disease	0.00	0.00	0.00	0.00	0.00

Table 3.4.2.

Percent paling, bleaching, concentrated fish biting, isolated fish biting, and disease (± SE) observed in 8-m^2 repetitive quadrats at the WFGB from 2004 through 2008.

Observation	2004	2005	2006	2007	2008
Paling	0.06 ± 0.05	0.00	0.12 ± 0.04	0.17 ± 0.08	0.05 ± 0.03
Bleaching	0.09 ± 0.07	0.03 ± 0.03	0.36 ± 0.12	0.54 ± 0.21	0.10 ± 0.08
Concentrated Fish Biting	0.46 ± 0.22	0.65 ± 0.19	0.25 ± 0.07	0.52 ± 0.09	0.95 ± 0.14
Isolated Fish Biting	0.77 ± 0.29	1.49 ± 0.53	1.24 ± 0.17	2.00 ± 0.27	1.36 ± 0.25
Disease	0.00	0.00	0.00	0.00	0.00

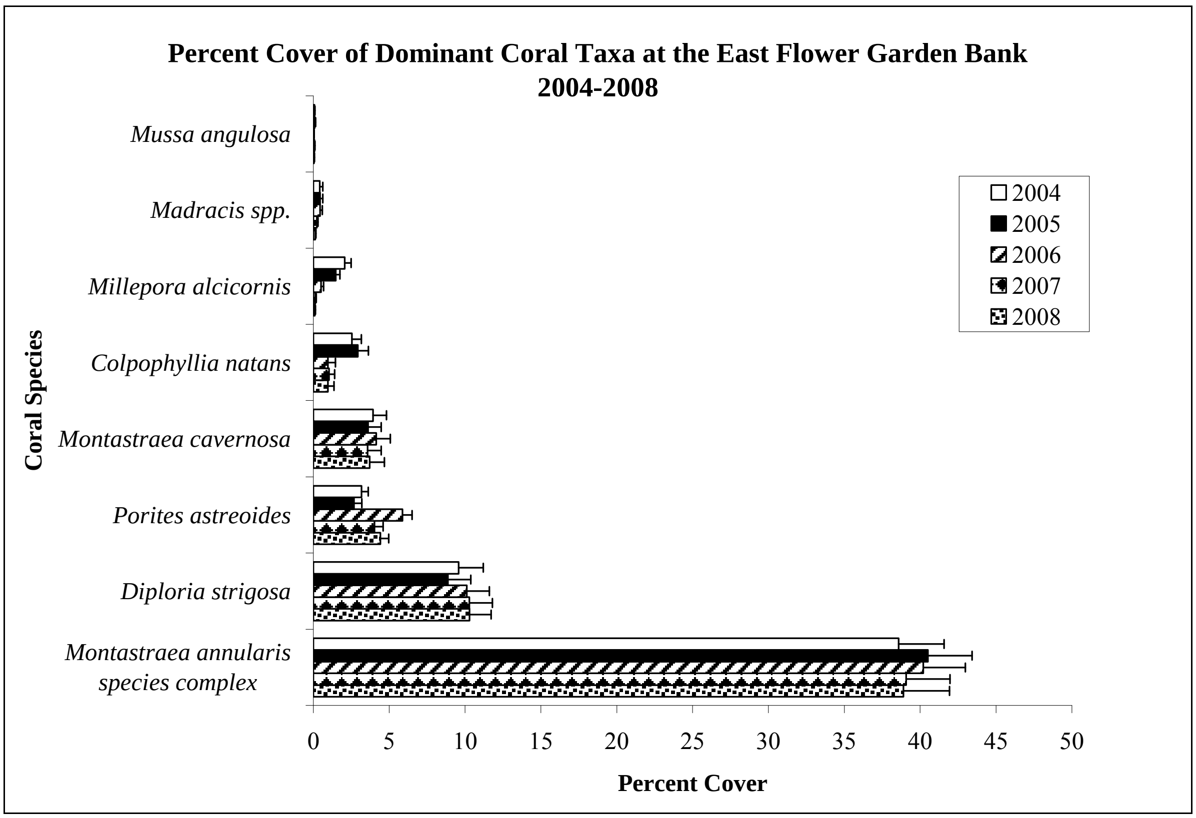


Figure 3.4.3. Percent cover (+ SE) of the dominant coral taxa at the EFGB in 8-m^2 repetitive quadrats.

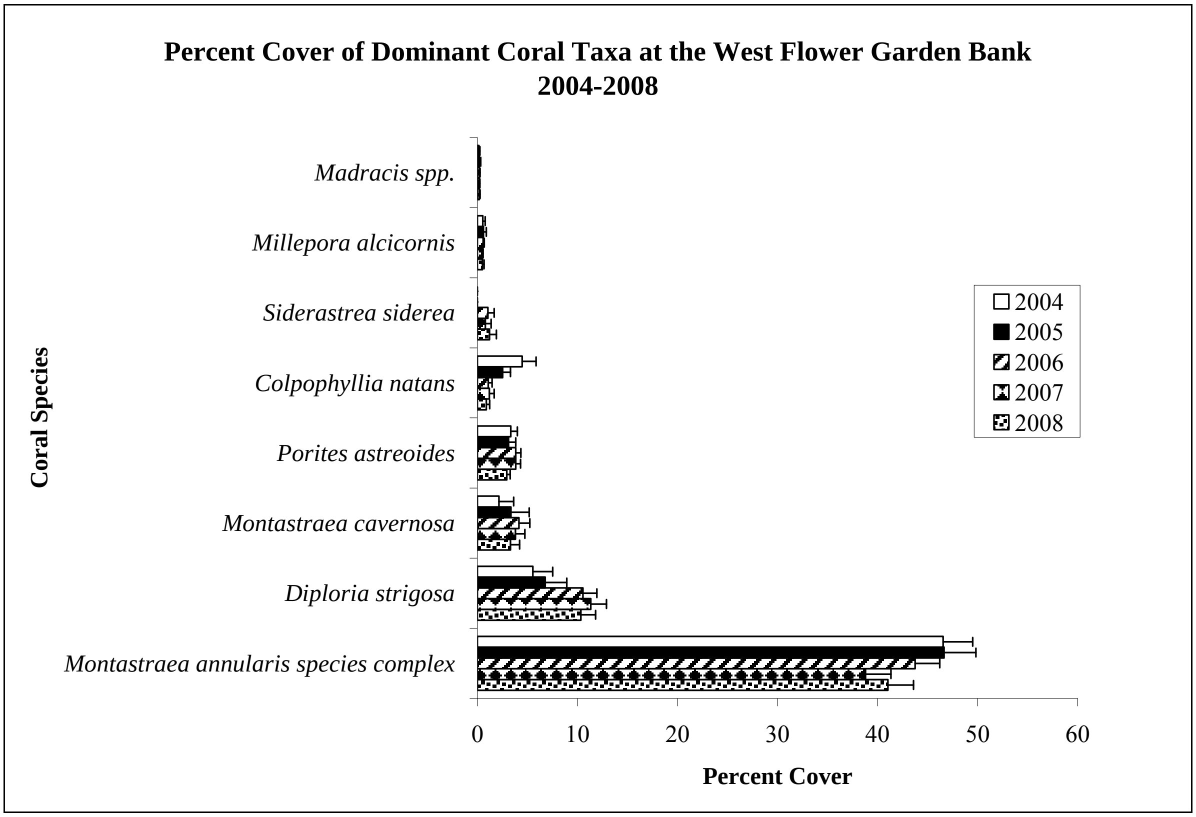


Figure 3.4.4. Percent cover (+ SE) of the dominant coral taxa at the WFGB in 8-m^2 repetitive quadrats.

From 2004 through 2008, coral disease was absent from the analyzed photographs at both Banks (Tables 3.4.1 and 3.4.2); however, the identification of disease in photographs is not reliable because of the 2-m distance from the substrate (B. Zimmer, personal observation). The percentage of corals impacted by concentrated/isolated fish biting was similar at the EFGB and WFGB, ranging from 0.21-4.73% (Tables 3.4.1 and 3.4.2). Fish biting occurred primarily on the *Montastraea annularis* species complex and appeared to be more common at the EFGB from 2004 to 2006 and more common at the WFGB in 2007 and 2008 (Tables 3.4.3 and 3.4.4).

Paling and bleaching were extremely low at both Banks, ranging from 0-0.62% (Tables 3.4.1 and 3.4.2). At the EFGB, bleaching was highest in 2006 (0.62%) and at the WFGB, bleaching was highest in 2007 (0.54%; Tables 3.4.1 and 3.4.2). In 2004-2008, *Millepora alcicornis* was the species most frequently bleached at the EFGB, with bleaching rates ranging from (0.02-0.43%; Table 3.4.3). At the WFGB, *M. alcicornis* was the most bleached coral (0.03-0.27%) in all years except 2006, when the *Montastraea annularis* species complex showed the highest bleaching (0.19%; Table 3.4.4). Paling was more frequent at the EFGB, mainly occurring on *Diploria strigosa* and *Montastraea annularis* species complex (Table 3.4.3).

Table 3.4.3.

Percent cover by coral species of isolated and concentrated fish biting, paling, and bleaching in 8-m^2 repetitive quadrats at the EFGB, 2004-2008. IFB= isolated fish biting, CFB= concentrated fish biting, P= paling, BL= bleaching. The *Montastraea annularis* species complex includes *M. annularis*, *M. faveolata* and *M. franksi*. EFGB 2004 (n=6025), 2005 (n= 6497), 2006 (n=6271), 2007 (n=5764) and 2008 (n= 5976). n = number of coral points within repetitive quadrats.

Observation	2004				2005				2006			
	IFB	**CFB**	**P**	**BL**	**IFB**	**CFB**	**P**	**BL**	**IFB**	**CFB**	**P**	**BL**
Colpophyllia natans	0.02	0.00	0.02	0.00	0.00	0.02	0.02	0.00	0.00	0.00	0.00	0.00
Unidentified Coral	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00
Diploria strigosa	0.08	0.00	0.07	0.08	0.20	0.00	0.06	0.00	0.00	0.00	0.00	0.10
Madracis spp.	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Millepora alcicornis	0.00	0.00	0.00	0.13	0.03	0.00	0.00	0.43	0.00	0.00	0.00	0.30
Montastraea annularis species complex	2.57	0.28	0.07	0.02	4.43	0.28	0.06	0.06	2.09	0.21	0.02	0.21
Montastraea cavernosa	0.02	0.00	0.03	0.00	0.05	0.02	0.05	0.00	0.02	0.00	0.00	0.02
Mussa angulosa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Porites astreoides	0.02	0.02	0.02	0.00	0.02	0.00	0.00	0.03	0.00	0.00	0.00	0.00
Total	**2.72**	**0.30**	**0.20**	**0.32**	**4.73**	**0.31**	**0.18**	**0.57**	**2.10**	**0.21**	**0.02**	**0.62**

Table 3.4.3. Percent cover by coral species of isolated and concentrated fish biting, paling, and bleaching in 8-m^2 repetitive quadrats at the EFGB, 2004-2008 (continued).

Observation	**2007**				**2008**			
	IFB	**CFB**	**P**	**BL**	**IFB**	**CFB**	**P**	**BL**
Colpophyllia natans	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Unidentified Coral	0.02	0.03	0.00	0.02	0.03	0.05	0.00	0.00
Diploria strigosa	0.00	0.00	0.00	0.00	0.13	0.02	0.00	0.00
Madracis spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Millepora alcicornis	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.02
Montastraea annularis species complex	0.92	0.38	0.05	0.00	1.22	0.18	0.02	0.00
Montastraea cavernosa	0.00	0.02	0.02	0.00	0.00	0.12	0.02	0.02
Mussa angulosa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Porites astreoides	0.09	0.02	0.00	0.00	0.02	0.00	0.00	0.00
Total	**1.02**	**0.45**	**0.07**	**0.03**	**1.41**	**0.37**	**0.03**	**0.03**

Table 3.4.4.

Percent cover by coral species of isolated and concentrated fish biting, paling, and bleaching in 8-m^2 repetitive quadrats at the WFGB, 2004-2008. IFB= isolated fish biting, CFB= concentrated fish biting, P= paling, BL= bleaching. The *Montastraea annularis* species complex includes *M. annularis*, *M. faveolata* and *M. franksi*. WFGB 2004 (n= 3236), 2005 (n= 3218), 2006 (n= 6919), 2007 (n= 5907), and 2008 (n= 5972). n = number of coral points within repetitive quadrats.

	2004				**2005**				**2006**			
Observation	**IFB**	**CFB**	**P**	**BL**	**IFB**	**CFB**	**P**	**BL**	**IFB**	**CFB**	**P**	**BL**
Colpophyllia natans	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Unidentified Coral	0.03	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diploria strigosa	0.00	0.00	0.00	0.00	0.06	0.06	0.00	0.00	0.00	0.00	0.03	0.03
Madracis spp.	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Millepora alcicornis	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.12
Montastraea annularis species complex	0.71	0.37	0.06	0.00	1.43	0.59	0.00	0.00	1.24	0.22	0.06	0.19
Montastraea cavernosa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.03
Mussa angulosa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Porites astreoides	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Siderastrea siderea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Stephanocoenia intersepta	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**0.77**	**0.46**	**0.06**	**0.09**	**1.49**	**0.65**	**0.00**	**0.03**	**1.24**	**0.25**	**0.12**	**0.36**

Table 3.4.4. Percent cover by coral species of isolated and concentrated fish biting, paling, and bleaching in 8-m^2 repetitive quadrats at the WFGB, 2004-2008 (continued).

	2007				2008			
Observation	**IFB**	**CFB**	**P**	**BL**	**IFB**	**CFB**	**P**	**BL**
Colpophyllia natans	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Unidentified Coral	0.03	0.00	0.00	0.02	0.00	0.05	0.00	0.00
Diploria strigosa	0.00	0.00	0.00	0.02	0.13	0.12	0.00	0.00
Madracis spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Millepora alcicornis	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.05
Montastraea annularis species complex	1.91	0.47	0.10	0.15	1.14	0.69	0.02	0.00
Montastraea cavernosa	0.00	0.00	0.05	0.02	0.00	0.07	0.03	0.00
Mussa angulosa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
Porites astreoides	0.00	0.00	0.00	0.05	0.03	0.03	0.00	0.00
Siderastrea siderea	0.02	0.05	0.00	0.02	0.03	0.00	0.00	0.00
Stephanocoenia intersepta	0.03	0.00	0.02	0.00	0.02	0.00	0.00	0.00
Total	**2.00**	**0.52**	**0.17**	**0.54**	**1.36**	**0.95**	**0.05**	**0.10**

3.4.1.2. Planimetry Analysis

Planimetry was used to measure tissue change between select coral colonies within quadrat matches for the following intervals: 2003-2004, 2004-2005, 2005-2006, 2006-2007, and 2007-2008. Within each repetitive quadrat match, coral colonies were selected for planimetry analysis based on the ability of the observers to decipher their boundaries, as well as their importance to reef accretion. Colonies from important frame-building species, including the *Montastraea annularis* species complex, *M. cavernosa*, *Diploria strigosa*, *Colpophyllia natans*, and *Porites astreoides* were selected. The results of the planimetry analysis are presented as a proportional growth or loss of tissue, based on the areal measurements of tissue change (cm^2). Appendix 5 provides the tissue change results (proportional change in planar area) for all of the corals colonies measured from 2003-2008.

Because the *Montastraea annularis* species complex was by far the dominant coral taxon and builder of reef framework in the repetitive quadrats, the planimetry measurements for only this taxon were used in the comparisons between Banks and over time. For each quadrat containing colonies of *M. annularis* species complex that were used in the analysis, the overall proportional change in planar area for the measured colonies was calculated. This procedure yielded sample sizes (number of quadrats) between 26 and 33 for the EFGB, between 6 and 8 for the EFGB deep stations, and between 17 and 33 for the WFGB (Table 3.4.5). Figure 3.4.5 displays the proportional change in cover of the *M. annularis* species complex for both the EFGB and WFGB over the time intervals 2003-2004, 2004-2005, 2005-2006, 2006-2007, and 2007-2008. Mean proportional change for each interval was calculated by taking the average of the total proportional change of *M. annularis* species complex at each station.

Table 3.4.5.

Number of repetitive quadrat stations with measured *Montastraea annularis* species complex colonies used in statistical analysis.

Time Interval	EFGB	EFGB Deep Stations	WFGB
2003-2004	33	7	19
2004-2005	31	8	17
2005-2006	31	6	33
2006-2007	29	6	29
2007-2008	26	8	28

A repeated-measures analysis was used to compare the change in planar area of *Montastraea annularis* species complex over the entire study period, which is to say over the time intervals 2003-2004, 2004-2005, 2005-2006, 2006-2007, and 2007-2008. In total, 22 quadrats at the EFGB and 12 quadrats at the WFGB were photographed each year from 2003 to 2008. The Anderson-Darling test showed that the data were normally distributed, with the exceptions of the EFGB in 2005-2006 and the EFGB in 2006-2007 ($P<0.005$ in both cases). The results for the EFGB in 2003-2004 also suggested a departure from normality ($P=0.022$), but adjustment of α to control experiment-wise error among the 10 tests (testing the data from each of two Banks for each of five years) rendered that result non-significant. Levene's test showed the variances to be homogeneous (P=0.453). Transformation did not correct the departures from normality; however, analysis of variance is robust to violations of the normality assumption.

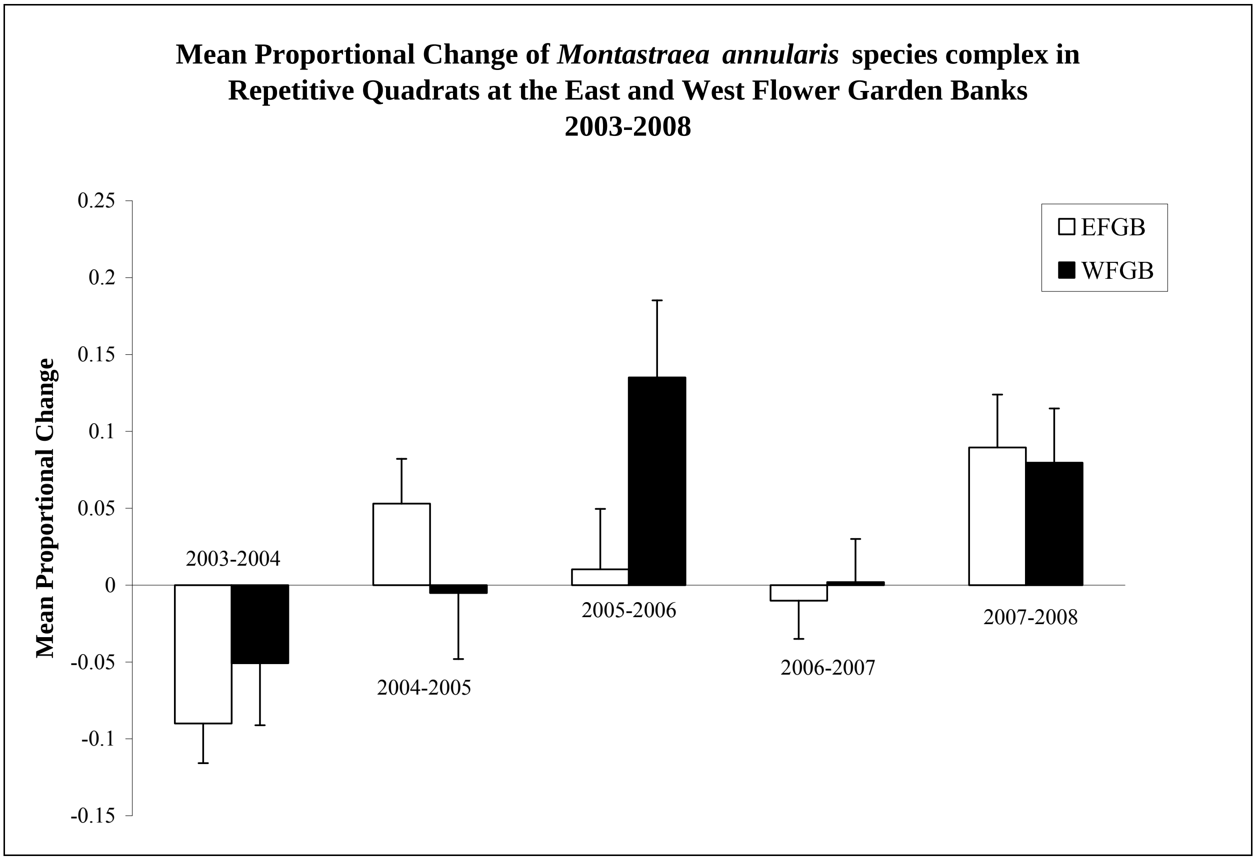


Figure 3.4.5. Mean proportional change ± SE in *Montastraea annularis* species complex at the EFGB and WFGB for the intervals 2003-2004, 2004-2005, 2005-2006, 2006-2007, and 2007-2008.

Table 3.4.6 displays the results of a repeated measures analysis of covariance (ANCOVA), in which Bank and Interval were fixed factors, and Quadrats were nested within Banks. The covariate was Initial Area, which was the area of living tissue of *Montastraea annularis* species complex in the quadrat at the beginning of the interval in question: for changes in area from 2003 to 2004, the covariate for each datum from 2003-2004 was the area of *M. annularis* species complex in 2003; for changes in area from 2004 to 2005, the covariate for each datum from 2004-2005 was the area in 2004; and so on. The rationale for including the covariate was that a given absolute amount of growth represents a lower proportional increase of a larger colony (or a larger group of colonies) than a smaller colony (or group of colonies). The ANCOVA assumption of equality of slopes was tested by examining the interactions between Bank and the covariate Initial Area, and, separately Interval and Initial Area; there were no significant deviations, indicating that the assumption was met.

Table 3.4.6.

Results of repeated-measures ANCOVA on proportional change in colony areas of *Montastraea annularis* species complex, comparing the EFGB and WFGB during the intervals 2003-2004 through 2007-2008. Data were not transformed.

Source	df	SS	MS	F	P
Bank	1	0.0079	0.0079	0.35	0.557
Quadrat(Bank)	33	0.5083	0.0154	0.46	0.995
Interval	4	0.4016	0.1004	2.97	0.022
Bank*Interval	4	0.2965	0.0741	2.20	0.073
Initial Area	1	0.1996	0.1996	5.91	0.016
Error	126	4.2536	0.0338		
Total	169	5.71294			

The factor time Interval and the covariate Initial Area were significant, and Bank was not significant, but the nearly-significant Bank x Interval interaction made interpreting the effects of factors problematic (see Figure 3.4.5). Because the effect of Quadrats (nested within Banks) was so strongly non-significant (P=0.995), the ANCOVA was run with the nested term removed from the model (Table 3.4.7). In this analysis, Interval was highly significant, Bank was not significant, and the covariate Initial Area was no longer significant.

Table 3.4.7.

Results of repeated-measures ANCOVA on proportional change in colony areas of *Montastraea annularis* species complex, comparing the EFGB and WFGB during the intervals 2003-2004 through 2007-2008. The nested term in Table 3.4.6 (Quadrats nested within Banks) was removed. Data were not transformed.

Source	df	SS	MS	F	P
Bank	1	0.07038	0.0704	2.35	0.127
Interval	4	0.6136	0.1534	5.12	0.001
Bank*Interval	4	0.2354	0.0589	1.97	0.102
Initial Area	1	0.0098	0.0098	0.33	0.568
Error	159	4.7620	0.0200		
Total	169	5.7129			

Further simplifying the analysis by removing the non-significant covariate yielded the repeated-measures ANOVA in Table 3.4.8. Interval was again highly significant. Tukey *a posteriori* multiple comparisons revealed two groups of time intervals. The intervals are arranged below in descending order of mean growth, with intervals that are not significantly different underlined:

2005-2006 2006-2007 2004-2005 2006-2007 2003-2004

In summary, the colonies of *Montastraea annularis* species complex in the quadrats showed overall positive growth, but there was no temporal trend in growth during the study period.

Table 3.4.8.

Results of repeated-measures ANOVA on proportional change in colony areas of *Montastraea annularis* species complex, comparing the EFGB and WFGB during the intervals 2003-2004 through 2007-2008. The covariate in Table 3.4.6 (Quadrats nested within Banks) was removed. Data were not transformed.

Source	df	SS	MS	F	P
Bank	1	0.0855	0.0855	2.87	0.092
Interval	4	0.6444	0.1610	5.4	<0.001
Bank*Interval	4	0.2334	0.0584	1.96	0.104
Error	160	4.7717	0.0298		
Total	169	5.7129			

A series of supplementary ANCOVAs was performed to compare proportional change in planar area of *Montastraea annularis* species complex in sequential pairs of one-year intervals (Table 3.4.9). The ANCOVA assumption of equality of slopes was tested by examining the interactions between Bank and the covariate Initial Area, and, separately Interval and Initial Area. There were no significant deviations, indicating that the assumption was met for the analyses in Table 3.4.9.

In total, 47 quadrats were photographed each year during 2003-2005 and were, therefore, available for comparing 2003-2004 to 2004-2005: 30 from the EFGB and 17 from the WFGB. The data from the WFGB were normally distributed in each of the two years, but they were non-normal in both years for the EFGB (Anderson-Darling test, P<0.005 for 2003-2004 and P=0.014 for 2004-2005). The variances were homogeneous (Levene's test, P=0.566). The square-root transformation $\{y = (x + 1)^{0.5}\}$ did not improve normality of the EFGB data for 2003-2004 (Anderson-Darling test, P<0.005), but it improved normality of the EFGB data for 2004-2005 (P=0.051). A repeated-measures ANCOVA on the transformed data revealed significant effects of Bank and the covariate Initial Area, but no significant effect of Quadrat (nested within Bank) or Interval, and no significant Bank x Interval interaction (Table 3.4.9A). Overall, growth was more negative at the WFGB than the EFGB during the interval 2003-2005.

A total of 43 quadrats were available to compare 2004-2005 to 2005-2006: 27 from the EFGB and 16 from the WFGB. The data were normally distributed, except for the EFGB in 2005-2006 (Anderson-Darling test, P<0.005; note that they were marginally non-normal for the EFGB in 2004-2005, at P=0.067). The variances were homogeneous (Levene's test, P=0.427). Transformation did not correct the normality problem, and the analysis was performed on the untransformed data (Table 3.4.9B). Adjusting α to maintain an overall experiment-wise error rate of 0.05 for the 4 analyses in Table 3.4.9 yielded a significant effect of the covariate Initial Area but no other significant effects.

Table 3.4.9.

Results of repeated-measures ANCOVAs on proportional change in colony areas of *Montastraea annularis* species complex, comparing the EFGB and WFGB from 2003-2004 through 2007-2008 by pairs of sequential intervals. Data transformations as noted.

A. 2003-2004 compared to 2004-2005: $(x+1)^{0.5}$ transformation

Source	df	SS	MS	F	P
Bank	1	0.1552	0.1552	21.76	<0.001
Station(Bank)	46	0.4029	0.0088	1.58	0.067
Interval	1	0.0024	0.0024	0.44	0.512
Bank*Interval	1	0.0020	0.0020	0.36	0.551
Initial Area	1	0.2689	0.2689	48.50	<0.001
Error	43	0.2384	0.0055		
Total	93	0.7691			

B. 2004-2005 compared to 2005-2006: untransformed data

Source	df	SS	MS	F	P
Bank	1	0.1951	0.1951	6.02	0.017
Station(Bank)	41	1.6560	0.0404	1.35	0.173
Interval	1	0.1342	0.1342	4.48	0.041
Bank*Interval	1	0.1014	0.1014	3.39	0.073
Initial Area	1	0.4680	0.4680	15.63	<0.001
Error	40	1.1974	0.0299		
Total	85	3.2480			

C. 2005-2006 compared to 2006-2007: 1/(x+1) transformation

Source	df	SS	MS	F	P
Bank	1	0.2995	0.2995	7.71	0.007
Quadrat(Bank)	56	3.2149	0.05741	1.16	0.289
Interval	1	0.0035	0.0035	0.49	0.594
Bank*Interval	1	0.0065	0.0065	0.13	0.718
Initial Area	1	0.7878	0.7878	15.98	<0.001
Error	53	2.6134	0.0493		
Total	113	6.2505			

D. 2006-2007 compared to 2007-2008: untransformed data

Source	df	SS	MS	F	P
Bank	1	0.0012	0.0012	0.12	0.733
Quadrat(Bank)	52	0.5165	0.0099	0.23	~1.00
Interval	1	0.1505	0.1505	3.43	0.070
Bank*Interval	1	0.0074	0.0074	0.17	0.684
Initial Area	1	0.0038	0.0038	0.09	0.770
Error	51	2.2396	0.0439		
Total	107	3.0060			

A total of 57 quadrats were available to compare 2005-2006 to 2006-2007: 29 from the EFGB and 28 from the WFGB. All the data violated the normality assumption, based on Anderson-Darling tests (EFGB data for 2005-2006, P<0.005; EFGB for 2006-2007, P<0.005; WFGB for 2005-2006, P=0.013; WFGB for 2006-2007, P=0.010). The variances were marginally heterogeneous (Levene's test, P=0.068). Transformation to {y = 1/(x+1)} homogenized the variances (Levene's test, P=0.598) but did not correct the normality problem (EFGB for 2005-2006, P<0.005; EFGB for 2006-2007, P<0.005; WFGB for 2005-2006, P=0.018; WFGB for 2006-2007, P<0.005). Analysis of the transformed data (Table 3.4.9C) yielded a significant effect of the covariate Initial Area and a significant Bank effect. Overall, growth was positive at the WFGB and slightly negative at the EFGB during 2005-2007.

A total of 54 quadrats were available to compare 2006-2007 to 2007-2008: 26 from the EFGB and 28 from the WFGB. The data violated the normality assumption in three of the four cases, based on Anderson-Darling tests (EFGB for 2006-2007, P<0.005; EFGB for 2007-2008, P<0.180; WFGB for 2006-2007, P=0.019; WFGB for 2007-2008, P=0.010). The variances were homogeneous (Levene's test, P=0.430). Transformation did not correct the normality problem, and the analysis was performed on the untransformed data (Table 3.4.9D). There were no significant effects of factors, nor were the interaction or the covariate significant.

The analyses of Table 3.4.9 largely corroborate the results presented in Tables 3.4.6, 3.4.7, and 3.4.8. Growth was generally positive but temporally variable. At times the EFGB and WFGB were heterogeneous with respect to change in *M. annularis* species complex in the quadrats, but there was no apparent trend in the data.

3.4.1.3. Deep Stations – Percent Cover

The deep stations at the EFGB were analyzed for benthic cover type using random dot analysis (Table 2.5.2). Coral cover was high at the deep stations (ranging from 72-86% between 2004 and 2008), while algal cover consisted of a mixture of low levels of macroalgae and CTB (Figure 3.4.6). The *Montastraea annularis* species complex was consolidated for analysis and was the predominant coral taxon. *M. cavernosa* was the second most common coral taxon (Figure 3.4.7). An example of a deep station repetitive quadrat is shown in Figure 3.4.8.

3.4.1.4. Deep Stations – Planimetry Analysis

Because the *Montastraea annularis* species complex (mostly *M. franksi*) was the dominant coral taxon and builder of reef framework in the deep station repetitive quadrats (Precht et al. 2005), the change in cover of this taxon was compared over the following periods: 2003-2004, 2004-2005, 2005-2006, 2006-2007, and 2007-2008 (Figure 3.4.9). For each quadrat containing colonies of *M. annularis* species complex that were used in the analysis, the overall proportional change in planar area for the measured colonies was calculated for each interval. This procedure yielded sample sizes (number of quadrats) between six and eight for the EFGB deep stations (Table 3.4.5).

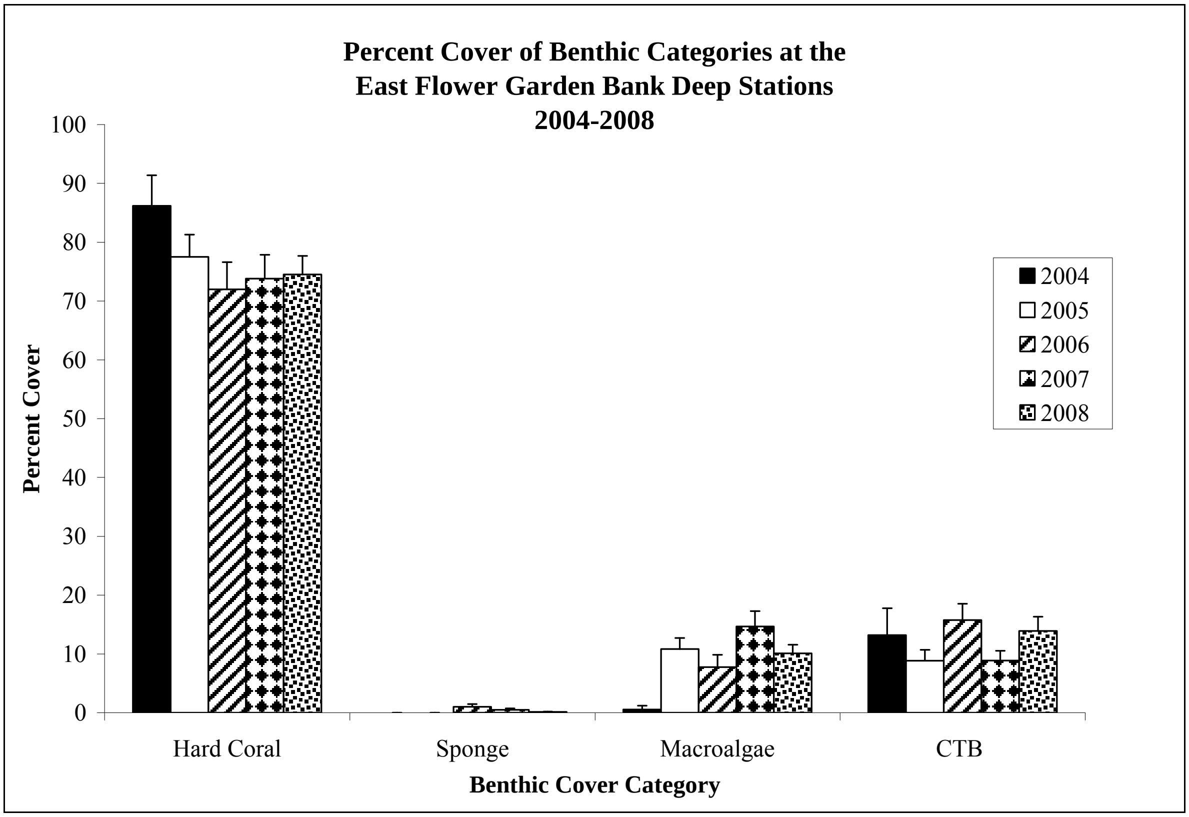


Figure 3.4.6. Percent cover (+ SE) data for four benthic categories in the EFGB deep repetitive quadrats during 2004-2008. Abbreviation CTB- crustose coralline algae, fine turf algae, and bare rock. Macroalgae includes thick turf algae as well as macroalgal species.

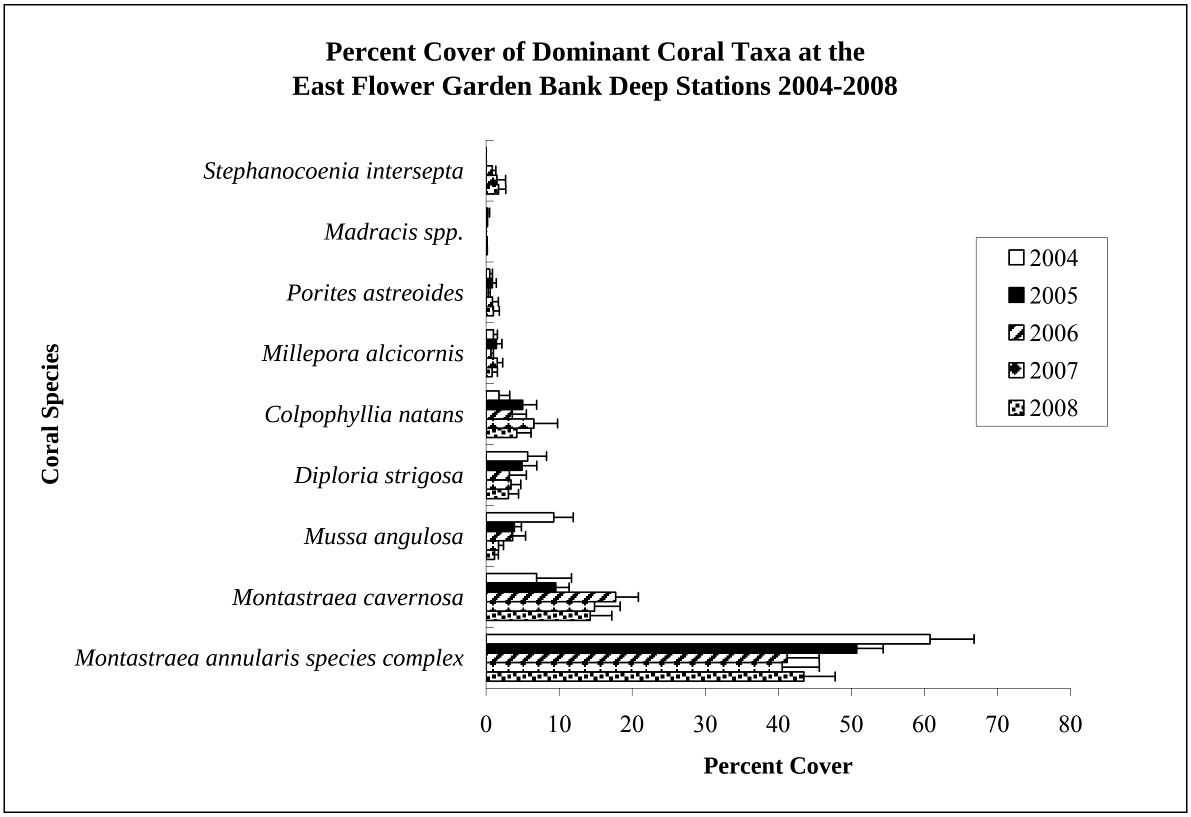


Figure 3.4.7. Percent cover (+ SE) of the dominant coral taxa at the EFGB deep repetitive quadrats during 2004-2008. Abbreviation: CTB- crustose coralline algae, fine turf algae, and bare rock. Macroalgae includes thick turf algae as well as macroalgal species.

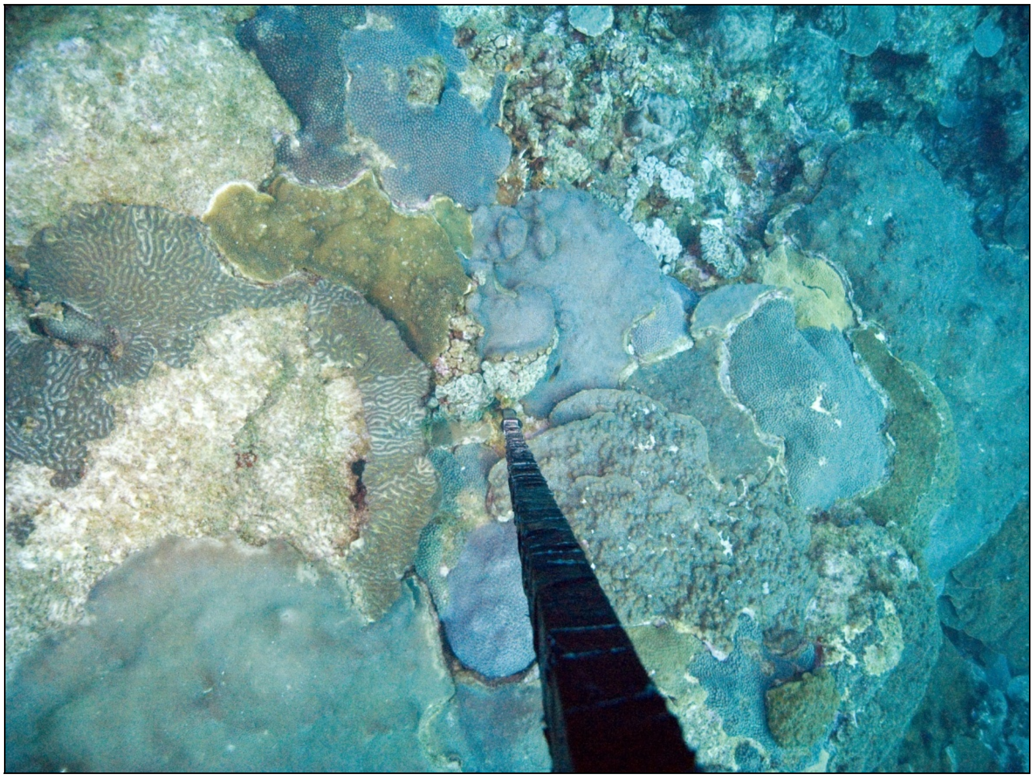


Figure 3.4.8. Deep repetitive quadrat station 83 at the EFGB in November 2008.

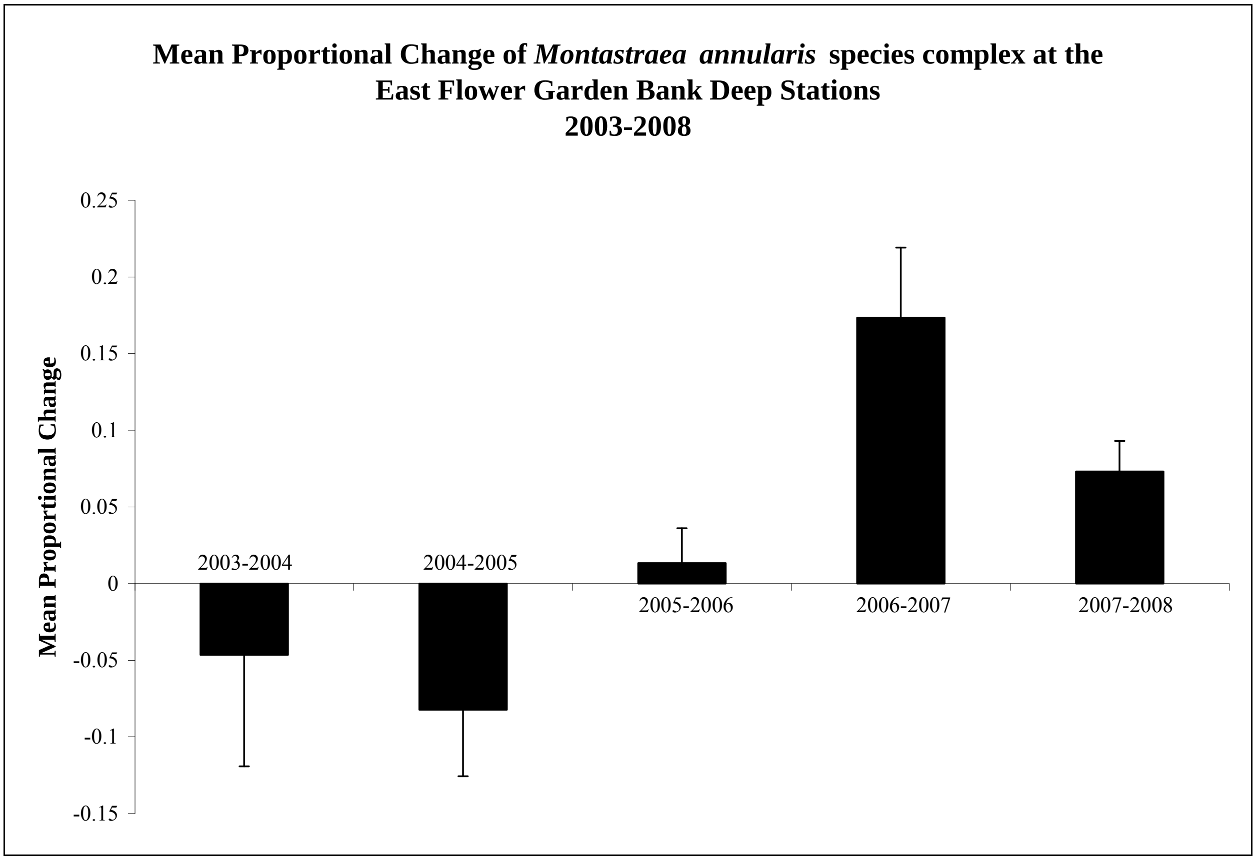


Figure 3.4.9. Mean proportional change + SE in *Montastraea annularis* species complex at EFGB deep stations, 2003-2004, 2004-2005, 2005-2006, 2006-2007, and 2007-2008.

Six quadrats at the EFGB deep stations were photographed in all six years of monitoring. Anderson-Darling tests revealed marginally non-significant departures from normality for all intervals: 2003-2004 (P=0.060), 2004-2005 (P=0.051), 2005-2006 (P=0.087), 2006-2007 (P=0.081), and 2007-2008 (P=0.108). Levene's test showed the variances to be homogeneous (P=0.122), and the data were, therefore, not transformed.

A repeated-measures ANCOVA, with Interval as the fixed factor, Quadrat as the repeated factor, and Initial Area as the covariate, revealed that only Interval was significant (Table 3.4.10). Because the covariate, Initial Area, was not significant, the analysis was run again as a repeated-measures ANOVA, with the covariate removed from the model. Interval was again significant (Table 3.4.11).

Tukey *a posteriori* multiple comparisons revealed two groups of time intervals. The intervals are arranged below in descending order of mean growth, with intervals that are not significantly different underlined:

2006-2007   2007-2008   2005-2006   2004-2005   2003-2004

Growth during the interval 2006-2007 was significantly greater than during 2004-2005 and 2003-2004. There was no obvious temporal trend in the data (see Figure 3.4.9).

Table 3.4.10.

Results of repeated-measures ANCOVA on proportional change in areas of *Montastraea annularis* species complex in EFGB deep station repetitive quadrats, comparing the intervals 2003-2004 through 2007-2008. Data were not transformed.

Source	df	SS	MS	F	P
Interval	4	0.2130	0.0533	3.62	0.023
Quadrat	5	0.05691	0.0114	0.77	0.580
Initial Area	1	0.0115	0.0115	0.78	0.387
Error	19	0.2794	0.0147		
Total	29	0.5833			

Table 3.4.11.

Results of repeated-measures ANOVA on proportional change in areas of *Montastraea annularis* species complex in EFGB deep station repetitive quadrats, comparing the intervals 2003-2004 through 2007-2008. The covariate in Table 3.4.10, Initial Area, was removed from the model. Data were not transformed.

Source	df	SS	MS	F	P
Interval	4	0.2460	0.0615	4.23	0.012
Quadrat	5	0.0464	0.0093	0.64	0.674
Error	20	0.2909	0.0146		
Total	29	0.5833			

As was done for the data from the repetitive quadrats on the reef caps, a series of supplementary analyses was performed to compare the results from the deep-station quadrats over sequential pairs of one-year intervals. Seven quadrats were available for comparison between the 2003-2004 and 2004-2005 intervals. The data were normally distributed, based on Anderson-Darling tests (2003-2004 data, P=0.434; 2004-2005 data, P=0.103). An F-test (for normally distributed data) showed that the variances were homogeneous (P=0.289; Levene's test for non-normal data, P=0.323). A repeated-measures ANCOVA on the untransformed data, with time Interval as the fixed factor, Quadrat as the repeated factor, and Initial Area as the covariate, and with α adjusted to control experimentwise error over the 8 analyses in Table 3.4.12 (α_{adj}=0.05/8=0.00625), showed non-significant effects of any of these (Table 3.4.12A). Removal of the non-significant covariate corroborated the results for Interval and Quadrat (Table 3.4.12B).

Table 3.4.12.

Results of repeated-measures analyses of proportional change in areas of *Montastraea annularis* species complex in EFGB deep station repetitive quadrats.

A. 2003-2004 compared to 2004-2005: ANCOVA; untransformed data

Source	df	SS	MS	F	P
Interval	1	0.0041	0.0041	0.18	0.682
Quadrat	6	0.1940	0.0323	1.48	0.341
Initial Area	1	0.1329	0.1329	6.10	0.057
Error	5	0.1089	0.0218		
Total	13	0.3050			

B. 2003-2004 compared to 2004-2005: ANOVA; untransformed data

Source	df	SS	MS	F	P
Interval	1	0.0012	0.0012	0.03	0.868
Quadrat	6	0.0620	0.0103	0.26	0.939
Error	6	0.2417	0.0403		
Total	13	0.3050			

C. 2004-2005 compared to 2005-2006: ANCOVA; untransformed data

Source	df	SS	MS	F	P
Interval	1	0.0010	0.0010	0.40	0.563
Quadrat	5	0.0786	0.0157	6.43	0.048
Initial Area	1	0.0100	0.0100	4.07	0.114
Error	4	0.0100	0.0025		
Total	11	0.0990			

D. 2004-2005 compared to 2005-2006: ANOVA; untransformed data

Source	df	SS	MS	F	P
Interval	1	0.0102	0.0102	2.59	0.169
Quadrat	5	0.0691	0.0138	3.50	0.098
Error	5	0.0197	0.0039		
Total	11	0.0990			

E. 2005-2006 compared to 2006-2007: ANCOVA; untransformed data

Source	df	SS	MS	F	P
Interval	1	0.09333	0.09333	9.48	0.037
Quadrat	5	0.0369	0.0369	0.75	0.627
Initial Area	1	0.0197	0.0197	2.00	0.230
Error	4	0.0394	0.0394		
Total	11	0.1534			

Table 3.4.12. Results of repeated-measures analyses of proportional change in areas of *Montastraea annularis* species complex in EFGB deep station repetitive quadrats (continued).

F. 2005-2006 compared to 2006-2007: ANOVA; untransformed data

Source	df	SS	MS	F	P
Interval	1	0.0768	0.0768	6.5	0.051
Quadrat	5	0.0175	0.0035	0.3	0.896
Error	5	0.0591	0.0118		
Total	11	0.1534			

G. 2006-2007 compared to 2007-2008: ANCOVA; untransformed data

Source	df	SS	MS	F	P
Interval	1	0.0188	0.0188	1.94	0.236
Quadrat	5	0.0373	0.0075	0.77	0.617
Initial Area	1	0.0032	0.0032	0.33	0.597
Error	4	0.0389	0.0097		
Total	11	0.0989			

H. 2006-2007 compared to 2007-2008: ANOVA; untransformed data

Source	df	SS	MS	F	P
Interval	1	0.0227	0.0227	2.71	0.160
Quadrat	5	0.0343	0.0069	0.82	0.584
Error	5	0.04186	0.0084		
Total	11	0.0989			

Six quadrats were available for comparison between the 2004-2005 and 2005-2006 intervals. The data were normally distributed, based on Anderson-Darling tests (2004-2005 data, P=0.444; 2005-2006 data, P=0.189). An F-test showed that the variances were homogeneous when α was adjusted to control experiment-wise error (P=0.044; Levene's test for non-normal data, P=0.323). A repeated-measures ANCOVA on the untransformed data showed non-significant effects of Interval, Quadrat, and the covariate Initial Area, with α adjusted to control experiment-wise error (Table 3.4.12C). Removal of the non-significant covariate corroborated the results for Interval and Quadrat (Table 3.4.12D).

Six quadrats were available for comparison between the 2005-2006 and 2006-2007 intervals. The data were normally distributed, based on Anderson-Darling tests (2005-2006 data, P=0.189; 2006-2007 data, P=0.836). An F-test showed that the variances were homogeneous when α was adjusted to control experiment-wise error (P=0.149; Levene's test for non-normal data, P=0.257). A repeated-measures ANCOVA on the untransformed data showed non-significant effects of Quadrat, and the covariate Initial Area (Table 3.4.12E). The effect of Interval was non-significant at P=0.037 with α adjusted to maintain an experiment-wise error rate of 0.05 in the eight analyses in Table 3.4.12; clearly, there was a difference between the two intervals, with considerably greater growth in 2006-2007 (Figure 3.4.9). Removal of the non-significant covariate corroborated the results for Interval and Quadrat (Table 3.4.12F).

Six quadrats were available for comparison between the 2006-2007 and 2007-2008 intervals. The data were normally distributed, based on Anderson-Darling tests (2006-2007 data, P=0.836; 2007-2008 data, P=0.118). An F-test showed that the variances were homogeneous (P=0.142; Levene's test for non-normal data, P=0.215). A repeated-measures ANCOVA on the untransformed data showed non-significant effects of Interval, Quadrat, and the covariate Initial Area (Table 3.4.12G). Removal of the non-significant covariate corroborated the results for Interval and Quadrat (Table 3.4.12H).

Like the analyses of all years combined (Tables 3.4.10 and 3.4.11), this series of sequential analyses highlights the high growth rate in 2006-2007. Overall, growth was variable among intervals and among quadrats at the deep stations.

3.4.2. Comparison of Film and Digital Repetitive Quadrat Photographs

Using the digital photographs of the eight repetitive quadrats taken at the EFGB in August 2007, it was possible to compare the film and digital results. Estimates of percent cover were derived using random-dot analysis as follows: two different sets of 300 dots were analyzed for each film photograph ("Film1" and "Film2"), and a third set of 300 dots was analyzed for each corresponding digital photograph ("Digital"). The film and digital photographs both covered the entirety of each quadrat. Color saturation in the digital photographs was lower than in the film photographs (Figure 3.4.10), a problem that is potentially correctable with image processing prior to random-dot analysis.

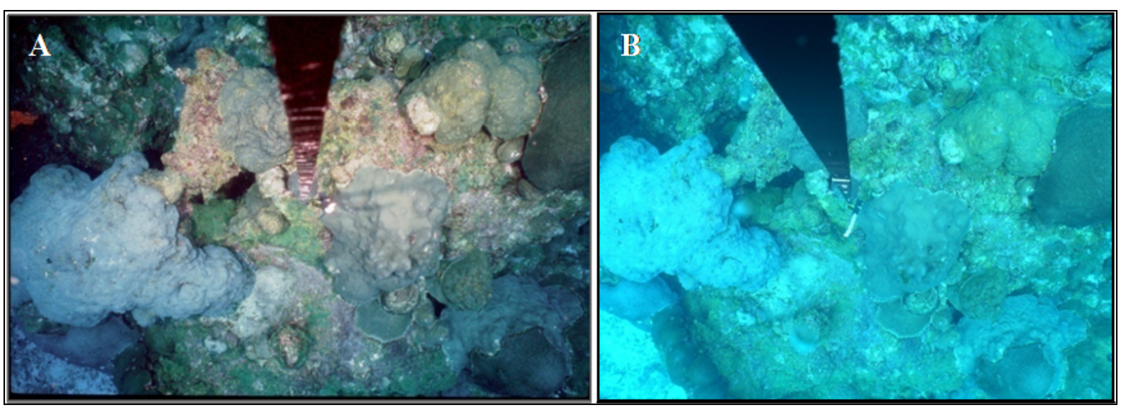


Figure 3.4.10. Film (left) and digital (right) photographs of station 5 at the EFGB in 2007. Note the lower color saturation in the digital photograph.

All of the random dots assigned in the study were accounted for by six substratum categories: 1) hard coral, 2) sponge, 3) macroalgae, 4) other living benthos, 5) CTB, and 6) sand/rubble/shell matrix. The absolute values of the differences between estimates derived from the digital photographs and estimates derived from the film photographs (Digital compared to Film1) were greater than the corresponding differences between the two analyses of the film photographs (Film2 compared to Film1; Table 3.4.13). When the actual differences were used, rather than taking absolute values of the differences, the contrasts between the means for the two comparisons disappeared (Table 3.4.14). The larger standard errors in Table 3.4.14 reflect the broader ranges of actual differences between assessments, which included negative numbers.

Table 3.4.13.

Mean ± SE of the absolute value of the difference in percent cover estimates (proportional cover x 100) for repeated analyses of the eight repetitive quadrats that were photographed both with film and digitally.

Category	Film1 vs. Digital	Film1 vs. Film2
Hard Coral	5.71 ± 1.01	2.68 ± 0.74
Sponge	0.57 ± 0.30	0.46 ± 0.12
Macroalgae	5.62 ± 1.39	2.74 ± 0.59
CTB	4.56 ± 1.14	2.52 ± 0.57
Other Living Benthos	0.92 ± 0.43	0.49 ± 0.15
Sand, Rubble and Shell	0.14 ± 0.09	0.28 ± 0.20

Table 3.4.14.

Mean ± SE of the difference in percent cover estimates (proportional cover x 100) for repeated analyses of the eight repetitive quadrats that were photographed both with film and digitally.

Category	Film1 vs. Digital	Film1 vs. Film2
Hard Coral	0.93 ± 2.36	0.51 ± 1.24
Sponge	0.57 ± 0.30	0.057 ± 0.21
Macroalgae	-1.94 ± 2.43	1.44 ± 1.06
CTB	-0.17 ± 2.07	-2.21 ± 0.74
Other Living Benthos	0.61 ± 0.50	-0.076 ± 0.23
Sand, Rubble and Shell	-0.022 ± 0.11	0.28 ± 0.20

The three assessments of the eight quadrats—Film1, Film2, and Digital—were compared statistically using a repeated-measures ANOVA design. For the three most ecologically important categories of proportional benthic cover—hard coral, macroalgae, and CTB—the data were normally distributed (Anderson-Darling test, $P>0.164$ in all cases except macroalgae in Film2 for macroalgae, for which $P=0.049$). The variances were homogeneous in all cases (Bartlett's and Levene's tests, $P>0.538$). Therefore, the data were not transformed.

For the three most ecologically important categories of benthic cover (hard coral, macroalgae, CTB), there was no significant effect of Assessment (Tables 3.4.15, 3.4.16, and 3.4.17). In each case, however, there was a significant effect of Quadrat, which is not surprising considering the patchy nature of benthic cover on coral reefs at this small scale.

Although the independent estimates within individual quadrats diverged more in the Film1–Digital comparison than the Film1–Film2 comparison (Table 3.4.13), in aggregate the film and digital methods performed comparably (Tables 3.4.15-3.4.17). The lack of any significant difference between the three assessments suggests that switching to digital photography is feasible. Digital photographs, enhanced by basic image processing, can be directly compared to film photographs of the same repetitive quadrat stations from previous years.

Table 3.4.15.

Repeated measures ANOVA for three assessments of hard-coral cover in eight repetitive quadrats that were photographed both with film and digitally. Three assessments were performed for each quadrat using 300 random dots each: two on the film photograph and one on the digital photograph.

Source	df	SS	MS	*F*-ratio	*P*-value
Assessment	2	3.47	1.73	0.13	0.876
Quadrat	7	5499.61	785.66	60.40	<0.001
Error	14	182.10	13.01		
Total	23	5685.17			

Table 3.4.16.

Repeated measures ANOVA for three assessments of macroalgal cover in eight repetitive quadrats that were photographed both with film and digitally. Three assessments were performed for each quadrat using 300 random dots each: two on the film photograph and one on the digital photograph.

Source	df	SS	MS	*F*-ratio	*P*-value
Type	2	45.83	22.92	1.62	0.232
Quadrat	7	2237.11	319.59	22.66	<0.001
Error	14	197.49	14.11		
Total	23	2480.44			

Table 3.4.17.

Repeated measures ANOVA for three assessments of CTB cover in eight repetitive quadrats that were photographed both with film and digitally. Three assessments were performed for each quadrat using 300 random dots each: two on the film photograph and one on the digital photograph.

Source	df	SS	MS	*F*-ratio	*P*-value
Type	2	24.32	12.16	1.28	0.310
Quadrat	7	617.06	88.15	9.25	<0.001
Error	14	133.36	9.526		
Total	23	774.74			

3.5. Perimeter Videography

The perimeter video was reviewed for a qualitative analysis of the general condition of coral health and fish populations 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. The review of the 2004-2008 perimeter videos suggests that, in general, the coral condition and fish population levels along the perimeter lines at the EFGB and WFGB study sites were comparable to those observed in past perimeter videos. The coral assemblages displayed low levels of stress and high coral cover and most distressed corals were affected by fish biting, with only a few incidences of paling and bleaching. 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 from 2004 through 2008, although, as mentioned previously, disease is difficult to identify in photographic analysis. Tables 1-9 in Appendix 6 provide the results of the perimeter video analysis from 2004-2008.

3.5.1. EFGB Perimeter Lines

3.5.1.1. September 2004-June 2005 Comparison

In September 2004, isolated fish biting (typical of damselfish) occurred on 11 colonies, followed by concentrated fish biting (eight colonies), paling (four colonies), and bleaching (two colonies). *Montastraea faveolata* and *M. franksi* were the coral species most impacted by these stressors. Twelve colonies appeared healthy in 2004. However, these colonies were later affected by coral stressors in 2005 as described below (Table 1 in Appendix 6).

In June 2005, coral stresses included isolated fish biting (13 colonies), concentrated fish biting (eight colonies), paling (two colonies), and bleaching (two colonies). There were four colonies that were healthy following paling or bleaching the previous year, and three colonies that had recovered from fish biting (i.e., growth infilling). In addition, former fish biting locations observed on three colonies in 2004 were replaced with turf algae in 2005 (two *Diploria strigosa* and one *Montastraea faveolata*; Table 1 in Appendix 6).

In September 2004, the most abundant fish species were creole wrasse, creole fish, and damselfishes. In June 2005, brown chromis, damselfishes, and the bluehead wrasse were the most abundant fish species observed (Table 3.5.1 and Table 9 in Appendix 6).

Table 3.5.1.

Most abundant fish species observed in perimeter video at the EFGB from 2004 to 2008. Includes fish species observed along perimeter lines and during 360° panoramic views.

Year	Creole fish	Brown chromis	Blue Chromis	Unidentifiable Damselfishes	Creole wrasse	Bluehead wrasse
2004	86	24	20	26	78	17
2005	15	55	16	24	14	43
2006	22	103	74	0	3	20
2007	195	59	0	33	33	13
2008	53	99	67	11	42	13

3.5.1.2. June 2005-June 2006 Comparison

A total of 49 coral colonies were compared on the perimeter video between June 2005 and June 2006 at the EFGB. In June 2005, stresses included isolated fish biting (23 colonies) and concentrated fish biting (two colonies), while 24 colonies were healthy. The 24 colonies that appeared healthy in 2005 were later affected by coral stressors in 2006 as described below (Table 2 in Appendix 6).

In June 2006, coral stresses included isolated fish biting (14 colonies), concentrated fish biting (six colonies), paling (five colonies), and bleaching (seven colonies; Table 2 in Appendix 6). One colony of *Montastraea annularis* had died and been overtaken by turf algae and partial mortality was observed on a single colony of *Diploria strigosa* (the colony appeared noticeably smaller). There were 15 colonies that were observed to be in some stage of recovery (e.g., growth infilling or complete recovery) following a stressor in the previous year. Eight of the 15 recovering colonies were *Montastraea franksi*.

In June 2005, brown chromis, damselfishes, and the bluehead wrasse were the most abundant fish species observed. In June 2006, the most abundant fish species observed were brown chromis and blue chromis (Table 3.5.1 and Table 9 in Appendix 6).

3.5.1.3. June 2006-June 2007 Comparison

A total of 51 coral colonies were compared on the perimeter video between June 2006 and June 2007 at the EFGB. In June 2006, stresses included isolated fish biting (13 colonies), concentrated fish biting (seven colonies), paling (four colonies), and bleaching (five colonies). The remaining 22 colonies were healthy. These healthy colonies were later affected by coral stressors in 2007 as described below (Table 3 in Appendix 6).

In June 2007, stresses included isolated fish biting (23 colonies), concentrated fish biting (seven colonies), and bleaching (one colony). In addition, six colonies had died and the surface was replaced by turf algae (three colonies of *Diploria strigosa*, one colony of *Montastraea annularis*, and two colonies of *M. faveolata*; Table 3 in Appendix 6). A former fish biting location observed on one colony of *M. annularis* in 2006 was replaced with turf algae in 2007. There were 13 colonies that were observed to be in some stage of recovery (e.g., growth infilling or complete recovery) following a stressor in the previous year. These 13 recovering colonies included *Montastraea franksi* (six colonies), *M. cavernosa* (six colonies), and *M. faveolata* (one colony).

In June 2006, the most abundant fish species observed were brown chromis and blue chromis. The most abundant fish species observed in June 2007 were creole fish, brown chromis, creole wrasse, and damselfishes (Table 3.5.1 and Table 9 in Appendix 6).

3.5.1.4. June 2007-November 2008 Comparison

In November 2008, the northwest corner marker was missing. Despite the concerted efforts of divers (with the aid of a Garmin GPS system and weighted chain), the replacement of the northwest corner marker was not in the same location as the previous year. Also, the southeast corner shifted further southwest in the 2008 video compared to the 2007 video. As a result of these shifts in corner locations, few coral colonies were comparable along the north and east perimeter lines between 2007 and 2008 at the EFGB.

Only 21 coral colonies were compared on the perimeter video between June 2007 and November 2008 at the EFGB. In 2007, stresses included isolated fish biting (five colonies) and concentrated fish biting (nine colonies). The remaining seven colonies appeared healthy in 2007 and were later affected by coral stressors in 2008 as described below (Table 4 in Appendix 6).

In November 2008, one colony of *Montastraea faveolata* experienced substantial coral mortality (cause unknown). In addition to the coral mortality, concentrated fish biting was also observed on another part of the same colony. Stresses observed in 2008 included isolated fish biting (two colonies) and concentrated fish biting (six colonies). In addition, former fish biting locations observed on five colonies in 2007 were replaced by turf algae in 2008 (three colonies of *Montastraea franksi*, one colony of *M. faveolata*, and one colony of *M. cavernosa*; Table 4 in Appendix 6). There were eight *Montastraea franksi* colonies that were observed to be in some stage of recovery (e.g., growth infilling or complete recovery) following a stressor in the previous year.

The most abundant fish species observed in June 2007 were creole fish, brown chromis, creole wrasse, and damselfishes. In November 2008, brown and blue chromis, creole fish, and creole wrasse were the dominant fish species observed (Table 3.5.1 and Table 9 in Appendix 6).

3.5.2. EFGB 360° Panoramic Views

3.5.2.1. September 2004-June 2005 Comparison

At the northwest corner, only one colony of *Montastraea* exhibited concentrated fish biting in 2004, which appeared as fine turf or bare substrate in 2005. In 2004, only one school of creole fish was visible, while in 2005, multiple schools of creole wrasse, creole fish, and chromis were present.

At the northeast corner in 2004, the only impacted coral was one colony of *Montastraea franksi*, which displayed large amounts of tissue loss from concentrated fish biting. The species composition of fish was similar between years; however, the schools of creole fish and creole wrasse were larger in 2004 than in 2005.

At the southeast corner in 2004, only one incidence of concentrated fish biting was recorded. During 2004, there were large schools of creole wrasse, chromis, and creole fish. In 2005, there were fewer fish, although species such as black durgon and creole fish were observed.

3.5.2.2. June 2005-June 2006 Comparison

The northwest corner marker was present and intact in June 2005 and June 2006. At the northwest corner in 2005, adverse coral conditions (i.e., fish biting, paling, or bleaching) were not noted. However, in 2006, two *Montastraea* colonies that appeared healthy in 2005 exhibited bleaching and paling, respectively. In 2005, schools of creole wrasse, creole fish, and chromis were present. Queen parrotfish and an unidentifiable acanthurid were also observed. In 2006, creole wrasse, creole fish, queen parrotfish, brown chromis, and damselfish were observed at the northwest corner.

Physical damages (i.e., overturned and displaced corals) that were not present at the northwest corner in June 2005 were observed in June 2006 (Figure 3.5.1). These damages are likely attributable to Hurricane Rita, which passed near the FGB in September 2005. Note the large *Diploria strigosa* colony missing from Figure 3.5.2.

Figure 3.5.1. Overturned coral colony, most likely a result of Hurricane Rita, located at the northwest corner of the EFGB study site in June 2006. Image captured from perimeter videography.

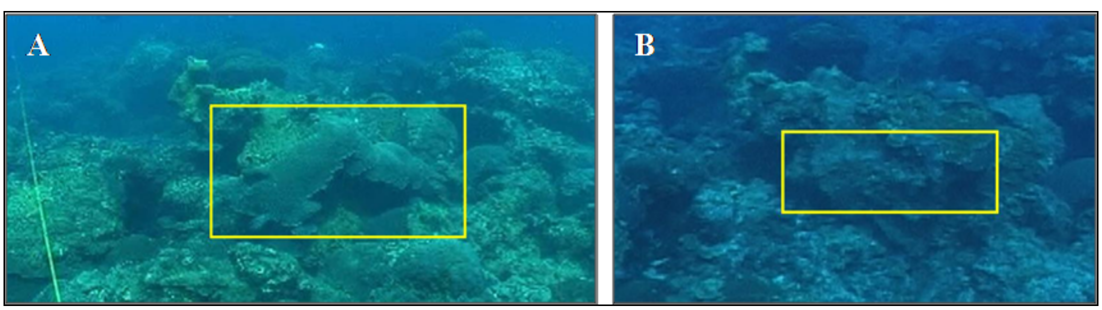


Figure 3.5.2. *Diploria strigosa* colony (A) present in June 2005 and (B) missing in 2006. Image captured from perimeter videography.

The northeast corner marker was in place in June 2005 but absent in June 2006, mostly likely removed by Hurricane Rita. As a result, the corner shifted between years and matching coral colonies were not videotaped in both years. In 2005, videotaped coral colonies did not display adverse coral conditions (i.e., fish biting, paling, or disease). In 2006, two *Montastraea cavernosa* colonies exhibited paling; however, these colonies were not videotaped in June 2005 for comparison. In 2005, creole fish, creole wrasse, bicolor damselfish, and queen parrotfish were observed. In 2006, bluehead wrasse, blue chromis, and bicolor damselfish were observed.

The southeast corner marker was also in place in June 2005 but absent in June 2006, most likely removed by Hurricane Rita. As a result, the corner shifted between years and the exact same coral colonies were not videotaped in both years. In 2005, a *Diploria strigosa* colony displayed isolated fish biting; however, this colony was healthy in 2006. An unidentifiable coral colony exhibited paling in 2006 but was not videotaped in 2005. Therefore, a comparison could not be made. In 2005, fish abundance was low at the southeast corner and included creole fish and black durgon. Fish abundance was greater in 2006 compared to 2005. In 2006, fish species included creole fish, black durgon, blue tang, and blue chromis.

It is important to note that the northeast, southeast, and southwest corner markers at the EFGB study site were refurbished in June 2006, after the perimeter lines had been videotaped.

3.5.2.3. June 2006-June 2007 Comparison

The northwest corner marker was present in both June 2006 and June 2007. In June 2006, coral colonies at the northwest corner were healthy with the exception of two colonies of *Montastraea* (one colony exhibited bleaching and the other exhibited paling). In 2007, one *Montastraea* colony completely recovered (from paling) and the other appeared unchanged (still bleached). In 2006, creole wrasse, creole fish, queen parrotfish, brown chromis, and damselfish were observed at the northwest corner. Fish abundance was greater at the northwest corner in 2007 compared to 2006. In 2007, observed fish species included bluehead wrasse, black durgon, threespot damselfish, creole wrasse, an unidentifiable serranid, and schools of brown chromis and creole fish. As previously mentioned in section 2.9.2, divers observed *Agelas clathrodes* spawning at the EFGB during the June 2007 annual monitoring cruise. In the perimeter video, decreased visibility was apparent at the northwest corner of the EFGB study site, which was most likely due to the sponge-spawning event.

The northeast corner marker was missing in June 2006 at the time of the perimeter video collection. The corner marker was later refurbished after all other annual monitoring tasks were completed. In 2007, divers located the southeast corner, identified by a stainless steel eyebolt and shackle. The panoramic views were not completed in the same position in both years, and thus the same coral colonies were not videotaped. At the northeast corner in June 2006, two colonies of *Montastraea cavernosa* exhibited paling. These colonies were not videotaped in 2007 due to the shifting corner location and a different camera angle. Several colonies exhibited fish biting in 2007; however these colonies were not recorded in 2006. Thus, a comparison could not be made. In 2006, bluehead wrasse, blue chromis, and bicolor damselfish were observed. Fish abundance was greater at the northeast corner in 2007 compared to 2006. In 2007, observed fish species included creole fish, bluehead wrasse, and bicolor damselfish.

The southeast corner marker was missing in June 2006 at the time of the perimeter video collection. The corner marker was later refurbished after all other annual monitoring tasks were completed. However, the refurbished corner marker was removed between June 2006 and June 2007. As a result, divers approximated the location of the southeast corner in 2007. The June

2006 video revealed one coral colony (unidentifiable species) that exhibited paling at the southeast corner. This colony was not videotaped in 2007 due to the difference in camera angle. Isolated fish biting was observed on two colonies of *Diploria strigosa* in 2007; however, these colonies were not visible in the 2006 video footage. Many creole fish were observed swimming above the reef in June 2006 and 2007. In addition, black durgon, blue tang, and blue chromis were observed in 2006 and creole wrasse, bicolor damselfish, and blue tang were observed in 2007.

3.5.2.4. June 2007-November 2008 Comparison

The northwest corner marker was present in June 2007 but missing in November 2008, most likely removed by the passing of Hurricane Ike. Despite the concerted efforts of divers (with the aid of a Garmin GPS system and weighted chain), the replacement of the northwest corner marker was not in the same location as the previous year. As a result, comparisons in coral condition could not be made between June 2007 and November 2008. In June 2007, a majority of the coral colonies appeared healthy, with only two colonies of *Montastraea annularis* species complex exhibiting signs of concentrated fish biting. In November 2008, isolated fish biting was observed on one colony of *Diploria strigosa* and concentrated fish biting was observed on two colonies of *M. annularis* species complex.

Bluehead wrasse, black durgon, threespot damselfish, creole wrasse, an unidentifiable serranid, and schools of brown chromis and creole fish were observed at the northwest corner in June 2007. In November 2008, a lower abundance of fish was observed compared to 2007. Fish species included threespot, yellowtail, and bicolor damselfish; blue tang; blue and brown chromis; black durgon; and rock beauty. Several fish were observed in the distance but were unidentifiable due to poor water clarity.

The northeast corner was identified by a stainless steel eyebolt and shackle in June 2007 and November 2008. In June 2007, four coral colonies exhibited fish biting. In November 2008, three of these colonies experienced tissue re-growth and appeared healthy. However one colony of *Montastraea franksi* displayed an increased amount of concentrated fish biting in 2008 compared to 2007. In addition, two coral colonies that appeared healthy in 2007 exhibited fish biting in 2008.

In June 2007, many creole fish were observed swimming above the reef. Bluehead wrasse and bicolor damselfish were also observed. In November 2008, juvenile queen parrotfish were observed feeding on coral colonies. Creole wrasse, brown and blue chromis, creole fish, and threespot damselfish were also observed.

The southeast corner was not marked in June 2007. A new corner marker was installed at the southeast corner in August 2007 during the rehabilitation cruise. After viewing the perimeter video, the location of the southeast corner appeared to be further southwest in the 2008 video than in the June 2007 video. As a result, few coral colonies were comparable between years. In June 2007, isolated fish biting was observed on two colonies of *Diploria strigosa*; however, these colonies were not visible in the 2008 video footage. In November 2008, videotaped corals appeared in good health and adverse coral conditions (i.e., fish biting, bleaching, or paling) were not noted.

Many creole fish were observed swimming above the reef in June 2007. Creole wrasse, bicolor damselfish, and blue tang were also observed. In 2008, creole fish were the dominant fish species at the southeast corner. Brown and blue chromis, threespot and bicolor damselfish, and ocean surgeonfish were also observed in small numbers.

3.5.3. WFGB Perimeter Lines

3.5.3.1. November 2004-June 2005 Comparison

A total of 16 coral colonies were compared on the perimeter video between November 2004 and June 2005 at the WFGB. In 2004, the coral stresses included isolated fish biting (four colonies), concentrated fish biting (four colonies), paling (two colonies), and bleaching (two colonies). The remaining four coral colonies were healthy. However, these healthy colonies were later affected by coral stressors in 2005 as described below (Table 5 in Appendix 6).

In June 2005, stresses included isolated fish biting (two colonies), concentrated fish biting (three colonies), paling (one colony), and bleaching (two colonies). A former fish biting location observed on a colony of *Montastraea faveolata* had been overtaken by turf algae since the previous year. There were seven colonies that showed growth infilling following a stressor in the previous year. These seven recovering colonies included *Montastraea franksi* (four colonies), *M. cavernosa* (one colony), *Porites astreoides* (one colony), and *Siderastrea siderea* (one colony; Table 5 in Appendix 6).

In November 2004, the most abundant fish species were brown chromis, damselfishes, and creole fish. In June 2005, brown chromis, creole fish, and creole wrasse were the most abundant fish species observed (Table 3.5.3 and Table 9 in Appendix 6).

Table 3.5.3.

Most abundant fish species observed in perimeter video at the WFGB from 2004 to 2008. Includes fish species observed along perimeter lines and during 360° panoramic views.

Year	Creole fish	Brown chromis	Blue Chromis	Unidentifiable Damselfishes	Creole wrasse	Bluehead wrasse	Threespot Damselfish	Chub
2004	22	31	8	23	10	12	1	0
2005	75	102	10	22	37	25	7	1
2006	100	169	46	0	1	37	46	0
2007	251	244	21	32	162	4	24	90
2008	24	11	89	0	6	0	26	0

3.5.3.2. June 2005-June 2006 Comparison

A total of 31 coral colonies were compared on the perimeter video between June 2005 and June 2006 at the WFGB. In June 2005, there were no recorded incidences of coral paling along the

WFGB perimeter lines. The coral stresses included isolated fish biting (six colonies), concentrated fish biting (one colony), and bleaching (seven colonies). The remaining 17 coral colonies were healthy. The colonies that appeared healthy in 2005 were later affected by coral stressors in 2006 as described below (Table 6 in Appendix 6).

In June 2006 at the WFGB, coral stresses included isolated fish biting (five colonies), concentrated fish biting (seven colonies), paling (one colony), and bleaching (eight colonies). Three colonies of *Montastraea faveolata* had died and been overtaken by turf algae since bleaching in the previous year. There were seven colonies that were in some stage of recovery (e.g., growth infilling or complete recovery) following a stressor in the previous year. These seven recovering colonies included *Montastraea franksi* (four colonies), *M. faveolata* (two colonies), and *Diploria strigosa* (one colony; Table 6 in Appendix 6).

In June 2005, brown chromis, creole fish, and creole wrasse were the most abundant fish species observed. In June 2006, brown chromis, creole fish, blue chromis, threespot damselfish, and bluehead wrasse were the most abundant fish species observed (Table 3.5.3 and Table 9 in Appendix 6).

3.5.3.3. June 2006-June 2007 Comparison

A total of 36 coral colonies were compared on the perimeter video between June 2006 and June 2007 at the WFGB. In June 2006, there were no recorded incidences of coral paling along the WFGB perimeter lines. The coral stresses included isolated fish biting (17 colonies), concentrated fish biting (five colonies), and bleaching (three colonies). The remaining 11 coral colonies were healthy. These healthy colonies were later affected by coral stressors in 2007 as described below (Table 7 in Appendix 6).

In June 2007 at the WFGB, stresses included isolated fish biting (17 colonies) and concentrated fish biting (seven colonies). No paling or bleached colonies were observed. Former locations of fish biting observed on two *Montastraea* colonies in 2006 were replaced by turf algae in 2007. There were 10 colonies that were in some stage of recovery (e.g., growth infilling or complete recovery) following a stressor in the previous year. These 10 recovering colonies included *Montastraea franksi* (four colonies), *M. faveolata* (two colonies), *M. cavernosa* (one colony), and *Diploria strigosa* (three colonies; Table 7 in Appendix 6).

In June 2006, brown chromis, creole fish, blue chromis, threespot damselfish, and bluehead wrasse were the most abundant fish species observed. In June 2007, the most abundant fish species observed were brown chromis, creole fish, creole wrasse, Bermuda/yellow chub, and damselfishes (Table 3.5.3 and Table 9 in Appendix 6).

3.5.3.4. June 2007-November 2008 Comparison

In June 2007 and November 2008, the southeast corner marker was in place and the southwest corner, which was marked by weights, chain, and rope, was successfully located in both years. However, the southern perimeter line was placed further south in 2008 (the line was placed on the southern face of a massive coral colony, shifting the entire line further south) compared to 2007, limiting the number of coral comparisons that could be made between matching coral colonies. Of the few matching coral colonies along the south line, all colonies appeared healthy. The northwest corner marker was absent in 2007 and 2008 at the time of perimeter videography. Despite the concerted efforts of divers (with the aid of a Garmin GPS system and weighted chain), the replacement of the northwest corner marker in 2008 was not in the same location as the previous year. As a result, coral comparisons could only be made along the southern portion of the west line.

Only 18 coral colonies were compared on the perimeter video between June 2007 and November 2008 at the WFGB. In 2007, no incidences of coral paling were observed at the WFGB. Stresses included isolated fish biting (five colonies), concentrated fish biting (four colonies), and bleaching (one *Porites astreoides* colony). The remaining eight colonies that were healthy in 2007 were later affected by coral stressors in 2008 as described below (Table 8 in Appendix 6).

In November 2008, coral stresses included isolated fish biting (six colonies), concentrated fish biting (four colonies), bleaching (one *Millepora alcicornis* colony), and paling (one colony of *Montastraea cavernosa*). In addition, former fish biting locations observed on two *Diploria strigosa* colonies in 2007 were replaced by turf algae in 2008 (Table 8 in Appendix 6). There were four colonies that were observed to be in some stage of recovery (e.g., growth infilling or complete recovery) following a stressor in the previous year (two *Montastraea franksi*, one *M. cavernosa*, and one *Porites astreoides* colonies).

In June 2007, the most abundant fish species observed were the brown chromis, creole fish, creole wrasse, Bermuda/yellow chub, and damselfishes. In November 2008, the most abundant fish species observed were the blue chromis, threespot damselfish, and creole fish (Table 3.5.3 and Table 9 in Appendix 6).

3.5.4. WFGB 360° Panoramic Views

3.5.4.1. November 2004-June 2005 Comparison

In November 2004, two *Montastraea* colonies at the southeast corner showed isolated fish biting. In June 2005, both colonies had increased incidences of isolated fish biting. More fish were observed in 2005 than 2004. Creole fish, damselfish, black durgon, and a barracuda were observed in 2004. In 2005, schools of creole fish were noted, as well as damselfish, Spanish hogfish, and surgeonfish.

At the southwest corner, coral colonies exhibited normal coloration in 2004. In 2005, several *Montastraea* colonies showed signs of isolated and concentrated fish biting. The fish population in 2004 consisted of wrasses, creole fish, and the occasional damselfish. In 2005, fish abundance was greater than 2004 and included creole wrasse and schools of chromis and creole fish.

Two *Montastraea* colonies showed new tissue loss due to concentrated fish biting at the northwest corner in June 2005. Again, fish abundance increased in 2005, compared to 2004. In 2004, there was a relatively small school of creole fish and the occasional damselfish. In 2005, creole wrasse, schools of creole fish, and brown chromis were observed.

3.5.4.2. June 2005-June 2006 Comparison

The southeast corner marker was present in both June 2005 and June 2006. However, comparisons were difficult because the video was captured at different distances from the substrate each year. Because the 2005 video was collected at a much further distance from the substrate than the 2006 video, more coral colonies were in view in 2005. At the southeast corner in 2005, two coral colonies (unidentifiable coral species and *Porites astreoides*) exhibited isolated and concentrated fish biting, respectively. The unidentifiable coral species completely recovered from isolated fish biting in 2006 while the *P. astreoides* colony remained unchanged. In addition, a *Montastraea franksi* colony that appeared healthy in 2005 displayed concentrated fish biting in 2006.

At the southeast corner in 2005, schools of creole fish were observed, as well as damselfish, Spanish hogfish, and surgeonfish. Fish abundance was greater in 2006 compared to 2005. In 2006 observed fish species included threespot damselfish, reef butterflyfish, bluehead wrasse, blue and brown chromis, and schools of creole fish swimming over the reef cap. Several juvenile fish species were also observed and included juvenile queen parrotfish, juvenile bluehead wrasse, and unidentifiable juvenile damselfishes.

The southwest corner marker was in place in June 2005 but absent in June 2006, most likely a result of the passage of Hurricane Rita. Comparisons between matching coral colonies were difficult because the video was captured at different heights and angles each year. At the southwest corner, two colonies (*Diploria strigosa* and *Montastraea franksi*) displayed isolated fish biting in 2005. In 2006, the *D. strigosa* colony exhibited an increased incidence of isolated fish biting while the *M. franksi* colony displayed growth infilling/partial recovery. In addition, an unidentifiable coral colony that appeared healthy in 2005 exhibited concentrated fish biting in 2006. Isolated and concentrated fish biting were also observed on several colonies of *Montastraea* in 2005; however, these colonies were not videotaped in 2006. In 2006, isolated fish biting was observed on two colonies, *D. strigosa* and *M. franksi*; unfortunately, these two colonies were not captured on video in 2005. Evidence of hurricane damage was also observed in 2006, including a fractured colony of *M. faveolata*.

At the southwest corner in 2005, the fish population consisted of creole wrasse and schools of chromis and creole fish. In 2006, observed fish species included blue tang, brown and blue chromis, threespot damselfish, black durgon, creole fish, and queen parrotfish. Juvenile queen parrotfish and juvenile bluehead wrasse were also observed.

The northwest corner marker was present in June 2005, but missing in June 2006, most likely a result of the passage of Hurricane Rita. The northwest corner marker was reinstalled in the same position on a later dive. Two *Montastraea* colonies showed tissue loss due to concentrated fish biting in 2005 and subsequent recovery (tissue regrowth) in 2006. In addition, a colony of *Diploria strigosa* that exhibited concentrated fish biting in 2005 was replaced with turf algae in 2006. In 2005, creole wrasse, schools of creole fish, and brown chromis were observed at the northwest corner. In 2006, great barracuda, bicolor damselfish, bluehead wrasse, and schools of brown chromis and creole fish were observed.

3.5.4.3. June 2006-June 2007 Comparison

The southeast corner marker was present in both June 2006 and June 2007. In 2006, a colony of *Diploria strigosa* displayed isolated fish biting and two coral colonies (*Porites astreoides* and an unidentifiable coral species) displayed concentrated fish biting. In 2007, the *D. strigosa* colony remained unchanged and the concentrated fish biting locations on the *P. astreoides* and unidentifiable colonies were replaced with turf algae. In addition, a *Montastraea annularis* colony that appeared healthy in 2006 displayed concentrated fish biting in 2007. Isolated fish biting was also observed on a colony of *M. franksi* in 2006; however, this colony was not videotaped in 2007.

Fish observed at the southeast corner in 2006 included threespot damselfish, reef butterflyfish, bluehead wrasse, blue and brown chromis, and schools of creole fish swimming over the reef cap. Several juvenile fish species were also observed including juvenile queen parrotfish, juvenile bluehead wrasse, and juvenile damselfishes. Similar to 2006, schools of creole fish were also observed swimming over the reef cap near the southeast corner in 2007. Creole wrasse, threespot and bicolor damselfish, blue chromis, sharpnose puffer, and reef butterflyfish were also observed in 2007.

The southwest corner marker was absent in 2006 and marked with weights, chain, and rope in 2007. Two colonies, including *Diploria strigosa* and *Montastraea franksi* exhibited isolated fish biting in 2006. In the same year, a single unidentifiable coral colony displayed concentrated fish biting. In 2007, the *D. strigosa* colony experienced increased, isolated fish biting while the former fish biting locations on the *M. franksi* and unidentifiable colonies were replaced with turf algae. Two colonies, *M. faveolata* and *D. strigosa* appeared healthy in 2006 but displayed signs of concentrated fish biting and isolated fish biting, respectively, in 2007. Isolated fish biting was also observed on one colony of *D. strigosa* in 2006; however, this colony was not videotaped in 2007.

At the southwest corner in 2006, observed fish species included blue tang, brown and blue chromis, threespot damselfish, black durgon, creole fish, and queen parrotfish. Juvenile queen parrotfish and juvenile bluehead wrasse were also observed. A school of creole fish was observed swimming over the reef cap near the southeast corner in 2007. Creole wrasse, threespot damselfish, bluehead wrasse, and barracuda were also observed.

The northwest corner marker was absent in June 2006 and June 2007. Comparisons in coral condition were difficult because the corner shifted slightly east in the 2007 video. Of the few matching coral colonies observed in both 2006 and 2007, all colonies appeared healthy. In addition, a colony of *Diploria strigosa* displayed isolated fish biting in 2007; however, this colony was not collected on video in 2006.

In 2006, great barracuda, bicolor damselfish, bluehead wrasse, and schools of brown chromis and creole fish were observed at the northwest corner. Fish abundance was greater at the northwest corner in 2007 compared to 2006. Observed fish species included schools of creole fish and Bermuda/yellow chub. Juvenile queen parrotfish were also observed.

3.5.4.4. June 2007-November 2008 Comparison

Panoramic views were not included in the 2008 WFGB data collection. Therefore, coral condition and fish populations can not be compared between June 2007 and November 2008.

3.6. HURRICANE IKE IMPACTS

The track of Hurricane Ike (Category 3, Saffir-Simpson Index) passed ~0.7 km (0.4 mi) from the EFGB study site on September 12, 2008. However, the eye of the storm passed directly over the Bank. On October 9, 2008, FGBNMS staff and volunteers travelled to the FGB and documented hurricane impacts, including dislodged, broken, and sediment-scoured coral colonies; sheared *Xestospongia muta*; and branch loss on the *Acropora palmata* colony at the EFGB (Hickerson 2008b; Figures 3.6.1 and 3.6.2). In addition, several of the metal rods marking the long-term monitoring stations were dislodged or bent and the YSI/Seabird equipment was partially buried in the sand (Hickerson 2008b; Figures 3.6.3 and 3.6.4).

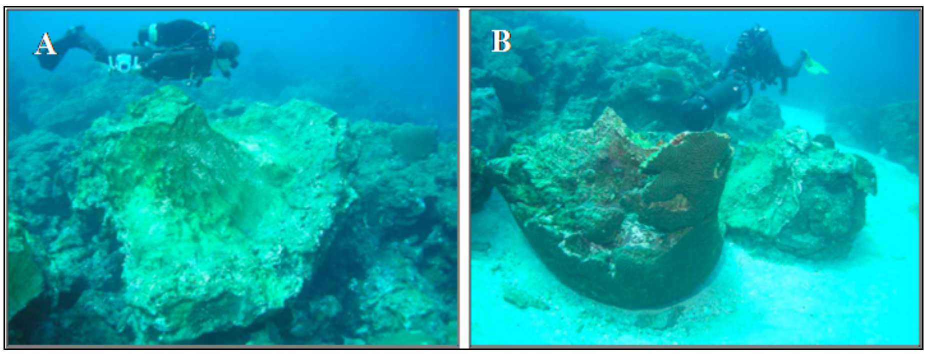


Figure 3.6.1. (A) Diver swims over an overturned coral colony at the EFGB in October 2008. (B) Toppled colony of *Colpophyllia natans* at the EFGB in October 2008. Photographs from Hickerson (2008b).

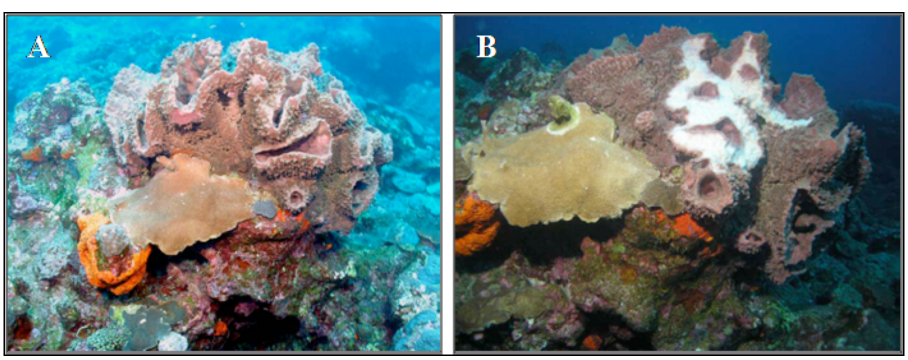


Figure 3.6.2. (A) Photograph of healthy *Xestospongia muta* in February 2005. (B) The same *X. muta* colony sheared in October 2008. Photographs from Hickerson (2008b).

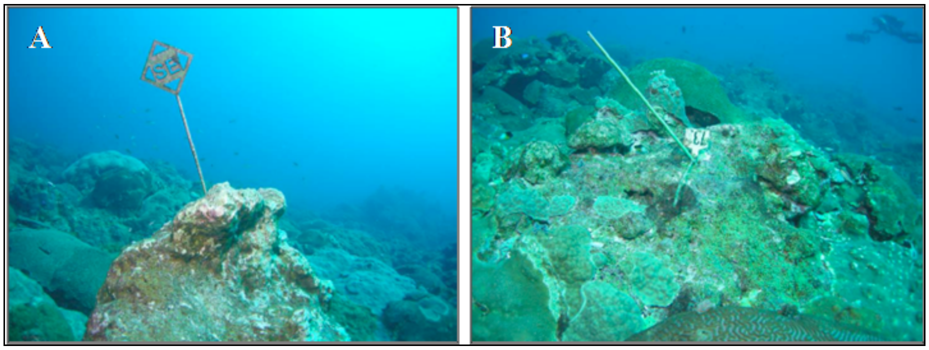


Figure 3.6.3. (A) Damaged southeast corner marker and (B) bent repetitive quadrat station marker at the EFGB study site in October 2008. Photographs from Hickerson (2008b).

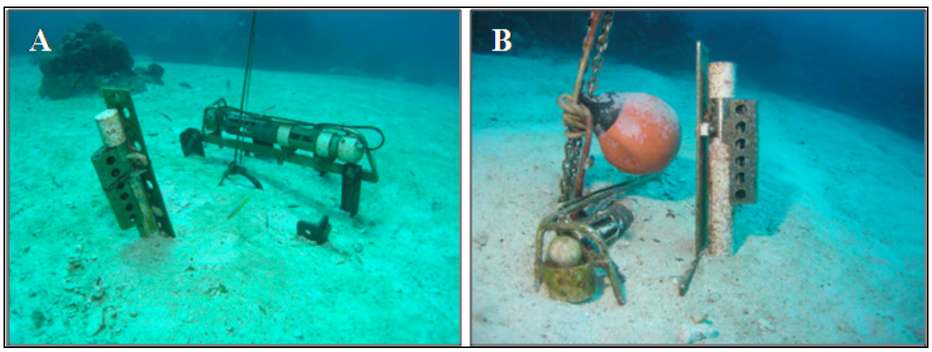


Figure 3.6.4. YSI and Seabird units partially buried in sand at the (A) EFGB and (B) WFGB long-term monitoring sites in October 2008. Photographs from Hickerson (2008b).

Hurricane impacts were assessed in both repetitive quadrat photographs and perimeter video surveys at the EFGB and WFGB in November 2008.

3.6.1. Repetitive Quadrat Observations

Repetitive quadrat photographs were compared between June 2007 and November 2008 to assess potential impacts from the passage of Hurricane Ike. Thirty-two matching repetitive quadrat stations were analyzed for the EFGB and 34 stations for the WFGB. Within the study-site repetitive quadrat stations at the EFGB and WFGB between June 2007 and November 2008, a total of 41 coral colonies were no longer in position (missing). Of these 41 colonies, 35 were missing from the EFGB (Table 3.6.1) and six were missing from the WFGB (Table 3.6.2). To obtain a total area of live coral cover that was lost, measurements of all missing corals were made from the June 2007 photographs using Sigma Scan Pro 5® planimetry software.

Table 3.6.1.

Area of coral colonies missing in November 2008 photographs at the EFGB.
Asterisks indicate that the colony was located on the edge of the photograph. The RQS is an identifier used during planimetry analysis.

EFGB				
Colony #	**RQS**	**Station #**	**Coral Species**	**Area (m^2)**
1	2b	715	*Diploria strigosa*	0.086
2			*Diploria strigosa*	0.032
3	7	703	*Diploria strigosa*	0.006
4	10	717	*Diploria strigosa*	0.025
5			*Diploria strigosa*	0.436
6	12b	185	*Diploria strigosa*	0.031
7			*Porites astreoides*	0.016
8			*Porites astreoides*	0.011
9			*Porites astreoides*	0.013
10			*Porites astreoides*	0.024
11			*Porites astreoides*	0.034
12			*Porites astreoides*	0.010
13			*Porites astreoides*	0.002
14			*Porites astreoides*	0.003
15			*Porites astreoides*	0.006
16			*Porites astreoides*	0.008
17			*Porites astreoides*	0.008
18			*Porites astreoides*	0.005
19			*Madracis decactis*	0.009
20			*Madracis decactis*	0.005
21			*Madracis decactis*	0.012
22			*Diploria strigosa*	0.013
23			*Porites astreoides*	0.031
24			*Porites astreoides*	0.009
25			*Porites astreoides*	0.007
26			*Porites astreoides*	0.017
27			*Porites astreoides*	0.059
28			*Mussa angulosa*	0.009
29			*Porites astreoides*	0.003
30	18b	4	*Porites astreoides*	0.019
31			*Diploria strigosa*	0.137
32	21b	27	*Diploria strigosa*	0.041

Table 3.6.1. Area of coral colonies missing in November 2008 photographs at the EFGB (continued).

EFGB				
Colony #	**RQS**	**Station #**	**Coral Species**	**Area (m^2)**
33			*Diploria strigosa*	0.035
34	29b	739?	*Diploria strigosa**	0.106
35	UNK2	708?	*Diploria strigosa*	0.294
			Total	**1.561**

Table 3.6.2.

Area of coral colonies missing in November 2008 photographs at the WFGB.
Asterisks indicate that the colony was located on the edge of the photograph. The RQS is an identifier used during planimetry analysis.

WFGB				
Colony No.	**RQS**	**Station #**	**Coral Species**	**Area (m^2)**
1			*Diploria strigosa*	0.040
2			*Diploria strigosa**	0.119
3	16	42	*Montastraea annularis* species complex *	0.071
4	19	879	*Montastraea annularis* species complex *	0.225
5	UNK8	73	*Diploria strigosa**	0.179
6	UNK6	865	*Diploria strigosa*	0.123
			Total	**0.758**

An estimated total area of ~2.3 m^2 of coral was missing from the study-site repetitive quadrat stations between June 2007 and November 2008 at the EFGB and WFGB, mostly likely due to the effects of Hurricane Ike (Tables 3.6.1 and 3.6.2). The affected coral species at the EFGB study site were *Diploria strigosa* (12 colonies and 1.243 m^2 missing), *Porites astreoides* (19 colonies and 0.283 m^2 missing), *Madracis decactis* (three colonies and 0.027 m^2 missing), and *Mussa angulosa* (one colony totaling 0.009 m^2). At the WFGB study site, the affected coral species were *D. strigosa* (four colonies and 0.462 m^2 missing) and *Montastraea annularis* species complex (two colonies and 0.296 m^2 missing).

One of the EFGB repetitive quadrat stations (Station 4) was particularly impacted, with 24 coral colonies missing from this quadrat, including 19 colonies of *Porites astreoides*, three colonies of *Madracis decactis*, and one colony each of *Diploria strigosa* and *Mussa angulosa* (Table 3.6.1 and Figure 3.6.5). The coral losses from Station 4 alone comprised ~69% of the total number of coral colonies missing and 21% of the total missing coral cover from the EFGB study site repetitive quadrat stations (Table 3.6.1). The largest amount of coral cover removed from a single repetitive quadrat station (0.467 m^2) was observed at Station 185 at the EFGB (Table 3.6.1 and Figure 3.6.6), which comprised ~30% of the total coral cover lost at the EFGB study site.

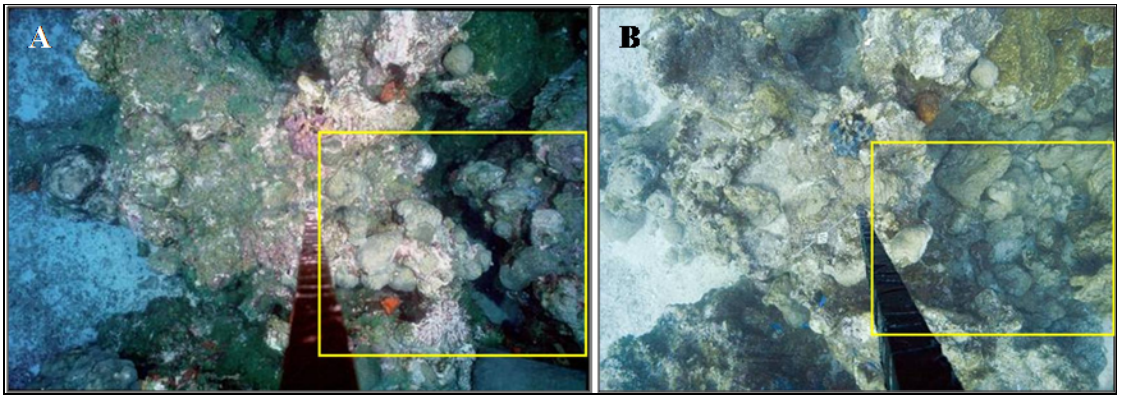


Figure 3.6.5. (A) Photograph of repetitive quadrat Station 4 in June 2007 at the EFGB. (B) Photograph of matching repetitive quadrat station in November 2008. The yellow boxes highlight the locations of potential hurricane impacts.

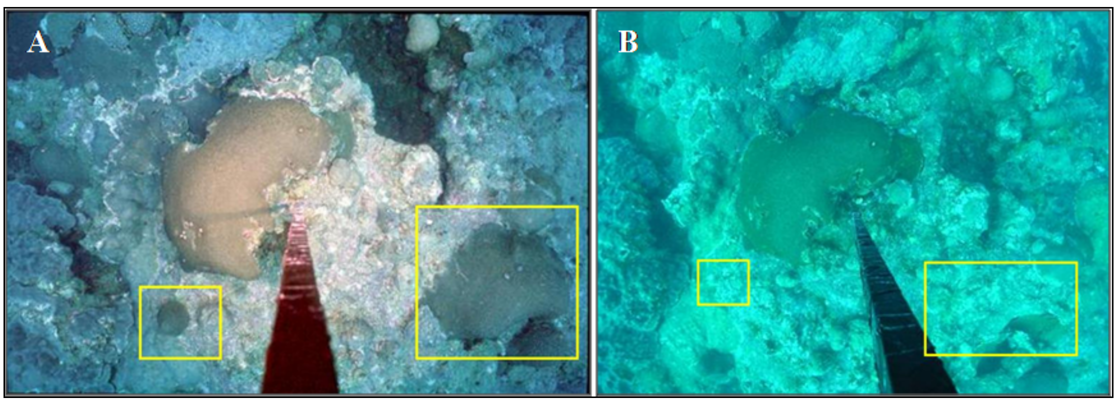


Figure 3.6.6. (A) Photograph of repetitive quadrat Station 185 in June 2007 at the EFGB. (B) Photograph of matching repetitive quadrat station in November 2008. The yellow boxes highlight the locations of potential hurricane impacts.

Despite depths of 32 m to 40 m (105 ft to 131 ft), three coral colonies were removed from the EFGB deep stations, totaling 0.101 m^2 of coral cover loss (Table 3.6.3). The three missing coral colonies were *Mussa angulosa*, *Montastraea* sp., and *Colpophyllia natans*. Figure 3.6.7 illustrates the two coral colonies that were removed from Deep Station 86.

Table 3.6.3.

Area of coral colonies missing in November 2008 photographs at the EFGB deep stations.

EFGB Deep Stations			
Colony No.	**Station #**	**Coral Species**	**Area (m^2)**
1		*Mussa angulosa*	0.013
2	86	*Montastraea* sp.	0.046
3	88	*Colpophyllia natans*	0.042
		Total	**0.101**

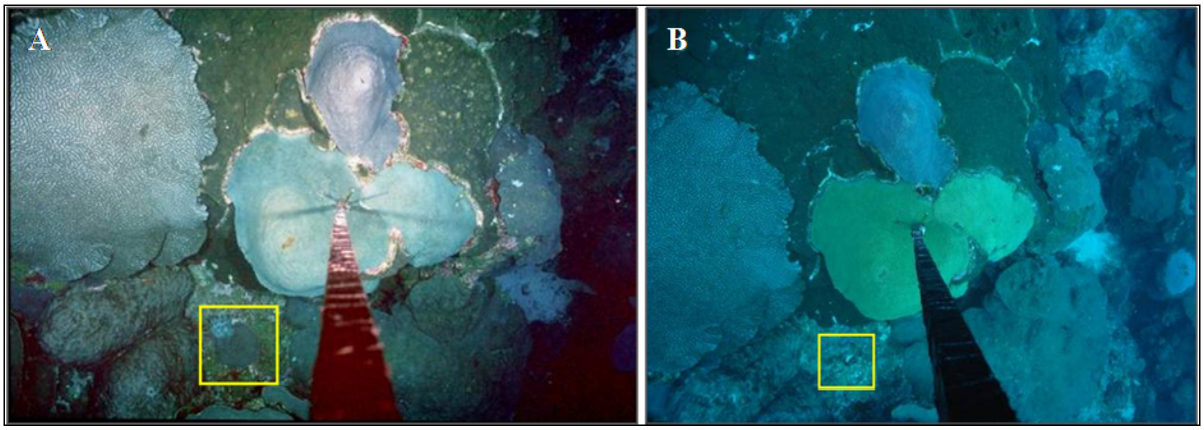


Figure 3.6.7. (A) Photograph of deep repetitive quadrat Station 86 in June 2007 at the EFGB. (B) Photograph of matching deep repetitive quadrat station in November 2008. The yellow boxes highlight the locations of potential hurricane impacts.

3.6.2. Perimeter Video Observations

Coral colonies previously observed along perimeter lines at the EFGB (north and east lines) and WFGB (south and west lines) in June 2007 were missing in November 2008, likely a result of Hurricane Ike.

3.6.2.1. EFGB Perimeter Video Observations

In November 2008, the northwest corner marker was missing. Despite the concerted efforts of divers, the replacement of the northwest corner marker was not in the same location as the previous year. In addition, in the 2008 video, the southeast corner shifted further southwest compared to the 2007 video. As a result of these shifts in corner locations, few comparisons of coral colonies were possible along the north and east perimeter lines between 2007 and 2008. A single colony of *Diploria strigosa* was no longer in place along the north perimeter line in November 2008 (Figure 3.6.8). No additional signs of hurricane damage were observed in the 2008 perimeter video.

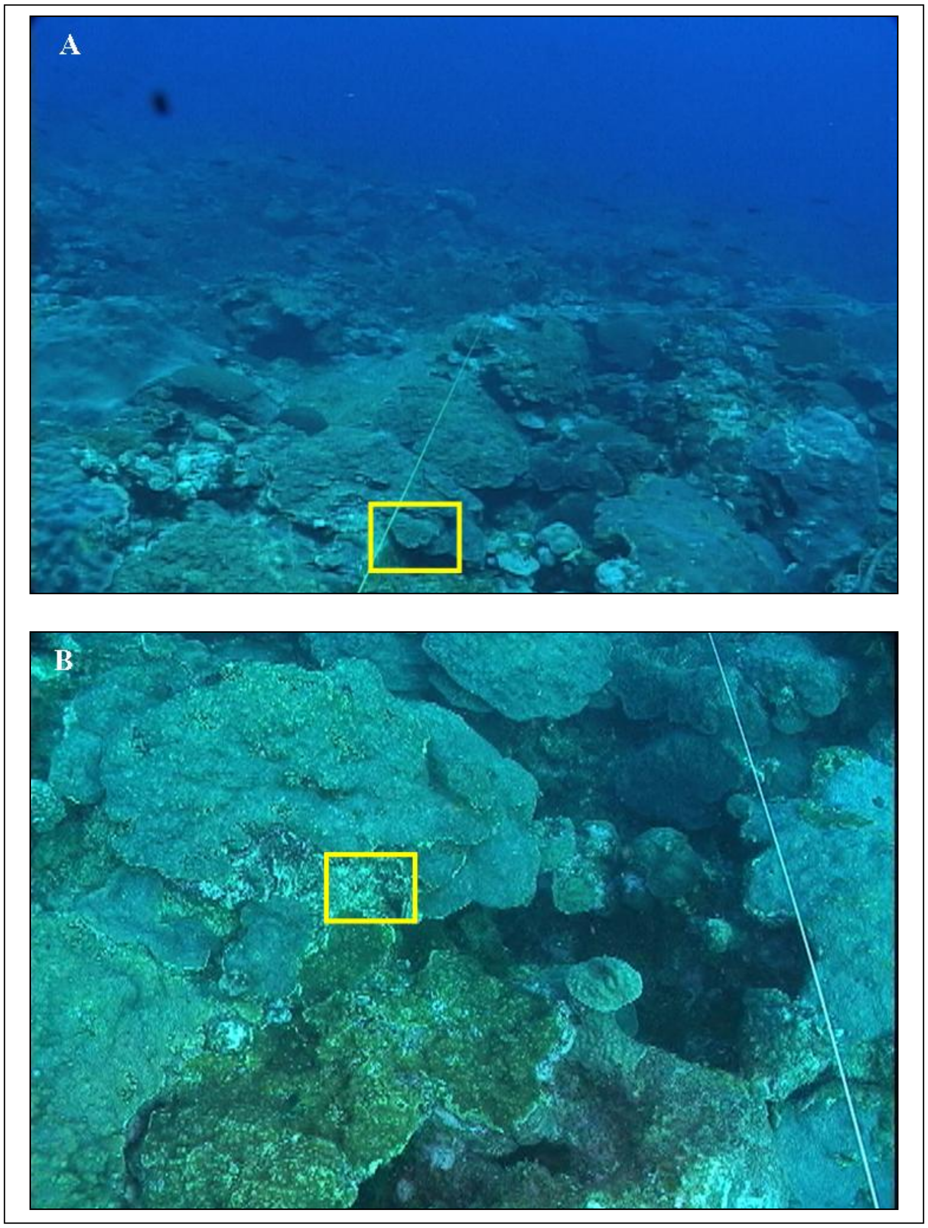


Figure 3.6.8. Video frames taken in (A) June 2007 and (B) November 2008 of a colony of *Diploria strigosa* that was missing in November 2008. The yellow box highlights the approximate location of hurricane impact.

The previously-mentioned hurricane impacts are likely an underestimate of the actual hurricane damages for two reasons: 1) only a portion of the perimeter surveys were comparable between June 2007 and November 2008 at the EFGB due to shifting northwest and southeast corner locations and 2) the 2008 perimeter video was recorded at an angle of 90º to the substrate (rather than at 45º as in previous surveys), providing a smaller area of view and fewer coral colonies for comparison.

3.6.2.2. WFGB Perimeter Video Observations

Despite the fact that both the southeast and southwest corner markers were in place at the WFGB in both years, the south perimeter line was located further south in 2008 compared to 2007. It appears that the line was placed on the opposite side of a massive coral colony, shifting the entire line to the south. Because of the line shift, few matching coral colonies were videotaped along the south perimeter line in both 2007 and 2008. From the small portion of comparable video, no obvious hurricane impacts were observed.

The northwest corner marker was absent in 2007 and 2008 at the time of perimeter videography. Despite the concerted efforts of divers, the replacement of the northwest corner marker in 2008 was not in the same location as the previous year. As a result, coral comparisons could only be made along the southern portion of the west line. From the small portion of comparable video, no hurricane impacts were observed.

As was mentioned above, the lack of observed hurricane impacts is likely an underestimate of hurricane damage at the WFGB. Panoramic views were not recorded at the WFGB in 2008 and as a result, hurricane impacts could not be assessed around corner marker locations. In addition, comparable video between June 2007 and November 2008 was only available for small portions of the perimeter surveys, and the 2008 video was recorded at 90º to the substrate (rather than 45º), decreasing the viewing area and possible coral comparisons.

3.7. CORAL HEALTH SURVEYS

The presence, types, and prevalence of coral diseases and other coral health issues were assessed using haphazardly placed 20-m² band transects at both the EFGB and WFGB in June 2007. All colonies of all coral species within each of the band transects were counted and checked for signs of disease, predation, and any other damage or identifiable health problem. The proportion of healthy colonies, diseased colonies (ciliate infections, bleaching, and growth anomalies), and colonies with signs of predation were calculated for both the EFGB and WFGB.

The vast majority of colonies surveyed at the EFGB and WFGB were healthy (Table 3.7.1). In June 2007, the percentage of healthy colonies at the EFGB and WFGB were 96.80% and 90.04%, respectively.

Prevalence is defined as the percentage of a population that is affected by a certain condition at a given time. In June 2007, the prevalence of all coral health issues (including predation, bleaching, ciliate infections, growth anomalies, and other miscellaneous health issues) was higher at the WFGB (9.96%) than at the EFGB (3.20%). The overall prevalence of all coral health issues at the community-wide level (consisting of the EFGB and WFGB combined) was 6.78%. When predation and bleaching are excluded, the prevalence of "disease" (ciliate infections, growth anomalies, and other coral maladies) at the community-wide level (EFGB and WFGB combined) is 1.72%. The disease prevalence at the EFGB and WFGB are 1.89% and 1.57%, respectively.

Table 3.7.1.

The percentage of healthy coral colonies and coral colonies exhibiting health problems at the FGB in June 2007. Other = compromised health problems that are not consistent with any of the common diseases/syndromes described for the Caribbean.

Coral Health Condition	EFGB		WFGB	
	# Colonies	Percent	# Colonies	Percent
Healthy	818	96.80%	859	90.04%
Predation	8	0.95%	75	7.86%
Bleaching	3	0.36%	5	0.52%
Ciliate Infection	1	0.12%	4	0.42%
Growth Anomaly	2	0.24%	11	1.15%
Other	13	1.54%	0	0.00%
Total	**845**	**100.00%**	**954**	**100.00%**

At the community-wide level, predation by fish, snails, hermit crabs, and fireworms impacted 4.61% of the corals surveyed. Predation was the most prominent coral health issue impacting corals on the WFGB (prevalence of predation was 7.86%; Table 3.7.1; Figure 3.7.1). In comparison, the prevalence of predation at the EFGB was only 0.95%. Predation impacted colonies of a wide variety of the major reef-building species (Tables 3.7.2 and 3.7.3; Figure 3.7.2, 3.7.4, and 3.7.5). At the WFGB, predation affected 30.2% of the *Montastraea annularis* colonies surveyed, 26.2% of *M. faveolata*, 14.6% of *Diploria strigosa*, 9.9% of *Stephanocoenia intersepta*, and 8.3% of *Colpophyllia natans* (Table 3.7.3; Figure 3.7.4). Predation was less prevalent at the EFGB (0.95%) and affected only five coral species: *M. faveolata* (5.6%), *S. intersepta* (4.0%), *M. cavernosa* (1.4%), *Porites astreoides* (1.0%), and *M. franksi* (0.4%; Table 3.7.2; Figure 3.7.5).

The prevalence of coral bleaching at the community-wide level was 0.44%. The prevalence of bleaching was slightly higher on the WFGB (0.52%) than on the EFGB (0.36%; Table 3.7.1). At the EFGB, only two coral species exhibited bleaching in the band transects (9.1% of *Siderastrea siderea* and 2.0% of *Stephanocoenia intersepta* were bleached; Table 3.7.2, Figure 3.7.5). At the WFGB, bleaching was observed in only one species, *Porites astreoides*, within the survey transects (1.9% bleached; Table 3.7.3, Figure 3.7.4). Outside of the coral health survey transects, *Montastraea franksi* and *M. faveolata* showed signs of bleaching (Figure 3.7.3).

The prevalence of infection by the ciliate, *Halofoliculina* sp., at the community-wide level was 0.28%. Ciliate infections were slightly higher on the WFGB (prevalence of 0.42%) than the EFGB (0.12%; Figure 3.7.1). The coral species exhibiting ciliate infections included *Montastraea faveolata* (7.1% at the WFGB) and *Colpophyllia natans* (3.8% at the EFGB and 2.8% at the WFGB; Tables 3.7.2 and 3.7.3; Figures 3.7.3-3.7.5).

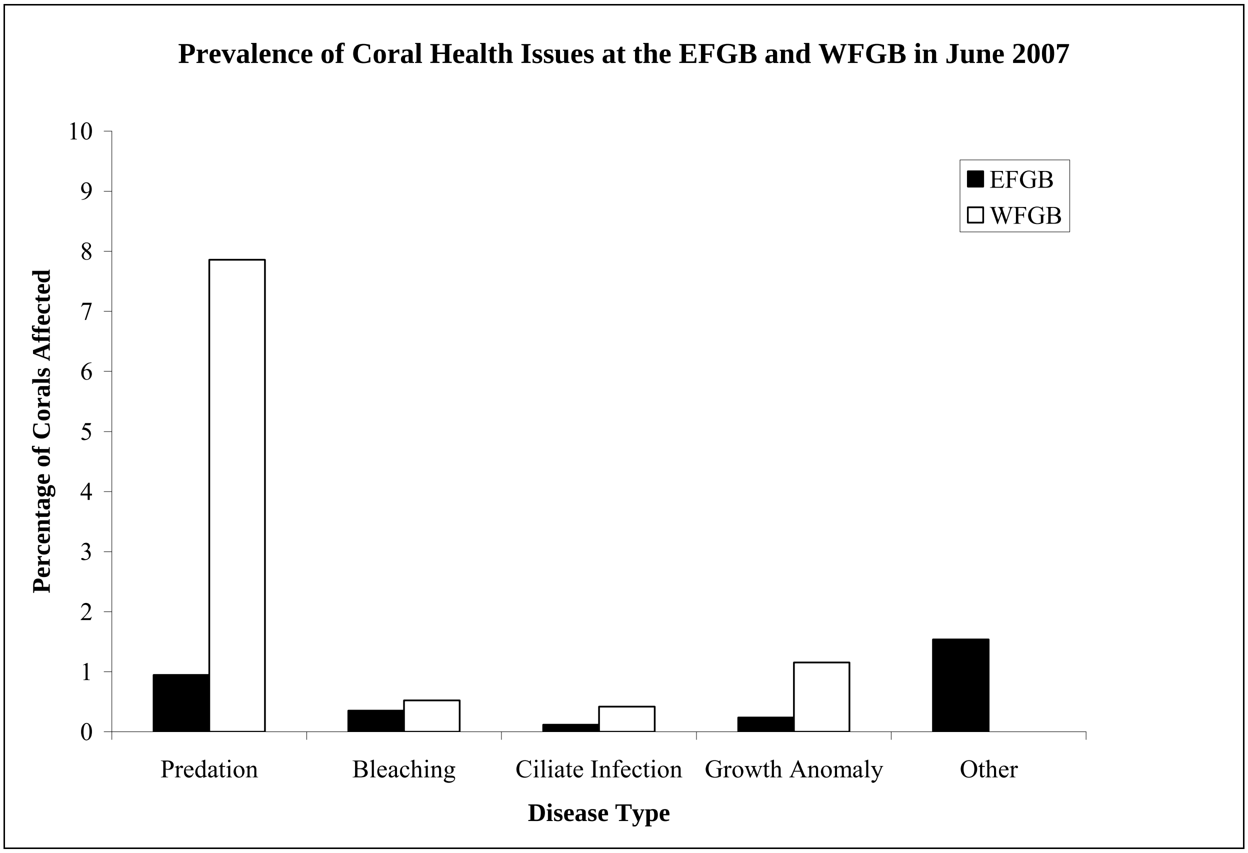


Figure 3.7.1. The prevalence of the various coral health issues on the EFGB and WFGB in June 2007.

Table 3.7.2.

The percentage of colonies in the major coral taxa that exhibited coral health issues at the EFGB in June 2007. N/A = species not found within coral health survey transects. Other = health problems that are not consistent with any of the common diseases/syndromes described for the Caribbean.

East Flower Garden Bank							
Coral Species	**Healthy**	**Predation**	**Bleached**	**Ciliates**	**Growth Anomaly**	**Other**	**Total**
Diploria strigosa	90.9	0.0	0.0	0.0	1.5	7.6	100
Montastraea faveolata	94.4	5.6	0.0	0.0	0.0	0.0	100
Montastraea annularis	100.0	0.0	0.0	0.0	0.0	0.0	100
Montastraea cavernosa	98.6	1.4	0.0	0.0	0.0	0.0	100
Montastraea franksi	98.7	0.4	0.0	0.0	0.0	0.9	100
Stephanocoenia intersepta	94.0	4.0	2.0	0.0	0.0	0.0	100
Siderastrea siderea	90.9	0.0	9.1	0.0	0.0	0.0	100
Porites astreoides	99.0	1.0	0.0	0.0	0.0	0.0	100
Agaricia agaricites	100.0	0.0	0.0	0.0	0.0	0.0	100
Agaricia fragilis	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Madracis decactis	100.0	0.0	0.0	0.0	0.0	0.0	100
Colpophyllia natans	92.3	0.0	0.0	3.8	0.0	3.8	100
Scolymia spp.	100.0	0.0	0.0	0.0	0.0	0.0	100
Mussa angulosa	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Millepora alcicornis	100.0	0.0	0.0	0.0	0.0	0.0	100
Sponges	100.0	0.0	0.0	0.0	0.0	0.0	100

Table 3.7.3.

The percentage of colonies in the major coral taxa that exhibited coral health issues at the WFGB in June 2007. N/A = species not found within coral health survey transects. Other = health problems that are not consistent with any of the common diseases/syndromes described for the Caribbean.

West Flower Garden Bank							
Coral Species	**Healthy**	**Predation**	**Bleached**	**Ciliates**	**Growth Anomaly**	**Other**	**Total**
Diploria strigosa	79.2	14.6	0	0	6.3	0	100
Montastraea faveolata	64.3	26.2	0	7.1	2.4	0	100
Montastraea annularis	69.8	30.2	0	0	0	0	100
Montastraea cavernosa	95.5	4.5	0	0	0	0	100
Montastraea franksi	97.9	1.6	0	0	0.5	0	100
Stephanocoenia intersepta	90.1	9.9	0	0	0	0	100
Siderastrea siderea	100	0	0	0	0	0	100
Porites astreoides	93	5.2	1.9	0	0	0	100
Agaricia agaricites	100	0	0	0	0	0	100
Agaricia fragilis	100	0	0	0	0	0	100
Madracis decactis	94.7	5.3	0	0	0	0	100
Colpophyllia natans	88.9	8.3	0	2.8	0	0	100
Scolymia sp.	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Mussa angulosa	100	0	0	0	0	0	100
Millepora alcicornis	100	0	0	0	0	0	100
Sponges	100	0	0	0	0	0	100

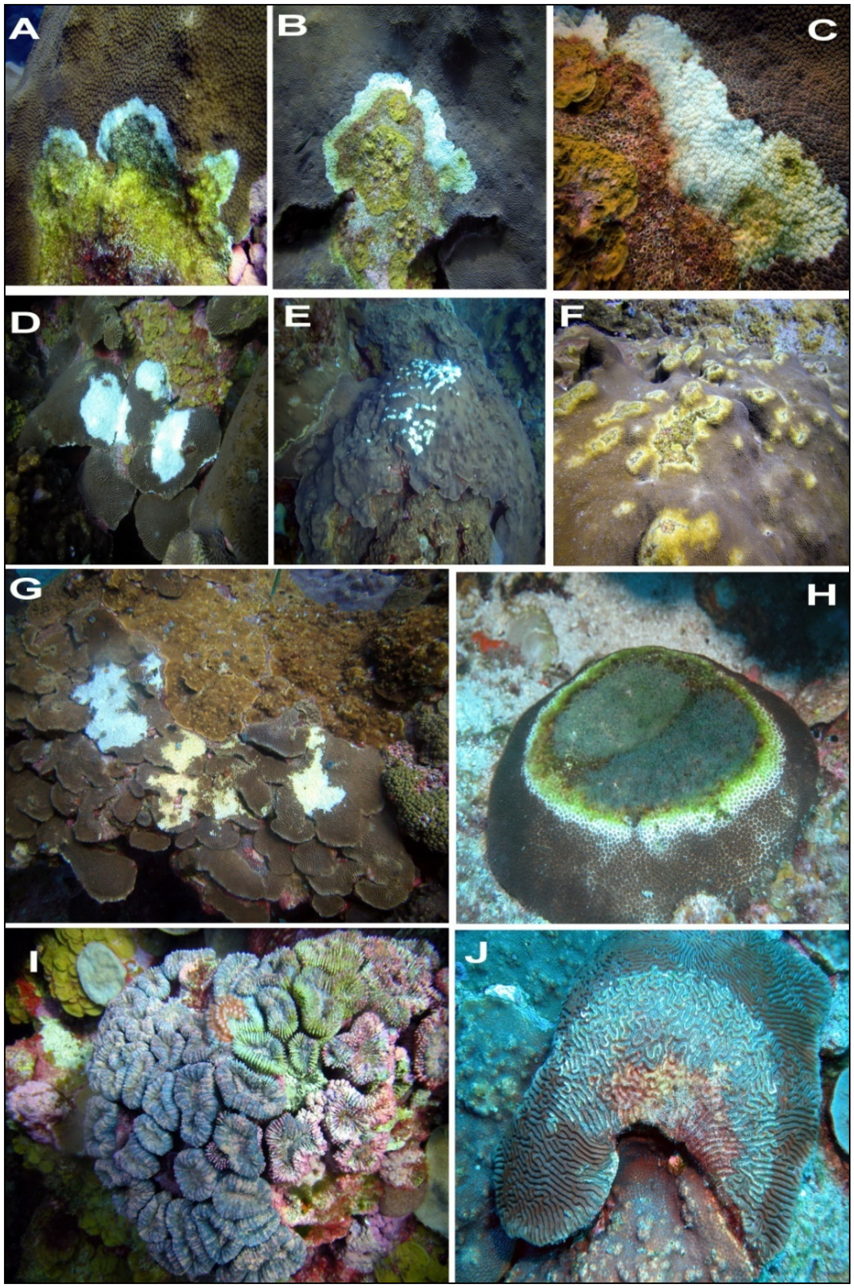


Figure 3.7.2. Predation scars observed in various scleractinian coral species at the EFGB and WFGB. Fireworm and snail predation was common on *Montastraea faveolata* (A, B, G), *M. franksi* (C), *Diploria strigosa*, and *Mussa angulosa* (I). Parrot fish predation mostly affected *M. faveolata* (D, E, F) and *Colpophyllia natans*. Damselfish territories were mostly found on *Stephanocoenia intersepta* (H), *M. faveolata*, and *D. strigosa* (J). Photographs by E. Weil.

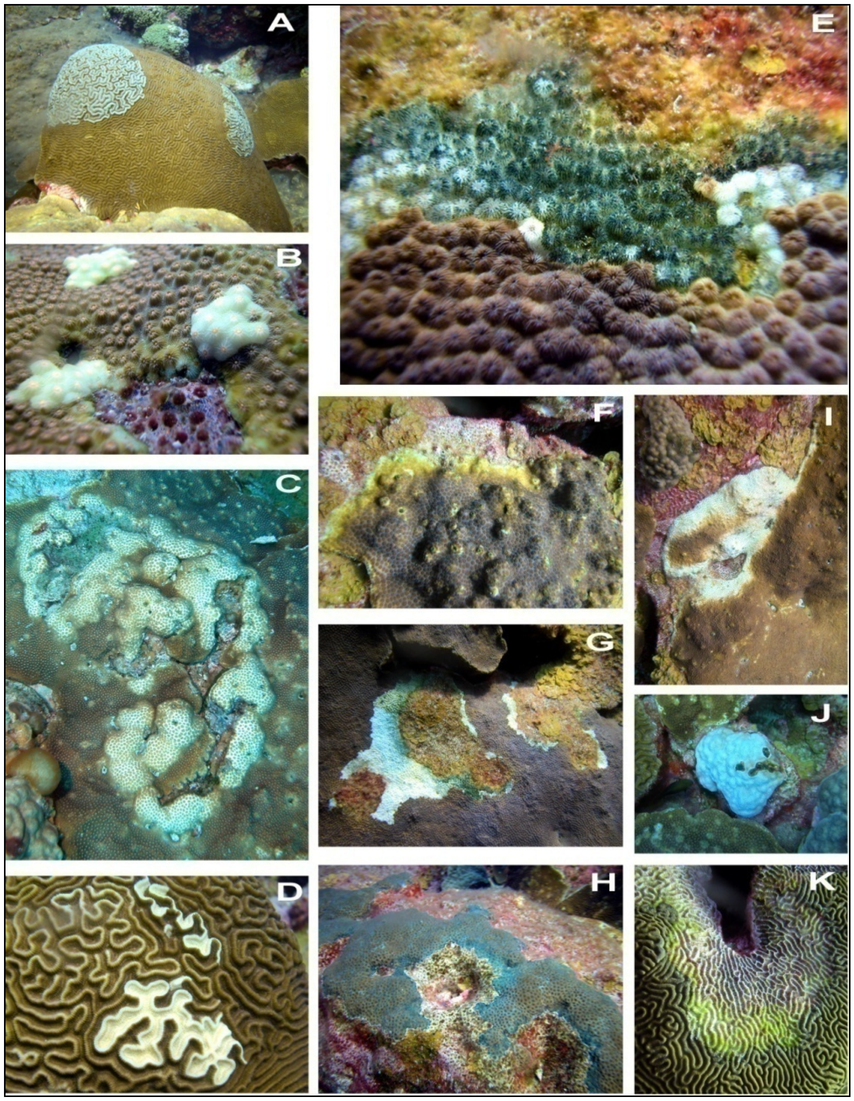


Figure 3.7.3. Diseases and other health problems in coral species of the FGB. Growth anomalies were more common in *Diploria strigosa* and *Montastraea franksi* (A-D) at the FGB. Ciliate infections, a new report for the area, were mostly observed in *M. faveolata* (E). Two colonies of *M. franksi* exhibited signs similar to those of Caribbean yellow band disease (F) and several colonies of *M. faveolata* showed signs similar to those of white plague (G). Signs similar to those of dark spots disease were observed in *Siderastrea siderea* (H). Some bleaching (I-J) was observed on the FGB and several colonies of showed signs of other coral health problems (K). Photographs by E. Weil.

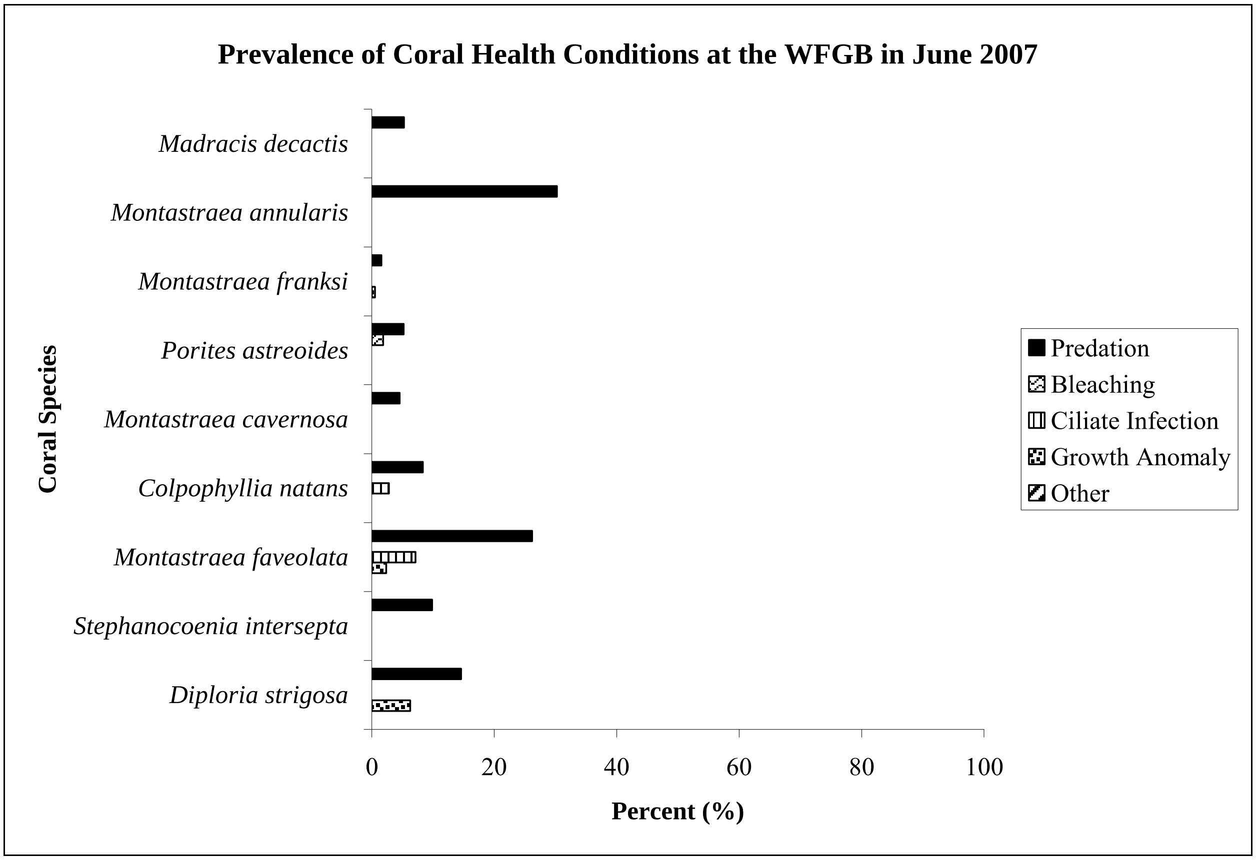


Figure 3.7.4. Prevalence of different health conditions found in the major reef-building coral species of the WFGB during June 2007.

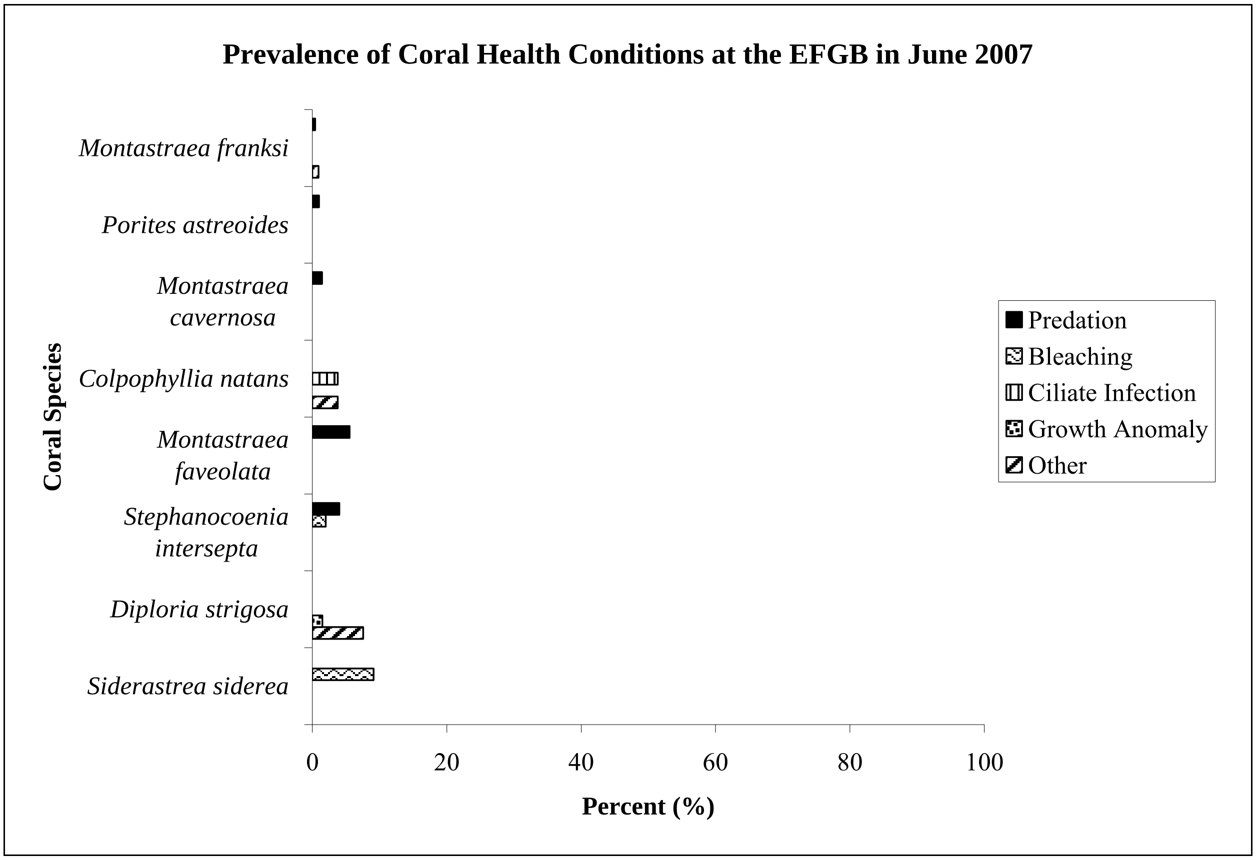


Figure 3.7.5. Prevalence of different health conditions found in the major reef-building coral species of the EFGB during June 2007.

The prevalence of coral growth anomalies (Figure 3.7.3) at the community-wide level was 0.72%. The prevalence of coral growth anomalies was higher at the WFGB (1.15%) than at the EFGB (0.24%; Figure 3.7.1). Coral growth anomalies were observed in *Diploria strigosa* (6.3% and 1.5% at the WFGB and EFGB, respectively), *Montastraea faveolata* (2.4% at the WFGB), and *M. franksi* (0.5% at the WFGB; Tables 3.7.2 and 3.7.3; Figures 3.7.3-3.7.5). Outside of the survey transects, a few colonies of *Colpophyllia natans* also exhibited growth anomalies.

The coral health issue category named "other" describes corals that exhibited signs of compromised health problems that are not consistent with signs of any of the common diseases/syndromes described for the Caribbean. The prevalence of "other" coral health issues at the community-wide level was 0.72%. No colonies within transects exhibited such maladies at the WFGB; however, at the EFGB, the prevalence of "other" coral health issues was 1.54%. Only three coral species were affected: 7.6% of the *Diploria strigosa* colonies, 3.8% of *Colpophyllia natans* colonies, and 0.9% of *Montastraea franksi* colonies showed signs of compromised health within the transects (Table 3.7.2). Outside of the coral health survey transects, colonies of *Siderastrea siderea*, *Colpophyllia natans*, *Montastraea faveolata*, *Stephanocoenia intersepta*, and *Diploria strigosa* (Figure 3.7.3K) also showed different signs of health problems. For example, two colonies of *S. siderea* showed signs similar to advanced stages of dark spots disease (Figure 3.7.3H).

Montastraea and *Diploria* are the two most common genera at the FGB. At the EFGB, the most prevalent coral issues affecting these two genera are predation and "other" coral health problems (Figure 3.7.6). At the WFGB, the most prevalent coral issues affecting these genera are predation, ciliate infections, and growth anomalies (Figure 3.7.7). Outside of the coral health survey transects, three colonies of *Montastraea franksi* at the EFGB exhibited signs similar to those of Caribbean yellow band disease (Figure 3.7.3F), which is one of the most damaging coral diseases in the region (Weil 2004). Future surveys should assess any indications of increasing numbers of colonies affected by Caribbean yellow band disease and coral mortality associated with it. White plague-like disease signs were observed on only two colonies of *Montastraea faveolata* located outside of survey transects; however, because of the apparently slow advance rates and jagged, irregular lesion edges, these signs could also have been produced by snail and/or fireworm predation, or other disease.

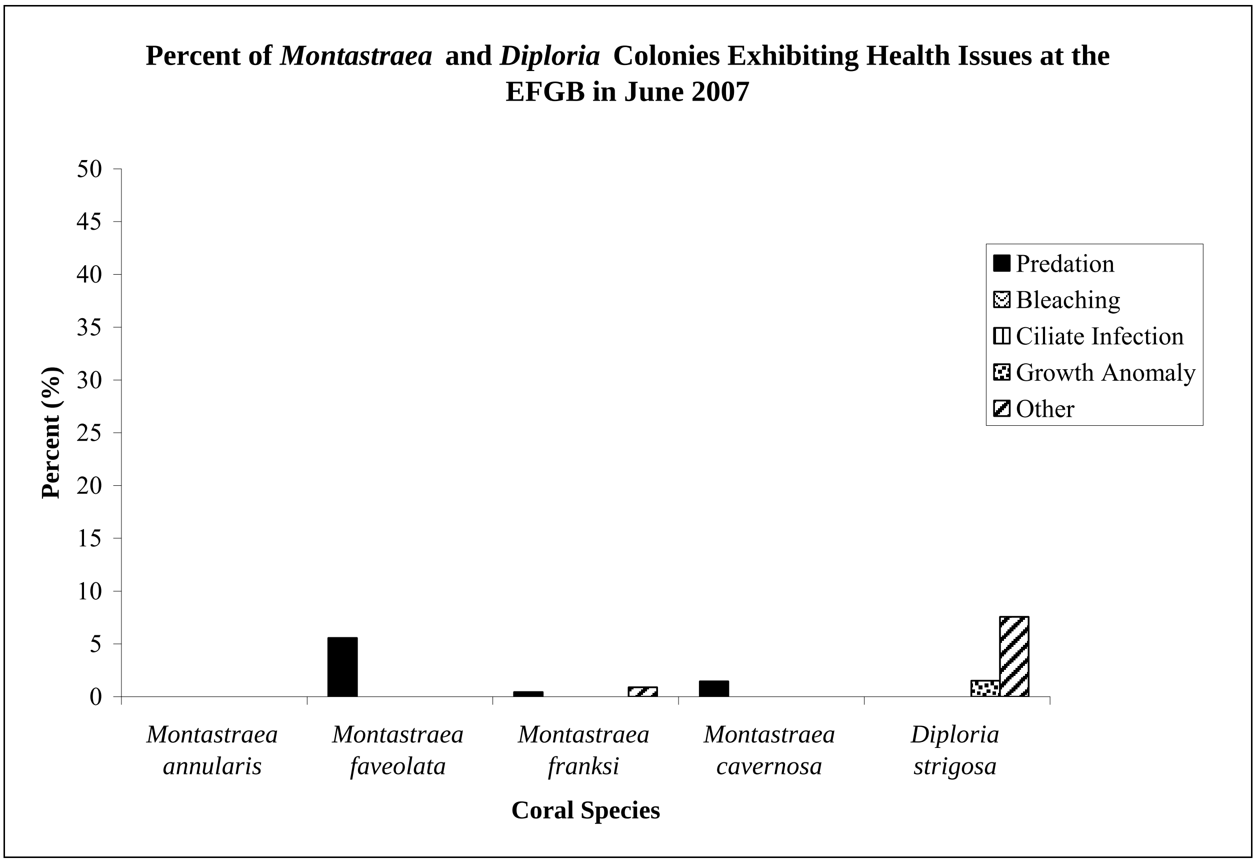


Figure 3.7.6. Percentage of colonies of the two most common genera (*Montastraea* and *Diploria*) at the EFGB in June 2007showing signs of predation, growth anomalies, and other health problems that are not consistent with any of the common diseases/syndromes described for the Caribbean.

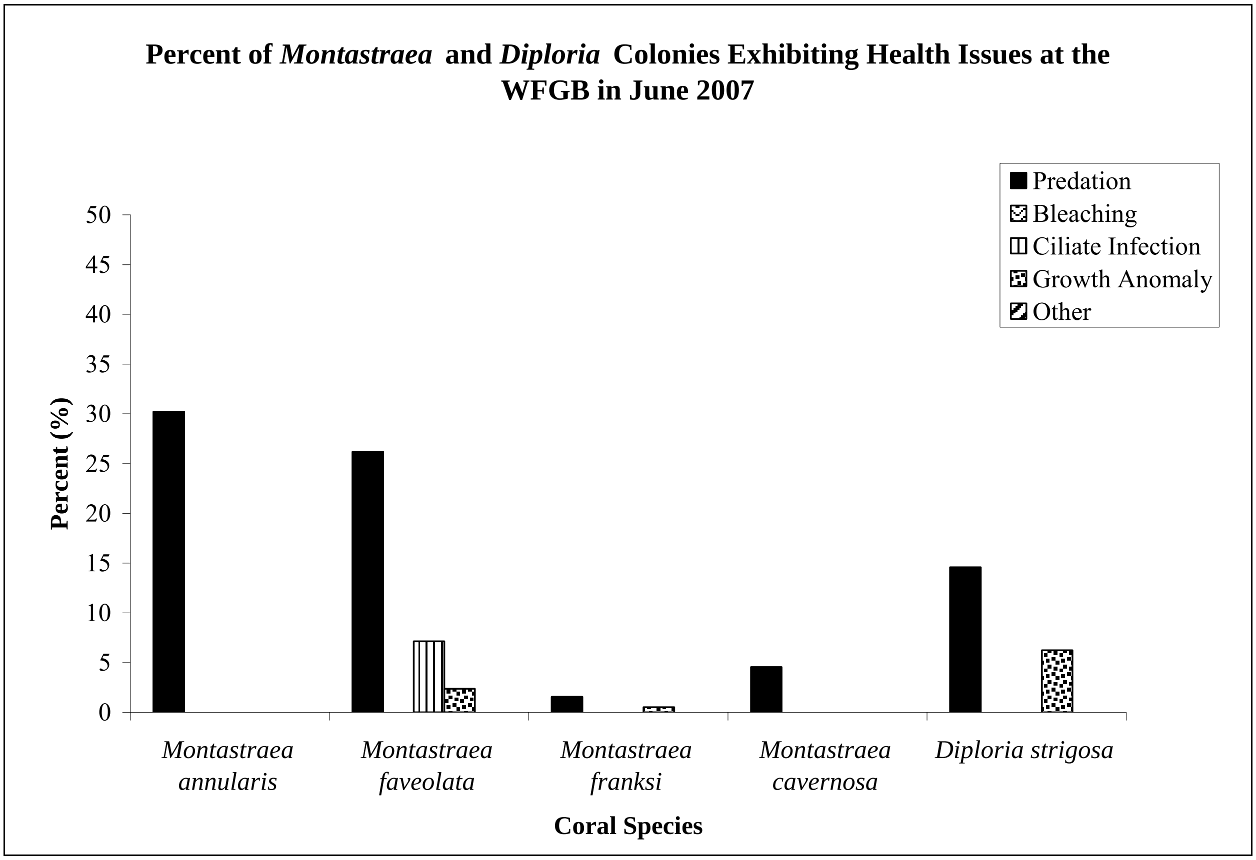


Figure 3.7.7. Percentage of colonies of the two most common genera (*Montastraea* and *Diploria*) showing signs of predation, ciliate infections, and growth anomalies at the WFGB in June 2007.

No diseases or health problems were observed in any of the other important reef community groups such as crustose coralline algae and sponges. Several colonies of the endolithic and crustose sponge *Cliona tenuis* (Zea and Weil 2003) were observed at both the EFGB and WFGB.

3.8. Qualitative Field Observations

3.8.1. Sponge Spawning

During the June 2007 annual monitoring cruise, divers observed broadcast spawning activity by *Agelas clathrodes* within the EFGB study site, and *Xestospongia muta* within the WFGB study site. At 14:51 CST on June 11, 2007, *A. clathrodes* male and female sponges began to spawn en masse at the EFGB. The *X. muta* spawning event occurred on the morning (beginning at approximately 08:00 CST) of June 14, 2007. The spawning events were synchronous, with male and female sponge colonies participating. Positively buoyant spermatozoa formed a dense 'cloud' within the water column in the vicinity of the sponges (Figure 3.8.1A and B), causing a substantial reduction in visibility. Ova were negatively buoyant and had accumulated within the atria and had begun to spill adjacent to the female sponges (Figure 3.8.1C). Fish, including the

French angelfish (*Pomacanthus paru*), Spanish hogfish (*Bodianus rufus*), and ocean triggerfish (*Canthidermis sufflamen*) were observed feeding on the gametes.

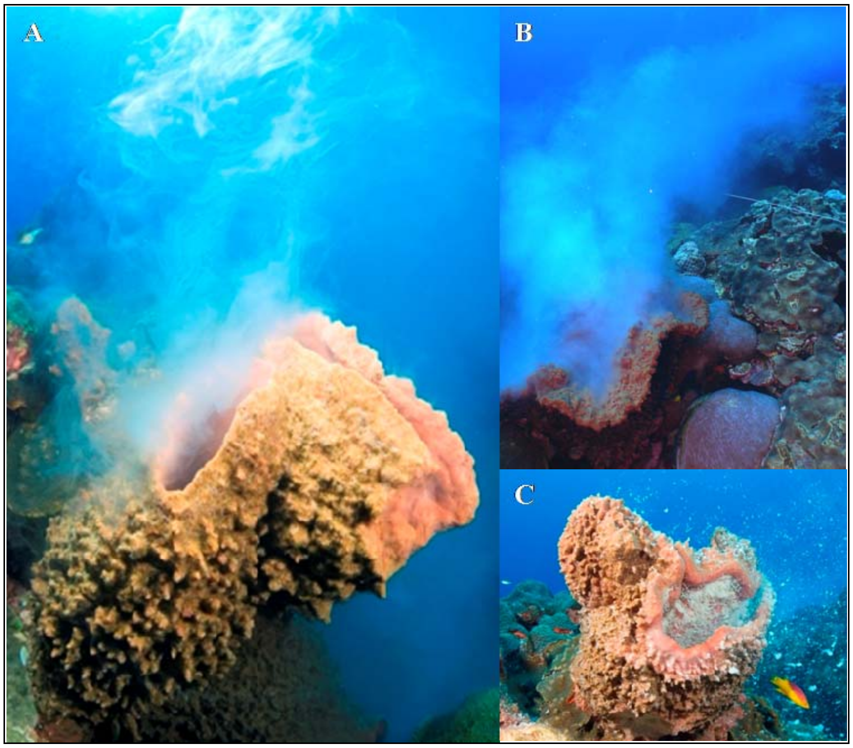


Figure 3.8.1. Both male (A and B) and female (C) colonies of *Xestospongia muta* observed spawning on the WFGB in June 2007. Photographs by W. Stearns (A, C) and K.J.P. Deslarzes (B).

3.8.2. *Acropora* spp.

3.8.2.1. Discovery of Live Acropora palmata

During the June 2005 annual monitoring cruise, a colony of *Acropora palmata* was discovered outside the EFGB study site, in close proximity to the southeast corner marker. This 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 (Figure 3.8.2; Hickerson 2008b). In addition, the colony also displayed tissue loss on the southern side of the colony due to an unidentified coral health issue and a white band of exposed coral skeleton was observed on one of the branches (E. Hickerson, personal communication, 2008c; Figure 3.8.2). Algal farming by a threespot damselfish (*Stegastes planifrons*) was also evident on the colony and may have contributed to the coral tissue loss.

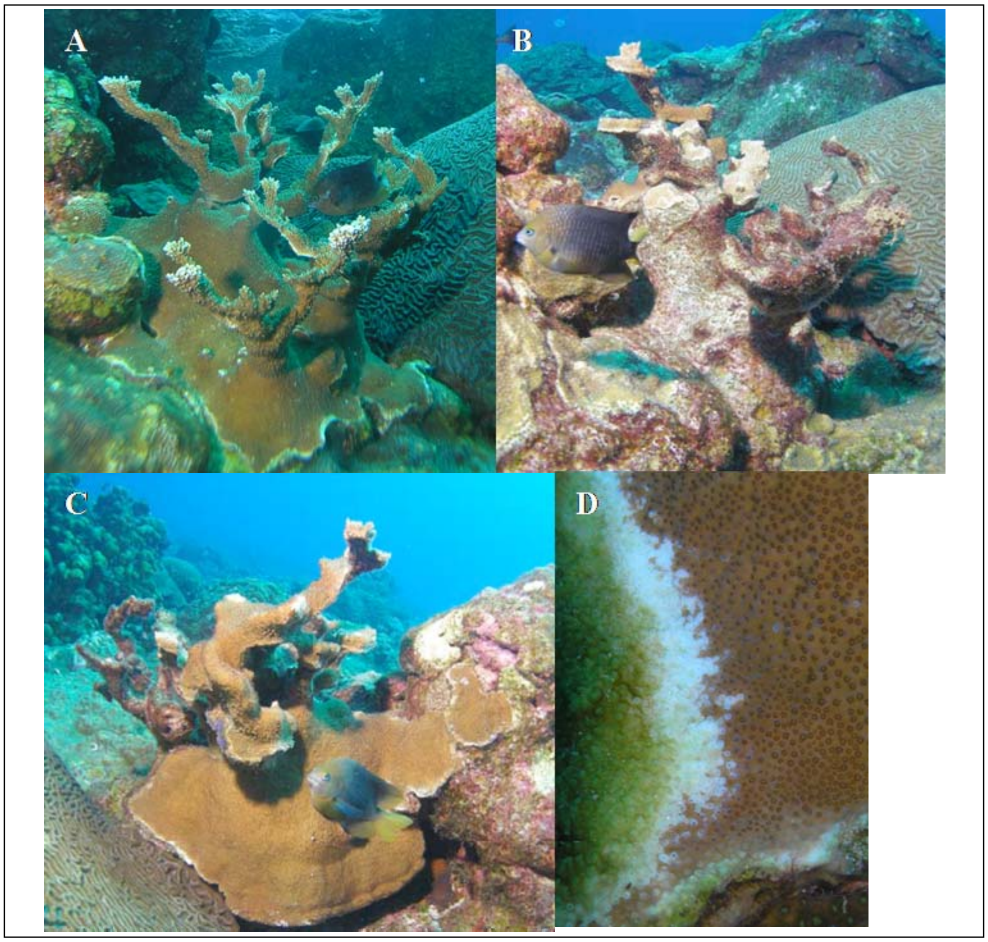


Figure 3.8.2. The *Acropora palmata* colony discovered at the EFGB in (A) June 2005. The north side (B) and south side (C) of the same colony in October 2008. (D) White band of exposed coral skeleton observed on the *A. palmata* colony in 2006. Photographs courtesy of E. Hickerson.

It should be noted that prior to this discovery, only one other colony of *Acropora palmata* had been documented on the reefs of the FGB. 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).

3.8.2.2. Discovery of Sub-Fossil Acropora spp.

Surveys were conducted in June 2006 and June 2007 to investigate whether *Acropora*-dominated reefs underlie and form the structural foundation of the living reef community at the EFGB and WFGB. In June 2006, while scuba diving on the southeast corner of the EFGB study site, W.F. Precht and K.J.P. Deslarzes examined an open cave at 21-m (68.9-ft) depth, which exposed a 3-m (9.8-ft) vertical section of the reef subsurface just below the living community. Within that exposure, large branches and trunks of *A. palmata* (>1 m in height) were discovered in growth position. A sample of this sub-fossil *A. palmata* was collected from a branch of a colony at the top of the section (Figure 3.8.3). Radiocarbon dating of this specimen yielded a date of 6330 ± 60 14Cyr (radiocarbon years before 1950), corresponding to a calibrated age of 6780 calbp (calendar years before present). Follow-up surveys by Precht and Deslarzes in June 2007 revealed an *A. palmata*-dominated understory dating between 10,000-6,000 years before present on both the EFGB and WFGB.

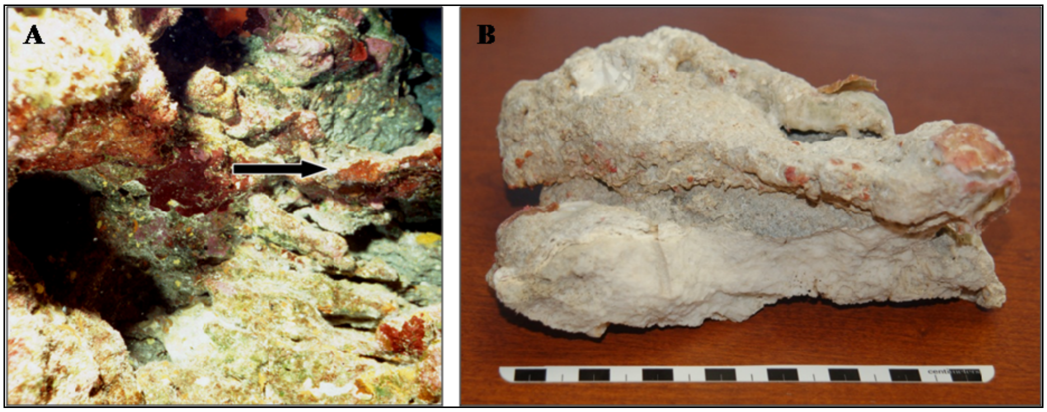


Figure 3.8.3. (A) Sub-fossil *Acropora palmata* in growth position at the WFGB in June 2007. Arrow indicated location of *A. palmata* branch in growth position. (B) Specimen of sub-fossil *A. palmata* collected from the WFGB in June 2007. Note thick crusts of crustose coralline algae, encrusting benthic foraminifera, bryozoa, and mollusks above *A. palmata* blade. Photographs courtesy of W.F. Precht.

The June 2007 follow-up surveys by Precht, Deslarzes, Hickerson, and Schmahl also resulted in the discovery of the first sub-fossil *Acropora cervicornis* at the FGB. The sub-fossil *A. cervicornis* was observed within the *Madracis auretenra* field located at the southeastern edge of the EFGB study site (depths of 24 m or 80 ft; Figure 3.8.4). In addition to *A. cervicornis*, sub-fossil *Eusmilia fastigiata* was also discovered within the same *M. auretenra* field. Sub-fossil *A. cervicornis* was also observed east of the *M. auretenra* field, at a water depth of 32 m (106 ft).

3.8.3. Coral Disease

3.8.3.1. Qualitative Coral Health Assessments

During the 2004-2008 annual monitoring cruises, scientific divers made qualitative observations of coral colonies exhibiting signs of disease or other coral health issues. A potentially diseased colony of *Siderastrea siderea* was identified at the WFGB during the June 2005 monitoring cruise (Figure 3.8.5). This colony was photographed around its margin using a close-up kit. The coral was approximately 2 m (6.6 ft) in diameter and showed an apparent lesion, separating healthy coral tissue from exposed coral skeleton. The pink coloration observed on the exposed skeleton was atypical of described diseases (Richardson et al. 1998a, b; Weil and Hooten 2008). The lesion was not always a sharp line and there were patches of apparently healthy coral tissue in the affected area (Figure 3.8.5 A-B). A portion of the colony had *Millepora* sp. growing over the dead skeleton and had a black margin between healthy tissue and skeleton (Figure 3.8.5 C-

D). Although this colony exhibited possible disease signs, its condition could also be the result of an unusual bleaching pattern.

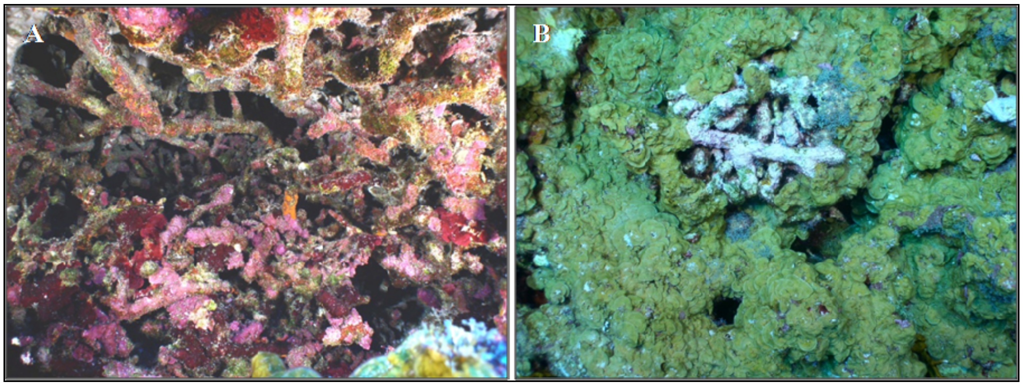


Figure 3.8.4. Sub-fossil *Acropora cervicornis* (A) branches in growth position covered with epibionts in a cave at 32 m (105 ft.) and (B) cemented rubble covered with Lobophora spp. at the same depth on the EFGB in June 2007. Photographs courtesy of K.J.P. Deslarzes.

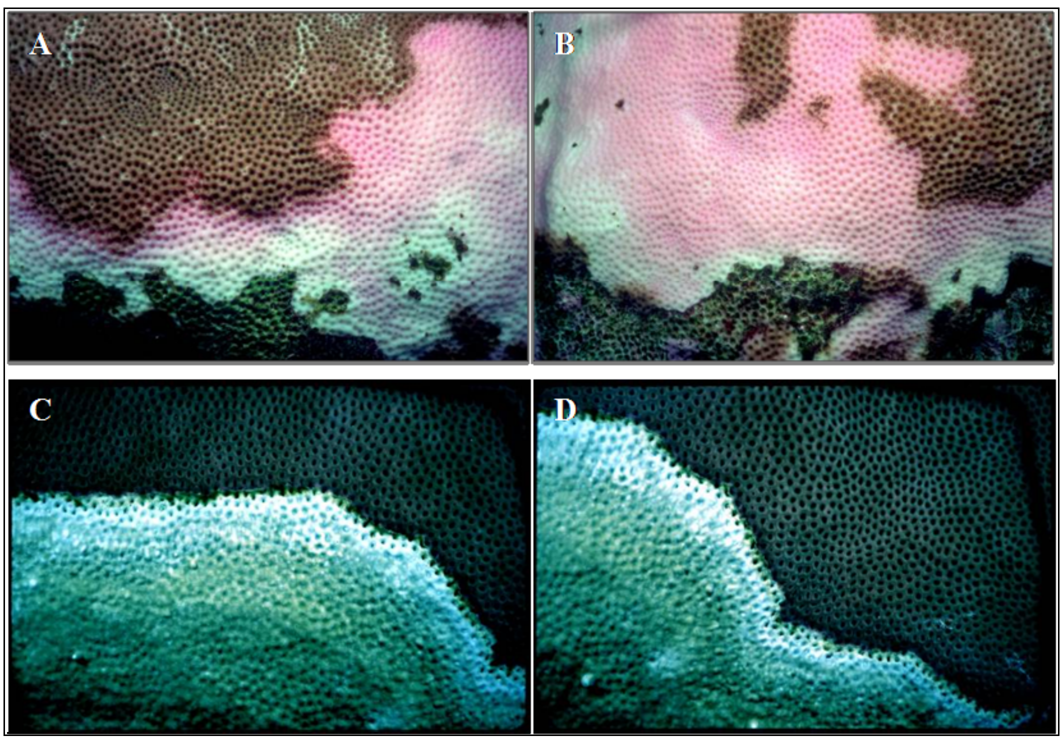


Figure 3.8.5. *Siderastrea siderea* colony showing disease-like signs at the WFGB in June 2005. Photographs A and B were taken around the perimeter of the 2-m (6.6-ft) coral head, documenting the possible disease lesion. Photographs C and D show overgrowth of the colony by *Millepora* sp. Photographs by W. F. Precht.

3.8.3.2. Plague-Like Disease at the FGB

In February 2005, managers of the FGBNMS observed the first documented outbreak of coral disease on the EFGB and WFGB (Hickerson 2005). The disease signs appeared very similar to white plague-like diseases documented elsewhere on Caribbean reefs. Signs consist of a migrating line/band of bright white, exposed coral skeleton separating apparently healthy coral tissue from algal-colonized coral skeleton (Richardson et al. 1998a, b). In many colonies, the disease appeared to initiate at the colony base or margin and then progressed outward or across the colony (Figure 3.8.6).

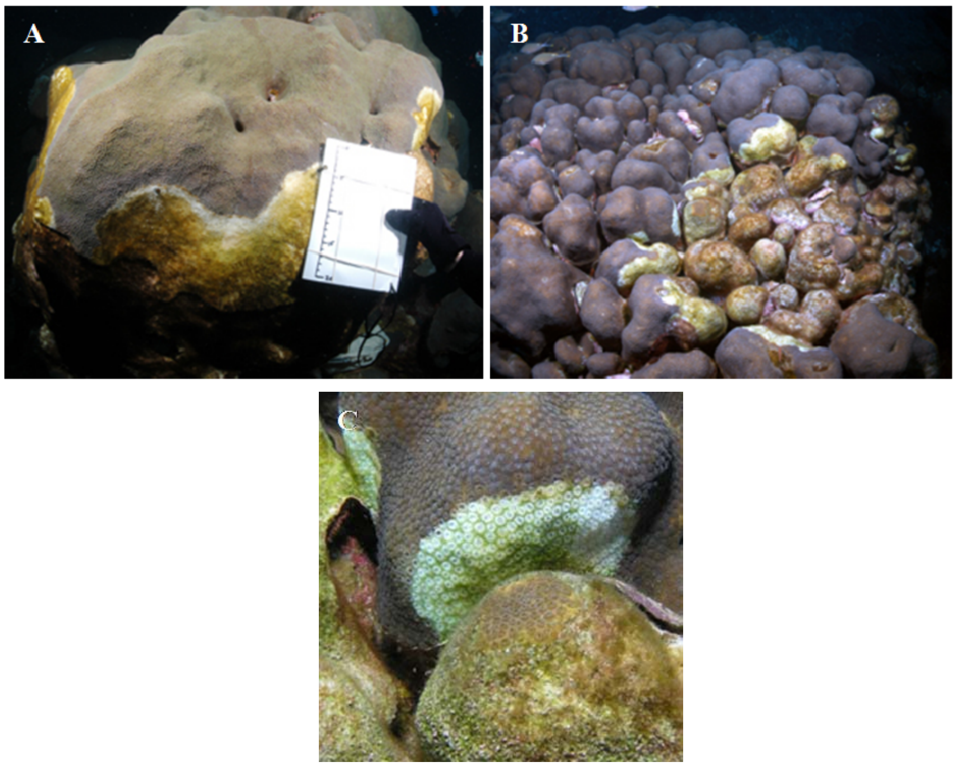


Figure 3.8.6. The white plague-like disease documented on the reefs of the EFGB and WFGB in April 2005. (A) An infected *Montastraea faveolata* colony, (B) an infected *Montastraea annularis* colony, and (C) a close-up photograph of the white plague-like lesion on the *M. annularis* colony pictured in (B). All photographs by G.P. Schmahl.

The plague-like disease has been reported to occur annually at the FGB from 2005-2008, particularly during periods of cooler water temperature (Hickerson 2008a, 2009), and has been reported to affect seven scleractinian species: *Montastraea faveolata*, *M. franksi*, *M. annularis*, *Colpophyllia natans*, *Diploria strigosa*, *Stephanocoenia intersepta*, and *Porites astreoides* (Hickerson 2006b; Schmahl 2006). Surveys conducted by FGBNMS staff have reported the prevalence of this disease at 0.0-8.3% of surveyed coral colonies along belt transects at the FGB (Hickerson 2006b; Schmahl 2006). However, no observations of the plague-like disease were observed in random transect, repetitive quadrat, or perimeter video data from 2004-2008.

3.8.4. Exotic/Invasive Species

3.8.4.1. Tubastraea coccinea

A single colony of the exotic, invasive species *Tubastraea coccinea* (orange cup coral) was first reported on the reefs of the FGB in August 2002 (Fenner and Banks 2004; Schmahl et al. 2008; Hickerson et al. 2008). This *T. coccinea* colony was ~15 cm (5.9 in) in diameter and located at approximately 26 m (85 ft) on the EFGB. Since this occurrence, no colonies of *T. coccinea* have been observed on the EFGB or WFGB, including the 2004-2008 annual monitoring cruises.

3.8.4.2. Thecacera pacifica

In 2006, two individuals of *Thecacera pacifica*, a nudibranch native to the Pacific and Indian Oceans, were documented on Stetson Bank (Hickerson et al. 2008). The species has not been observed on the EFGB or WFGB. Interestingly, the two individuals were mating at the time of observation, so it is possible that the species could have established a viable population on Stetson Bank.

3.8.5. Coral Biodiversity and Taxonomy

In previous long-term monitoring reports, the number of zooxanthellate, scleractinian species has oscillated between 12 and 18, with doubts about the status of some ecomorphs and species. Twelve dives were conducted during the June 2007 annual monitoring cruise to qualitatively assess the scleractinian biodiversity present on the reef caps at the EFGB and WFGB. A total of 21 zooxanthellate and one azooxanthellate coral species were identified (Table 3.8.5). Because these dives were never deeper than 35 m (115 ft), many of the deep-water coral species were not observed.

3.9. WATER QUALITY

3.9.1. HoboTemp Thermograph Data

HoboTemp data were acquired at the EFGB and WFGB from March 2004 through November 2008. During this time, the HoboTemp data were generally reliable and provided a stable backup to the more erratic YSI data. The two datasets were found to have varied significantly numerous times during the course of study. For instance, concurrent YSI and HoboTemp data gathered at the EFGB from 11/15/05 to 05/12/06 were significantly different (homoscedastic variances; paired t-test, $t_{0.05\ (2),\ 178} = 9.10$; $P = 0.001$). At the WFGB, mean temperatures were significantly different between the YSI and the HoboTemp for the 05/15/06 to 06/12/06 period (non-homoscedastic variances, arcsine transformed data, paired t-test, $t_{0.05\ (2),\ 28} = 13.42$; $P = 0.001$). Since the two types of instrumentation were in close proximity most of the time, we believe that differences in recordings likely indicate performance-related issues and were not reflective of true differences in water temperatures. This belief is based on the fact that HoboTemp thermistors have consistently provided reliable data over the past 20 years of monitoring and that during the course of this monitoring effort the YSI temperature sensors tended to overestimate temperature. Temperature overestimates by the YSI were clearly shown at the EFGB throughout the times of significant difference between the HoboTemp and the YSI.

Table 3.8.5.

Comparative lists of scleractinian species observed at the EFGB and WFGB. Official List = official list of documented species from Schmahl et al. (2008). * = azooxanthellate taxa; ** = there are ≥ 4 consistent color/morphological variants of *Montastraea franksi*; *** = species requires verification since its morphology and coloration are different from the typical Caribbean *Scolymia cubensis* and *S. lacera*; **** = a new record for the FGBNMS found by W.F. Precht and photographically confirmed by E. Weil; [1] = deep-water species, commonly below 40 m (131 ft); [2] = dubious species usually synonomized with *Madracis auretenra* (=*M. mirabilis*; Locke et al. 2007), [3] = possible misidentification because *Siderastrea radians* is restricted to shallow water habitats

Species/Ecomorph	**EFGB**	**WFGB**	**Official List**
Acropora palmata	✓	✓	✓
Agaricia agaricites	✓	✓	✓
Agaricia fragilis	✓	✓	✓
Agaricia humilis	✓	✓	
Agaricia undata[1]			✓
Colpophyllia amaranthus	✓	✓	✓
Colpophyllia natans	✓	✓	✓
Dichocoenia stokesii			✓
Diploria strigosa	✓	✓	✓
Helioseris (Leptoseris) cucullata	✓		✓
Madracis asperula[2]			✓
Madracis auretenra (formerly *M. mirabilis*)	✓	✓	✓
*Madracis brueggemanni**[,1]			✓
Madracis decactis	✓	✓	✓
Madracis formosa			✓
*Madracis myriaster**[,1]			✓
*Madracis pharensis**	✓	✓	✓
*Madrepora carolina**[,1]			✓
Montastraea annularis	✓	✓	✓
Montastraea cavernosa	✓	✓	✓
Montastraea faveolata	✓	✓	✓
*Montastraea franksi***	✓	✓	✓
Mussa angulosa	✓	✓	✓
*Mycetophyllia ferox*****	✓		

Table 3.8.5. Comparative lists of scleractinian species observed at the EFGB and WFGB (continued).

Species/Ecomorph	EFGB	WFGB	Official List
*Oxysmilia rotundifolia**[,1]			✓
*Paracyathus pulchellus**			✓
*Polycyathus senegalensis**[,1]			✓
Porites astreoides	✓	✓	✓
Porites furcata	✓	✓	✓
*Scolymia cubensis****	✓	✓	✓
Siderastrea radians[3]			✓
Siderastrea siderea	✓	✓	✓
Stephanocoenia intersepta	✓	✓	✓
*Tubastraea aurea** (cf. *T. coccinea*)			✓
Total azooxanthellate corals	**1**	**1**	**7**
Total zooxanthellate corals	**21**	**19**	**24**
Total scleractinian corals	**22**	**20**	**31**

Depictions of the HoboTemp data records are presented in Figures 3.9.1 and 3.9.2. The HoboTemp annual data were complete for 2006 at the EFGB and for 2006 and 2007 at the WFGB. There were partial records of reef cap temperature for other years mainly due to the deployment/retrieval and maintenance schedules of the YSI datasondes.

Several thermal anomalies on the reef cap were recorded from 2004 through 2008. There were unusually low summer temperatures on the WFGB reef cap in 2004 compared to the long-term average (no HoboTemp summer temperature records were available for the EFGB in 2004; Figures 3.9.1-A and 3.9.2-A**)**. At the WFGB, from late July 2004 to late August 2004, there was a 2°C difference between the recorded temperature and the long-term average (Figure 3.9.2-A). In 2005, both Banks experienced a thermal oscillation (4°C amplitude) from mid-June to mid-July (Figures 3.9.1-B and 3.9.2-B). The temperature over the reef cap was slightly higher during the summer (1°C) and fall (1 to 1.5°C) of 2005 compared to the long-term average, and higher on both Banks during the winter of 2006 (by as much as 3°C; Figures 3.9.1-C and 3.9.2-C) and the fall of 2007 (as much as 1.5°C; Figures 3.9.1-D and 3.9.2-D). The spring and early summer temperatures of 2006 were also higher than average on the WFGB (by as much as 1.5°C) but stayed close to average on the EFGB (Figures 3.9.1-C and 3.9.2-C).

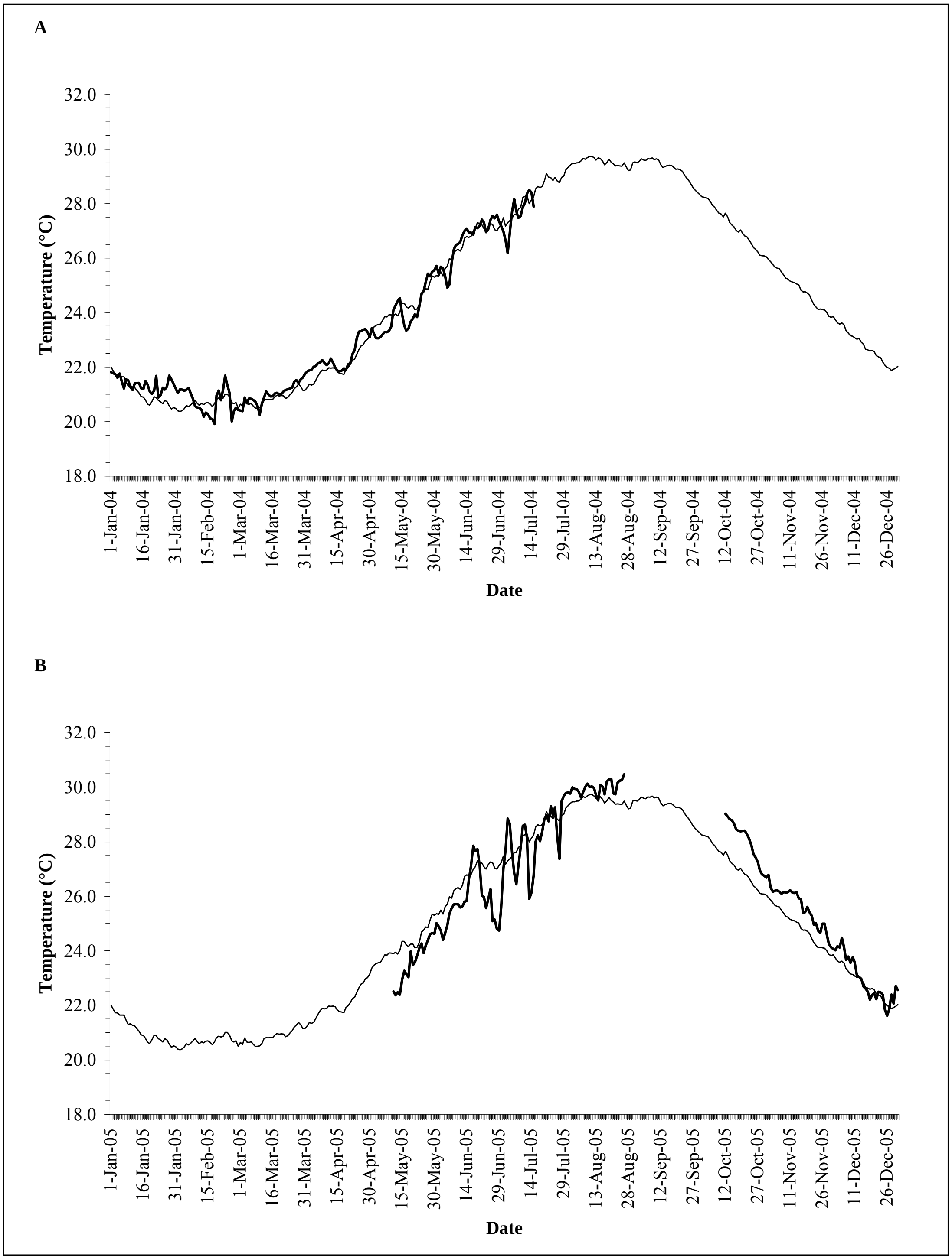


Figure 3.9.1. Seawater temperature measured near the reef cap of the EFGB from 2004 to 2008 (bold line) and the long-term average temperature (thin line: 1990 to 1997, and 2002 to 2008) using HoboTemp thermographs. (A) 2004 (B) 2005 (C) 2006 (D) 2007 and (E) 2008 temperature data.

C

D

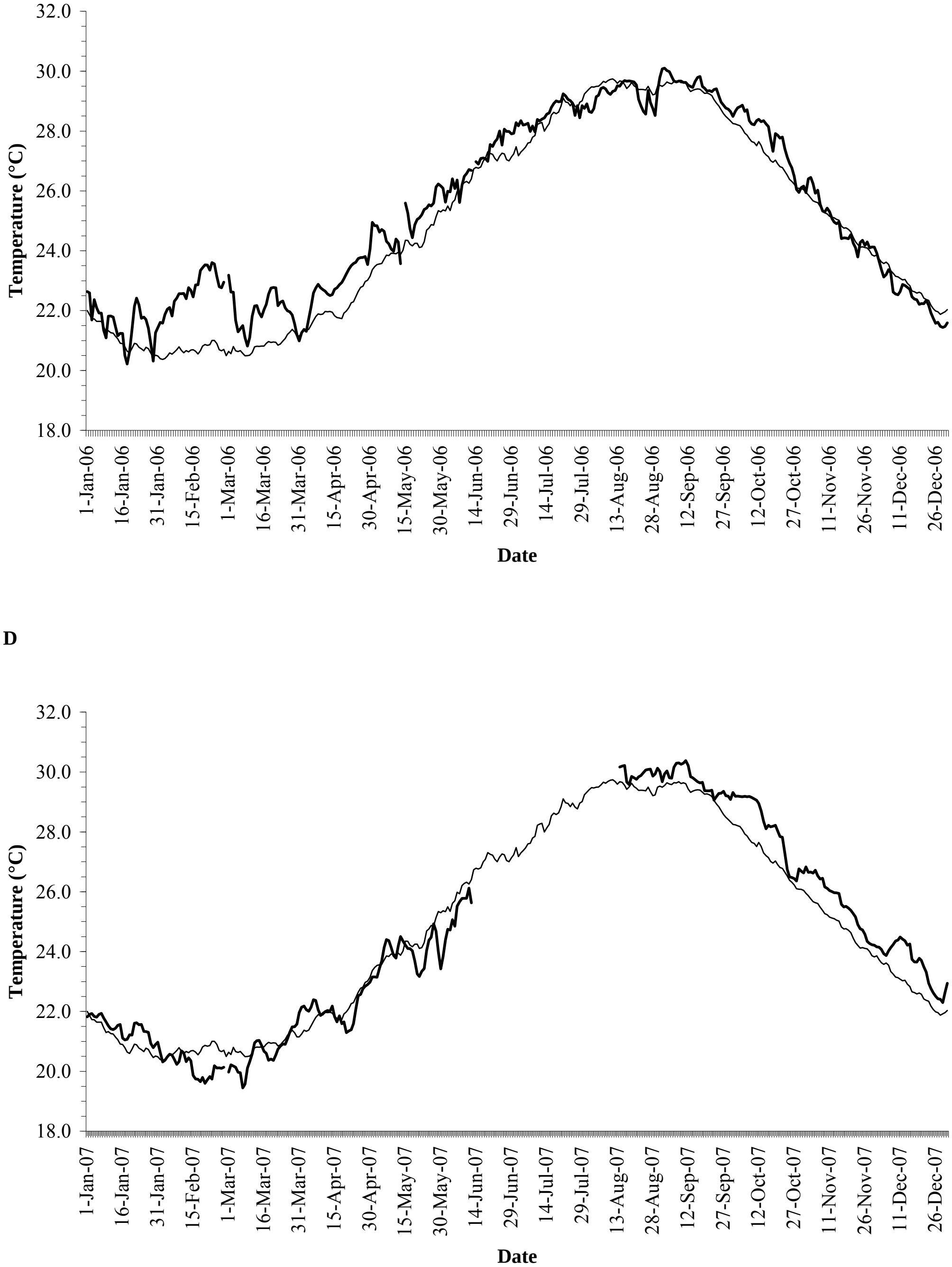


Figure 3.9.1. Seawater temperature measured near the reef cap of the EFGB from 2004 to 2008 (bold line) and the long-term average temperature (thin line: 1990 to 1997, and 2002 to 2008) using HoboTemp thermographs. (A) 2004 (B) 2005 (C) 2006 (D) 2007 and (E) 2008 temperature data (continued).

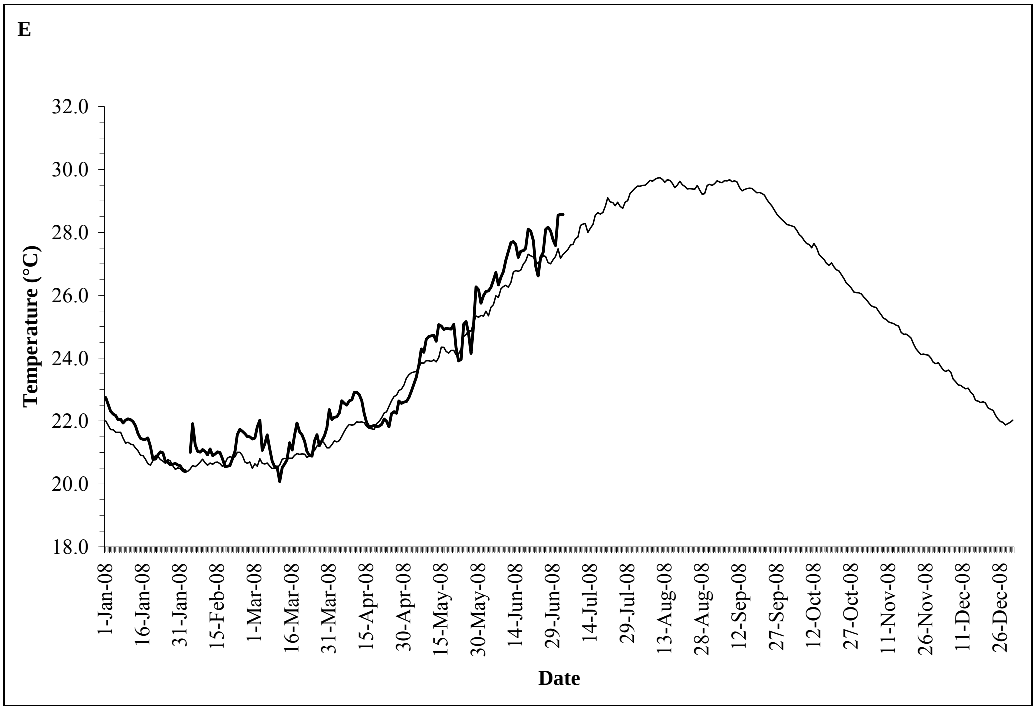


Figure 3.9.1. Seawater temperature measured near the reef cap of the EFGB from 2004 to 2008 (bold line) and the long-term average temperature (thin line: 1990 to 1997, and 2002 to 2008) using HoboTemp thermographs. (A) 2004 (B) 2005 (C) 2006 (D) 2007 and (E) 2008 temperature data (continued).

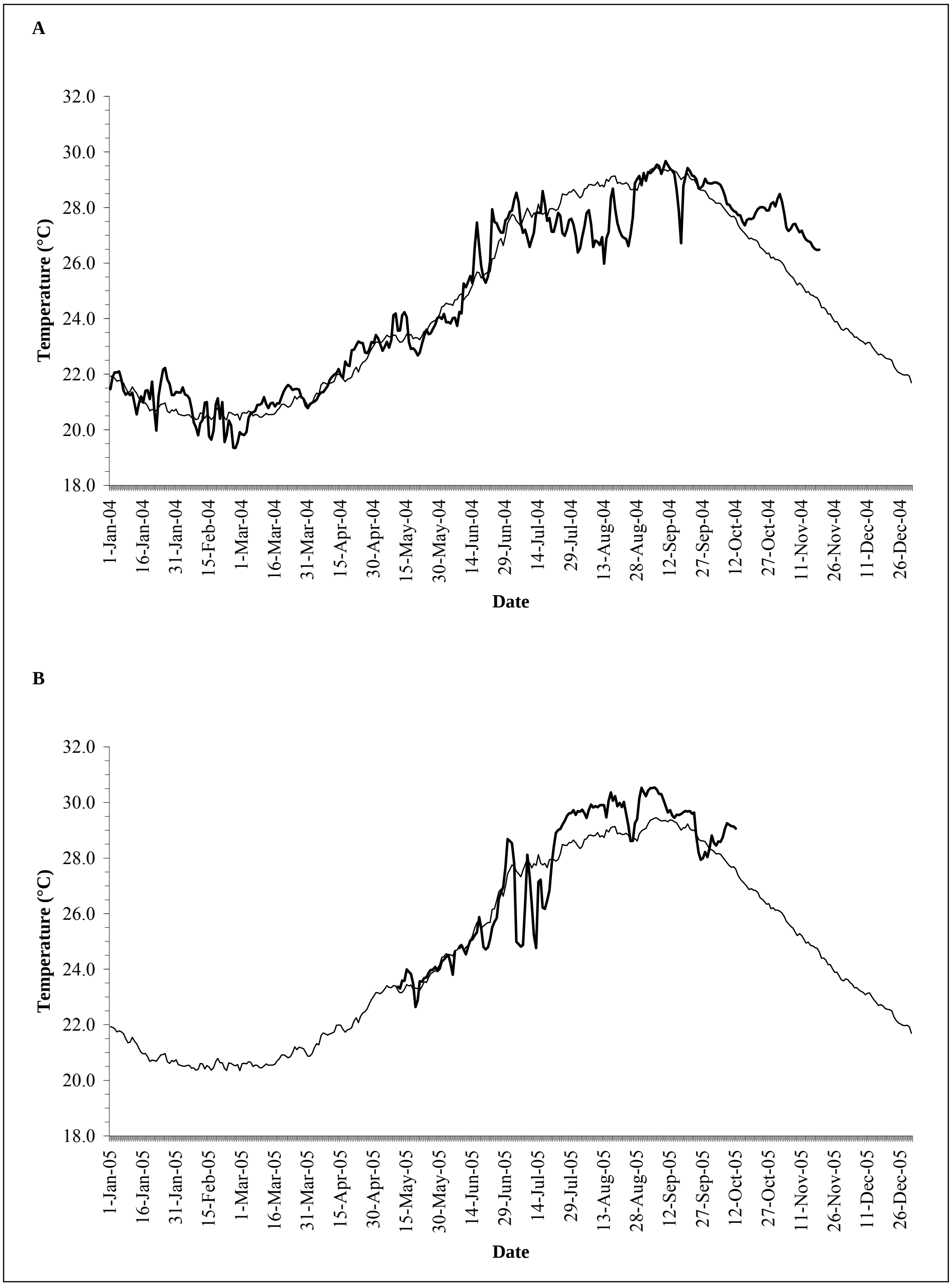


Figure 3.9.2. Seawater temperature measured near the reef cap of the WFGB from 2004 to 2008 (bold line) and the long-term average temperature (thin line: 1990 to 1997, and 2002 to 2008) using HoboTemp thermographs. (A) 2004 (B) 2005 (C) 2006 (D) 2007 and (E) 2008 temperature data.

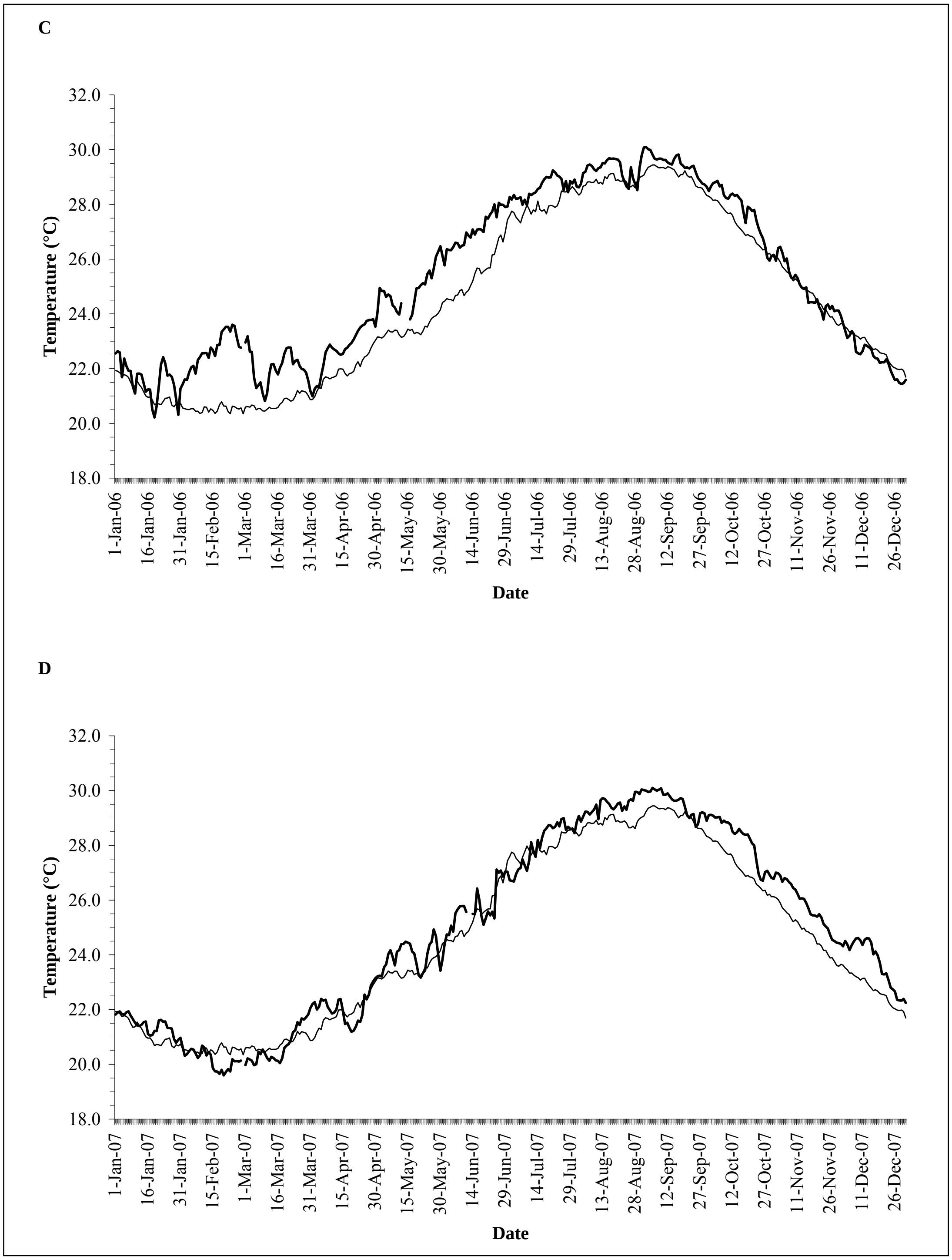


Figure 3.9.2. Seawater temperature measured near the reef cap of the WFGB from 2004 to 2008 (bold line) and the long-term average temperature (thin line: 1990 to 1997, and 2002 to 2008) using HoboTemp thermographs. (A) 2004 (B) 2005 (C) 2006 (D) 2007 and (E) 2008 temperature data (continued).

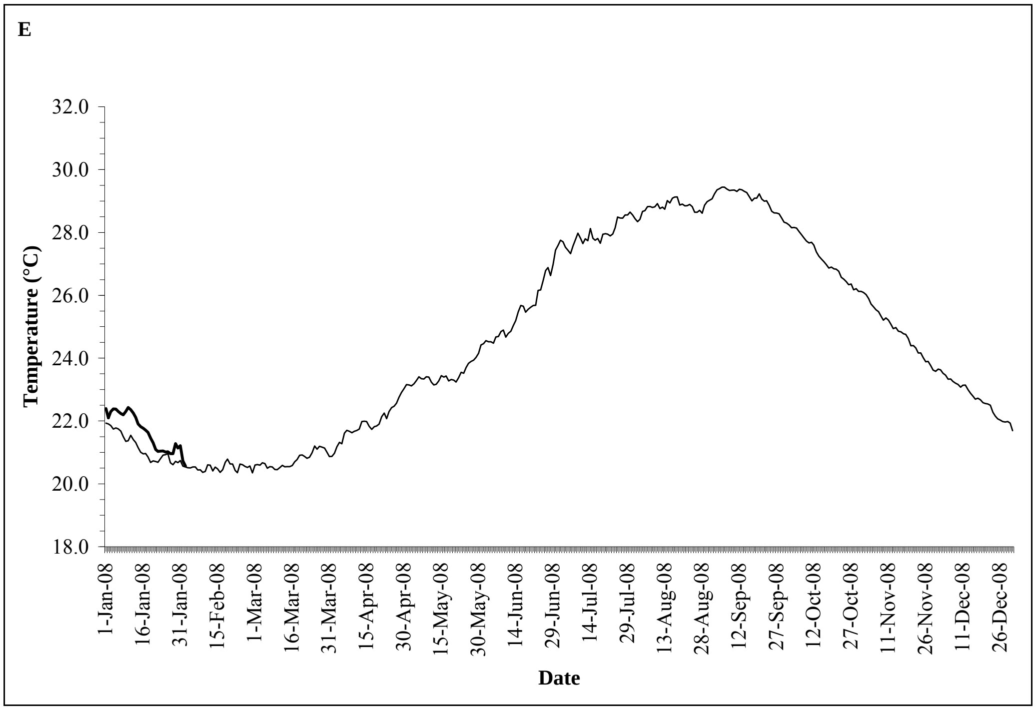


Figure 3.9.2. Seawater temperature measured near the reef cap of the WFGB from 2004 to 2008 (bold line) and the long-term average temperature (thin line: 1990 to 1997, and 2002 to 2008) using HoboTemp thermographs. (A) 2004 (B) 2005 (C) 2006 (D) 2007 and (E) 2008 temperature data (continued).

3.9.2. YSI Quality Assurance

A second YSI instrument was set on or above the reef cap at the EFGB on August 13, 2007 (20-m or 66-ft water depth) for roughly 12 hrs (deployment lasted from 0949 to 2109 hrs; data were collected every 10 seconds and later averaged by 30 minute increments). Parameters measured on 08/13/07 were temperature, salinity, depth, pH, and turbidity. Dissolved oxygen was not measured since the DO sensor failed during calibration. Data collected with this YSI were compared to those collected the same day by the YSI that had been deployed at the EFGB since 06/12/07. Battery voltage during the brief deployment on 08/13/07 ranged from 10.5 to 10.9 volts (±0.1 SD) indicating no loss of power. Temperature ranged from 29.8°C to 30.4°C (±0.18 SD). Salinity ranged from 35.1 to 35.2 PSU (±0.03 SD) and pH ranged from 8.1 to 8.2 (±0.01 SD). Turbidity measurements were negative and probably erroneous.

Temperature, salinity, and pH values were within reasonable limits. Data collected by the two separate YSI units were significantly different.

- Temperature: non-homoscedastic variances; log-transformed data; two sample t-test, $t_{0.05(2), 23} = 2.69$; $P = 0.01$
- Salinity: non-homoscedastic variances; log-transformed data; two sample t-test, $t_{0.05(2), 14} = 13.80$; $P < 0.05$

- pH: non-homoscedastic variances; log-transformed data; two sample t-test, $t_{0.05(2),\,13} = 45.56$; $P < 0.05$

Differences between the datasets most likely reflected the effects of water depth and not necessarily differences in accuracy. There was a 4-m (13-ft) difference in water depth between the two YSI instruments (Table 3.9.1). The short-term deployment was set on the reef cap (20 m or 66 ft) while the long-term YSI was located in the sand flat at 24 m (79 ft). The two YSI units should have been set side by side or at least at the same depth for an optimal quality assurance test. While the data were statistically different, mean values were generally similar, with the exception of turbidity (Table 3.9.1). Between YSI instruments, there was a 0.1°C, a 0.1 PSU, and a 0.3 difference in temperature, salinity, and pH, respectively. The significant differences between data sets seen here should not discount that accurate temperature, salinity, and pH data were probably recorded.

Table 3.9.1.

Comparison of YSI data collected on August 13, 2007 at the EFGB using two independent YSI instruments.

Parameter	**YSI deployed since 06/12/07 (*n* = 616)**	**YSI deployed on 08/13/07 (*n* = 13)**
Temperature	30.2 (0.1 *SD*)	30.3 (0.1 *SD*)
Salinity	35.0 (0.1 *SD*)	35.1 (0.02 *SD*)
pH	7.9 (0.04 *SD*)	8.2 (0.01 *SD*)
Turbidity	33.5 (2.0 *SD*)	-2.1 (0.1 *SD*)
Voltage	11.7 (0.03 *SD*)	10.8 (0.1 *SD*)

3.9.3 YSI Water Quality

Previous deployments of YSI instruments at the FGB (e.g., Precht et al. 2006) have shown that a number of YSI sensors have failed post-deployment calibrations, particularly following prolonged emersion (i.e., >15 days). Following extended deployments (several months) data collected toward the end of the duration have had a tendency to be erroneous. In some cases, however, data were already faulty within the first few days of deployment. During the course of the study, sensors were deployed with greater frequency in an attempt to increase the amount of credible data. Unfortunately, the strategy did not solve the problem since a substantial portion of the YSI data collected was unreliable even during short deployments.

As in previous water quality assessments at the FGB, the data were compared to published values (Pickard and Emery 1982; Valiela 1984; Gittings et al. 1992; Sorokin 1995; Lugo-Fernández 1998; Nowlin et al. 1998; Kleypas et al. 1999a; Dokken et al. 2003; Precht et al. 2006) in order to assess data quality. Further, QA/QC testing was conducted by temporarily deploying a second YSI unit on a given Bank. This second unit was usually deployed for approximately one day per Bank to coincide with the annual monitoring efforts. Short deployments were useful to assess the quality of the data collected during the first 24 hours.

Data reviews showed that temperature data were the most reliable (Tables 3.9.2 and 3.9.3). Unfortunately, there were few reliable data for other parameters (i.e., salinity, DO, turbidity, pH, and PAR). The data retained for analysis are presented in Appendix 7: Long Term Water Quality Data at the East and West Flower Garden Banks. A thorough review of each individual data file gathered from 2004 through 2008 at the EFGB and WFGB can be found in Appendix 8. Summary review tables are presented as Tables 3.9.2 and 3.9.3.

3.9.3.1. Temperature

The YSI temperature probe deployed at the EFGB recorded prolonged periods of unusually low summer and fall temperatures (2 to 3°C difference; mid July through late October) on the EFGB in 2004 (Figure 3.9.3-A). Unfortunately, there were no corresponding HoboTemp records at the EFGB to validate the finding. HoboTemp records at the WFGB showed unusually low summer temperatures in 2004 (as much as 3°C less than average; Figure 3.9.2-A).

The 2005 YSI temperature record at the EFGB was similar to what was captured by the HoboTemp unit: a strong thermal oscillation from mid-June to mid-July (3°C amplitude) and an unusually warm summer (1°C greater than average) and fall (as much as 1°C greater than average; Figures 3.9.1-B and 3.9.3-B). The YSI temperature probe on the WFGB captured similar results including the thermal oscillation of mid-June to mid-July (4°C amplitude), high summer temperature (up to 1.5°C greater than average), and a warm fall (up to 2°C greater than average; Figures 3.9.2-B and 3.9.4-B). In addition, the YSI at the WFGB captured unusually warm winter temperatures of 2°C greater than average (Figure 3.9.4-B).

In 2006, the YSI recorded nominal temperatures on the EFGB reef cap from 01/01/06 through early June (up to 3°C greater than average; Figure 3.9.3-C). At the WFGB, temperature was unusually warm in the early summer (as much as 2°C above average) and it continued to be anomalous until late August (Figure 3.9.4-C).

In 2007, the YSI at the EFGB recorded thermal anomalies during late spring when temperatures were 1°C below average (Figure 3.9.3-D). Thereafter, temperature was above average starting in mid-August and particularly from late September to late October (up to 2°C above average; Figure 3.9.3-D). Temperature remained unusually high through the rest of the year on the EFGB. The YSI on the WFGB recorded unusually warm temperatures during the fall as well (up to 2°C above average; Figure 3.9.4-D). The EFGB and WFGB records mostly concur with what was found with the HoboTemp. However, the HoboTemp placed at the WFGB did not record the thermal anomaly (up to 2°C) from mid-May to mid-June as was found with the YSI (Figures 3.9.2-D and 3.9.4-D).

The 2008 YSI and HoboTemp temperature records at the EFGB extended from January to late June at the EFGB and were limited to January at the WFGB. There was a general concurrence between YSI and HoboTemp temperature records during that time. At the EFGB, both devices recorded thermal anomalies in early January (0.5°C), early March (0.6°C), April (1°C), and mid-May (0.8°C) (Figures 3.9.1-E and 3.9.3-E). Also, at the WFGB, both devices recorded a thermal anomaly in January (2°C; Figures 3.9.2-E and 3.9.4-E). Overall, thermal anomalies were more pronounced on the EFGB than the WFGB throughout the survey.

Table 3.9.2.

Summary review of the individual YSI water quality data files at the EFGB. Gray cells indicate that the data were faulty and "NR" indicates that the parameter was not recorded.

EFGB YSI								
Time Period	**Temperature**	**Salinity**	**Dissolved Oxygen (DO)**	**Depth**	**pH**	**PAR**	**Turbidity**	**Notes**
03/11/04 to 04/15/04	✓	NR		✓	✓		✓	**Turbidity**: credible from 3_12_04 to 3_23_04
07/15/04 to 12/03/04	✓			✓	✓			
05/11/05 to 06/08/05	✓	✓	✓	✓	✓	✓		
06/08/05 to 08/27/05	✓	✓	✓	✓	✓	✓	✓	**Salinity**: evidence that freshwater reached the reef cap (06/21/05 0130 hrs to 06/21/05 1100 hrs). Eight salinity data points were deleted because they were immediately surrounded by higher values and too low to be real. **DO**: credible from 06/08/05 to 06/14/05 **PAR**: credible from 06/08/05 to 06/14/05 **Turbidity**: credible from 06/08/05 to 06/26/05
08/27/05 to 10/12/05	✓	✓	✓	✓	✓	✓		**Hurricanes Katrina and Rita** **Salinity**: two faulty values deleted **DO**: credible from 08/27/05 to 09/23/05 **PAR**: credible from 08/27/05 to 09/23/05
10/12/05 to 11/02/05	✓		✓	✓	✓	✓		**DO**: a few faulty values deleted
11/14/05 to 05/13/06	✓		✓	✓	✓			
05/13/06 to 06/13/06	✓	✓	✓	✓	✓		NR	
06/12/06 to11/ 27/06	✓	✓		✓	✓	✓		
03/07/07 to 05/19/07	✓			✓	✓			
05/19/07 to 06/12/07	✓				✓			
06/12/07 to 08/13/07	✓	✓	✓		✓			**DO**: credible from 06/12/07 to 06/21/07
08/14/07 to 10/13/07	✓	✓		✓	✓	✓		
10/13/07 to 02/02/08	✓	✓		✓	✓			
02/02/08 to 06/29/08	✓						NR	
07/03/08 to 11/03/08								

Table 3.9.3.

Summary review of the individual YSI water quality data files at the WFGB. Gray cells indicate that the data were faulty and “NR” indicates that the parameter was not recorded.

WFGB YSI								
Time Period	**Temperature**	**Salinity**	**Dissolved Oxygen (DO)**	**Depth**	**pH**	**PAR**	**Turbidity**	**Notes**
03/11/04 to 07/15/04	✓			✓	✓			
07/15/04 to 11/19/04				✓	✓			
11/19/04 to 02/23/05	✓	✓	✓	✓	✓			**DO**: credible from 11/19/04 to 02/21/05
05/09/05 to 06/07/05	✓	✓	✓	✓	✓	✓		
06/07/05 to 08/25/05	✓	✓		✓	✓	✓		
10/11/05 to 12/15/05	✓		✓	✓	✓			
05/13/06 to 06/14/06	✓			✓	✓			
06/14/06 to 02/19/07	✓	✓		✓	✓			**Salinity**: included relatively low values but still considered credible
03/06/07 to 05/19/07	✓	✓		✓	✓		✓	**Salinity**: included relatively low values but still considered credible **Turbidity**: credible even though the dataset included some isolated, high values
05/19/07 to 06/11/07	✓	✓		✓	✓	✓		**PAR**: credible even though the dataset included isolated, elevated values
06/14/07 to 08/14/07	✓	✓			✓			**Salinity**: included relatively low values but still considered credible **Depth**: readings were steady but too deep
10/14/07 to 02/02/08	✓	✓		✓	✓		✓	**Salinity**: credible even though the dataset included extended periods of low salinity **Turbidity**: credible even though the dataset included isolated, elevated values
02/02/08 to 07/02/08				✓				**Temperature**: included some accurate values but overall the dataset was faulty **Salinity**: included some accurate values but overall the dataset was faulty
07/02/08 to 09/17/08								

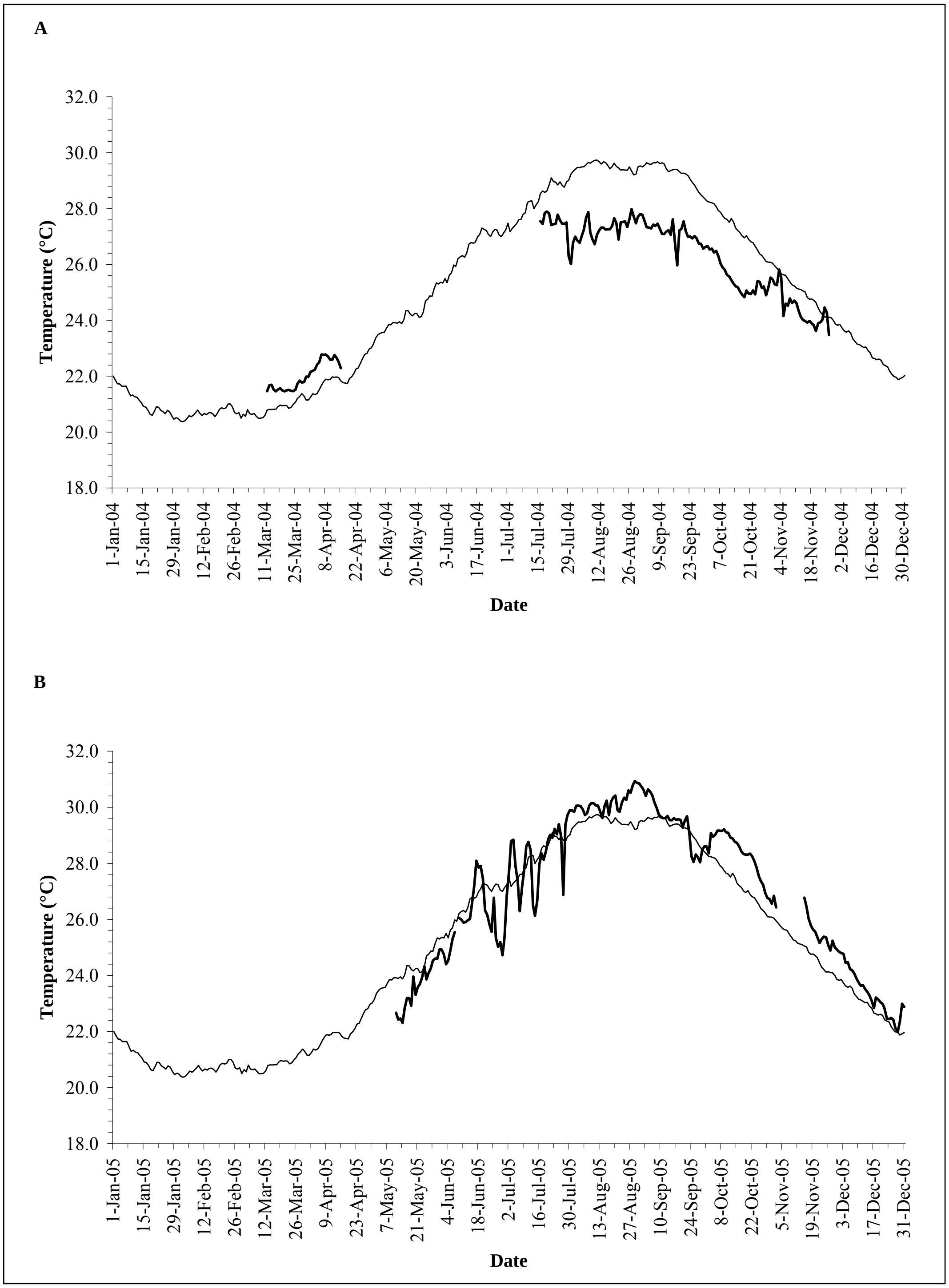


Figure 3.9.3. Seawater temperature measured near the reef cap of the EFGB from 2004 to 2008 (bold line) and the long-term average temperature (thin line: 1990 to 1997, and 2002 to 2008) using a YSI temperature probe. (A) 2004 (B) 2005 (C) 2006 (D) 2007 and (E) 2008 temperature data.

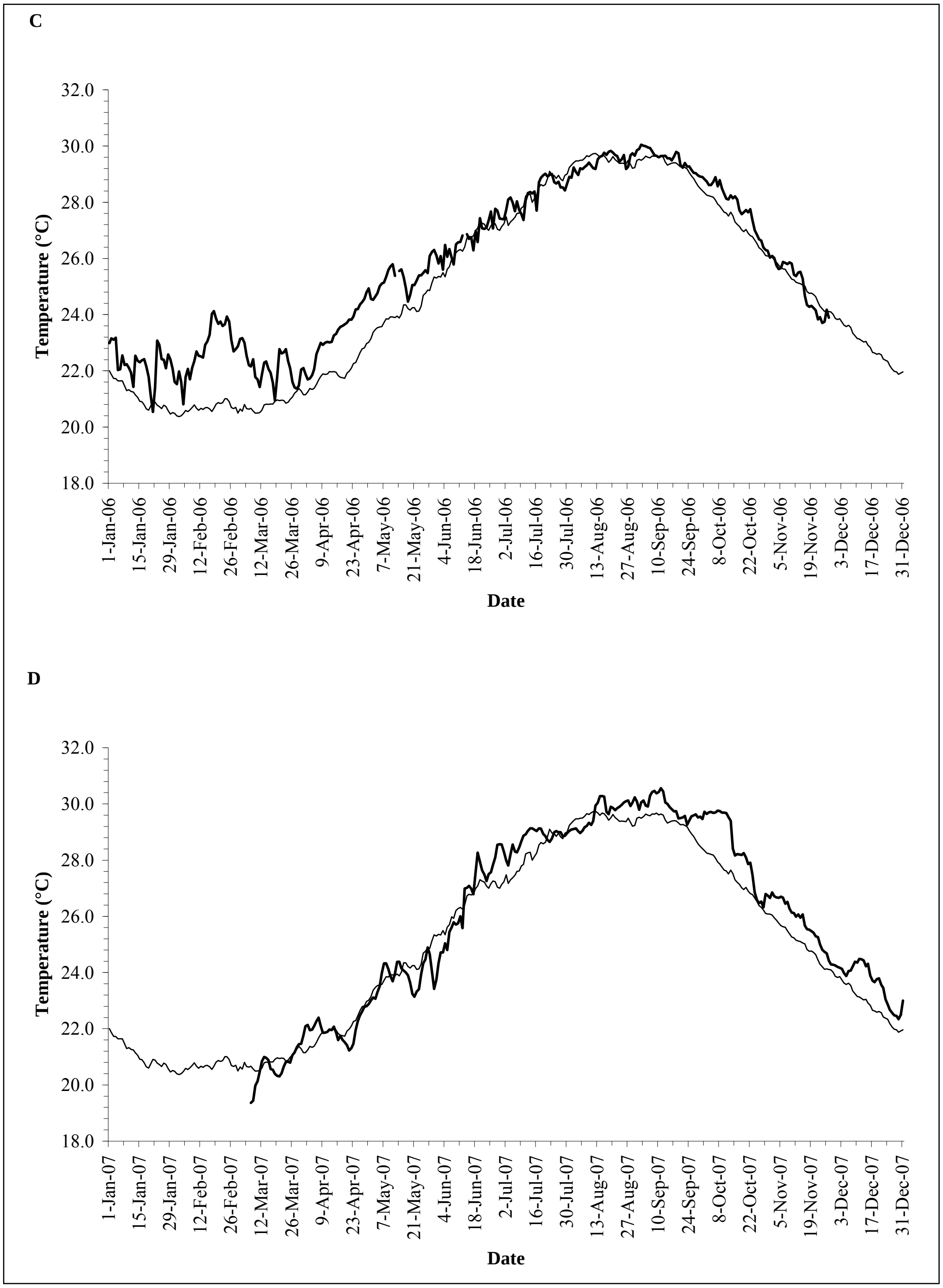


Figure 3.9.3. Seawater temperature measured near the reef cap of the EFGB from 2004 to 2008 (bold line) and the long-term average temperature (thin line: 1990 to 1997, and 2002 to 2008) using a YSI temperature probe. (A) 2004 (B) 2005 (C) 2006 (D) 2007 and (E) 2008 temperature data (continued).

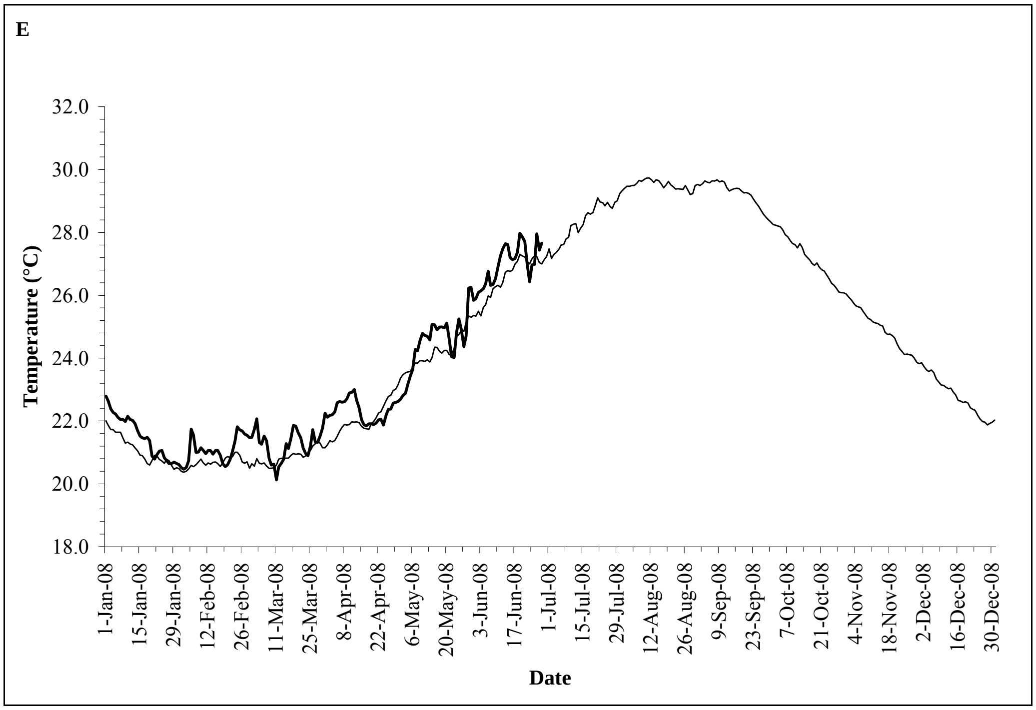


Figure 3.9.3. Seawater temperature measured near the reef cap of the EFGB from 2004 to 2008 (bold line) and the long-term average temperature (thin line: 1990 to 1997, and 2002 to 2008) using a YSI temperature probe. (A) 2004 (B) 2005 (C) 2006 (D) 2007 and (E) 2008 temperature data (continued).

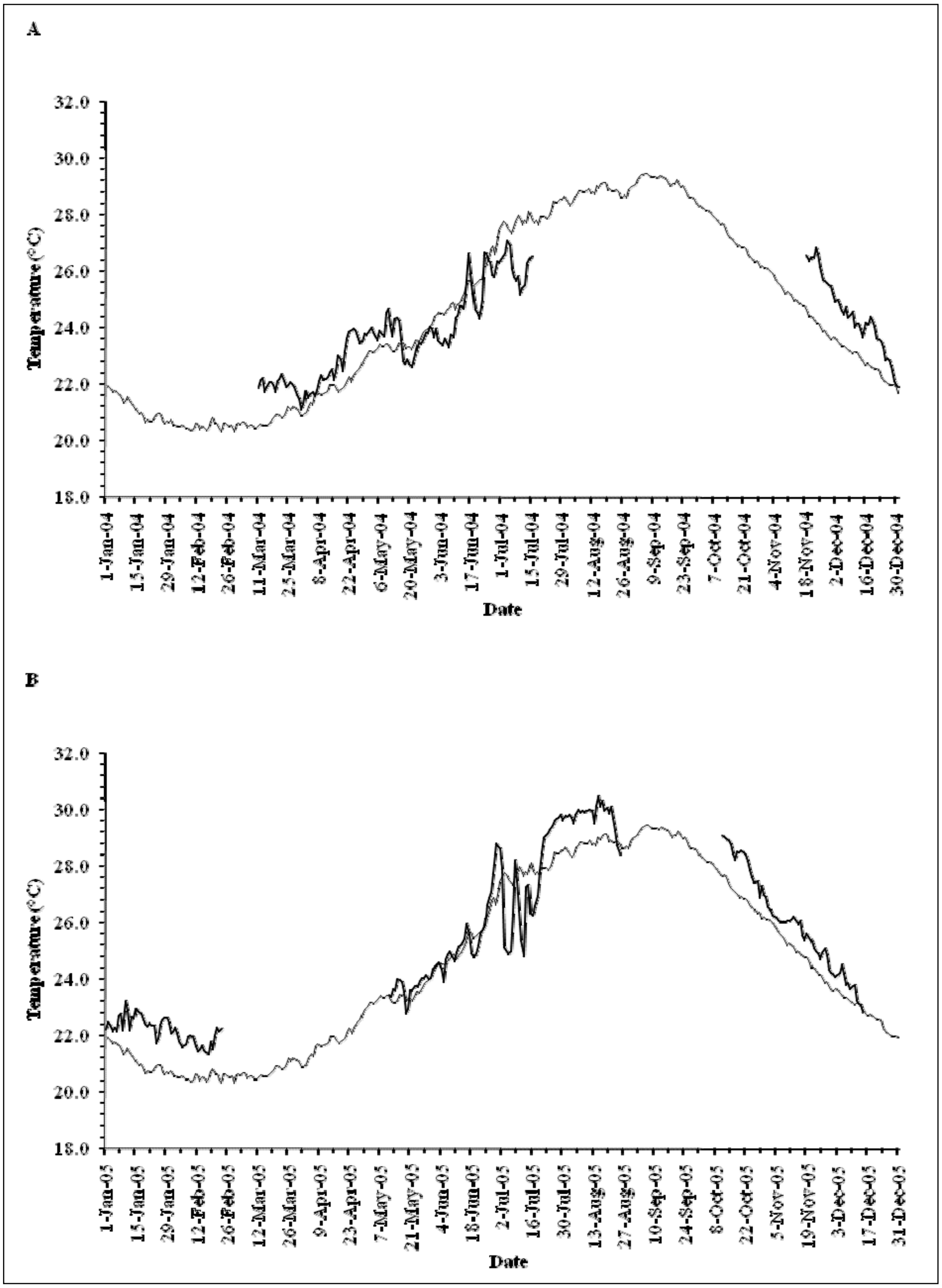


Figure 3.9.4. Seawater temperature measured near the reef cap of the WFGB from 2004 to 2008 (bold line) and the long-term average temperature (thin line: 1990 to 1997, and 2002 to 2008) using a YSI temperature probe. (A) 2004 (B) 2005 (C) 2006 (D) 2007 and (E) 2008 temperature data.

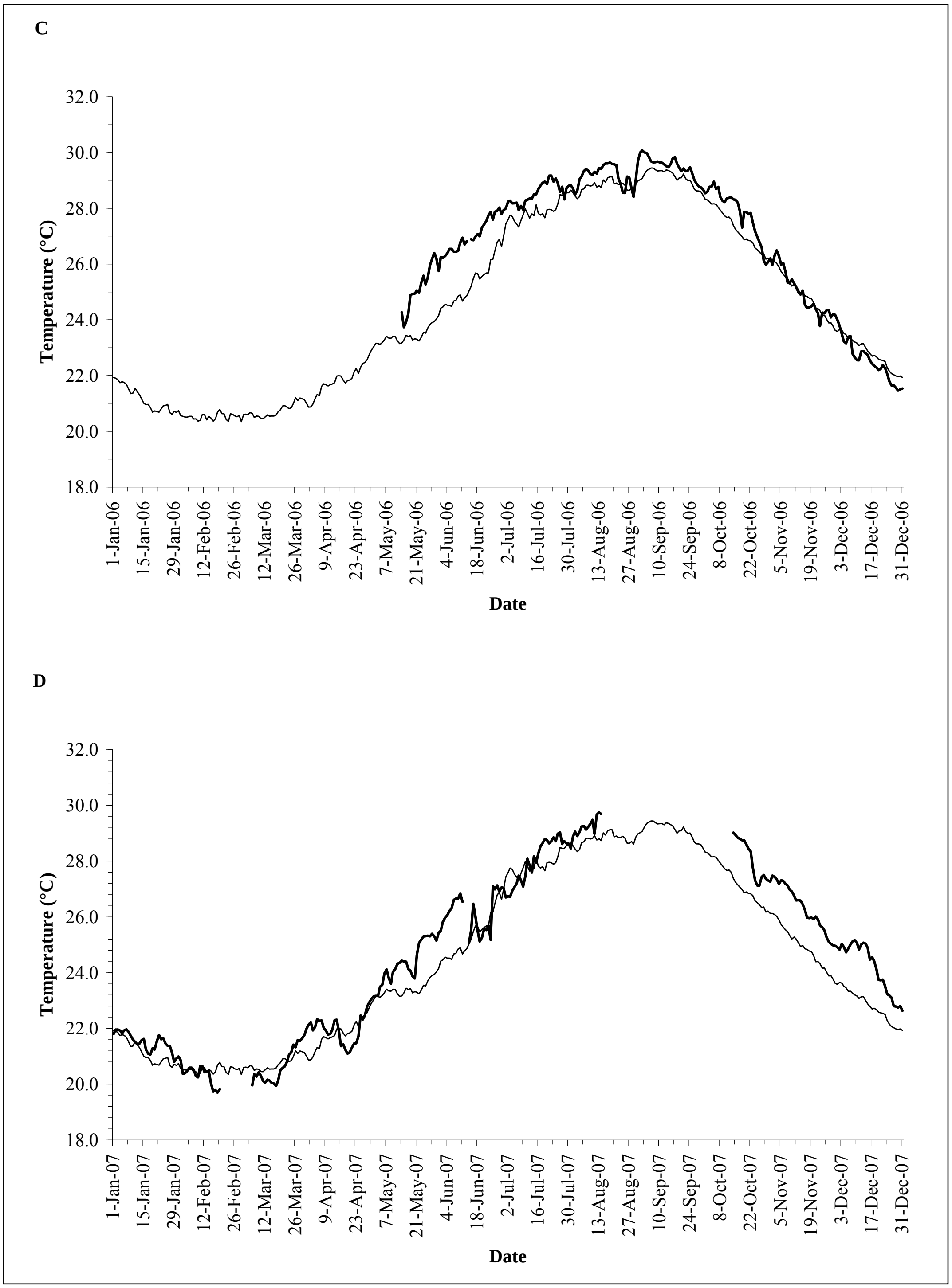


Figure 3.9.4. Seawater temperature measured near the reef cap of the WFGB from 2004 to 2008 (bold line) and the long-term average temperature (thin line: 1990 to 1997, and 2002 to 2008) using a YSI temperature probe. (A) 2004 (B) 2005 (C) 2006 (D) 2007 and (E) 2008 temperature data (continued).

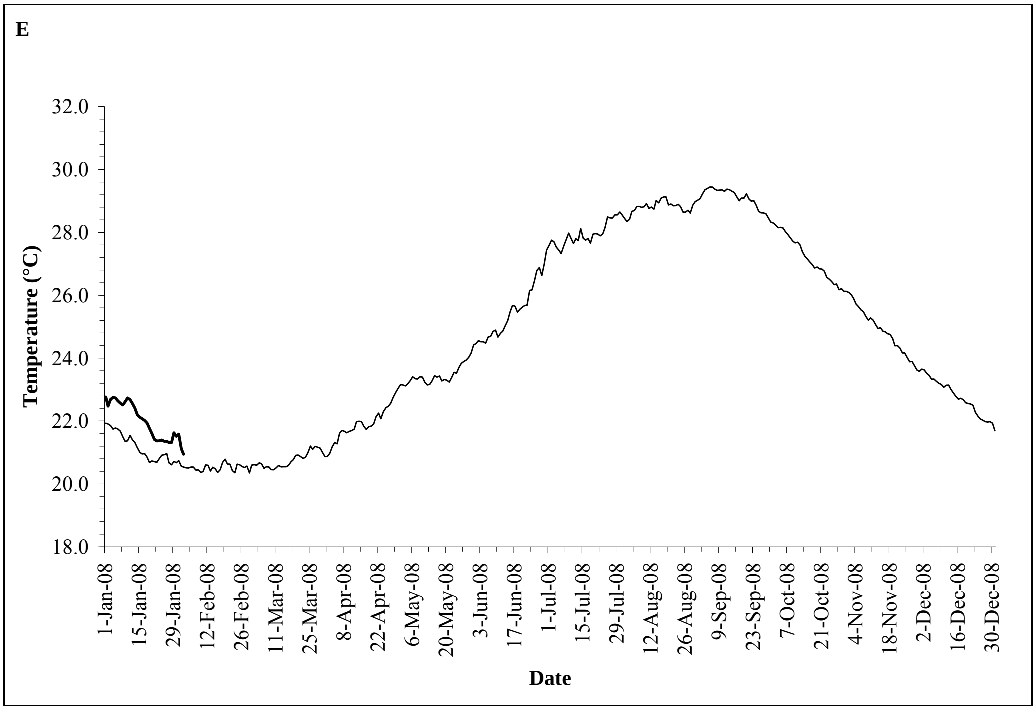


Figure 3.9.4. Seawater temperature measured near the reef cap of the WFGB from 2004 to 2008 (bold line) and the long-term average temperature (thin line: 1990 to 1997, and 2002 to 2008) using a YSI temperature probe. (A) 2004 (B) 2005 (C) 2006 (D) 2007 and (E) 2008 temperature data (continued).

3.9.3.2. Salinity

YSI-derived salinity records ranged from 28 to 37 PSU at the EFGB and WFGB from 2004 to 2008 (Figure 3.9.5). The EFGB salinity data included two minima: one in mid-October 2006 (28.1 PSU) and another in mid-August 2007 (30.2 PSU). Both minima were shortly followed by elevated salinities of 34 PSU in 2006 and 36 PSU in 2007 (Figure 3.9.5). The mid-October 2006 minimum was preceded by a drop of salinity from 36 to 32 PSU from June to October. The August 2007 minimum was preceded by a drop in salinity from 36 to 34.5 PSU between 06/18/07 and 08/10/07. The 2005 EFGB salinity data did not contain a similar decreasing trend in salinity (Figure 3.9.5). Salinity remained steady at about 36 PSU from late May 2005 to early October 2005. This contrasted with the 2005 WFGB data, which revealed a gradual drop in salinity from 36 to 33 PSU from mid-May to mid-July. Salinity then increased back to 36 PSU by 08/25/05. From mid-October to mid-December 2005, salinity at the WFGB decreased from 36 to 31 PSU. In 2006, salinity dropped from late July to 08/27/06, from 36 PSU to 30 PSU. Salinity remained low (<33 PSU) until 09/25/06. Thereafter, salinity oscillated between 36 and 30 PSU until February 2007. From March to May 2007, salinity varied between 35 and 37 PSU. From mid-June to mid-July 2007 salinity decreased from 36 to 34 PSU. From 10/21/07 to 02/02/08, salinity at the WFGB varied from 32 to 37 PSU.

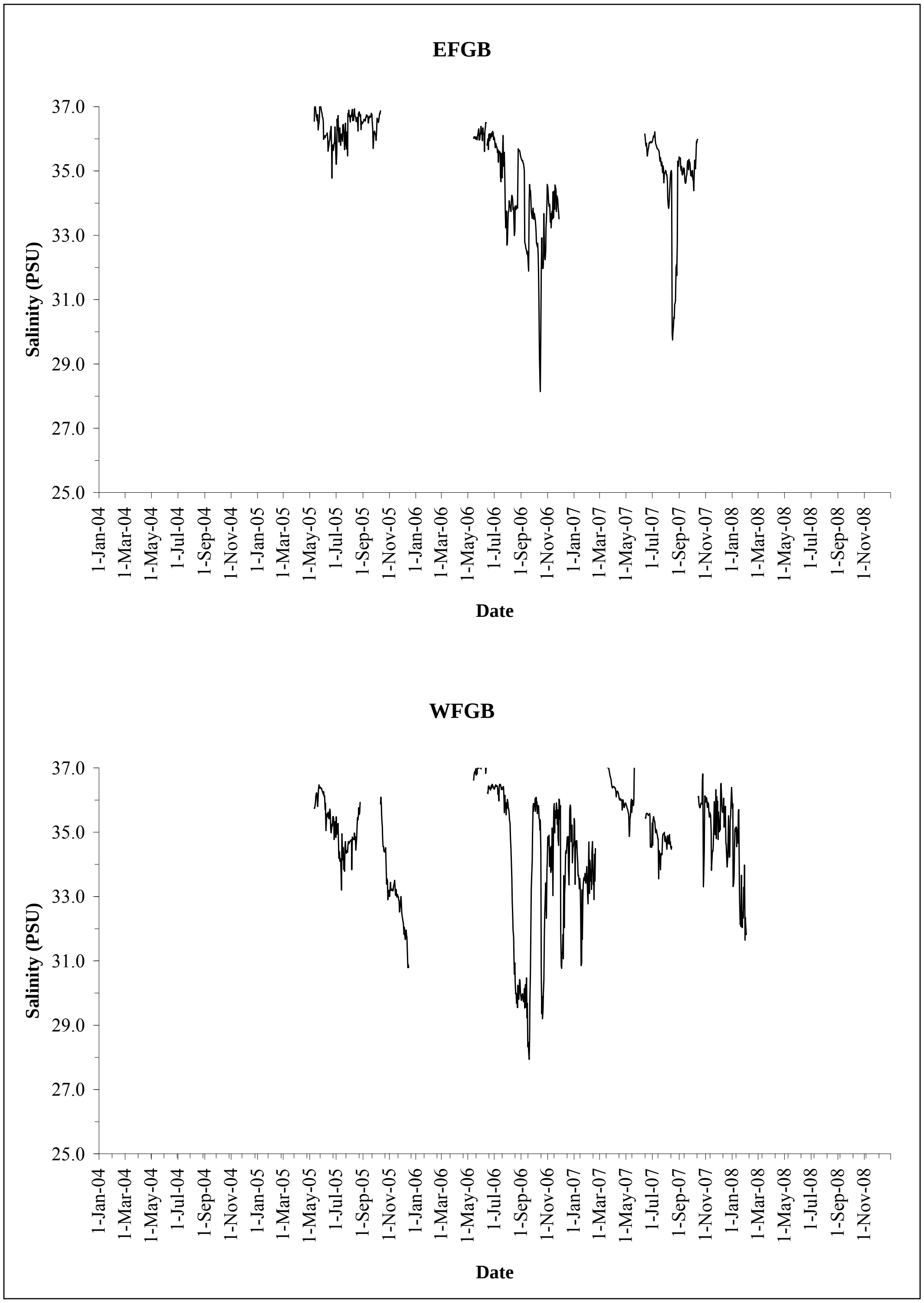


Figure 3.9.5. Salinity measured near the reef cap of the EFGB and WFGB from 2004 to 2008 using YSI salinity probes.

3.9.3.3. Dissolved Oxygen

Few credible dissolved oxygen (DO) data were obtained during the course of the study. Most of the data were outside of published ranges. At the EFGB, DO likely ranged from 3.2 to 12.4 mg/l. At the WFGB, DO may have ranged from 5.1 to 8.0 mg/l (Figure 3.9.6). Mean DO on the EFGB reef cap was 6.7 mg/l (±1.5 *SD*, *n* = 198) and 6.8 mg/l (±0.5 *SD*, *n* = 188) at the WFGB. Such DO concentrations were comparable to those previously reported (e.g., Gittings et al. 1992; Precht et al. 2006). No definitive DO trends were observed amongst the data.

3.9.3.4. pH

The mean daily pH data recorded at the EFGB varied from 7.4 to 9.0 (mean = 8.2 ± 0.3 *SD*, *n* =1054) and from 6.9 to 8.4 at the WFGB (mean = 7.8 ± 0.3 *SD*, *n* = 965; Figure 3.9.7). These values fall within the typical range of 7.5 to 8.4 reported for seawater (Sverdrup et al. 1970). Differences in pH observed between the WFGB and EFGB probably indicate differences in instrument performance. It is difficult to tell which instrument gathered the most accurate data. One significant feature in the pH record is the abrupt drop at the EFGB in early February 2006 from 8.4 to 7.7 and the low pH values recorded into late March. The pH increased back to 8.4 by early June 2006. The drop in pH coincides with the coldest period of the year on the reef cap. This period may also coincide with a lowered photosynthetic activity and an increased content of carbon dioxide (CO_2).

3.9.3.5. Turbidity

There were few, credible turbidity data to draw conclusions regarding turbidity fluctuations at the FGB. Measured turbidity was highly variable ($\text{mean}_{\text{EFGB}}$ = 20.2 NTU ± 38.2, *n* = 53; $\text{mean}_{\text{WFGB}}$ = 23.7 ± 11.5 *SD*, *n* = 200; Figure 3.9.8).

3.9.3.6. Photosynthetically Active Radiation (PAR)

Credible measurements of PAR using the YSI instruments were consistently difficult to acquire. No continuous series of PAR estimates were gathered during the reporting period. The data were highly variable ($\text{mean}_{\text{EFGB}}$ = 59 µeinst s^{-1} m^{-2} ± 30 *SD*, *n* = 312; $\text{mean}_{\text{WFGB}}$ = 40 µeinst s^{-1} m^{-2} ± 26 *SD*, *n* = 195) and were not suggestive of temporal trends (Figure 3.9.9). We do, however, believe that accurate PAR values were recorded during the first five days of the deployment from 06/12/07 to 06/17/07, as sensor fouling and instrument failures were less likely during that time. These data are presented in Figure 3.9.10 to exemplify the daily variation of PAR on the EFGB reef cap during early June 2007.

3.9.4. Vertical Profiles

During the annual monitoring cruise in June 2005, a discolored sea surface layer was observed and scientists decided to document water quality along vertical profiles using the YSI datasonde. At the EFGB, vertical profiles were collected on 06/08/05, 03/07/07, 03/08/07, 06/12/07, 08/13/07, 08/14/07, and 11/04/08. At the WFGB, vertical profiles were collected on 06/06/05, 06/13/06, 03/06/07, 06/14/07, and 11/05/08. Vertical profiles with significant information are presented below. All other vertical profiles recorded a well-mixed water column overlying the reef cap (Appendix 9).

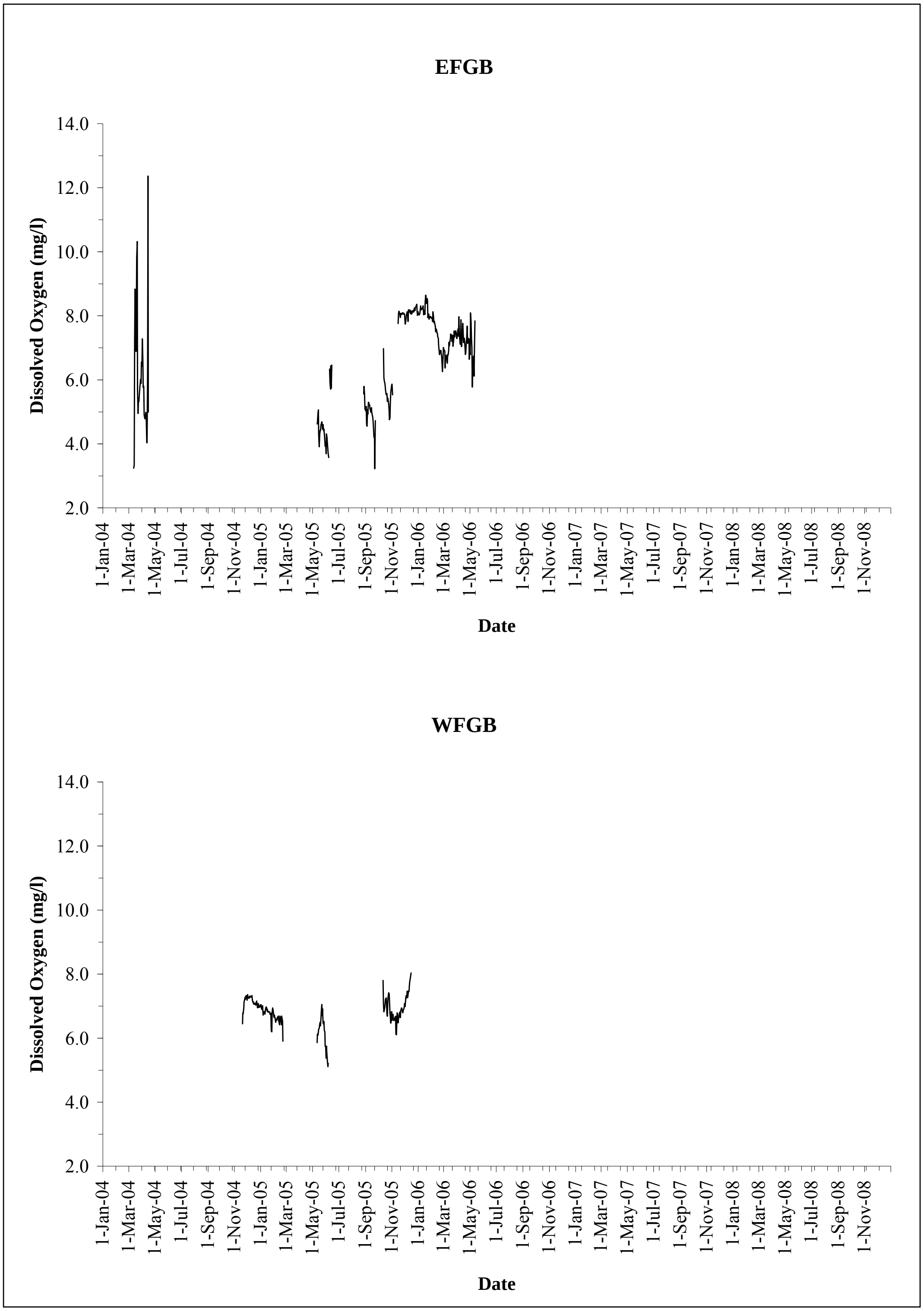


Figure 3.9.6. Dissolved oxygen (DO) measured near the reef cap of the EFGB and WFGB from 2004 to 2008 using YSI DO probes.

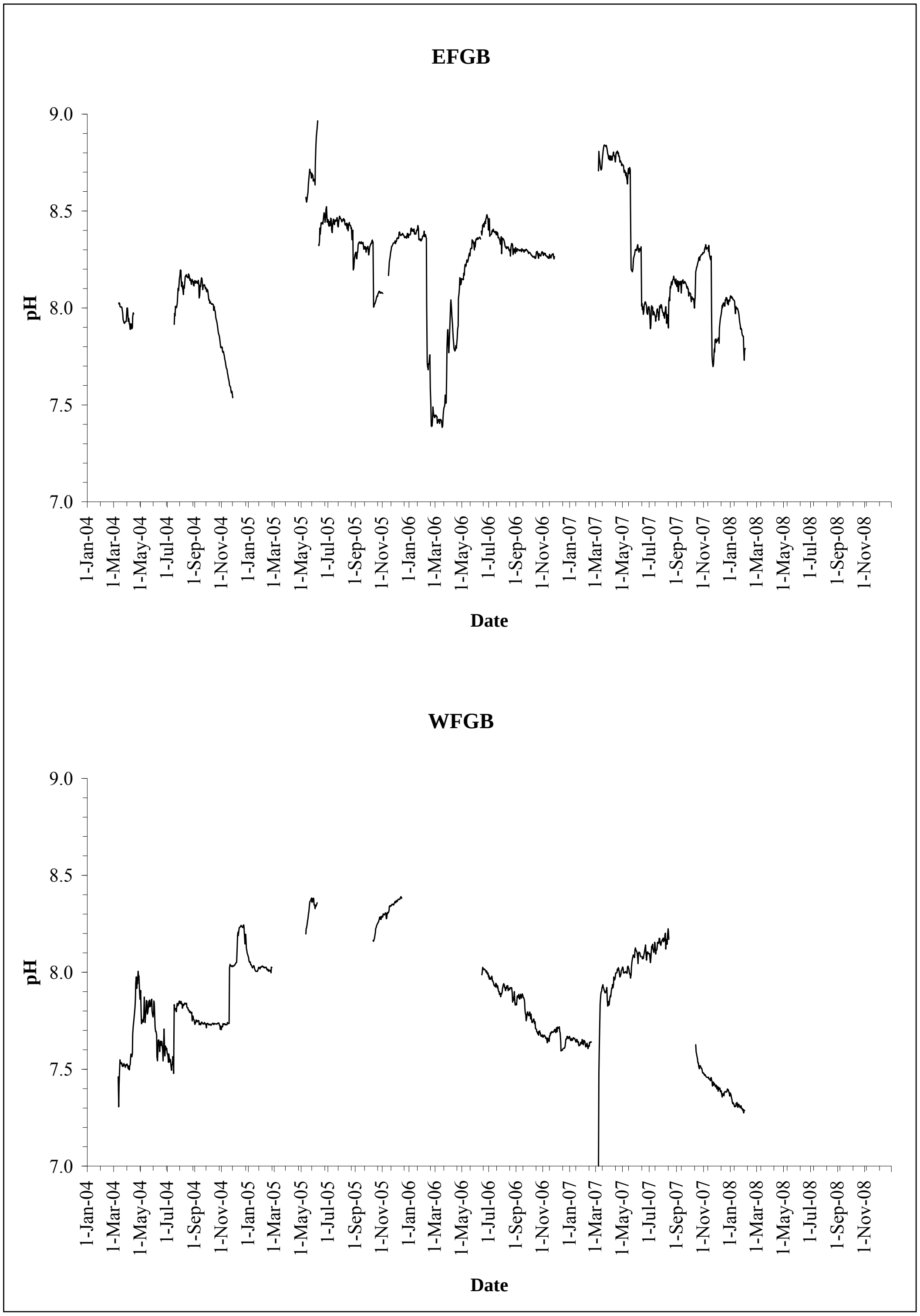


Figure 3.9.7. Hydrogen ion concentration (pH) measured near the reef cap of the EFGB and WFGB from 2004 to 2008 using YSI pH probes.

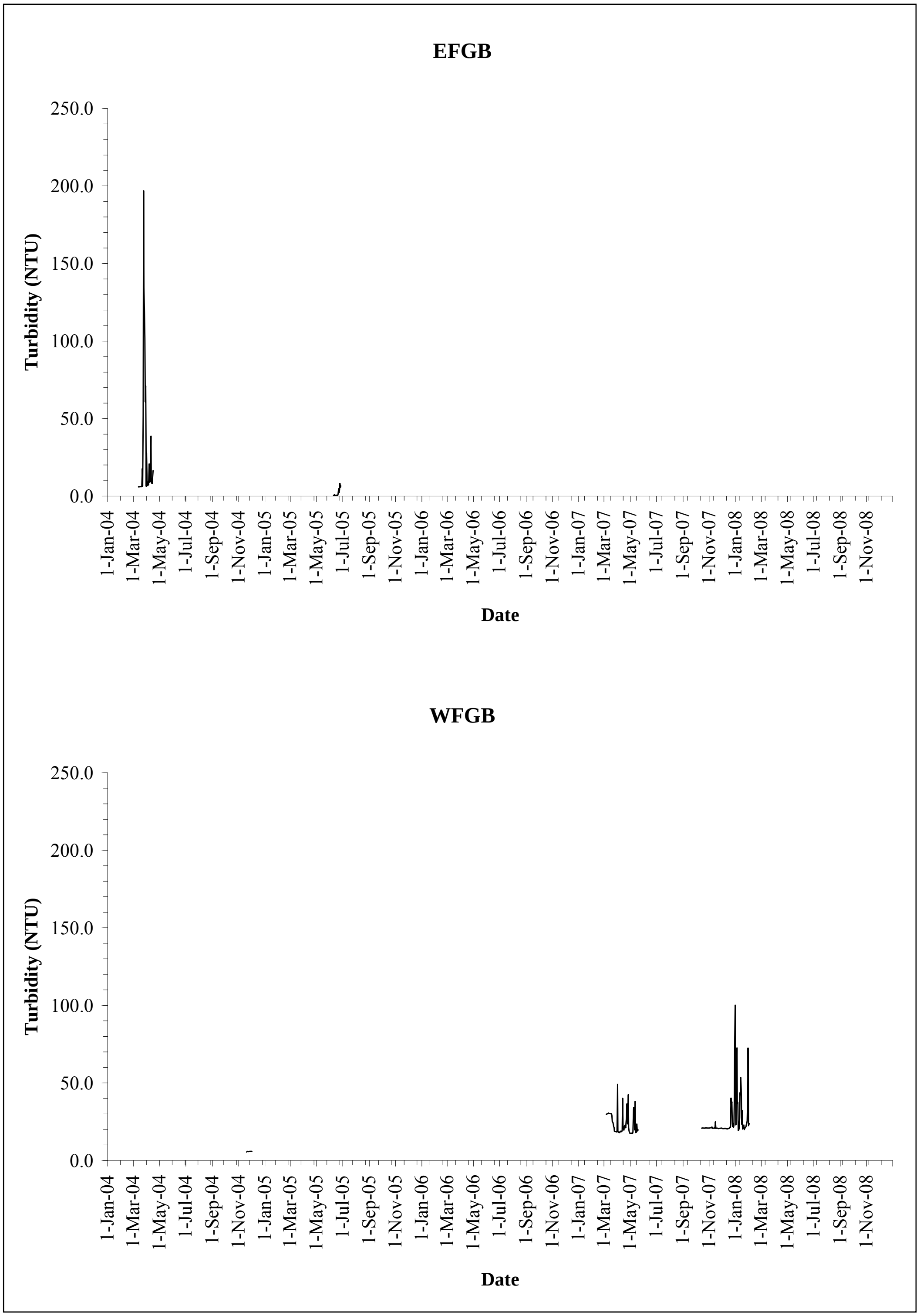


Figure 3.9.8. Turbidity measured near the reef cap of the EFGB and WFGB from 2004 to 2008 using YSI turbidity probes.

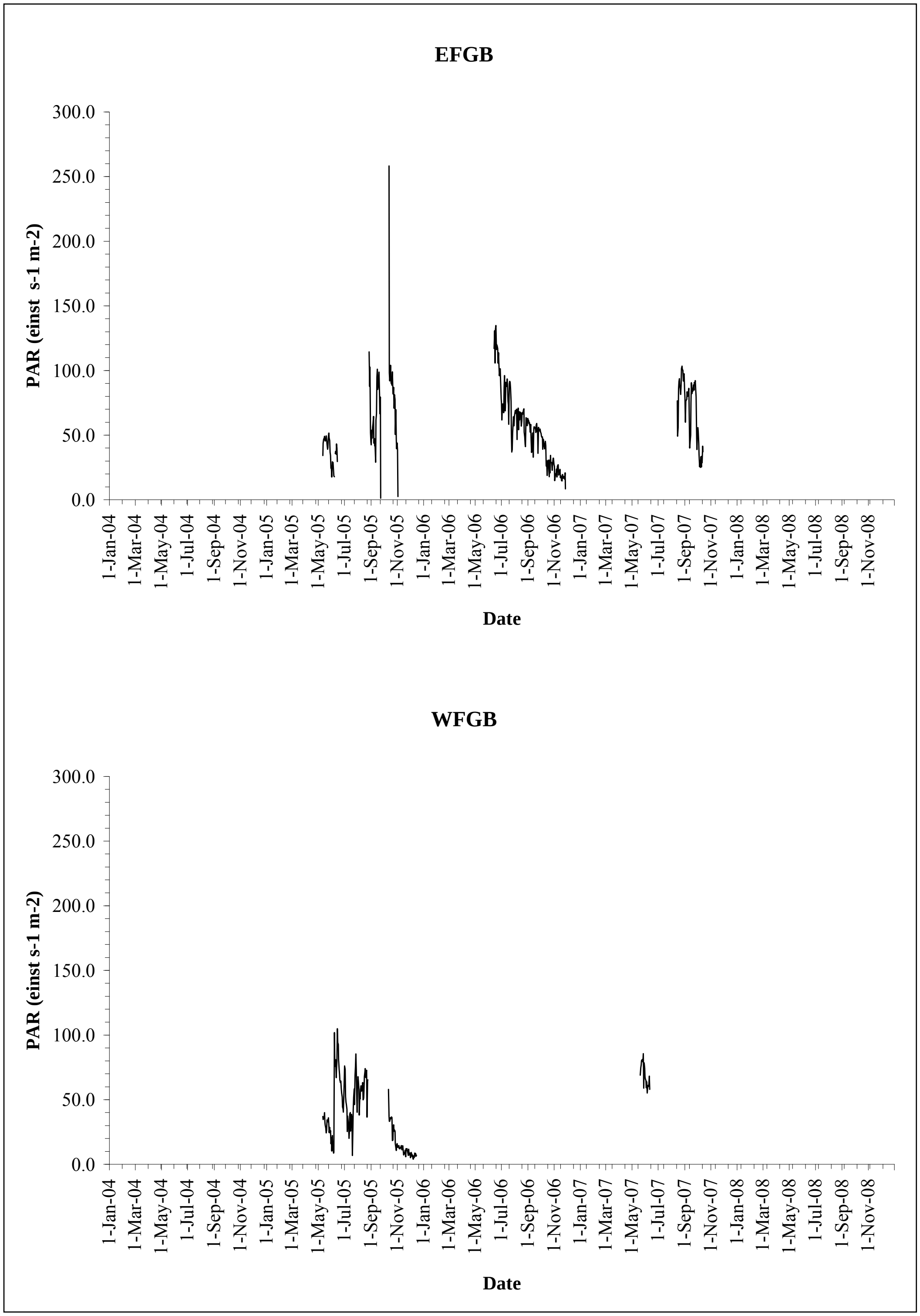


Figure 3.9.9. Photosynthetically active radiation (PAR) measured near the reef cap of the EFGB and WFGB from 2004 to 2008 using YSI PAR probes.

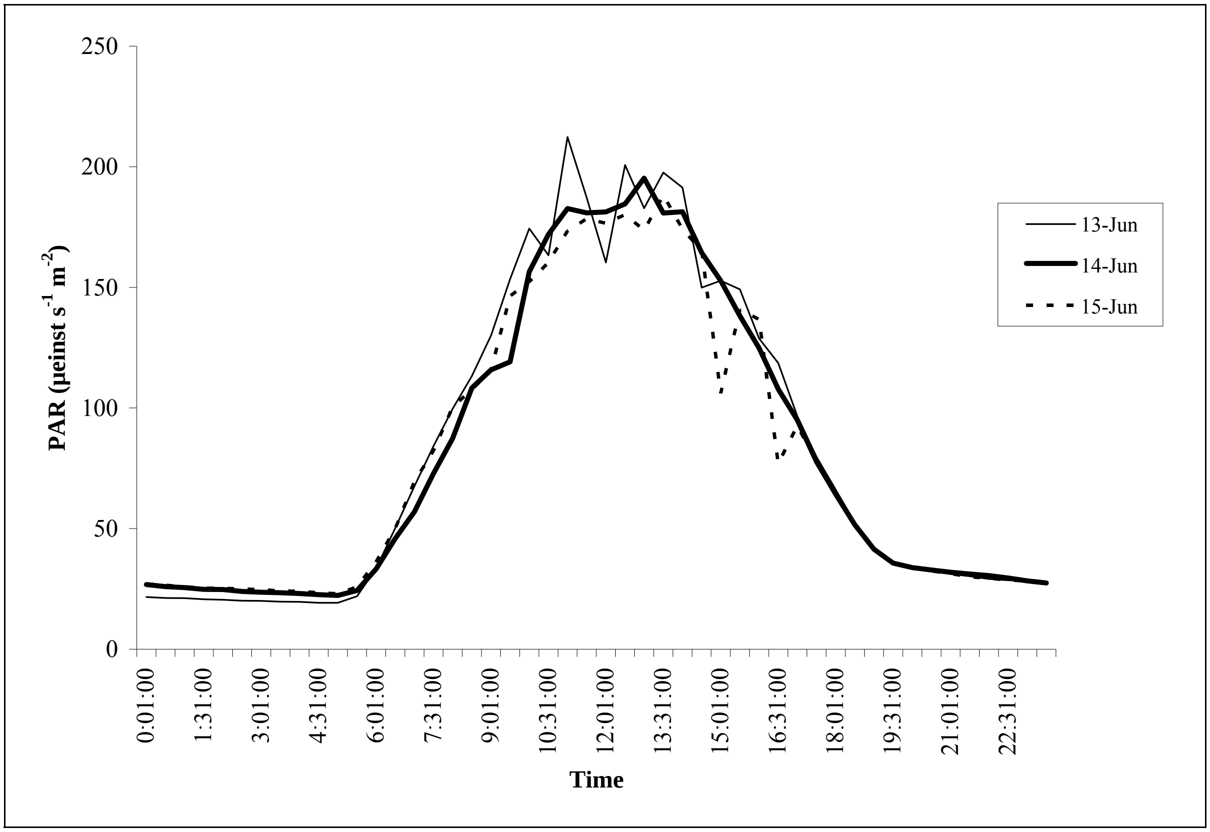


Figure 3.9.10. Daily Photosynthetically Active Radiation (PAR) measured near the reef cap at the EFGB on June 13-15, 2007.

EFGB 06/08/05: The turbidity probe showed that the discolored layer near the sea surface was indeed more turbid than the underlying water and that the turbid layer reached down to an approximate depth of 7.5 m (25 ft; Figure 3.9.11; Appendix 9). From the sea surface to a depth of 7.5 m (25 ft), turbidity decreased from 0.9 to 0.6 NTU. From 7.5 m (25 ft) to the reef cap (~20 m or 66 ft) the turbidity remained at 0.6 NTU. Furthermore, the turbid layer was fresher and warmer than the underlying water (Figure 3.9.12; Appendix 9). While the turbidity data showed a clear break between a surface layer and the underlying water, salinity and temperature values did not. There was a salinity and temperature cline in a depth range of 7.5 m (25 ft) to 10.5 m (34 ft). The salinity of the upper 7.5 m (25 ft) ranged from 32 PSU to 33 PSU. At the interface, salinity changed from 33 PSU to 36 PSU. Below the interface, salinity was approximately 36 PSU. Temperature ranged from 28.0°C to 28.4°C in the upper layer. At the cline, water temperature dropped from 28.0°C to 27.2°C and then continued to decline with increasing depth to 26.2°C on the reef cap.

EFGB 06/12/07. The water quality vertical profile taken at the EFGB on 06/12/07 using a YSI datasonde revealed a stratified water column. Temperature, salinity, pH, and DO data revealed a near surface layer (35 to 36 PSU) extending from the surface to a depth of 7 m (23 ft) underlain by oceanic water (36 PSU). The pH data showed that the surface water had a slightly lower pH (7.9) and a higher DO content (up to 6.5 mg/l) compared to the oceanic water (Figure 3.9.13).

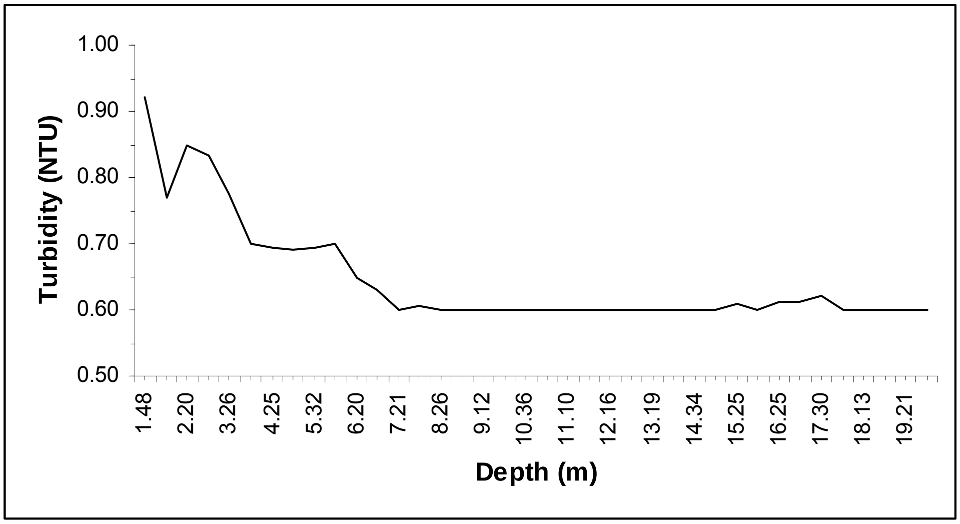


Figure 3.9.11. Vertical profile of turbidity collected at the EFGB on 06/08/05.

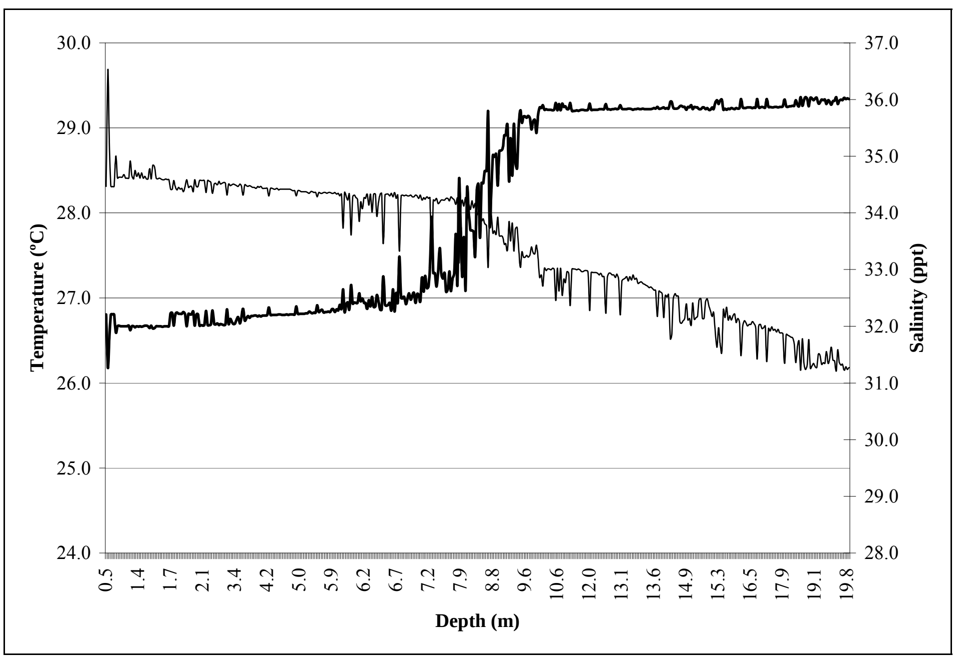


Figure 3.9.12. Vertical profiles of temperature and salinity (bold line) collected at the EFGB study site on 06/08/05.

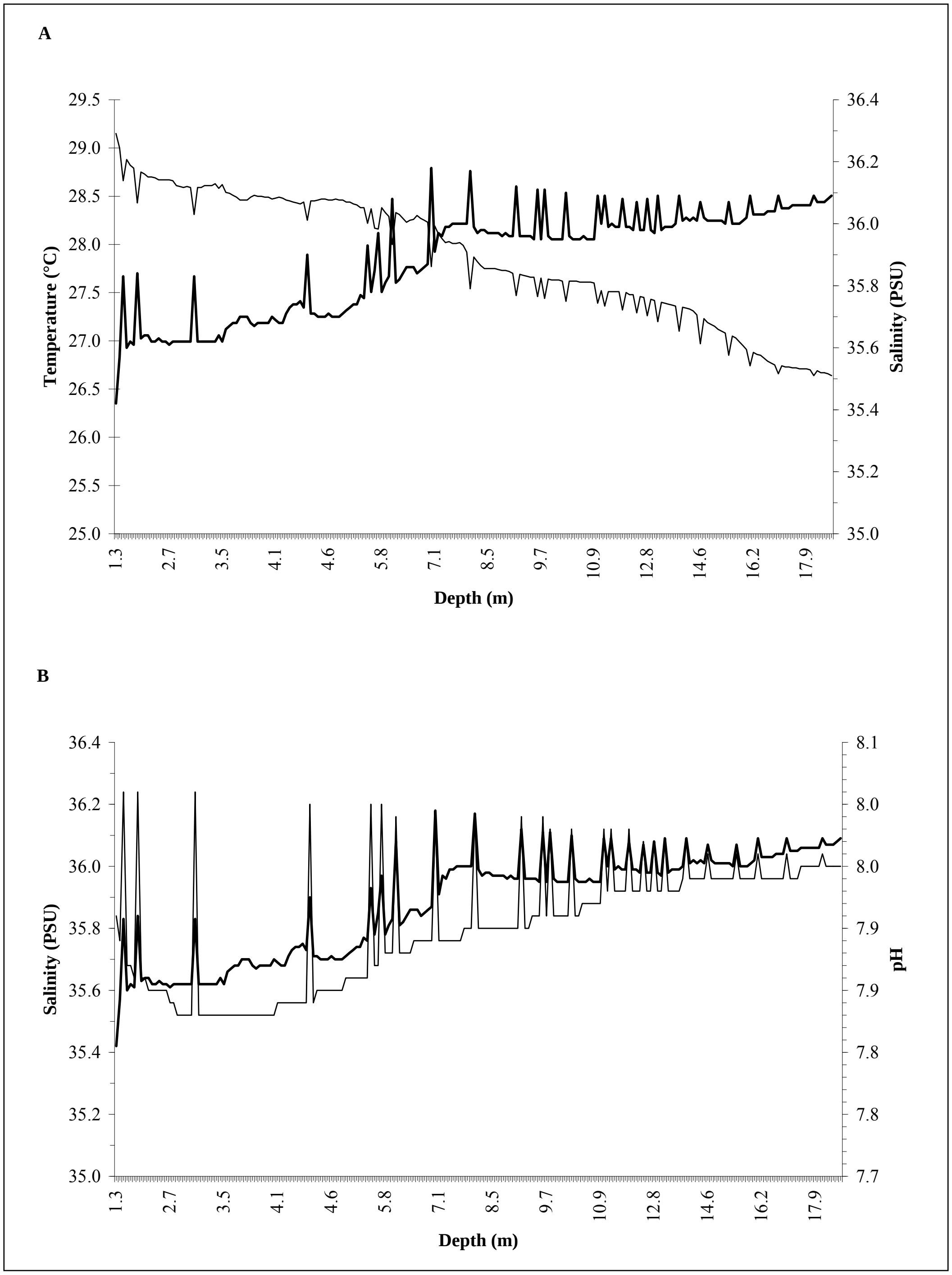


Figure 3.9.13. Vertical profile of seawater (A) temperature and salinity (bold line), (B) salinity and pH, and (C) salinity and dissolved oxygen over the reef cap at the EFGB on 06/12/07.

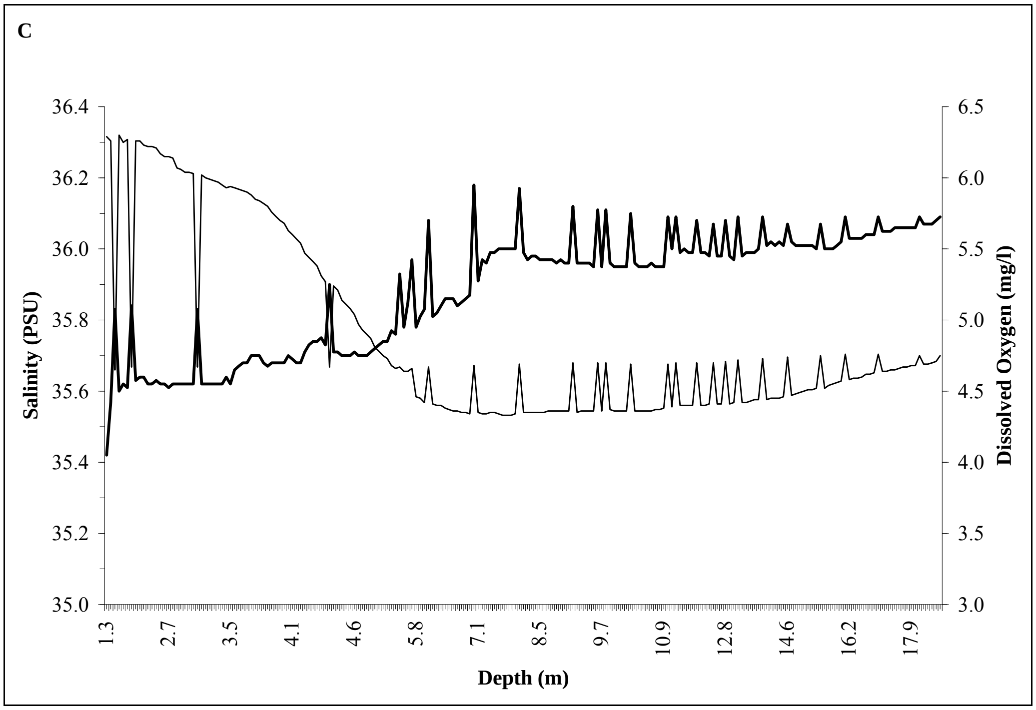


Figure 3.9.13. Vertical profile of seawater (A) temperature and salinity (bold line), (B) salinity and pH, and (C) salinity and dissolved oxygen over the reef cap at the EFGB on 06/12/07 (continued).

EFGB 08/13/07. Vertical profiles of salinity, temperature, and pH taken over the EFGB reef cap on August 13, 2007 using a YSI device showed that there was a surface layer (upper 4 m or 13 ft) characterized by low salinity (33 PSU) and high pH (8.3) compared to the underlying water column which was characterized by a salinity of 35 PSU and pH of less than 8.2 (Figure 3.9.14).

WFGB 06/06/05. The water column overlying the reef cap of the WFGB was stratified on 06/06/05. The upper 10 m (33 ft) of the water column was characterized by a salinity of 31 PSU and a temperature of 28°C. This upper layer was underlain by water that had more oceanic characteristics with a salinity of approximately 35 PSU (Figure 3.9.15). Further, pH was somewhat greater in the upper layer compared to the water immediately above the reef cap (7.5 on the reef cap and 7.6 in the upper layer). The trend of pH values closely followed that of the temperature data. Dissolved oxygen values were less than those found immediately over the reef cap (6.0 mg/l on the reef cap and 5.0 mg/l near the sea surface). PAR values declined predictably and became considerably less variable below 5-m (16-ft) depth (Figure 3.9.15).

WFGB 06/13/06. The vertical profile taken on 06/13/06 over the reef cap at the WFGB shows a surface layer water mass down to approximately 13 m (43 ft) characterized by a temperature of about 28.5°C and a salinity of 34.6 PSU. Water immediately over the reef cap had a 27.4°C temperature and a salinity of about 35.3 PSU (Figure 3.9.16).

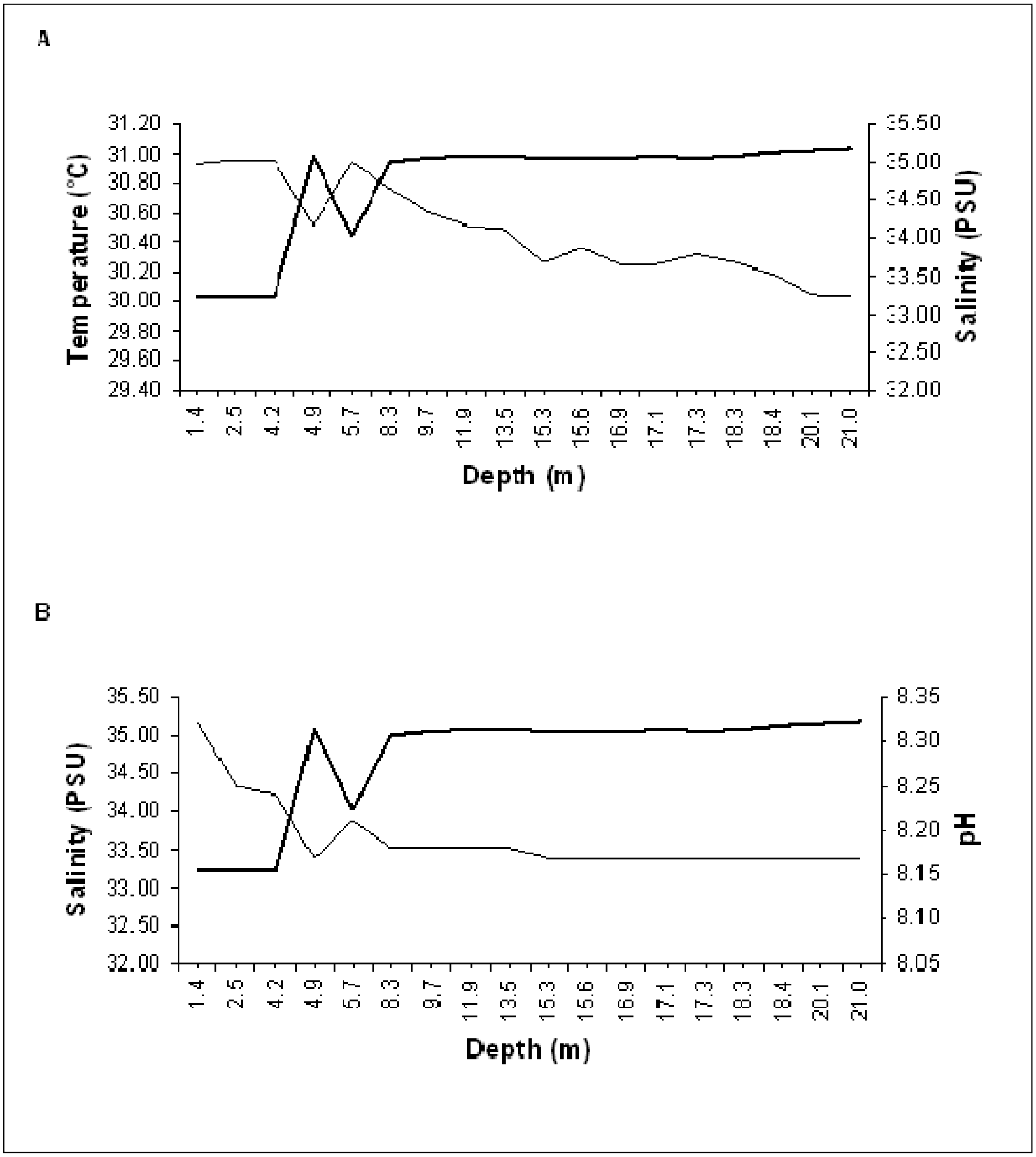
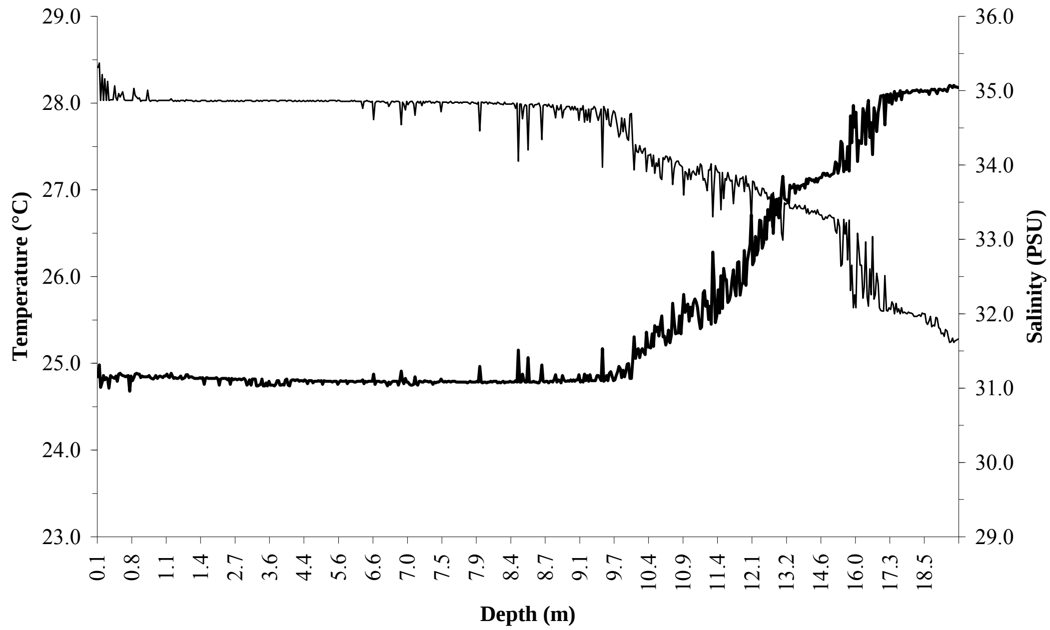


Figure 3.9.14. Vertical profile of seawater (A) temperature and salinity (bold line) and (B) salinity and pH over the reef cap at the EFGB on 08/13/07.

A



B

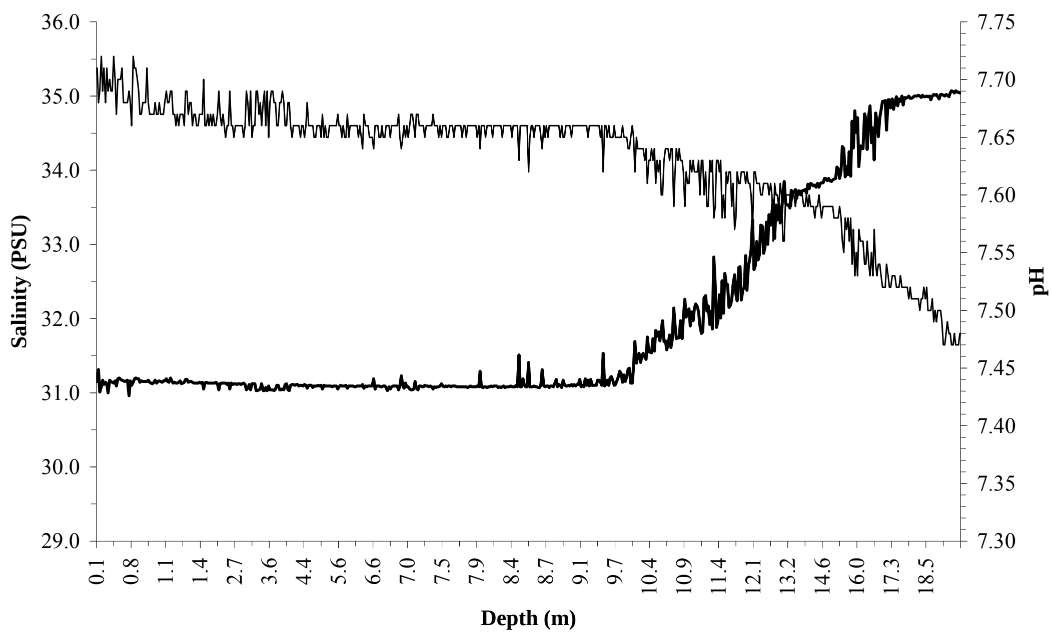


Figure 3.9.15. Vertical profile of seawater (A) temperature and salinity (bold line), (B) salinity and pH, (C) salinity and dissolved oxygen, and (D) salinity and PAR over the reef cap at the WFGB on 06/06/05.

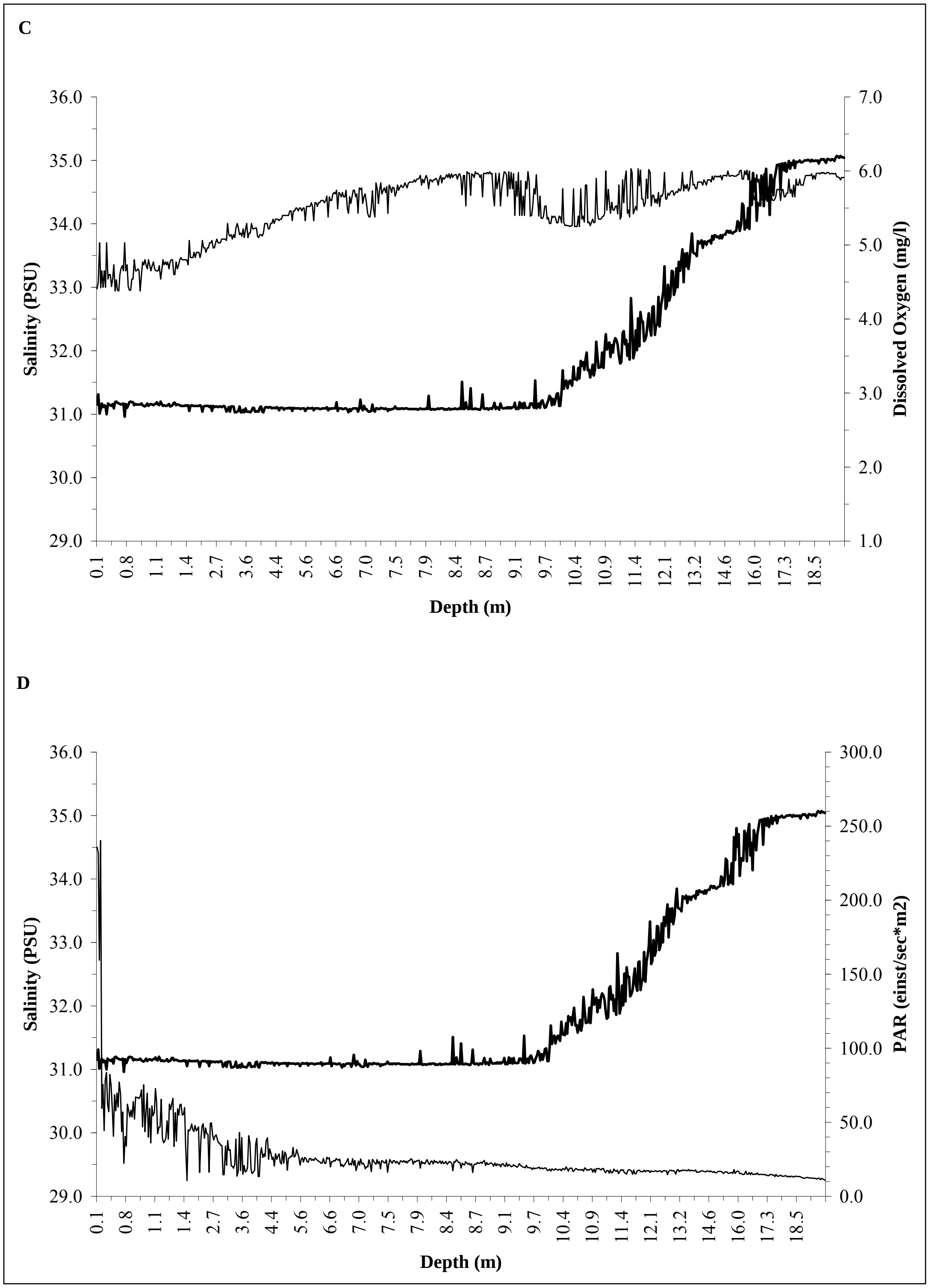


Figure 3.9.15. Vertical profile of seawater (A) temperature and salinity (bold line), (B) salinity and pH, (C) salinity and dissolved oxygen, and (D) salinity and PAR over the reef cap at the WFGB on 06/06/05 (continued).

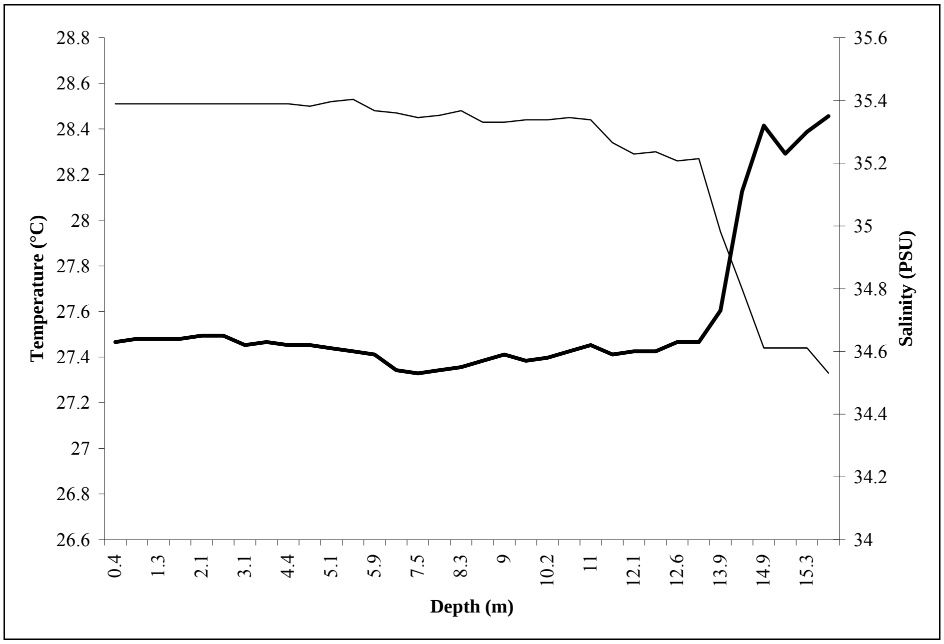


Figure 3.9.16. Vertical profile of seawater temperature and salinity (bold line) over the reef cap at the WFGB on 06/13/06.

3.9.5. Sea-Bird Temperature and Salinity

3.9.5.1. Temperature

Temperature was simultaneously measured on the reef caps of the EFGB and WFGB using a Sea-Bird 37-SMP MicroCAT from 02/04/08 to 07/03/08. The temperature records include the winter minimum and the spring/summer maxima. Daily average temperatures rose from 20 to 29°C at the EFGB and from 20 to 28°C at the WFGB from 02/04/08 to 07/03/08 (Figures 3.9.17 and 3.9.18). Temperature in 2008 was anomalous throughout most of the year compared to the long-term average, showing a cumulative thermal anomaly of 68°C (sum of the daily difference in temperature between 2008 and the long-term average) at the EFGB and 76°C at the WFGB. Overall, seawater temperatures were anomalously high on the reef cap in 2008. Appendix 10 presents the Sea-Bird data at the EFGB and WFGB from 02/04/08 to 11/04/08.

3.9.5.2. Salinity

From February to July 2008, salinity on the reef caps of the FGB ranged from 35 to 36.5 PSU. The salinity minimum occurred on 05/25/08 at the EFGB and 05/29/08 at the WFGB. The salinity record clearly shows an oscillation of salinity on both reef caps from late May to mid-June (Figures 3.9.19 and 3.9.20). The WFGB salinity record extends into early November and shows that salinity remained in the vicinity of 36 PSU despite minor oscillations (Figure 3.9.20).

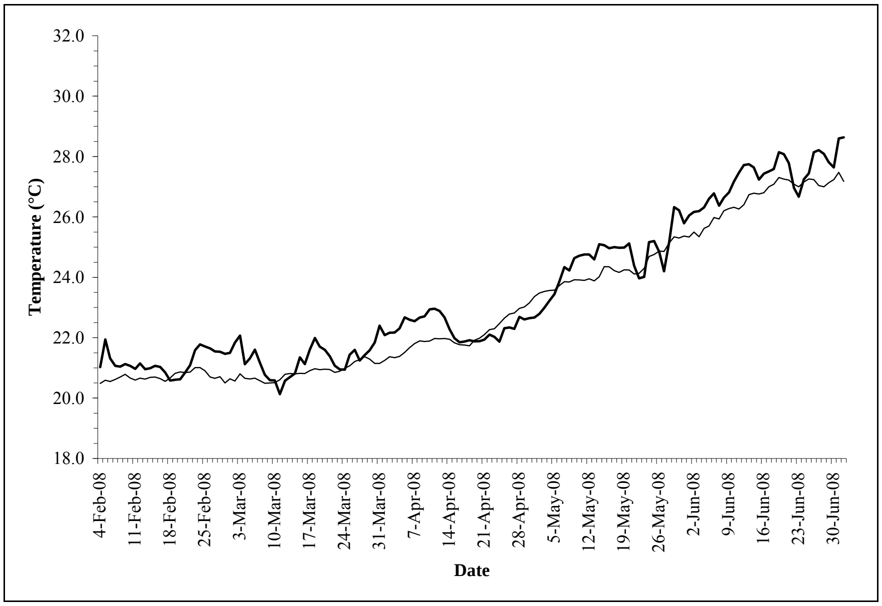


Figure 3.9.17. Seawater temperature at the EFGB reef cap from February 2008 to July 2008 as measured with the Sea-Bird (bold line) and average seawater temperature of the EFGB reef cap from 1990 to 2008 as measured using thermistors including HoboTemp devices.

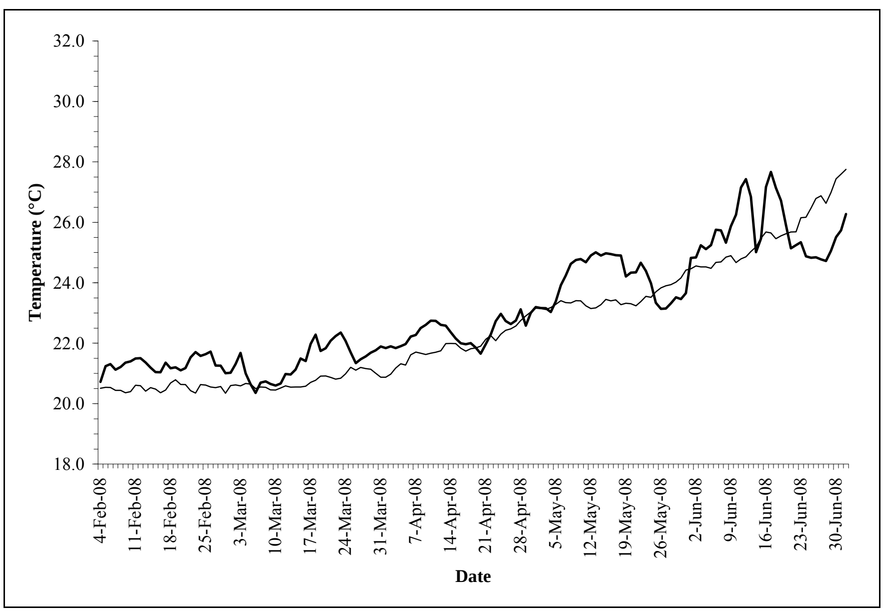


Figure 3.9.18. Seawater temperature at the WFGB reef cap from February 2008 to July 2008 as measured with the Sea-Bird (bold line) and average seawater temperature of the WFGB reef cap from 1990 to 2008 as measured using thermistors including HoboTemp devices.

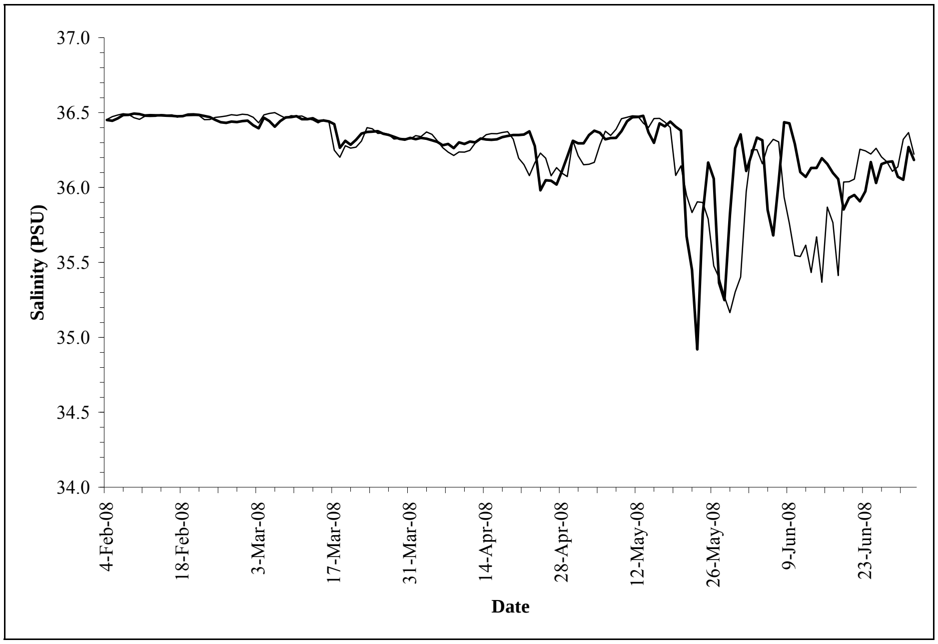


Figure 3.9.19. Salinity of the reef cap at the EFGB (bold line) and WFGB reef cap from February 2008 to July 2008 as measured with the Sea-Bird.

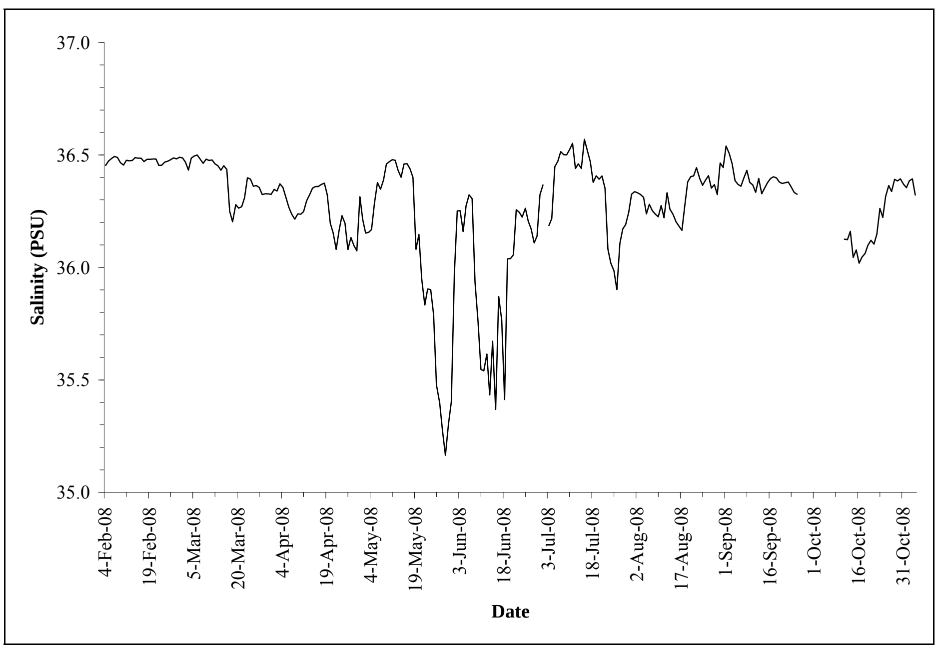


Figure 3.9.20. Salinity of the reef cap at the WFGB reef cap from February 2008 to November 2008 as measured with the Sea-Bird.

3.9.6. Water Samples

Surface (<1 m or <3 ft), midwater (~9 m or 30 ft), and near bottom (~18 m or 59 ft) water samples were acquired at 17 different times on the EFGB and WFGB from March 2004-November 2008. Water samples were analyzed for chl *a*, ammonia, nitrate, nitrite, TKN, and soluble reactive phosphorous. Appendix 11 presents the water chemistry results at the EFGB and WFGB from March 2004 to November 2008.

3.9.6.1. Chlorophyll a

From March 2004 to November 2008 chl *a* was detected (>1 mg/m^3) in water samples taken at the WFGB in May 2007, October 2007, and July 2008 (Tables 3.9.4 and 3.9.5). At the EFGB, chl *a* was measurable in water samples taken in October 2007 and in July 2008. Concentrations ranged from 1.1 mg/m^3 to 4.8 mg/m^3 at the sea surface, 1.3 mg/m^3 to 2.1 mg/m^3 in mid-water, and was 1.3 mg/m^3 on the reef cap (Tables 3.9.4 and 3.9.5).

3.9.6.2. Nutrients

Water samples taken at the FGB at the sea surface, in midwater, and on the reef cap from 2004 to 2008 were analyzed for ammonia, nitrate and nitrite, soluble reactive phosphorous, and TKN (sum of organic nitrogen and ammonia). The detection limits for reactive soluble phosphorous were typically 0.40 mg/l. A few samples were analyzed using a detection limit of 0.01 mg/l (May 19 and 20, 2007). Reactive soluble phosphorous was only detected using the latter method (Tables 3.9.7 and 3.9.8). TKN detection limits were 0.10 mg/l for most of the samples. A few water samples (November 4 and 5, 2008) were analyzed for TKN using a detection limit of 0.55 mg/l. TKN was only found in samples analyzed at the 0.10 mg/l detection limit. Nitrite was not detected in any of the tested samples.

Ammonia was detected in most samples and ranged from 0.03-2.18 mg/l (Tables 3.9.6-3.9.8). The modal value for ammonia levels was 0.03 mg/l. Samples containing the greatest amount of ammonia were obtained during February 2008 (1.8-2.6 mg/l).

Nitrate was usually below detection limits (<0.15 mg/l). There were only four water samples that contained detectable nitrate: three of the 12 samples gathered in May 2007 with concentrations ranging from 0.18-0.24 mg/l, and one sample collected in February 2008 (0.58 mg/l; Tables 3.9.6-3.9.8).

TKN was detectable in the majority of the water samples. Concentrations ranged from 0.2-4.1 mg/l (Tables 3.9.6-3.9.8). Samples collected from 2006 through 2008 contained substantially more TKN than those acquired in 2004 and 2005 (Tables 3.9.6-3.9.8).

Table 3.9.4.

Concentration of chl *a* (mg/m^3) in water samples taken at the EFGB and WFGB from 2004 to 2007. Empty cells indicate that water samples were not collected. Note that two sets of water samples were collected at the WFGB and EFGB on 05/19/07 and 05/20/07, respectively, in order to meet contractual obligations. ND = not detected at the reporting limit.

chl *a* (Detection limit: 1-mg/m^3)	**2004**					**2005**							
	03/11	**07/15**	**07/16**	**09/21**	**11/19**	**02/23**	**05/10**	**05/11**	**06/07**	**06/08**	**08/25**	**08/26**	**10/11**
EFGB Surface	ND		ND	ND		ND		ND		ND		ND	
EFGB Midwater	ND		ND	ND		ND		ND		ND		ND	
EFGB Bottom	ND		ND	ND		ND		ND		ND		ND	
WFGB Surface	ND	ND			ND	ND	ND		ND		ND		ND
WFGB Midwater	ND	ND			ND	ND	ND		ND		ND		ND
WFGB Bottom	ND	ND			ND	ND	ND		ND		ND		ND

chl *a* (Detection limit: 1-mg/m^3)	**2005**	**2006**			**2007**							
	10/12	**05/13**	**06/13**	**06/15**	**05/19**	**05/19**	**05/20**	**05/20**	**08/14**	**08/15**	**10/13**	**10/14**
EFGB Surface	ND	ND	ND				ND	ND	ND			ND
EFGB Midwater	ND	ND	ND				ND	ND	ND			1.07
EFGB Bottom	ND	ND	ND				ND	ND	ND			1.34
WFGB Surface		ND		ND	ND	4.81				ND	1.07	
WFGB Midwater		ND		ND	ND	2.14				ND	1.6	
WFGB Bottom		ND		ND	ND	ND				ND	1.34	

Table 3.9.5.

Concentration of chl *a* (mg/m^3) in water samples taken at the EFGB and WFGB in 2008. Empty cells indicate that water samples were not collected. ND = not detected at the reporting limit.

chl *a* (Detection limit: 1-mg/m^3)	**2008**				
	02/02	**07/02**	**07/03**	**11/04**	**11/05**
EFGB Surface	ND		ND	ND	
EFGB Midwater	ND		1.34	ND	
EFGB Bottom	ND		1.34	ND	
WFGB Surface	ND	1.07			ND
WFGB Midwater	ND	1.34			ND
WFGB Bottom	ND	1.34			ND

Table 3.9.6.

Concentrations of ammonia, nitrate, and TKN in water samples taken at the EFGB and WFGB from March 2004 to October 2005. Soluble reactive phosphorus not detected in any samples collected in 2004 and 2005. Empty cells indicate that water samples were not collected. ND = not detected at reporting limit.

	2004					**2005**								
Ammonia (Detection limit: 0.03-mg/l)	**03/11**	**07/15**	**07/16**	**09/21**	**11/19**	**02/23**	**05/10**	**05/11**	**06/07**	**06/08**	**08/25**	**08/26**	**10/11**	**10/12**
EFGB Surface	0.26		ND	0.03		0.04		0.03		0.03		0.03		0.03
EFGB Midwater	0.25		0.04	0.03		0.04		0.03		0.03		0.04		0.03
EFGB Bottom	0.16		0.03	0.03		0.04		0.03		0.03		0.05		0.03
WFGB Surface	0.13	0.04			0.03	0.05	0.04		0.03		0.03		0.03	
WFGB Midwater	0.10	ND			0.03	0.05	0.03		0.04		0.04		ND	
WFGB Bottom	0.12	ND			0.03	0.04	0.03		0.04		0.04		0.03	
Nitrate (Detection limit: 0.15-mg/l)	**03/11**	**07/15**	**07/16**	**09/21**	**11/19**	**02/23**	**05/10**	**05/11**	**06/07**	**06/08**	**08/25**	**08/26**	**10/11**	**10/12**
EFGB Surface	ND		ND	ND		ND		ND		ND		ND		ND
EFGB Midwater	ND		ND	ND		ND		ND		ND		ND		ND
EFGB Bottom	ND		ND	ND		ND		ND		ND		ND		ND
WFGB Surface	ND	ND			ND	ND	ND		0.20		ND		ND	
WFGB Midwater	ND	ND			ND	ND	ND		ND		ND		ND	
WFGB Bottom	ND	ND			ND	ND	ND		ND		ND		ND	
TKN (Detection limit: 0.10-mg/l)	**03/11**	**07/15**	**07/16**	**09/21**	**11/19**	**02/23**	**05/10**	**05/11**	**06/7**	**06/8**	**08/25**	**08/26**	**10/11**	**10/12**
EFGB Surface	0.42		0.33	0.75		0.98		0.70		1.07		0.56		2.24
EFGB Midwater	0.51		ND	0.84		1.03		0.79		0.75		1.17		2.01
EFGB Bottom	0.37		ND	0.65		0.98		0.61		0.61		1.35		1.96
WFGB Surface	0.19	ND			0.70	1.26	0.89		0.65		0.61		1.68	
WFGB Midwater	ND	ND			0.89	1.12	0.84		0.70		1.21		2.01	
WFGB Bottom	0.19	ND			0.75	1.07	0.93		0.84		1.40		1.96	

Table 3.9.7.

Concentrations of ammonia, nitrate, soluble reactive phosphorous, and TKN in water samples taken at the EFGB and WFGB from May 2006 to October 2007. Empty cells indicate that water samples were not collected. Note that two sets of water samples were collected at the WFGB and EFGB on 05/19/07 and 05/20/07, respectively, in order to meet contractual obligations. * indicates that samples were tested for orthophosphate and dissolved phosphorus (method SM-4500-P) instead of soluble reactive phosphorus. ND = not detected at the reporting limit.

	2006			**2007**							
Ammonia (Detection limit: 0.03-mg/l)	**05/13**	**06/13**	**06/15**	**05/19**	**05/19**	**05 /20**	**05 /20**	**08/14**	**08/15**	**10/13**	**10/14**
EFGB Surface	0.1	0.05				0.03	0.03	0.04			0.07
EFGB Midwater	0.1	0.06				0.03	0.03	0.03			0.06
EFGB Bottom	0.09	0.06				0.03	0.03	0.04			0.05
WFGB Surface	0.11		0.05	0.03	0.03				0.03	0.49	
WFGB Midwater	0.1		0.09	0.03	0.03				0.04	0.16	
WFGB Bottom	0.1		0.1	0.03	0.03				0.04	0.11	
Nitrate (Detection limit: 0.15-mg/l)	**05/13**	**06/13**	**06/15**	**05/19**	**05/19**	**05/20**	**05 /20**	**08/14**	**08/15**	**10/13**	**10/14**
EFGB Surface	ND	ND				ND	ND	ND			ND
EFGB Midwater	ND	ND				0.18	ND	ND			ND
EFGB Bottom	ND	ND				ND	ND	ND			ND
WFGB Surface	ND		ND	0.24	0.23				ND	ND	
WFGB Midwater	ND		ND	ND	ND				ND	ND	
WFGB Bottom	ND		ND	ND	ND				ND	ND	
Soluble Reactive Phosphorous (Detection limit: 0.01-mg/l)	**05/13**	**06/13**	**06/15**	**05/19***	**05/19***	**05/20***	**05/20***	**08/14**	**08/15**	**10/13**	**10/14**
EFGB Surface	ND	ND				0.02	ND	ND			ND
EFGB Midwater	ND	ND				ND	ND	ND			ND
EFGB Bottom	ND	ND				0.01	ND	ND			ND
Soluble Reactive Phosphorous (Detection limit: 0.01-mg/l)	**05/13**	**06/13**	**06/15**	**05/19***	**05/19***	**05/20***	**05/20***	**08/14**	**08/15**	**10/13**	**10/14**
WFGB Surface	ND		ND	ND	ND				ND	ND	
WFGB Midwater	ND		ND	0.08	ND				ND	ND	
WFGB Bottom	ND		ND	ND	ND				ND	ND	

Table 3.9.7. Concentrations of ammonia, nitrate, soluble reactive phosphorous, and TKN in water samples taken at the EFGB and WFGB from May 2006 to October 2007 (continued).

TKN (Detection limit: 0.10-mg/l)	**05/13**	**06/13**	**06/15**	**05/19**	**05/19**	**05/20**	**05/20**	**08/14**	**08/15**	**10/13**	**10/14**
EFGB Surface	1.45	2.38				2.38	2.24	2.8			1.77
EFGB Midwater	1.35	2.71				2.24	2.15	2.75			1.59
EFGB Bottom	1.49	2.71				2.24	2.24	2.29			1.31
WFGB Surface	1.77		1.82	2.47	2.52				2.66	3.87	
WFGB Midwater	1.54		2.52	2.71	2.43				3.13	3.17	
WFGB Bottom	1.63		3.08	2.43	2.24				3.13	2.52	

Table 3.9.8.

Concentrations of ammonia, nitrate, soluble reactive phosphorous, and TKN in water samples taken at the EFGB and WFGB from February 2008 to November 2008. Empty cells indicate that water samples were not collected. ND = not detected at the reporting limit.

	2008				
Ammonia (Detection limit: 0.03-mg/l)	**02/02**	**07/02**	**07/03**	**11/04**	**11/05**
EFGB Surface	2.14		0.04	0.13	
EFGB Midwater	2.39		0.03	0.99	
EFGB Bottom	1.93		0.04	0.17	
WFGB Surface	2.64	0.04			0.30
WFGB Midwater	2.06	0.04			0.32
WFGB Bottom	1.84	0.03			0.33
Nitrate (Detection limit: 0.15-mg/l)	**02/02**	**07/02**	**07/03**	**11/04**	**11/05**
EFGB Surface	0.58		ND	ND	
EFGB Midwater	ND		ND	ND	
EFGB Bottom	ND		ND	ND	
WFGB Surface	ND	ND			ND
WFGB Midwater	ND	ND			ND
WFGB Bottom	ND	ND			ND
Soluble Reactive Phosphorous (Detection limit: 0.01-mg/l)	**02/02**	**07/02**	**07/03**	**11/04**	**11/05**
EFGB Surface	ND		ND	ND	
EFGB Midwater	ND		ND	ND	
EFGB Bottom	ND		ND	ND	
WFGB Surface	ND	ND			ND
WFGB Midwater	ND	ND			ND
WFGB Bottom	ND	ND			ND
TKN (Detection limit: 0.10-mg/l)	**02/02**	**07/02**	**07/03**	**11/04**	**11/05**
EFGB Surface	3.27		2.15	ND	
EFGB Midwater	3.08		2.10	ND	
EFGB Bottom	2.89		2.05	ND	
WFGB Surface	4.11	2.24			ND
WFGB Midwater	3.83	2.05			ND
WFGB Bottom	2.99	1.54			ND

3.10. FISH SURVEY RESULTS

Fish surveys were conducted on the EFGB in September 2004, on the WFGB in November 2004, and on both Banks (EFGB and WFGB) in June 2005, June 2006, and June 2007. Fish surveys were not collected during the 2008 annual monitoring cruise based on limited dive staff and impending inclement weather. Tables 3.10.1 and 3.10.2 present the fish species lists and fish counts observed during visual surveys at the EFGB and WFGB from 2004-2007.

Table 3.10.1.

Fish species list and fish counts observed during visual surveys at the EFGB from 2004-2007.

Fish Species	Fish Common Names	Family Name	Trophic Guild	EFGB 2004	EFGB 2005	EFGB 2006	EFGB 2007	Total
Acanthurus bahianus	Ocean surgeonfish	Acanthuridae	Herbivore	23	40	22	1	**86**
Acanthurus chirurgus	Doctorfish	Acanthuridae	Herbivore	15	11	4	9	**39**
Acanthurus coeruleus	Blue tang	Acanthuridae	Herbivore	22	31	35	28	**116**
Aluterus scriptus	Scrawled filefish	Balistidae	Omnivore	0	0	1	0	**1**
Melichthys niger	Black durgon	Balistidae	Omnivore	32	47	6	38	**123**
Canthidermis sufflamen	Ocean triggerfish	Balistidae	Omnivore	1	116	0	3	**120**
Parablennius marmoreus	Seaweed blenny	Blenniidae	Omnivore	1	0	0	0	**1**
Malacoctenus triangulatus	Saddled blenny	Blenniidae	Omnivore	0	0	0	0	**0**
Ophioblennius atlanticus	Redlip blenny	Blenniidae	Omnivore	3	23	0	4	**30**
Caranx hippos	Crevalle jack	Carangidae	Piscivore	0	59	0	191	**250**
Caranx latus	Horse-eye jack	Carangidae	Piscivore	0	1	6	6	**13**
Caranx lugubris	Black jack	Carangidae	Piscivore	5	5	0	32	**42**
Seriola lalandi	Amber jack	Carangidae	Piscivore	0	0	0	0	**0**
Caranx ruber	Bar jack	Carangidae	Piscivore	37	123	77	32	**269**
Elagatis bipinnulata	Rainbow runner	Carangidae	Piscivore	0	0	0	0	**0**
Chaetodon aculeatus	Longsnout butterflyfish	Chaetodontidae	Herbivore	0	15	2	1	**18**
Chaetodon ocellatus	Spotfin butterflyfish	Chaetodontidae	Herbivore	4	2	10	5	**21**
Chaetodon sedentarius	Reef butterflyfish	Chaetodontidae	Herbivore	11	23	16	4	**54**
Chaetodon striatus	Banded butterflyfish	Chaetodontidae	Herbivore	3	2	0	0	**5**
Amblycirrhitus pinos	Redspotted hawkfish	Cirrhitidae	Piscivore	0	4	1	0	**5**

Table 3.10.1. Fish species list and fish counts observed during visual surveys at the EFGB from 2004-2007 (continued).

Fish Species	Fish Common Names	Family Name	Trophic Guild	EFGB 2004	EFGB 2005	EFGB 2006	EFGB 2007	Total
Diodon hystrix	Porcupinefish	Diodontidae	Piscivore	0	1	1	1	**3**
Gnatholepis thompsoni	Goldspot goby	Gobiidae	Omnivore	1	0	0	0	**1**
Gobiosoma oceanops	Neon goby	Gobiidae	Omnivore	2	26	0	0	**28**
Holocentrus adscensionis	Squirrelfish	Holocentridae	Piscivore	0	1	0	0	**1**
Holocentrus rufus	Longspine squirrelfish	Holocentridae	Piscivore	0	2	0	1	**3**
Inermia vittata	Boga	Inermiidae	Planktivore	100	0	0	0	**100**
Emmelichthyops atlanticus	Bonnetmouth	Inermiidae	Planktivore	3200	0	645	0	**3845**
Kyphosus sectator/incisor	Bermuda/Yellow chub	Kyphosidae	Omnivore	39	13	163	68	**283**
Halichoeres bivittatus	Slippery dick	Labridae	Piscivore	0	0	0	4	**4**
Halichoeres burekae	Mardi gras wrasse	Labridae	Piscivore	0	0	1	0	**1**
Halichoeres garnoti	Yellowhead wrasse	Labridae	Piscivore	39	6	10	0	**55**
Halichoeres radiatus	Puddingwife	Labridae	Piscivore	2	1	2	0	**5**
Halichoeres maculipinna	Clown wrasse	Labridae	Piscivore	12	23	7	0	**42**
Clepticus parrae	Creole wrasse	Labridae	Piscivore	432	399	159	162	**1152**
Bodianus rufus	Spanish hogfish	Labridae	Piscivore	27	33	56	6	**122**
Thalassoma bifasciatum	Bluehead wrasse	Labridae	Piscivore	157	379	999	93	**1628**
Bodianus pulchellus	Spotfin hogfish	Labridae	Piscivore	1	3	1	0	**5**
Lutjanus jocu	Dog snapper	Lutjanidae	Piscivore	0	2	2	2	**6**
Lutjanus griseus	Gray snapper	Lutjanidae	Piscivore	0	0	1	1	**2**
Aluterus schoepfii	Orange filefish	Monocanthidae	Herbivore	1	0	0	1	**2**
Cantherhines pullus	Orangespotted filefish	Monocanthidae	Herbivore	1	1	3	2	**7**
Cantherhines macrocerus	Whitespotted filefish	Monocanthidae	Herbivore	0	2	0	2	**4**
Pseudupeneus maculatus	Spotted goatfish	Mullidae	Piscivore	0	0	0	1	**1**
Mulloidichthys martinicus	Yellow goatfish	Mullidae	Piscivore	11	4	1	21	**37**

Table 3.10.1. Fish species list and fish counts observed during visual surveys at the EFGB from 2004-2007 (continued).

Fish Species	Fish Common Names	Family Name	Trophic Guild	EFGB 2004	EFGB 2005	EFGB 2006	EFGB 2007	Total
Gymnothorax funebris	Green moray	Muraenidae	Piscivore	0	0	0	0	**0**
Gymnothorax moringa	Spotted moray	Muraenidae	Piscivore	0	0	0	0	**0**
Opistognathus aurifrons	Yellowhead jawfish	Opistognathidae	Piscivore	0	0	1	0	**1**
Lactophrys triqueter	Smooth trunkfish	Ostraciidae	Omnivore	1	6	4	5	**16**
Acanthostracion polygonius	Honeycomb cowfish	Ostraciidae	Omnivore	0	2	0	0	**2**
Lactophrys bicaudalis	Spotted trunkfish	Ostraciidae	Omnivore	1	0	0	0	**1**
Holacanthus tricolor	Rock beauty	Pomacanthidae	Herbivore	5	6	3	2	**16**
Holacanthus ciliaris	Queen angelfish	Pomacanthidae	Herbivore	3	0	4	2	**9**
Holacanthus townsendi	Townsend angelfish	Pomacanthidae	Herbivore	0	0	0	1	**1**
Pomacanthus paru	French angelfish	Pomacanthidae	Herbivore	1	5	4	3	**13**
Stegastes adustes	Dusky damselfish	Pomacentridae	Herbivore	9	8	0	1	**18**
Chromis scotti	Purple reeffish	Pomacentridae	Planktivore	0	1	13	0	**14**
Chromis insolata	Sunshinefish	Pomacentridae	Planktivore	0	1	8	0	**9**
Chromis cyanea	Blue chromis	Pomacentridae	Piscivore	42	72	28	17	**159**
Abudefduf saxatilis	Sergeant major	Pomacentridae	Herbivore	13	2	6	16	**37**
Chromis multilineata	Brown chromis	Pomacentridae	Piscivore	411	1606	1042	871	**3930**
Stegastes diencaeus	Longfin damselfish	Pomacentridae	Herbivore	0	1	1	0	**2**
Stegastes leucostictus	Beaugregory	Pomacentridae	Herbivore	0	5	0	2	**7**
Stegastes partitus	Bicolor damselfish	Pomacentridae	Herbivore	50	193	42	34	**319**
Stegastes planifrons	Threespot damselfish	Pomacentridae	Herbivore	89	188	72	26	**375**
Microspathodon chrysurus	Yellowtail damselfish	Pomacentridae	Herbivore	4	17	16	5	**42**
Stegastes variabilis	Cocoa damselfish	Pomacentridae	Herbivore	39	7	2	0	**48**
Sparisoma rubripinne	Redfin parrotfish or Yellowtail parrotfish	Labridae:Scarinae	Herbivore	0	0	0	0	**0**
Scarus taeniopterus	Princess parrotfish	Labridae:Scarinae	Herbivore	67	13	0	13	**93**

Table 3.10.1. Fish species list and fish counts observed during visual surveys at the EFGB from 2004-2007 (continued).

Fish Species	Fish Common Names	Family Name	Trophic Guild	EFGB 2004	EFGB 2005	EFGB 2006	EFGB 2007	Total
Scarus vetula	Queen parrotfish	Labridae:Scarinae	Herbivore	42	98	72	32	**244**
Sparisoma atomarium	Greenblotch parrotfish	Labridae:Scarinae	Herbivore	1	0	8	5	**14**
Sparisoma chrysopterum	Redtail parrotfish	Labridae:Scarinae	Herbivore	0	1	0	1	**2**
Sparisoma viride	Stoplight parrotfish	Labridae:Scarinae	Herbivore	26	64	17	25	**132**
Sparisoma aurofrenatum	Redband parrotfish	Labridae:Scarinae	Herbivore	19	10	18	6	**53**
Scarus iseri	Striped parrotfish	Labridae:Scarinae	Herbivore	0	1	1	11	**13**
Scarus coelestinus	Midnight parrotfish	Labridae:Scarinae	Herbivore	2	0	0	0	**2**
Equetus punctatus	Spotted drum	Sciaenidae	Piscivore	0	1	0	0	**1**
Hypoplectrus puella	Barred hamlet	Serranidae	Piscivore	0	0	0	0	**0**
Epinephelus striatus	Nassau Grouper	Serranidae	Piscivore	0	0	0	0	**0**
Mycteroperca tigris	Tiger grouper	Serranidae	Piscivore	3	37	5	1	**46**
Liopropoma eukrines	Wrasse bass	Serranidae	Piscivore	0	1	0	0	**1**
Mycteroperca bonaci	Black grouper	Serranidae	Piscivore	0	0	1	3	**4**
Mycteroperca interstitialis	Yellowmouth grouper	Serranidae	Piscivore	4	1	3	1	**9**
Epinephelus morio	Red grouper	Serranidae	Piscivore	0	0	0	0	**0**
Epinephelus guttatus	Red hind	Serranidae	Piscivore	0	0	0	1	**1**
Mycteroperca venenosa	Yellowfin grouper	Serranidae	Piscivore	3	0	0	0	**3**
Dermatolepis inermis	Marbled grouper	Serranidae	Piscivore	0	1	2	4	**7**
Serranus phoebe	Tattler bass	Serranidae	Piscivore	1	0	0	0	**1**
Paranthias furcifer	Creole fish	Serranidae	Piscivore	277	67	170	297	**811**
Cephalopholis cruentata	Graysby	Serranidae	Piscivore	2	6	6	2	**16**
Cephalopholis fulva	Coney	Serranidae	Piscivore	0	0	0	0	**0**
Epinephelus adscensionis	Rock hind	Serranidae	Piscivore	1	3	1	0	**5**
Sphyraena barracuda	Great barracuda	Sphyraenidae	Piscivore	18	81	17	97	**213**

Table 3.10.1. Fish species list and fish counts observed during visual surveys at the EFGB from 2004-2007 (continued).

Fish Species	**Fish Common Names**	**Family Name**	**Trophic Guild**	**EFGB 2004**	**EFGB 2005**	**EFGB 2006**	**EFGB 2007**	**Total**
Sphoeroides spengleri	Bandtail puffer	Tetraodontidae	Piscivore	0	0	1	0	**1**
Canthigaster rostrata	Sharpnose puffer	Tetraodontidae	Omnivore	15	59	36	14	**124**
Diodon holocanthus	Balloonfish	Tetraodontidae	Piscivore	1	0	0	0	**1**
			Total	**5332**	**3962**	**3835**	**2217**	

Table 3.10.2.

Fish species list and fish counts observed during visual surveys at the WFGB from 2004-2007.

Fish Species	Fish Common Names	Family Name	Trophic Guild	WFGB 2004	WFGB 2005	WFGB 2006	WFGB 2007	Total
Acanthurus bahianus	Ocean surgeonfish	Acanthuridae	Herbivore	0	3	7	2	**12**
Acanthurus chirurgus	Doctorfish	Acanthuridae	Herbivore	23	2	0	3	**28**
Acanthurus coeruleus	Blue tang	Acanthuridae	Herbivore	59	81	41	43	**224**
Aluterus scriptus	Scrawled filefish	Balistidae	Omnivore	0	0	0	0	**0**
Melichthys niger	Black durgon	Balistidae	Omnivore	46	21	11	16	**94**
Canthidermis sufflamen	Ocean triggerfish	Balistidae	Omnivore	0	2	0	9	**11**
Parablennius marmoreus	Seaweed blenny	Blenniidae	Omnivore	0	7	0	0	**7**
Malacoctenus triangulatus	Saddled blenny	Blenniidae	Omnivore	13	0	0	0	**13**
Ophioblennius atlanticus	Redlip blenny	Blenniidae	Omnivore	0	2	1	0	**3**
Caranx hippos	Crevalle jack	Carangidae	Piscivore	0	100	1	18	**119**
Caranx latus	Horse-eye jack	Carangidae	Piscivore	3	15	0	8	**26**
Caranx lugubris	Black jack	Carangidae	Piscivore	0	2	2	9	**13**
Seriola lalandi	Amber jack	Carangidae	Piscivore	12	0	0	0	**12**
Caranx ruber	Bar jack	Carangidae	Piscivore	0	29	150	47	**226**
Elagatis bipinnulata	Rainbow runner	Carangidae	Piscivore	8	0	0	0	**8**
Chaetodon aculeatus	Longsnout butterflyfish	Chaetodontidae	Herbivore	5	8	11	7	**31**
Chaetodon ocellatus	Spotfin butterflyfish	Chaetodontidae	Herbivore	15	24	0	1	**40**
Chaetodon sedentarius	Reef butterflyfish	Chaetodontidae	Herbivore	3	20	26	26	**75**
Chaetodon striatus	Banded butterflyfish	Chaetodontidae	Herbivore	12	0	2	0	**14**
Amblycirrhitus pinos	Redspotted hawkfish	Cirrhitidae	Piscivore	0	3	0	0	**3**

Table 3.10.2. Fish species list and fish counts observed during visual surveys at the WFGB from 2004-2007 (continued).

Fish Species	Fish Common Names	Family Name	Trophic Guild	WFGB 2004	WFGB 2005	WFGB 2006	WFGB 2007	Total
Diodon hystrix	Porcupinefish	Diodontidae	Piscivore	1	0	1	3	**5**
Gnatholepis thompsoni	Goldspot goby	Gobiidae	Omnivore	3	0	1	0	**4**
Gobiosoma oceanops	Neon goby	Gobiidae	Omnivore	37	12	0	0	**49**
Holocentrus adscensionis	Squirrelfish	Holocentridae	Piscivore	4	3	0	0	**7**
Holocentrus rufus	Longspine squirrelfish	Holocentridae	Piscivore	1	0	1	2	**4**
Inermia vittata	Boga	Inermiidae	Planktivore	0	0	0	0	**0**
Emmelichthyops atlanticus	Bonnetmouth	Inermiidae	Planktivore	0	0	0	0	**0**
Kyphosus sectator/incisor	Bermuda/Yellow chub	Kyphosidae	Omnivore	69	22	20	259	**370**
Halichoeres bivittatus	Slippery dick	Labridae	Piscivore	0	0	0	0	**0**
Halichoeres burekae	Mardi gras wrasse	Labridae	Piscivore	0	0	0	0	**0**
Halichoeres garnoti	Yellowhead wrasse	Labridae	Piscivore	1	15	17	5	**38**
Halichoeres radiatus	Puddingwife	Labridae	Piscivore	1	1	3	2	**7**
Halichoeres maculipinna	Clown wrasse	Labridae	Piscivore	154	18	12	11	**195**
Clepticus parrae	Creole wrasse	Labridae	Piscivore	208	401	97	88	**794**
Bodianus rufus	Spanish hogfish	Labridae	Piscivore	20	19	197	26	**262**
Thalassoma bifasciatum	Bluehead wrasse	Labridae	Piscivore	37	138	881	112	**1168**
Bodianus pulchellus	Spotfin hogfish	Labridae	Piscivore	0	36	1	0	**37**
Lutjanus jocu	Dog snapper	Lutjanidae	Piscivore	0	7	2	0	**9**
Lutjanus griseus	Gray snapper	Lutjanidae	Piscivore	4	0	0	0	**4**
Aluterus schoepfii	Orange filefish	Monocanthidae	Herbivore	0	0	0	0	**0**
Cantherhines pullus	Orangespotted filefish	Monocanthidae	Herbivore	0	0	6	4	**10**
Cantherhines macrocerus	Whitespotted filefish	Monocanthidae	Herbivore	0	2	0	1	**3**
Pseudupeneus maculatus	Spotted goatfish	Mullidae	Piscivore	0	0	1	0	**1**
Mulloidichthys martinicus	Yellow goatfish	Mullidae	Piscivore	40	21	4	7	**72**

Table 3.10.2. Fish species list and fish counts observed during visual surveys at the WFGB from 2004-2007 (continued).

Fish Species	Fish Common Names	Family Name	Trophic Guild	WFGB 2004	WFGB 2005	WFGB 2006	WFGB 2007	Total
Gymnothorax funebris	Green moray	Muraenidae	Piscivore	0	0	0	2	**2**
Gymnothorax moringa	Spotted moray	Muraenidae	Piscivore	0	1	1	0	**2**
Opistognathus aurifrons	Yellowhead jawfish	Opistognathidae	Piscivore	0	0	0	0	**0**
Lactophrys triqueter	Smooth trunkfish	Ostraciidae	Omnivore	0	3	5	5	**13**
Acanthostracion polygonius	Honeycomb cowfish	Ostraciidae	Omnivore	1	0	0	2	**3**
Lactophrys bicaudalis	Spotted trunkfish	Ostraciidae	Omnivore	0	0	1	0	**1**
Holacanthus tricolor	Rock beauty	Pomacanthidae	Herbivore	5	3	5	2	**15**
Holacanthus ciliaris	Queen angelfish	Pomacanthidae	Herbivore	6	2	3	2	**13**
Holacanthus townsendi	Townsend angelfish	Pomacanthidae	Herbivore	0	0	0	2	**2**
Pomacanthus paru	French angelfish	Pomacanthidae	Herbivore	0	0	1	2	**3**
Stegastes adustes	Dusky damselfish	Pomacentridae	Herbivore	11	1	0	1	**13**
Chromis scotti	Purple reeffish	Pomacentridae	Planktivore	0	7	40	0	**47**
Chromis insolata	Sunshinefish	Pomacentridae	Planktivore	30	2	12	0	**44**
Chromis cyanea	Blue chromis	Pomacentridae	Piscivore	114	98	95	52	**359**
Abudefduf saxatilis	Sergeant major	Pomacentridae	Herbivore	8	7	17	22	**54**
Chromis multilineata	Brown chromis	Pomacentridae	Piscivore	366	1385	642	1068	**3461**
Stegastes diencaeus	Longfin damselfish	Pomacentridae	Herbivore	1	0	3	0	**4**
Stegastes leucostictus	Beaugregory	Pomacentridae	Herbivore	2	9	1	0	**12**
Stegastes partitus	Bicolor damselfish	Pomacentridae	Herbivore	118	108	83	63	**372**
Stegastes planifrons	Threespot damselfish	Pomacentridae	Herbivore	63	78	109	63	**313**
Microspathodon chrysurus	Yellowtail damselfish	Pomacentridae	Herbivore	30	12	14	8	**64**
Stegastes variabilis	Cocoa damselfish	Pomacentridae	Herbivore	0	3	4	0	**7**
Sparisoma rubripinne	Redfin parrotfish or Yellowtail parrotfish	Labridae:Scarinae	Herbivore	0	0	0	0	**0**
Scarus taeniopterus	Princess parrotfish	Labridae:Scarinae	Herbivore	53	15	2	33	**103**

Table 3.10.2. Fish species list and fish counts observed during visual surveys at the WFGB from 2004-2007 (continued).

Fish Species	**Fish Common Names**	**Family Name**	**Trophic Guild**	**WFGB 2004**	**WFGB 2005**	**WFGB 2006**	**WFGB 2007**	**Total**
Scarus vetula	Queen parrotfish	Labridae:Scarinae	Herbivore	3	62	67	44	**176**
Sparisoma atomarium	Greenblotch parrotfish	Labridae:Scarinae	Herbivore	0	0	7	7	**14**
Sparisoma chrysopterum	Redtail parrotfish	Labridae:Scarinae	Herbivore	0	1	0	0	**1**
Sparisoma viride	Stoplight parrotfish	Labridae:Scarinae	Herbivore	36	23	15	29	**103**
Sparisoma aurofrenatum	Redband parrotfish	Labridae:Scarinae	Herbivore	32	5	39	11	**87**
Scarus iseri	Striped parrotfish	Labridae:Scarinae	Herbivore	66	5	0	4	**75**
Scarus coelestinus	Midnight parrotfish	Labridae:Scarinae	Herbivore	0	0	0	0	**0**
Equetus punctatus	Spotted drum	Sciaenidae	Piscivore	0	0	0	0	**0**
Hypoplectrus puella	Barred hamlet	Serranidae	Piscivore	0	0	0	2	**2**
Epinephelus striatus	Nassau Grouper	Serranidae	Piscivore	1	0	0	0	**1**
Mycteroperca tigris	Tiger grouper	Serranidae	Piscivore	2	6	4	4	**16**
Liopropoma eukrines	Wrasse bass	Serranidae	Piscivore	0	0	0	0	**0**
Mycteroperca bonaci	Black grouper	Serranidae	Piscivore	0	1	1	6	**8**
Mycteroperca interstitialis	Yellowmouth grouper	Serranidae	Piscivore	0	1	5	0	**6**
Epinephelus morio	Red grouper	Serranidae	Piscivore	0	2	0	0	**2**
Epinephelus guttatus	Red hind	Serranidae	Piscivore	4	2	0	4	**10**
Mycteroperca venenosa	Yellowfin grouper	Serranidae	Piscivore	0	1	0	0	**1**
Dermatolepis inermis	Marbled grouper	Serranidae	Piscivore	0	0	0	0	**0**
Serranus phoebe	Tattler bass	Serranidae	Piscivore	0	0	0	0	**0**
Paranthias furcifer	Creole fish	Serranidae	Piscivore	0	274	193	512	**979**
Cephalopholis cruentata	Graysby	Serranidae	Piscivore	4	3	17	3	**27**
Cephalopholis fulva	Coney	Serranidae	Piscivore	1	0	0	0	**1**
Epinephelus adscensionis	Rock hind	Serranidae	Piscivore	7	4	0	0	**11**
Sphyraena barracuda	Great barracuda	Sphyraenidae	Piscivore	134	64	67	28	**293**

Table 3.10.2. Fish species list and fish counts observed during visual surveys at the WFGB from 2004-2007 (continued).

Fish Species	Fish Common Names	Family Name	Trophic Guild	WFGB 2004	WFGB 2005	WFGB 2006	WFGB 2007	Total
Sphoeroides spengleri	Bandtail puffer	Tetraodontidae	Piscivore	0	0	1	0	**1**
Canthigaster rostrata	Sharpnose puffer	Tetraodontidae	Omnivore	6	50	57	59	**172**
Diodon holocanthus	Balloonfish	Tetraodontidae	Piscivore	0	0	0	1	**1**
			Total	**1883**	**3252**	**3007**	**2750**	

3.10.1. 2004-2005 Fish Survey Results

A mean of 21.5 diver surveys (± 6.56 SD) were conducted during the 2004-2005 fish survey efforts. The highest number of surveys conducted during this time period was in 2004 at the WFGB, while the lowest number was performed at the EFGB in this same year (Table 3.10.3). Surveys were performed during the day from 0700 through dusk. Each diver survey represented one sample. Unfavorable weather conditions hampered survey efforts and were the reason for the low number of samples (12) at the EFGB in 2004 (Table 3.10.3). These diver surveys, or visual fish surveys, conducted during 2004 and 2005 sampled an average of 38% of the 100- x 100-m study sites on the EFGB and WFGB.

Table 3.10.3.

Visual fish survey sampling statistics for the EFGB and WFGB in 2004 and 2005. Number of samples (n) represents the number of diver surveys performed.

	EFGB 2004	WFGB 2004	EFGB 2005	WFGB 2005
Number Samples (n)	12	27	24	23
% area of study site sampled	21%	48%	42%	41%
Fish cylinder sample area (m^2)	177	177	177	177
Area sampled (m^2)	2,124	4,779	4,248	4,071
Total Fish Abundance	5,331	1,876	3,928	3,252

A mean of 57 fish species (± 6.0 SD) were observed during the 2004-2005 surveys. This is an increase from the 51 (± 3.5 SD) mean fish species recorded at the FGB in 2002-2003 (Precht et al. 2006). A total of 85 fish species were recorded for all survey efforts combined at the EFGB and WFGB in 2004 and 2005 (Appendices 12 and 13). Species richness (number of species recorded per sample) comparisons between Banks and years showed a similar pattern to fish abundance, with a significant difference between Banks in 2004 but not in 2005 and a significant difference at EFGB, but not at WFGB, between 2004 and 2005. The highest mean species richness recorded per diver survey was at EFGB in 2004 (mean richness = 22 species per diver survey; Table 3.10.4).

Mean fish abundance per 100 m^2 (density) ranged from a high at the EFGB in 2004 of 251.39 to a low at the WFGB in 2004 of 39.32 (Table 3.10.4). Mean density values at the EFGB and WFGB in 2005 were 96.64 per 100 m^2 and 80.01 per 100 m^2, respectively (Table 3.10.4). In previous survey years, the mean density value for the EFGB had increased from 82.78 per 100 m^2 in 2002 to 157.53 per 100 m^2 in 2003 (Precht et al. 2006). Previous mean density values recorded in 2002 and 2003 at the WFGB were 73.29 and 84.62 per 100 m^2, respectively.

Fish abundances (mean fish abundance recorded per sample) showed a significant difference ($t=7.056$, $df=37$, $P=2.38E-08$) between the EFGB and WFGB in 2004, but not in 2005. The EFGB showed a significant difference ($t=4.470$, $df=34$, $P=8.26E-05$) in fish abundances between the years 2004 and 2005, but no inter-year difference was found at the WFGB.

Table 3.10.4.

Species richness, family richness, and density values for the EFGB and WFGB recorded during 2004 and 2005 survey efforts.

	EFGB 2004	WFGB 2004	EFGB 2005	WFGB 2005
Species Richness	55	50	64	60
Family Richness	18	19	22	21
Total Fish Abundance	5,331	1,876	3,928	3,252
Mean Abundance/Survey (± SD)	444.25 (± 275.36)	69.48 (± 35.62)	163.66 (± 101.64)	141.39 (± 79.29)
Mean Abundance/100-m^2 (Density)	251.39	39.32	96.64	80.01
Mean Species Richness/Survey (± SD)	22 (± 4.22)	14.96 (± 6.15)	17.21 (± 2.75)	16.61 (± 3.07)
Mean Species Richness/m^2	0.12	0.08	0.10	0.09
Mean Family Richness (± SD)	11.5 (± 2.11)	8.71 (± 2.88)	9.79 (± 1.91)	9.74 (± 1.79)
Mean Family Richness/m^2	0.07	0.049	0.06	0.06

The high value of fish density at the EFGB in 2004 was attributed to the high numbers of the small schooling bonnetmouth, *Emmelichthyops atlanticus.* The mean observed abundance for bonnetmouth (*E. atlanticus*) was 266.67 fish per survey (± 271.64 SD), corresponding to a mean density value of 150.9 fish per 100 m^2 for this species (Table 3.10.5). Creole wrasse (*Clepticus parrae*), brown chromis (*Chromis multilineata*), and creole fish (*Paranthias furcifer*) were also observed in high densities at the EFGB in 2004 with mean density values of 20.37, 19.38, and 13.06 per 100 m^2, respectively (Table 3.10.5).

Table 3.10.5.

Mean abundance/survey and density values for bonnetmouth, creole wrasse, brown chromis, and creole fish at the EFGB in 2004 and 2005.

	2004		2005	
	Mean Abundance/ Survey	Mean Abundance/100 m^2 (Density)	Mean Abundance/ Survey	Mean Abundance/100 m^2 (Density)
Bonnetmouth	266.67	150.9	N/A	N/A
Creole wrasse	36	20.37	16.63	9.41
Brown chromis	34.25	19.38	66.92	37.87
Creole fish	23.08	13.06	2.79	1.58

Density values of brown chromis (*Chromis multilineata*) and creole wrasse (*Clepticus parrae*), which ranked as the top two most abundant species at the EFGB in 2005, were 37.87 and 9.41 per 100 m^2, respectively (Table 3.10.5). Brown chromis (*C. multilineata*) and creole wrasse (*C.*

parrae) were also ranked as the top two most abundant species at the WFGB in 2005, with densities of 34.08 and 9.87 per 100 m^2, respectively.

The sighting frequency of fish species varied between years and Banks as they did during the 2002-2003 surveys (Precht et al. 2006). However, the species most frequently recorded per sample throughout the 2004-2005 surveys were brown chromis (*Chromis multilineata*), threespot damselfish (*Stegastes planifrons*), bicolor damselfish (*S. partitus*), queen parrotfish (*Scarus vetula*), bluehead wrasse (*Thalassoma bifasciatum*), blue tang (*Acanthurus coeruleus*), and creole wrasse (*Clepticus parrae*).

Fish species recorded fell into a mean of 20 fish families (±1.83 SD) per Bank and year. This is a decrease of one family from the 2002-2003 surveys, when there were 21 families (±0.82 SD) recorded (Precht et al. 2006). The most abundant families observed were the wrasses (Labridae), damselfishes (Pomacentridae), groupers and sea basses (Serranidae), and parrotfishes (Labridae: Scarinae). The bonnetmouths (Inermiidae) were the most abundant family observed in 2004 at the EFGB and the jacks and pompanos (Carangidae) were recorded in high numbers (within the five most abundant families) at both Banks in 2005. Mean densities of Labridae (excluding Scarinae) recorded per survey ranged from 8.80 to 31.60 per 100 m^2 at the WFGB and EFGB, respectively, in 2004. Pomacentridae densities ranged from 15.50 per 100 m^2 at the WFGB in 2004 to 49.51 per 100 m^2 at the EFGB in 2005. Labridae: Scarinae ranged in density from 2.73 per 100 m^2 at the WFGB in 2005 to 7.40 per 100 m^2 at the EFGB in 2004.

Families represented by the most species were the Pomacentridae, Labridae, Serranidae, and Labridae: Scarinae. The most species of Pomacentridae were recorded in 2005 at the EFGB with 12 representatives, and the fewest were recorded in 2004 at the EFGB with eight representative species. The greatest number of Serranid species (nine) was observed in 2005 at the WFGB. The number of Labridae: Scarinae species was consistent, ranging from five in 2004 at the WFGB to seven in 2005 at the EFGB. The Labridae were generally represented by seven species.

Mean number of species per sample was calculated for each representative family. The Pomacentridae were represented by means ranging from 4.00 species per sample at the WFGB in 2005 to 4.58 species per sample at the EFGB in 2004. The most common representatives of the Pomacentridae were brown chromis (*Chromis mulitilineata*), bicolor damselfish (*Stegastes partitus*), blue chromis (*C. cyanea*), and threespot damselfish (*S. planifrons*). The Labridae were represented by means ranging from 2.44 species per sample at the WFGB in 2004 to 3.67 species per sample at the EFGB in 2004. The most common representatives of the Labridae were creole wrasse (*Clepticus parrae*), bluehead wrasse (*Thalassoma bifasciatum*), and Spanish hogfish (*Bodianus rufus*). The Labridae: Scarinae were represented by means ranging from 1.78 species per sample at the WFGB in 2004 to 3.00 species per survey at the EFGB in 2004. The most common representatives of the Labridae: Scarinae were queen parrotfish (*Scarus vetula*), stoplight parrotfish (*Sparisoma viride*), princess parrotfish (*Scarus taeniopterus*), and redband parrotfish (*Sparisoma aurofrenatum*). The Serranidae were represented by means ranging from 0.63 species per sample at the WFGB in 2004 to 1.83 species per survey at the EFGB in 2004. Creole fish (*Paranthias furcifer*) was by far the most common representative of the Serranidae;

however, others included graysby (*Cephalopholis cruentata*), rock hind (*Epinephelus adscensionis*), and tiger grouper (*Mycteroperca tigris*).

The surgeonfishes (Acanthuridae) are important herbivores on coral reefs and are represented at the FGB by three species. Species representing the Acanthuridae are the blue tang (*Acanthurus coeruleus*), doctorfish (*A. chirurgus*), and ocean surgeonfish (*A. bahianus*). The Acanthuridae were represented by means ranging from 0.93 species per survey at the WFGB in 2004 to 1.92 species per sample at the EFGB in 2004.

Shannon-Wiener diversity indices were similar between the EFGB and WFGB in 2005. The 2004 diversity indices varied among Banks, as well as from the 2005 diversity indices (Table 3.10.6). The greatest diversity was calculated for the WFGB in 2004 and the lowest for the EFGB in 2004. Higher sampling effort (larger n) appears to have had a positive effect on diversity and evenness calculations.

Table 3.10.6.

Fish diversity and evenness values calculated for fish communities surveyed at the EFGB and WFGB in 2004 and 2005.

	EFGB 2004	**WFGB 2004**	**EFGB 2005**	**WFGB 2005**
Number of Samples (n)	12	27	24	23
Diversity (log10)	0.77	1.30	1.06	1.04
Evenness (J')	0.44	0.76	0.58	0.58

The families of large-sized fish (visually estimated fork lengths) at the EFGB and WFGB were the Carangidae, Serranidae, Sphyraenidae, and Lutjanidae. Other families with large individuals included the Labridae: Scarinae, Balistidae, Pomacanthidae, and Kyphosidae. Great barracuda (*Sphyraena barracuda*) weighted mean lengths ranged from 50 cm at the EFGB in 2005 to 88 cm at the WFGB in 2004. Weighted mean lengths of the tiger grouper (*Mycteroperca tigris:* 90 cm), black grouper (*M. bonaci*: 90 cm), dog snapper (*Lutjanus jocu*: 83 cm), and yellowmouth grouper (*M. interstitialis*: 50 cm) were the largest, aside from great barracuda (*S. barracuda*) at the FGB during the 2004-2005 surveys (Table 3.10.7).

Species in the families Acanthuridae and Labridae: Scarinae, as well as the pomacentrid, yellowtail damselfish (*Microspathodon chrysurus*), can be grouped in an herbivore category comprised of algae-scrapers and algae-denuders (Steneck 1988; Pattengill-Semmens and Gittings 2003). Three species of Acanthuridae and seven species of Labridae: Scarinae were recorded in the surveys, making a total of 11 species in this herbivore group. The mean number of herbivore species per sample ranged from 2.85 at the WFGB in 2004 to 5.07 at the EFGB in 2004. The mean number of herbivore species in 2005 was 3.75 at the EFGB and 3.35 at the WFGB. There was a significant difference (t=3.627, df=37, P=0.0009) in herbivore species richness between the EFGB and the WFGB in 2004, as well as between 2004 and 2005 at the EFGB (t=3.068, df=34, P=0.0002). Mean fish densities of the herbivore group ranged from 5.14 to 10.47 per 100 m^2 at the WFGB in 2005 and the EFGB in 2004, respectively. Densities at the EFGB in 2005 were 6.74 per 100 m^2. Densities at the WFGB in 2004 were 6.33 per 100 m^2. The only significant difference in mean densities of the herbivore group was found between the EFGB and WFGB in 2004 (t=6.639, df=37, P=8.62E-08; Table 3.10.8). Queen parrotfish (*Scarus vetula*) and blue tang (*Acanthurus coeruleus*) were the most frequent species in the herbivore group.

Table 3.10.7.

Weighted mean sizes (visual estimation of fork length in centimeters) of the top five largest piscivore species at the EFGB and WFGB in 2004 and 2005.

EFGB 2004		WFGB 2004		EFGB 2005		WFGB 2005	
Fish Species	**(cm)**	**Fish Species**	**(cm)**	**Fish Species**	**(cm)**	**Fish Species**	**(cm)**
Sphyraena barracuda	56	*Mycteroperca tigris*	90	*Lutjanus jocu*	83	*Mycteroperca bonaci*	90
Mycteroperca interstitialis	50	*Serioloa lalandi*	90	*Caranx latus*	60	*Gymnothorax moringa*	80
Caranx lugubris	49	*Sphyraena barracuda*	88	*Caranx hippos*	52	*Caranx lugubris*	73
Canthidermis sufflamen	45	*Caranx latus*	70	*Sphyraena barracuda*	50	*Sphyraena barracuda*	66
Epinephelus adscensionis	40	*Lutjanus griseus*	55	*Diodon hystrix*	50	*Caranx latus*	65

Table 3.10.8.

Mean densities of fishes recorded per survey at the FGB during the 2004-2005 surveys (densities in numbers of fish per 100 m^2).

Category	2004		2005	
	EFGB	**WFGB**	**EFGB**	**WFGB**
Herbivores	10.47	6.33	6.74	5.14
Piscivores	0.57	0.46	0.38	0.66
Sphyraena barracuda	0.85	2.81	1.91	1.51
Kyphosus sectator/incisor	1.84	1.45	0.31	0.54

The size-frequency distributions of the herbivorous fishes are normal curves for both years at both Banks. The curves for both Banks in 2004 are shifted to the lower end of the size ranges and those of the WFGB in 2004 show a more exaggerated (less dispersed) pattern. The curves for 2005 are more evenly dispersed and are shifted more toward the larger sizes (Figure 3.10.1).

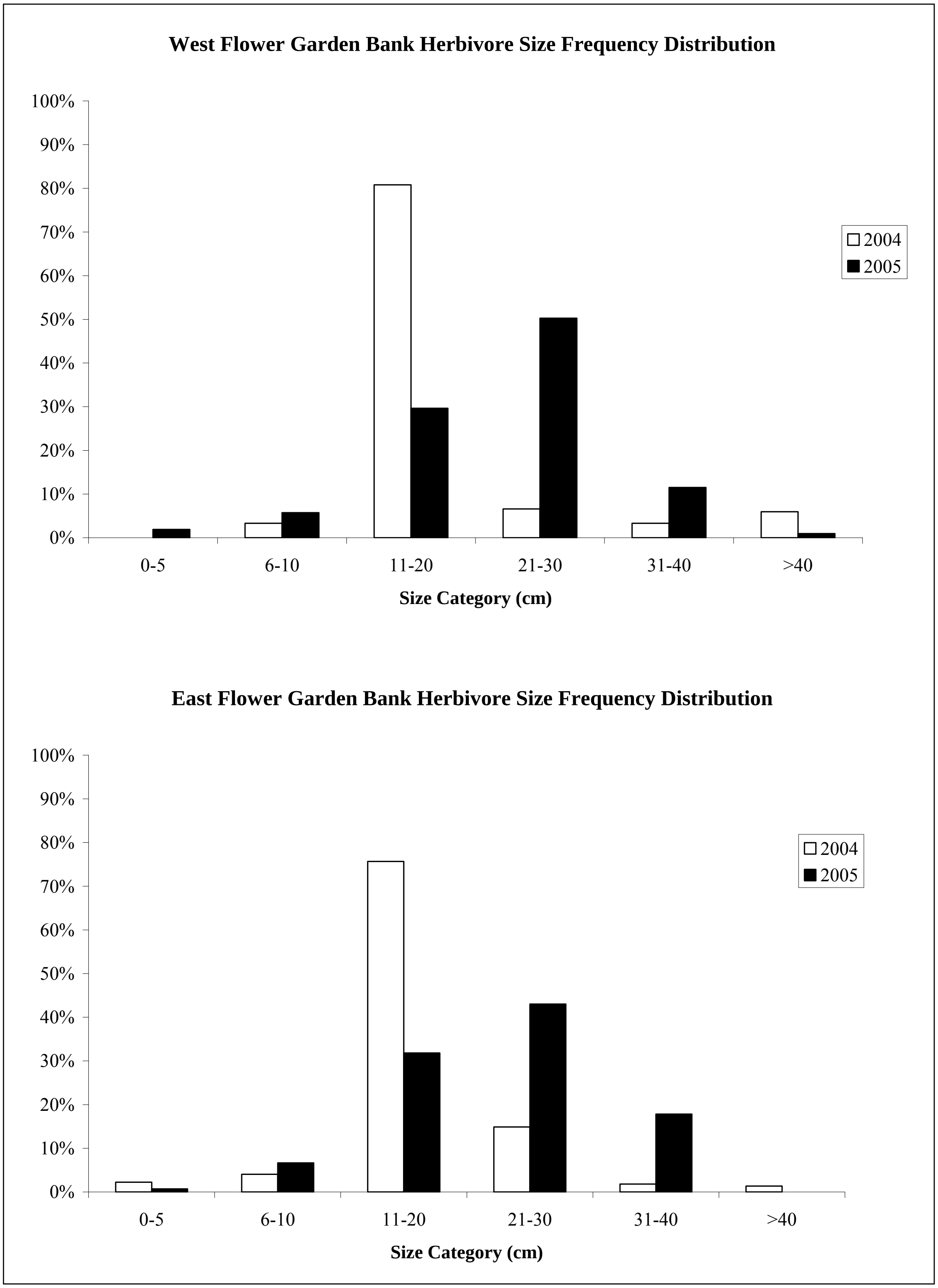


Figure 3.10.1. Herbivore size-frequency distributions at WFGB and EFGB recorded during 2004 and 2005.

Select species are grouped here as a piscivore category. These include Serranidae in the genera *Epinephelus*, *Cephalopholis*, *Mycteroperca*, and *Dermatolepis* as well as all species of Lutjanidae (Claro and Cantelar Ramos 2003; Pattengill-Semmens and Gittings 2003). A total of twelve species were observed in this group: two Lutjanidae and ten Serranidae (three more species than were observed in the 2002-2003 surveys; Precht et al. 2006). Although present in large numbers, the Serranid, creole fish (*Paranthias furcifer*), is not included in the piscivore group. The mean piscivore species richness recorded per survey ranged from 0.63 at the EFGB in 2005 to 1.09 at the WFGB in 2005. Mean species richness recorded in 2004 was 0.74 at the WFGB and 0.83 at the EFGB. No significant differences were found in mean species richness between Banks or years.

Mean densities of the piscivore group ranged from 0.38 per 100 m^2 at the EFGB in 2005 to 0.66 per 100 m^2 at the WFGB in 2005. Mean densities recorded for 2004 were 0.46 per 100 m^2 at the WFGB and 0.57 per 100 m^2 at the EFGB (Table 3.10.8). No significant differences were found in mean piscivore densities per survey between years or Banks. Tiger grouper (*Mycteroperca tigris*) and dog snapper (*Lutjanus jocu*) were among the most frequently recorded species in the piscivore group.

The size-frequency distributions of the piscivorous fishes were generally non-normal. Similarly, they were not normal in the 2002-2003 surveys (Precht et al. 2006). The distribution of piscivorous fish sizes appeared with two peaks for each Bank in both years, with the larger peak occurring in the smaller size range at the EFGB in 2004 and in the larger sizes for the other Banks and years. The diminished size ranges were primarily the 31- to 40-cm range and to a lesser degree the 21- to 30-cm range. The exception was the WFGB in 2004, with the most fishes in the 31- to 40-cm range. No piscivorous fishes were recorded in the ranges of 0-5 cm or 6-10 cm at either Bank in either year (Figure 3.10.2).

Analysis of selected species showed some differences in abundances between Banks and years. A significant difference (t=2.213, df=48, P=0.03) in great barracuda (*Sphyraena barracuda*) abundance was found between 2004 and 2005 at the WFGB. The opposite was found during the 2002-2003 surveys, with significant differences occurring between Banks but not years (Precht et al. 2006). A significant difference (t=2.422, df=34, P=0.02) was found for Bermuda/yellow chub (*Kyphosus sectator/incisor*) between 2004 and 2005 at EFGB (Table 3.10.8). During the 2002-2003 surveys, significant differences were found between Banks but not between years for this species (Precht et al. 2006).

3.10.2. 2006 Fish Survey Results

Twenty-four diver surveys were conducted at each Bank in June 2006 for a total survey area of 4,240.8 m^2 per Bank; thus, 42.4% of each 10,000-m^2 study site was surveyed. Average duration of a complete fish survey was 10 minutes. Surveys were conducted during the day from 0800 through dusk.

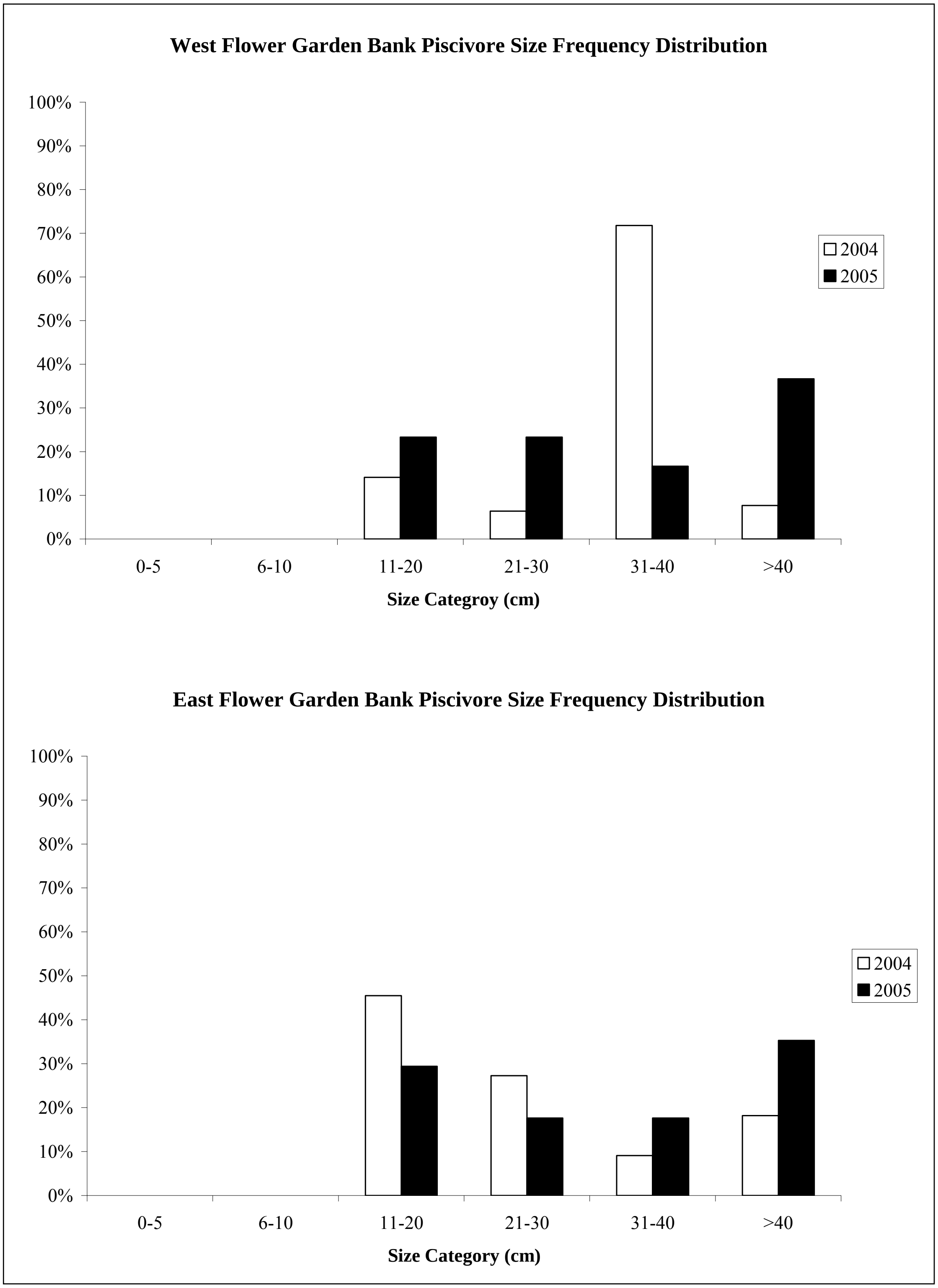


Figure 3.10.2. Piscivore size-frequency distributions at WFGB and EFGB recorded during 2004 and 2005.

For both the EFGB and WFGB, a total of 67 fish species in 24 families were recorded in the diver surveys (56 species in 20 families at EFGB; 55 species in 21 families at WFGB; Table 3.10.9; Appendix 12). The EFGB and WFGB had 44 fish species in common. The mean species richness per survey was significantly different ($t_{0.05\ (2),\ 46} = -3.664$, $P<0.001$) between the EFGB (16.5 species per survey) and WFGB (19.4 species per survey).

Table 3.10.9.

Visual fish survey sampling statistics for the EFGB and WFGB in June 2006.
Number of samples (n) represents the number of diver surveys performed.

Category	EFGB	WFGB
Number of Samples (n)	24	24
% Area of Study Site Sampled	42%	42%
Total Number of Fish Species Observed at Study Site	79	74
Species Richness	56	55
Family Richness	20	21
Mean Species Richness per Survey	16.5	19.4
Total Fish Abundance in All Surveys	3,835	3,007
Mean Fish Abundance/Survey	159.8	125.3
Mean Fish Abundance/100-m^2	90.3	70.9
Total Biomass in All Surveys (g/m^2)	1,957.12	2,876.17
Mean Biomass (g/m^2)	81.55	119.84

The fish species diversity at the EFGB (H' = 0.99) was significantly smaller than that at the WFGB (H' = 1.10; Hutcheson modified t-test; $t_{0.05\ (2),\ 6476} = -6.571$, $P<0.001$; Table 3.10.10). The maximum Shannon-Wiener diversity index was 1.75 at EFGB and 1.74 at WFGB ($H'_{max} = \log k$; where k = number of categories). While there were 56 fish species observed at the EFGB and 55 fish species at the WFGB, the calculation of evenness (*J'*) showed that species were more evenly distributed at the WFGB.

Table 3.10.10.

Shannon-Wiener diversity index (H') and Evenness (J') values for fish populations at the FGB in 2006.

Index	EFGB	WFGB
Diversity (H')	0.99	1.10
Evenness (J')	0.57	0.63

Total fish abundances in the surveyed area were 3,835 fish at EFGB and 3,007 fish at WFGB (Table 3.10.9). Mean fish abundance was 159.8 fish per survey for the EFGB and 125.3 fish per survey for the WFGB. To simplify, fish abundances can also be reported per 100 m^2. EFGB had

90.3 fish per 100 m^2 and WFGB had 70.9 fish per 100 m^2 (Table 3.10.9). No significant difference of fish abundance was found between Banks due to high standard deviations in the samples (variability in mobile fish). The high density at the EFGB was attributed to the abundance of bonnetmouth (*Emmelichthyops atlanticus)* with 15.21 fish per 100 m^2 and brown chromis (*Chromis multilineata*) with 24.57 fish per 100 m^2. No individuals of bonnetmouth (*E. atlanticus*) were recorded in samples at the WFGB, and the observed density of brown chromis at the WFGB was 15.14 fish per 100 m^2. Bluehead wrasse (*Thalassoma bifasciatum*), brown chromis (*Chromis multilineata*), and creole fish (*Paranthias furcifer*) were consistently among the top five most abundant fishes. Other abundant fishes most regularly encountered in diver surveys were bar jack (*Caranx ruber*), creole wrasse (*Clepticus parrae*), threespot damselfish (*Stegastes planifrons*), and Spanish hogfish (*Bodianus rufus*).

The EFGB and WFGB had a combined total of 24 fish families in the samples, 17 of which occurred at both Banks. Serranidae, Labridae, and Pomacentridae were consistently the most abundant families observed at the FGB (Table 3.10.11). The EFGB also had a high density of bonnetmouth (Inermiidae). The high abundance but low sighting frequencies of inermiids were caused by the schooling behavior of this species. Creole fish (*Paranthias furcifer*) was the most common Serranid species, ranked in the top three most abundant families at the FGB, ranging from 4.01 fish per 100 m^2 at the EFGB to 4.55 fish per 100 m^2 at the WFGB. Other Serranids observed were at much lower densities (e.g., 0.02 to 0.40 fish per 100 m^2), including graysby (*Cephalopholis cruentata*), yellowmouth grouper (*Mycteroperca interstitialis*), tiger grouper (*M. tigris*), rock hind (*Epinephelus adscensionis*), black grouper (*M. bonaci*), and marbled grouper (*D. inermis*). Although recorded in previous studies (Precht et al. 2006, 2008b), coney (*C. fulvus*) and yellowfin grouper (*M. venenosa*) were not recorded at either Bank in 2006.

Observed at moderate densities were members of the families Labridae: Scarinae, Carangidae, Kyphosidae, and Acanthuridae. Queen parrotfish (*Scarus vetula*) was the most abundant scarine (Labridae: Scarinae) and bar jack (*Caranx ruber*) was the most abundant carangid. The family Kyphosidae was represented by two species: Bermuda chub (*Kyphosus spectator*) and yellow chub (*K. incisor*), which were lumped together since they are indistinguishable underwater. Blue tang (*Acanthurus coeruleus*) was the most abundant acanthurid species recorded; however, this family was also represented by ocean surgeonfish (*A. bahianus*) and doctorfish (*A. chirurgus*).

Pomacentrids, labrids, serranids, and scarines were the four families with highest richness (Table 3.10.11). The pomacentrids were represented by brown chromis (*Chromis multilineata*) and blue chromis (*C. cyanea)*, threespot damselfish (*Stegastes planifrons*), bicolor damselfish (*S. partitus*), yellowtail damselfish (*Microspathodon chrysurus*), sergeant major (*Abudefduf saxatilis*), and other species of the genera *Stegastes* and *Chromis*. The labrids were represented primarily by creole wrasse (*Clepticus parrae*), Spanish hogfish (*Bodianus rufus*), and bluehead wrasse (*Thalassoma bifasciatum*). The serranids were best represented by creole fish (*Paranthias furcifer*), graysby (*Cephalopholis cruentata*), yellowmouth grouper (*Mycteroperca interstitialis*), and tiger grouper (*M. tigris*). Queen parrotfish (*Scarus vetula*), redband parrotfish (*Sparisoma aurofrenatum*), stoplight parrotfish (*S. viride*), and greenblotch parrotfish (*S. atomarium*) were the most abundant scarine species observed on diver surveys at the FGB.

Table 3.10.11.

Mean fish densities (number of individuals per 100 m^2) per diver survey, richness (number of species per family), and mean biomass by family at the EFGB and WFGB in June 2006.

	Density		Species Richness		Mean Biomass (g/m^2)	
Family	**EFGB**	**WFGB**	**EFGB**	**WFGB**	**EFGB**	**WFGB**
Acanthuridae	1.44	1.13	2	3	2.42	2.31
Balistidae	0.14	0.26	1	1	0.47	0.99
Blenniidae	0	0.02	1	0	0.00	0.00
Carangidae	1.96	3.61	3	2	10.24	14.70
Chaetodontidae	0.66	0.92	3	3	0.32	0.31
Cirrhitidae	0.02	0	0	1	0.00	0.00
Diodontidae	0.02	0.02	1	1	0.41	0.69
Inermiidae	15.21	0	0	1	0.37	0.00
Gobiidae	0	0.02	1	0	0.00	0.00
Holocentridae	0	0.02	1	0	0.00	0.03
Kyphosidae	3.84	0.47	1	1	17.90	1.50
Labridae	29.12	28.49	7	8	3.20	1.99
Lutjanidae	0.07	0.05	1	2	0.70	2.72
Monacanthidae	0.09	0.14	1	2	0.13	0.12
Mullidae	0.02	0.12	2	0	0.06	0.05
Muraenidae	0	0.02	1	0	0.00	0.49
Opistognathidae	0.02	0	0	1	0.00	0.00
Ostraciidae	0.09	0.14	2	1	0.11	0.16
Pomacanthidae	0.26	0.21	3	3	1.33	0.40
Pomacentridae	29	24.05	11	10	4.93	3.92
Labridae: Scarinae	2.74	3.07	5	5	5.85	8.25
Serranidae	4.43	5.19	5	7	12.27	15.52
Sphyraenidae	0.4	1.58	1	1	20.81	65.61
Tetraodontidae	0.87	1.37	2	2	0.03	0.09
Mean survey biomass (g/m^2)					**81.55 ± 90.46**	**119.84 ± 80.63**

Sighting frequencies varied between Banks, although eight species remained consistently in the 80% to 100% range: bicolor damselfish (*Stegastes partitus*), threespot damselfish (*S. planifrons*), creole fish (*Paranthias furcifer*), Spanish hogfish (*Bodianus rufus*), bluehead wrasse (*Thalassoma bifasciatum*), blue tang (*Acanthurus coeruleus*), brown chromis (*Chromis multilineata*), and queen parrotfish (*Scarus vetula*). The great barracuda (*Sphyraena barracuda*) was sighted in 100% of the samples at the WFGB and 42% of the samples at the EFGB. The sharpnose puffer (*Canthigaster rostrata*) was also consistently in the 75% to 80% sighting range.

Mean survey biomass was 119.84 g/m^2 (± 80.63 g/m^2 SD, n = 24) for the WFGB and 81.55 g/m^2 (± 90.46 g/m^2 SD, n = 24) for the EFGB (Table 3.10.11). No significant difference was found between Banks for mean survey fish biomass due to high standard deviations in the divers' surveys (variability in mobile fish).

While Sphyraenidae had the highest mean biomass at the WFGB (65.61 g/m^2), Kyphosidae had the highest mean biomass at the EFGB (17.90 g/m^2; Table 3.10.11). A large school of 100 kyphosids was recorded in one sample, accounting for the high mean biomass of this family. Removing this one field observation lowered the mean biomass of kyphosids at the EFGB by three-fold. Comparatively, Sphyraenidae had a mean biomass at the EFGB of 20.81 g/m^2 and Kyphosidae had a mean biomass at the WFGB of 1.50 g/m^2 (Table 3.10.11). The biomass of Carangidae was consistent across both Banks (10.24 g/m^2 at the EFGB and 14.70 g/m^2 at the WFGB). Serranidae had a mean biomass of 12.27 g/m^2 at the EFGB and 15.52 g/m^2 at the WFGB. Labridae: Scarinae had a mean biomass of 5.85 g/m^2 at the EFGB and 8.25 g/m^2 at the WFGB (Table 3.10.11).

3.10.2.1. Diurnal Abundance Differences

Divers noted differences in the morning versus afternoon behaviors of great barracuda (*Sphyraena barracuda*) and creole wrasse (*Clepticus parrae*) in 2006. During morning dives, divers observed great barracuda foraging near the reef and very few creole wrasses were present. During afternoon dives, great barracuda were observed high in the water column away from the reef, while creole wrasses were abundant near the reef. Fourteen afternoon and 10 morning dives were conducted at the EFGB and eight afternoon and 16 morning dives were conducted at the WFGB. A two-way ANOVA, with time of day and Bank as fixed factors, revealed significant differences in the abundances of both creole wrasses and great barracuda between morning (0800 to 1200) and afternoon (1200 to 1800) dives (Tables 3.10.12 and 3.10.13). Additionally, creole wrasse abundances were significantly different between the Banks, while great barracuda abundances were not.

Table 3.10.12.

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; F_{stat} = F statistic; F_{crit} = F critical; P = probability; NS = not significant; and S = significant.

Variance Source	DF	SS	MS	F_{stat}	F_{crit}	Significance	P
Cells	3	459.8462	153.2821				
Bank	1	73.9231	73.9231	1.1964	4.042	NS	0.2662
Time of Day	1	286.2308	286.2308	4.6324	4.042	S	0.0388
Bank x Time	1	99.6923	99.6923	1.6134	4.042	NS	0.2233
Error	48	2965.846	61.7885				
Total	51	3425.692	67.1704				

Table 3.10.13.

Two-way ANOVA for creole wrasse abundance, with fixed factors of Bank and time of day. DF = degrees of freedom; SS = sum of squares; MS = mean of squares; F_{stat} = F statistic; F_{crit} = F critical; P = probability; and S = significant.

Variance Source	DF	SS	MS	Fstat	Fcrit	Significance	P
Cells	3	103.875	34.625				
Bank	1	39.0625	39.0625	16.9991	4	S	<0.0005
Time of Day	1	42.25	42.25	18.3862	4	S	<0.0005
Bank x Time	1	22.5625	22.5625	9.8187	4	S	0.0027
Error	60	137.875	2.2979				
Total	63	241.75	3.8373				

The two-way ANOVA showed a significant Bank x time interaction for the abundance of creole wrasses (*Clepticus parrae*), confounding interpretation of the significant P-values for the two factors (Table 3.10.13). The effect of Bank was different at different times (morning versus afternoon) and conversely, the effect of time on the abundance of creole wrasses was different between Banks. In this case the directions of the effects were the same but the magnitudes differed.

Creole wrasses (*Clepticus parrae*) had a low mean biomass (1.72 g/m^2 for both Banks), contributing only 1% of the total biomass at the WFGB (29.62 g out of total 2876.17 g) and 2.7% at the EFGB (52.98 g out of total 1957.12 g). In contrast with creole wrasse (*C. parrae*), great barracuda (*Sphyraena barracuda*) had a high mean biomass (43.21 g/m^2 at both Banks), contributing 25.52% of the total biomass at the EFGB (499.48 g out of total 1,957.12 g) and 54.74% of the total biomass at the WFGB (1,574.78 g out of total 2,876.17 g).

3.10.2.2. Additional Species Outside of Diver Surveys

Twenty-two additional fish species were observed and recorded outside of the diver surveys in 2006, bringing the total for both Banks to 89 fish species in 30 families (75 species at the WFGB, 82 fish species at the EFGB).

3.10.2.3. Herbivores

In 2006, species in the families Acanthuridae and Labridae: Scarinae, as well as the Pomacentridae species, yellowtail damselfish (*Microspathodon chrysurus*), were grouped in an herbivore category comprised of scraping/denuding algae consumers (Appendix 12; Steneck 1988; Pattengill-Semmens and Gittings 2003). As noted above, three species of acanthurids and six species of scarines, along with the yellowtail damselfish, were recorded for a total of ten herbivore species. Densities of the herbivore group were 4.43 fish per 100 m^2 at the EFGB and 4.53 per 100 m^2 at the WFGB (Table 3.10.14). The most abundant scarine as noted above was the queen parrotfish (*Scarus vetula*) with densities ranging from 1.58 to 1.70 per 100 m^2 (sighting frequencies of 92% to 96%). The most abundant acanthurid was the blue tang (*Acanthurus coeruleus*) with densities ranging from 0.83 to 0.97 per 100 m^2 (sighting frequencies of 83% to

88%). Yellowtail damselfish densities were 0.33 per 100 m^2 at both Banks (sighting frequencies ranged from 38% to 46%).

Table 3.10.14.

Comparison of mean density (fish per 100 m^2), species richness per diver survey, and biomass (g/m^2) of herbivores and piscivores in diver surveys between the EFGB and WFGB in June 2006. NS = not significant.

Category	EFGB	WFGB	t	P value	Significance
Herbivore Density	4.43	4.53	-0.12	0.45	NS
Piscivore Density	0.50	0.68	-0.95	0.15	NS
Herbivore Richness	4.12	3.75	-1.06	0.15	NS
Piscivore Richness	0.83	0.79	0.17	0.43	NS
Herbivore Biomass	8.70	10.98	1.48	0.08	NS
Piscivore Biomass	6.11	11.95	-1.12	0.13	NS

The mean richness of these herbivore species in 2006 was 3.75 species per sample (± 1.76 SD, n=24) at the WFGB and 4.12 species per sample (± 1.24 SD, n=24) at the EFGB. No significant differences at the 95% confidence limits (Table 3.10.14) were found between Banks in the samples for herbivore richness ($t_{0.05\ (2),\ 46}$ = -1.060, P = 0.147), density ($t_{0.05\ (2),\ 46}$ = -0.121, P = 0.452), or mean biomass ($t_{0.05\ (2),\ 46}$ = 1.482, P = 0.078). However, a significant difference for herbivore biomass does exist at the 90% confidence level.

Sizes of herbivorous fishes observed at the FGB exhibited a normal distribution curve. Few fish fell within the 0- to 5-cm size range (1% to 4%) or in the greater than 40-cm category (0% to 1%). Most herbivorous fishes (78% to 83%) fell in mid-size ranges of 11-20 and 21-30 cm (Figure 3.10.3).

3.10.2.4. Piscivores

In 2006, select piscivore species included serranids (*Epinephelus* spp., *Cephalopholis* spp. and *Mycteroperca* spp.) and lutjanids (Claro and Cantelar Ramos 2003; Pattengill-Semmens and Gittings 2003). A total of eight species were observed at the FGB in the piscivore group (two lutjanids and six serranids; Appendix 12). The mean species richness of this piscivore group was 0.83 piscivore species per survey (± 0.84 SD, n=24) for the EFGB and 0.79 piscivore species per survey (± 0.61 SD, n=24) for the WFGB. Mean densities of the piscivore group were 0.50 fish per 100 m^2 at the EFGB and 0.68 fish per 100 m^2 at the WFGB (Table 3.10.14). Graysby (*Cephalopholis cruentata*) was the most abundant serranid (densities from 0.14 fish per 100 m^2 at the EFGB to 0.40 fish per 100 m^2 at the WFGB) and also was the most commonly observed serranid (sighting frequencies of 21% at the EFGB and 50% at the WFGB). Lutjanids were rarely recorded at the FGB.

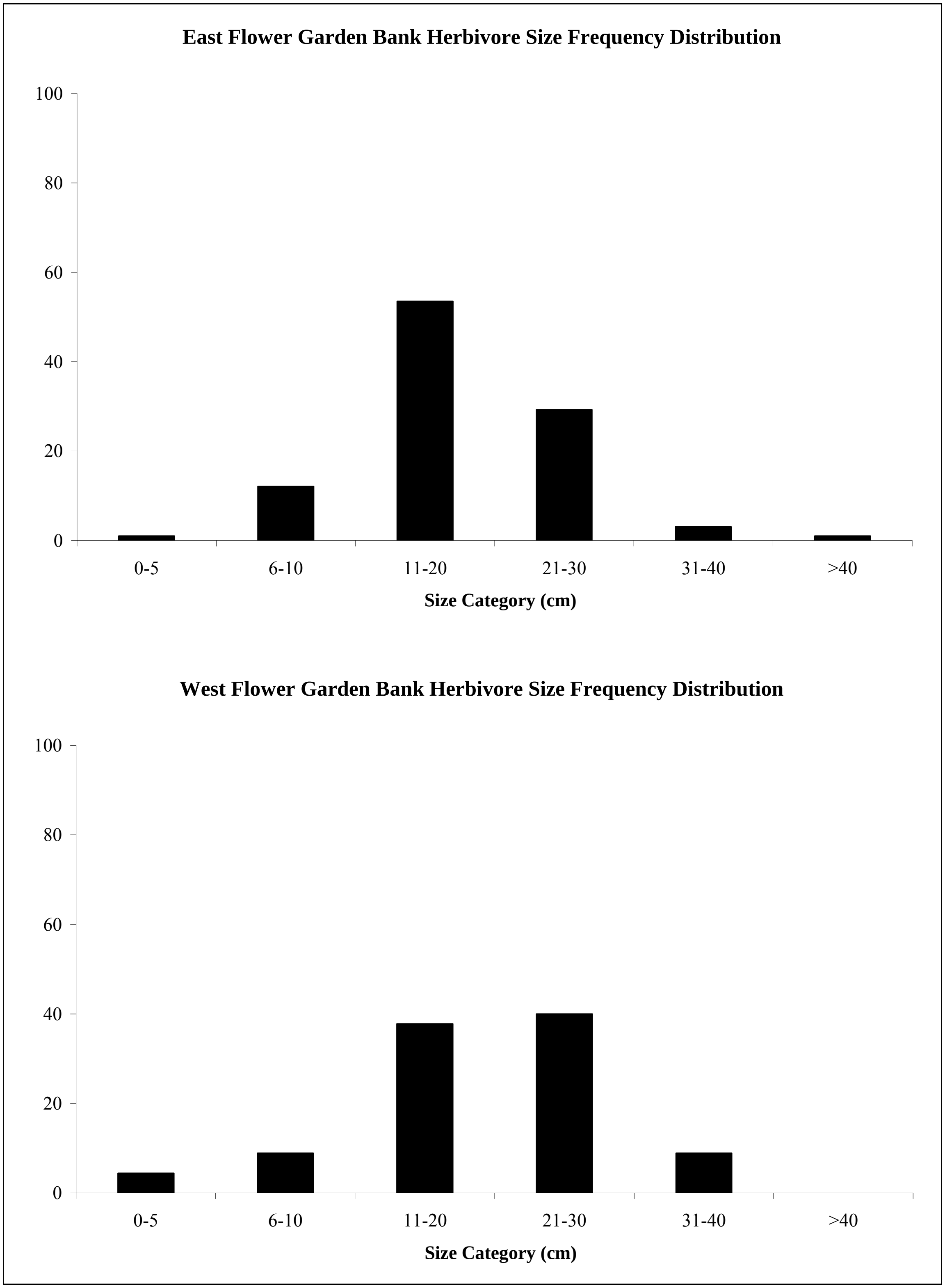


Figure 3.10.3. Herbivore size frequency (%) distributions at the EFGB and WFGB in June 2006.

No significant differences were found between Banks in the diver surveys for species richness of piscivores ($t_{0.05\ (2),\ 46}$ = 0.170, P = 0.433), density of piscivores ($t_{0.05\ (2),\ 46}$ = -0.945, P = 0.148), or mean biomass of piscivores ($t_{0.05\ (2),\ 46}$ = -1.119, P = 0.134; Table 3.10.14).

The size distribution of piscivores at the FGB was analyzed to see if the population fell within a normal distribution curve (i.e., bell-shaped with the majority of individuals in the medium size category and few individuals in the small and large size categories). The size distribution of piscivores at the FGB did not consistently exhibit a normal distribution curve (Figure 3.10.4). Of the 20 piscivores in the surveyed area at WFGB, 60% were 11- to 30-cm long and 35% were >40-cm long. Only one individual between 31 cm and 40 cm was recorded. No individual piscivores were less than 10 cm in length at either Bank. Of the 20 piscivores in the surveyed area at the EFGB, 10% were between 11 cm and 20 cm, 35% were between 21 cm and 30 cm, 25% were between 31 cm and 40 cm, and 30% were >40 cm. The pattern likely represents the differing sizes of the individual species in the piscivore group (Serranidae and Lutjanidae), rather than missing size classes of individuals from the whole group (size differences between *Epinephelus* spp. and *Mycteroperca* spp).

3.10.3. 2007 Fish Survey Results

Twenty-four diver surveys were conducted at each Bank in 2007; thus, 42.4% of each 10,000 m^2 study site was surveyed. Average duration of a complete fish survey was 10 minutes. Surveys were conducted during the day from 0800 through dusk with the latest survey beginning at 17:36.

A total of 61 fish species in 19 families were recorded on the EFGB and WFGB combined (55 species in 19 families at EFGB, 52 species in 17 families at WFGB), with 46 fish species in common (Table 3.10.15, Appendix 12). Total fish abundances in the surveyed area were 2,227 fish at EFGB and 2,750 fish at WFGB. Mean fish abundance was 92.8 fish per survey at the EFGB and 114.6 fish per survey at the WFGB, with respective densities of 52.7 and 65.1 fish per 100 m^2, which was not significantly different (parametric t-test, $t_{(2),\ 46}$=1.07, p=0.29).

The mean species richness per survey was 14.1 on the EFGB and 18.3 on the WFGB, which was significantly different ($t_{(2),\ 46}$ = 5.5106, P<0.001, Table 3.10.15). Diversity indices were similar on the two Banks (Welch's t-test; $t_{(2),\ 40}$ = 1.52, p=0.14), with the EFGB and WFGB having respective mean diversities of 0.776 and 0.859. Though the difference in diversity between EFGB and WFGB is approaching significance, the mean calculations of evenness (*J'*) are nearly equal.

3.10.3.1. Family-Level Differences Between Banks

Of the 19 total families reported in 2007, only four had significantly different densities between the two Banks (Table 3.10.16), most of which were driven by only a few influential species.

- Densities of carangids were 220% higher on the EFGB ($t_{(2)46}$=2.08, p=0.04) with the difference primarily driven by crevalle jack (*Caranx hippos*), which made up 81% of the carangids by number and segregated strongly to the EFGB ($t_{(2)46}$=2.50, p=0.016).

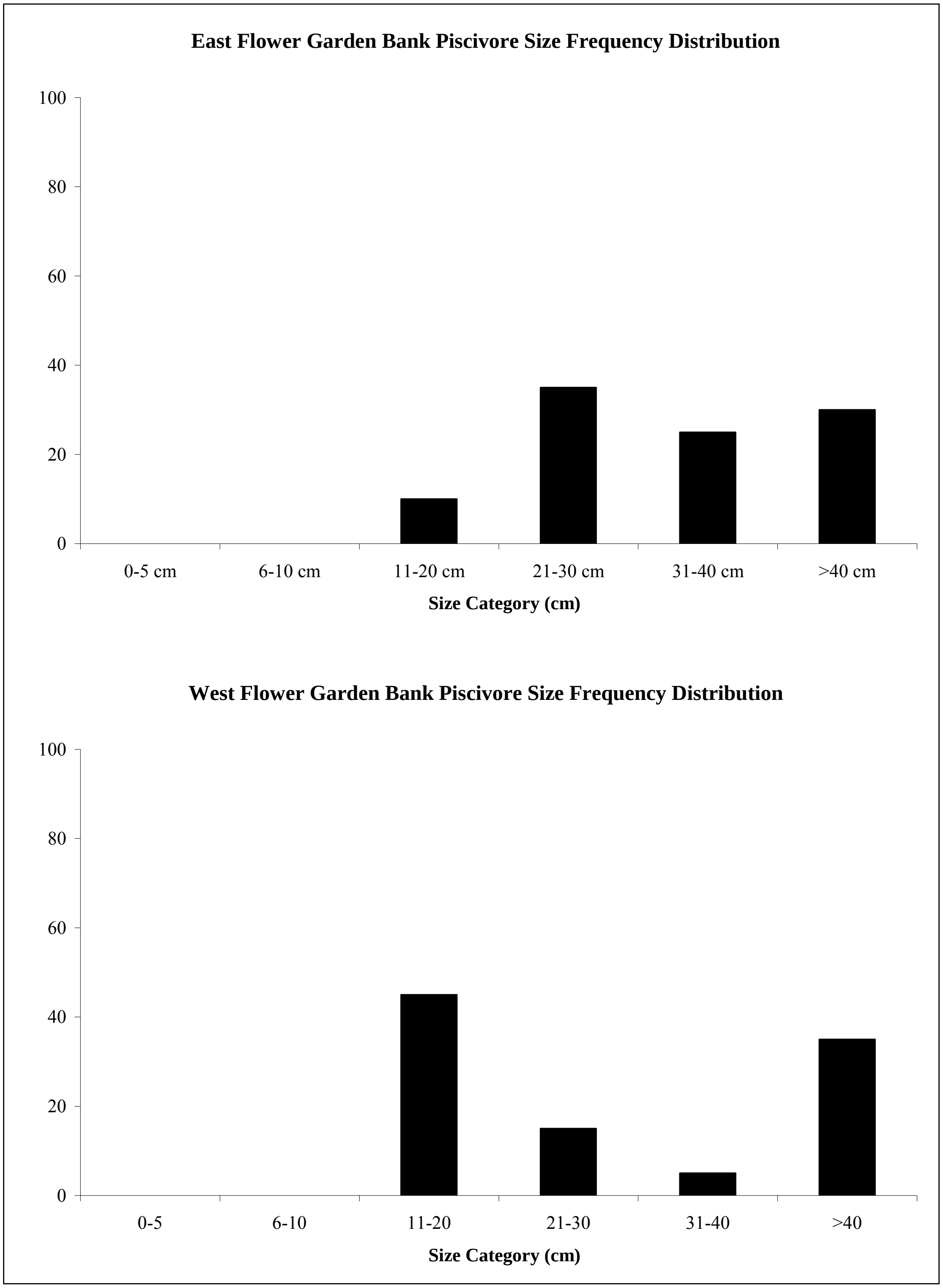


Figure 3.10.4. Piscivore size frequency (%) distributions at the EFGB and WFGB in June 2006.

Table 3.10.15.

Visual fish survey sampling statistics for the EFGB and WFGB in June 2007. Number of samples (n) represents the number of diver surveys performed.

Category	EFGB	WFGB
Number of Samples (n)	24	24
% area of study site sampled	42%	42%
Species Richness	55	52
Family Richness	19	17
Mean Species Richness per Survey	14.1	18.3
Total Fish Abundance in All Surveys	2,227	2,750
Mean Fish Abundance/Survey	92.8	114.6
Mean Fish Abundance/100-m^2	52.7	65.1
Total Biomass in All Surveys (g/ m^2)	5,825	4,147
Mean Biomass (g/ m^2)	242.7	172.8
Diversity (H')	0.776	0.859
Evenness (J')	0.674	0.668

- Densities of chaetodontids were 330% higher on WFGB than on the EFGB ($t_{(2)46}$=, p=0.001), due to high abundances of reef butterflyfish (*Chaetodon sedentarius*) and longsnout butterflyfish (*C. aculeatus*), which made up 68% and 18% of the chaetodontids, respectively. Both of these species were found predominantly on the WFGB ($t_{(2)46}=3.67$, p=0.0006 and $t_{(2)46}=2.41$, p=0.02, respectively).
- Densities of scarines were 40% higher on the WFGB than on the EFGB ($t_{(2)46}=2.40$, p=0.02), though the only species of parrotfish that had a statistically higher density on the WFGB was the princess parrotfish (*Scarus taeniopterus*). The princess parrotfish comprised only 21% of the scarines ($t_{(2)46}=3.93$, p=0.0003), suggesting that there may be similar but weaker trends among the other species.
- Tetraodontids, which only had one representative species, the sharpnose puffer (*Canthigaster rostrata*), were 320% denser on WFGB than on the EFGB $t_{(2)46}=4.06$, p=0.0002).

There were two families with a statistically higher total biomass, both of which were higher on the WFGB than on the EFGB (Table 3.10.16):

- Chaetodontid biomass was 29% higher on the WFGB ($t_{(2)46}=2.38$, p=0.02), which was driven, as before, by higher masses of reef butterflyfish and longsnout butterflyfish ($t_{(2)46}=3.26$, p=0.0002 and $t_{(2)46}=2.42$, p=0.02 respectively).

- Tetraodontid biomass was 333% higher on WFGB ($t_{(2)46}$=3.84, p=0.0004).

Table 3.10.16.

Mean fish densities (number of individuals per 100 m^2) per survey, biomass, and overall species richness (number of species per family) at the EFGB and WFGB in June 2007. Statistically significant comparisons are shown in bold font.

Family	Density (fishes/100-m^2)		Mean Biomass (g/m^2)		Species Richness	
	EFGB	**WFGB**	**EFGB**	**WFGB**	**EFGB**	**WFGB**
Acanthuridae	0.90	1.13	1.35	1.67	3	3
Balistidae	0.97	0.59	4.35	6.52	2	2
Blennidae	0.09	0.00	0.00	0.00	1	0
Carangidae	**6.15**	**1.93**	171.17	43.79	4	4
Chaetodontidae	**0.24**	**0.80**	**0.24**	**0.31**	3	3
Diodontidae	0.02	0.09	0.14	1.05	1	2
Holocentridae	0.02	0.05	0.05	0.05	1	1
Kyphosidae	1.60	6.11	14.59	60.40	1	1
Labridae	6.25	5.75	3.45	5.55	4	6
Lutjanidae	0.07	0.00	0.51	0.00	2	0
Monacanthidae	0.12	0.12	1.29	0.16	2	2
Mullidae	0.52	0.17	1.04	0.38	2	1
Ostraciidae	0.12	0.17	0.33	0.87	1	2
Pomacanthidae	0.19	0.19	1.29	1.86	4	4
Pomacentridae	22.92	30.11	4.05	6.15	8	7
Labridae: Scarinae	**2.19**	**3.07**	11.65	11.50	7	6
Serranidae	7.52	12.52	14.30	25.62	7	6
Sphyraenidae	2.29	0.66	13.84	7.49	1	1
Tetraodontidae	**0.33**	**1.39**	**0.03**	**0.13**	1	1

It is interesting to note that while scarines were more abundant on the WFGB than on the EFGB, their total biomasses are very similar (Table 3.10.16). One might hypothesize that this is due to larger body sizes on the EFGB; however, mean body size was not statistically different between the two Banks. Similarly, the effect size of biomass in chaetodontids, though statistically significant, is considerably smaller than the effect size of density reported above. Also, like numerical densities, carangid biomass was 290% higher on the EFGB than on the WFGB, but was not statistically significant while numerical density was only marginally significant, both probably due to the high variance of these species in regard to their schooling behavior. Finally, note that the above analysis on family abundance and biomass represents 38 individual contrasts; thus, it is probable that one or two of the differences noted above are due to α-error.

3.10.3.2. Fish Species Prevalence

Based on the number of surveys in which each fish species was recorded, the most prevalent species (those recorded on >20% of the visual censuses) in 2007 were creole fish (*Paranthias furcifer*), brown chromis (*Chromis multilineata*), and bluehead wrasse (*Thalassoma bifasciatum*), which appeared in 91%, 91%, and 83% of samples, respectively (Table 3.10.17). Other prevalent species of interest included great barracuda (*Sphyraena barracuda* - 72% of samples), queen parrotfish (*Scarus vetula* - 72%), stoplight parrotfish (*Sparisoma viride* - 66%), crevalle jack (*Caranx hippos* - 35%), and black grouper (*Mycteroperca bonaci* - 18%). Four species, including blue chromis (*C. cyanea*), Spanish hogfish (*Bodianus rufus*), reef butterflyfish (*Chaetodon sedentarius*), and clown wrasse (*Halichoeres maculipinna*), were statistically more prevalent on the WFGB than on the EFGB and no species were more prevalent on the EFGB. Note again that this represents 32 comparisons; thus, the potential for α-error is high, although the consistency of directionality is notable.

3.10.3.3. Herbivore and Piscivore Densities, Biomasses, and Size Distributions

Herbivore groups showed only weak differences between the EFGB and the WFGB. Herbivores, as a whole (group constrained to all Acanthuridae, yellowtail damselfish, and all Labridae: Scarinae), were 36% more numerous on the WFGB than on the EFGB (Table 3.10.18), which was statistically significant ($t_{(2)46}$=2.56, p=0.01). As mentioned above, only scarines were significantly different (p=0.02) with higher densities on the WFGB than on the EFGB. There were no significant differences in herbivore biomass between the Banks.

Piscivore groups showed a tendency for higher densities and biomasses on the EFGB than on the WFGB. The "All Piscivores" group, consisting of all Lutjanidae, most Serranidae, all Carangidae, and great barracuda (*Sphyraena barracuda*), showed no significant differences in density or biomass ($t_{(2)46}$=1.95, p=0.057, $t_{(2)46}$=1.44, p=0.15) between Banks despite having 194% greater densities and 225% higher biomasses on EFGB than WFGB (Table 3.10.18). The demersal piscivores (lutjanids and serranids) were not significantly different on the two Banks with respect to both density and biomass ($t_{(2)46}$=0.41, p=0.68 and $t_{(2)46}$=0.16, p=0.86 respectively). In contrast, the pelagics (carangids and *S. barracuda*) had 225% higher densities ($t_{(2)46}$=2.03, p=0.05) and 260% higher biomasses ($t_{(2)46}$=1.46, p=0.14) on the EFGB than on the WFGB, with density effects driven by both crevalle jack (*Caranx hippos*) and great barracuda (*S. barracuda*) and biomass driven by crevalle jack and black jack (*C. lugubris*; Table 3.10.18).

With regard to size frequency distributions, herbivores have a clear right-skewed distribution (Figure 3.10.5A). Both the pomacentrids and the acanthurids exhibit an approximately normal distribution with similar means around 15-20 cm in length. The scarines, in contrast, overlap the acanthurids and pomacentrids on the low end of their distribution but have a right-skewed distribution with modal sizes closer to 25-30 cm and a range up to 65 cm. Thus, parrotfishes in the 25- to 40-cm range appear to supply the majority of the herbivore biomass.

The size frequency distribution of the piscivores is bimodal with modes around 30-60 cm (Figure 3.10.5B). The serranids and lutjanids show little population structure at the group level due to the inclusion of smaller species (i.e., red hind - *Epinephelus guttatus* and graysby - *Cephalopholis cruentata*). Both the great barracuda (*Sphyraena barracuda*) and the carangids have bimodal distributions. The structure of the size distribution for great barracuda appears to be driven by age classes with a strong year-class at 30 cm and a second, much smaller mode at 60-70 cm. In contrast, the bimodal distribution exhibited by the carangids is driven by different species. The first mode consists almost entirely of bar jack (*Caranx ruber* - mode = 30 cm) while the second mode consists of crevalle jack (*C. hippos*), black jack (*C. lugubris*), and horse-eye jack (*C. latus*) at 70 cm, 60 cm, and 69 cm, respectively.

Table 3.10.17.

Ranked abundances for the most prevalent species at the FGB in 2007. Numbers in "Both Banks", "EFGB", and "WFGB" represent the number of surveys in which the species was observed (percent of surveys in parentheses). "P-value" represents the probability that species occurrence is randomly distributed between Banks. Statistically significant comparisons are shown in bold font. ns = not significant.

Common Name	Species	Both Banks	EFGB	WFGB	P-value
Creole fish	*Paranthias furcifer*	44 (91)	22 (91)	22 (91)	ns
Brown chromis	*Chromis multilineata*	44 (91)	23 (95)	21 (87)	ns
Bluehead	*Thalassoma bifasciatum*	40 (83)	18 (75)	22 (91)	ns
Great barracuda	*Sphyraena barracuda*	35 (72)	20 (83)	15 (62)	ns
Queen parrotfish	*Scarus vetula*	35 (72)	14 (58)	21 (87)	ns
Blue tang	*Acanthurus coeruleus*	35 (72)	13 (54)	22 (91)	ns
Threespot damselfish	*Stegastes planifrons*	34 (70)	13 (54)	21 (87)	ns
Princess parrotfish	*Scarus taeniopterus*	33 (68)	12 (50)	21 (87)	ns
Stoplight parrotfish	*Sparisoma viride*	32 (66)	14 (58)	18 (75)	ns
Bicolor damselfish	*Stegastes partitus*	29 (60)	10 (41)	19 (79)	ns
Creole wrasse	*Clepticus parrae*	29 (60)	17 (70)	12 (50)	ns
Blue chromis	*Chromis cyanea*	28 (58)	7 (29)	21 (87)	**0.014**
Sharpnose puffer	*Canthigaster rostrata*	28 (58)	9 (37)	19 (79)	ns
Black durgon	*Melichthys niger*	26 (54)	12 (50)	14 (58)	ns
Spanish hogfish	*Bodianus rufus*	23 (47)	5 (20)	18 (75)	**0.012**
Sergeant major	*Abudefduf saxatilis*	20 (41)	9 (37)	11 (45)	ns
Bermuda chub	*Kyphosus sectator*	18 (37)	10 (41)	8 (33)	ns
Crevalle jack	*Caranx hippos*	17 (35)	12 (50)	5 (20)	ns
Reef butterflyfish	*Chaetodon sedentarius*	16 (33)	3 (12)	13 (54)	**0.024**
Bar jack	*Caranx ruber*	15 (31)	9 (37)	6 (25)	ns
Redband parrotfish	*Sparisoma aurofrenatum*	14 (29)	5 (20)	9 (37)	ns
Black jack	*Caranx lugubris*	13 (27)	5 (20)	8 (33)	ns
Yellowtail damselfish	*Microspathodon chrysurus*	12 (25)	5 (20)	7 (29)	ns
Yellow goatfish	*Mulloidichthys martinicus*	11 (22)	7 (29)	4 (16)	ns
Greenblotch parrotfish	*Sparisoma atomarium*	11 (22)	4 (16)	7 (29)	ns
Doctorfish	*Acanthurus chirurgus*	9 (18)	6 (25)	3 (12)	ns
Black grouper	*Mycteroperca bonaci*	9 (18)	3 (12)	6 (25)	ns
Clown wrasse	*Halichoeres maculipinna*	8 (16)	0 (0)	8 (33)	**0.013**
Smooth trunkfish	*Lactophrys triqueter*	8 (16)	3 (12)	5 (20)	ns
Longsnout butterflyfish	*Prognathodes aculeatus*	8 (16)	1 (4)	7 (29)	ns
Ocean triggerfish	*Canthidermis sufflamen*	7 (14)	3 (12)	4 (16)	ns
Striped parrotfish	*Scarus iseri*	7 (14)	6 (25)	1 (4)	ns

Table 3.10.18.

Abundances and biomasses between Banks for herbivorous and piscivorous fishes. Comparisons of groups where t-tests were performed are in bold with appropriate p-values where significant. ns = not significant.

Species	Numbers/100-m^2			Mass g/m^2		
	EFGB	**WFGB**	**P-value**	**EFGB**	**WFGB**	**P-value**
All Herbivores	**3.21**	**4.36**	**0.01**	**13.35**	**13.43**	**ns**
F. Acanthuridae	**0.9**	**1.13**	**ns**	**1.35**	**1.67**	**ns**
Acanthurus bahianus	0.02	0.05		0.01	0.01	
Acanthurus chirurgus	0.22	0.07		0.27	0.09	
Acanthurus coeruleus	0.66	1		1.06	1.57	
Microspathodon chrysurus	**0.12**	**0.17**	**ns**	**0.36**	**0.27**	**ns**
F. Labridae: Scarinae	**2.19**	**3.07**	**0.02**	**11.65**	**11.5**	**ns**
Scarus iseri	0.26	0.09		0.54	0.03	
Scarus taeniopterus	0.3	0.76		2.22	5.27	
Scarus vetula	0.79	1.16		2.67	3.18	
Sparisoma atomarium	0.13	0.23		0.1	0.1	
Sparisoma aurofrenatum	0.15	0.27		0.51	0.23	
Sparisoma chrysopterum	0.02	0		0.05	0	
Sparisoma viride	0.53	0.53		5.55	2.68	
All Piscivores	**8.8**	**2.99**	**ns**	**190.28**	**58.59**	**ns**
Demersal Piscivores	**0.35**	**0.4**	**ns**	**6.01**	**7.52**	**ns**
Lutjanus griseus	0.02	0		0.07	0	
Lutjanus jocu	0.05	0		0.44	0	
Cephalopholis cruentata	0.05	0.07		0.06	0.11	
Epinephelus inermis	0.09	0		2.07	0	
Epinephelus guttatus	0.02	0.09		0.26	0.07	
Mycteroperca bonaci	0.07	0.14		1.93	6.01	
Mycteroperca interstitialis	0.02	0		0.82	0	
Mycteroperca tigris	0.02	0.09		0.34	1.32	
Pelagic Piscivores	**8.44**	**2.59**	**0.05**	**184.28**	**51.08**	**ns**
Caranx hippos	4.5	0.42		144.6	25.18	
Caranx latus	0.14	0.19		1.05	11.46	
Caranx lugubris	0.75	0.21		22.64	3.68	
Caranx ruber	0.75	1.11		2.2	3.29	
Sphyraena barracuda	2.29	0.66		13.78	7.46	

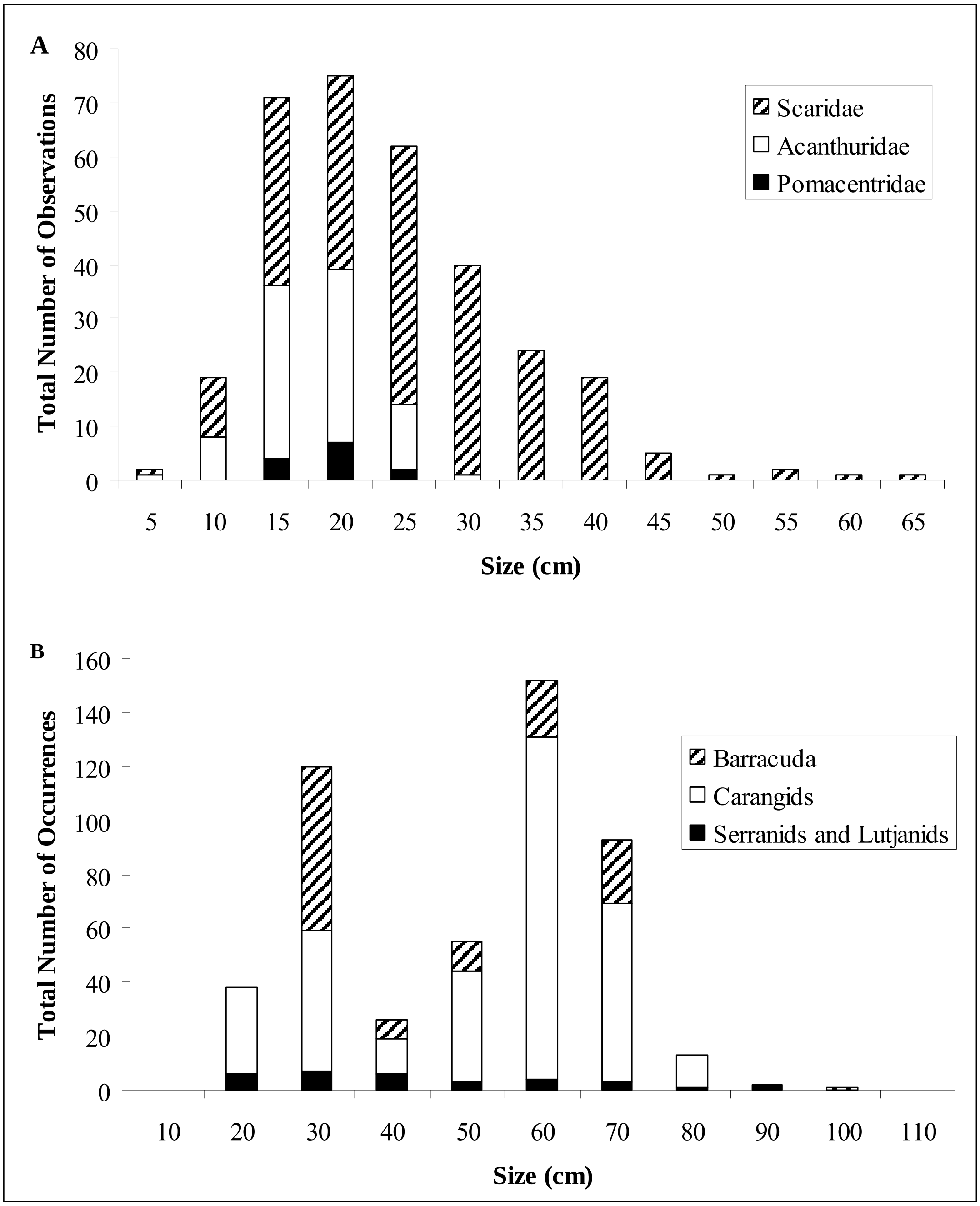


Figure 3.10.5. Size frequency distributions for (A) select herbivores and (B) select piscivores in 2007 for both Banks combined.

3.10.4. Long-Term Fish Community Trends for 2002-2007

3.10.4.1. Piscivore Biomass Analysis

Pelagic piscivore biomass, consisting of all Lutjanidae, most Serranidae, all Carangidae, and great barracuda (*Sphyraena barracuda*), was significantly different between Banks and across time (from 2002-2007), with a significant interaction (Table 3.10.19). Pelagic piscivore biomass averaged ~3.4 times higher on the WFGB than on the EFGB, though the difference varied considerably across years (Figure 3.10.6). The model only accounts for 14% of the variance but is statistically significant due to the large sample size. Though neither Bank shows a monotonic change in biomass, if time is treated as a continuous factor, there is a significant mean increase in pelagic biomass of 36% per year.

Table 3.10.19.

Factorial ANOVA of year (2002-2007) and Bank effects for pelagic piscivores (Carangidae and Sphyraenidae). **, p<0.01.

Factor	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Bank	1	4.494	4.494	10.6399	0.001271 **
Year	5	8.91	1.782	4.2193	0.001083 **
Bank: Year	5	7.799	1.56	3.6933	0.003088 **
Residuals	235	99.253	0.422		

Demersal piscivores (snappers and groupers), showed no differences between Banks and no significant variations over time (Table 3.10.20), despite the large sample sizes. Except for 2005, snapper and grouper biomasses at the two Banks track each other very closely.

3.10.4.2. Principle Components Analysis (PCA)

To eliminate rare species, we created a rank-abundance curve for all species recorded from 2002-2007, based on their prevalence in samples (Figure 3.10.7). The most prevalent species were the threespot damselfish (*Stegastes planifrons*), bicolor damselfish (*S. partitus*), bluehead wrasse (*Thalassoma bifasciatum*), and brown chromis (*Chromis multilineata*), occurring in 209, 208, 208, and 206 samples, respectively (Table 3.10.21). A total of 24 species were recorded in at least 20% of the samples (Table 3.10.21) and are referred to as the “prevalent” species in subsequent analyses.

The PCA resulted in the component loadings as indicated in Table 3.10.22 with bold-face correlation coefficients noted for their strength (>0.40). Principle Component 1 (PC1) is strongly, positively correlated to aspects of fish assemblage composition that are associated with a healthy and resilient coral reef. These include an abundance of hard-grazing herbivores such as the stoplight parrotfish (*Sparisoma viride*) and other large parrotfishes (*Scarus* spp.) whose activities favor space occupancy by crustose coralline algae, an ideal settlement surface for the settling larvae of reef-building corals, and an abundance of large piscivorous species. Also loading heavily onto PC1 were durophagous invertebrate piscivores (tetraodontiforms and porgies), which are again taxa whose abundance at large size is generally indicative of an intact reef community.

PC2 through PC4 appear to reflect independent dimensions of fish communities associated with overfished conditions and degraded reef habitat (mostly small species, although they could also be capturing simple year to year stochastic recruitment variation). The EFGB and WFGB both exhibited strong year X Bank interactions for PC2, PC3, and PC4, in no obviously interpretable pattern. Year to year variation in PC1 on the EFGB follows a strong pattern of rise to a peak value in 2004 and a subsequent, steady fall. The pattern on the WFGB is more erratic. Since mean values do not differ between the two Banks, the mean trend is plotted in Figure 3.10.8.

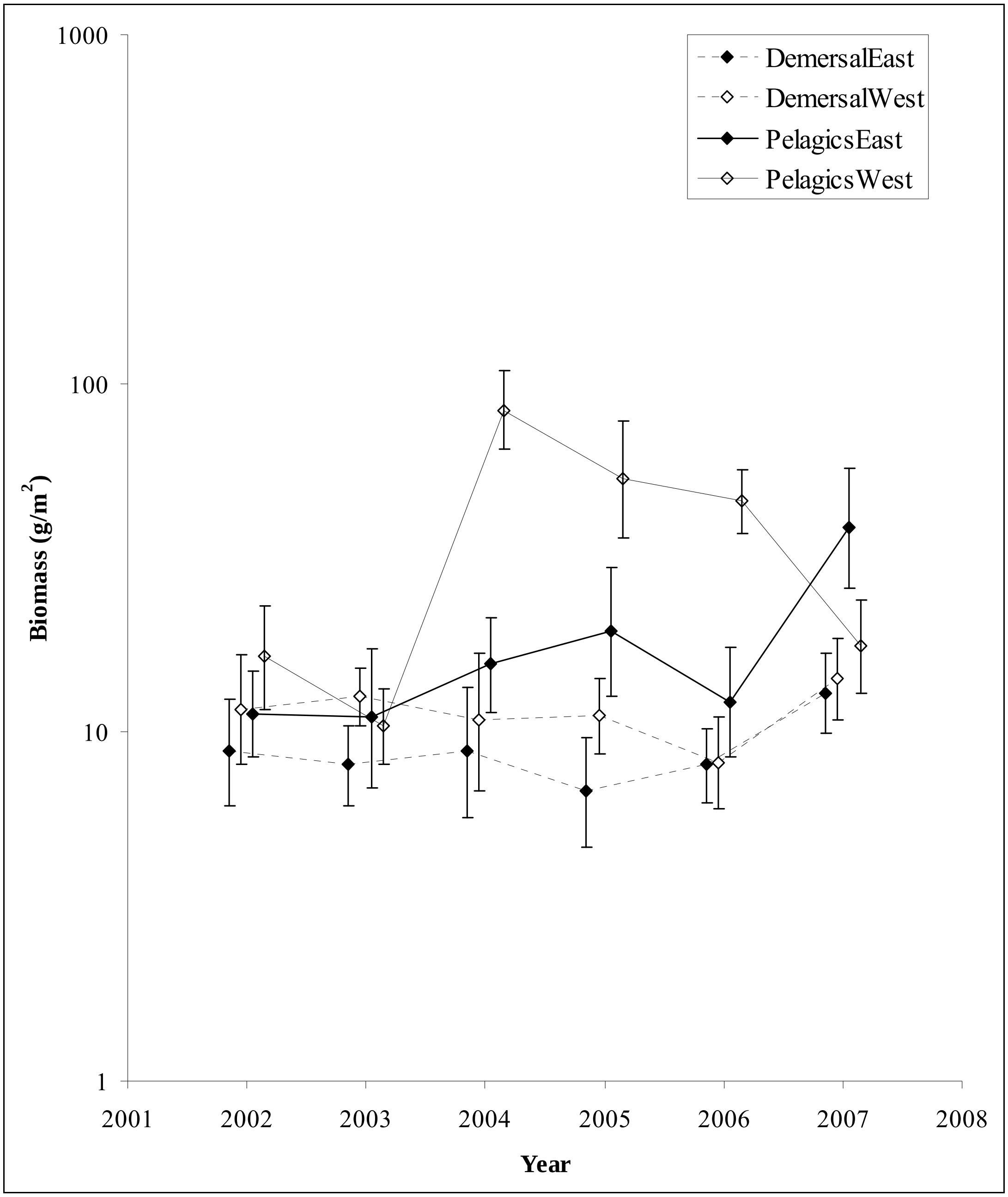


Figure 3.10.6. Temporal changes in biomass of pelagic (Carangidae and Sphyraenidae) and demersal (Lutjanidae and Serranidae) piscivorous fishes at the FGB from 2002-2007. Values are back-transformed means with standard error bars. Year values are staggered for clarity.

Table 3.10.20.

Factorial ANOVA of year (2002-2007) and Bank effects for demersal piscivores (Lutjanidae and Serranidae).

Factor	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Bank	1	0.555	0.555	1.6022	0.2068
Year	5	1.189	0.238	0.6869	0.6338
Bank: Year	5	0.305	0.061	0.1763	0.9713
Residuals	235	81.384	0.346		

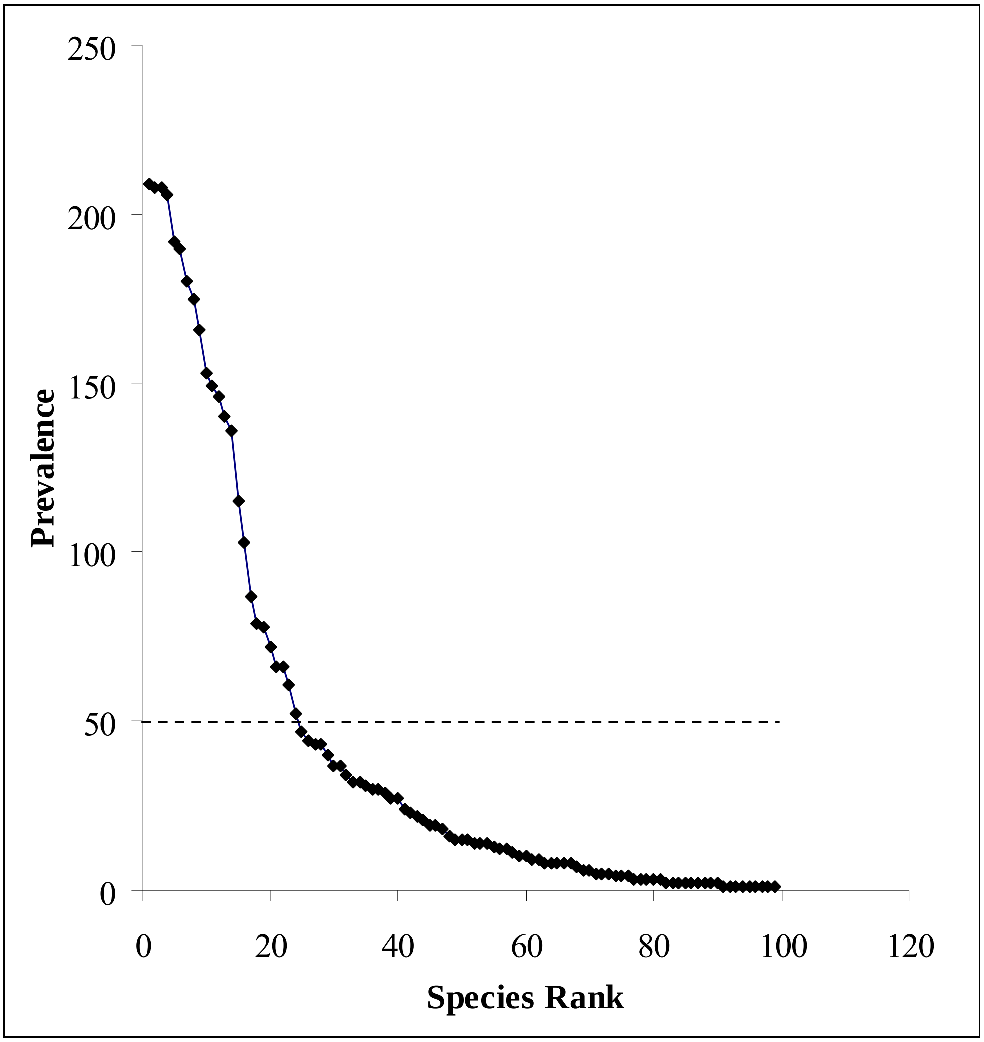


Figure 3.10.7. Rank abundance curve for the prevalence of all species recorded in surveys between 2002 and 2007. The dashed line indicates the cut-off for "prevalent" species, which represents the breakpoint where a functional shift in the relationship between successive species occurs.

Table 3.10.21.

"Prevalent" species at the EFGB and WFGB from 2002-2007.

Rank	Common Name	Scientific Name	# Surveys	Proportion of Surveys
1	Threespot damselfish	*Stegastes planifrons*	209	84.62%
2	Bicolor damselfish	*Stegastes partitus*	208	84.21%
3	Bluehead wrasse	*Thalassoma bifasciatum*	208	84.21%
4	Brown chromis	*Chromis multilineata*	206	83.40%
5	Blue tang	*Acanthurus coeruleus*	192	77.73%
6	Queen parrotfish	*Scarus vetula*	190	76.92%
7	Creole fish	*Paranthias furcifer*	180	72.87%
8	Great barracuda	*Sphyraena barracuda*	175	70.85%
9	Creole wrasse	*Clepticus parrae*	166	67.21%
10	Spanish hogfish	*Bodianus rufus*	153	61.94%
11	Blue chromis	*Chromis cyanea*	149	60.32%
12	Sharpnose puffer	*Canthigaster rostrata*	146	59.11%
13	Stoplight parrotfish	*Sparisoma viride*	140	56.68%
14	Black durgon	*Melichthys niger*	136	55.06%
15	Reef butterflyfish	*Chaetodon sedentarius*	115	46.56%
16	Bermuda chub	*Kyphosus sectator*	103	41.70%
17	Yellowtail damselfish	*Microspathodon chrysurus*	87	35.22%
18	Redband parrotfish	*Sparisoma aurofrenatum*	79	31.98%
19	Princess parrotfish	*Scarus taeniopterus*	78	31.58%
20	Bar jack	*Caranx ruber*	72	29.15%
21	Clown wrasse	*Halichoeres maculipinna*	66	26.72%
22	Sergeant major	*Abudefduf saxatilis*	66	26.72%
23	Doctorfish	*Acanthurus chirurgus*	61	24.70%
24	Yellowhead wrasse	*Halichoeres garnoti*	52	21.05%

Table 3.10.22.

Loadings of the first four principle components on trophic groups (linear correlations between principle component axes and trophic groups). Values in bold face are notably strong correlations.

Trophic Group	PC1	PC2	PC3	PC4
Soft Herbivore	0.34	**0.507**	0.076	0.267
Hard Herbivore	**0.829**	0.002	-0.129	-0.154
Low Invertivore	0.183	0.168	**0.793**	-0.344
Medium Invertivore	0.139	**0.496**	-0.178	-0.364
High Invertivore	**0.663**	-0.295	0.329	-0.067
Small Piscivore	0.17	0.166	0.282	**0.807**
Large Piscivore	**0.598**	**-0.415**	**-0.413**	0.1
Zooplanktivore	0.202	**0.706**	-0.289	-0.012

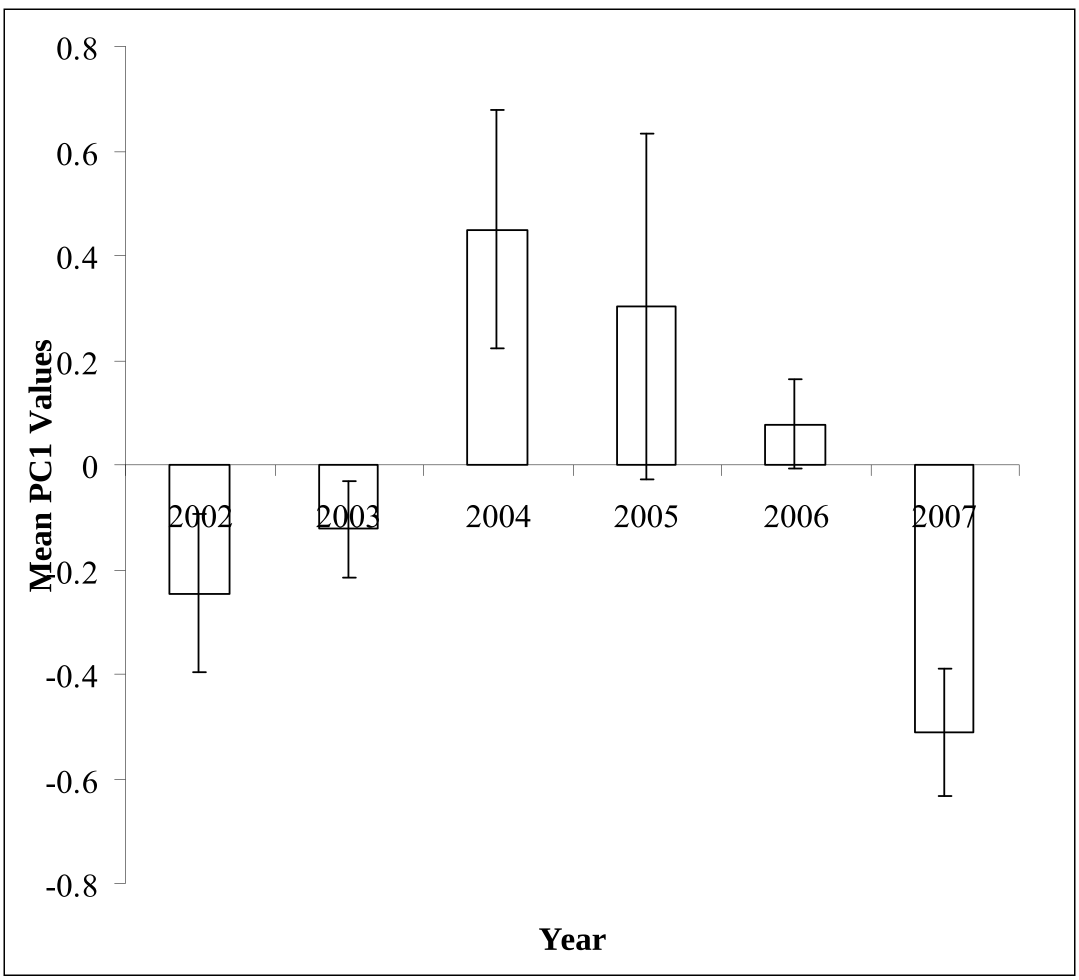


Figure 3.10.8. Temporal variation in PC1 (±SE) for both Banks.

3.11. SEA URCHIN AND LOBSTER SURVEYS

3.11.1. Qualitative Results

In 2004 through 2008, sea urchin and lobster surveys were conducted along the northern and eastern perimeter lines at the EFGB and along the southern and western boundaries at the WFGB. Table 3.11.1 shows the number of individuals recorded during each survey from 2004-2008.

2004. In 2004 at the EFGB, 0.005 individuals/m^2 of both *Diadema antillarum* (long-spined urchin) and *Echinometra lucunter* (rock-boring urchin) were documented during the sea urchin and lobster surveys. At the WFGB in 2004, 0.11 individuals/m^2 of *D. antillarum* and 0.005 individuals/m^2 of *Panulirus argus* (Caribbean spiny lobster) were observed.

Table 3.11.1.

Number of individual sea urchins and lobsters observed during the sea urchin and lobster surveys conducted on the EFGB and WFGB in 2004-2008.

No. of Individuals Observed	**EFGB**					**WFGB**				
	04	**05**	**06**	**07**	**08**	**04**	**05**	**06**	**07**	**08**
Sea Urchins										
Diadema antillarum	2	2	2	1	0	44	5	5	27	30
Echinometra lucunter	2	0	0	0	0	0	1	0	0	0
Echinometra viridis	0	0	1	0	0	0	0	4	0	0
Eucidaris tribuloides	0	0	0	0	0	0	0	1	0	0
Lobsters										
Panulirus argus	0	1	0	0	0	2	0	0	0	0
Panulirus guttatus	0	0	1	1	0	0	0	0	0	0
Scyllarides aequinoctialis	0	0	0	0	0	0	0	0	0	1

2005. In 2005 at the EFGB, *Diadema antillarum* remained at 0.005 individuals/m^2 and *Panulirus argus* was observed at 0.003 individuals/m^2. At the WFGB in 2005, the southern and western lines revealed 0.013 individuals/m^2 of *D. antillarum* and 0.003 individuals/m^2 of *Echinometra lucunter*.

2006. In 2006 at the EFGB, *Diadema antillarum* remained at 0.005 individuals/m^2, while both *Echinometra viridis* (reef urchin) and *Panulirus guttatus* (spotted, spiny lobster) were documented at 0.003 individuals/m^2. At the WFGB in 2006, *D. antillarum* was observed at 0.013 individuals/m^2, while *Echinometra viridis* was noted at 0.01 individuals/m^2, and *Eucidaris tribuloides* (pencil urchin) was documented at 0.003 individuals/m^2.

2007. In 2007 at the EFGB, both *Diadema antillarum* and *Panulirus guttatus* were observed at 0.003 individuals/m^2. At the WFGB in 2007, *D. antillarum* was noted at 0.068 individuals/m^2.

2008. No sea urchins or lobsters were observed at the EFGB in 2008; however, at the WFGB, *Diadema antillarum* was observed at 0.075 individuals/m^2 and *Scyllarides aequinoctialis* (Spanish lobster) was observed at 0.003 individuals/m^2.

It is interesting to note that a higher number of *Diadema antillarum* were observed during the sea urchin and lobsters surveys at the WFGB for the 2004-2008 period, particularly in 2004 (44 individuals; 0.11 individuals/m^2), 2007 (27 individuals; 0.068 individuals/m^2), and 2008 (30 individuals; 0.075 individuals/m^2).

3.11.2. Multidimensional Scaling (MDS) and Similarity Percentage (SIMPER) Analysis

Multidimensional scaling (MDS) analyses were performed on the sea urchin abundance data at the EFGB and WFGB using the 2004-2008 data. The MDS plot (Figure 3.11.1) highlights the dissimilarity between Banks, with the EFGB urchin abundance data clustering separately from the WFGB abundance data. This dissimilarity was due mainly to the abundance of *Diadema antillarum*. The stress level was low at 0.01, indicating high confidence in the relationships displayed. The MDS plot also revealed an outlier value obtained during the 2008 EFGB urchin survey, which yielded none of the targeted species. These null values separated it from all others by Bank or year.

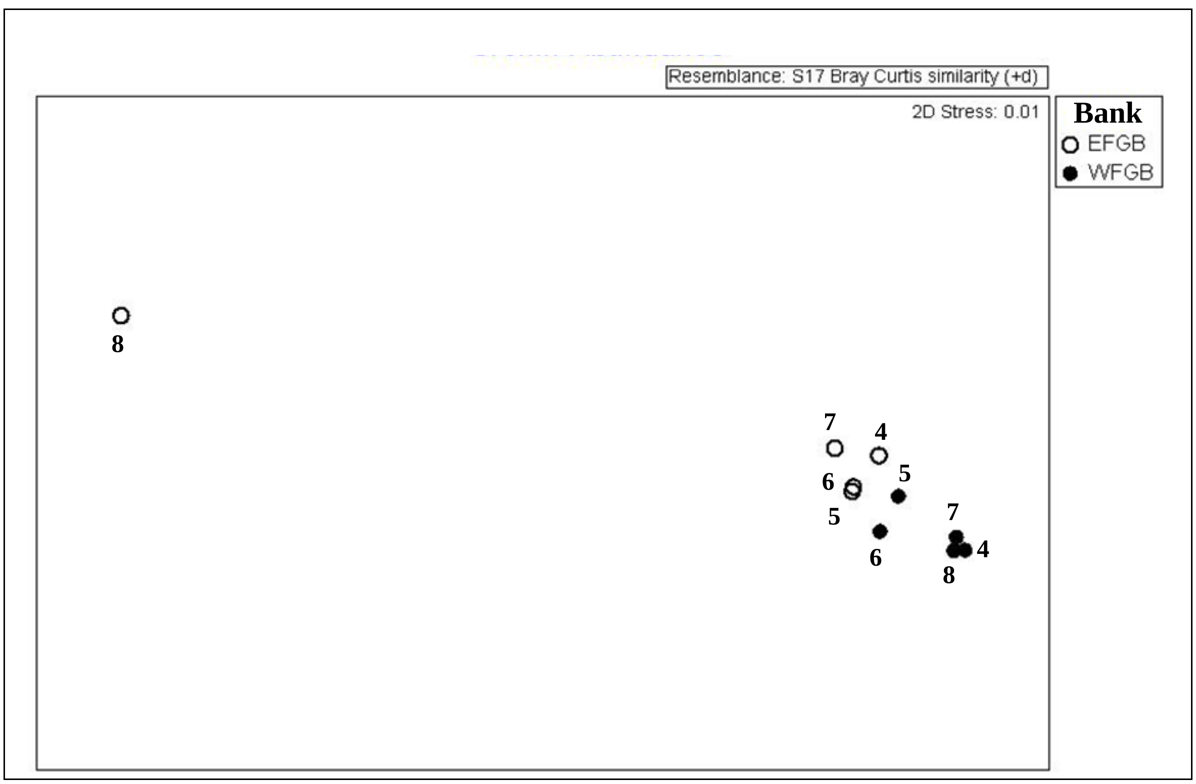


Figure 3.11.1. MDS plot comparing urchin abundance at the EFGB and WFGB from 2004-2008. Abbreviations: 4=2004, 5=2005, 6=2006, 7=2007, and 8=2008.

An analysis of similarity (ANOSIM), comparing Banks regardless of year, found significant separation based on urchin community abundance (R=0.496, p=0.008). A similarity percentage (SIMPER) analysis revealed somewhat low within-group cohesion at only 36.05% and 46.30% (EFGB and WFGB, respectively), but a strong average dissimilarity of 82.83%. All of these relationships were driven by the density of *D. antillarum* with 100% of the similarity and 84.62% of among-group separation values due to their abundance. Bank-wide averages for *Diadema* were 0.056 individuals/m^2 for WFGB and 0.004 individuals/m^2 for the EFGB. We, therefore, conclude that urchin community composition differed between the Banks during the course of study, and that *Diadema* densities were significantly higher on WFGB than EFGB. Due to the low sample size, no such determinations could be made by year.

4.0 DISCUSSION

4.1. Random Transects

The FGB continues to support high coral cover compared to other reefs of the western Atlantic (Aronson et al. 1994, 2005; Gardner et al. 2003). 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 ~50% to ~10%. Natural and anthropogenic factors, including storm events, temperature stress, predation, overfishing, sedimentation, eutrophication and habitat destruction have all played a part in the decline (Aronson and Precht 2001a; Rogers and Beets 2001; Gardner et al. 2003). The loss of acroporid corals to a regional outbreak of white-band disease beginning in the late 1970s was a primary cause of the decline in coral cover (Aronson and Precht 2001a, 2006). In contrast, coral cover at the FGB has remained stable over time (Figure 4.1.1). Univariate analysis of the random transect data revealed that coral cover at the EFGB and WFGB remained steady from 2004 through 2008. Coral cover was also consistent with values from earlier studies (Dokken et al. 2001, Dokken et al. 1999, CSA 1996, Gittings et al. 1992), highlighting the stability of the coral assemblage over time (Figure 4.1.1). 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 high sea-surface temperatures in summer months; 2) their remote offshore location, which limits human access and exposes these reefs to oligotrophic, oceanic waters; 3) the absence (until recently) of acroporid corals, which meant that large areas of bare space could not be opened by coral mortality from white-band disease; and 4) protective federal regulations, which prevent hydrocarbon-related effects, as well as effects from fishing and recreational diving (Aronson et al. 2005). The importance of the FGB, in terms of the entire Atlantic coral reef system as a whole, has been substantially elevated by the regional decline of corals. Consequently, the risk of loss (or estimated loss value) is elevated for the FGB in the event of a severe industrial accident or expansion of the zone of influence of the Mississippi River.

4.1.1. EFGB Comparison 2004-2008

The random transect data for the EFGB showed similar values for coral cover, sponge cover, and H' from year to year. The three most dominant coral taxa—the *Montastraea annularis* species complex, *Diploria strigosa* and *Porites astreoides*—fluctuated to a minor degree (Table 3.1.1). Much of that variation was likely due to the vagaries of 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 error (Dokken et al. 2003, 1999). 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 an increase in macroalgal cover and a decline in CTB cover in 2005, compared to the other sampling years.

4.1.2. WFGB Comparison 2004-2008

The patterns and proposed causes discussed for the EFGB in the preceding paragraph also apply to the WFGB.

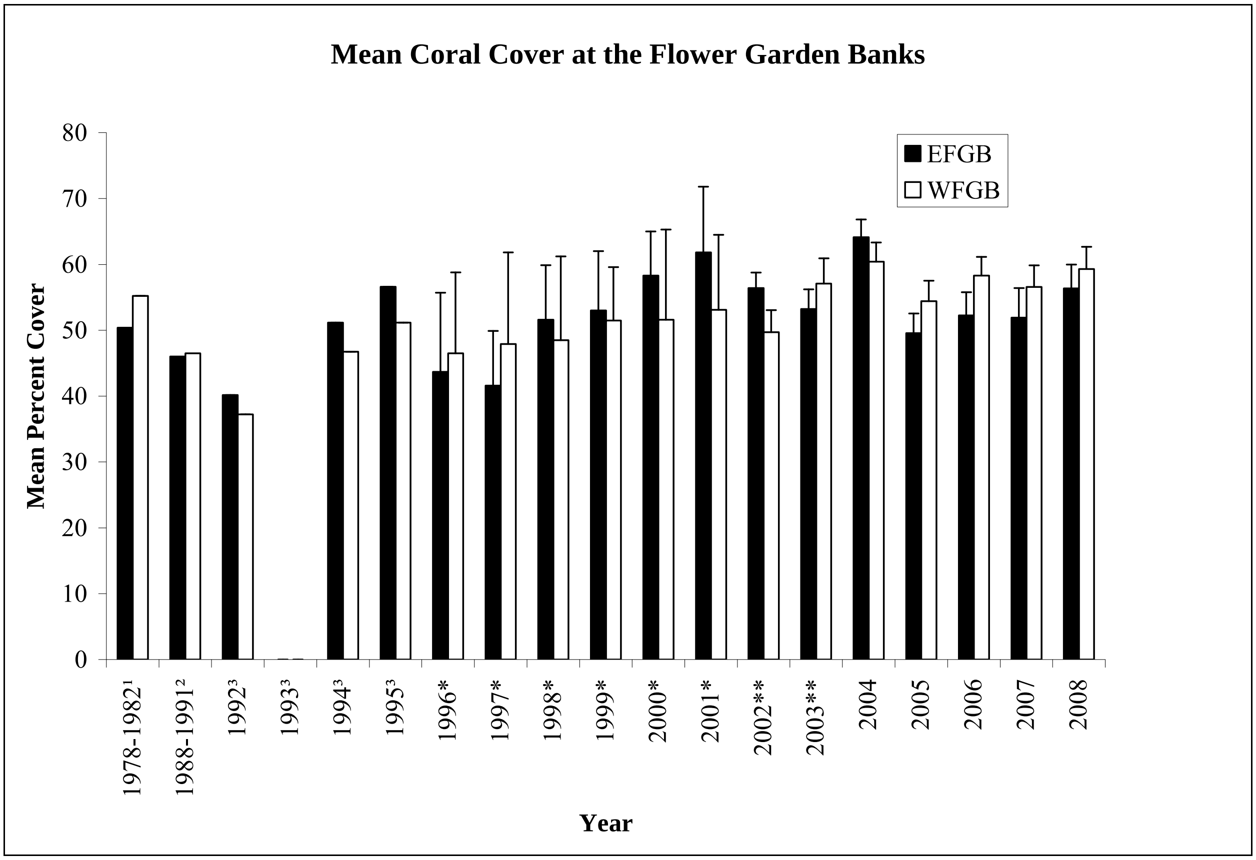


Figure 4.1.1. Mean percent coral cover at the EFGB and WFGB over time, showing the consistently high coral cover. No percent cover data were reported in 1993. Data for 1978-1982 from Gittings et al. (1992), who reported data from Kraemer (1982); for 1988-1991 from Gittings et al. (1992); for 1992-1995 from CSA (1996); for 1996-2001 from Dokken et al. (2003); for 2002-2003 from Precht et al. (2006); and for 2004-2005 from Precht et al. (2008b).

High macroalgal cover and low CTB cover in 2005 were initially thought to be artifacts of sampling season. Those data were collected in June, whereas in transects videotaped in the fall (September at the EFGB and November at the WFGB) of 2004, macroalgal cover was lower and CTB cover was higher. Seasonal effects have been documented for other coral reef macroalgal populations (Diaz-Pulido and Garzon-Ferreira 2002). The random transects from 2006 (data collected in June), 2007 (also collected in June) and 2008 (collected in November), however, do not support the hypothesis of a seasonal effect. Table 3.1.1 shows that the putative seasonal pattern is driven largely by the 2005 results from the EFGB. Any general mechanistic hypothesis to explain the 2005 anomaly would, therefore, be difficult to support with these data. Regardless of the cause(s) of the spike in macroalgae at the EFGB in 2005, it is unlikely that CTB disappeared during times of increased macroalgal coverage; rather, it was likely covered by macroalgae when conditions were favorable for macroalgal growth and survived cryptically. Seasonal variations were documented in previous studies at the FGB, but despite these variations coral cover remained stable (CSA 1996; Dokken et al. 1999, 2001).

4.1.3. Qualitative Comparison of Random Transect Results from 1992-2008

A qualitative comparison of the dominant cover components from the random transects showed interesting results for several cover categories: *Montastraea annularis* species complex, algae, and “reef rock.” The data analyzed in this section were collected by three different groups: Continental Shelf Associates, Inc. (CSA) from 1992 to 1995; Dokken et al. 2003 from 1996 to 2001; and PBS&J from 2002 to 2008 (Precht et al. 2006, 2008b; Tables 4.1.1 and 4.1.2). The ‘algae’ category from 1992 to 2001 was roughly equivalent to ‘macroalgae’, as analyzed in 2002-2008. The ‘reef rock’ category from 1992 to 1995 and 1998-2001 included bare substrate and was equivalent to the 2002-2008 ‘CTB’ category. In 1996 and 1997 no data were recorded for the reef rock category.

The *Montastraea annularis* species complex showed an overall increase in cover during the period of 1992-2008 at the WFGB. It fluctuated at the EFGB but remained consistently at or above 20% (Figure 4.1.2). There were slight decreases in the *M. annularis* species complex in 1996, 1999, and 2003 at the EFGB and in 1996, 2000, 2004, and 2007 at the WFGB. These decreases generally coincided with increases in the algal component and decreases in the reef rock category. Despite slight depressions in the *M. annularis* species complex, the upward trend was reestablished after one year at both Banks (Figure 4.1.2).

Local and regional weather patterns affect benthic communities such as 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 (Goreau and Hayes 1994; Glynn 1993; Glynn 1984; 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 different seasonal conditions (Diaz-Pulido and Garzon-Ferreira 2002). Algal cover at the FGB, here taken to mean macroalgae, remained relatively low from 1992 to 1998, never reaching more than 4.78% at either Bank until it increased dramatically in 1996 at EFGB and at both the EFGB and WFGB in 1999 (Tables 4.1.1 and 4.1.2, Figure 4.1.2). Concurrent with the increase in algae, the reef-rock category declined from ~28% to ~11% at the EFGB in 1999 and from ~21% to ~9% in 2000 at the WFGB. In 2001, the reef rock category began an increasing trend at both the EFGB and WFGB, while algae declined (Figure 4.1.2). At the same time that algae increased and reef rock decreased, the *Montastraea annularis* species complex decreased slightly in 1999 (EFGB) and 2000 (WFGB), but the *M. annularis* species complex continued to trend upward a year later (Figure 4.1.2).

Table 4.1.1.

EFGB and WFGB random transect data for predominant cover categories as reported in CSA (1996) for data from 1992-1995 and Dokken et al. (2003) for data from 1996-1999. Values listed in table are the mean percent covers for coral, algae, and reef rock. Standard deviations are shown in parentheses.

EFGB Random Transect Data

	1992	1994	1995	1996	1997	1998	1999
Montastraea annularis species complex	24.12	26.93	35.65	21.3 (14.2)	21.6 (8.1)	30.4 (11.1)	28.2 (11.7)
Diploria strigosa	4.69	8.92	7.92	10.1 (7.1)	5.1 (4.4)	8.3 (3.7)	12.4 (6.0)
Montastraea cavernosa	1.49	4.80	3.20	3.7 (5.3)	4.7 (4.9)	3.5 (2.9)	2.4 (2.8)
Porites astreoides	4.57	3.89	2.71	3.6 (1.5)	5.3 (3.0)	4.2 (3.0)	3.4 (1.7)
Algae	4.78	0.29	0.57	6.1 (5.2)	0.5 (0.6)	3.2 (2.6)	24.7 (13.2)
Reef Rock	54.46	47.31	42.15	-	-	27.6 (5.9)	11.1 (8.2)

WFGB Random Transect Data

	1992	1994	1995	1996	1997	1998	1999
Montastraea annularis species complex	23.02	24.95	31.00	27.2 (8.3)	27.7 (9.9)	28.4 (11.9)	31.7 (8.6)
Diploria strigosa	6.15	10.15	6.66	7.9 (3.5)	9.1 (5.9)	9.6 (4.8)	10.9 (7.8)
Montastraea cavernosa	0.87	3.15	2.33	1.5 (2.2)	4.3 (4.2)	2.6 (2.4)	2.4 (3.5)
Porites astreoides	1.49	2.55	2.44	2.5 (1.4)	2.7 (2.3)	2.4 (2.0)	2.7 (1.9)
Algae	4.45	0.42	2.7	4.5 (2.9)	0.1 (0.1)	2.3 (1.3)	18.8 (6.2)
Reef Rock	56.56	51.08	45.85	-	-	20.7 (11.2)	21.1 (9.8)

Table 4.1.2.

EFGB and WFGB random transect data for predominant cover categories as reported in Dokken et al. (2003) for data from 2000-2001, Precht et al. (2006) for data from 2002-2003, and Precht et al. (2008b) for data from 2004-2005, and this report for 2006-2008. Values listed in table are the mean percent covers for coral, algae, and reef rock. Standard deviations are shown in parentheses for 2000-2001 and standard errors for 2002-2008.

EFGB Random Transect Data

	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Montastraea annularis species complex	39.5 (9.6)	44.8 (12.9)	33.59 (3.86)	28.47 (2.98)	30.14 (4.76)	26.8 (4.09)	31.45 (4.09)	32.44 (4.62)	33.58 (4.52)
Diploria strigosa	6.2 (2.8)	3.9 (4.1)	6.96 (1.69)	6.19 (1.55)	12.13 (2.82)	5.95 (1.26)	10.25 (1.52)	5.82 (1.11)	7.69 (2.00)
Montastraea cavernosa	4.8 (5.7)	3.6 (5.0)	3.9 (1.08)	4.24 (1.41)	7.73 (1.94)	3.4 (1.14)	2.48 (0.67)	3.74 (0.94)	2.84 (0.92)
Porites astreoides	2.6 (1.7)	4.6 (2.7)	6.79 (0.83)	5.69 (0.98)	8.19 (0.99)	7.55 (1.19)	4.91 (0.83)	5.81 (0.88)	7.27 (1.19)
Algae	17.3 (4.9)	14.9 (5.6)	4.06 (0.75)	16.74 (2.05)	12.03 (2.77)	34.03 (2.58)	21.10 (2.32)	21.73 (2.28)	24.06 (2.16)
Reef Rock	4.3 (1.7)	5.7 (3.6)	37.07 (2.69)	28.12 (2.05)	20.89 (3.08)	11.96 (1.49)	23.15 (1.94)	24.43 (2.11)	17.64 (1.77)

WFGB Random Transect Data

	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Montastraea annularis species complex	30.9 (11.6)	35.1 (12.0)	31.73 (3.57)	33.8 (4.31)	31.70 (2.70)	36.2 (3.50)	40.13 (3.29)	35.50 (3.81)	37.01 (4.65)
Diploria strigosa	8.1 (6.7)	9.5 (5.8)	3.2 (0.91)	9.04 (2.68)	13.41 (1.74)	6.68 (1.29)	10.14 (1.64)	9.56 (1.85)	8.98 (2.43)
Montastraea cavernosa	5.8 (11.7)	2.1 (3.7)	2.74 (1.16)	2.67 (1.10)	3.70 (1.01)	2.43 (0.69)	2.25 (0.84)	1.84 (0.53)	2.81 (1.05)
Porites astreoides	2.5 (1.6)	2.0 (0.9)	3.44 (0.74)	3.77 (0.46)	5.19 (0.62)	4.04 (0.46)	3.39 (0.57)	3.61 (0.44)	3.62 (0.64)
Algae	22.6 (14.0)	25.4 (7.3)	19.14 (1.4)	8.41 (1.41)	14.75 (1.50)	18.35 (1.44)	12.38 (1.34)	17.64 (2.44)	12.06 (1.31)
Reef Rock	8.5 (3.7)	4.6 (2.9)	27.63 (3.14)	31.63 (3.04)	20.85 (2.11)	18.27 (1.67)	25.64 (2.06)	24.27 (1.89)	26.74 (2.41)

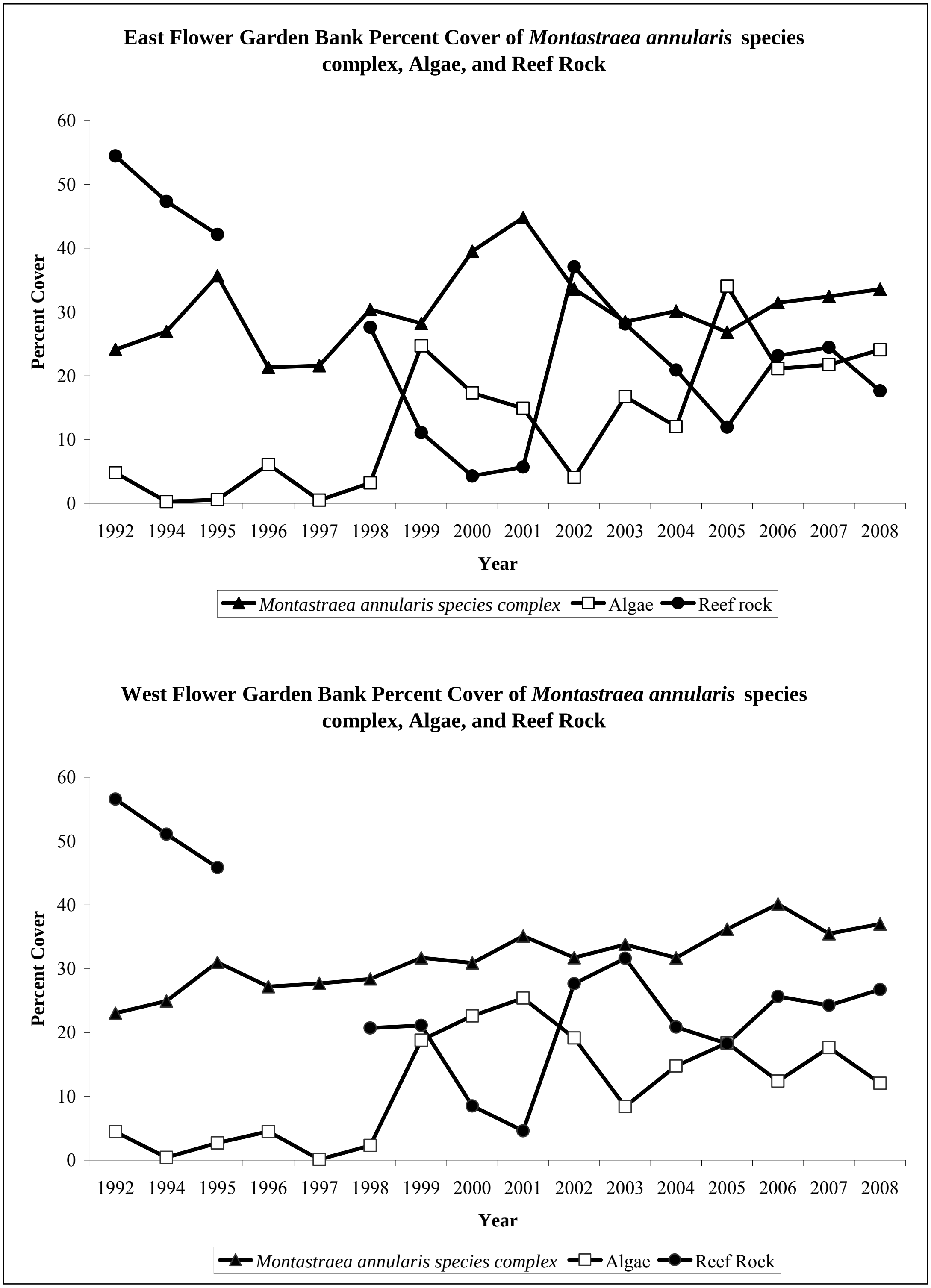


Figure 4.1.2. Percent cover of *Montastraea annularis* species complex, algae, and reef rock from 1992-2008: EFGB and WFGB.

Shifts in algae, *Montastraea annularis* species complex, and reef rock occurred in many parts of the Caribbean in the aftermath of the strong ENSO events of 1995 and 1998, which caused widespread coral bleaching throughout the region. Many areas affected by severe bleaching experienced coral mortality, and increased turf and macroalgae cover, in the weeks and months following ENSO-related heating events (McField 1999; Aronson et al. 2000; Ostrander et al. 2000). After the 1995 ENSO in Belize, McField (1999) documented 50% coral bleaching at fore-reef sites in Belize. Six months after the high-temperature event, ~10% of colonies experienced at least partial mortality. Kramer and Kramer (2000) reported remnant bleaching at fore-reef sites eight months following the onset of bleaching in 1998. Aronson et al. (2000, 2002; see also Peckol et al. 2003) reported nearly 100% mortality of the dominant coral *Agaricia tenuifolia* at southern lagoon reefs of the Pelican Keys, Belize. Mumby (1999) found that although ~80% of coral colonies bleached at Glover's Atoll (Belize), the colonies regained their pigment in subsequent months. In contrast to these events, after the ENSO of 1995 and 1998, the FGB experienced a slight increase in macroalgae and a decline in bare rock (CTB). While *M. annularis* species complex, the dominant coral taxon at the FGB, declined slightly at the EFGB in 1996, there was no measurable effect at the WFGB. By 2000, *M. annularis* species complex cover was near its highest level (Tables 4.1.1 and 4.1.2, Figure 4.1.2). These slight shifts in community dynamics continue to be an interesting avenue of research, and the coral reef system of the FGB remains one of the best places to study the subtleties of these patterns.

4.2. Sclerochronology

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 growth rates of *Montastraea annularis* documented over a wide geographic range throughout the Caribbean vary from 3-12 mm/yr (Weber and White 1977). Growth rates have been shown to vary with depth, 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 1928-1978. The accretionary growth of *M. annularis* at the FGB was documented by Hudson and Robbin (1980), who obtained an average annual growth rate of 8.46 mm/yr and a range of 7.15 to 10.58 mm/yr from 1887 to 1979. Dokken et al. (2001) showed a lower growth rate for the period 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 an explanation for the observed differences. However, Dodge and Lang (1983) used data from Hudson and Robbin (1980) to correlate growth rates at the FGB with temperature and discharge from the Atchafalaya River. Their data indicated that coral extension rates varied positively with seasonal (February through May – 4 months) surface water temperature and negatively with annual discharge from the Atchafalaya River. They found an overall decline in temperature and growth rates from 1950 to 1960, with a marked depression after 1957. From the early 1960s to 1979, coral growth was variable and lower than pre-1957 rates (Dodge and Lang 1983).

During our 2005 sampling period, *Montastraea faveolata* growth ranged from 3.19-14.54 mm/yr at the EFGB and 2.24-8.78 mm/yr at the WFGB. These results differed slightly from the growth rates reported by Precht et al. (2006) but agreed with 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 EFGB, and less so at the WFGB, continued to be in the middle to upper range of FGB growth rates as recorded by Hudson and Robbin (1980). Three out of four 2005 cores showed discontinuities in accretion, occurring at different times in each core (Table 3.2.1). In all cases, the colonies had subsequently recovered. Stress or partial mortality may have been caused by bleaching, which has occurred throughout the Caribbean region and the FGB since long-term monitoring began in 1988 (Dokken et al. 2001, 2003).

When compared to the past two coring events (2003 and 2005), the 2007 core data do not appear substantially different with respect to mean growth rates (Figure 4.2.1). However, the range of annual growth from the 2007 samples does not show the same magnitude as the 2003 and 2005 samples. The 2007 observations exhibited a reduced range of individual growth rates with a variance of only 0.74, whereas previous sampling years (2003 and 2005) found drastically higher degrees of intracolonial variability with variances of 4.72 and 4.11, respectively.

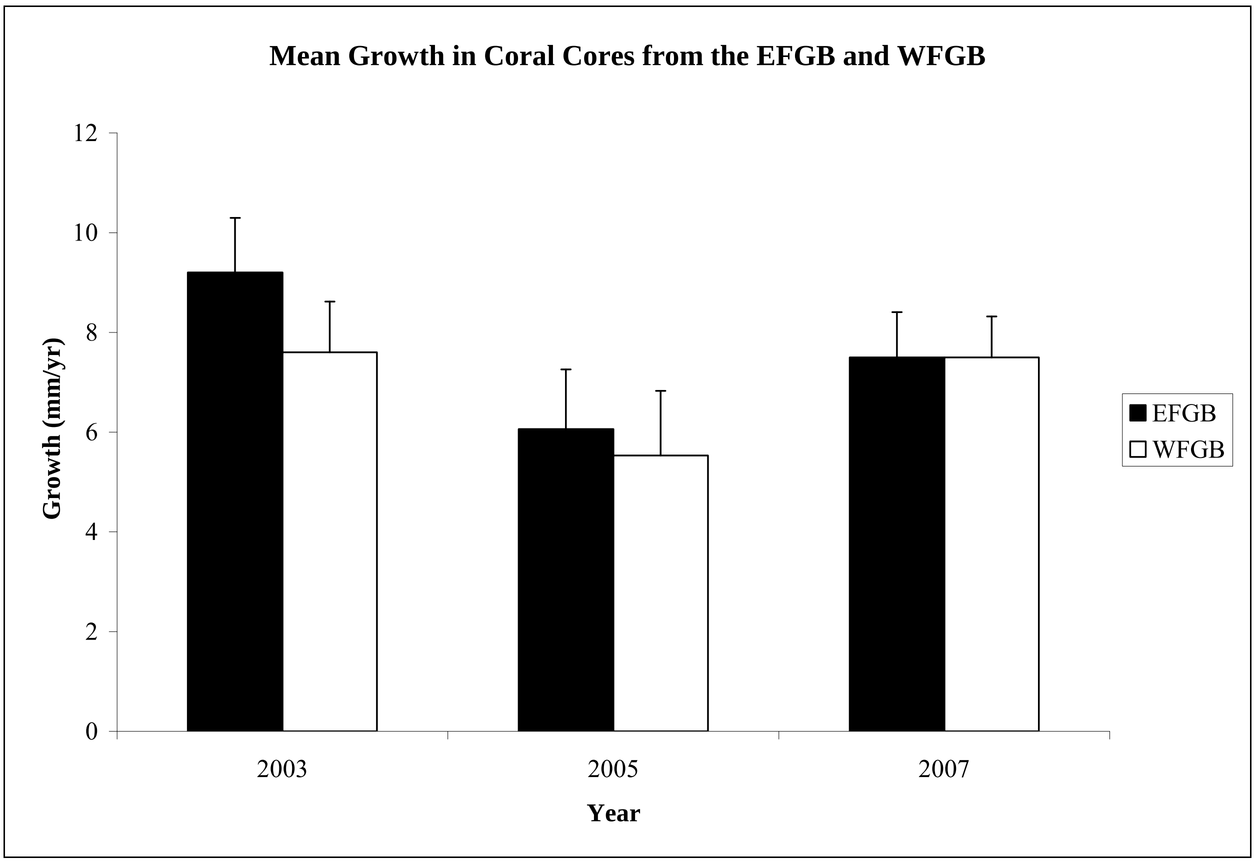


Figure 4.2.1. Overall mean annual growth rates based on analysis of *Montastraea faveolata* cores collected in 2003, 2005, and 2007 from the EFGB and WFGB. Error bars represent standard error in 2003 and 2005, and standard deviation in 2007.

The current sampling protocol, in which four cores are taken from each Bank every other year, is useful for tracking the short-term growth rates (~10 years) of large *Montastraea faveolata* colonies and monitoring physical changes within the cores. Long-term growth rates (10+ years) cannot be obtained using this method. Longer cores on which stable isotope analysis can be conducted, such as the ones taken by Amy Bratcher at Texas A&M University, Department of Oceanography, will show salinity and temperature data over time. This information will be a valuable addition, potentially revealing regional influences, such as Mississippi River output, on water quality affecting the corals at the FGB.

4.2.1. Why *Montastraea faveolata*?

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). These studies have demonstrated that growth in massive colonies of *M. faveolata* is more or less evenly distributed over the entire surface, except for the underside, and distinct annual growth bands are accreted along the axis of growth. An annual band is comprised of a high and low-density portion, representing changes in both the rate of linear skeletal extension and calcification. It has also 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.

4.2.2. Reef Disturbance, Coral Growth and Stress Bands

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. The use of X-radiography, however, has shown significant suppression of coral growth as a result of disturbance. This has been observed during short-term exposure of *M. faveolata* to high concentrations of drilling mud (Hudson and Robbin 1980), as well as by transferring *M. faveolata* from an offshore location to a more stressful inshore site (Hudson 1981b).

In long-term growth studies of *Montastraea faveolata* from the EFGB (Hudson and Robbin 1980), and also sites within the Key Largo Coral Reef National Marine Sanctuary, Florida (Hudson 1981a; 1984), a decline in growth rates has been observed. In these studies, the authors could not directly attribute apparent growth suppression to any single environmental disturbance. They did note, however, that reduced growth rates in the Florida Keys coincided with a period of dredge-and-fill operations. Whereas, Dodge and Lang (1983) and Dodge and Szmant-Froelich (1984) suggested that the decline in *M. faveolata* growth rates at the FGB may have been due to water temperature fluctuations and increasing river discharge.

Another 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). The skipped bands or lost years (visible as disconformity surfaces) in our 2005 core samples resulted from localized coral mortality followed by healing and re-sheeting of the colony.

From August through November 2005, the EFGB and WFGB experienced an extreme warming of the water column which was associated with severe coral bleaching (Hickerson and Schmahl, personal communication, 2005b). In November 2005, at the EFGB, approximately 9.74% of coral points assessed were bleached. The species most impacted were *Montastraea cavernosa* (4.81%), the *M. annularis* species complex (3.28%), and *Millepora alcicornis* (1.13%; Precht et al. 2008a). The 2005 coral core collection occurred prior to this bleaching event; thus, the 2007 coral cores were examined for evidence of impacts to *Montastraea faveolata*. The 2007 coral cores did not indicate a substantial drop in growth during 2005 (Figure 3.2.3). Rather, for all eight of the 2007 coral cores, the largest decrease in growth (2000-2007) occurred in 2006. Possible explanations for the 2006 reduction remain unclear; however, post-hurricane bleaching events occurred late in 2005 and may have impacted *M. faveolata* skeletal extension well into 2006. By June 2006, the bleaching event had subsided at the EFGB (Robbart et al. 2009) and the 2007 coral cores show that coral skeletal extension during 2007 had returned to previously recorded levels.

4.3. LATERAL GROWTH

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 (Dokken et al. 2001, 2003; Precht et al. 2006). Lateral growth measurements do not take into account the fact that individual corals may grow at different rates along different margins. While some margins may be advancing, others on the same colony may be retreating, potentially altering the overall picture of lateral change in a given colony and by extension a given Bank and year. Additionally, lateral growth measurements do not take into account the height extension of *Diploria strigosa*.

Net lateral growth of *Diploria strigosa* was positive during the study period. Variability was high at multiple spatiotemporal scales, however, and in one case the results were strongly influenced by a significant effect of the initial area of living tissue in the photo-stations. For future monitoring efforts, sample sizes sufficient for an ANCOVA approach to data analysis across multiple intervals (which was not possible in this study) will ensure that the initial area does not confound the detection and interpretation of pattern.

4.4. REPETITIVE QUADRATS

4.4.1. Study Site Quadrats

Repetitive 8-m^2 quadrats were analyzed for percent cover of benthic components, including coral species, sponge, macroalgae, CTB, and the cover of coral health indicators (bleaching, paling, concentrated fish biting, isolated fish biting, and disease), and were compared for the period 2004-2008. Higher coral cover estimates were obtained from the repetitive quadrats in comparison to the random transects at both the EFGB and WFGB. Higher percent coral cover in repetitive quadrats relative to random transects was also documented in previous reports (Dokken et al. 2003; Precht et al. 2006, 2008b). One likely reason for this difference is that repetitive quadrat stations were not installed in random locations but were placed in areas of high coral cover (large coral colonies) to monitor community change over time.

Species distributions were similar to that in the random transects, with the predominant 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 2004-2008: 39.45%; WFGB average for the same period: 43.36%) than in the random transects (EFGB average from 2004-2008: 30.88%; WFGB average for the same time period: 36.11%). *Porites astreoides* and *M. cavernosa* were roughly equivalent in repetitive quadrats, whereas *P. astreoides* was consistently higher than *M. cavernosa* in the random transect data (see also Dokken et al. 2003). These differences were small and were probably methodological artifacts.

Coral disease was absent from analyzed quadrats at both Banks in all years (Table 3.4.1-3.4.2). This could signify a decline in disease within the study areas from past monitoring efforts, when low levels of disease were observed (WFGB 2000-2001: 0.3-0.4% cover; Dokken et al. 2003). It should be remembered however, that disease identification from photographs is problematic and that the quadrat photos are taken at a distance of $\geq$ 2 m (6.6 ft). Paling and bleaching were extremely rare, ranging from 0-0.62% (Tables 3.4.1 and 3.4.2). These values are similar to findings of previous investigations (Dokken et al. 2003). Bleaching occurred most frequently on colonies of *Millepora alcicornis*, while paling occurred primarily on *Diploria strigosa* and on the *Montastraea annularis* species complex (Tables 3.4.3 and 3.4.4). Concentrated fish biting and isolated fish biting were similarly rare at each Bank, ranging from 0.21-4.73% in all years (Tables 3.4.1 and 3.4.2). Fish biting occurred primarily on the *Montastraea annularis* species complex (Tables 3.4.3 and 3.4.4).

To document the dynamics of particular coral colonies at the FGB, the repetitive quadrats were analyzed using planimetry. In each frame, one to four colonies of framework-building corals, the margins of which were clearly defined, were chosen for analysis. *Montastraea annularis* species complex, the main contributor to coral cover at the FGB, showed proportional growth similar to the *Diploria strigosa* colonies documented in the lateral growth stations.

4.4.2. Deep Station Quadrats

Coral cover was high in the deep-station quadrats, ranging from 72-86% between 2004 and 2008 and averaging 77% over all years and both Banks. The deep stations were dominated by

Montastraea annularis species complex. *M. cavernosa* was the second-most dominant coral species, unlike the shallower study sites and unlike the deeper *Stephanocoenia-Millepora* zone (36-48 m or 118-157 ft) described by Rezak et al. (1985). The difference between this area and the one described by Rezak et al. (1985) was probably due to natural spatial variability and/or the small sample area of 72 m^2 or 775 ft^2 (9 stations x 8 m^2).

Lateral growth of colonies of *Montastraea annularis* species complex was variable from year to year and highest in 2006-2007. Low sample sizes limited statistical power, however, making it difficult to draw firm conclusions.

4.5. PERIMETER VIDEOGRAPHY

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 and fish populations at the study sites from 2004 to 2008. Similar to the findings from the random transects, coral condition appeared to be very good at both Banks in all years. There were no signs of coral disease and only a few incidences of bleaching, with the highest bleaching levels occurring at the EFGB and the WFGB in June 2006. The most noticeable impacts to coral colonies, observed at both Banks during the sampling period (2004-2008), were concentrated and isolated fish biting. Concentrated fish biting is likely caused by fish from the genus *Sparisoma* (Bruckner and Bruckner 2000). Initial- and terminal-phase stoplight parrotfish (*Sparisoma viride*) are known to remove coral polyps during their foraging activities, creating deep lesions on coral colonies (Bruckner and Bruckner 2000; Figure 4.5.1). When *S. viride* were experimentally removed from affected reef areas in the Caribbean, fish biting lesions either healed completely or ceased to increase in size (Bruckner and Bruckner 2000). Isolated fish biting at the FGB may be attributed to damselfish territories. From 2004 to 2008, the *Montastraea annularis* species complex was the coral taxa most impacted by fish biting on the EFGB and the WFGB.

Based upon perimeter video surveys, fish populations were similar at both Banks in all years (Appendix 6). Dominant fish species included creole fish (*Paranthias furcifer*), brown chromis (*Chromis multilineata*), blue chromis (*C. cyanea*), damselfishes (Pomacentridae), and creole wrasse (*Clepticus parrae*; Appendix 6). Fish abundance levels fluctuated at the FGB from 2002-2008 (Figure 4.5.2). At the EFGB, fish abundance levels drastically decreased between 2003 and 2004 and then remained relatively stable until 2008 (Figure 4.5.2). At the WFGB, fish abundance decreased from 2002 to 2004, increased from 2004 to 2007, and then drastically decreased between 2007 and 2008 (Figure 4.5.2). According to perimeter video results, fish were most abundant at the WFGB in June 2007 (905 documented individuals) due to the large numbers of creole fish (*P. furcifer* – 251 individuals), brown chromis (*C. multilineata* – 244 individuals), and creole wrasse (*C. parrae* – 162 individuals; Appendix 6). Fish abundance was also high at the EFGB in 2003 (901 documented individuals; Figure 4.5.2; Precht et al. 2006). Dominant species at the EFGB in 2003 included brown chromis (*C. multilineata* – 209 individuals), creole wrasse (*C. parrae* – 172 individuals), and blue chromis (*C. cyanea* – 158 individuals; Precht et al. 2006; Appendix 6). According to perimeter video data, fish abundance was lowest at the WFGB in November 2004 (Figure 4.5.2).

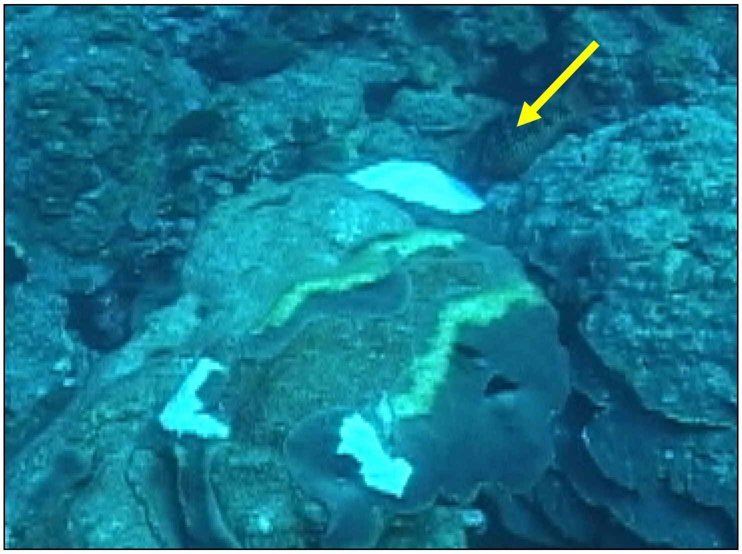


Figure 4.5.1. Concentrated fish biting on colony of *Montastraea annularis* species complex by initial-phase stoplight parrotfish (*Sparisoma viride*).

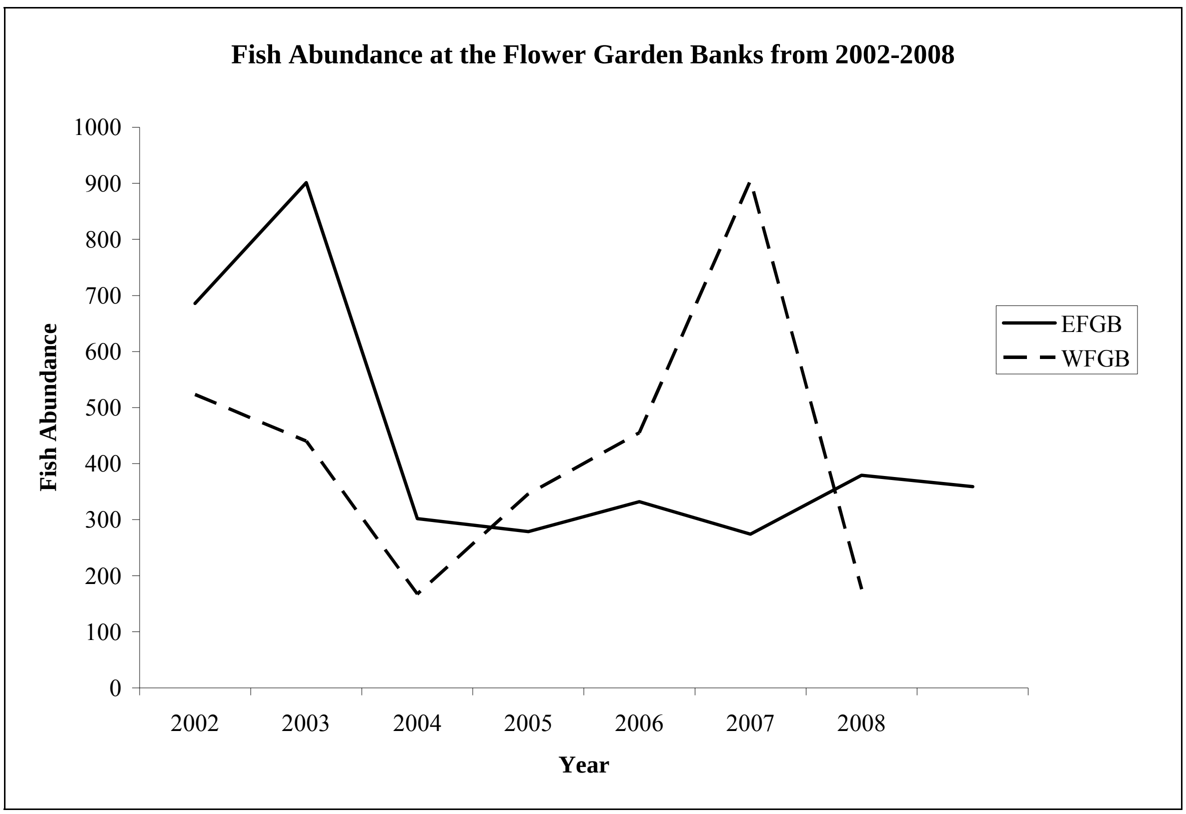


Figure 4.5.2. Fish abundance at the FGB along perimeter lines and 360º panoramic views from 2002-2008.

Fish recorded in the 360° panoramic views were largely represented by species that inhabit the water-column, including creole wrasse (*Clepticus parrae*), creole fish (*Paranthias furcifer*), brown chromis (*Chromis multilineata*), and blue chromis (*C. cyanea*). In comparison to the perimeter video surveys, damselfish numbers were notably less abundant in the 360° panoramic views. This is a result of the camera angle during the 360° panoramic views (horizontal to the substrate), which documents only a small portion of the substrate.

According to the fish cylinder survey results presented in this report (section 3.10), the highest fish abundance occurred at the EFGB in 2004 (5,332 individuals; Tables 3.10.1 and 3.10.2), which differs from the perimeter video results. In addition, it is not possible to determine fish sizes from perimeter video lines or panoramic views because there is no scale reference. Thus, the perimeter video data may not accurately reflect the status of the FGB fish populations. The perimeter surveys are intended to provide a general overview of ecosystem health.

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. This is due to the flexible nature of the perimeter lines between the fixed corner markers, which are 100 m apart, as well as the reinstallation of missing corner markers in slightly different positions compared to previous years. Shifting perimeter lines and/or corner marker positions were mostly apparent at the FGB between 2005 and 2006 and between 2007 and 2008. Two major hurricanes passed near the FGB in September 2005 (Hurricane Rita) and September 2008 (Hurricane Ike), damaging and removing some corner marker locations (Figure 3.6.3). Because of shifting perimeter lines and the corresponding lack of overlapping video footage, fewer coral comparisons were made between 2005 and 2006, and 2007 and 2008 at the FGB. In addition, the 2-m height above the substratum and the 45º angle were not always maintained, which changed the view and therefore the corals analyzed each year.

4.6. HURRICANE IKE IMPACTS

The storm track of Hurricane Ike, a Category 3 Saffir-Simpson Index storm, passed ~0.7 km (0.4 mi) from mooring buoy number 2 at the EFGB study site on September 12, 2008. Hurricane impacts were observed in both repetitive quadrat photographs and perimeter video surveys at the FGB in November 2008.

Repetitive quadrat photographs were compared between June 2007 and November 2008 to assess potential impacts from the passage of Hurricane Ike. The results of this analysis indicated that 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. At the EFGB study site, 35 coral colonies (1.56 m^2 or 0.6% of the area evaluated in the repetitive quadrat photographs from the EFGB) were missing, whereas only six colonies (0.76 m^2 or 0.3% of the area evaluated in the repetitive quadrat photographs from the WFGB) were missing at the WFGB study site. These values are likely an under-representation of hurricane impacts. Dislodged coral colonies were observed outside of the repetitive quadrats at the FGB and not included in the sampling. Similarly, some quadrats were not found and photographed in November 2008 (i.e., eight repetitive quadrat stations at the EFGB and six at the WFGB) and could contain additional, missing coral colonies. The coral species at the EFGB study site that were affected were *Diploria strigosa* (12 colonies and 1.243 m^2 missing), *Porites astreoides* (19 colonies and 0.283 m^2 missing), *Madracis decactis* (3 colonies and 0.027 m^2 missing), and *Mussa angulosa* (1 colony totaling 0.009 m^2). While fewer colonies of *D. strigosa* were missing compared to *P. astreoides*, the *D. strigosa* colonies were substantially larger, accounting for the greater impact to coral area. The missing *P. astreoides* colonies were mostly small (between 0.0017 m^2 to 0.059 m^2), with 79% of missing colonies less than 0.02 m^2. At the WFGB study site, the affected coral species were *D. strigosa* (four colonies and 0.462 m^2 missing) and *Montastraea annularis* species complex (two colonies and 0.296 m^2 missing).

The EFGB deep stations repetitive quadrat data showed that the deep stations were slightly less impacted than the two, relatively shallow study sites. Only three coral colonies (0.101 m^2 or 0.1% of the area evaluated in repetitive quadrat photographs from the EFGB deep stations) were impacted at the EFGB deep stations. Located at greater depths (32-40 m), the EFGB deep repetitive quadrat stations are more protected from waves and high water velocities than the shallower study sites. However, it is important to note that despite this protection, corals at the deep stations were still impacted, suggesting that the effects of Hurricane Ike were experienced at depths of at least 32 m, if not deeper.

The June 2007 and November 2008 perimeter videos were compared and observations of missing corals along the perimeter lines at the EFGB (north and east lines) and WFGB (south and west lines) were noted as evidence of hurricane impacts (i.e., dislodgement of entire coral colonies). Few coral comparisons were possible along perimeter lines at the FGB between 2007 and 2008 due to shifts in corner locations and line placement. Storm impacts were greater along the EFGB perimeter lines compared to the WFGB. A single colony of *Diploria strigosa* was no longer in place along the EFGB north perimeter line in November 2008 and no obvious hurricane impacts were observed at the WFGB video. Similar to the results of the repetitive quadrat analysis, *D. strigosa* accounted for the greatest loss of coral cover. It is important to note that the hurricane impacts observed along perimeter lines at the FGB in November 2008 are likely an underestimate of the actual hurricane damages (see section 3.6.2).

Diploria strigosa was the only coral species with colonies missing in both the EFGB and WFGB repetitive quadrat stations. Of the 41 colonies missing from the EFGB and WFGB repetitive quadrat stations, 39% were *D. strigosa.* In addition, *D. strigosa* was the only coral species with missing colonies from the perimeter video in November 2008. Although the water depth of the Banks provides some protection, bioeroded coral colonies remain susceptible to breakage and dispersal from the waves and high water velocities associated with hurricanes. Colonies of *D. strigosa* at the EFGB and WFGB experience intense bioerosion around their bases, forming mushroom-shaped colonies (Figure 4.6.1).

Both the repetitive quadrat data and the perimeter video analysis indicate that the storm impacts observed at the EFGB were greater than those at the WFGB. This result is likely attributed to the close proximity of the storm from the EFGB study site. Hurricane Ike passed directly over the EFGB, with the storm track ~0.7 km (0.4 mi) from mooring buoy number 2 at the EFGB study site. The EFGB was situated on the east side of the Hurricane Ike storm track and the right side of a hurricane (relative to its direction of travel) is the most powerful portion of a storm in terms of wind speed and storm surge (USDOC, NOAA 1999). The location of the EFGB relative to the path of Hurricane Ike may have been a contributing reason for the observations of higher storm impacts on the EFGB than the WFGB. Considering that the two Banks are only ~19 km (12 miles) apart, with the storm track passing between the two Banks, a portion of the eye of Hurricane Ike must have also passed directly over the WFGB. Yet, apparent hurricane damage is less at the WFGB.

Figure 4.6.1. Typical bioerosion pattern of *Diploria strigosa*, resulting in mushroom-shaped colonies at the EFGB.

The hurricane impact estimates at the EFGB for Hurricane Ike appear to be slightly less than the estimated impacts from Hurricane Rita even though Rita was ~93 km (58 mi) away from the EFGB. Robbart et al. (2009) estimated damages at the EFGB following Hurricane Rita and found that 21 colonies (3.20 m^2) were missing from 40 repetitive quadrat stations between June 2005 and November 2005. This 3.20 m^2 represents ~1% of the area evaluated (230 m^2). The Hurricane Ike coral loss estimate of 35 colonies from 32 repetitive quadrat stations represents 1.56 m^2, which is approximately 0.6% of the area evaluated (256 m^2). In addition, the Hurricane Ike impact estimates along perimeter lines at the EFGB appear to be less than the estimated impacts observed in November 2005 from Hurricane Rita. Robbart et al. (2009) reported damages at several locations along the north perimeter line at the EFGB in November 2005, most likely due to the effects of Hurricane Rita. A partially-bleached, dislodged colony of the *Montastraea annularis* species complex was deposited along the perimeter line (Figure 4.6.2) and several colonies of *Diploria strigosa* were either shattered or completely dislodged (Figure 4.6.3; Precht et al. 2008a). Both storms were classified as Category 3 storms on the Saffir-Simpson Index. However, while Hurricane Ike passed much closer (~0.7 km or 0.4 mi) to the EFGB than Hurricane Rita (~93 km or 58 mi), Hurricane Ike appeared to cause less damage. It is likely that Hurricane Rita was responsible for removing many of the corals most susceptible to breakage and dispersal (e.g., corals experiencing substantial bioerosion).

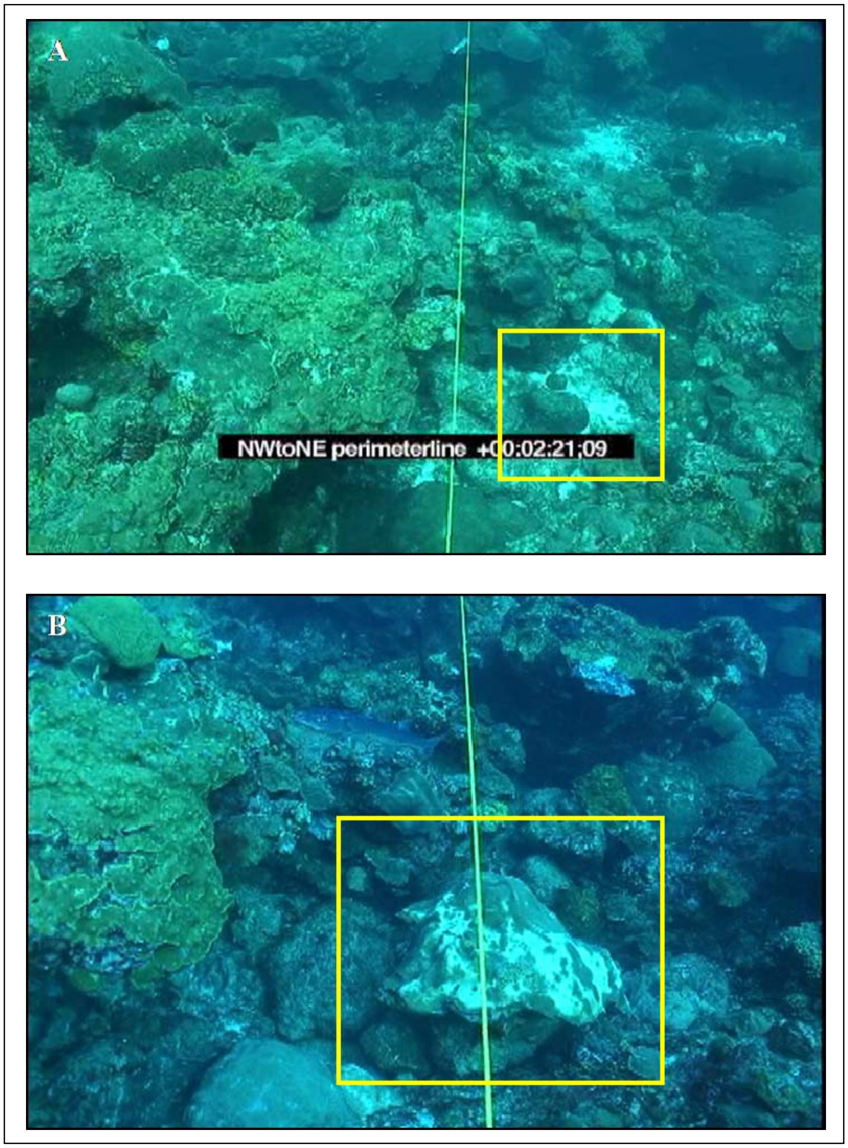


Figure 4.6.2. Photographs taken in (A) June 2005 and (B) November 2005 of a partially bleached colony of the *Montastraea annularis* species complex deposited along the perimeter line (Precht et al. 2008a). The yellow box highlights the approximate location of hurricane impact.

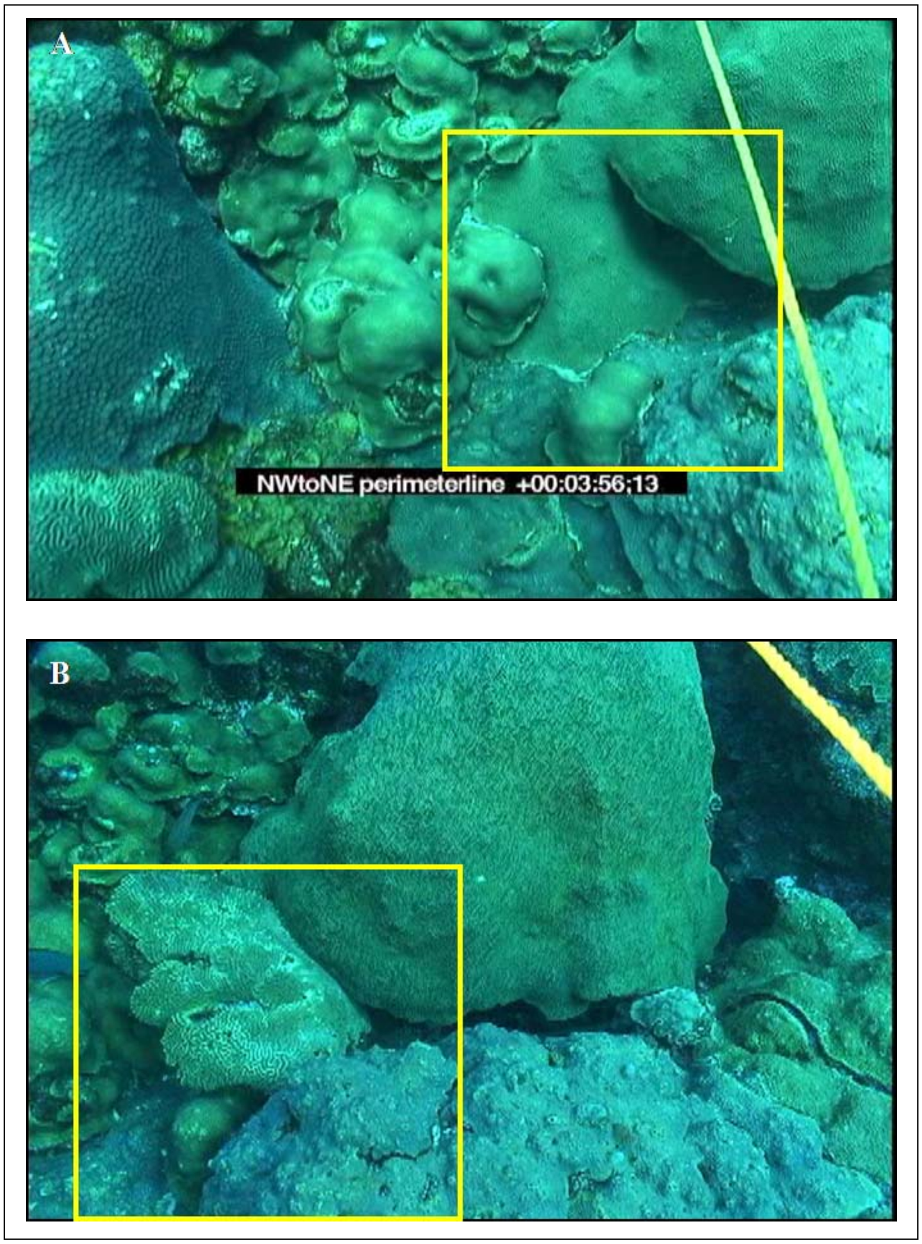


Figure 4.6.3. Photographs taken in (A) June 2005 and (B) November 2005 of a *Diploria strigosa* colony that appeared to be deposited in a new location (Precht et al. 2008a). The yellow box highlights the approximate location of hurricane impact.

In addition, for both Hurricanes Ike and Rita, *Diploria strigosa* was the coral species with the largest area of coral cover lost during the storms. During Hurricane Rita, 2.76 m^2 of *D. strigosa* was lost and 1.243 m^2 was lost during Hurricane Ike. This is likely explained by the intense bioerosion of *D. strigosa* that occurs at the FGB, making this species more susceptible to breakage and dispersal during storm events.

4.7. CORAL HEALTH ISSUES

4.7.1. Coral Disease

Coral colonies displaying signs of coral disease were not observed in the random transect videos, repetitive quadrat photographs, or the perimeter videos taken at the EFGB and WFGB from 2004-2008. However, because the disease lesion cannot be closely assessed and corallite structure is not discernable, it is generally difficult to accurately and reliably assess whether a coral colony is exhibiting disease signs using these methodologies.

4.7.1.1. June 2007 Coral Health Surveys

This report is the first annual monitoring report to include dedicated coral health surveys. These June 2007 coral health surveys revealed that the majority of corals at the EFGB and WFGB were healthy (≥ 96.80% at the EFGB and ≥ 90.04% at the WFGB). The overall community-level disease (i.e., ciliate infections, growth anomalies, and other coral maladies) prevalence was 1.72%, and disease was slightly higher at the EFGB (1.89%) than the WFGB (1.57%). The remaining 1.30% and 8.39% of coral colonies observed at the EFGB and WFGB, respectively, exhibited bleaching or predation. It is interesting to note that the June 2007 coral health transect surveys detected coral disease while the random transect videos, repetitive quadrat photographs, and perimeter videos taken at the same time did not. It is often difficult or impossible to identify coral disease in photographs. To accurately and reliably distinguish coral disease lesions, it is necessary to closely assess the tissue lesion as well as the corallite tissue and structure adjacent to the lesion. Thus, dedicated *in situ* transect surveys allow for higher resolution in the detection of coral health problems and are recommended for assessing coral disease prevalence in future surveys.

Although coral disease has previously been identified on the reefs of the FGB, published reports of coral disease prevalence at the FGB have historically been low compared to other sites within the western Atlantic reef-building province (Gittings et al. 1992; CSA 1996; Dokken et al. 1999, 2001, 2003; Borneman and Wellington 2005; Precht et al. 2006, 2008b). The June 2007 community-level disease prevalence (1.7%) is lower than reported for other reefs within the wider Caribbean region. Weil and Cróquer (2009) conducted disease surveys along four permanent 10-m x 2-m band transects during the summer and fall of 2005 in Bermuda, Puerto Rico, Curacao, Grenada, Grand Cayman, and Panamá. Community-level disease prevalence ranged from 2.9 ± 3.1% in Bermuda to 4.3 ± 5.9% in the northern Caribbean region, although local prevalence as high as 14.8% were found. Weil and Cróquer (2009) suggest that the current "normal or background" typical disease prevalence in the Caribbean might be considered somewhere within the range of 1-6%. The June 2007 prevalence of disease detected during the FGB coral health surveys falls within this range.

4.7.1.2. White Plague-Like Disease

The first documented outbreak of coral disease on the reefs of the FGB occurred in February 2005. The FGB plague-like disease was reported to occur during the winters of 2005-2008. Refer to section 3.8.3 for a more thorough description of this disease outbreak. During the 2007 coral health surveys, no signs of the white plague-like coral disease outbreak were observed. The outbreak exhibited disease signs that are very similar to those of other white plague-like diseases that have been documented on Caribbean reefs (Hickerson and Schmahl 2005a). In the Caribbean, three epizootics of white plague-like diseases were documented on the reefs of the northern Florida Keys: White Plague Types I, II, and III, hereafter referred to as WPL-I, WPL-II, and WPL-III, respectively (Sutherland et al. 2004). Each of these white plague types differed in rate of tissue loss, pattern of disease progression over the colony, susceptible coral species, and apparent virulence of the disease. WPL-I was reported in the 1970s and displayed a slow progression rate ($\leq$ 3.1 mm per day) and disease lesions that typically radiated outward from an initial point of infection at the base or in the middle of the colony (Dustan 1977). WPL-II was documented in 1995 and exhibited a more rapid lesion progression rate ($\leq$ 2.0 cm per day; Richardson et al. 1998a). WPL-III occurred in 1999 with an even faster progression rate of up to decimeters per day (Bythell et al. 2004). While the cause of WPL-I and WPL-III remain unknown, Koch's postulates were fulfilled for the etiological agent of WPL-II, the Gram-negative bacterium *Aurantimonas coralicida* (Richardson et al. 1998b; Denner et al. 2003).

White plague is one of the most detrimental coral diseases affecting the reefs of the wider Caribbean, as it has been shown to be a contributor to considerable declines in coral populations (Nugues 2002; Kaczmarsky et al. 2005; Richardson and Voss 2005). The white plague-like disease observed on the reefs of the FGB since 2005 is of considerable concern because (1) it is affecting the major reef-building species at the FGB, including the *Montastraea annularis* species complex, *Colpophyllia natans*, and *Diploria strigosa* and (2) because, at times, it has been documented to have a substantial prevalence (up to 8.3% of coral colonies affected; Hickerson 2005; Hickerson and Schmahl 2005a; Hickerson 2006b).

It should be noted that the FGB white plague-like disease displays a unique characteristic from other descriptions of white plague diseases affecting Caribbean reefs. While many of the coral diseases in the Caribbean, including white plague, report an association between increased disease activity and increased water temperatures (Sutherland et al. 2004), the plague-like disease at the FGB appears to be most active during periods of cooler water temperatures (Hickerson 2005, 2008a, 2009; Hickerson and Schmahl 2005a). No instances of extensive coral health problems associated with the FGB white plague-like disease were observed during the 2004-2008 annual monitoring cruises. However, this is likely due to the fact that these cruises occurred during months with warmer water temperatures (June – November). Only two colonies of *Montastraea faveolata* were observed with white plague-like disease signs during the June 2007 coral health surveys; however, because of the apparently slow advance rates and jagged, irregular edges of the lesions, these signs could also have been produced by snail and/or fireworm predation or other disease. Corals are simple organisms that can show very limited signs of stress. In the case of white plague disease, the field observer only sees the result of tissue mortality (i.e., a bare white skeleton), rather than the tissue-level problems (pathology). If the lesion is not followed through time or tested for pathogens, it may be confused with other coral health problems, such as predation (Weil 2004; Weil et al. 2006).

It is necessary to characterize this white plague-like disease at the FGB in order to develop effective management strategies for these reefs. Additional study of this disease should be conducted, including further ecological assessment, traditional and molecular microbiological assessments, and histological evaluations of affected corals.

4.7.1.3. Other Coral Diseases

Three colonies of *Montastraea franksi* located outside of the EFGB June 2007 coral health survey transects exhibited signs similar to those of Caribbean yellow band disease (Figure 3.7.3F; Weil and Hooten 2008), which is one of the most damaging coral diseases in the region (Weil 2004; Weil et al. 2006). Future coral health surveys at the FGB should assess for signs of Caribbean yellow band disease, along with monitoring for increasing numbers of colonies affected, and/or coral mortality associated with it. Three colonies of *Siderastrea siderea* located outside of the June 2007 coral health transects were observed with signs similar to those of advanced stages of dark spots disease, with dark bands at the edge of unhealthy-looking tissues, usually covered with turf algae and/or sediment (slow mortality rates; Figure 3.7.3H). Another colony showed the darkened, depressed surface spots characteristic of this disease. A pigmentation response of the coral to encroaching algae or other stressful conditions at the tissue edges might produce signs similar to dark spots disease (Weil and Hooten 2008). These are the first reports of the possible occurrence of Caribbean yellow band disease and dark spots disease at the FGB.

Studies focused on Caribbean reefs have documented alarming trends related to increases in the number and incidence of coral diseases (Richardson 1998; Green and Bruckner 2000; Porter et al. 2001; Richardson et al. 2001; Sutherland et al. 2004; Weil 2004; Weil et al. 2006), as well as the number of coral species susceptible to disease (Richardson et al. 1998a, b; Porter et al. 2001; Weil 2004). The Gulf of Mexico is considered part of the wider Caribbean (Weil 2004) and the reefs of the FGB share many biological similarities with other reefs of this region. For example, all coral species found in the FGB are also found on reefs of the wider Caribbean, and like the reefs of the Caribbean, the FGB is subject to seasonal fluctuations in water temperature. Furthermore, currents provide a hydrologic connection between the western Gulf of Mexico and other reefs within the wider Caribbean (Rezak et al. 1985). Thus, the reefs of the FGB may be exposed to coral pathogens occurring on the reefs in the wider Caribbean. In June 2007, there was the first report of disease signs similar to Caribbean yellow band disease and dark spots disease at the FGB. Continued disease monitoring should be a priority for the FGB.

4.7.2. Coral Bleaching

Bleaching levels at the FGB were variable from 2004-2008 (ranging from 0.00% to 0.91%), depending upon the sampling year and the data collection technique (i.e., random transects, repetitive quadrats, and coral health surveys). The random transect data indicated that bleaching levels were highest at both the EFGB and WFGB in 2005 (0.91% and 0.90%, respectively). However, the repetitive quadrat data showed that the greatest bleaching was observed on the EFGB in 2006 (0.62%) and the WFGB in 2007 (0.54%). These bleaching levels fall within the range of levels reported in the more recent annual monitoring reports for the FGB (i.e., Dokken et al. 2003; Precht et al. 2006; Precht et al. 2008b). Higher bleaching levels were revealed in the 1992-1995 annual report (CSA 1996) and the 1989-1991 annual report (Gittings et al. 1992). CSA (1996) noted average annual bleaching levels ranging from a low of 2.7% in 1995 to a high of 3.8% in 1992. Gittings et al. (1992) reported bleaching levels ranging from 0.2% at the WFGB in 1991 to 2.4% at the EFGB in 1990. The 2004-2008 repetitive quadrat data indicates that the *Millepora alcicornis* is the coral species most frequently affected by bleaching at the

FGB. Previous reports (e.g., Dokken et al. 2003; CSA 1996; Gittings et al. 1992) at the FGB also named *Millepora alcicornis* as the species most frequently affected by bleaching.

The 2004-2008 repetitive quadrat data indicates that *Millepora alcicornis* is the species most frequently affected by bleaching at the FGB. This result is not surprising, as *M. alcicornis*, a hydrocoral, is often the first species to bleach and is also typically one of the most impacted species during a bleaching event (e.g., Lasker et al. 1984; Williams and Bunkley-Williams 1990; Marshall and Baird 2000; Jeffrey et al. 2006).

The bleaching levels observed during the June 2007 coral health surveys did not correspond to the bleaching levels detected by both the random transect and repetitive quadrat methodologies. At the EFGB in June 2007, the coral health surveys detected a substantially higher level of bleaching than the random transect and repetitive quadrat methods. The coral health surveys found that 0.36% of EFGB corals were bleached, whereas the random transects and repetitive quadrats observed bleaching levels at 0.05% and 0.03%, respectively. At the WFGB in June 2007, the coral health surveys did not follow a specific trend in reference to the random transect and repetitive quadrat methods. The coral health surveys found that 0.52% of corals at the WFGB were bleached, whereas the random transects and repetitive quadrats observed bleaching levels at 0.34% and 0.54%, respectively. Thus, the method used to collect bleaching data may impact the bleaching levels detected. Other factors that might contribute to varied detection of bleaching levels would include a "patchy" distribution of bleached corals, as well as the criteria used by observers to define bleaching (e.g., corals exhibiting paling in the June 2007 coral health surveys were lumped with fully bleached corals, while the random transect and repetitive quadrat analyses from 2004-2008 distinguished between pale and bleached colonies).

2005 Bleaching Event. Widespread coral bleaching, in response to anomalously high summer-season temperatures, has become more frequent since the 1980s throughout the western Atlantic-Caribbean region and the association of thermal stress with coral disease is of particular concern. At the FGB, two major bleaching episodes were reported in 1990 and 2005, with minor bleaching episodes occurring in 1992, 1994, 1995, and 1998 (Precht et al. 2008b). Coral reefs at locations throughout the western Atlantic-Caribbean region experienced low to high levels of bleaching in 2005, including locations such as Puerto Rico, Trinidad and Tobago, the U.S. Virgin Islands, Florida, Panama, Costa Rica, and the FGB (USDOC, NOAA 2005). Sea surface temperatures at the EFGB were elevated above 30°C, the HotSpot bleaching threshold for the FGB, for 38 days from 30 July to 8 September 2005 (Precht et al. 2008a). Unprecedented coral bleaching was documented at the EFGB in November 2005 (Precht et al. 2008a). Repetitive quadrats photographed at that time showed ~10% bleaching of the coral population. This is the highest level of bleaching reported for the FGB since the bleaching event of 1990, when ~5% of corals at the EFGB bleached (Hagman and Gittings 1992). Bleaching was evident in all coral species in November 2005, but it was most prevalent in the *Montastraea annularis* species complex, *M. cavernosa*, and *Millepora alcicornis* (Precht et al. 2008a). These high 2005 bleaching levels (~10%) were not reflected in the June 2005 annual monitoring data because the data collection occurred before the onset of the bleaching event. By the 2006 annual monitoring cruise, bleaching had returned to previous levels (0.62%; Robbart et al. 2009).

All of the reported bleaching episodes at the FGB were followed by recovery (Gittings et al. 1992; Hagman and Gittings 1992; CSA 1996; Dokken et al. 1999, 2001; Precht et al. 2008b). Bleaching episodes on reefs in the western Atlantic-Caribbean region have also generally been followed by recovery, with partial or whole mortality events affecting populations locally (Aronson and Precht 2000). Although bleaching events are a natural occurrence, the increased frequency and severity of bleaching events is of concern because the likelihood of bleaching-associated mortality increases with exposure (Hoegh-Guldberg 1999). Additionally, higher temperatures have been linked to increased virulence of marine pathogens implicated in coral diseases (Harvell et al. 2002). Thus, it is vital to continue the monitoring of bleaching levels and responses on the reefs of the FGB.

4.7.3. Coral Predation

Predation of coral by fish and invertebrates such as corallivorous snails, hermit crabs, and fireworms (Figures 3.7.2 and 4.7.3) is regularly observed at the EFGB and WFGB. Fish predation includes both isolated fish biting (Figure 4.7.4) and concentrated biting, possibly resulting from the high abundance of *Sparisoma* spp. (Figure 4.7.5; Dokken et al. 2003). As was the case with bleaching, the levels of predation in 2004-2008 were dependent upon the sampling year and the data collection technique.

Figure 4.7.3. Predation of *Mussa angulosa* by a bearded fireworm (*Hermodice carunculata*).

Isolated fish biting was the most frequent form of predation from 2004-2008. The percentage of coral points assessed with isolated fish biting in both random transects and repetitive quadrats at the EFGB and WFGB from 2002-2008 are depicted in Figures 4.7.6 and 4.7.7. The isolated fish biting levels observed in the 2004-2008 EFGB repetitive quadrat data appear to be higher than the levels reported in the 2002-2003 repetitive quadrat data (fish biting was not reported for the 2002-2003 random transect data; Figure 4.7.6). However, the isolated fish biting levels observed at the WFGB from 2002 to 2004 were lower than values observed from 2005-2008 (Figure 4.7.7). The 2002-2008 random transect and repetitive quadrat data indicated that the *Montastraea annularis* species complex was the coral taxa most affected by isolated fish biting.

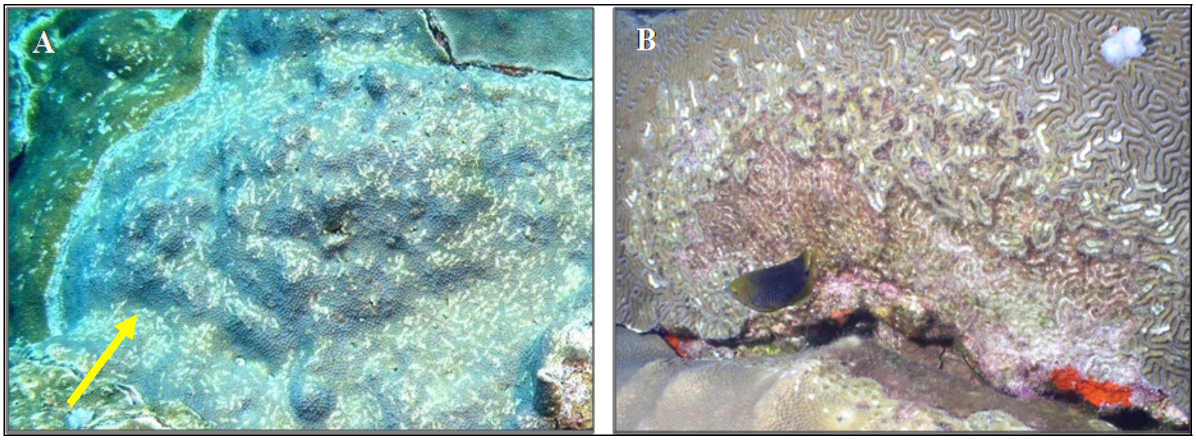


Figure 4.7.4. Isolated fish biting on (A) *Montastraea annularis* species complex and (B) *Diploria strigosa* by a threespot damselfish (*Stegastes planifrons*).

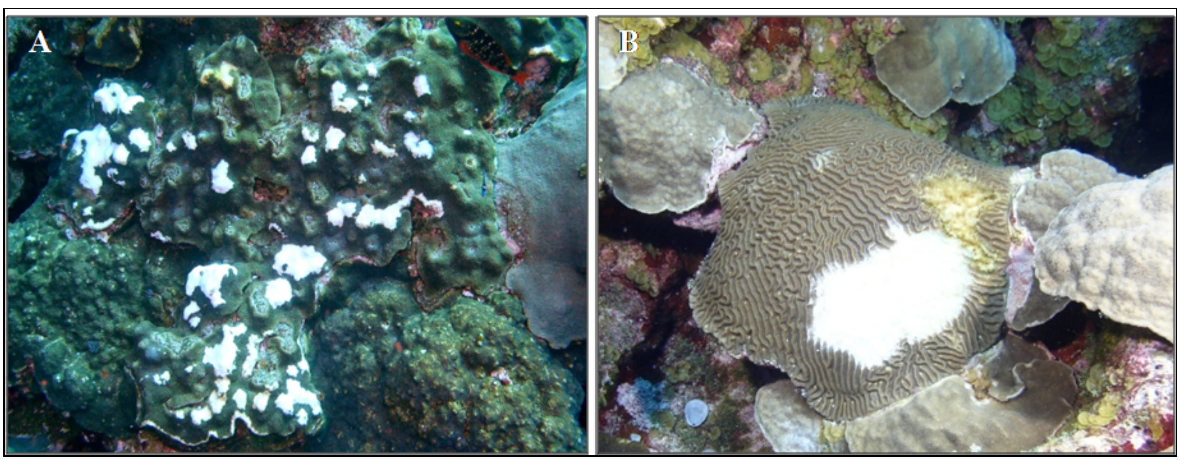


Figure 4.7.5. Photographs of concentrated fish biting on (A) *Montastraea annularis* species complex and (B) *Diploria strigosa* at the FGB.

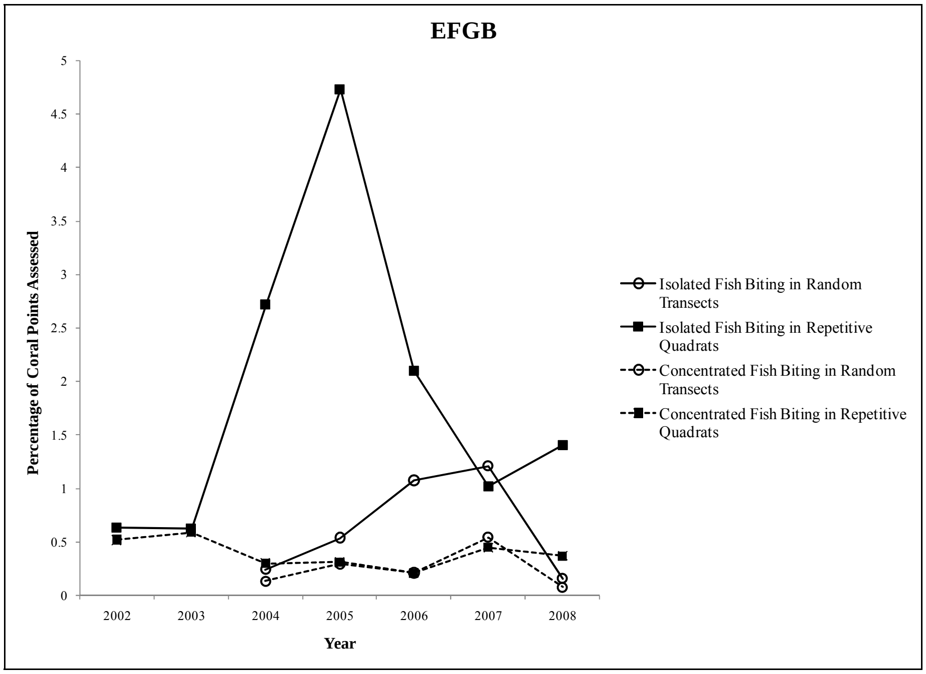


Figure 4.7.6. Percentage of coral points assessed with isolated and concentrated fish biting in random transects and repetitive quadrats from 2002-2008 at the EFGB.

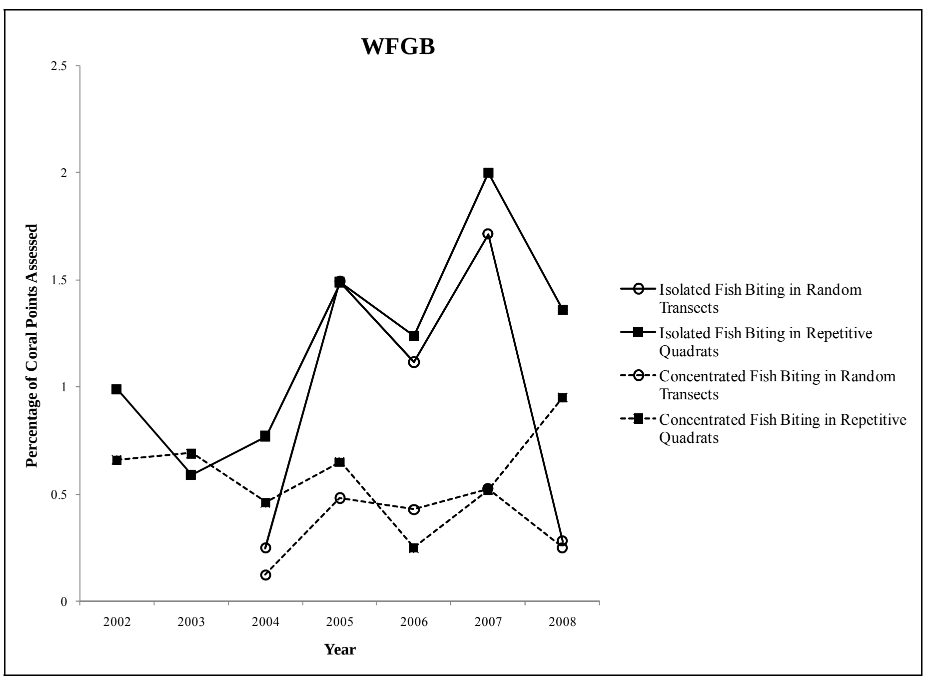


Figure 4.7.7. Percentage of coral points assessed with isolated and concentrated fish biting in random transects and repetitive quadrats from 2002-2008 at the WFGB.

Concentrated fish biting appeared to be less common than isolated fish biting on the reefs of the FGB in 2004-2008. The percentage of coral points assessed with concentrated fish biting in both random transects and repetitive quadrats at the EFGB and WFGB from 2002-2008 are depicted in Figures 4.7.6 and 4.7.7. The concentrated fish biting levels observed in the 2004-2008 EFGB repetitive quadrat data appear to be similar to the levels reported in the 2002-2003 repetitive quadrat data (fish biting was not reported for the 2002-2003 random transect data). The concentrated fish biting levels observed at the WFGB during 2004-2008 are also similar to the 2002-2003 levels with the exception of 2006. In 2006, 0.25% of coral points assessed exhibited concentrated fish biting, a decrease compared to other years. The 2002-2008 random transect and repetitive quadrat data indicated that the *Montastraea annularis* species complex was the coral taxa most affected by concentrated fish biting.

The 2000-2001 repetitive quadrat data indicated no incidences of fish biting at the EFGB and WFGB (Dokken et al. 2003). Between 1995 and 1997, only three coral colonies showed signs of fish biting in the repetitive quadrat data at the FGB (Dokken et al. 1999). Prior to 1995, fish biting data were not collected. The implications of isolated and concentrated fish biting on corals of the FGB are not understood. Fish biting at the FGB should be investigated further to better understand the phenomenon and its impact on coral health and mortality.

The June 2007 coral health surveys indicated that at the community-wide level (the EFGB and WFGB combined), predation by fish, snails, hermit crabs, and fireworms impacted 4.61% of the corals surveyed; however, this survey did not distinguish between the various forms of predation (e.g., fish biting versus invertebrate predation). The survey found that predation was more prevalent on the WFGB (7.86% of corals impacted) than the EFGB (0.95% of corals impacted). The coral species most impacted by predation were *Montastraea annularis, M. faveolata, Diploria strigosa, Stephanocoenia intersepta,* and *Colpophyllia natans.*

It is important to note that the visual signs exhibited by invertebrate predation can mimic the signs of white diseases (e.g., white plague, white band, white syndromes), and could also be confused with other white scarring (Weil and Hooten 2008). The coral lesions left by corallivorous snails and fireworms typically exhibit irregular edges that are devoid of tissue with no damage to the underlying coral skeleton (Figure 3.7.2; Weil and Hooten 2008). The tissue-devoid lesion (white band) is typically narrow and small, with turf algae already colonizing the edges opposite the live coral tissue, indicating a slow advance rate or low mortality rate that is not characteristic of white-plague like signs (Richardson 1998, Weil 2004). Typically, only a few coral colonies show these predation signs, unless there are high densities of corallivorous invertebrates at that location (Weil and Hooten 2008). Surveys should be conducted by scientists that are trained to distinguish between lesions resulting from disease and invertebrate predation.

4.7.4. Other Coral Health Issues

A new species of ciliate was recently found to be infecting up to 25 scleractinian species in several localities of the Caribbean region and Bermuda (Cróquer et al. 2006; Weil et al. 2006). The finding that ciliates are infecting colonies of *Montastraea faveolata* at the WFGB and *Colpophyllia natans* at the EFGB and WFGB is the first report of this problem for the FGB and extends the geographic area of these ciliates into the Gulf of Mexico. Ciliates are usually opportunistic parasites moving behind another infectious disease or health problem affecting live coral tissue.

Several colonies of the new species of endolithic and crustose sponge *Cliona tenuis* (Zea and Weil 2003) were observed at both the EFGB and WFGB. This sponge has caused high coral mortality in many reef localities in the southwestern, western, and northern Caribbean during the last 15 years (Zea and Weil 2003; López-Victoria et al. 2006, 2003; Weil, unpublished data). This is the first report of its presence at the FGB.

4.8. Qualitative Field Observations

4.8.1. Sponge Spawning

During the June 2007 annual monitoring cruise, divers observed broadcast spawning activity by colonies of *Agelas clathrodes* within the EFGB study site at 14:51 CST on June 11, 2007 and *Xestospongia muta* within the WFGB study site beginning at 08:00 CST on June 14, 2007. The giant barrel sponge, *X. muta*, had previously been observed to spawn on the reefs of the EFGB and WFGB (Schmahl et al. 2008).

Xestospongia muta is found throughout the Caribbean and western Atlantic. In some locations, this species is an abundant and conspicuous component of the reef community (McMurray et al. 2008; Zea 1993). *X. muta* can grow to considerable sizes (heights and diameters of >1.0 m) and substantial age with estimates that exceed 2,000 years (earning it the moniker "redwood of the reef"; McMurray et al. 2008). Synchronous spawning of *Xestospongia* sp. has been observed in other parts of the Caribbean (Ritson-Williams et al. 2005), as well as the Pacific (Fromont and Bergquist 1994). Little is known about the timing of these spawning events, although Fromont and Bergquist (1994) found that *Xestospongia* spawning on the Great Barrier Reef is linked to lunar phase. Spawning of *X. muta* at the FGB is often observed during the annual mass coral-spawning event that occurs after the full moon in August or September (Schmahl et al. 2008).

The June 2007 mass spawning of *Agelas* sp. was the first documented spawning of this species at the FGB (Hickerson 2008a). *Agelas clathrodes* (elephant ear sponge) is an oviparous hermaphrodite occurring in the Caribbean and western Atlantic (Reiswig 1971; Hoppe 1988). Extensive information regarding the reproductive biology of this species is not available; however, it is known that it does not invest substantial amounts of time or energy in reproduction (Hoppe 1988). Synchronous spawning of this species has been observed in other areas of the Caribbean in July (Hoppe 1988).

Sponges play an ecologically important role in marine benthic ecosystems by providing habitat for associated marine invertebrates, contributing to primary production, nitrification, calcification, cementation, and bioerosion, and impacting water quality via filtration and exhalation of secondary metabolites (Diaz and Ruetzler 2001). Increases in sponge disease epidemics have been reported globally, and these epidemics have been particularly devastating in the Caribbean and Mediterranean (Webster 2007). Over the past 15 years, multiple sponge disease epidemics have been reported in the Caribbean and western Atlantic, including the Florida Keys (Cowart et al. 2006), Bahamas (Olson et al. 2006), Curacao (Nagelkerken et al.

2000), Mexico (Gammill and Fenner 2005), and Belize (Paz 1997). Such epidemics can have devastating, long-term effects on the affected sponge populations (Webster 2007) and, thus, their invertebrate associates. It is recommended that a sponge-monitoring program be undertaken at the FGB to assess long-term sponge ecology and health on these reefs.

4.8.2. *Acropora spp.*

Acropora palmata (elkhorn coral) and *A. cervicornis* (staghorn coral) are two of the most important reef-building coral species in the Caribbean (Bruckner 2002; Precht and Aronson 2006). On May 9, 2006, *A. palmata* and *A. cervicornis* were officially placed on the Endangered Species List (71 FR 26852). Populations of these Acroporid species in the Caribbean were decimated in the 1970s and 1980s by white band disease, with little 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 (prior to 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 Caribbean; Schmahl et al. 2008).

Prior to the discovery of sub-fossil *Acropora palmata* and *A. cervicornis* in June 2006 and June 2007, sub-fossil Acroporids had not previously been reported on the reefs of the FGB. The radiocarbon dating of the sub-fossil *A. palmata* specimen from the WFGB revealed an age of 6330 ± 60 14Cyr (radiocarbon years before 1950), corresponding to a calibrated age of 6780 calbp (calendar years before present), which corresponds to the later portion of the Holocene Thermal Optimum from 10,000-6,000 years ago, when sea surface temperatures were warmer than they are today.

The discovery of sub-fossil, early- to mid-Holocene *Acropora palmata* colonies has profound implications for understanding the history of reef development at the FGB. The Banks supported a shallow, warm-water, reef-coral assemblage up until ~6000 years ago. This community lagged behind rapidly rising sea level in the middle Holocene. As sea temperatures cooled in the late Holocene, the reef was capped by a eurythermal deeper-water assemblage dominated by massive corals, which persists to this day. The discovery of the first sub-fossil assemblage of *A. cervicornis* on the EFGB indicated that this species appears to have persisted (and flourished) until the Little Ice Age in deeper water on the flanks of the EFGB. 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).

4.8.3. Exotic/Invasive Species

A copulating pair of the exotic nudibranch *Thecacera pacifica* was observed on Stetson Bank in 2006 (Figure 4.8.3). No additional sightings of this species have occurred within the FGBNMS.

Figure 4.8.3. A copulating pair of *Thecacera pacifica* observed at Stetson Bank in March 2006. Photograph courtesy of Frank and Joyce Burek.

Tubastraea coccinea has begun to colonize Geyer Bank, which is located ~49 km (31 mi) east of the EFGB (USDOC, NOAA, ONMS 2008). Approximately 50 colonies of *T. coccinea* were removed by Sanctuary divers in 2004. A single colony of *T. coccinea* (orange cup coral) was reported on the reefs of the FGB in August 2002 (Fenner and Banks 2004). Since this original observation, no individuals of this species have been observed over the course of the long-term monitoring data. *T. coccinea* is an azooxanthellate 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 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 increase survival in the face of competition from other sessile invertebrates (e.g., sponges) 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 of Asia, Africa, Australia, Pacific, 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 upon 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 an invasion by *T. coccinea* (Sammarco et al. 2006).

It is recommended that the FGBNMS continue to monitor for *Tubastraea coccinea*, *Thecacera pacifica*, and other exotic, invasive 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, a 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* to the region.

4.8.4. Coral Biodiversity and Taxonomy

4.8.4.1. Scleractinian Biodiversity

Qualitative field observations regarding coral biodiversity and taxonomy were made during the June 2007 annual monitoring cruise. Overall scleractinian diversity observed on the EFGB and the WFGB were similar or lower than other reef areas at equal or greater latitudes (e.g., Florida and Bermuda), excluding depth as a factor. However, if depth is considered, then the diversity at the FGB is similar to many reef areas in the Caribbean; however, important differences do exist. For instance, areas of intermediate depth (15-25 m or 49-82 ft) such as the top and edge of slopes, are typically more diverse in the southern Caribbean. These habitats are usually dominated by platy species, such as agaricids (*Agaricia lamarcki, A. undata,* and *A. humilis*), *Montastraea franksi*, *M. cavernosa*, *Porites astreoides, Stephanocoenia intersepta, Colpophyllia natans, Diploria labyrinthyformis*, and musids such as *Mycetophyllia* spp. It should be noted that species of *Agaricia* (*A. lamarcki*, *A. grahamae*, and *A. undata*) and *Madracis formosa*, which are common in intermediate to deep waters (15-40 m or 49-131 ft), were not observed in our surveys. Deeper water species are probably present in the deeper and cryptic habitats of the EFGB and WFGB. These species are likely to be mostly azooxanthellate, such as *Oculina* spp. and other small, cryptic, solitary species.

Qualitative observations of interest regarding scleractinian biodiversity included sightings of rare and previously undocumented species. A rare colony of *Agaricia* with unusual color patterns (green colony with red and pale brown stripes/bands) was observed in a cryptic habitat (light attenuation) at the EFGB (Figure 4.8.4C). Surface colony morphology resembled *A. humilis*, although calices appeared larger and more-widely separated. A single colony of *Mycetophyllia ferox* was observed under a ledge at the EFGB at 25 m (82 ft; Table 3.8.5 and Figure 4.8.4F). In addition, *Madracis pharensis* was also observed on both the EFGB and WFGB. This is a new species record for the EFGB and WFGB; however, *M. pharensis* has been previously documented at Stetson Bank by FGBNMS divers.

4.8.4.2. Scleractinian Taxonomic Issues

The continuing deterioration of Caribbean reefs is a major challenge, and lack of consensus on the status of many Caribbean coral species may exacerbate the problem for local and regional managers and individual species protection. A major quantitative, multivariate review of the extant Caribbean scleractinian diversity is needed to clarify taxonomic problems and to efficiently manage coral reefs in the region. Most species lists are for restricted geographic areas and mostly based on older, usually incomplete descriptions and classification keys lacking good diagnostic characters, which weakens any attempt to characterize and understand geographic coral diversity and distribution patterns. Historically, coral diversity in the Caribbean has fluctuated depending on where and who produced the species list. "Lumpers" tend to synonomize many species into one, and "splitters" tend to describe true ecomorphs as separate species. Of the 27 genera (with some 65 zooxanthellate species) currently described, 20 genera (78%) have taxonomic problems. A recently described genus, *Goreaugyra*, has a doubtful status (only one specimen, the holotype, has ever been found). Most problems are produced by the natural variability in calical structures and colony forms, which have been further exacerbated by: (1) longstanding emphasis on the importance of non-genetic sources of variation; (2) use of few specimens and few characters from reduced number of calices; (3) lack of quantitative morphometrics and statistical analyses; (4) lack of information on the natural variability, the ecology, and the geographic range of the taxa being studied, and more recently; (5) lack of molecular information. *Montastraea, Meandrina, Agaricia, Colpophyllia, Porites, Madracis*, and *Diploria* are some of the most important reef building genera that still have ecomorphs with an unclear taxonomic status that can potentially be designated as new species. Multivariate approaches must be used in any attempt to separate coral species, since results from this approach will clarify important taxonomic confusions and suggest a much more diverse and specialized coral fauna that could significantly increase the total number of zooxanthellate species in the region.

Furthermore, the name for *Madracis mirabilis* is an invalid name. The name is more appropriately a synonym of *M. myriaster*, which is a completely different deep-water species. The new name for this common, long and thin branching species is *M. auretenra* (Locke et al. 2007). An extensive, healthy patch of this species dominates a slope area from around 30 m to more than 40-m deep in the north-eastern corner of the EFGB (Figure 4.8.4H).

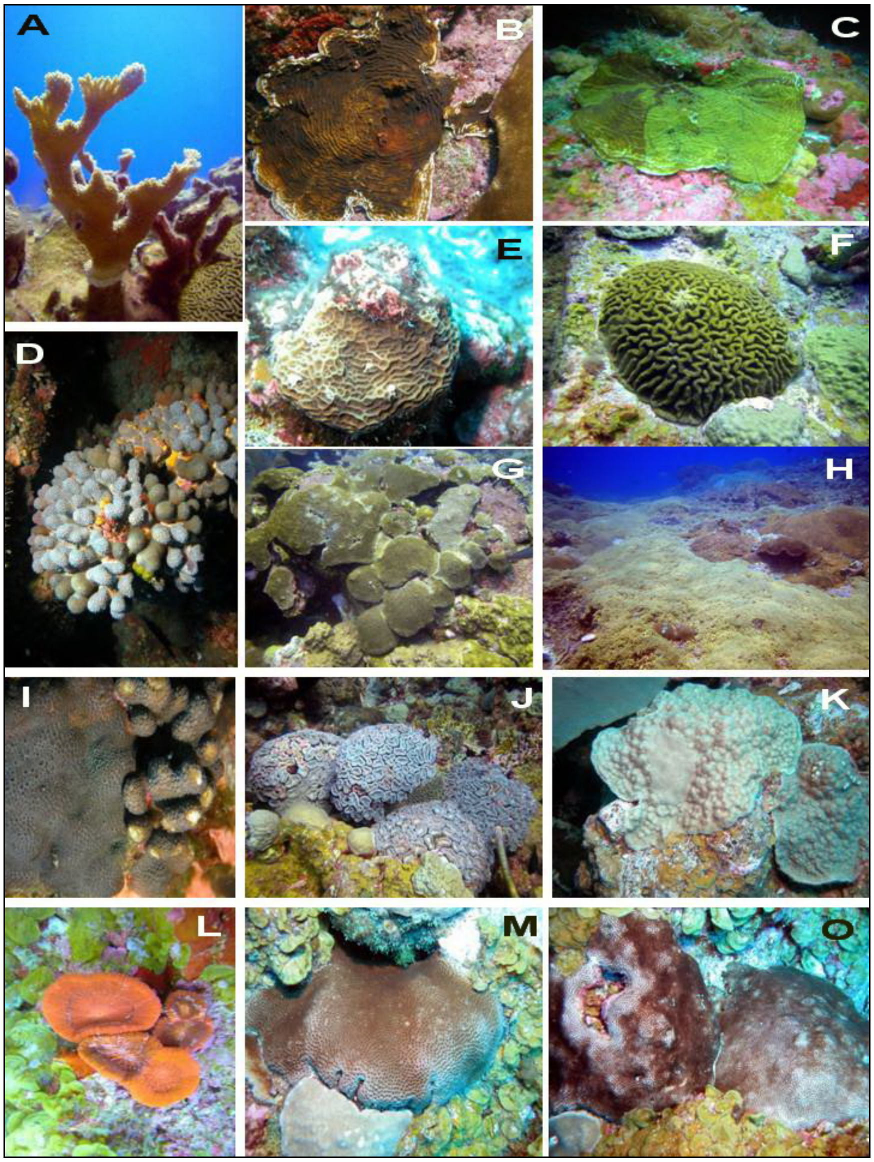


Figure 4.8.4. Scleractinian coral diversity at the EFGB and WFGB. A) *Acropora palmata* (photo not from FGB), B) *Agaricia fragilis*, C) Unidentified agaricid, D) *Madracis decactis*, E) *Agaricia agaricites*; F) *Colpophyllia amaranthus*; G) *Diploria strigosa*, H) *Madracis auretenra*, I) *Madracis pharensis* and *Madracis decactis*, J) *Mussa angulosa*, K) *Porites astreoides*, L) *Scolymia* sp., M) *Siderastrea siderea*, O) *Stephanocoenia intersepta*.

What has been identified as *Scolymia cubensis* will require further verification. It is possible that this ecomorph might be a new species for the region. Solitary calices are larger, with thicker septa and longer spines on the top of the septa. Live polyps show different coloration and texture patterns (red-orange, dull gray, and striped colors; Figure 4.8.5), compared to the typical Caribbean *S. cubensis*. Polyps sometimes aggregate by induced settlement by the parental calices and/or short dispersion capabilities of the mature planulae (Figure 4.8.5). They also are capable of intramural asexual budding producing independent but genetically identical polyps (Figure 4.8.5B). Solitary polyps were smaller and less fleshy, with fewer septa and spines that were shorter and less numerous than the other Caribbean species, *S. lacera*.

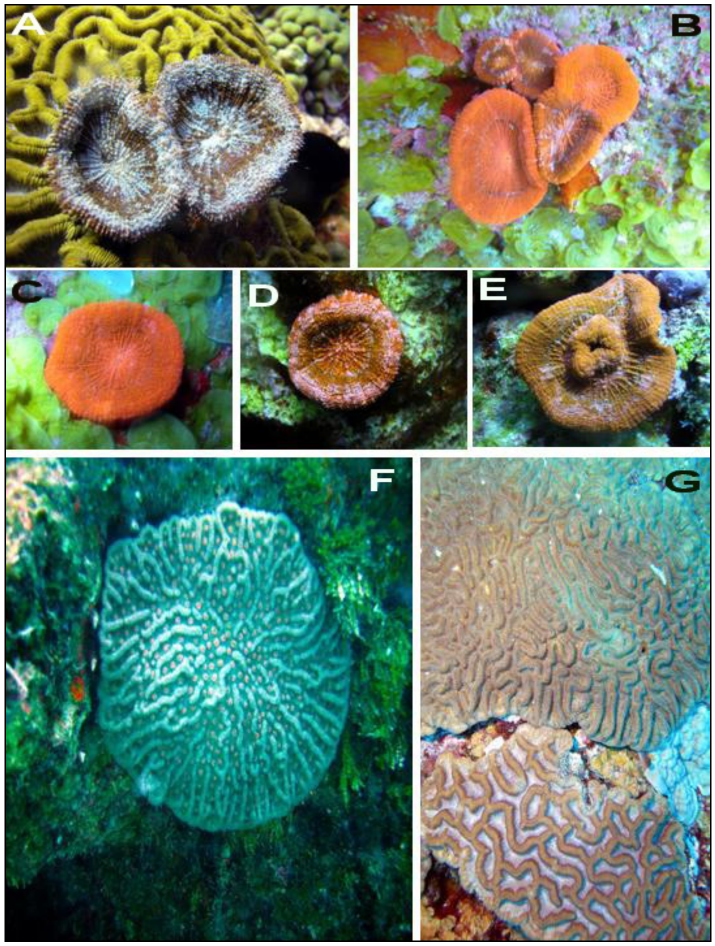


Figure 4.8.5. Scleractinian diversity at the FGB. Photos (A) through (E) show different color morphs of what has been called *Scolymia cubensis* in the past, but could be a new taxon. Photo (E) shows the asexual budding and aggregation of polyps of *S. cubensis*. Photo (F) shows a single colony of *Mycetophyllia ferox* found in a large crevice - a newly recorded species for the FGB. Photo (G) shows a *Colpophyllia natans* (top) and *Colpophyllia amaranthus* (bottom) coexisting in the same habitat.

There are reports of *Siderastrea radians* from the EFGB and WFGB; however, this is usually a small, shallow-water planulating species that is seldom found below 3-5 m. If specimens of this species were collected for identification in the past and are in storage, they should be re-analyzed and compared morphometrically with *S. siderea* and *S. stellata*, the congener more frequently observed at deeper depths.

Two species of *Colpophyllia*, *C. natans* and *C. amaranthus* (Figure 4.8.5G), appear to be consistently abundant at the EFGB and WFGB. These species have been reported to spawn gamete bundles after the full moon in the summer, right after the other favids in the area. However, in the southern Caribbean, *C. natans* is a spring spawner, releasing large gamete bundles after the full moon in April-May (Weil and Urreiztieta, unpublished data) which poses the interesting question of potential taxonomic differences between these taxa.

All three common species in the *Montastraea annularis* species complex, *M. annularis*, *M. faveolata*, and *M. franksi*, are dominant at the top and edge of slopes on the EFGB and WFGB, frequently intermingled with colonies of *Diploria strigosa*, *M. cavernosa*, *Siderastrea siderea*, *Stephanocoenia intersepta*, and *Colpophyllia natans*. The three star coral species were visually distinguishable on the EFGB and WFGB (Figure 4.8.6). Their morphological differences were consistent and diagnostic with very few potential "hybrid" colonies showing intermediate morphologies observed in the area. However, *M. franksi* colonies displayed some morphological variation and high color variability. At least four distinct color morphs could be easily separated (Figure 4.8.6). The *Montastraea annularis* species complex was lumped for analysis throughout this report to preserve comparability across datasets dating back to the 1990s when the species separation was not so commonly accepted (Knowlton 1993).

Two distinct morphologies of *M. cavernosa* commonly found throughout the Caribbean were observed on both Banks (Figure 4.8.6I). Since both the large- and small-polyped variants co-occur in the same habitat where no environmentally-induced morphological differences are possible (Ruiz and Weil, unpublished data), we propose them to be different taxa. Further exploration and careful taxonomic analysis could reveal additional species within this complex.

Because of the isolated geography of the FGB, a comprehensive taxonomic review of those taxa showing morphometric and other differences with their Caribbean and Floridian counterparts is recommended.

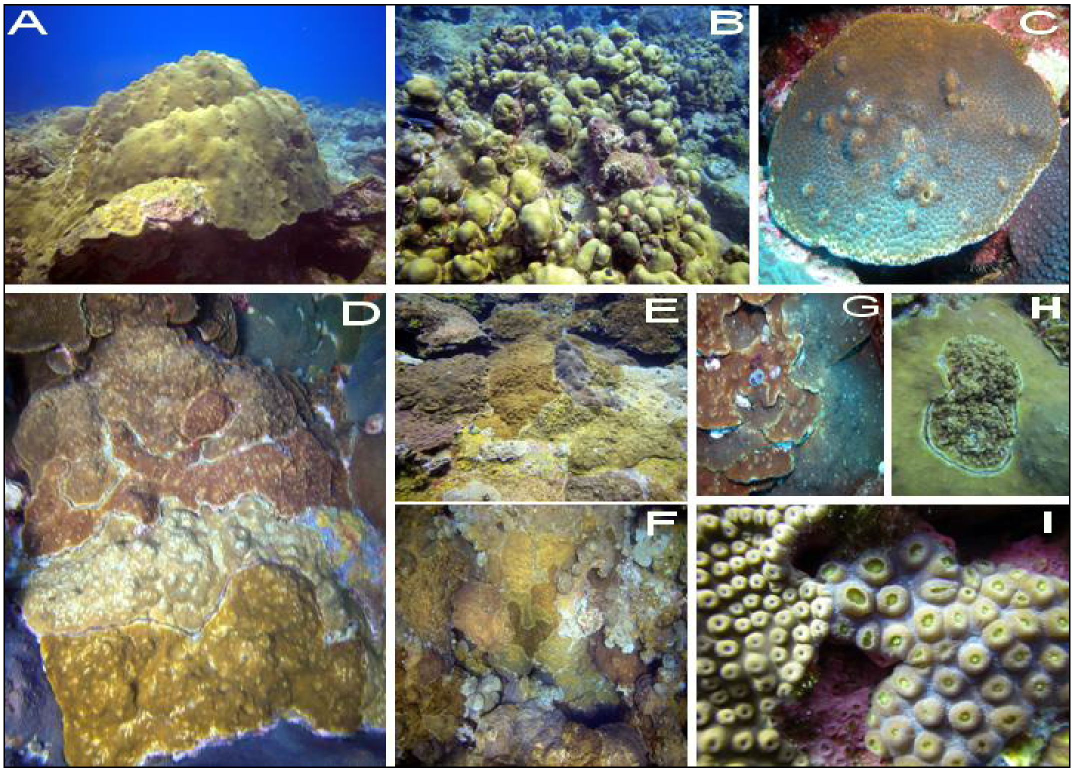


Figure 4.8.6. The three different species in the *Montastraea annularis* species complex. A= *M. faveolata*, B= *M. annularis* and C= *M. franksi* were clearly distinguishable. Within the *M. franksi* morphologies, a high color variability was observed in colonies growing side by side (D, E and F) and some of these color morphs showed morphological differences at the colony level and calyx distribution patterns that merit further investigation (G, H). The large and small polyped morphologies of *M. cavernosa* (I), common in the Caribbean, were also found at the FGB.

4.9. WATER QUALITY

4.9.1. Water Quality Parameters

Water quality parameters investigated at the FGB from March 2004 through November 2008 were temperature, salinity, DO, pH, turbidity, PAR, chl *a*, and nutrients. The accuracy of the water quality reported here depended largely on the performance of the sensors. The HoboTemp thermistors and the SBE MicroCATs consistently provided us with reliable temperature records. Further, the SBE MicroCATs provided reliable salinity measurements. Unfortunately, substantial amounts of YSI data could not be used; only temperature, salinity, and pH could be reported here with sufficient confidence. There remains a definite need to use equipment suited for long-term oceanic deployments. Oceanographic instruments such as the SBE MicroCATs deployed since February 2008 will enhance the continued and long-term monitoring of temperature and salinity on the reef cap, and will enable the validation of salinity trends found during the 2004 to 2008 period.

4.9.1.1. Physical Paramters: Temperature and Sea State

Temperature. The temperature minimum on the reef cap typically occurred from February to mid-March and the temperature maximum from mid-August through mid-September (Figures 3.9.1 and 3.9.2). Due to the shallower depth of the EFGB compared to the WFGB, temperature on the EFGB reef cap was typically warmer than that on the WFGB, especially during the summer months. The average temperature range on the FGB reef cap from 1990 to 2008 was 18 to 31°C (daily average temperatures are provided in Appendix 7: Long-Term Water Quality Data at the East and West Flower Garden Banks).

Seasonal thermal changes over the reef caps of the EFGB and WFGB are very apparent in the Figures 3.9.1-3.9.4. From a winter minimum, the temperature gradually rose through the end of March to reach a maximum during mid-August. The temperature decreased gradually starting around the end of September to reach an annual minimum by mid-February. During the 2004 to 2008 period, there were several thermal anomalies (both positive and negative), particularly in 2005 and 2006. Of greatest importance was the extreme warming that the western Atlantic region experienced in 2005. A prolonged sea surface thermal anomaly had begun in the summer and continued well into the fall, causing significant bleaching and coral mortality throughout the western Atlantic (Donner et al. 2007). Thermal anomalies observed during the 2004 to 2008 period were assessed by comparing the annual HoboTemp records with the 1990 to 2008 long-term average. Anomalies are presented in Figures 4.9.1-4.9.5.

A winter minimum did not occur in 2006. Indeed, from the end of January to the end of March, reef cap water temperature rose by as much as 3°C above the long-term mean (1990 to 2008 mean daily temperatures; Figures 3.9.1, 3.9.2, and 4.9.1-4.9.5).

During the spring and early summer warming phase in 2004 and 2005, temperature noticeably oscillated in June and July by as much as 3°C (Figures 3.9.1 and 3.9.2). Also, in 2006 the spring to summer warming phase saw unusually high temperatures particularly on the WFGB (by as much as 2°C).

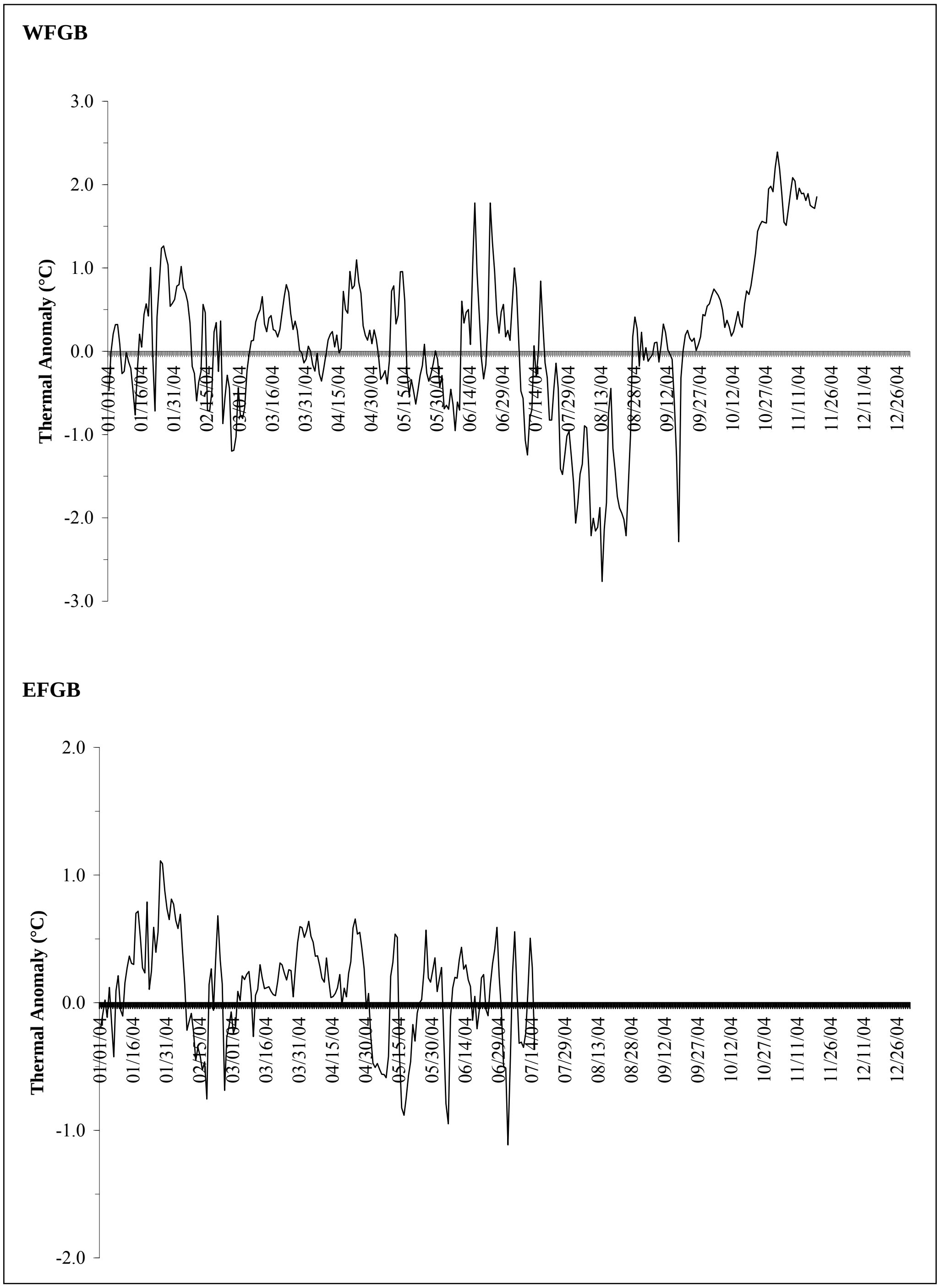


Figure 4.9.1. Thermal anomalies (°C) observed on the reef cap at the EFGB and WFGB in 2004 as compared to the long-term temperature average (1990 to 2008).

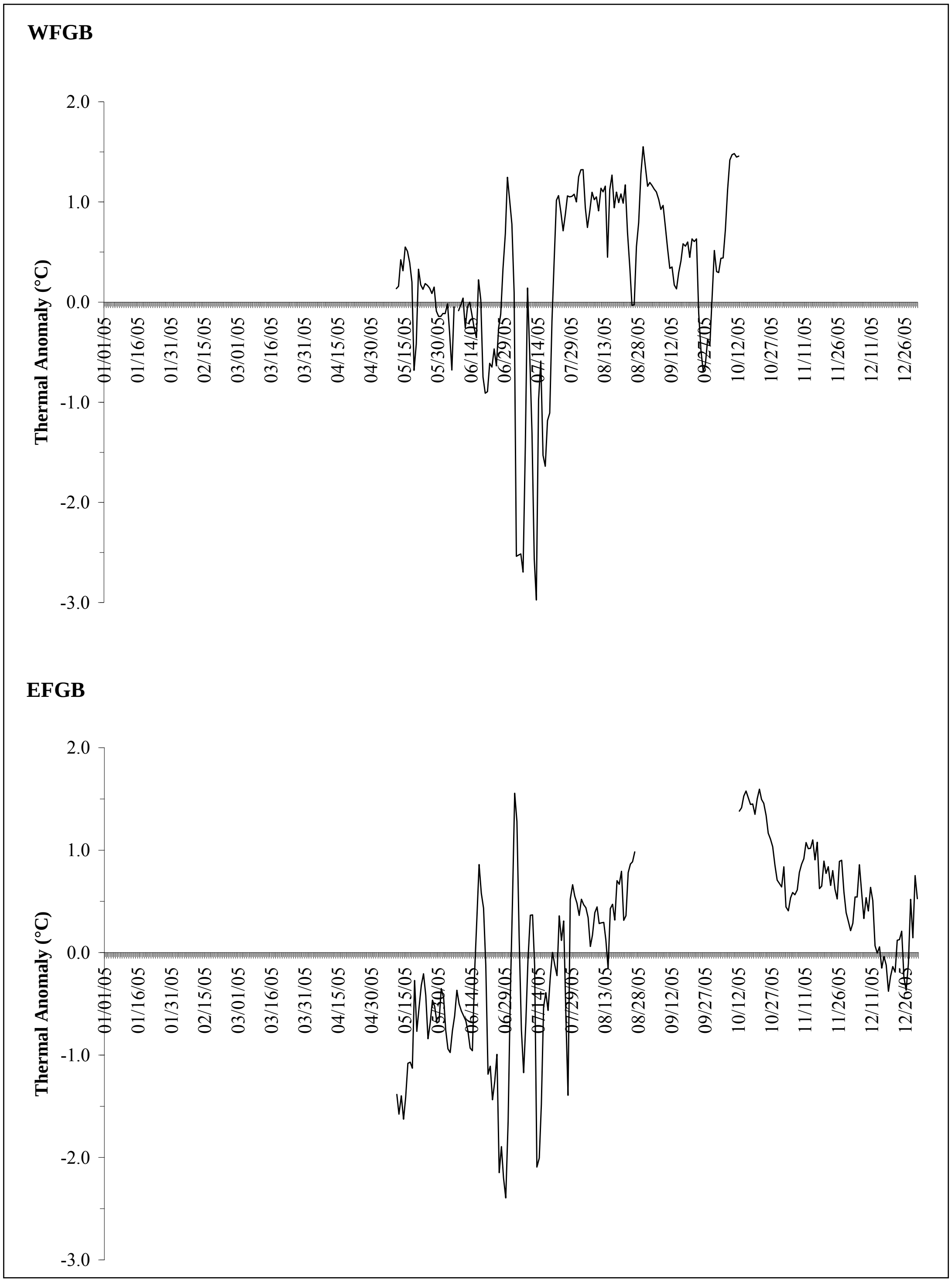


Figure 4.9.2. Thermal anomalies (°C) observed on the reef cap at the EFGB and WFGB in 2005 as compared to the long-term temperature average (1990 to 2008).

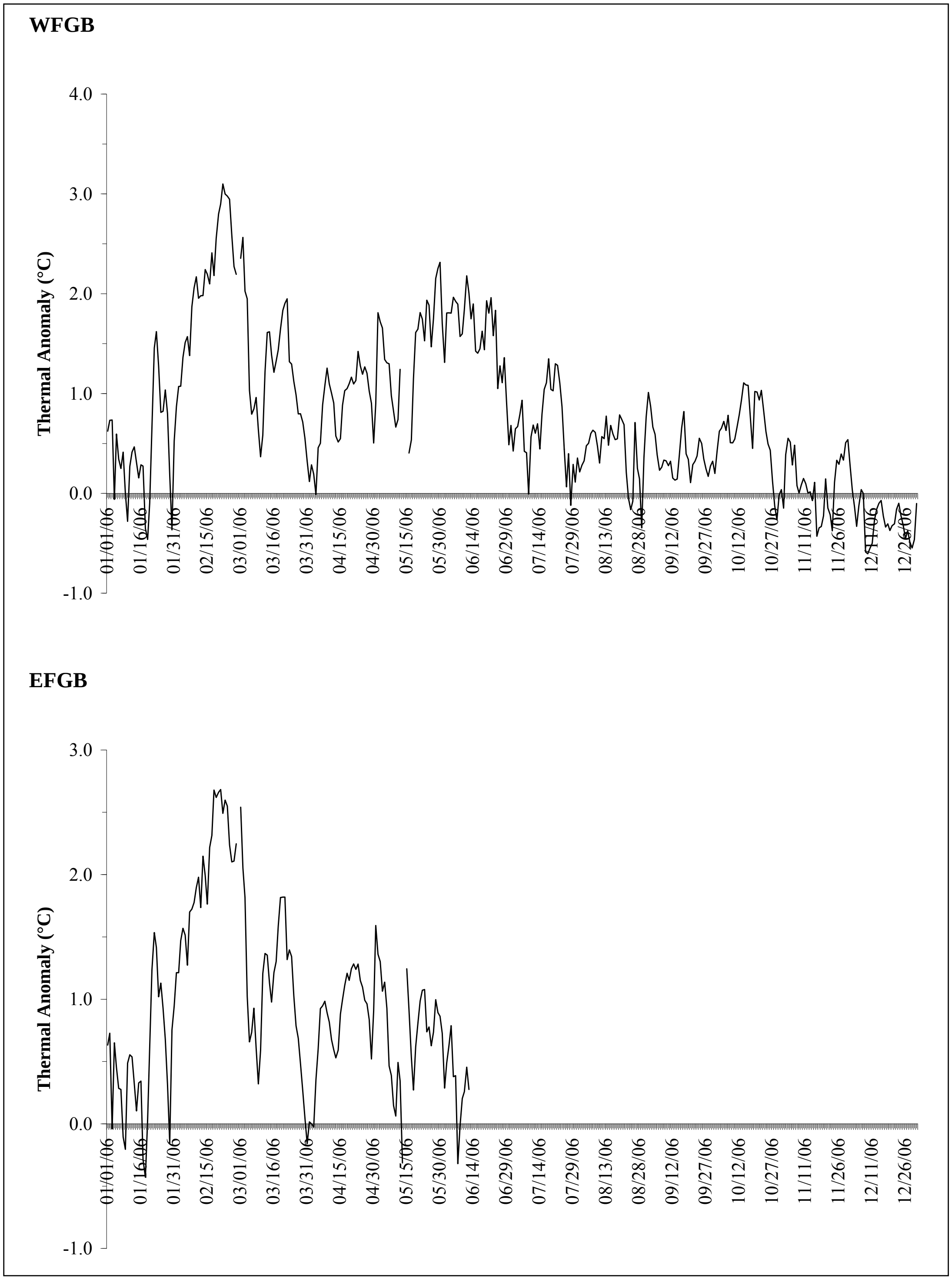


Figure 4.9.3. Thermal anomalies (°C) observed on the reef cap at the EFGB and WFGB in 2006 as compared to the long-term temperature average (1990 to 2008).

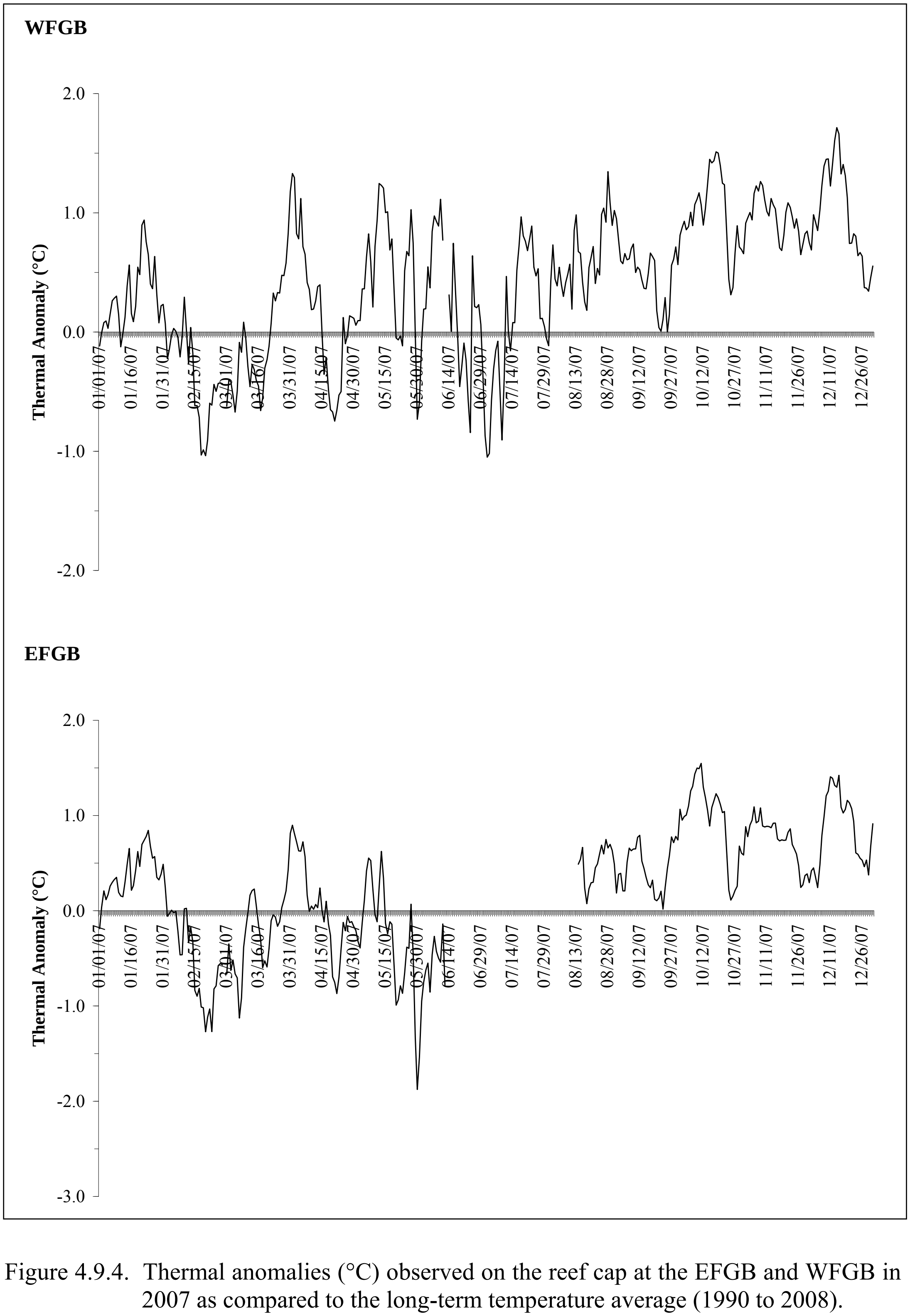


Figure 4.9.4. Thermal anomalies (°C) observed on the reef cap at the EFGB and WFGB in 2007 as compared to the long-term temperature average (1990 to 2008).

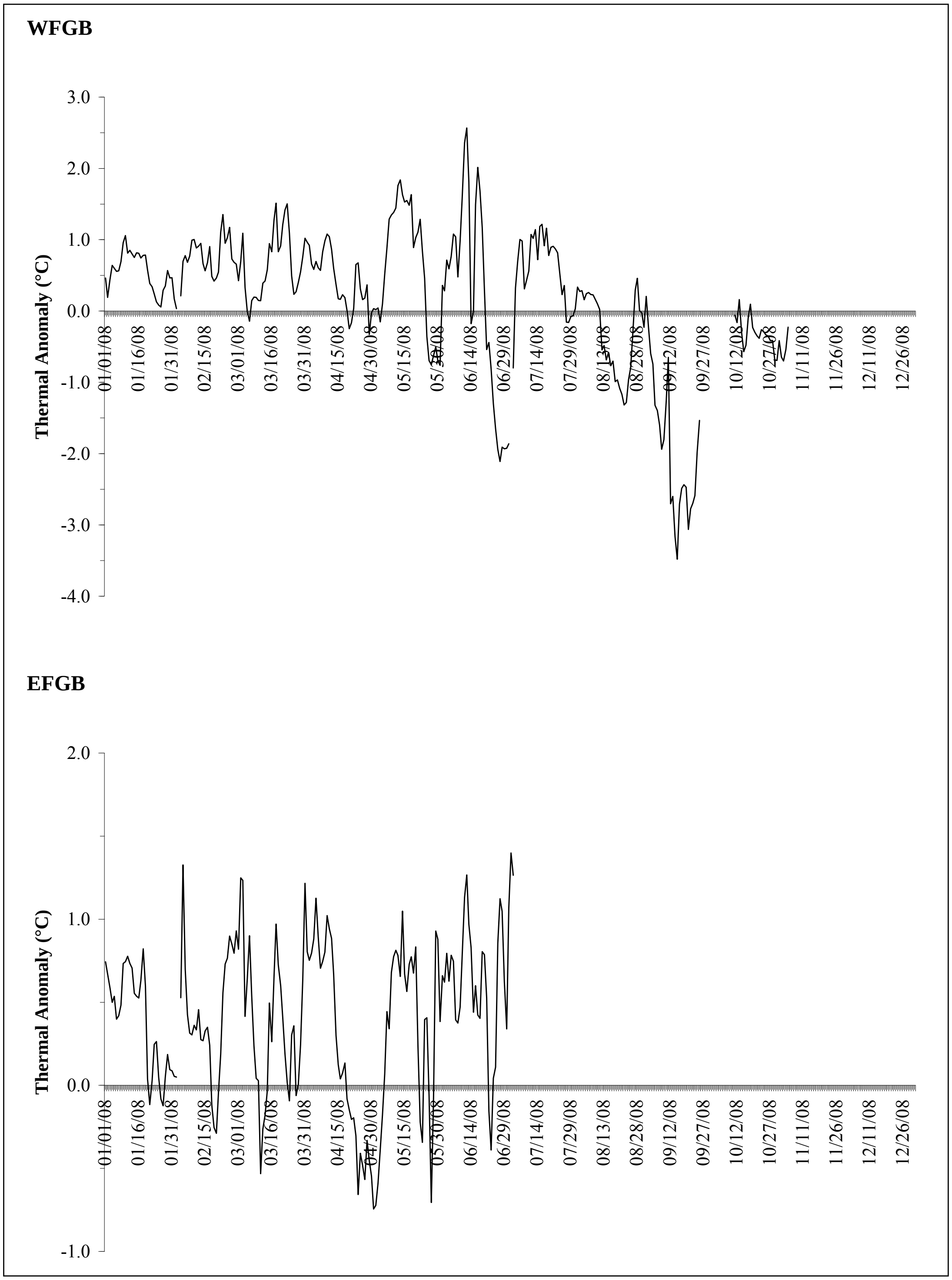


Figure 4.9.5. Thermal anomalies (°C) observed on the reef cap at the EFGB and WFGB in 2008 as compared to the long-term temperature average (1990 to 2008).

The summer of 2004 was unusually cool at the WFGB (by as much as 3°C) compared to the long-term average (no HoboTemp data were available for the EFGB in the summer of 2004).

The summer temperature of 2005 was unusually high on both Banks. It exceeded 30°C (coral bleaching threshold; Hagman and Gittings 1992) on both reefs. At the EFGB average daily temperature was greater or equal to 29.5°C from 07/29/05 to 09/19/05 (53 consecutive days). During that time, temperature exceeded 30°C during 29 days (including 16 consecutive days). At the WFGB, temperature on the reef cap was equal to or exceeded 29.5°C from 07/26/05 to 08/22/05 (29 days) and temperature exceeded 30°C during seven days from 08/06/05 to 08/21/05. During the passage of Hurricane Katrina (28 and 29 August 2005), temperature on the reef cap exceeded 30°C at the EFGB and no temperature was acquired at the WFGB. During the passage of Hurricane Rita (23 and 24 September 2005), temperature on the reef cap was 29.1°C and 28.3°C at the EFGB. No temperature data were gathered at the WFGB during that time.

Fall temperatures differed from the long-term average in 2004 (WFGB; no data for the EFGB), in 2005 (EFGB; partial data for WFGB), and in 2007 (both Banks). The anomalous temperatures recorded during these years prevented the typical cooling anticipated over the reef caps.

The annual sum of thermal anomalies on the reef caps of the FGB observed from 1990 to 2008 is summarized in Figure 4.9.6 and Table 4.9.1. At the EFGB, the winter of 2006 stands out as a major positive anomaly. Furthermore, winter temperatures on the EFGB reef cap in 1992, 2003, and 2007 were anomalously cold and so was the summer temperature of 1993. While both the EFGB and WFGB reef caps experienced unusually warm winters in 2006, unusually warm temperatures were also observed in the summer of 2006 at the WFGB (and not on the EFGB) compared to the long-term average. The summers of 2005 and 2007 were also uncommonly warm at the WFGB. The EFGB was also anomalously warm in the summer of 2007; however, data was not available for the EFGB in the summer of 2005 due to Hurricane Rita. As a result, thermal anomalies could not be calculated for the summer of 2005 (Figure 4.9.6).

Finally, to determine any significant difference of temperature among years, statistical comparisons were conducted on concurrent temperatures (i.e., temperatures for those days where data were collected for all five years). Differences in variances in the concurrent temperature distributions among the five years were tested using the parametric ANOVA test. Prior to the application of the parametric tests, the temperature datasets were first tested to determine whether their distributions were normal (via the Kolmogorov-Smirnov test) and homoscedastic (i.e., exhibit homogeneity of variances via the Bartlett test). Datasets that did not pass these tests for normality and homoscedasticity were data-transformed via an appropriate data transformation method (e.g., logarithmic, arcsin, square-root). The transformed dataset was then re-tested for normality and homoscedasticity. If these tests were passed, then the data were subjected to the parametric tests (i.e., t-test to test for differences in mean temperature and ANOVA to test for differences in variances in the temperature distributions).

Days with concurrent temperatures at the EFGB included the period from May 11 to June 12, with omission of May 14, yielding a sample size of $n = 32$ for each of the five years. No days existed with concurrent temperatures at the WFGB. Mean temperatures at the EFGB for 2004, 2005, 2006, 2007, and 2008 (over these days with concurrent temperatures) were 24.97°C, 24.29°C, 25.60°C, 24.49°C, and 25.56°C, respectively. The five temperature distributions for these five years passed the normality and homoscedasticity tests, and hence no data transformation was necessary prior to application of the parametric tests.

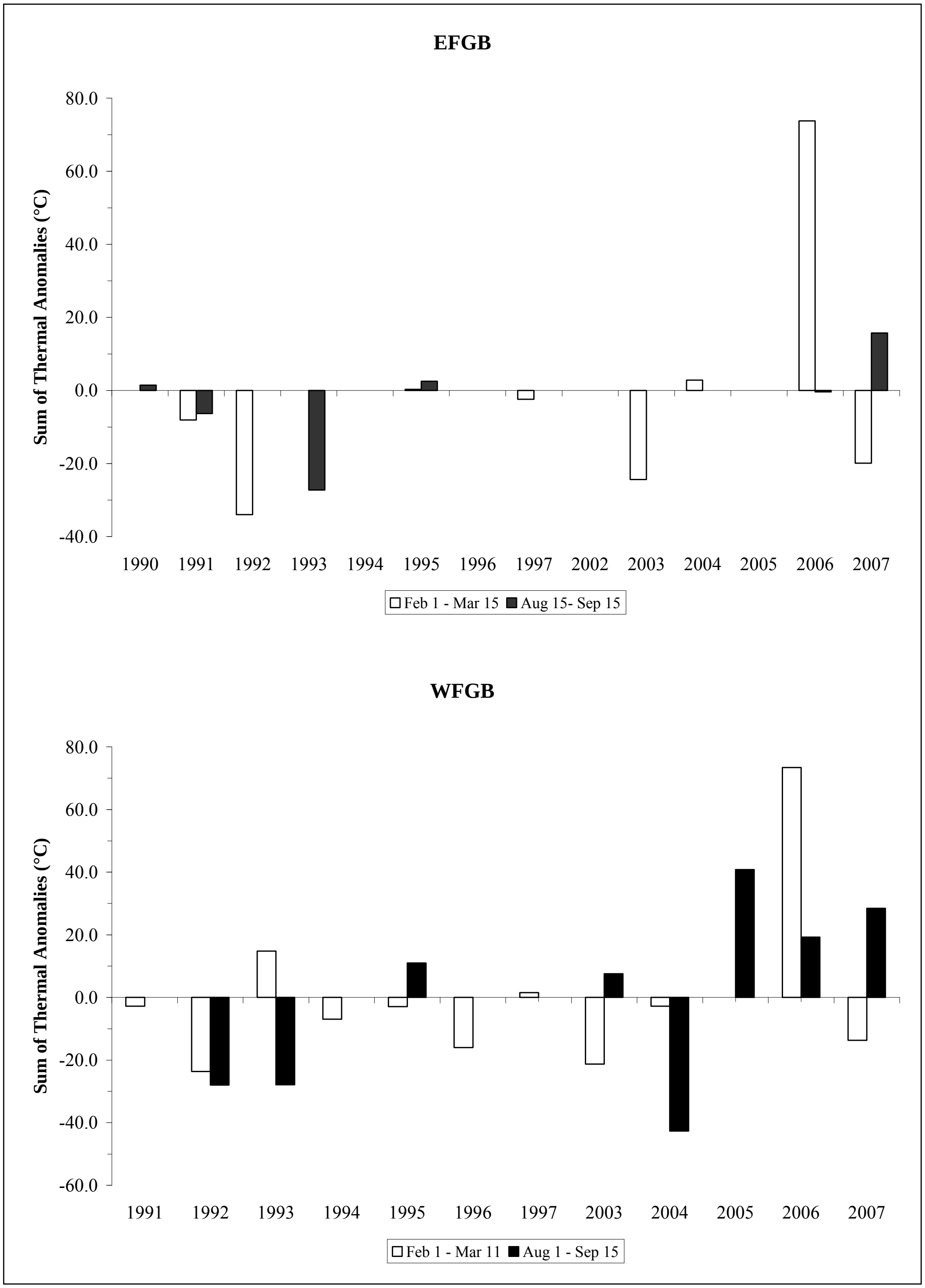


Figure 4.9.6. Sum of thermal anomalies on the reef cap of the EFGB and WFGB from 1990 to 2008 during the winter minimum and summer maximum.

Table 4.9.1.

Annual sum of minimum and maximum thermal anomalies at the EFGB and WFGB from 1990 to 2004.

Year	EFGB		WFGB	
	February 1-March 15	August 15-September 15	February 1-March 11	August 1-September 15
1990	N/A	1.4	N/A	N/A
1991	-8.1	-6.3	-2.8	N/A
1992	-33.9	N/A	-23.6	-28.0
1993	N/A	-27.2	14.8	-27.9
1994	N/A	N/A	-6.9	N/A
1995	0.3	2.6	-2.9	11.0
1996	N/A	N/A	-16.0	N/A
1997	-2.4	N/A	1.6	N/A
2002	N/A	N/A	N/A	N/A
2003	-24.4	N/A	-21.3	7.6
2004	2.8	N/A	-2.7	-42.7
2005	N/A	N/A	N/A	40.8
2006	73.8	-0.4	73.4	19.3
2007	-19.9	15.7	-13.7	28.4

Results of the parametric ANOVA test showed a significant difference in variances in the temperature distributions among the five years at the EFGB. At the 95% confidence level, F=13.1654, critical F=2.4325, and P<0.0005 (Table 4.9.2).

Since the null hypothesis (H_o) of no significant difference in temperature distributions among the five years was rejected (Table 4.9.2), a subsequent Tukey multiple comparisons test was conducted to determine the source of the differences (i.e., which specific pairs of years exhibited significant differences in their temperatures). The following pairs of years showed significant differences in temperature between them at the EFGB according to the Tukey test (SE=0.1657, DF_1=155, DF_2=5, Q_{crit}=3.9169): (1) 2005 and 2006 (Q=7.9); (2) 2006 and 2007 (Q=6.7); (3) 2005 and 2008 (Q=7.7); (4) 2007 and 2008 (Q=6.5); and (5) 2004 and 2005 (Q=4.1).

HoboTemp versus Sea-Bird Temperature Records at the EFGB in 2008. Daily average temperatures over the EFGB reef cap were obtained from 02/04/08 to 07/03/08 with a HoboTemp and Sea-Bird MicroCAT (SBE). Statistical comparisons were conducted to determine any significant differences in mean temperature (averaged over this time period) and differences in variances in the time-series temperature distributions between the two instruments. Differences in mean temperature between the two instruments were tested using the parametric two-sample t-test and the paired-sample t-test. Differences in variances in the temperature distributions between the two instruments were tested using the parametric two-sample ANOVA test.

Table 4.9.2.

Results of the parametric ANOVA on variances in temperature distributions among the five years at the EFGB.

Variance Source	DF	SS	MS	F_{stat}	# Tails	DF_1	DF_2	CI Level	F_{crit}	Reject H_o?	P_{low}	P_{high}	P_{int}
Between Means (Model):	4	46.2866	11.5716	13.17	1	4	155	0.05	2.4325	Y	0	0.0005	0
Within Sets (Error):	155	136.24	0.8789										
Total:	159	182.52	1.1479										

Table 4.9.3.

Results of the parametric ANOVA on variances in temperature distribution between the HoboTemp and SBE.

Variance Source	DF	SS	MS	F_{stat}	# Tails	DF_1	DF_2	CI Level	F_{crit}	Reject H_o?	P_{low}	P_{high}	P_{int}
Between Means (Model):	1	0.1535	0.1535	0.025	1	1	300	0.05	3.87	N	0.3	0.5	0.4
Within Sets (Error):	300	1838	6.1267										
Total:	301	1838.15	6.1068										

Prior to application of the parametric tests, the temperature datasets were first tested to determine whether their distributions were normal (via the Kolmogorov-Smirnov test) and homoscedastic (i.e., exhibit homogeneity of variances, via the Bartlett test). Datasets that did not pass these tests for normality and homoscedasticity were data-transformed via an appropriate data transformation method (e.g., logarithmic, arcsin, square-root). The transformed dataset was then re-tested for normality and homoscedasticity. If the data passed these tests, then the data were subjected to the parametric tests (i.e., t-test to test for differences in mean temperature, and ANOVA to test for differences in variances in the temperature distributions).

Mean temperatures for the HoboTemp (n=151) and SBE (n=151) were 23.4°C and 23.5°C, respectively. The two temperature distributions for the HoboTemp and SBE passed the normality and homoscedasticity tests, and hence no data transformation was necessary prior to application of the parametric tests.

Results of the two-tailed, two-sample t-test showed no significant difference in mean temperature between the HoboTemp and SBE. At the 95% confidence level, for the two-tailed test, n=151, DF=300, t=0.1583, critical t=1.9680, $0.50<P<1.00$, P=0.7545, with a 95% confidence interval of -0.5155 to 0.6057. Results of the one-tailed, two-sample t-test showed that HoboTemp mean temperature (23.4°C) is not significantly less than the SBE mean temperature (23.5°C). At the 95% confidence level, for the one-tailed test, n=151, DF=300, t=0.1583, critical t=1.6500, $0.25<P<0.50$, P=0.3773, with a 95% confidence interval of -0.4249 to 0.5151.

Results of the two-tailed, paired-sample t-test showed a significant difference in mean temperature between the HoboTemp and SBE. At the 95% confidence level, for the two-tailed test, n=151, DF=150, t=37.5953, critical t=1.9760, $P<0.001$, with a 95% confidence interval of -0.0475 to -0.0427. Results of the one-tailed, paired-sample t-test showed that HoboTemp mean temperature (23.4°C) is significantly less than the SBE mean temperature (23.5°C). At the 95% confidence level, for the one-tailed test, n=151, DF=150, t=-37.5953, critical t=1.6550, $P<0.0005$, with a 95% confidence interval of -0.0471 to -0.0431.

Results of the parametric ANOVA test showed no significant difference in variances in the temperature distribution between the HoboTemp and SBE. At the 95% confidence level, F=0.0251, critical F=3.8700, $0.25<P<0.50$, and P=0.3908 (Table 4.9.3).

The results of the two-sample t-tests, both one-tailed and two-tailed, showed no significant difference in mean temperature between the HoboTemp and SBE. However, results of the paired-sample t-tests, both one-tailed and two-tailed, did show a significant difference in mean temperature between the two instruments. Lastly, results of the parametric ANOVA test showed no significant difference in variances in the temperature distribution between the HoboTemp and SBE. Overall, three of the five statistical tests showed that the HoboTemp and SBE instruments were equally reliable in recording accurate temperatures over the FGB reef caps. Also, note that the above discussions on seawater temperature based on HoboTemp data collected in 2008 apply to the SBE.

Sea State. To evaluate changes in sea state at the FGB, we used significant wave height (SWH) recorded from 2004 to 2008 at the Coastal-Marine Automated Network (C-MAN) buoy 42019 located 152-km (94-mi) west of the WFGB (27°54'47"N, 95°21'36"W; USDOC, NOAA/NDBC 2008). Significant wave height is commonly defined as the "average of the highest one-third of all the wave heights" during a given sampling period. Significant wave height data recorded at C-MAN buoy 42019 were available from January 2004 through 11/30/08 (USDOC, NOAA/NDBC 2008). Mariner Energy Station FGBL1 and TABS stations 42046 and 42047 are located closer to the FGB than C-MAN buoy 42019. However, these stations did not provide significant wave height data and thus were not used to evaluate changes in sea state at the FGB.

From 2004 to 2008, calm seas (SWH ~1 m) occurred mostly during the summer from mid-June to mid-July (Figures 4.9.7 to 4.9.11- mean values calculated by averaging mean daily significant wave heights for 2004-2008). Seas were generally roughest (SWH ~3 m) from January to June and from September to December, but particularly so in 2005 and 2008 (Figures 4.9.8 and 4.9.11). In 2005, there were numerous bouts of heavy seas starting in mid-July through December, some of which coincided with the unusually active hurricane season (Table 4.9.4). On 09/23/05, Hurricane Rita passed near the FGB as a Category 3 hurricane which caused a substantial surge of SWH. In 2008, seas were particularly rough during January and March, the end of July, and mid-September. Hurricanes Dolly and Ike probably caused the spikes of SWH recorded in July and September, respectively.

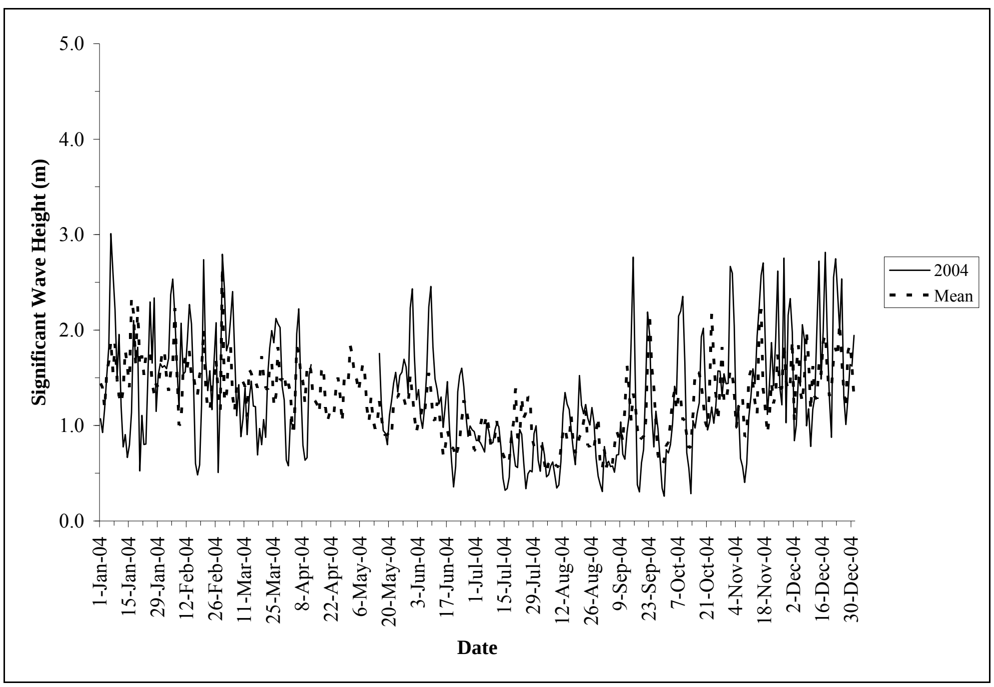


Figure 4.9.7. Mean daily SWH measured at C-MAN buoy 42019 located 152-km (94-mi) west of the WFGB in 2004. Source data: USDOC, NOAA/NDBC (2008).

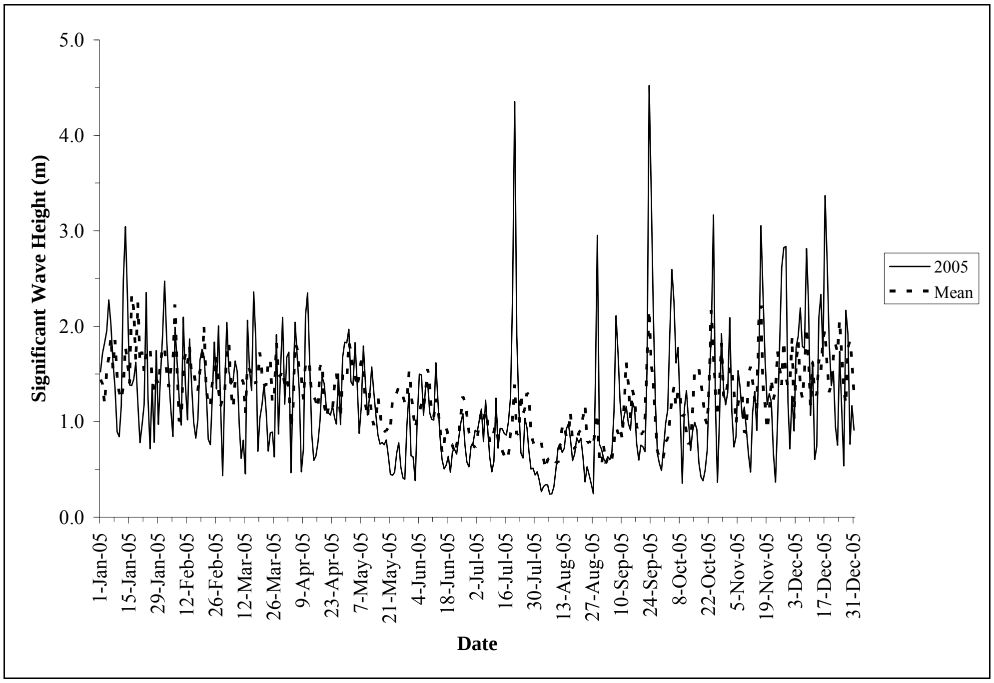


Figure 4.9.8. Mean daily SWH measured at C-MAN buoy 42019 in 2005. Source data: USDOC, NOAA/NDBC (2008).

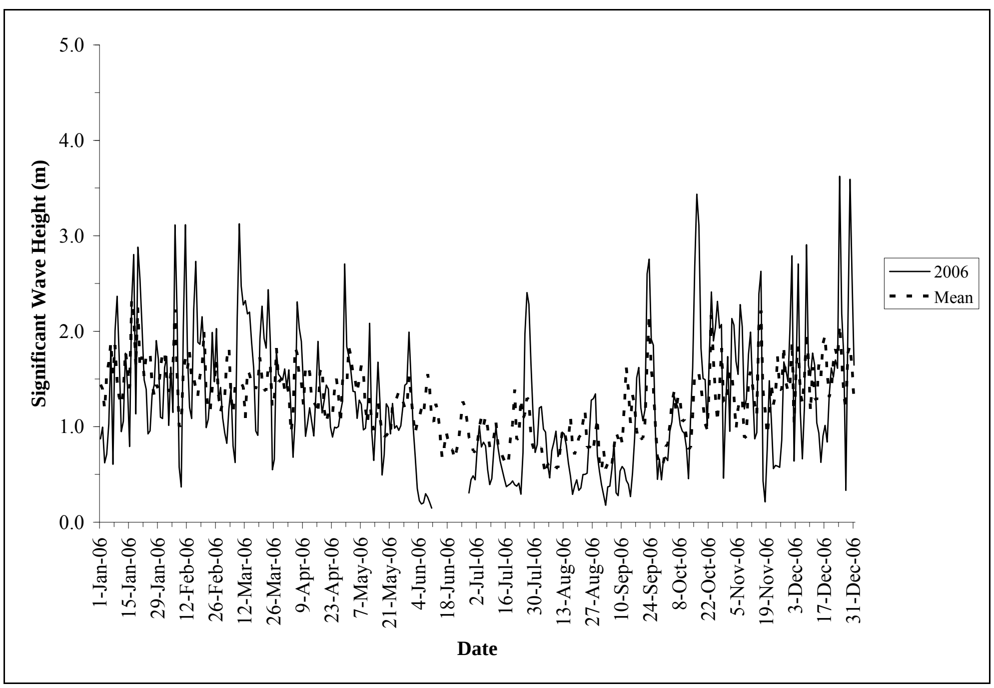


Figure 4.9.9. Mean daily SWH measured at C-MAN buoy 42019 in 2006. Source data: USDOC, NOAA/NDBC (2008).

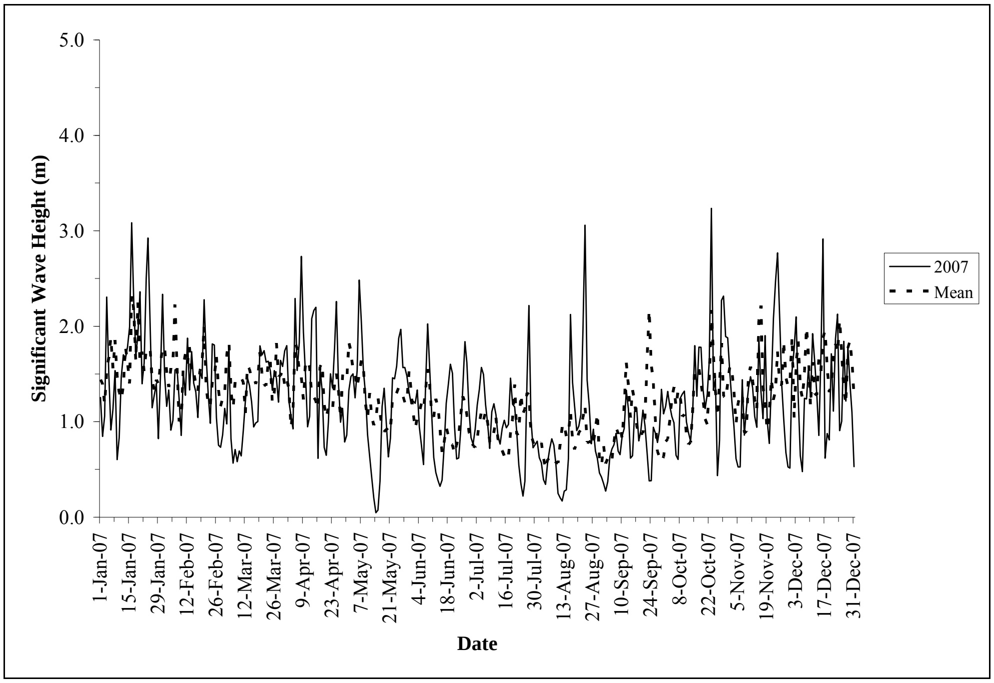


Figure 4.9.10. Mean daily SWH measured at C-MAN buoy 42019 in 2007. Source data: USDOC, NOAA/NDBC (2008).

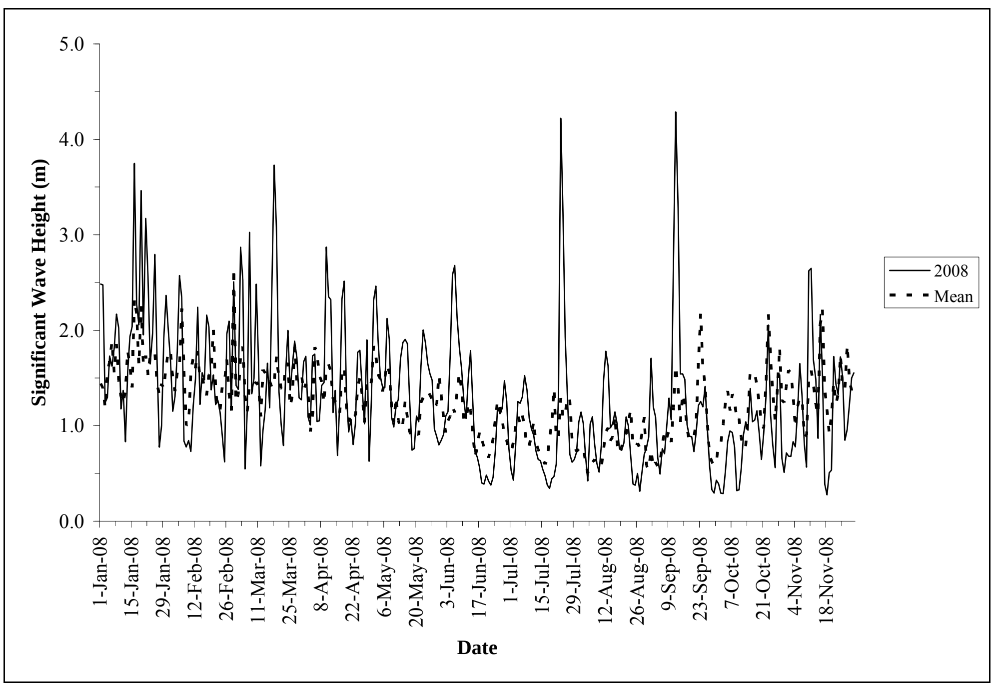


Figure 4.9.11. Mean daily SWH measured at C-MAN buoy 42019 in 2008. Source data: USDOC, NOAA/NDBC (2008).

Table 4.9.3.

List of tropical cyclones that entered the Gulf of Mexico (GOMEX) from 2004 to 2008. The wind speed (mph) represents the wind speed or category of a given storm when it was closest to the FGB. Source data: The Weather Underground, Inc. (2008). Cat = category. Distance represents the closest distance of the storm track to either the EFGB or WFGB. Source data: NOAA, National Hurricane Center (2009a). Maximum wind speed data also obtained from NOAA, National Hurricane Center (2009a).

Name/Category	Date	Wind Speed or Category (mph)	Maximum Wind Speed (mph)	Location and Distance
Tropical Storm Bonnie	08/10/04	50	63	Central GOMEX, ~401 km (249 mi) east of the EFGB
Hurricane Charley	08/13/04	Cat 4	144	Florida Straits, ~1132 km (703 mi) from the EFGB
Tropical Storm Frances	09/04/04	65	144	Northeast GOMEX, ~924 km (574 mi) east of the EFGB
Hurricane Ivan	09/15/04	Cat 4	167	Eastern GOMEX, ~168 km (104 mi) east of the EFGB
Tropical Storm Matthew	10/09/04	40	46	Northwest GOMEX, ~191 km (119 mi) east of the EFGB
Tropical Storm Arlene	06/11/05	69	69	Central GOMEX, ~635 km (395 mi) east of the EFGB
Tropical Storm Bret	06/25/05	40	40	Southwest GOMEX, ~805 km (500 mi) southwest of the WFGB
Tropical Storm Cindy	07/05/05	70	75	Central GOMEX, ~307 km (191 mi) east of the EFGB
Hurricane Dennis	07/10/05	Cat 4	150	Central GOMEX, ~686 km (426 mi) east of the EFGB
Hurricane Emily	07/19/05	Cat 1	161	Southwest GOMEX, ~437 km (272 mi) south of the WFGB
Tropical Storm Gert	07/25/05	45	46	Southwest GOMEX, ~770 km (479 mi) south of the WFGB
Tropical Storm Jose	08/23/05	50	52	Southwest GOMEX, ~924 km (574 mi) south of the WFGB
Hurricane Katrina	08/28/05	Cat 5	173	Central GOMEX, ~394 km (245 mi) east of the EFGB
Hurricane Rita	09/23/05	Cat 3	178	Central GOMEX, ~93 km (58 mi) east of the EFGB
Tropical Storm Stan	10/03/05	40	81	Southwest GOMEX, ~862 km (535 mi) south of the EFGB
Hurricane Wilma	10/24/05	Cat 3	184	Southeast GOMEX, ~965 km (600 mi) SE of the EFGB

Table 4.9.3. List of tropical cylones that entered the GOMEX from 2004 to 2008 (continued).

Name/Category	Date	Wind Speed or Category (mph)	Maximum Wind Speed (mph)	Location and Distance
Tropical Storm Alberto	06/12/06	69	69	Eastern GOMEX, ~659 km (409 mi) southeast of the EFGB
Tropical Storm Barry	06/02/07	58	58	Southeast GOMEX,~926 km (576 mi) southeast of the EFGB
Tropical Storm Erin	08/15/07	40	58	Western GOMEX, ~216 km (134 mi) east of the WFGB
Hurricane Humberto	09/13/07	Cat 1	92	Northwest GOMEX, ~123 km (76 mi) west of the WFGB
Hurricane Lorenzo	09/25/07	Cat 1	81	Southwest GOMEX, 680 km (423 mi) southwest of the WFGB
Hurricane Dolly	07/22/08	75	98	South central GOMEX, ~360 km (224 mi) southeast of the WFGB
Tropical Storm Edouard	08/05/08	63	63	Central GOMEX, ~139 km (86 mi) northeast of the EFGB
Tropical Storm Fay	08/23/08	45	69	Eastern GOMEX, ~512 km (318 mi) east of the EFGB
Hurricane Gustav	09/01/08	Cat 3	144	East central GOMEX, ~300 km (186 mi) east of the EFGB
Hurricane Ike	09/13/08	Cat 2	144	Central GOMEX, ~0.7 km (0.4 mi) from the EFGB
Tropical Storm Marco	10/07/08	63	63	Southwest GOMEX, ~916 km (569 mi) south of the WFGB

In 2004, sea state at C-MAN buoy 42019 was roughest from January through early March, and again during fall and winter (Figure 4.9.7; USDOC, NOAA/NDBC 2008). The calmest period was from June to early September. Two hurricanes and three tropical storms entered the Gulf of Mexico in 2004, the closest track to the FGB being Hurricane Ivan, some 168-km (104-mi) east (Table 4.9.3; USDOC, NOAA, National Hurricane Center 2009a). During Hurricane Ivan, SWH at C-MAN buoy 42019 rose from about 1.0 m (3.0 ft) on 09/13/04 to 2.8 m (9.2 ft) on 09/15/04 (Figure 4.9.7; USDOC, NOAA/NDBC 2008).

The winter and early spring (January to March) of 2005 were not unusually rough when compared to the other years reported here (USDOC, NOAA/NDBC 2008; Figure 4.9.8). Mid-June to mid-July was the calmest period in 2005. Rough seas were recorded during late summer, and in the fall and winter (SWH >2 m or >7 ft). These anomalies coincided with an exceptionally active 2005 Atlantic hurricane season, with 31 named tropical disturbances (USDOC, NOAA, National Hurricane Center 2009b). The first elevated reading of SWH at C-MAN buoy 42019 was probably generated by Hurricane Emily which tracked approximately 437 km (272 mi) south of the WFGB (USDOC, NOAA, National Hurricane Center 2009a). SWH rose from 1 m (3 ft) on 07/17/05 to 4.4 m (14.4 ft) on 07/20/05 (Figure 4.9.8; USDOC, NOAA/NDBC 2008). Starting in late August, there were a series of spikes in SWH caused (in large part) by three hurricanes and three tropical storms. Despite the distance of the FGB from most of the tropical cyclones that entered the Gulf of Mexico that year, the sea state in 2005 at C-MAN buoy 42019 was substantially affected by Hurricanes Emily (07/19/05; SWH = 4.35 m or 14.27 ft), Katrina (08/28/05; SWH = 2.95 m or 9.68 ft), and Wilma (10/24/05; SWH = 3.16 m or 10.37 ft), even though the storms passed more than 394 km (245 mi) away from the buoy (USDOC, NOAA/NDBC 2008; USDOC, NOAA, National Hurricane Center 2009a; Figure 4.9.8). Hurricane Rita caused the largest surge in SWH, from less than 1 m (3 ft) on 09/21/05 to 4.5 m (14.8 ft) on 09/23/05. The SWH was probably greater at the FGB considering that the storm track of Hurricane Rita traversed ~93 km (58 mi) east of the EFGB on 09/23/05 while it was Category 3 hurricane (Figure 4.9.12; USDOC, NOAA, National Hurricane Center 2009a). Depth measured by the YSI instrument at the EFGB rose from 23 m (75 ft) to 25 m (82 ft) from 09/23/05 0300 hrs to 09/24/05 0400 hrs, indicating the passage of Hurricane Rita. On 09/23/05, SWH reached 5.9 m (19.4 ft) at 2000 hrs at C-MAN buoy 42019 (USDOC, NOAA/NDBC 2008).

The sea state in 2006 was rough (SWH >3 m or >10 ft) from January through early spring, and from mid-October through December (Figure 4.9.9; USDOC, NOAA/NDBC 2008). A period of relative calm from mid-June to mid-September was interrupted by a spike of SWH in late July (from 0.4 m or 1.3 ft on 07/22/06 to 2.4 m or 7.9 ft on 07/26/06). In contrast to the high cyclonic activity in the Gulf of Mexico during 2005, only one tropical storm, Tropical Storm Alberto, entered the Gulf of Mexico in 2006 (The Weather Underground Inc. 2008). Tropical Storm Alberto crossed the eastern Gulf of Mexico from 06/11/06 to 06/13/06. It was closest to the FGB on 06/12/06, approximately 659 km (409 mi) to the southeast (USDOC, NOAA, National Hurricane Center 2009a). As indicated by the SWH data recorded at C-MAN buoy 42019, there was no evidence of a change in sea state during the passage of this storm (USDOC, NOAA/NDBC 2008). In fact, most of the month of June was calm, with SWH less than 0.5 m (1.6 ft; Figure 4.9.9).

Figure 4.9.12. Hurricane Rita in the Gulf of Mexico on September 23, 2005. Photo courtesy of NOAA.

In 2007, episodes of SWH greater than 3 m (10 ft) took place in mid-January, late August, and late October (USDOC, NOAA/NDBC 2008). Two tropical storms and two hurricanes entered the Gulf of Mexico: Tropical Storm Barry, Tropical Storm Erin, Hurricane Humberto, and Hurricane Lorenzo (The Weather Underground Inc. 2008; Table 4.9.3). None of these storms precipitated measurable changes in SWH at C-MAN buoy 42019 (Figure 4.9.10; USDOC, NOAA/NDBC 2008).

Episodes of rough seas (SWH >3 m or >10 ft) in 2008 took place in mid to late January, mid March, late July, and mid September (USDOC, NOAA/NDBC 2008). There were six cyclonic weather events in 2008 within the Gulf of Mexico (The Weather Underground Inc. 2008). The events consisted of three tropical storms and three hurricanes: Hurricane Dolly, Tropical Storm Edouard, Tropical Storm Fay, Hurricane Gustav, Hurricane Ike (Figure 4.9.13), and Tropical Storm Marco (Table 4.9.3). Only Hurricanes Dolly (07/22/08) and Ike (09/13/08) caused a surge of 4+ m (13+ ft) in SWH at C-MAN buoy 42019 (Figure 4.9.11; USDOC, NOAA/NDBC 2008).

4.9.1.2. Biological Parameter: Chlorophyll a

Chl *a* concentrations from 2004 to 2008 revealed that the water column overlying the FGB reef caps could contain as much as 5 mg/m^3. Not all water samples contained detectable levels of chl *a* (>1 mg/m^3). This was expected since chl *a* concentrations at the shelf edge in the northwestern Gulf of Mexico typically range from 0.1-0.3 mg/m^3 (Nowlin et al. 1998). The highest values for surface chl *a* are typically anticipated in the summer (July-August; Nowlin et al. 1998). The relatively high values of chl *a* (by FGB standards) observed in the fall are worth noting and need further investigation. The chl *a* values observed on 05/19/07 and 10/13/07 at the FGB may be indicative of an algal bloom. Nutrient levels (ammonia and TKN) were also relatively high on

10/13/07 compared to other sampling efforts (Table 3.9.6). Elevated nutrient levels may have been related to the increased production of phytoplankton as indicated by chl *a* levels. 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 October 2007. Monitoring chl *a* at the FGB may be indicative of episodic nutrient fluxes.

Figure 4.9.13. Hurricane Ike in the Gulf of Mexico on September 12, 2008. Photo courtesy of NOAA.

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 groundtruthing purposes and to examine vertical profiles over the reef cap. The CoastWatch database did not contain data on chl *a* or turbidity for the Gulf of Mexico for 2005 through 2007. There were, however, data on chl *a* in CoastWatch for 2008 (MODIS/AQUA chlorophyll NASA SeaDas; MODIS is the acronym for MODerate Resolution Imaging Spectroradiometer, a sensor on board of TERRA and AQUA satellites of the Earth Observing System operated by NASA; USDOC, NOAA Satellite and Information Service 2008).

All chl *a* images were obtained from the NOAA Satellite and Information Service for the Gulf of Mexico region (USDOC, NOAA Satellite and Information Service 2008). Images were available from 09/09/08 through 12/29/08 (last day of data search). Images taken from various satellites were collected. Satellites were programmed to take images at various times throughout the day. Therefore, several images were available per day. Images of chl *a* were taken after 1505 UTC. Even though seasonal variations of chl *a* were anticipated, they were not recorded since only data for late fall through early winter were available. Detailed comparisons were not made between image sets per day; however, during favorable weather conditions concentrations were expected to be higher toward noon and to decrease with incident sunlight. Note that we did not conduct a comparison of weather patterns and chl *a* concentrations. The highest chl *a* concentrations were observed on 12/26/08 (Figure 4.9.14) in an image taken between 1520 and 1710 UTC (0920-1110 CT). There was a marked increase in chl *a* concentration compared to an image taken on 12/24/08, collected around the same time. A concentration of approximately 3 mg/m^3 was observed throughout the northern region of the Gulf of Mexico and small areas of higher concentration, 5.0-6.0 mg/m^3, were observed in the eastern and western central regions.

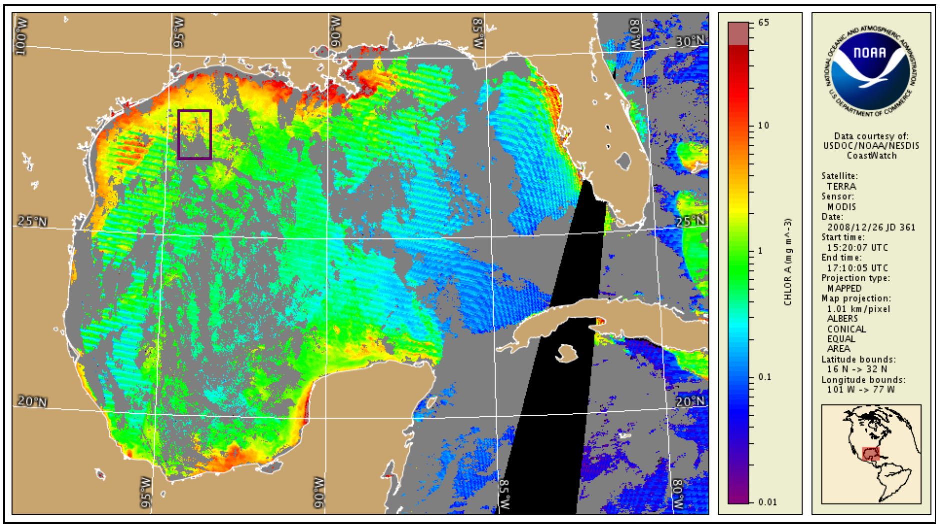


Figure 4.9.14. Chlorophyll *a* concentrations of the Gulf of Mexico on December 26, 2008 (1520-1710 UTC) as recorded by the NASA SeaDAS, TERRA satellite, MODIS sensor. The black rectangle shows the approximate location of the FGB (28°N 94°W). Photo courtesy of NOAA.

4.9.1.3. Chemical Parameters: Salinity, Turbidity, Dissolved Oxygen, pH, and Nutrients

Salinity. Accurate salinity data were obtained from the SBE MicroCAT for February through November 2008. Using what seemed to be the most credible YSI salinity data, salinity may have varied from 28 to 36 PSU from June through November 2006. Furthermore, the variations of salinity were simultaneous on both Banks (Figure 3.9.5). The YSI data revealed decreasing salinity from 36 to 33 PSU from June to July, a trend consistent on both Banks in 2005 and 2006. During the course of the study, there were as many as two annual events of low salinity on the reef caps of the FGB: one in June/July/August and another, more pronounced event in September/October. However, the SBE data collected in 2008 (Figures 3.9.19 and 3.9.20) showed a much tighter range of salinity (35 to 36.5 PSU) and one main episode during which salinity oscillated (May to July 2008).

From 1992 to 1994, the low salinity events Nowlin et al. (1998) recorded 30-48 km (19-30 mi) west of the FGB were more intense from June to August than in September/October as seen here. Differences between these data sets may have resulted from differences in the timing of the dispersion of peak freshwater runoff into the northern Gulf of Mexico. In addition to the reef cap measurements of low salinity, vertical profiles showed evidence of low salinity (31 to 33 PSU) in the upper 4-10 m (13-33 ft) of the water column in June 2005, June 2007, and August 2007

(Figures 3.9.12-3.9.14). Also, in June 2005, several members of the dive team reported a density discontinuity layer just above the reef cap. The resultant shimmering may have been caused by differences in water density, resulting from parcels of near surface water being driven down into the water column.

Future salinity data collected by the SBE 37-SMP 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 probable source of low salinity recorded at the FGB during this study both near the sea surface and on the reef cap is the supply of nearshore river-seawater mix to the outer continental shelf, principally from the Mississippi River watershed, as discussed in Deslarzes and Lugo-Fernandez (2007). The FGB are therefore physically linked to nearshore processes and to regional river runoff.

Turbidity. The FGB are periodically exposed to nearshore turbidity as documented in satellite images such as those of 10/26/08 (USDOC, NOAA Satellite and Information Service 2008; Figure 4.9.15). This example of turbidity reaching the FGB was acquired from a collection of images taken by the MODIS sensor and two satellites: AQUA and TERRA from 10/21/08 through 12/29/08. Turbidity images were not taken by the AQUA satellite in the FGB region prior to 1855 UTC or after 2025 UTC. Images from the Terra satellite fall between 1625 UTC and 1735 UTC. Strong sediment coverage was observed in several of the images collected. The picture shown in Figure 4.9.15 was taken on 10/26/08 between 1905 and 1910 UTC.

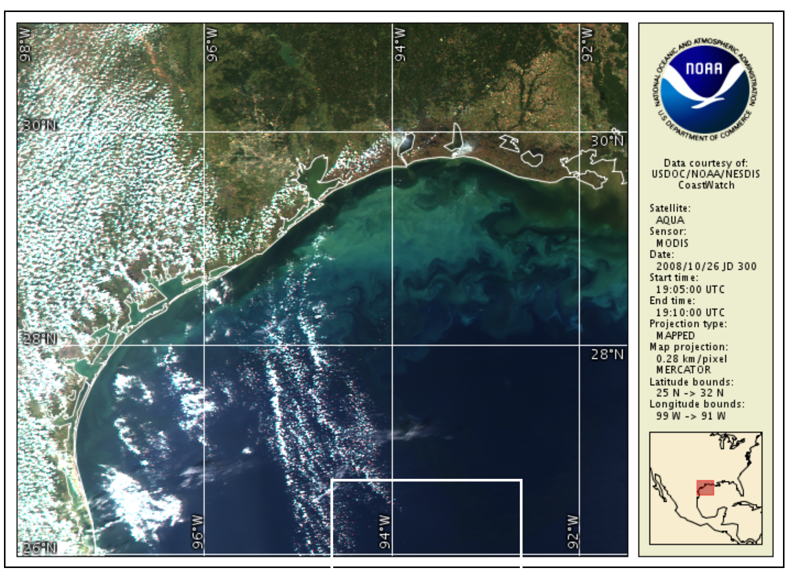


Figure 4.9.15. Turbidity in the northwestern Gulf of Mexico as photographed on October 26, 2008 by the AQUA Satellite (MODIS sensor). The FGB region is represented by the white rectangle. Photo from USDOC, NOAA Satellite and Information Service (2008).

Dissolved Oxygen (DO). More DO data are needed to accurately interpret DO variations at the FGB. The long-term monitoring program would also have benefited from DO values recorded on the reef proper instead of on the sand flat. Primary productivity is thought to be greater on the sand flats rather than the reef proper (Gregory S. Boland unpublished data). The DO reported here are records of net oxygen production by microorganisms and algae over the sand flats. Main factors positively affecting primary production are light, nutrients, and temperature (Valiela 1984). Adequate instrumentation would allow examination of correlations of DO concentrations with variations of light and temperature.

pH. There is a need to acquire accurate pH data at the FGB or at least use reliable instrumentation to validate data collection. Since pH in shallow ocean environments may decrease in the future as a result of increased atmospheric CO_2 (Kleypas et al. 1999a; Andersson et al. 2003), the continued and accurate measuring of pH at the FGB may help detect environmental changes associated with changing anthropogenic inputs. When pH decreases, so does the concentration of the carbonate ion and the calcification of corals and algae (Kleypas et al. 1999b). Furthermore, there is a need to monitor the calcium carbonate saturation state (Ω) and to examine the calcification rate of massive corals at the FGB. Indeed, massive corals of the Great Barrier Reef are showing a 14% decline in calcification since 1990 (De'ath et al. 2009). Further increases in concentrations of atmospheric CO_2 may accentuate the decline in calcification rates of massive corals of the Great Barrier Reef and possibly of many other reefs around the world. Cores taken from massive corals at the FGB should reveal regional calcification trends. Assessing Ω should provide further insight into the progression of global change and its effects on the northwestern Gulf of Mexico.

Nutrients. No definitive trends could be determined from these data. Ammonia values were typically less than 1 mg/l from the sea surface to the reef cap. Nitrate levels were typically very low (less than 0.15 mg/l). TKN (organic nitrogen and ammonia) was detected in most of the water samples. Nitrite and soluble reactive phosphorous were not detected. The data gathered here could not provide trends 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. Probable sources of nutrients found in the water column at the FGB are nearshore waters (Nowlin et al. 1998), sediments (Entsch et al. 1983), and benthic and planktonic organisms (D'Elia and Wiebe 1990). More frequent sampling is required to understand variations of nutrient concentrations over the reef caps. Based on the findings of the spot checks conducted in this study and the results reported in Nowlin et al. (1998), nutrient inputs to the FGB are probably very limited.

4.10. Fish Surveys

The fish assemblages of the EFGB and WFGB are unique in two respects: (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. These two factors are important in shaping the fish assemblages at the FGB. They also differ from fish assemblages in other reef/hard bottom systems in the Gulf of Mexico. Comparisons between artificial reefs in the Gulf of Mexico (both standing platforms and toppled platforms) and the FGB showed that the natural reefs of the Banks were distinct (Rooker et al. 1997; Wilson et al. 2003).

Fishing and recreational diving pressure, shipping traffic, water quality (including temperature and planktonic composition), and current flow patterns also affect the fish assemblages at the FGB to varying degrees. Since the late 1800's, fishermen have practiced long-line fishing at the EFGB and WFGB (Scarborough-Bull 1988). Commercial fishing with bottom long-lines, traps, nets, and bottom trawls are now prohibited within the Sanctuary's boundaries, yet illegal long-line fishing has still been observed (Scarborough-Bull 1988). Although hand-line and hook and line fishing, including bandit reels (powered reels), are allowed within the Sanctuary's boundaries, the distance from shore does provide some protection to its fish populations from human interference.

The fish surveys in 2004 through 2007 revealed a thriving reef-fish assemblage, as observed in previous annual monitoring surveys. The large number of oil and gas production platforms in the Gulf of Mexico and mooring buoys may have assisted additional fish species in reaching the FGB and establishing themselves permanently (Boland et al. 1983; Rooker et al. 1997; Gittings 1998). Tables 3.10.1 and 3.10.2 present the list of fish species observed during visual fish surveys at the FGB in 2004-2007 at EFGB and WFGB, respectively. It appears that the multiple hurricanes that moved through the area during this time period did not impact the FGB fish assemblages.

4.10.1. Species Richness

From 2004-2007, fish species and family richness fluctuated only slightly, with the greatest number of species recorded in 2005 at both Banks (Figure 4.10.1). During the 2004 and 2005 visual fish surveys at the FGB, divers recorded a total of 85 fish species (Appendix 12). In 2006, 67 fish species were recorded during the fish surveys and 22 additional fish species were recorded during transit between survey locations (89 total species). In 2007, 61 fish species were documented during fish surveys and 5 additional fish species (wahoo, banded butterflyfish, silky shark, greater amberjack, and tiger shark) were recorded during transit between survey locations (66 total species). At least 117 species of reef fish have been documented at the FGB (Pattengill-Semmens and Gittings 2003). A total of 99 fish species were recorded in our surveys at the FGB from 2002 to 2007 (Appendix 13). Of these 99 fish species, 36 species have been recorded every year from 2002 to 2007 at the FGB (Table 4.10.1).

Mean fish abundance recorded per diver survey decreased at the EFGB from 2004 to 2005, remained relatively constant in 2005 and 2006, and decreased slightly in 2007 (Figure 4.10.2). The large decrease observed from 2004 to 2005 was due to the school of bonnetmouth (*Emmelichthyops atlanticus*) that was present in 2004 (3,200 individuals) and absent in 2005. Mean fish abundance recorded per diver survey increased at the WFGB from 2004 to 2005 and remained relatively stable from 2005 to 2007 (Figure 4.10.2).

Small and/or cryptic species in the Blenniidae, Gobiidae, and Muraenidae families were likely underestimated as a result of conducting stationary fish surveys instead of roving diver surveys. Furthermore, our surveys intentionally excluded sand-covered bottom areas, and thus, also excluded species associated with that habitat such as sand tilefish (*Malacanthus plumieri*) and yellowhead jawfish (*Opistognathus aurifrons*). Species richness values in the surveys performed in 2004-2007 are comparable with other stationary fish surveys conducted at the FGB using the Bohnsack-Bannerot approach (43 species; Rooker et al. 1997).

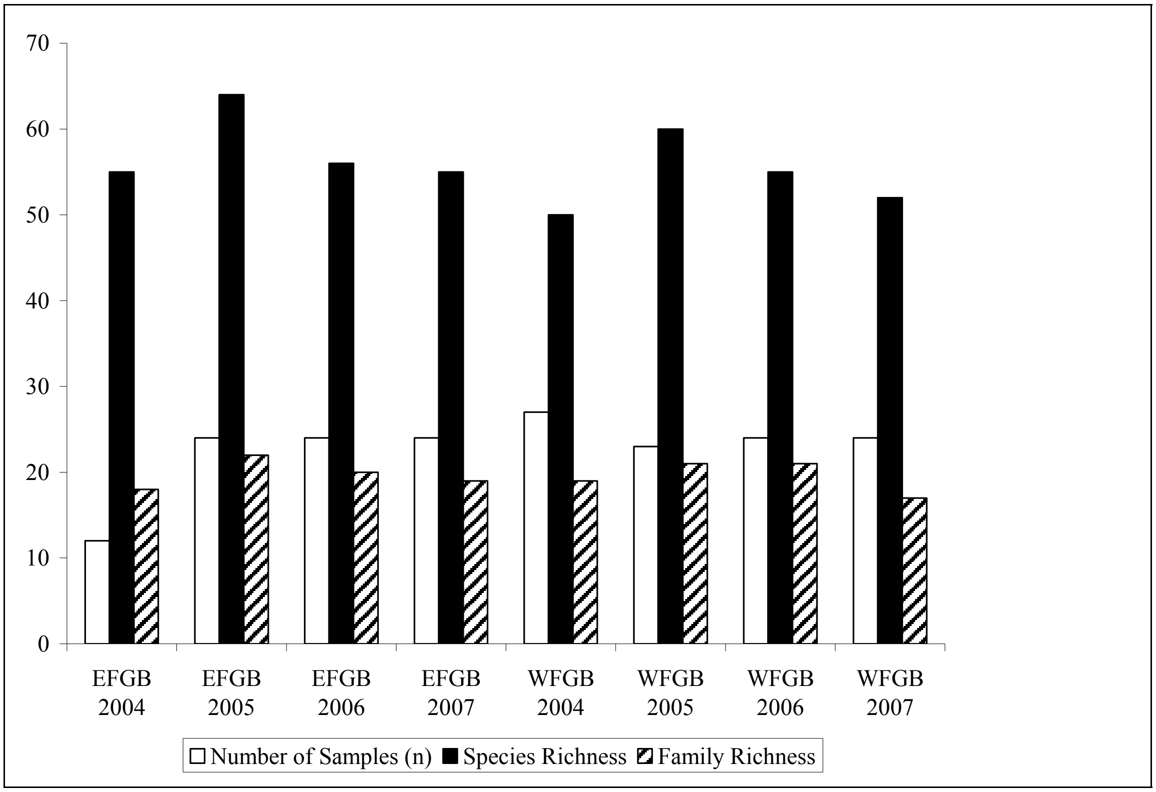


Figure 4.10.1. Fish species richness and family richness found at the EFGB and WFGB from 2004 to 2007, with number of diver surveys/samples (n) shown.

Potential disturbance caused by multiple divers present in the study sites while fish surveys were being conducted was minimized by conducting censuses before other divers entered the water and by conducting surveys at distances away from other divers. However, some degree of disturbance to the natural density and distribution of the local fishes is likely to have occurred during sampling. The presence of divers most likely affected the distribution of mid-water pelagic piscivores such as the Carangidae and Carcharhinidae. Low counts of larger, reef-associated piscivores such as the Serranidae may have also been caused by the presence of divers. Although not recorded in any fish censuses, several manta (*Manta birostris*) and one unidentified carcharinid were observed at the EFGB in 2006. Although these sightings were not recorded inside the stationary fish surveys, the species were added to the master species list for each Bank (Appendix 12).

Table 4.10.1.

Fish species recorded in visual fish surveys in all years from 2002 to 2007 at the FGB.

Common Name	Scientific Name
Bermuda/Yellow chub	*Kyphosus sectator/incisor*
Bicolor damselfish	*Stegastes partitus*
Bar jack	*Caranx ruber*
Black durgon	*Melichthys niger*
Blue chromis	*Chromis cyanea*
Blue tang	*Acanthurus coeruleus*
Bluehead wrasse	*Thalassoma bifasciatum*
Brown chromis	*Chromis multilineata*
Sharpnose puffer	*Canthigaster rostrata*
Creole fish	*Paranthias furcifer*
Creole wrasse	*Clepticus parrae*
Doctorfish	*Acanthurus chirurgus*
Graysby	*Cephalopholis cruentata*
Great barracuda	*Sphyraena barracuda*
Horse-eye jack	*Caranx latus*
Longsnout butterflyfish	*Chaetodon aculeatus*
Ocean surgeonfish	*Acanthurus bahianus*
Princess parrotfish	*Scarus taeniopterus*
Puddingwife	*Halichoeres radiatus*
Queen angelfish	*Holacanthus ciliaris*
Queen parrotfish	*Scarus vetula*
Redband parrotfish	*Sparisoma aurofrenatum*
Redlip blenny	*Ophioblennius atlanticus*
Reef butterflyfish	*Chaetodon sedentarius*
Rock beauty	*Holacanthus tricolor*
Sergeant major	*Abudefduf saxatilis*
Smooth trunkfish	*Lactophrys triqueter*
Spanish hogfish	*Bodianus rufus*
Spotfin butterflyfish	*Chaetodon ocellatus*
Stoplight parrotfish	*Sparisoma viride*
Threespot damselfish	*Stegastes planifrons*
Tiger grouper	*Mycteroperca tigris*
Yellow goatfish	*Mulloidichthys martinicus*
Yellowhead wrasse	*Halichoeres garnoti*
Yellowmouth grouper	*Mycteroperca interstitialis*
Yellowtail damselfish	*Microspathodon chrysurus*

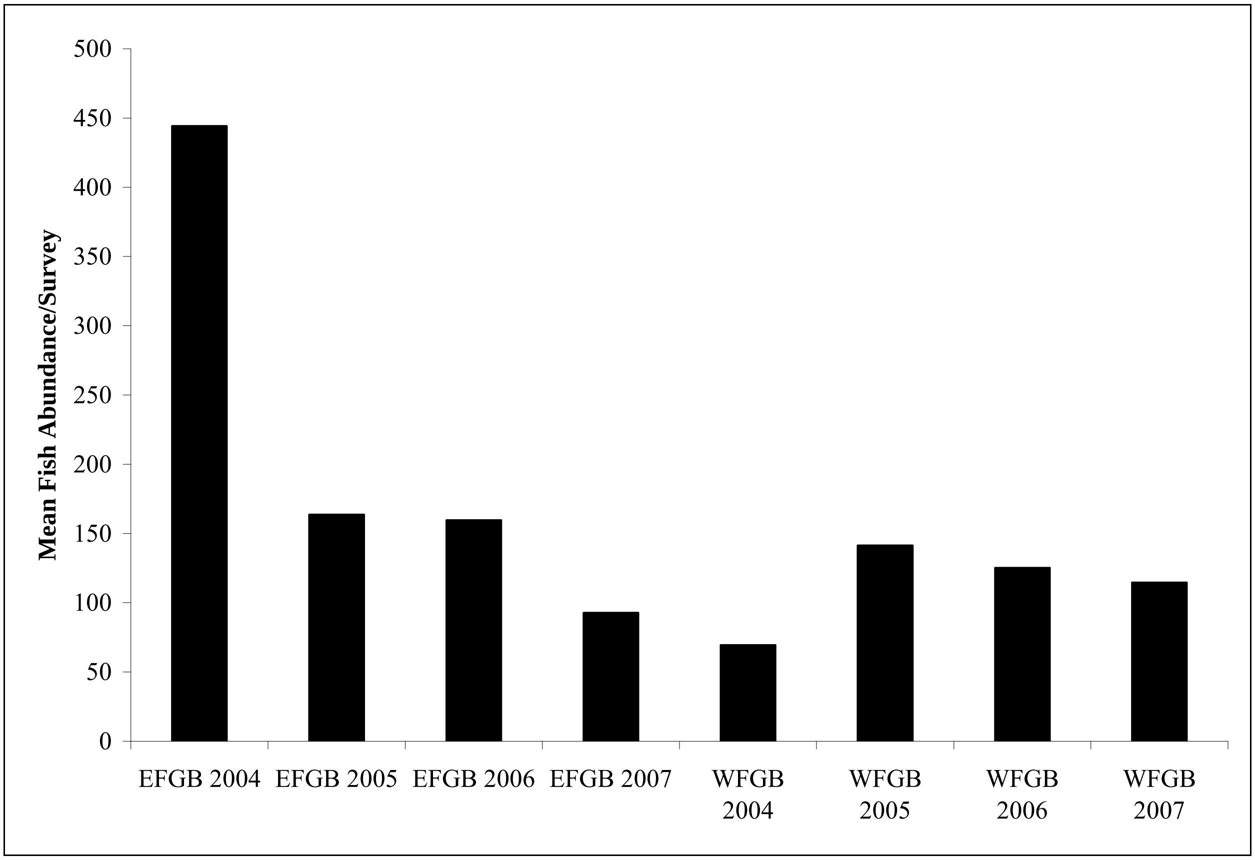


Figure 4.10.2. Mean fish abundance per survey observed at the EFGB and WFGB from 2004-2007.

4.10.2. Dominant Taxa

In 2004-2007, the Pomacentridae, Labridae, and Serranidae were the dominant or most frequently recorded fish taxa at the FGB. The Pomacentridae were well represented, although fewer species exist at the FGB when compared to the Caribbean region as a whole. Brown chromis (*Chromis multilineata*), blue chromis (*C. cyanea*), threespot damselfish (*Stegastes planifrons*), and bicolor damselfish (*S. partitus*) were the dominant species of pomacentrids at the FGB. Labridae were primarily represented by creole wrasse (*Clepticus parrae*), bluehead wrasse (*Thallasoma bifasciatum*), and Spanish hogfish (*Bodianus rufus*). Serranidae were also common, particularly the creole fish (*Paranthias furcifer*), tiger grouper (*Mycteroperca tigris*), and graysby (*Cephalopholis cruentata*).

In 2004-2007, the most common species of Acanthuridae was the blue tang (*Acanthurus coeruleus*). The abundances of acanthurids varied depending upon the year. Large schools of acanthurids as seen on some coral reefs in the Caribbean (Bell and Kramer 2000; Robertson et al. 2005) are not common at the FGB. The number of species of Labridae: Scarinae recorded at the FGB from 2004-2007 was less than that in the wider Caribbean (Pattengill-Semmens and Semmens 2003). Queen parrotfish (*Scarus vetula*), stoplight parrotfish (*Sparisoma viride*), and princess parrotfish (*S. taeniopterus*) were the dominant or most frequently recorded species. The families Chaetodontidae (butterflyfishes) and Pomacanthidae (angelfishes) are not well represented at the study sites and are lower in diversity as compared to Caribbean reefs (Pattengill-Semmens and Semmens 2003). Recorded Chaetodontidae species included reef butterflyfish (*Chaetodon sedentarius*), spotfin butterflyfish (*C. ocellatus*), longsnout butterflyfish (*C. aculeatus*), and banded butterflyfish (*C. striatus*). Four species of Pomacanthidae observed at the FGB from 2004-2007 included rock beauty (*Holocanthus tricolor*), queen angelfish (*H. ciliaris*), Townsend angelfish (*H. townsendi*), and French angelfish (*Pomacanthus paru*).

In contrast to Caribbean reefs, the FGB reef cap has a distinctly lower number of Lutjanidae species (*Lutjanus jocu* and *L. griseus*) and a near absence of Haemulidae mainly due to lack of diverse and nearby seagrass and mangroves habitats (Jones and Clark 1981; Lukens 1981; Rezak 1985; Rooker et al. 1997). Several large dog snapper (*L. jocu*) were observed at the WFGB in 2005. In 2006, a total of four dog snapper (*L. jocu*) were observed at the FGB, ranging in size from 26-70 cm. Previous study years reported larger and more frequently observed dog snapper (*L. jocu*; Precht et al. 2006). No Haemulidae were observed at either Bank from 2004-2007.

On shallow reefs, Carangidae and Kyphosidae typically swim in the water column. At the FGB, they were occasionally seen close to the reef cap. Large schools of Carangidae were regularly recorded at both Banks from 2005-2007. The dominant carangid species included the bar jack (*Caranx ruber*), crevalle jack (*C. hippos*), horse-eye jack (*C. latus*), and black jack (*C. lugubris*). The family Kyphosidae was represented by the two indistinguishable species Bermuda and yellow chub (*Kyphosus* spp.).

The great barracuda (*Sphyraena barracuda*) was persistent at the FGB in all years and were regularly active throughout the study sites, patrolling the reef. Many exhibit a curiosity of diver activities and were often attracted to diver surveys. Great barracuda were often observed swimming in large and small schools, as well as individually, near reef formations. They were rarely observed feeding. Great barracuda were recorded in exceptionally large numbers at the WFGB in 2004 (134 individuals total) and the EFGB in 2007 (97 individuals total). Outside of fish survey areas, barracuda were attracted to the dive vessel and its shadow. It has been previously suggested that the reef cap of the FGB may serve as a nursery for these fish (Precht et al. 2006).

Some components of the fish assemblages have experienced large fluctuations in the past. Herbivore populations appeared to have responded to the mass mortality of *Diadema antillarum* at the FGB in 1983-1984 (Gittings et al. 1992). Also, red snapper (*Lutjanus campechanus*) were overexploited in the late 1950s, and their numbers have never recovered at the FGB (Boland et al. 1983). No observations of red snapper (*L. campechanus*) were recorded at the study sites from 2002-2007. However, this was possibly a factor of habitat preference on the part of red snapper (*L. campechanus*), considering that they are often documented during ROV surveys in the mesophotic zones of the FGBNMS.

Fish surveys suggest a decline in abundance of certain species. In sharp contrast with previous fish surveys at the FGB, only one rock hind (*Epinephelus adscensionis*) was observed at the EFGB in 2006 (2002: nine individuals (Precht et al. 2006); 2003: four individuals (Precht et al. 2006); 2004: eight individuals; 2005: seven individuals). These species were not observed at either Bank in 2007. General fish observations made at the FGB since 2005 indicate that the numbers of rock hind have greatly diminished (Hickerson, personal communication, 2006c). Prior to 2006, rock hind (*E. adscensionis*) was a common serranid at the FGB (Boland et al. 1983; Wilson et al. 2003; Precht et al. 2006). Furthermore, coneys (*Cephalopholis fulvus*) were not observed from 2005 to 2007 at the FGB and only one individual was observed at the WFGB in 2004. Similarly, yellowfin grouper (*Mycteroperca venenosa*) were not observed in 2006 or 2007, but had been reported in previous years (Precht et al. 2006). The conspicuous absence/decline of these three serranid species (*C. fulvus*, *M. venenosa*, and *E. adscensionis*) merits further study. However, note that graysby (*C. cruentata*) was reported in higher abundances in 2006 compared to data from previous years (Precht et al. 2006).

4.10.3. Diversity and Evenness

Interannual comparisons of fish statistics indicated generally stable assemblages (Table 4.10.2); however, diversity and evenness values did fluctuate among years from 2004-2007 (Figure 4.10.3). The EFGB generally appeared to support lower overall fish diversity but greater abundance when compared to the WFGB. Large schools of fish (e.g., inermiids and kyphosids) can be responsible for a lower diversity index. Following the pattern of coral species present at the FGB (low diversity, compared to Caribbean reefs, but high coral cover), the fish assemblages at the FGB appear to be following the previously reported trend of low diversity and high abundance (Pattengill-Semmens and Gittings 2003).

Table 4.10.2.

Fish diversity (H') and evenness (J') values calculated for fish communities at the FGB from 2004-2007.

	EFGB				WFGB			
	2004	2005	2006	2007	2004	2005	2006	2007
Diversity (H')	0.77	1.06	0.99	0.78	1.30	1.04	1.10	0.86
Evenness (J')	0.44	0.58	0.57	0.67	0.76	0.58	0.63	0.67

Differences in depth and reef cap topography between the Banks are possible environmental factors influencing the distribution of reef species. The reef cap at the WFGB is deeper and its depth more homogeneous than the EFGB. The topographic complexity is probably similar at both Banks, yet the relatively sharp slope along the eastern edge of the EFGB study site is such that both shallow and deeper habitats occur within the study site.

4.10.4. Diurnal Abundance Differences

The 2006 fish data were analyzed to determine the impact of time of day on the fish assemblages. A two-way ANOVA, with time of day and Bank as fixed factors, revealed significant differences in the abundances of both creole wrasse (*Clepticus parrae*) and great barracuda (*Sphyraena barracuda*) between morning (0800 to 1200) and afternoon (1200 to 1800) dives. Additionally, creole wrasse (*C. parrae*) abundances were significantly different between the Banks, but great barracuda (*S. barracuda*) abundances were not. Species other than great barracuda and creole wrasse may exhibit differences in behaviors throughout the day, resulting in disparate data on morning dives and afternoon dives. Therefore, the 24 fish surveys should be evenly distributed throughout the day over a period of two days. For example, two divers could conduct two fish surveys each for three dives (8 am, 12 pm, and 4 pm), accomplishing 12 surveys for the first day of sampling and 12 surveys for the second day of sampling. If the divers have good air consumption, two divers could conduct three fish surveys each for four dives (8 am, 11 am, 2 pm, and 5 pm), completing 24 fish surveys in one day of sampling. Whichever method is chosen, it should be followed for both Banks to ensure that samples are collected from the same time throughout the sampling days.

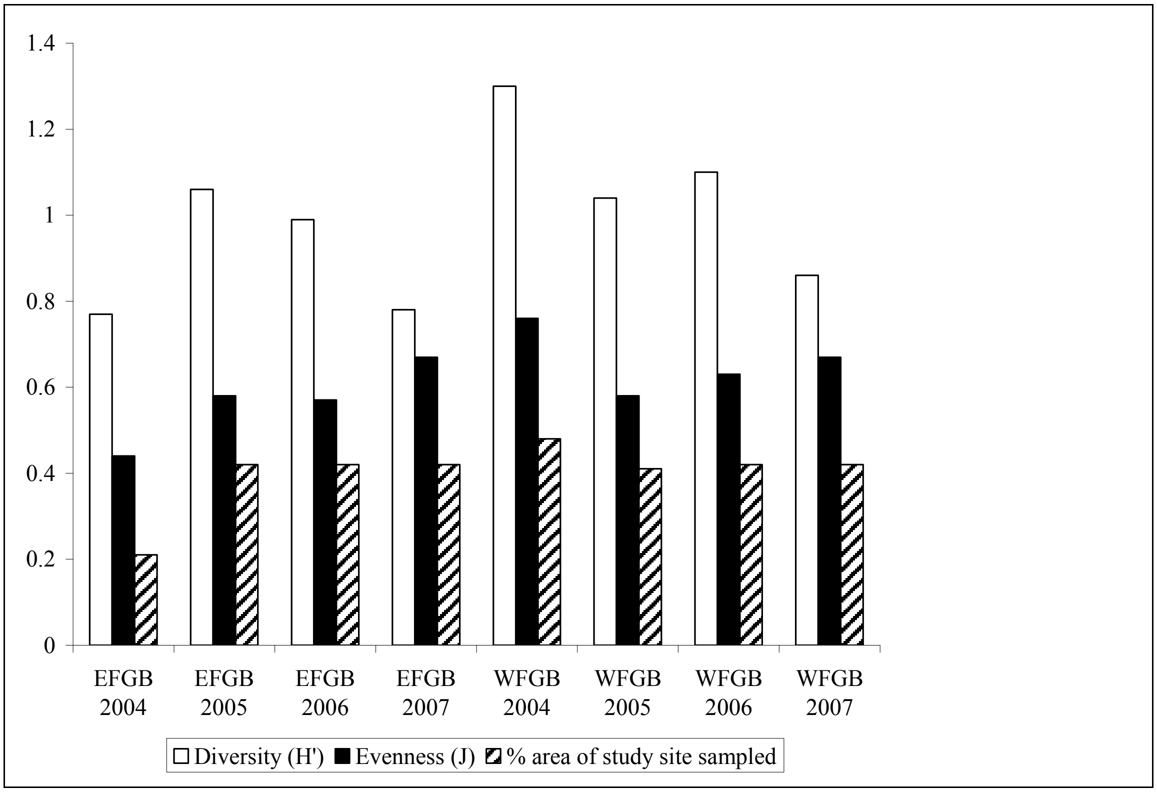


Figure 4.10.3. Fish diversity and evenness found at the EFGB and WFGB from 2004 to 2007, with the percent of the study-site area covered by the surveys.

4.10.5. Functional Groups: Herbivores and Piscivores

While the abundance of herbivorous fish species at the FGB is low compared to abundances found on Caribbean reefs (Rezak 1985; Dennis and Bright 1988; Steneck 1988; Pattengill-Semmens and Gittings 2003), FGB abundance has remained consistent since the 2002 fish surveys. As determined from 2002 to 2003 data (Precht et al. 2006), the percentages of Acanthuridae and Labridae: Scarinae at the FGB are similar to deep/fore reefs of western Cuba and Akumal (Yucatan, Mexico; Claro and Cantelar Ramos 2003; Steneck and Lang 2003). Algal cover, which is low at the FGB (2004: 13.39%; 2005: 26.19%; 2006: 16.74%; and 2007: 19.69%), is probably kept in check by a robust functional group of herbivorous fish.

The size-frequency distributions of herbivores at the FGB were normally distributed in the 2002-2007 surveys. The ecological significance of a bell-shaped size distribution is that the majority of individuals are medium-sized, with only a few individuals in the small and large size categories. Fishing pressure or other factors can result in a curve shift towards smaller individuals (Polunin and Roberts 1993; Berkeley et al. 2004; Olsen et al. 2004).

The size-frequency distributions of piscivores at the FGB were generally non-normal from 2002-2007. The non-normal pattern likely represents the differing sizes of the individual species in the piscivore group (Serranidae and Lutjanidae) rather than missing size classes of individuals from the whole group (size differences between *Epinephelus* and *Cephalopholis* spp. and *Mycteroperca* spp.). From 2004 to 2007, no piscivorous fishes were recorded under 10 cm in length (Figures 3.10.2, 3.10.4, and 3.10.5).

4.10.6. 2006 and 2007 Fish Biomass Analysis

The assessment of fish biomass, an important component of coral reef ecology, was added to the data analysis of reef fish populations at the FGB in 2006 and 2007. Biomass estimates are based on size spectra of all fish species at the FGB. The monitoring of fish biomass is a means of evaluating the status of fish population levels. In particular, biomass monitoring will provide an effective tool to assess fishing pressure at the FGB (Jennings and Polunin 1997; Dulvy et al. 2004; Palumbi 2004). Additionally, fish abundances and corresponding sizes can be used to evaluate piscivore and grazing (herbivore) pressure.

In 2006, the average fish biomass per sample (diver survey) at the WFGB was 119.84 g/m^2 and 81.55 g/m^2 at the EFGB. In 2007, fish biomass at the WFGB and EFGB (combination of all herbivores and all piscivores) was 72.02 g/m^2 and 203.63 g/m^2, respectively. In 2007, there were no significant differences in herbivore biomass between Banks. Piscivore groups showed a tendency for higher biomasses on the EFGB (190.28 g/m^2) than on the WFGB (58.59 g/m^2) in 2007; however, no significant differences were detected between Banks despite having 225% higher biomasses on EFGB than WFGB (Table 3.10.18). The demersal piscivore (lutjanids and serranids) biomasses were not significantly different between the two Banks. In contrast, the pelagic piscivore (carangids and *S. barracuda*) biomasses were significantly different between Banks. Pelagic piscivore biomass was 260% higher on the EFGB than on the WFGB, with biomass driven by crevalle jack and black jack (Table 3.10.18).

Fish biomasses observed at the FGB are high compared to other locations including Puerto Rico (22.71 g/m^2 [2002 to 2006]; CCMA), the U.S. Virgin Islands (25.23 g/m^2 for St. Croix [2001 to 2006] and 28.52 g/m^2 for St. John [2001 to 2005]; CCMA), and Belize (32.6 g/m^2 for inshore reefs to 76.6 g/m^2 for Lighthouse Atoll; B. Shank, unpublished data). Puerto Rico and the U.S. Virgin Islands are considered overfished locations with low-selectivity fisheries. Unlike the FGB, data collected by NOAA in Puerto Rico and the U.S. Virgin Islands were from all habitat types including seagrass, sand, mangrove, coral reef, and colonized pavement (CCMA). The reefs of Belize support a local commercial fishery but fishing activities are constrained to hook and line fishing and spearfishing while free-diving, giving Belize fairly selective fisheries by Caribbean standards (B. Shank, unpublished data). For central and southern Belize, average regional biomass varies from 32.6 g/m^2 for inshore reefs to 76.6 g/m^2 for Lighthouse Atoll (B. Shank, unpublished data). The highest average biomass is for Half Moon Caye Natural Monument, a no-take zone on Lighthouse Atoll which had 92.5 g/m^2 (B. Shank, unpublished data). The biomass data from Belize was collected in 12-16 m water depths and therefore more comparable to the FGB than the Puerto Rico or U.S. Virgin Islands biomass data. By composition, one of the main differences between the FGB and Belize is the relative lack of caranjids in Belize (which are a major component in the fish assemblage on the FGB) with the Belize piscivore group consisting predominantly of lutjanids and some serranids (B. Shank, unpublished data). In summary, the high biomasses observed at the FGB are indicative of relatively healthy reef fish populations on both Banks. The reef fish populations at the FGB appear to be healthier than the overfished locations of Puerto Rico and the U.S. Virgin Islands, and also healthier than the best reefs in Belize, including the protected areas.

Contrasting with the higher fish abundance at the EFGB as compared to the WFGB in 2006, mean biomass per sample was lower at the EFGB (82 g/m^2) compared to the WFGB (120 g/m^2). Two main sources of differences recorded in abundance and biomass are: (1) large schools of small inermiids recorded at the EFGB in 2006, which increased fish abundance but not biomass, and (2) a much higher biomass of sphyrenids in 2006 at the WFGB as compared to the EFGB. Total fish abundance was higher at the WFGB than the EFGB in 2007 (Table 3.10.15). In contrast, fish biomass was much higher at the EFGB than the WFGB. Large schools of crevalle jack and black jack contributed to the high biomass observed at the EFGB. These species were not present in large numbers at the WFGB.

4.10.7. Long-Term Fish Community Trends for 2002-2007

4.10.7.1. Piscivore Biomass Analysis

Comparing the biomass of pelagic piscivores to the more demersal snapper/grouper species, pelagic biomass averaged 10.2 times higher than the snapper/groupers species. It is suggested that a comparison be made between this dataset and data from other parts of the Caribbean to determine if snapper/grouper biomasses are actually anomalously low at the FGB, or if the pelagics are anomalously high.

The patterns observed in the piscivore biomass analysis have interesting implications for community trophic structure and resource management. First, the predominant source of predation pressure on the FGB is from the pelagic piscivores, which vary both spatially and temporally, making their role as a fishing resource and a factor structuring food webs unpredictable.

4.10.7.2. Principle Components Analysis

Although the cause of the temporal pattern in PC1 (Figure 3.10.8) can not be explained on the basis of the available data, what is important is that the major axis of variation in the data over time is strongly related to functional aspects of the fish community with respect to reef health and resilience. This compound parameter, or more correctly, its contributing species and functional groups, are clearly worth watching in future monitoring of the FGB. This also provides a handle for assessing the outcome of any future zoning or spatial management experiments.

It is interesting to note that the temporal dynamics of PC1 neatly parallel fluctuations in pelagic piscivore biomass on the EFGB as depicted in Figure 3.10.6. While this is partially expected as pelagic piscivores are included among the "Large Piscivore" class that correlates well with PC1 (r=0.598), many of the pelagic species have been excluded from the principle components analysis due to low prevalence and, thus, are not represented in Figure 3.10.8. Also, two other groups, the High Invertivores and Hard Herbivores, have higher loadings (r=0.663 and 0.829, respectively), suggesting that a suite of species may be sharing a common dynamic.

4.10.7.3. Overall Summary

In summary, the fish assemblages on the two Banks over a six-year period (2002-2007) are different, but not in a consistent manner from year to year. There is, however, one overarching pattern in year-to-year variation that may be of biological significance, and that is the one captured by PC1. Within this pattern, there is a downward trend worth noting, though it is premature to view it as a cause for alarm: i.e., the significant decline in PC1 between 2004 and 2007 (parametric ANOVA, $F_{1,178}$=3.99, p=0.009, Figure 3.10.8). It is important to keep in mind that this encompasses only four replicated observations, one set per year. Nonetheless, if this trend were to continue, it would certainly be worth looking for concomitant declines in hard coral cover and other indicators of benthic community health. Gathering of sufficient data on ecologically key fish species in concert with the examination of these benthic community parameters would aid in gaining a richer picture of what is transpiring on the FGB.

4.11. SEA URCHIN AND LOBSTER SURVEYS

The population densities of lobsters at the FGB were low from 2004-2008, ranging from 0-2 individuals per survey (0-0.005 individuals/m^2). Such densities are similar to those reported in previous studies at the FGB (Dokken et al. 2001; Precht et al. 2006, 2008b).

In 2004-2008, sea urchin population densities at the EFGB were generally low and similar to those reported in previous studies at the FGB (Precht et al. 2006; Dokken et al. 2003; Dokken 1999; Table 4.11.1). However, at the WFGB in 2004, 2007, and 2008, substantially higher densities of *Diadema antillarum* were recorded (0.11 individuals/m^2 in 2004; 0.068 individuals/m^2 in 2007; 0.075 individuals/m^2 in 2008). Statistical analysis of the 2004-2008 urchin survey results indicates that the urchin community composition differs between the EFGB and WFGB. In addition, *D. antillarum* densities were significantly higher on the WFGB than on the EFGB. These densities might suggest the initiation of an urchin population recovery on the WFGB; however, continued monitoring of urchin populations will be required to determine whether or not this is the case.

4.12. FILM TO DIGITAL CONVERSION

Like film photography, digital photography/videography provides a permanent record and is a reliable and logistically simple method of obtaining benthic cover data. However, digital photography and videography provide several advantages over film photography for data collection including providing immediate, in situ feedback regarding image capture and avoiding the need to convert film into a digital format prior to analysis. Furthermore, film production will cease in the foreseeable future. Thus, assessments were conducted to determine the feasibility of converting to digital photography for the random transect, lateral growth, and repetitive quadrat data collection.

Table 4.11.1.

Sea urchin densities at the EFGB and WFGB from 1996 through 2008.
Data from [1] Dokken et al. 1999, [2] Dokken et al. 2003, [3] Precht et al. 2006, and [4] Precht et al. 2008b.* The 1997 urchin abundance data did not differentiate between the EFGB and WFGB. The 3 (# of urchins) and 0.038 (urchin density) apply to the FGB as a whole.

Year	Area Surveyed per Bank (m^2)	EFGB		WFGB	
		# Urchins	Urchin Density (# indiv/m^2)	# Urchins	Urchin Density (# indiv/m^2)
1996[1]	300	N/A	N/A	1	0.003
1997[1]	800			3*	0.038*
1998[2]	400	9	0.023	N/A	N/A
1999[2]	400	N/A	N/A	N/A	N/A
2000[2]	400	7	0.018	12	0.030
2001[2]	400	2	0.005	20	0.050
2002[3]	340	2	0.006	5	0.015
2003[3]	340	1	0.003	3	0.009
2004[4]	400	4	0.010	44	0.110
2005[4]	400	2	0.005	6	0.015
2006	400	3	0.008	10	0.025
2007	400	1	0.003	27	0.068
2008	400	0	0.000	30	0.075

4.12.1. Random Transects

Precht et al. (2006) assessed the utility of using videography for surveying transects at the FGB and the comparability of video to still photography. The 2002 and 2003 random transect data were collected from 14 transects at both the EFGB and WFGB using three techniques: (1) still photography, (2) videography, and (3) visual assessment in the field using the linear-point intercept (LPI) method (Precht et al. 2006). The LPI results were used to ascertain whether data recorded in situ were different than data derived from either of the photographic methods (still photography or videography). Benthic cover was estimated from the data and a power analysis was conducted. The results of the power analysis demonstrated that the coverage estimates from video transects were equal in power and accuracy to still photography along transects. The LPI method yielded slightly higher estimates of percent cover for the high- and intermediate-cover categories than the video transects and still photography. However, the differences were smaller than the 5-10% changes in coral cover considered to be biologically meaningful, and the differences were also smaller than the minimum detectable difference using the videographic method (Precht et al. 2006; Aronson et al. 2005). Thus, Precht et al. (2006) concluded that it was appropriate to convert from still photography to digital videography for the random transects. Digital videography has been used to collect the random transect data since 2002.

4.12.2. Lateral Growth

During the August 2007 cruise, a preliminary assessment was conducted to evaluate the potential for converting from film to digital photography for lateral growth data collection. Subsamples of the lateral growth stations at both the EFGB and WFGB were photographed with a film setup, as well as two digital setups (one Olympus and one Sea&Sea digital camera setup). Using the digital photographs taken in 2007, it was possible to compare the film and digital results for that year. In addition, comparisons were made between the 2006-2007 results using film for both years and the 2006-2007 results using film in 2006 and digital photography in 2007.

Comparing the lateral growth stations photographed with both film and the digital setups in 2007, the absolute value of the mean proportional difference between the two overlaid images (film image and digital image) was >0.05 in 40% of the sample for the Olympus setup and >0.05 in 56% of the sample for the Sea&Sea setup.

Estimates of proportional change in the lateral margins of colonies from 2006 to 2007 differed depending on whether film or digital photographs from 2007 were compared to film photographs from 2006. The mean difference in the estimates of annual change in the area of individual coral colonies from 2006-2007 averaged 0.121 ± 0.025 SE (n=18).

Each lateral growth station was then analyzed separately depending on whether the Olympus or Sea&Sea setup was used in 2007. The mean proportional difference was 0.130 ± 0.027 SE (n=9) for the stations in which the Olympus setup was used in 2007 and 0.111 ± 0.023 SE (n=9) for stations in which the Sea&Sea setup was used in 2007. The two digital photography setups performed equivalently in terms of data quality.

These comparisons demonstrated that the methodology used for digital photography must be further refined before meaningful comparisons can be made between digital and film photographs of the growth margins of *Diploria strigosa* colonies. Additional digital setups should be tested. Once the two photographic methods (film and digital) consistently give results within 2-3% of each other, then conversion to digital photography at the lateral growth stations is appropriate. As an alternative, an immediate conversion to digital photography could be made in 2008, with forward comparisons (2009 and later). However, comparisons between the 2007 film photographs and 2008 digital photographs would not be meaningful, and one year of lateral growth comparisons would be lost.

4.12.3. Repetitive Quadrats

The potential for converting from film to digital photography for the repetitive quadrat data collection was assessed during the August 2007 cruise. A subsample of the repetitive quadrat stations at the EFGB was photographed with both a film camera setup and a digital camera setup (Olympus C4000). Estimates of percent cover were derived from each photograph using random-dot analysis as follows: two different sets of 300 dots were analyzed for each film photograph ("Film1" and "Film2"), and a third set of 300 dots was analyzed for each corresponding digital photograph ("Digital"). The statistical comparison of the 2007 film and 2007 digital photographs (section 3.4.2) indicated that there was no significant difference between the three assessments (Film1, Film2, and Digital). The lack of any significant difference suggested that switching to digital photography was feasible. Thus, digital photographs can be directly compared to film photographs of the same repetitive quadrat stations from previous years. Based on these results, only digital photographs were collected at the repetitive quadrat stations during the annual monitoring cruise in November 2008.

The Olympus C4000 did not provide the necessary resolution to analyze benthic components to lowest possible taxonomic group. Consequently, a Sea&Sea DX-1G digital camera setup was purchased in order to produce high-resolution photographs at a distance of >2.0 m from the substrate. Field tests in May and June 2008 provided the appropriate mounting height and camera settings needed to gather the FGB repetitive quadrat data using the Sea&Sea DX-1G digital camera setup. The Sea&Sea DX-1G camera setup was utilized to collect the repetitive quadrat data at the FGB in November 2008. These digital photographs allowed for the analysis of the benthic components to lowest possible taxonomic group.

5.0 RECOMMENDATIONS

The following are recommendations for improving the monitoring protocol and increasing the scientific value of the contract:

- Perform a one-time sclerochronology study, incorporating at least a dozen coral colonies from each Bank. The purpose would be to correlate stress events temporally between the Banks.

- Continue to work towards the film to digital conversion for the lateral growth stations at the FGB. As an alternative, an immediate conversion to digital photography for the lateral growth stations could be made; however, the digital photographs would not be comparable to the previous year's film photographs and one year of lateral growth comparisons would be lost.

- Perform studies to characterize the white plague-like disease at the FGB in order to develop effective management strategies for these reefs. Additional studies of this disease should be conducted including further ecological assessment, traditional and molecular microbiological assessments, and histological evaluations of affected corals.

- Perform dedicated in situ transect surveys to allow for higher detection of coral health issues and to assess coral disease prevalence. To accurately and reliably distinguish coral disease lesions, it is necessary to closely assess the tissue lesion as well as the corallite structure adjacent to the lesion.

- Continue the monitoring of bleaching levels and responses on the reefs of the FGB.

- Conduct a sponge-monitoring program at the FGB in order to assess long-term sponge ecology and health on these reefs.

- Search for species representing range extensions to the Banks (e.g., *Acropora palmata*).

- Monitor the previously-identified exotic/invasive species on the reefs of the FGB, including *Tubastraea coccinea*, and *Thecacera pacifica*. Monitor for newly arriving exotic/invasive species. If an exotic/invasive species invasion becomes a problem at the FGB, a removal program should be initiated.

- Because of the isolated geography of the FGB, a comprehensive taxonomic review of those taxa showing morphometric and other differences with their Caribbean and Floridian counterparts is recommended.

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

- Purchase additional Seabird instrumentation for rotation and repair so there are always units available to use for change-outs. At present, two dives are used to retrieve and replace the Seabird sondes. If spare instruments are available, this could be accomplished in one dive.

- Mount the Seabird water quality monitoring sonde on the reef cap to measure water quality parameters more accurately in the reef community. Consider removing the Seabird sondes from sand flats, where they are currently located. Certain parameters, in particular, PAR and turbidity may be affected by the sandflat environment, where sedimentation and reflectance exert an influence. Furthermore, dissolved oxygen is potentially greater on the sand flats during daylight hours.

- Monitor the concentration of trace metals in bivalves to evaluate the bioavailability of trace metals at the FGB. Filter-feeders are known to concentrate the heavy metals they ingest from surrounding waters.

- Future monitoring of fish population levels should examine the relationship between habitat characteristics (including live coral cover) and fish species richness, abundance, and biomass.

- Discuss modification of the fish survey technique to allow for better estimation of fish biomass and better tracking of size-based cohorts.

- Future monitoring efforts should include a review of fish biomass 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 with management decision-making.

- Compare the biomass of pelagic piscivores and demersal snapper/grouper species at the FGB to corresponding data available for other parts of the Caribbean to determine if snapper/grouper biomasses are actually anomalously low at the FGB or if pelagic piscivores are anomalously high.

- Additional species other than barracuda and creole wrasse may exhibit differences in behaviors throughout the day, resulting in disparate data on morning dives compared to afternoon dives. Diver surveys should be evenly distributed throughout 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.

- Monitor areas outside of the 100- x 100-m study sites. In particular, *Madracis auretenra* forms a large field located near the southeast corner of the EFGB study site. This field should be monitored and cored to chronicle disturbances, such as hurricanes and illegal anchoring, within the Sanctuary.

- Expand the ongoing invitations to visiting scientists and graduate students on the annual monitoring cruises to represent a wide range of scientific disciplines.

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

6.0 LITERATURE CITED

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