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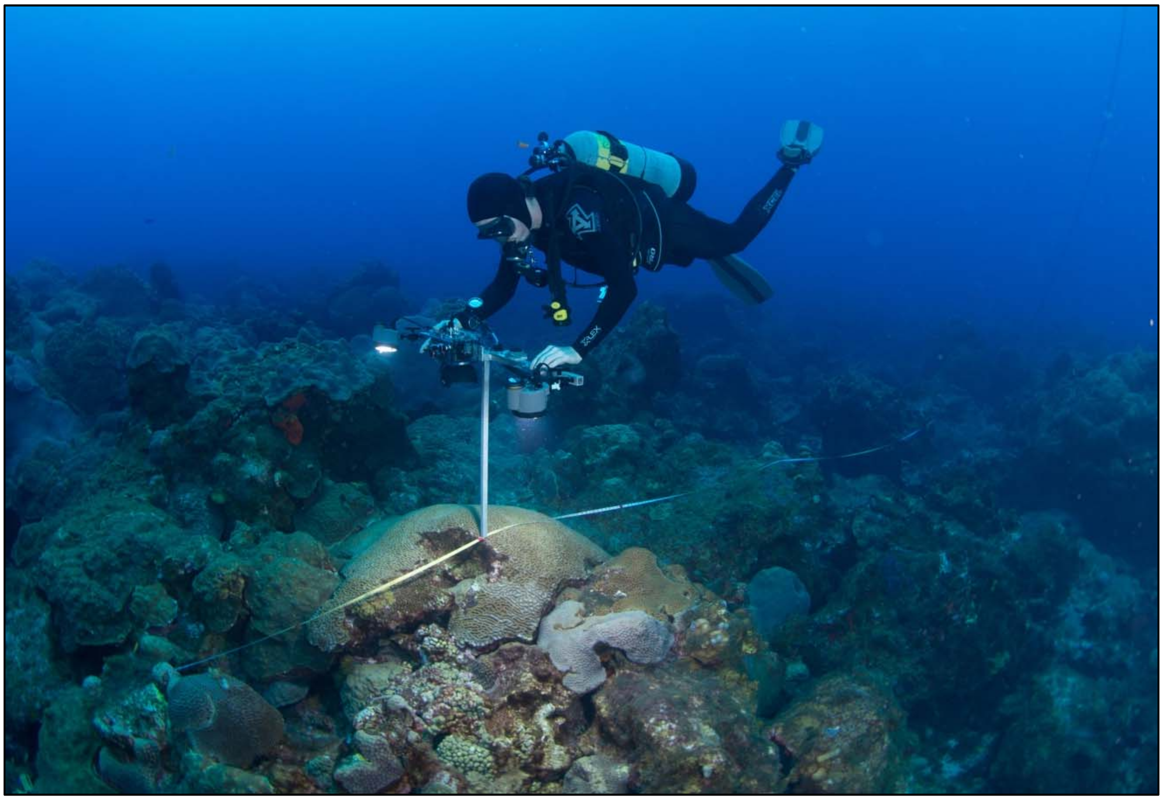
Long-Term Monitoring at East and West Flower Garden Banks National Marine Sanctuary, 2011–2012

Volume 1: Technical Report



U.S. Department of the Interior
Bureau of Ocean Energy Management
Gulf of Mexico OCS Region

National Oceanic and Atmospheric Administration
Flower Garden Banks National Marine Sanctuary

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ABOUT THE COVER

The cover photograph features NOAA Flower Garden Banks National Marine Sanctuary diver Ryan Eckert capturing a benthic scene in the East Flower Garden Bank. He is using a camera mounted on an aluminmum T-frame on a random transect line. Photograph by G.P. Schmahl (NOAA FGBNMS).

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LIST OF ABBREVIATIONS

AGRRA	Atlantic and Gulf Rapid Reef Assessment
ANOSIM	Analysis of similarity
ANOVA	Analysis of variance
BOEM	Bureau of Ocean Energy Management
BOEMRE	Bureau of Ocean Energy Management, Regulation and Enforcement
CCMA	Center for Coastal Monitoring and Assessment
CFB	Concentrated fish biting
CFR	Code of Federal Regulations
CPCe	Coral Point Count with Microsoft® Excel® Extensions
CRCP	Coral Reef Conservation Program
CREIOS	Coral Reef Ecosystem Integrated Observing System
CSA	Continental Shelf Associates
CT	Computerized tomography
CTB	Crustose Coralline Algae, Fine Turf Algae, and Bare Rock
EA	Environmental Assessment
EFGB	East Flower Garden Bank
ENSO	El Niño Southern Oscillation
FGB	Flower Garden Banks (East and West Flower Garden Banks combined)
FGBNMS	Flower Garden Banks National Marine Sanctuary
GOMEX	Gulf of Mexico
GREAT	Gulf Reef Environmental Action Team
IFB	Isolated fish biting
IMO	International Maritime Organization
IUCN	International Union for Conservation of Nature
JMP	"Jump" statistical software®
MASC	*Montastraea annularis* Species Complex
MDS	Multidimensional scaling
MMS	Minerals Management Service
MSD	Marine sanitation device
NAZ	No Activity Zone
NEPA	National Environmental Policy Act
NESDIS	National Environmental Satellite Data and Information Service
NIH	National Institute of Health
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
NRDA	Natural Resource Damage Assessment
OASC	*Orbicella annularis* species complex
OCS	Outer Continental Shelf

ONMS	Office of National Marine Sanctuaries
PAR	Photosynthetically active radiation
PBSJ	Post, Buckley, Schuh & Jernigan, Inc.
PRIMER-E	PRIMER® Enterprises
PSU	Practical salinity units
QA/QC	Quality Assurance/Quality Control
R/V	Research vessel
RDT	Roving diver technique
SCUBA	Self-contained underwater breathing apparatus
SD	Standard deviation
SE	Standard error
SIMPER	Similarity percentage
SOW	Scope of Work
SPMD	Semipermeable membrane devices
TAMU	Texas A&M University
TAMU-CC	Texas A&M University Corpus Christi
TAMUG	Texas A&M University Galveston
TKN	Total Kjeldahl Nitrogen
USA	U.S. of America
USCG	U.S. Coast Guard
USDOI	U.S. Department of Interior
USEPA	U.S. Environmental Protection Agency
WFGB	West Flower Garden Bank
YSI	Yellow Springs Instrument Company

EXECUTIVE SUMMARY

In the 1970s, because of concern about potential impacts of offshore oil and gas development, the Department of Interior (DOI) (initially through the Minerals Management Service, now the Bureau of Ocean Energy Management) started monitoring East and West Flower Garden Banks (EFGB and WFGB), which are now part of the Flower Garden Banks National Marine Sanctuary (FGBNMS). The purpose was to establish baseline data and determine if these reefs were impacted by nearby oil and gas exploration and production activities. In 1988, DOI established a long-term monitoring program to evaluate the potential ongoing impacts of oil and gas development to EFGB and WFGB. The long-term monitoring effort evaluates changes in living coral and benthic community cover, coral growth rates, reef fish population dynamics, water quality, and other indices of reef vitality within designated study sites. Though many coral reefs in the western Atlantic and Caribbean region have experienced significant declines in coral cover, the reefs of EFGB and WFGB support healthy coral and fish assemblages. Through a continued interagency agreement, this program is of significant interest to both NOAA and BOEM, who share responsibility of protecting and monitoring these important marine resources.

In over 25 years of continuous monitoring, the coral reefs of EFGB and WFGB have maintained levels of coral cover above 50% and have suffered minimally from hurricanes, coral bleaching, and disease outbreaks; they support relatively diverse and abundant fish populations and other vertebrate and invertebrate species. No significant long-term changes have been detected in coral cover or coral diversity at the Flower Garden Banks (FGB, East and West Flower Garden Bank combined) since 1988 and likely not since the first measurements were made in the early 1970s; however, macroalgae cover has been increasing since 1999. During the 2011–2012 monitoring period, analyses indicated that coral cover at EFGB and WFGB averaged approximately 56%.

Results of the 2011–2012 monitoring efforts illustrate the continued stability of the coral assemblage and associated fish populations of the FGB when compared to other reefs in the Caribbean. Random transect results revealed mean coral cover within the study site at EFGB to be 57% in 2011 and 52% in 2012. Mean coral cover at WFGB in 2011 was 60% and 55% in 2012. These results are consistent with previous monitoring efforts of coral cover above 50% at the FGB highlighting the coral stability at the study site since the start of the monitoring program.

Results of the random transect data indicate that *Orbicella franksi* was the principal component of mean percent coral cover at both banks. Mean cover of *Orbicella franksi* at EFGB was estimated at 26% in 2011 and 26% in 2012. At WFGB, mean cover was 24% in 2011 and 26% in 2012. *Pseudodiploria strigosa* was the next most abundant species during this period, with 6% at EFGB in 2011 and 8% in 2012. WFGB estimates were 12% and 9% for the two years. The importance of the FGB, in terms of the Atlantic coral reef system as a whole, has been substantially elevated because the NOAA Fisheries Endangered Species Act lists all coral under the *Orbicella annularis* species complex as threatened; all are found at the FGB.

In 2011 and 2012, macroalgae mean percent cover was more abundant than crustose coralline algae, fine turf algae, and bare rock (abbreviated as Crustose/Turf/Bare or CTB), ranging from approximately 30–38% at EFGB and 29–31% at WFGB. Despite continued stability in mean coral cover, macroalgae mean cover has been increasing since 1999. The most dominant components of macroalgal cover were fleshy algae, *Dictyota* spp., and *Lobophora variegata*. CTB was the second-ranked non-coral category of mean substratum percent cover, ranging from approximately 9–12% at EFGB and 10–12% at WFGB from 2011–2012. Mean sponge cover continues to be extremely low at both banks (less than 1%). An ANOVA and ANOSIM revealed that no significant differences between sites or years occured at EFGB and WFGB, this makes the banks similar in terms of benthic composition.

Sclerochronology was used to measure the accretionary extension rates of *Orbicella faveolata* coral cores. Annual extension of *Orbicella faveolata* at EFGB averaged 6.5 mm/year (sample range = 4.6–9.6 mm/year). At WFGB, annual growth averaged 5.6 mm/year (range = 3.3–10.3 mm/year). Extension rates did not differ significantly between banks.

Repetitive qudarats stations were photographed in 2011 and 2012 to monitor changes in specific coral reef locations over time. Mean coral cover in the repetitive quadrats averaged approximately 63% for both banks in all years. Macroalgae and CTB cover showed reciprocal patterns between banks. An ANOVA on the proportional cover of sponge and CTB showed significant differences between both bank and year. The incidences of bleaching, paling, and fish biting were low (ranging from 0.00–0.63% of area assessed) and there was little evidence of coral disease. The coral assemblages remained consistent at both banks, and the dominant corals were *Orbicella franksi* and *Pseudodiploria strigosa*.

At repetitive photostations in 32–40 m depths, mean coral cover ranged between 72–76% in 2011 and 2012. *Orbicella franksi* and *Montastraea cavernosa* were the dominant species in this depth range. Macroalgae averaged 19% and CTB averaged 7%.

Seawater temperature and salinity were recorded at EFGB and WFGB using Sea-Bird 37-SMP MicroCAT datasondes from 2011–2012. During the 2011–2012 period, seawater temperature at EFGB ranged from 18.62°C to 30.49°C from 2011–2012, and at WFGB from 17.92°C to 30.55°C. High seawater temperatures were observed during the late summer months, exceeding the 30°C coral bleaching threshold; however, because only limited time was spent above this temperature, the risk of bleaching was low. Though most Chl-*a* and nutrient concentrations were below detectable limits, total Kjeldahl Nitrogen (TKN) was detected in all water samples collected at the banks in 2011, with concentrations ranging from 1.3–45.2 mg/l (above the 0.55 mg/l detection limit), and in 50% of the samples collected in 2012.

Fish surveys were conducted using a modified Bohnsack and Bannerot (1986) method in 2011 and 2012. Pomacentridae, Labridae, and Serranidae were the dominant fish families at both banks. Diversity varied between banks and years, with the greatest diversity occurring at WFGB in 2012. The most frequently sighted species during this study period were brown chromis (*Chromis multilineata*), closely followed by Spanish hogfish (*Bodianus rufus*), and bluehead (*Thalassoma bifasciatum*). Mean fish density (abundance per 100 m^2) was highest at WFGB in 2012 and lowest at EFGB in 2012.

Invertivores were the dominant fish guild; Pomacentridae and Labridae represented the largest density. The size-frequency distributions of invertivores were non-normally distributed, and the majority of individuals were small damselfish. The greatest mean biomass was seen in 2011 at

WFGB, where the piscivores possessed the highest mean biomass for all surveys, with over 50% of total biomass. Following the pattern of coral species present at the FGB (low diversity compared to Caribbean reefs, but high coral cover), the fish assemblages reflect a similar trend of low diversity and high abundance (Pattengill-Semmens and Gittings 2003). Although no lionfish (*Pterois* spp.) were observed within the fish surveys conducted, in 2012 lionfish were sighted within the study site after first being observed to invade sanctuary waters in 2011.

Sea urchin surveys documented continued low densities of *Diadema antillarum* at WFGB in 2011 (3.75 per 100 m^2) and 2012 (12.5 per 100 m^2). No sea urchins were observed at EFGB. These populations have not recovered to pre-1984 levels, which were at least 140 per 100 m^2 at EFGB and 50 per 100 m^2 at WFGB (Gittings et al. 1998).

An ongoing monitoring program at the FGB is critical to ensure data are available to disinguish among the drivers of ecosystem variation in the northern Gulf of Mexico. The relatively stable conditions on the reef since the beginning of the monitoring program, combined with the historical data collection and the proximity to oil and gas development, makes the FGB an ideal sentinel site for continued support of a long-term monitoring program. Problems that affect coral reefs throughout the region, including land-based sources of pollution and disease have not had a major impact at the FGB, partially due to their relative isolation and depth; however, increased incidence of bleaching events, algal cover, and invasive species, are reasons for increased vigilance and perhaps concern for the future of the resources. Continued monitoring will document long-term changes in condition and will be useful for management decisions and future research focused on the dynamics of the robust benthic communities and the fish populations they support.

CHAPTER 1.0: INTRODUCTION

1.1. CORAL REEF MONITORING AT EAST AND WEST FLOWER GARDEN BANKS

The biotic assemblages of East and West Flower Garden Banks (EFGB and WFGB), part of Flower Garden Banks National Marine Sanctuary (FGBNMS), constitute a healthy community of coral and fish assemblages (Gittings et al. 1992; CSA 1996; Dokken et al. 1999, 2001, 2003; Pattengill-Semmens and Gittings 2003; Precht et al. 2006; Zimmer et al. 2010; Johnston et al. 2013). Although coral species richness is lower at the Flower Garden Banks (FGB) than at other Caribbean reefs, 31 species of scleractinian corals have been documented (Schmahl et al. 2008). In more than 25 years of continuous monitoring, the coral reefs of EFGB and WFGB have maintained high levels of coral cover compared to reefs in the Caribbean region; suffered minimally from hurricanes, coral bleaching and disease outbreaks; and supported relatively diverse and abundant fish and invertebrate populations (Pattengill-Semmens and Gittings 2003). No significant long-term changes have been detected in coral cover or coral diversity in coral monitoring study sites at EFGB and WFGB from 1988–2010 (Zimmer et al. 2010; Johnston et al. 2013), and probably not since the first measurements were taken in the mid-1970s (Gittings, 1998). The Caribbean has experienced declines in zooxanthellate scleractinian coral cover (Gardner et al. 2003) and subsequent increases in macroalgal cover; however, the coral cover at EFGB and WFGB has remained above 50% in the northwest Gulf of Mexico. These reefs, therefore, represent a natural laboratory for understanding factors influencing stability and change in reef systems. The importance of EFGB and WFGB as representative western Atlantic coral reefs has been substantially elevated by the regional decline of corals, as well as by the listing of all coral under the *Orbicella annularis* species complex as threatened (79 FR 53851). Consequently, the risk of loss would be elevated for FGBNMS in the event of a severe industrial accident or other significant change in environmental conditions (Gittings et al. 1992; ONMS 2008).

The long-term monitoring program was initiated in 1988 by the Department of the Interior's Minerals Management Service (now the Bureau of Ocean Energy Management [BOEM]) to ensure protective measures regulating potential impacts of offshore oil and gas development in the northwestern Gulf of Mexico were effective. Gittings et al. (1992) established a single, 100 x 100 m (10,000 m^2) study site at both EFGB and WFGB to monitor benthic community structure from 1988 to 1991 using coral cover, relative dominance, species diversity, evenness, accretionary and encrusting growth rates, and water quality parameters as potential indicators of reef health. Comparisons between their 1988–1991 results and those of previous studies from 1978–1982 (Rezak et al. 1985) showed no significant differences in any of the parameters, which suggests some degree of ecological stability over the period examined. During this time, mean coral cover was approximately 50% and dominated by the *Montastraea annularis* species complex (25%), now known as the *Orbicella annularis* species complex, and *Diploria strigosa* (8%), now known as *Pseudodiploria strigosa* (Gittings et al. 1992). Gittings et al. (1992) considered spills from oil tankers, discharges of mud and drill cuttings during oil and gas exploration and production, noise from seismic surveys, and accidents on platforms leading to spills to be the greatest localized threats to these reefs.

No significant changes in coral community structure were reported between 1992–1995 by CSA (1996). However, variation in mean percent cover of individual coral species was detected between banks and among sampling years in 1992, 1994, and 1995. Minor occurences of coral bleaching were documented in individual colonies in repetitive photostations in 1992 (91 colonies) and 1994 (24 colonies), and 1995 (429 colonies) was the first main bleaching event documented at the FGB coinciding with seawater temperatures in excess of 30°C for prolonged periods (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). 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 10,000 m^2 study sites at EFGB and WFGB; however, macroalgae levels increased ranging from 6.1–24.7% at EFGB and 0.1–25.4% at WFGB. Biodiversity inventories were conducted for algae and mollusks: 72 species of algae were documented and 100 new species were added to the catalog of 4,294 mollusks found at the FGB (Dokken et al. 2001, 2003). Fish assemblages were also documented and 177 species were identified (Pattengill 1998).

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

Continued monitoring of the study sites in 2002 and 2003 by Precht et al. (2006) highlighted the stability of the coral reef communities since the start of monitoring efforts. Mean coral cover was approximately 50% at both banks during those years, macroalgae cover averaged 12%, and no significant diseases were detected. The relative dominance of coral species also remained consistent with past findings. 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. Fish population surveys were added to the long-term monitoring protocol in 2002 and sea urchin (*Diadema antillarum*) and lobster (*Panulirus spp.*) abundance remained low.

Zimmer et al. (2010) continued the monitoring effort from 2004 through 2008 and documented the relative stability of the coral reef community and associated fish populations at the monitoring study sites at EFGB and WFGB. Mean coral cover averaged over 50% at both banks, macroalgae cover increased to an average of 18%, and the *Orbicella annularis* species complex remained the dominant component of coral cover.

On September 23, 2005 Hurricane Rita (Category 3 on the Saffir-Simpson Index) passed approximately 93 km from EFGB on its route north to the mainland of the United States. Two months later, Precht et al. (2008a) conducted a post-hurricane assessment and reported that approximately 10% of the coral in repetitive quadrat stations at EFGB were bleached. This was the highest level of bleaching reported for the FGB since the bleaching event of 1995; however, there was no evidence of coral disease in any of the repetitive quadrats analyzed from 2004 through 2008. It should be noted that it was known the FGB bleaching event was ongoing before the hurricane, because 2005 was a severe bleaching year throughout the Caribbean (Eakin et al. 2010). After Hurricane Rita passed through the Gulf of Mexico, the seawater temperature at the FGB dropped considerably, which may have helped counteract the bleaching event.

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

Continued monitoring of the study sites in 2009 and 2010 was conducted by FGBNMS in partnership with BOEM. Johnston et al. (2013) highlighted the continued relative stability of the coral assemblage at the study site and associated fish populations. Random transect results revealed the mean coral cover within study sites at both banks from 2009 to 2010 to be approximately 57%. Macroalgae cover was significantly higher at EFGB (32%) than WFGB (26%). High seawater temperatures were observed during the late summer months of 2010, exceeding the 30°C coral bleaching threshold; however, minimal bleaching was observed within the study sites during sampling as signs of bleaching did not manifest until late fall in 2010. Fish populations continued to be robust; however, *Diadema antillarum* and *Panulirus* spp. abundance remained low.

April 20, 2010 marked the beginning of the *Deepwater Horizon* explosion, oil spill, and subsequent response; an estimated 53,000 barrels per day escaped from the well before it was capped. NOAA acted as the lead science support agency to the U.S. Coast Guard during the spill response. The spill site was approximately 520 km from EFGB, but because of the size of the spill, the potential for impact to the resources of the sanctuary was of great concern. As part of the Natural Resource Damage Assessment (NRDA) activities, FGBNMS personnel were assigned to the shallow and deep water coral response groups. In addition, semi-permeable membrane devices (SPMDs) were deployed at EFGB and WFGB, and at Stetson and Sonnier Banks, and total petroleum hydrocarbons were added to the suite of analysis parameters for the May 2010 water quality sampling at EFGB and WFGB.

Though the oil spill caused damage to wildlife and marine habitats in other areas of the Gulf of Mexico, no visible oil or immediate oil-related impacts were observed in or near the FGBNMS. Total petroleum hydrocarbon concentrations were undetectable (<5 mg/L) in all water samples collected at the surface, midwater, and reef cap at both EFGB and WFGB. Nevertheless, the long-term monitoring data would have provided a valuable baseline from which impacts could have been detected, if they occurred.

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

1.2.1. Habitat Description

East and West Flower Garden Banks, located in the northwestern Gulf of Mexico, are part of a discontinuous arc of reef environments along the outer continental shelf (Rezak et al. 1985; Figure 1.2.1). These coral reef-capped banks are the largest Holocene carbonate accumulations in the northwestern Gulf of Mexico and the northernmost coral reefs in North America (Bright et al. 1984; Bright et al. 1985). Although coral and non-coral dominated communities exist on neighboring banks (e.g., Bright Bank, Geyer Bank, Sonnier Bank, Stetson Bank, McGrail Bank) and on the Florida Middle Grounds in the eastern Gulf, the reefs of Lobos-Tuxpan Flora and Fauna Protected Area near Cabo Rojo, Mexico are the nearest shallow-water coral reefs in the Gulf of Mexico.

The large-scale topographic features of the FGB were created by geologic activity associated with salt diapirs of the Jurassic Louann Formation and subsequent loading and uplifting of sedimentary rocks (Rezak 1981). Many such diapirs exist in the northern Gulf of Mexico and dozens form substantial elevated banks. The caps of some of the banks extend into the photic zone in clear oceanic waters, where conditions are ideal for colonization by species of corals, algae, invertebrates, and fish typical of coral reefs found in the Caribbean and western central Atlantic (Figure 1.2.2 and Figure 1.2.3). Although coral species richness is lower at the FGB than on most Caribbean reefs, 31 species of scleractinian corals have been documented at the FGB (Schmahl et al. 2008) and 298 species of tropical Atlantic fish have been reported sanctuary wide, including the deepwater communities (FGBNMS 2013). Salinity conditions at the FGB range from 34 to 36 PSU, with water temperatures ranging from 18°C (in mid-February) to 30°C (in late August). Water clarity across both banks is more then sufficient to transmit light to benthic photosynthetic organisms (40 m or more vertical visibility).

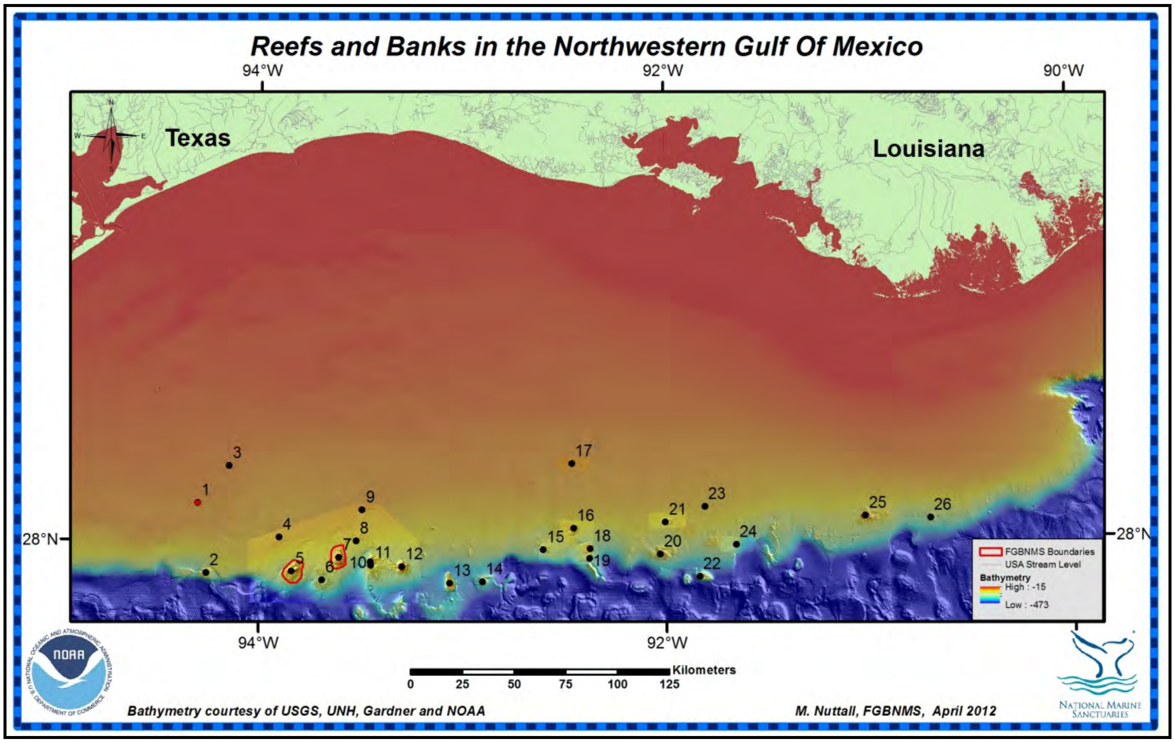


Figure 1.2.1. Map of EFGB and WFGB in relation to the Texas-Louisiana continental shelf and other topographic features of the northwestern Gulf of Mexico (NOAA/FGBNMS).

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

1.2.2. East and West Flower Garden Banks

East Flower Garden Bank (27º 54.5' N, 93º 36.0' W) is a pear-shaped dome located approximately 193 km (120 mi) southeast of Galveston, Texas. EFGB is 8.7 by 5.1 km in size, sloping from its shallowest point at 17 m to the terrigenous mud seafloor at a depth of 100–120 m. The eastern and southern edges of the bank have steep slopes, whereas the northern and western edges descend more gently (Figure 1.2.2). West Flower Garden Bank (27º 52.4' N, 93º 48.8' W) is an oblong-shaped dome located 20 km west of EFGB and 172 km southeast of Galveston. It is 11.0 by 5.0 km in size (Figure 1.2.3). The WFGB study site is located on the eastern knoll and is 18 m at its shallowest. Coral species diversity at both banks is low; 31 species from 18 genera are represented (Schmahl et al. 2008), compared to 67 species found on some Caribbean reefs (Goreau and Wells 1967). Shallow-water gorgonians and live acroporids have not been reported at the FGB. However, one colony of *Acropora palmata* was discovered in 2003 at WFGB, but is in decline due to stressors, such as damselfish predation, algal growth, and possible disease. Another living colony of *Acropora palmata* was discovered at EFGB, southeast of the study site in 2005 and has a resident damselfish and minimal tissue loss (Zimmer et al. 2006).

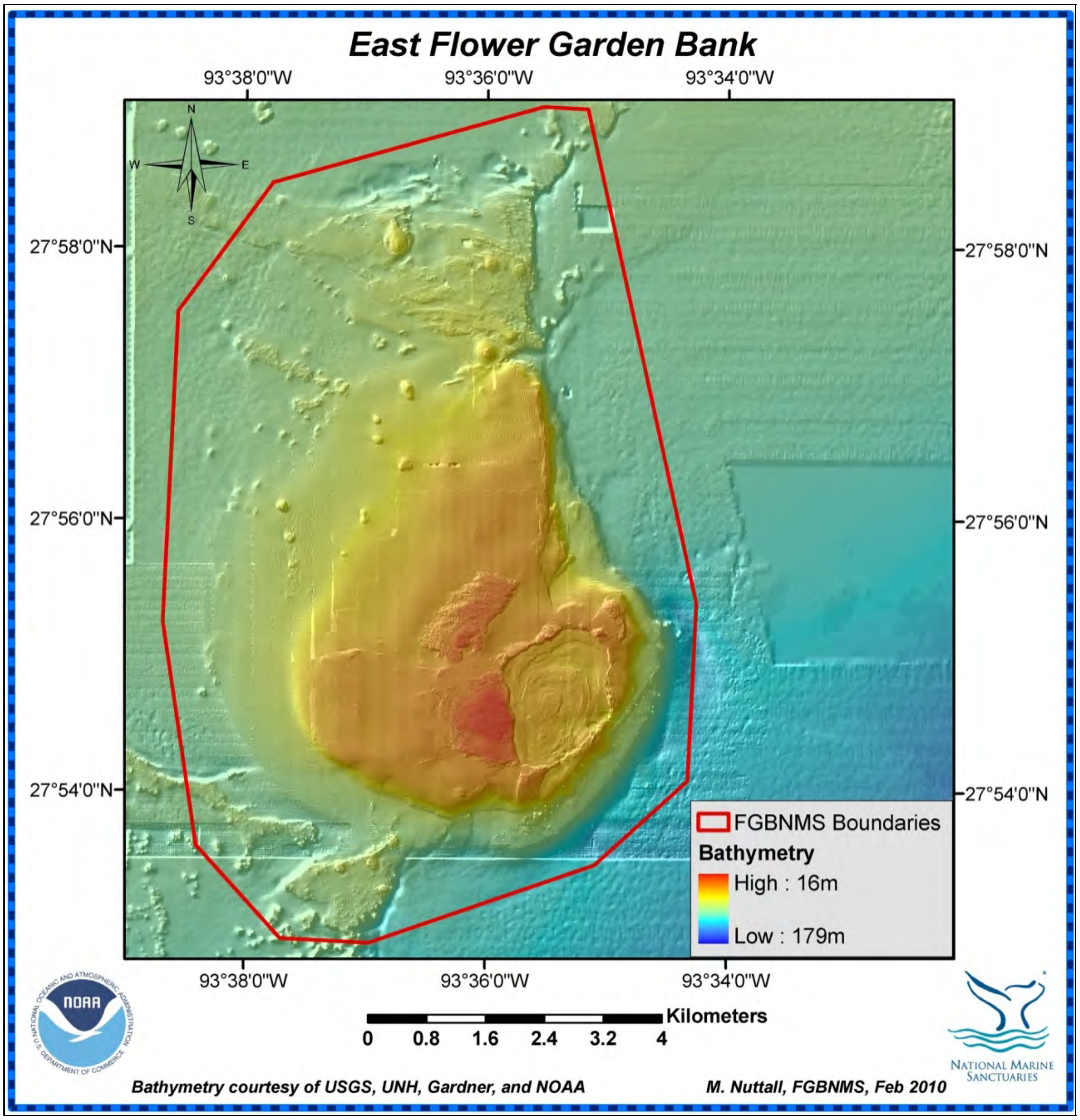
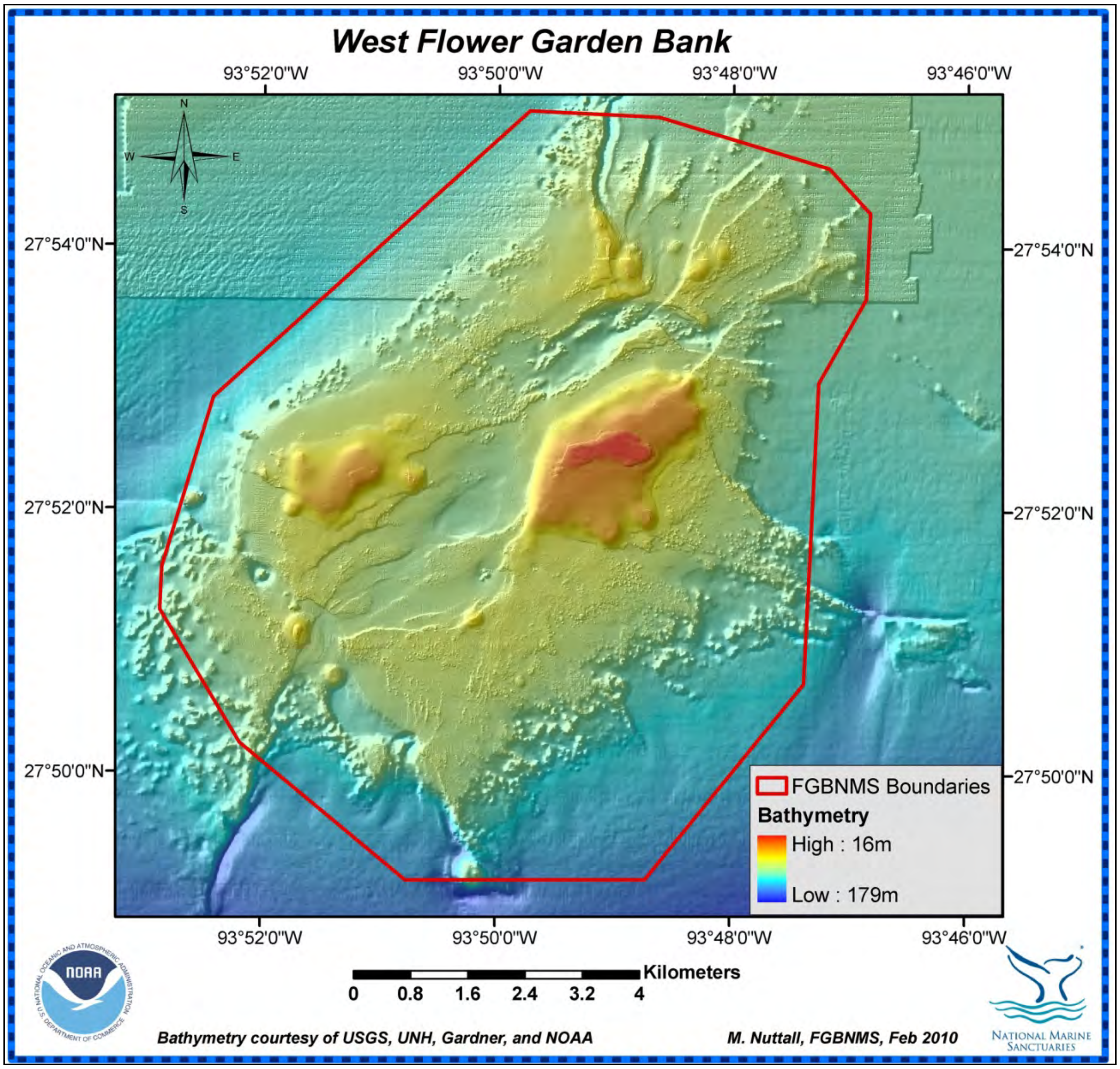


Figure 1.2.2. Bathymetric map of EFGB.

EFGB is 8.7 by 5.1 km in size, capped by 1.43 sq. km of coral reef rising 17 m to the surface (NOAA/FGBNMS).



Bathymetry courtesy of USGS, UNH, Gardner, and NOAA

M. Nuttall, FGBNMS, Feb 2010

Figure 1.2.3. Bathymetric map of WFGB.

WFGB is 11.0 by 5.0 km, capped by 0.42 sq km of coral reef starting 18 meters below the surface (NOAA/FGBNMS).

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

1.3. BOEM AND FGBNMS PROTECTIVE MEASURES

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

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

In addition to the protections provided by BOEM, the FGB were designated as an U.S. National Marine Sanctuary in 1992 (Code of Federal Regulations, 15 CFR Part 992, Subpart L, Section 922.120), and Stetson Bank was later added in 1996. In April 2012, FGBNMS released an updated Management Plan, because the original management plan for FGBNMS dated back to its designation (USDOC NOAA ONMS 2012). Detailed FGBNMS regulations can be found in Volume II Appendix 1 of this report. Though certain exceptions exist for oil and gas operations, FGBNMS regulates, restricts and prohibits:

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

(7) possessing or using explosives within the sanctuary boundaries or releasing electrical charges within the sanctuary boundaries.

In July of 2001, the U.S. delegation to the International Maritime Organization (IMO), submitted a proposal to ban anchoring in FGBNMS for vessels greater than 30.5 m (100 ft). The IMO, out of concern for impacts to corals, modified the proposal to prohibit all anchoring, but vessels 30.5 m (100 ft) and under would be allowed to moor using existing FGBNMS mooring buoys. The new international measure also ensured that no-anchoring zones are marked on all charts internationally. Code of Federal Regulations, 15 CFR Part 922.122. amended FGBNMS regulations to align with IMO no-anchor rule within the sanctuary.

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

CHAPTER 2.0: STUDY SITES

2.1. STUDY SITE METHODS

EFGB and WFGB are located roughly 190 km offshore in water depths of 17 m and greater. The monitoring effort was conducted from the NOAA R/V *Manta*. Data was collected within 100 x 100 m (10,000 m² or 1 hectare) study sites located at each bank. The benthos (with an emphasis on corals and algae) was examined along random 10 m transects and stationary repetitive photoquadrats. Sclerochronology was used to document the accretionary growth rate of specific coral colonies, and photography was used at permanent stations to monitor the lateral growth of corals. General aspects of coral condition were documented along study sites perimeter lines at EFGB and WFGB. During each annual monitoring cruise, observations of general coral reef health within the study sites, and 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 randomly located sites and sea urchin and lobster surveys were conducted along the study site perimeter lines.

2.1.1. 10,000 m² Study Sites

Water depth at EFGB ranges from 17 m to 134 m and 18 m to 140 m at WFGB (Figures 2.1.1 and 2.1.2). For the long-term monitoring program, data were collected within 10,000 m² study sites (hereafter referred to as “study sites”) located on the shallow reef cap at each bank. Within the locations of the study sites, depths range between 17 m to 27m at EFGB and 18 m to 25 m at WFGB. Divers installed reference lines to 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 site into four 25 x 25 m quadrants (Volume II Appendix 2). The lines aided divers in orientation-navigation through the study site and they allowed for efficient completion of monitoring tasks. Established in 1988, the study sites are marked by permanent mooring buoys: FGBNMS permanent mooring No. 2 at EFGB and mooring No. 5 at WFGB (Figure 2.1.1, Figure 2.1.2, and Table 2.1.1). Data were collected within the study sites at EFGB and WFGB in 2011 and 2012 (Table 2.1.2).

Within each study site at EFGB and WFGB, permanent monitoring stations were established at the beginning of the monitoring program. There are two types of permanent monitoring stations within the study sites: 1) lateral growth stations on *Pseudodiploria strigosa* colonies, which are marked by two short rods per station; and 2) repetitive quadrats, the centers of which are marked by 0.5 m tall rods. Historically, 40 repetitive quadrats and 60 lateral growth stations were maintained at each bank. The repetitive growth stations have been maintained over time and the lateral growth stations have been replaced as stations become overgrown.

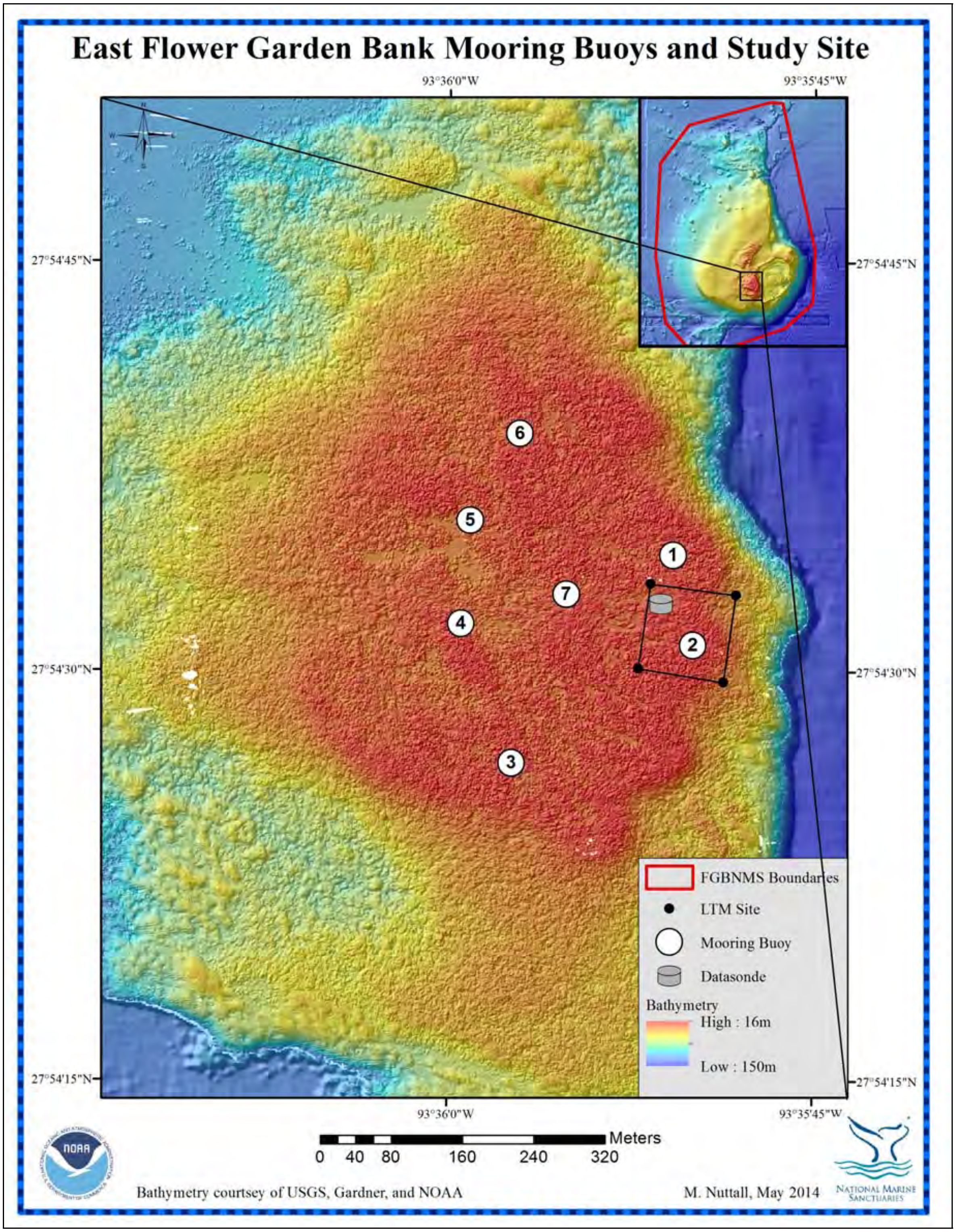


Figure 2.1.1. Bathymetric map of EFGB with long-term monitoring study site (LTM site), mooring buoy, and datasonde locations (NOAA/FGBNMS).

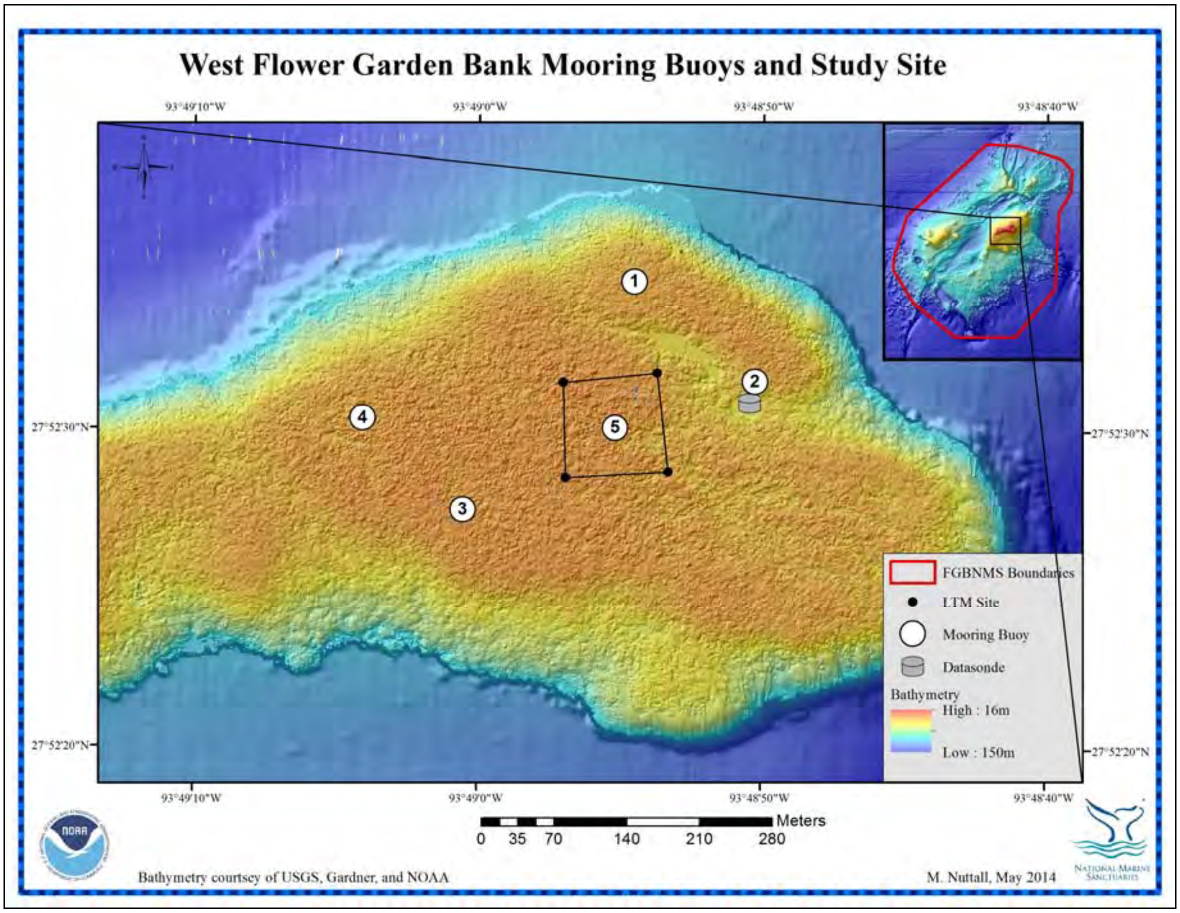


Figure 2.1.2. Bathymetric map of WFGB with the long-term monitoring study site (LTM site), mooring buoy, and datasonde locations (NOAA/FGBNMS).

Table 2.1.1.

Coordinates for EFGB and WFGB Study Site Permanent Mooring Buoys

EFGB Mooring No. 2			**WFGB Mooring No. 5**		
Year	**Lat (DDM)**	**Long (DDM)**	**Year**	**Lat (DDM)**	**Long (DDM)**
2011	27°54.319 N	93°35.490 W	2011	27°52.519 N	93°48.889 W
2012	27°54.516 N	93°35.831 W	2012	27°52.501 N	93°48.918 W

Table 2.1.2.

Cruise Dates at EFGB and WFGB for 2011 and 2012

EFGB	**WFGB**
11-12 July 2011	13-14 July 2011
23-25 July 2012	25-27 July 2012

2.1.1.1. Study Site Refurbishment

In 2012, the monitoring team conducted study site rehabilitation at EFGB and WFGB. This was necessary to install permanent study site corner markers that had been lost or loosened over the years. Permanent eye-bolts were also installed at the 25 m, 50 m, and 75 m marks along each perimeter and crosshair line location to allow each perimeter line and crosshair to be clipped into these guide pins when the study site boundary lines are placed (Figure 2.1.3). These modifications ensure consistent location of study site lines from year to year. Permanent mooring buoys were reinstalled to the center location of each study site (Table 2.1.1).

Also during study site rehabilitation, repetitive 5 m^2 quadrat photostations were renumbered and tagged to create custom numbers based on bank and quadrant to avoid confusion among stations. Eye bolts were used to remark the repetitive stations, and numbered tags were attached to the eye bolts. These 5 m^2 repetitive quadrat photostations were mapped in relation to corner and/or center eyeblots on perimeter lines or crosshairs. The distance and heading to each station was obtained by divers using measuring tapes and compasses. This information was incorporated into the master maps, to assist with locating stations and study site navigation (Volume II Appendix 2). It should be noted that when the long-term monitoring study site boundaries were adjusted to make accurate 100 x 100 m sites, the corner locations shifted slighty. For this reason, some of the repetitive quadrat stations that are monitored are now located outside of the study site boundaries (Volume II Appendix 2).

Figure 2.1.3. Divers install new permanent eye-bolts at the WFGB study site (NOAA/FGBNMS).

2.1.2. Repetitive Deep Stations

Eleven repetitive deep photostations are located outside the study site at EFGB (Figure 2.1.4). Nine original deep stations were established in April 2003 for comparison with the shallower repetitive quadrat photostations already in place (Precht et al. 2005), and two more stations were added in 2012. The photostations were located east of EFGB study site at depths between 32 m and 40 m (Precht et al. 2005).

Twelve repetitive deep photostations are located outside the study site at WFGB near buoy No. 2 (Figure 2.1.5). These deep stations were established in 2012 for comparison with EFGB deep photostations and the shallower repetitive quadrat photostations already in place. The stations were located 78 m north of the WFGB study site mooring at depths between 24 m and 38 m. Deep station information is incorporated into the master maps to assist with locating stations and site navigation (Volume II Appendix 2).

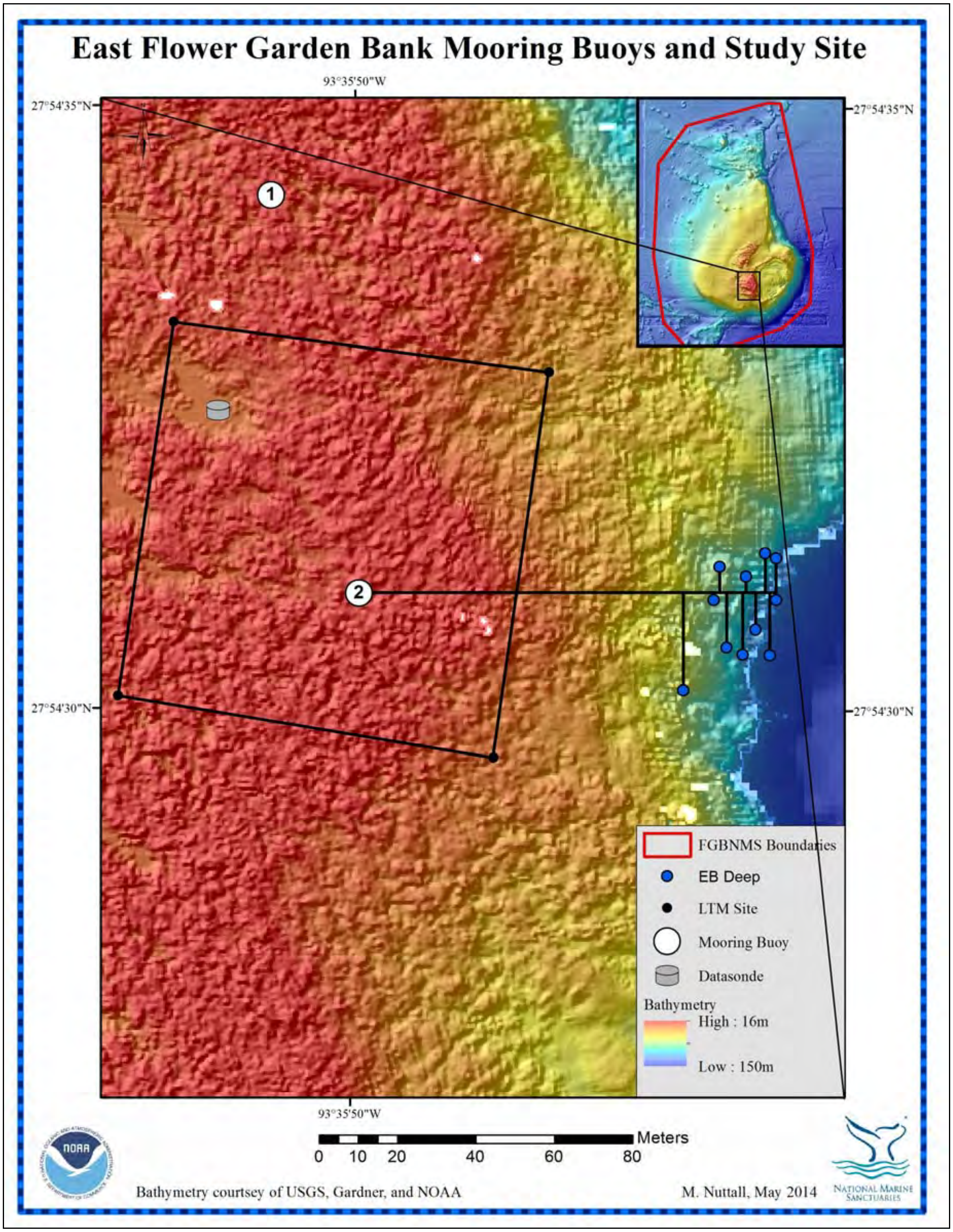


Figure 2.1.4. Bathymetric map of EFGB with long-term monitoring study site (LTM site), mooring buoy, and repetitive deep photostation locations (EB Deep) (NOAA/FGBNMS).

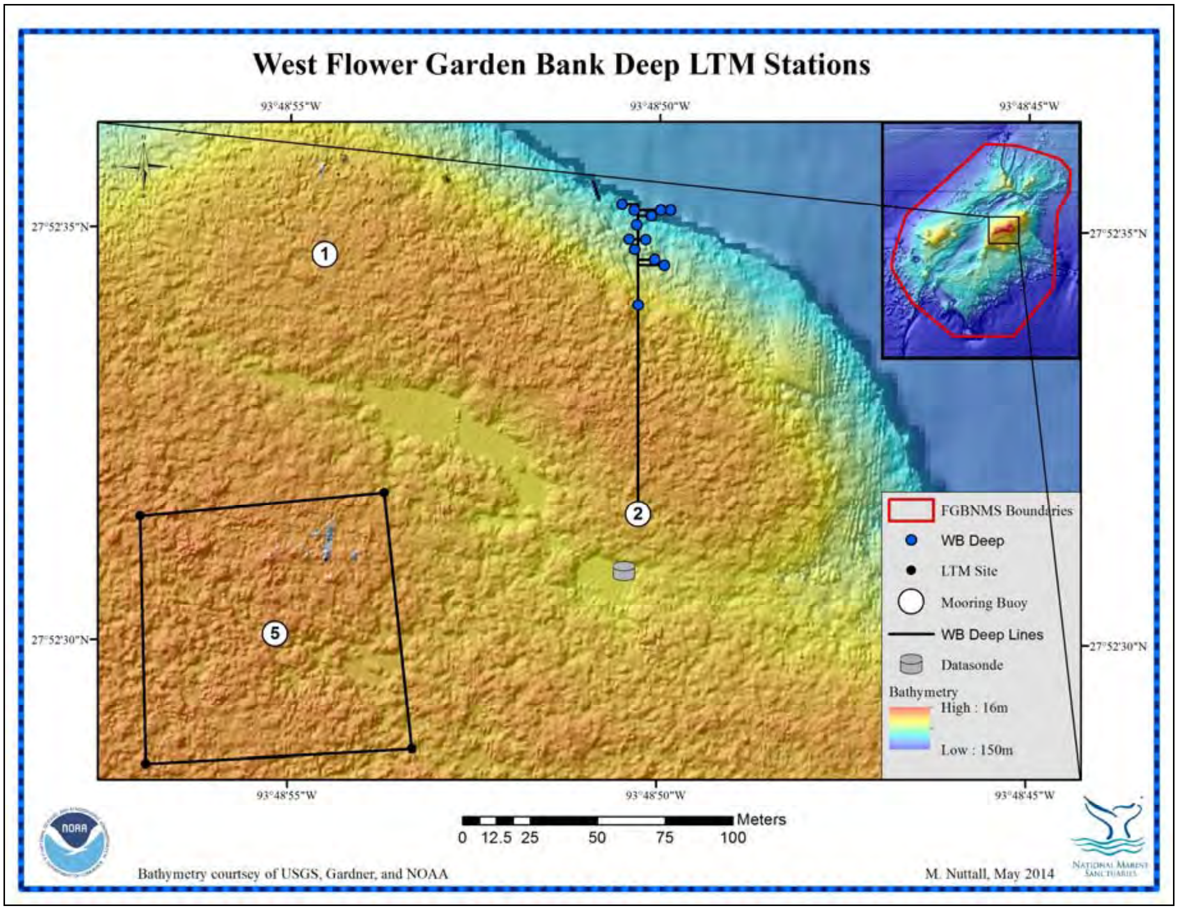


Figure 2.1.5. Bathymetric map of WFGB with long-term monitoring study site (LTM site), mooring buoy, and repetitive deep photostation locations (WB Deep) (NOAA/FGBNMS).

CHAPTER 3.0: RANDOM TRANSECTS

3.1. RANDOM TRANSECT METHODOLOGICAL RATIONALE

To estimate the areal coverage of benthic components such as corals, sponges, and macroalgae, 10 m transect tapes were positioned randomly within each study site. Conducted at random locations, the transect surveys were used to compare habitat types and provide information to document the benthic reef community of EFGB and WFGB in 2011 and 2012.

3.2. RANDOM TRANSECT METHODS

3.2.1. Random Transect Field Methods

Four random transects within each quadrant of each study site, totaling 16 transects, were completed. For each quadrant, a random number between 0 and 50 was generated to indicate the starting location along the perimeter boundary line in the designated quadrant (e.g., if the random number is 27 and the corner of the transect tape is 0, the transect is started at 27 m along the transect tape, and if the lowest corner of the transect tape is 50, the transect is started at 77 m along the transect tape). A second random number was generated between 0 and 40 to determine the number of fin kicks perpendicular from the boundary line into the study site, as it takes approximately 40 fin kicks to swim 50 m, assuming no opposing current. This randomly generated number of kicks provides the start location for the first transect. A random number between 0° and 359° was also generated for the direction of the 10 m transect from the starting point.

The subsequent survey starting point was determined with a second set of randomly generated numbers. First, the number of fin kicks, between 12 and 40, was determined to ensure the starting point was at least 15 m away from the previous location. Second, the compass heading, between 0° and 359°, was established for the direction of the next 10 m transect. If a quadrant boundary was encountered, the line was reflected at a 90° angle back into the quadrant. Random numbers and headings were given to divers before each survey.

Each transect was designed to capture approximately 8 m^2 of benthic habitat. A still camera, mounted on a 0.65 m t-frame with bubble level and strobes, was used to capture non-overlapping images above the reef (Figure 3.2.1). The bubble level mounted to the center of the t-frame ensured images were taken in a vertical orientation to standardize the area captured.

A Canon Power Shot® G11 digital camera was used in an Ikelite® housing with a 28 mm equivalent wet mount lens adaptor with two Inon® Z240 strobes set 1.2 m apart on the t-frame. The mounted camera was placed at intervals marked on the spooled, fiberglass, measuring tape at 55.88 cm apart producing 19 non-overlapping images along the 10 m transect. Each still frame image captured an 80 x 55 cm area. This produced a total photographed area of 8.36 m^2 per transect, or a minimum of 117.04 m^2 photographed per study site per year.

Figure 3.2.1. NOAA scientific diver with camera and strobes mounted on aluminum t-frame taking random transect photographs (NOAA/FGBNMS).

3.2.2. Random Transect Data Processing

Mean percent cover in the random transect images was analyzed using Coral Point Count with Microsoft® Excel® extensions (CPCe). CPCe is Microsoft® Windows®-based software that provides a tool for the determination of coral cover using transect photographs (Kohler and Gill 2006). A total of 500 points was distributed evenly between all the photos that were within a transect. Points were randomly overlaid on each image and benthic species lying under these points were identified. Microsoft® Excel® spreadsheets were created automatically in the program using customized code files pertinent to the cover of coral and other benthic species in the region. CPCe is provided by the National Coral Reef Institute as freeware to researchers from scientific institutions and government agencies.

Organisms positioned beneath each random dot were identified as corals, sponges, or macroalgae and all were identified to the lowest possible taxonomic group. The macroalgae group included algae longer than approximately 3 mm and thick algal turfs. Crustose coralline algae, fine turfs, and bare rock were collectively identified as “CTB” (Aronson and Precht 2000). The components of the CTB group were combined for analysis because they represent potential habitat where settlement of coral or other organisms could occur. Macroalgae is not included in this category since settlement has already occurred. Additional categories included other live components (ascidians, fish, serpulids, etc.), sand, rubble, and unknown (Volume II Appendix 1).

The coverages of coral bleaching, paling, concentrated and isolated fish biting, and disease were recorded as "notes," providing additional information for each random point. Any point that landed on a portion of coral that was white with no visible zooxanthallae was characterized as "bleached." Any point that landed on coral that was pale relative to what was considered "normal" for the species, was characterized as "paling" coral (AGRRA 2010). If the colony displayed some bleaching or paling, but the point landed on a healthy area of the organism, the point was "healthy" and no bleaching or paling was noted in CPCe. To classify fish biting, any point that landed where fish biting occurred on a coral head more than once was classified as concentrated fish biting, and any point where there was only one occurance of fish biting was classified as isolated fish biting. Fish biting that results in the removal of coral polyps from an affected area is due primarily to stoplight parrotfish activity (*Sparisoma viride*) (Bruckner and Bruckner 1998; Bruckner et al. 2000).

After each image was analyzed, the data were entered into project-specific Microsoft® Excel® spreadsheets. Quality assurance/quality control (QA/QC) for the photographic methods consisted of multiple, scientific divers all trained on the same camera systems for correct camera operation. Divers were able to practice camera setup and operation with mock corals in a swimming pool before field work began. Statistical comparisons of identifications by multiple investigators were conducted to confirm the same identifications in the photographs to ensure that they agreed on species identifications within the photo frames. Each investigator was given photographs from the same transect from EFGB and WFGB and identified all benthic components in each photograph of that transect. Identification of benthic components agreed 95% of the time for transects analyzed from EFGB and WFGB in 2011 and 2012, with no significant difference (α=0.05) between the benthic components identified in the identical transects by different investigators.

3.2.3. Random Transect Statistical Analyses

Mean percent cover was calculated for each transect from the 500 analyzed points for each of the taxa and benthic categories. Factor plots were produced in CPCe to compare the average percent cover of major benthic categories and coral species between banks and through time. CPCe spreadsheet contents included header information, statistical parameters of each species/substrate type (mean, standard deviation, standard error) and the calculation of the Shannon–Weaver diversity index for each species (Kohler and Gill 2006). Results are presented as mean percent cover ± standard error. Previous examination of means and variances, using different numbers of random dots, determined that 500 dots per transect provided the required accuracy and precision for estimates of the coverage of benthic components, regardless of the transect length (Aronson et al. 1994; Murdoch and Aronson 1999; Aronson et al. 2005).

Analyses of Variance (ANOVA) were performed to test the null hypotheses that the response variables of univariate benthic cover did not differ by year (2011 and 2012) and bank (EFGB and WFGB). ANOVAs were calculated for each variable with the statistical software JMP® version 10.0. Data were tested for normality and square root transformed as necessary to assume a normal distribution to meet the assumptions of parametric statistical tests (Zimmer et al. 2010).

Multivariate statistical techniques were used to compare how the two banks may differ in benthic composition. Based on benthic mean percent cover, comparisons in community differences between the two banks were made using nonparametric analysis for non-normal data. Significant dissimilarities were tested using analysis of similarity (ANOSIM) with square root transformation and Bray-Curtis similarity resemblance measure (Bray and Curtis, 1957). Cluster analyses were performed on similarity matrices, and multidimensional scaling (MDS) was used to visualize community dissimilarities by bank (Kruskal, 1964). Ordinations were run using 100 random starting configurations to determine the best fit model and minimize stress. The R statistic, typically ranging between 0 and 1, indicates between and within group dissimilarities, where R values less than 0.3 indicate that similarities between sites and within sites are the same (Clarke & Warwick 2001). Species contributing to the observed dissimilarities were identified using similarity percentages (SIMPER). All analyses were all carried out using Primer® version 6.0.

For long-term trends (1978-2012), each functional group sample was averaged by year and compared using nonparametric analysis for non-normal data. Percent cover data of each functional group were used to calculate ecological distance via Bray-Curtis similarity matrices. Data were square root transformed to minimize the impacts of extremely dominant members of the community. Cluster analyses were performed on similarity matrices, and MDS plots were used to visualize community dissimilarities between years, with time series trajectory to highlight community shifts over time. SIMPER identified the greatest contributors to the observed dissimilarity.

3.3. RANDOM TRANSECT RESULTS

The point count data from the random transects was expressed as mean percent cover ± standard error (SE). The major benthic component of the random transects from 2011 and 2012 was coral cover (56%), followed by macroalgae cover (32%) and CTB (11%). The sponge cover (including encrusting sponges) was very low (0.5%) because not many macrosponges are found at the FGB; encrusting sponges are common but rarely seen in photographs because they are generally found on the underside of boulders (Figure 3.4.1). Volume II Appendix 4 of this report contains the random transect data from 2011 and 2012 at the FGB.

At EFGB, mean coral cover remained above 50 percent from 2011–2012 (57.49% ± 2.28 to 52.49% ± 4.50), and the sponge cover remained extremely low for both years (0.49% ± 0.17 to 0.62% ± 0.23) (Figure 3.3.1 and Table 3.3.1). Macroalgae cover (mainly fleshy algae and *Dictyota* spp.) increased slightly from 2011–2012 (30.10% ± 1.59 to 37.59% ± 3.80), and CTB cover decreased (11.53% ± 0.07 to 8.63% ± 0.17).

At WFGB, coral cover was above 50 percent, consistent with previous monitoring periods. The 2011 coral cover was the highest between the two years and banks (59.51% ± 2.09), and the coral cover decreased in 2012 (54.78% ± 3.41). The sponge cover remained extremely low for both years (0.31% ± 0.11 to 0.68% ± 0.24). Macroalgae remained stable from 2011–2012 (29.11% ± 1.90 to 31.43% ± 2.48) along with relatively stable CTB cover (10.40% ± 0.25 to 12.27% ± 0.26) (Figure 3.3.1 and Table 3.3.1).

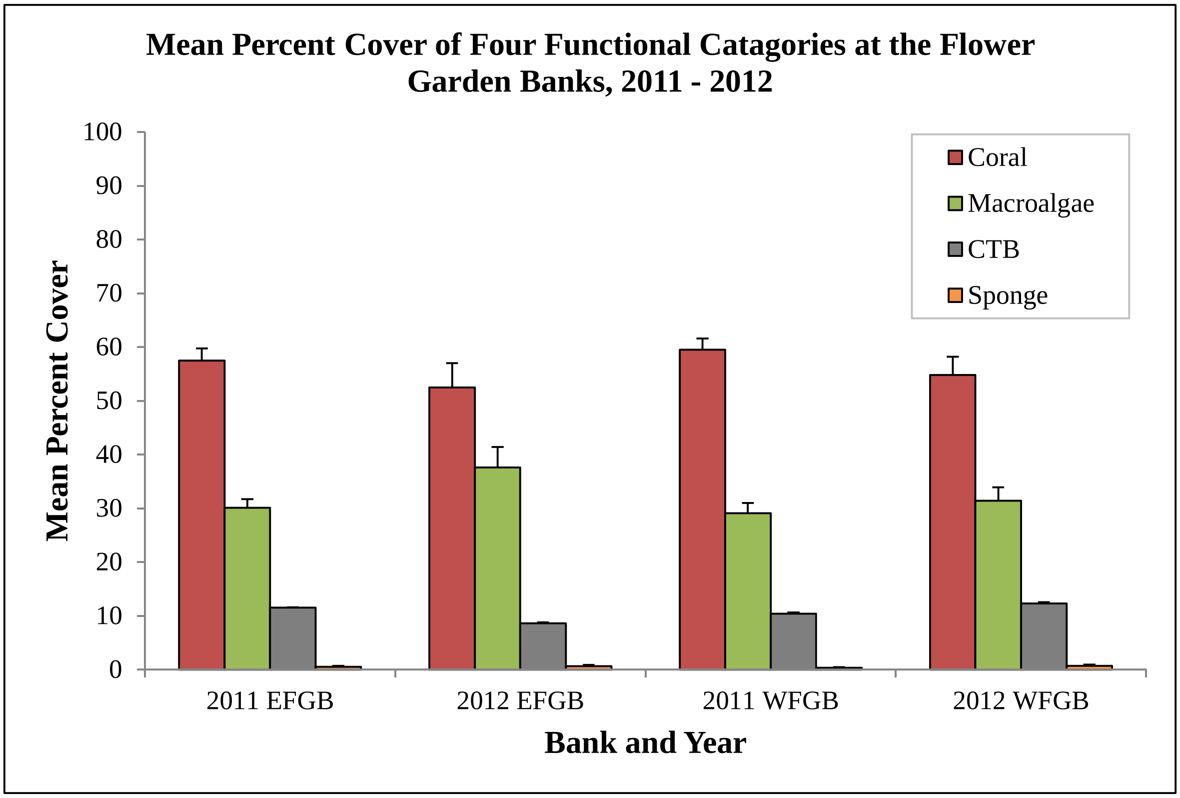


Figure 3.3.1. Mean percent cover + SE of four functional benthic categories from random transects at the FGB from 2011–2012.

Table 3.3.1.

Mean Percent Cover ± SE of Benthic Categories in Random Transects at EFGB and WFGB from 2011 and 2012 (listed from most to least abundant).

Cover Category	**2011 EFGB**	**2012 EFGB**	**2011 WFGB**	**2012 WFGB**
Coral				
Orbicella franksi	25.53 ± 4.16	25.76 ± 3.96	23.52 ± 3.11	26.06 ± 3.94
Pseudodiploria strigosa	6.13 ± 1.91	7.65 ± 2.05	12.36 ± 2.62	9.32 ± 1.94
Orbicella spp.	5.26 ± 1.74	2.65 ± 0.89	6.16 ± 3.06	2.03 ± 0.42
Montastraea cavernosa	5.25 ± 1.14	3.24 ± 0.77	2.92 ± 0.81	1.89 ± 1.01
Porites astereoides	4.17 ± 0.74	5.35 ± 0.88	3.60 ± 0.64	4.24 ± 0.55
Orbicella faveolata	3.86 ± 1.28	2.82 ± 0.66	5.26 ± 1.69	7.33 ± 2.80
Orbicella annularis	2.93 ± 2.07	0.13 ± 0.06	0.39 ± 0.31	0.20 ± 0.20
Colpophyllia natans	1.66 ± 0.69	2.54 ± 0.67	0.75 ± 0.25	0.77 ± 0.28
Siderastrea siderea	0.93 ± 0.31	0.19 ± 0.19	2.56 ± 1.87	0.60 ± 0.41
Unidentified coral	0.57 ± 0.26	0.98 ± 0.30	0.64 ± 0.28	0.51 ± 0.18
Stephanocoenia intersepta	0.38 ± 0.23	0.60 ± 0.22	0.69 ± 0.27	0.88 ± 0.24
Scolymia cubensis	0.17 ± 0.14	0.00	0.00	0.00
Madracis decactis	0.15 ± 0.09	0.14 ± 0.09	0.03 ± 0.02	0.11 ± 0.09
Siderastrea spp.	0.13 ± 0.05	0.06 ± 0.06	0.01 ± 0.01	0.00
Agaricia agaricites	0.13 ± 0.05	0.15 ± 0.05	0.25 ± 0.09	0.14 ± 0.05
Millepora alcicornis	0.11 ± 0.07	0.14 ± 0.05	0.21 ± 0.13	0.15 ± 0.06
Mussa angulosa	0.08 ± 0.05	0.07 ± 0.04	0.03 ± 0.02	0.02 ± 0.02
Colpophyllia amaranthus	0.02 ± 0.02	0.00	0.01 ± 0.01	0.00
Scolymia spp.	0.01 ± 0.01	0.00	0.00	0.00
Agaricia spp.	0.01 ± 0.01	0.00	0.01 ± 0.01	0.00
Porites furcata	0.00	0.03 ± 0.02	0.01 ± 0.01	0.00
Madrepora spp.	0.00	0.02 ± 0.02	0.01 ± 0.01	0.00
Madracis spp.	0.00	0.01 ± 0.01	0.00	0.08 ± 0.05
Madracis auretenra	0.00	0.00	0.05 ± 0.02	0.04 ± 0.03
Colpophyllia spp.	0.00	0.00	0.02 ± 0.02	0.00
Siderastrea radians	0.00	0.00	0.00	0.39 ± 0.37
Leptoseris cucullata	0.00	0.00	0.00	0.01 ± 0.01
Agaricia fragilis	0.00	0.00	0.00	0.01 ± 0.01
Total Mean Coral Cover	**57.49 ± 2.28**	**52.49 ± 4.50**	**59.51 ± 2.09**	**54.78 ± 3.41**
Sponge				
Agelas clathrodes	0.16 ± 0.06	0.12 ± 0.05	0.07 ± 0.04	0.10 ± 0.05
Aiolochroia (Pseudoceratina) crassa	0.04 ± 0.04	0.08 ± 0.07	0.01 ± 0.01	0.05 ± 0.04
Ircinia strobilina	0.04 ± 0.04	0.03 ± 0.02	0.02 ± 0.02	0.08 ± 0.08
Unidentifiable sponge	0.04 ± 0.04	0.15 ± 0.08	0.04 ± 0.04	0.06 ± 0.04
Placospongia melobesioides	0.01 ± 0.01	0.01 ± 0.01	0.00	0.00
Xestospongia muta	0.00	0.09 ± 0.09	0.01 ± 0.01	0.25 ± 0.17
Mycale laxissima	0.00	0.04 ± 0.04	0.00	0.00

Cover Category	**2011 EFGB**	**2012 EFGB**	**2011 WFGB**	**2012 WFGB**
Ectyoplasia ferox	0.00	0.02 ± 0.02	0.03 ± 0.02	0.00
Aplysina spp.	0.00	0.01 ± 0.01	0.00	0.00
Ircinia felix	0.00	0.00	0.00	0.01 ± 0.01
Encrusting sponge	0.19 ± 0.06	0.03 ± 0.02	0.13 ± 0.05	0.03 ± 0.02
Unidentifiable encrusting sponge	0.00	0.02 ± 0.02	0.00	0.08 ± 0.05
Total Mean Sponge Cover	0.49 ± 0.17	0.62 ± 0.23	0.31 ± 0.11	0.68 ± 0.24
Macroalgae				
Fleshy algae	14.04 ± 1.41	23.36 ± 3.05	13.45 ± 1.48	17.37 ± 2.05
Dictyota spp.	11.62 ± 1.47	9.60 ± 1.26	1.44 ± 0.30	1.96 ± 0.61
Lobophora variegata	3.09 ± 0.62	1.23 ± 0.23	11.17 ± 0.98	9.52 ± 1.60
Thick turf algae	1.32 ± 0.31	3.29 ± 0.78	2.95 ± 0.58	2.43 ± 0.42
Peysonnelia spp.	0.03 ± 0.02	0.00	0.00	0.00
Filamentous algae	0.00	0.08 ± 0.05	0.08 ± 0.05	0.01 ± 0.01
Unidentifiable macroalgae	0.03 ± 0.03	0.00	0.02 ± 0.02	0.13 ± 0.13
Total Mean Macroalgae Cover	30.10 ± 1.59	37.59 ± 3.80	29.11 ± 1.90	31.43 ± 2.48
CTB				
Fine turf algae	5.20 ± 1.10	4.11 ± 0.59	4.66 ± 0.56	5.81 ± 1.11
Bare substrate	3.94 ± 0.76	2.86 ± 0.51	4.33 ± 0.54	3.63 ± 0.34
Crustose coralline algae	1.89 ± 0.38	1.25 ± 0.28	1.30 ± 0.23	2.71 ± 0.61
Substrate rubble	0.36 ± 0.15	0.03 ± 0.02	0.07 ± 0.03	0.05 ± 0.04
Coral rubble	0.15 ± 0.08	0.37 ± 0.27	0.04 ± 0.02	0.07 ± 0.05
Total Mean CTB Cover	11.53 ± 1.41	8.63 ± 0.96	10.40 ± 0.61	12.27 ± 1.36

Orbicella franksi was the most abundant coral species observed in 2011 (25.53% ± 4.16) and 2012 (25.76% ± 3.96) at EFGB. *Pseudodiploria strigosa* (6.13% ± 1.91 and 7.65% ± 2.05 in 2011 and 2012, respectively) was the next most abundant species, followed by unidentified *Orbicella* spp., *Montastraea cavernosa*, and *Porites astreoides* (Figure 3.3.2 and Table 3.3.1). The remaining coral cover was made up of twenty-four species, none of which exceeded 4.0% cover individually in either 2011 or 2012 (Table 3.3.1). Corals that could not be differentiated (less than 1%) because of camera angle or camera distortion were labeled as “unidentified coral.” Shannon-Wiener diversity values remained consistent at EFGB (H’=0.95 and H’=0.91 in 2011 and 2012, respectively).

As with EFGB, *Orbicella franksi* was the most abundant coral species observed in 2011 (23.52% ± 3.11) and 2012 (26.06% ± 3.94) at WFGB. *Pseudodiploria strigosa* (12.36% ± 2.62 and 9.32% ± 1.94 in 2011 and 2012, respectively) was the next most abundant species, followed by *Orbicella faveolata* (5.26% ± 1.69 to 7.33% ± 2.80). Other abundant species included *Porites astreoides*, unidentified *Orbicella* spp., and *Monastraea cavernosa* (Figure 3.3.3 and Table 3.3.1). The remaining coral cover was made up of twenty-five species, none of which exceeded 3.0% individually in either 2011 or 2012 (Table 3.3.1). Corals that could not be differentiated (less then 1%) because of camera angle or camera distortion were labeled as “unidentified coral.” Shannon-Wiener diversity values were higher at WFGB in 2011 than in 2012 (H’=0.93 and H’=0.98 in 2011 and 2012, respectively).

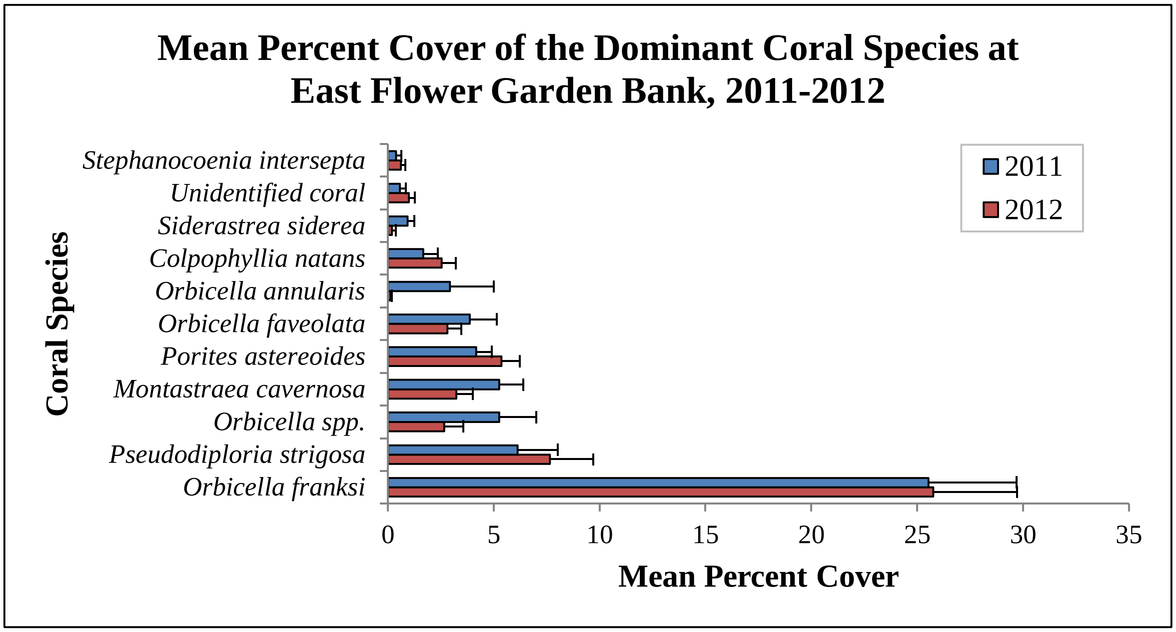


Figure 3.3.2. Mean percent cover + SE of observed dominant coral species from random transect photographs at EFGB in 2011 and 2012.

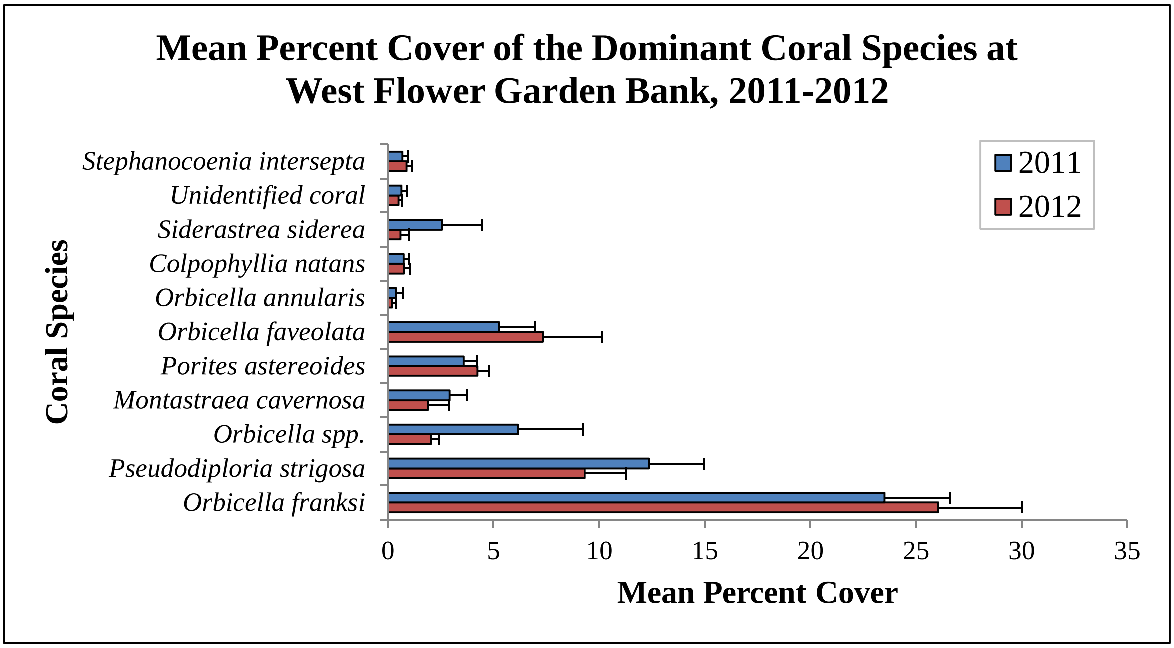


Figure 3.3.3. Mean percent cover + SE of observed dominant coral species from random transect photographs at WFGB in 2011 and 2012.

The *Montastraea annularis* species complex (MASC), containing *Montastraea annularis*, *Montastraea faveolata*, and *Montastraea franksi*, has now been taxonomically reclassified as the *Orbicella annularis* species complex (OASC), containing *Orbicella annularis*, *Orbicella faveolata*, and *Orbicella franksi* (Budd et al. 2012). *Diploria strigosa* has also been reclassified as *Pseudodiploria strigosa*. The *Orbicella annularis* species complex was grouped together throughout the monitoring program until 2008; after that time individual species within the complex were identified. In past monitoring years, the OASC has been difficult to differentiate using the photographic techniques employed in this study (primarily because the scale of the photograph does not allow visualization of the entire colony formation, which is sometimes essential for identification). However, with improved digital photography resolution and the FGBNMS staff's familiarity with the species in the study site, most components of the OASC were individually indentified. Still, the use of OASC remains relevant when comparing historical data before separation. Approximately 16% of the OASC components were unable to be differentiated during the monitoring period, which may be due to OASC hybridization or genotypic variation. These were referred to as unidentified OASC, or *Orbicella* spp. (Table 3.3.1).

In the 2011 and 2012 random transects, the incidences of bleaching, paling, and fish biting were low at each bank and coral disease was absent (Table 3.3.2). The mean percentage of corals impacted by isolated/concentrated fish biting was 0.00–0.07%. Less than 1% of the coral cover analyzed in the random transects was diseased or bleached in 2011 and 2012. It is important to note that bleaching as determined by the long-term monitoring methodology may be incomplete, as surveys usually occur when weather is optimal (e.g., before hurricane season) in earlier summer months before signs of bleaching occur.

Table 3.3.2.

Mean Percent Cover ± SE of Coral Condition Categories in Random Transects at EFGB and WFGB from 2011 and 2012.

Cover Category	2011 EFGB	2012 EFGB	2011 WFGB	2012 WFGB
Coral Condition (occurrences in coral)				
Bleached Coral	0.00	0.00	0.07 ± 0.05	0.02 ± 0.02
Paling Coral	0.37 ± 0.14	0.18 ± 0.14	0.31 ± 0.12	0.11 ± 0.06
Concentrated Fish Biting	0.06 ± 0.04	0.00	0.05 ± 0.03	0.00
Isolated Fish Biting	0.00	0.02 ± 0.02	0.07 ± 0.05	0.00
Disease	0.00	0.00	0.00	0.00

In summary, combined mean percent coral cover averaged approximately 56% at EFGB and WFGB in the period 2011 through 2012. These values were consistent with measurements of coral cover above 50% at the FGB in previous years (Dokken et al. 2003; Precht et al. 2006; Johnston et al. 2013) and they are high compared to other western Atlantic reefs (Aronson et al. 1994; Gardner et al. 2003). Macroalgae ranked second behind the corals, and sponge cover was below one percent each year. This pattern was consistent with previous monitoring from EFGB and WFGB (Aronson et al. 2005; Precht et al. 2006; Zimmer et al. 2010; Johnston et al. 2013) and previous work in the Caribbean (Aronson and Precht 2000).

3.3.1. Random Transect Univariate Analysis

The random transect point count data expressed as mean percent cover was analyzed by one-way ANOVA, with bank and year as fixed factors with an experimentwise error rate of α=0.05. The data on proportional cover of sponges were non-normal, so categories were square root transformed. The one-way ANOVA on the proportional cover of all observed corals, sponge, macroalgae, and CTB showed no significant difference between bank or year. A two-way ANOVA displaying the bank by year interaction was also not significant (Table 3.3.3).

Table 3.3.3.

Results of ANOVA on Mean Percent Cover Estimates from Random Transects in 2011 and 2012

Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**	**P-value**
(A) Corals					
Bank	2.46	1	2.46	2.97	0.09
Year	0.50	1	0.50	0.58	0.45
Bank*Year	2.96	2	1.48	1.77	0.18
Error	50.74	61	0.83		
Total	53.70	63			
(B) Sponges					
Bank	0.66	1	0.66	3.25	0.08
Year	0.01	1	0.01	0.05	0.82
Bank*Year	0.67	2	0.34	1.63	0.21
Error	12.66	61	0.21		
Total	13.34	63			
(C) Macroalgae					
Bank	2.18	1	2.18	2.66	0.11
Year	1.37	1	1.37	1.65	0.20
Bank*Year	3.55	2	1.77	2.19	0.12
Error	49.33	61	0.02		
Total	52.88	63			
(D) CTB					
Bank	0.16	1	0.16	0.31	0.58
Year	0.90	1	0.90	1.79	0.19
Bank*Year	1.06	2	0.53	1.04	0.36
Error	31.15	61	0.51		
Total	32.22	63			

3.3.2. Random Transect Multivariate Analysis

The point counts for the random transects were further analyzed by using multivariate techniques. Multivariate cover analysis was compared between bank and year using ANOSIM. There were no significant differences between years. ANOSIM results indicate a biologically significant, but small spatial variation, with dissimilarities between banks (Global R=0.05, p<4.6%). Though differences are detected, the very small R value indicates that the dissimilarities between groups are less than some of the within-group dissimilarities. In most cases, a small R value with significant P-value is uninformative.

Cluster analysis and MDS plot placed the benthic cover between bank and year in one cluster (80% similarity), with the exception of one outlier from WFGB. The stress level of the MDS was low at 0.1, indicating good goodness-of-fit in a two-dimensional scale, suggesting high confidence in the pattern displayed (Figure 3.3.4). These results agree with both the ANOVA and ANOSIM that no significant differences of bank or year occur between EFGB and WFGB, making the banks similar in terms of benthic composition.

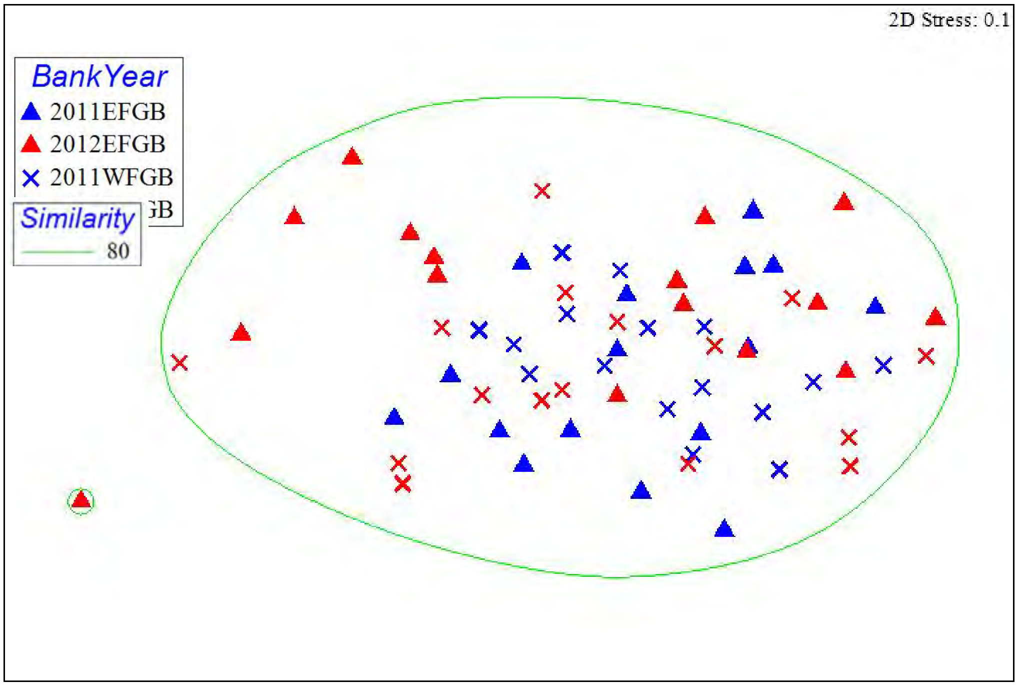


Figure 3.3.4. Two-dimensional MDS plot based on Bray-Curtis similarities showing the spatial representation of benthic community similarities between EFGB and WFGB in 2011 and 2012.

The green circle groups surveys that are 80% similar.

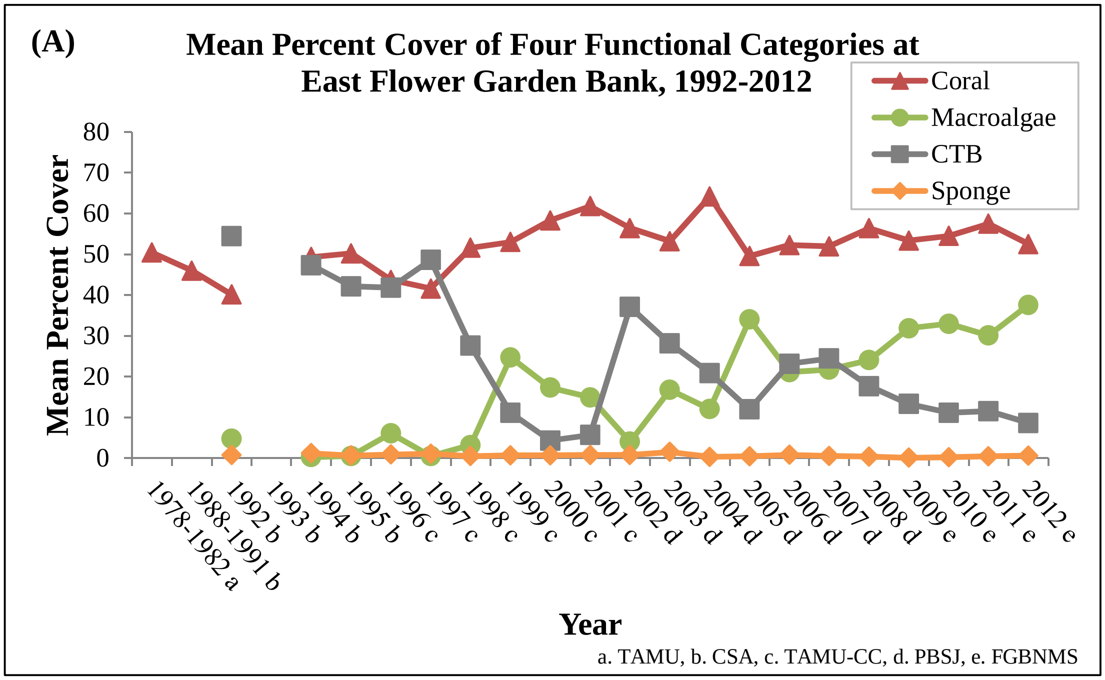
3.3.3. Historical Comparison of Random Transect Benthic Cover

A historical comparison of dominant benthic cover components is an important part of monitoring to measure changes over long time periods. Therefore, the mean percent benthic cover from the four functional random transect categories were analyzed. Mean percent coral cover was first collected in 1978; however, data for the remaining three categories (sponge, macroalgae, and CTB) did not begin until 1992. No data were collected in 1993 due to poor weather, and in 1996 and 1997 no data were recorded for the CTB category (known as reef rock from previous monitoring periods).

Mean percent coral cover showed an overall increase during the period from 1992–2012 at WFGB; the highest cover recorded was in 2010 and a mean of approximately 52% cover over time. Estimates varied at EFGB but remained consistently at or above 52% (Figure 3.3.5 and Table 3.3.4). Periods of lower coral cover generally coincided with increases in the algal component and decreases in the CTB category.

Multivariate historical mean percent cover analysis from EFGB and WFGB was compared among years (1994 to 2012) to calculate benthic cover change over a large time scale. SIMPER analysis indicated that for most comparisons between 1994 and 2012, the greatest contributors to the observed dissimilarity were CTB and macroalgae. Cluster analysis and MDS plot placed the mean percent cover from 1994–2012 in two clusters (80% similarity). The stress level of the MDS was low at 0.03, indicating good goodness-of-fit in a two-dimensional scale, suggesting high confidence in the pattern displayed (Figure 3.3.6). The data suggests communities were similar between 1994 and 1998; a significant shift in community composition occurred between 1999 and 2002, then similar again between 2003 and 2012.

The macroalgae increases generally coincided with lower CTB cover (Figure 3.3.5. and Table 3.3.4). In 1999, a sudden increase in macroalgae cover was observed, leading to a reciprocal relationship between macroalgae and CTB cover until 2008. After 2008, macroalgae dominated CTB cover, as macroalgae cover continued to increase. These trends correspond to SIMPER results, suggesting that the greatest contributors to the observed dissimilarity over time were CTB and macroalgae. This also corresponds to the MDS plot, suggesting that from 1994–1998 the community was stable, and starting in 1999 there was a shift due to changes in the CTB and macroalgae cover, causing the community to stabilize once again from 2009–2012, but with higher macroalgae percent cover than ever recorded on both banks (Figure 3.3.6).



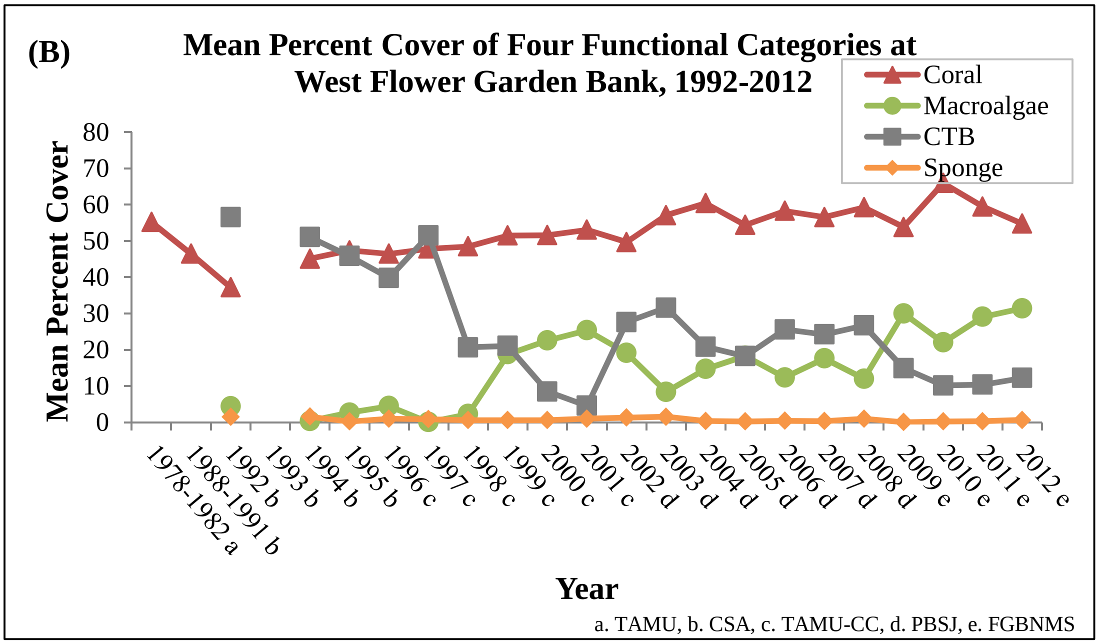


Figure 3.3.5. Historical representation of mean percent cover of coral, sponge, macroalgae, and CTB at (A) EFGB and (B) WFGB.

No mean 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 Continental Shelf Associates, Inc. (CSA) (1996); for 1996–2001 from Dokken et al. (2003); 2002–2008 from PBS&J (Precht et al. 2006, 2008b); and FGBNMS for 2009–2012 (Johnston et al. 2013).

Table 3.3.4.

EFGB and WFGB Random Transect Data for Dominant Cover Categories.

EFGB Random Transect Data				
Year	**Coral**	**Macroalgae**	**CTB**	**Sponge**
1978-1982	50.40	NA	NA	NA
1988-1991	46.00	NA	NA	NA
1992	40.15	4.78	54.46	0.74
1994	49.30	0.29	47.31	1.23
1995	50.20	0.57	42.15	0.67
1996	43.70 ± 12.0	6.10 ± 5.20	NA	0.90 ± 1.00
1997	41.6 ± 8.30	0.50 ± 0.60	NA	1.10 ± 1.70
1998	51.60 ± 8.30	3.20 ± 2.60	27.60 ± 5.90	0.50 ± 0.90
1999	53.0 ± 9.00	24.70 ± 13.20	11.10 ± 8.20	0.70 ± 0.90
2000	58.30 ± 6.70	17.30 ± 4.90	4.30 ± 1.70	0.70 ± 0.80
2001	61.80 ± 10.0	14.90 ± 5.60	5.70 ± 3.60	0.80 ± 1.00
2002	56.43 ± 2.36	4.06 ± 0.75	37.07 ± 2.69	0.79 ± 0.36
2003	53.2 ± 3.01	16.74 ± 2.05	28.12 ± 2.05	1.54 ± 0.40
2004	64.13 ± 2.70	12.03 ± 2.77	20.89 ± 3.08	0.31 ± 0.24
2005	49.55 ± 3.01	34.03 ± 2.58	11.96 ± 1.49	0.48 ± 0.26
2006	52.26 ± 3.50	21.10 ± 2.32	23.15 ± 1.94	0.83 ± 0.33
2007	51.93 ± 4.46	21.73 ± 2.28	24.43 ± 2.11	0.56 ± 0.22
2008	56.37 ± 3.62	24.06 ± 2.16	17.64 ± 1.77	0.40 ± 0.15
2009	53.35 ± 4.17	31.85 ± 3.49	13.32 ± 1.07	0.13 ± 0.05
2010	54.49 ± 3.69	32.94 ± 3.05	11.15 ± 0.86	0.25 ± 0.13
2011	57.49 ± 2.28	30.10 ± 1.59	11.53 ± 0.07	0.49 ± 0.17
2012	52.49 ± 4.50	37.59 ± 3.80	8.63 ± 0.17	0.62 ± 0.23

WFGB Random Transect Data				
Year	**Coral**	**Macroalgae**	**CTB**	**Sponge**
1978-1982	55.20	NA	NA	NA
1988-1991	46.50	NA	NA	NA
1992	37.20	4.45	56.56	1.53
1994	45.10	0.42	51.08	1.58
1995	47.40	2.70	45.85	0.27
1996	46.50 ± 12.30	4.50 ± 5.20	NA	1.00 ± 1.00
1997	47.90 ± 13.90	0.10 ± 0.60	NA	0.90 ± 1.30
1998	48.50 ± 12.70	2.30 ± 2.60	20.70 ± 5.90	0.60 ± 0.60
1999	51.50 ± 8.10	18.80 ± 13.20	21.10 ± 8.20	0.60 ± 0.70
2000	51.60 ± 13.70	22.60 ± 14.00	8.50 ± 3.70	0.60 ± 0.80
2001	53.10 ± 11.40	25.40 ± 7.30	4.60 ± 2.90	1.00 ± 1.10
2002	49.70 ± 3.35	19.14 ± 1.40	27.63 ± 3.14	1.31 ± 0.32
2003	57.10 ± 3.81	8.41 ± 1.41	31.63 ± 3.04	1.56 ± 0.38
2004	60.41 ± 2.94	14.75 ± 1.50	20.85 ± 2.11	0.40 ± 0.15
2005	54.41 ± 3.13	18.35 ± 1.44	18.27 ± 1.67	0.25 ± 0.11
2006	58.28 ± 2.88	12.38 ± 1.34	25.64 ± 2.06	0.46 ± 0.12
2007	56.58 ± 3.28	17.64 ± 2.44	24.27 ± 1.89	0.35 ± 0.10
2008	59.27 ± 3.40	12.06 ± 1.31	26.74 ± 2.41	1.00 ± 0.47
2009	53.84 ± 3.73	30.03 ± 2.63	14.93 ± 1.52	0.10 ± 0.05
2010	65.95 ± 2.85	22.03 ± 2.00	10.20 ± 1.03	0.25 ± 0.10
2011	59.51 ± 2.09	29.11 ± 1.90	10.40 ± 0.25	0.31 ± 0.11
2012	54.78 ± 3.41	31.43 ± 2.48	12.27 ± 0.26	0.68 ± 0.24

Values listed in table are the mean percent covers. Standard deviations are shown for 1996 to 2001 based on analysis by Dokken et al. (2003) and standard errors (± SE) are reported from 2002–2012. 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 Continental Shelf Associates, Inc. (CSA) (1996); for 1996–2001 from Dokken et al. (2003); 2002–2008 from PBS&J (Precht et al. 2006, 2008b); and FGBNMS for 2009–2012 (Johnston et al. 2013).

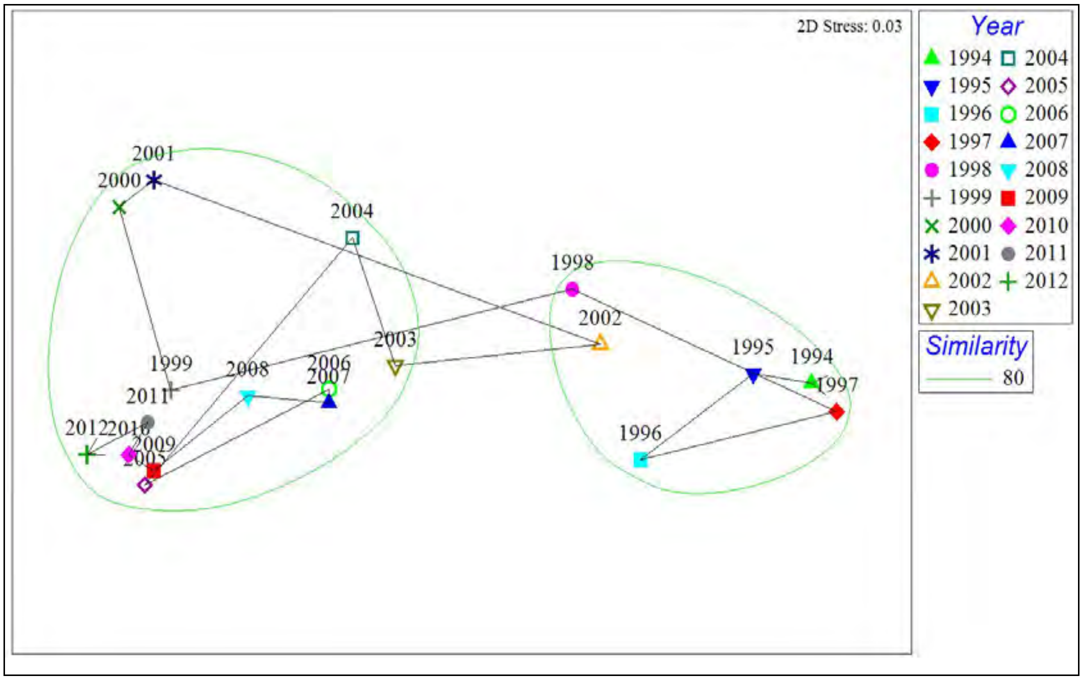


Figure 3.3.6. Two-dimensional MDS plot based on Bray-Curtis similarities comparing benthic cover analysis from 1994–2012 at EFGB and WFGB.

The green circles group years that are 80% similar.

3.4. RANDOM TRANSECT DISCUSSION

In a global trend of declining coral reef health and cover, the FGB continues to support high coral cover compared to other reefs of the western Atlantic and Caribbean region (Aronson et al. 1994, 2005; Gardner et al. 2003; AGRRA 2003; Pina Amargós et al. 2008; ONMS 2011; Steneck et al. 2011; Johnston et al. 2013) (Table 3.4.1). Gardner et al. (2003) reported the regional decline of corals across the Caribbean basin over the last three decades, with the average hard coral cover on reefs decreasing from approximately 50% to 10%. Natural and anthropogenic factors, including storm events, temperature stress, disease, predation, overfishing, sedimentation, eutrophication, and habitat destruction have all played a part in the decline (Aronson and Precht 2001; Rogers and Beets 2001; Gardner et al. 2003).

Caribbean reefs that have historically displayed high coral cover are showing declines, mainly due to algae competition, and bleaching or coral disease, or both. Bonaire reported a decrease in coral cover from 38% to 10% in 2011 (Steneck et al. 2011). Mean coral cover in Florida Keys National Marine Sanctuary decreased from 13% to approximately 7% with ranges from approximately 3% to 20% (ONMS 2011). The Cuban reefs within Jardin de la Reina range from 7% to 9% cover (Pina Amargós et al. 2008). In contrast, coral cover at the FGB has remained relatively stable throughout the monitoring program, and is between 6 to 11 times higher than cover values estimated for other locations in the Caribbean region (Caldow et al. 2009) (Figure 3.5.1). Analysis of the random transect data revealed that the mean percent coral cover at EFGB and WFGB was 56.07% from 2011–2012. Coral cover was also similar to values from earlier studies, (Dokken et al. 1999, 2001; CSA 1996; Gittings et al. 1992), highlighting the stability of the coral assemblage at the FGB (Figure 3.4.1).

Table 3.4.1.

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

Location	Percent Coral Cover	Source
Flower Garden Banks	56	this report
Netherlands Antilles	10–47	AGRRA 2003
St. Vincent Grenadines	29–44	AGRRA 2003
Bonaire	38	Steneck et al. 2011
Puerto Rico	7-36	Waddell and Clark 2008
Navassa Island	10-25	Waddell and Clark 2008
Cayman Islands	21	AGRRA 2003
Florida Keys NMS	3–20	ONMS 2011
Jardin de la Reina, Cuba	7–19	Pina Amargós et al. 2008
Pedro Bank, Jamaica	5-19	Bruckner 2013
Akumal, Mexico	17	AGRRA 2003
Cay Sal Bank, Bahamas	7-9	Bruckner 2011
St. Kitts and Nevis	6-13	Bruckner and Willams 2012
U.S. Virgin Islands	5-7	Caldow et al. 2009

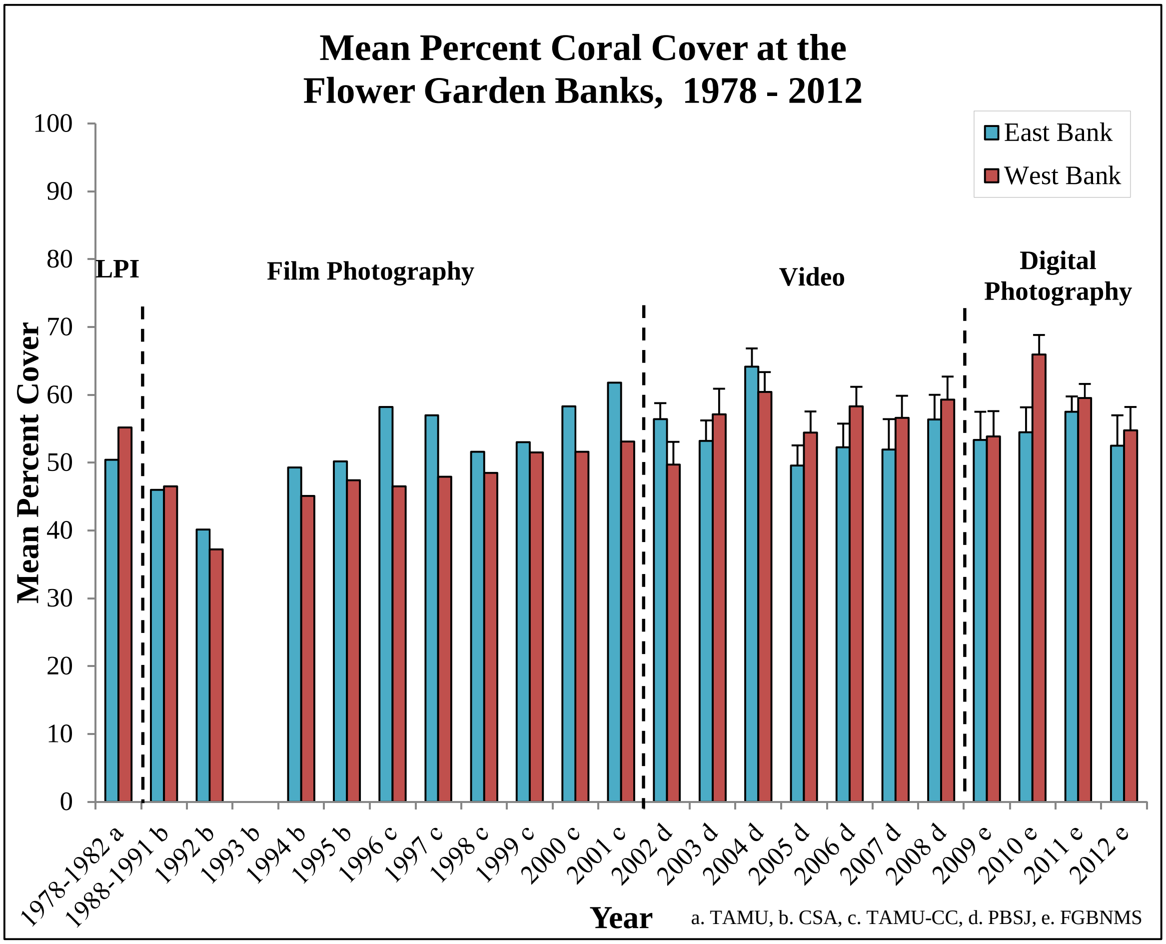


Figure 3.4.1. Random transect mean percent coral cover + SE at EFGB and WFGB over time.

Values calculated from random transect photographs. SE not available from 1978-2001. No mean 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 Continental Shelf Associates, Inc. (CSA) (1996); for 1996–2001 from Dokken et al. (2003); 2002–2008 from PBS&J (Precht et al. 2006, 2008b); and FGBNMS for 2009–2010 (Johnston et al. 2013).

Some reasons for the exceptional condition of the FGB include 1) water depth of the reefs, which buffers the reef cap from the effects of storm waves and variable seasurface temperatures; 2) the remote offshore location, which limits human access and exposes these reefs consistently to oligotrophic, oceanic waters; 3) healthy grazer populations; and 4) protective federal regulations, which prevent direct hydrocarbon-related impacts, as well as effects from anchoring and certain fishing methods (Aronson et al. 2005). The importance of the FGB, in terms of the Atlantic coral reef system as a whole, has been substantially elevated because of the regional decline of corals. On August 27, 2014, NOAA Fisheries listed 22 corals as threatened under the Endangered Species Act (ESA). The listing classifies the *Orbicella annularis* species complex and *Acropora palmata* as threatened.

3.4.1. Historical Comparison of Random Transect Benthic Cover

Changes in the frequency and severity of the El Niño–Southern Oscillation (ENSO) have been partially responsible for transitions from coral-dominated communities to algae-dominated reef systems in the Caribbean (Glynn 1984, 1993; Goreau and Hayes 1994; Wilkinson and Souter 2008), and these local and regional weather patterns may also affect benthic communities like those at the FGB. 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).

Macroalgae cover has increased since the beginning of the monitoring program (Figure 3.3.5). Algae cover at the FGB, represented primarily within the macroalgae category, remained relatively low until 1999, and never reached greater than 6.1% at either bank. It increased dramatically in 1999 and, while fluctuating, has remained comparatively high ever since when compared to previous years. Historically, macroalgae mean cover has been approximately 17% at EFGB and 15% at WFGB (Table 3.3.4). Concurrent with high algae cover, the CTB category was lower at EFGB in 1999, 2004, and 2012 and at WFGB in 2000, 2004, and 2010. Overall, the most noticeable pattern was the inverse relationship between macroalgae and CTB cover. Macroalgae tend to be ephemeral, with different species becoming abundant under certain seasonal conditions (Diaz-Pulido and Garzon-Ferreira 2002). The results suggest that algal overgrowth can significantly affect estimates of underlying benthic cover (since coral does not grow/die at the same rate as algae), but due to the ephemeral nature of algae blooms, does not necessarily lead to longer, reductions in those populations. Macroalgae cover is a highly dynamic component of the ecosystem, varying in relation to seasonal eutrophication caused by up upwelling and nutrient availability, and in relation to grazer community composition in reef habitats. In some areas within the region, increased algae cover has driven coral decline; however, this has not yet happened at the FGB (ONMS 2011).

Despite increasing algal cover, coral cover remains greater than 50% at the FGB. Dominant coral cover at the FGB from 1992 to 2012 included the *Orbicella* spp., *Pseudodiploria strigosa*, *Montastraea cavernosa*, *Porites astereoides*, and *Colpophyllia natans*. These major reef building corals have remained stable since the beginning of the monitoring program. The *Orbicella annularis* species complex, dominanted by *Orbicella franksi*, showed an overall increase in benthic cover during the period from 1992–2012 at the FGB (Table 3.4.2 and Figure 3.4.2). It should be noted that before 2002, species of *Orbicella* were not individually analyzed, so for historical comparison they are grouped together. The highest OASC cover at EFGB was recorded in 2001, an average of approximately 45% cover. The highest OASC cover at WFGB was recorded in 2010, an average of approximately 46% cover. From 2011–2012 at the FGB, *Pseudodiploria strigosa* coral cover averaged 8%, *Porites astereoides* averaged 4%, *Montastraea cavernosa* averaged 3%, *Colpophyllia natans* averaged 2%. This suggests that coral health at the FGB has remained stable throughout the monitoring program, a trend of increasing growth from 1978–2012.

Table 3.4.2.

EFGB and WFGB Random Transect Data for Dominant Coral Cover

EFGB Random Transect Data					
Year	OASC	*Pseudodiploria strigosa*	*Montastraea cavernosa*	*Porites astereoides*	*Colpophyllia natans*
1978-1982	NA	NA	NA	NA	NA
1988-1991	NA	NA	NA	NA	NA
1992	24.12	4.69	1.49	4.57	2.14
1993	NA	NA	NA	NA	NA
1994	26.93	8.92	4.80	3.89	1.59
1995	35.65	7.92	3.20	2.71	3.78
1996	21.30	10.10	3.70	3.60	0.80
1997	21.60	5.10	4.70	5.30	0.80
1998	30.40	8.30	3.50	4.20	2.10
1999	28.20	12.40	2.40	3.40	3.60
2000	39.50	6.20	4.80	2.60	2.60
2001	44.80	3.90	3.60	4.60	2.60
2002	33.59 ± 3.86	6.96 ± 1.69	3.90 ± 1.08	6.79 ± 0.83	0.57 ± 0.39
2003	28.47 ± 2.98	6.19 ± 1.55	4.24 ± 1.41	5.69 ± 0.98	3.29 ± 1.40
2004	30.14 ± 4.76	12.13 ± 2.82	7.73 ± 1.94	8.19 ± 0.99	2.81 ± 1.28
2005	26.80 ± 4.09	5.95 ± 1.26	3.40 ± 1.14	7.55 ± 1.19	1.77 ± 1.08
2006	31.45 ± 4.09	10.25 ± 1.52	2.48 ± 0.67	4.91 ± 0.83	1.73 ± 1.06
2007	32.44 ± 4.62	5.82 ± 1.11	3.74 ± 0.94	5.81 ± 0.88	1.56 ± 0.85
2008	33.58 ± 4.52	7.69 ± 2.00	2.84 ± 0.92	7.27 ± 1.19	1.65 ± 0.58
2009	29.52 ± 12.99	10.08 ± 2.54	3.58 ± 1.22	4.93 ± 1.29	3.21 ± 1.00
2010	33.89 ± 3.84	9.38 ± 1.72	3.71 ± 1.46	5.11 ± 0.69	2.45 ± 0.63
2011	37.58 ± 9.25	6.13 ± 1.91	5.25 ± 1.14	4.17 ± 0.74	1.66 ± 0.69
2012	31.36 ± 5.58	7.65 ± 2.05	3.24 ± 0.77	5.35 ± 0.88	2.54 ± 0.67

WFGB Random Transect Data					
Year	OASC	*Pseudodiploria strigosa*	*Montastraea cavernosa*	*Porites astereoides*	*Colpophyllia natans*
1978-1982	NA	NA	NA	NA	NA
1988-1991	NA	NA	NA	NA	NA
1992	23.02	6.15	0.87	1.49	3.11
1993	NA	NA	NA	NA	NA
1994	24.95	10.15	3.15	2.55	2.82
1995	31.00	6.66	2.33	2.44	0.97
1996	27.20	7.90	1.50	2.50	1.30
1997	27.70	9.10	4.30	2.70	1.30
1998	28.40	9.60	2.60	2.40	1.70
1999	31.70	10.90	2.40	2.70	0.70
2000	30.90	8.10	5.80	2.50	3.60
2001	35.10	9.50	2.10	2.00	2.80
2002	31.73 ± 3.57	3.20 ± 0.91	2.74 ± 1.16	3.44 ± 0.74	1.67 ± 1.21
2003	33.80 ± 4.31	9.04 ± 2.68	2.67 ± 1.10	3.77 ± 0.46	2.17 ± 0.84
2004	31.70 ± 2.70	13.41 ± 1.74	3.70 ± 1.02	5.19 ± 0.62	3.48 ± 1.56
2005	36.20 ± 3.50	6.68 ± 1.29	2.43 ± 0.69	4.04 ± 0.46	1.40 ± 0.54
2006	40.13 ± 3.29	10.14 ± 1.64	2.25 ± 0.84	3.39 ± 0.57	0.55 ± 0.28
2007	35.50 ± 3.81	9.56 ± 1.85	1.84 ± 0.53	3.61 ± 0.44	3.35 ± 1.24
2008	37.01 ± 4.65	8.98 ± 2.43	2.81 ± 1.05	3.62 ± 0.64	1.14 ± 0.45
2009	27.25 ± 3.32	10.84 ± 2.70	4.03 ± 0.97	3.85 ± 0.64	4.26 ± 1.38
2010	45.98 ± 3.68	5.39 ± 0.94	5.09 ± 1.12	3.20 ± 0.62	1.45 ± 0.42
2011	35.34 ± 8.18	12.36 ± 2.62	2.92 ± 0.81	3.60 ± 0.64	0.75 ± 0.25
2012	35.62 ± 7.35	9.32 ± 1.94	1.89 ± 1.01	4.24 ± 0.55	0.77 ± 0.28

Values listed in the table are mean percent coral cover. Standard errors (± SE) are reported from 2002–2012. 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 Continental Shelf Associates, Inc. (CSA) (1996); for 1996–2001 from Dokken et al. (2003); 2002–2008 from PBS&J (Precht et al. 2006, 2008b); and FGBNMS for 2009–2012 (Johnston et al. 2013).

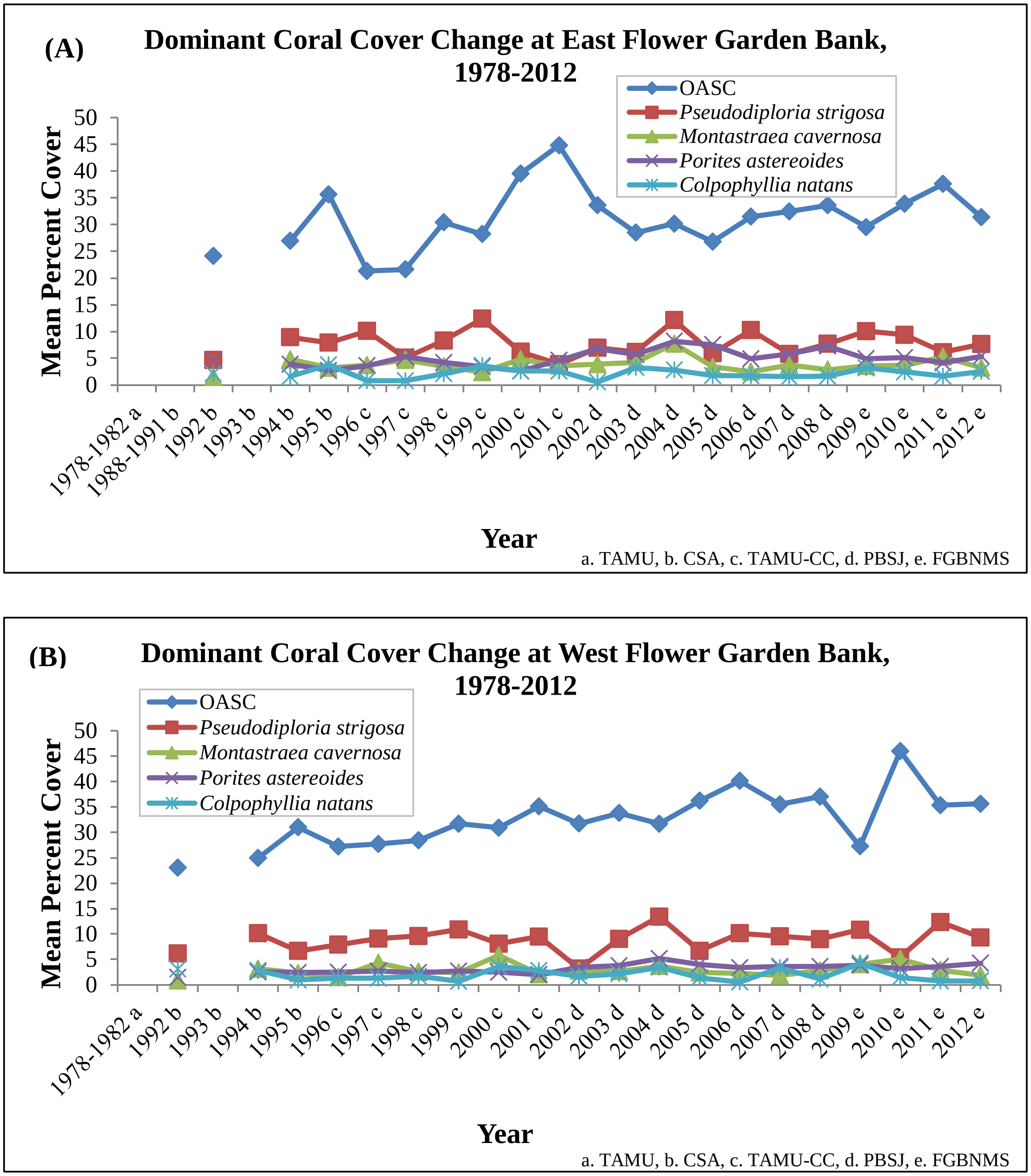


Figure 3.4.2. Historical representation of mean percent dominant coral cover at (A) EFGB and (B) WFGB.

No mean 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 Continental Shelf Associates, Inc. (CSA) (1996); for 1996–2001 from Dokken et al. (2003); 2002–2008 from PBS&J (Precht et al. 2006, 2008b); and FGBNMS for 2009–2010 (Johnston et al. 2013).

CHAPTER 4.0: REPETITIVE QUADRATS

4.1. REPETITIVE QUADRAT METHODOLOGICAL RATIONALE

Permanent photostation quadrats were used to monitor changes in the composition of benthic assemblages in repetitive sites and individual colonies at the FGB. The repetitive quadrats were located within the EFGB and WFGB study sites, except for the deep stations at EFGB and WFGB. The photographs were analyzed in two ways. The first method measured percent benthic cover components in 2011 and 2012 using random-dot analysis. For the second method, selected corals within the repetitive quadrats were analyzed using planimetry to measure gain or loss of planar tissue area in individual colonies.

4.2. REPETITIVE QUADRAT METHODS

4.2.1. Repetitive Quadrat Field Methods

Repetitive quadrats are located and marked by SCUBA divers using underwater maps (Volume II, Appendix 2), and then divers photograph each station. In 2011, thirty-five and forty 5 m^2 repetitive quadrats were photographed at EFGB and WFGB, respectively. In 2012, thirty-seven and forty-one 5 m^2 quadrats were photographed at EFGB and WFGB respectively (Figure 4.2.1). All nine EFGB deep photostations were photographed in 2011, and a total of twelve were photographed in 2012 after two were added during site refurbishment. Twelve WFGB deep photostations were installed and photographed in 2012.

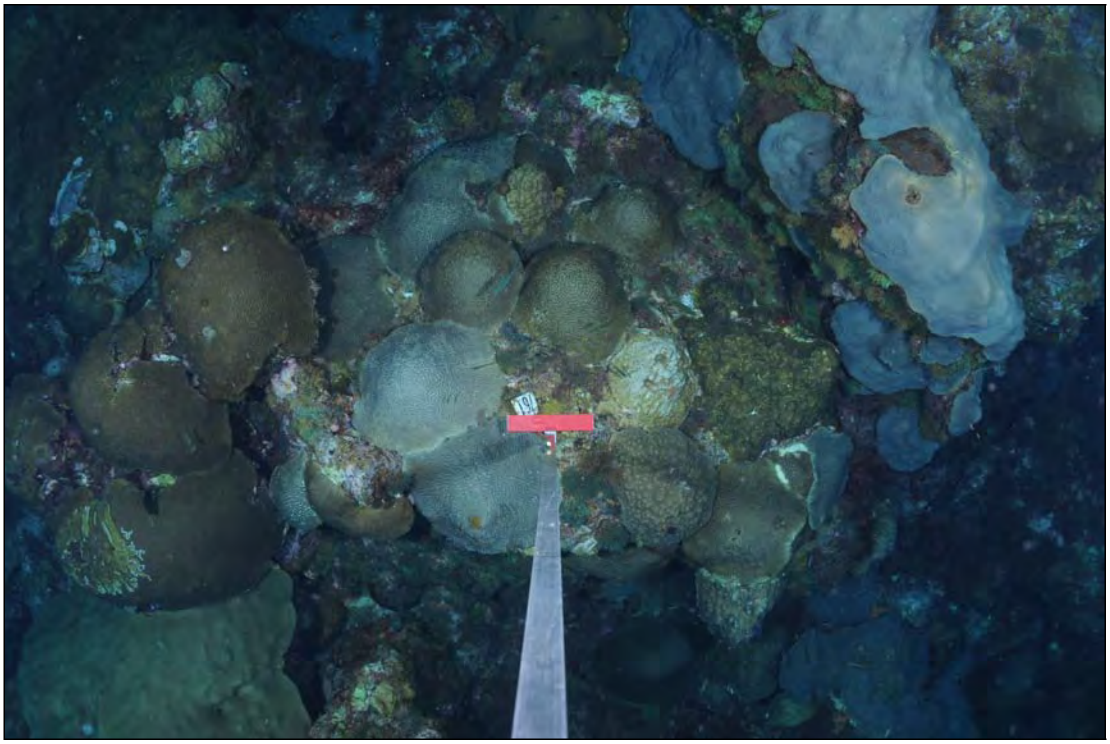


Figure 4.2.1. Repetitive quadrat station #761 at EFGB in 2012 (NOAA/FGBNMS).

In 2011 and 2012, stations were photographed using a Nikon® D300® SLR camera with 16 mm lens in Sea&Sea® housing with small dome port. The camera was mounted in the center of a T-shaped camera frame, at a distance of 2 m from the substrate. Two strobes (Inon Z240®) were mounted 1.2 m apart on the ends of the T-frame and set on TTL. This set-up produced images with a coverage of 5 m². A compass and bubble level mounted to the center of the t-frame ensured images were taken in a vertical and northward orientation to standardize the area captured, ensuring that the same quadrats were photographed in the same manner each year.

4.2.2. Repetitive Quadrat Data Processing

4.2.2.1. Percent Cover Analysis of Benthic Components

Mean percent cover in the repetitive quadrat images was analyzed using Coral Point Count with Microsoft® Excel® extensions (CPCe). The percent cover was determined by overlaying 100 random dots on each photograph, then benthic species lying under these points were identified. Microsoft® Excel® spreadsheets were created automatically in the program using customized code files pertinent to the cover of coral and other benthic species in the region.

Organisms positioned beneath each random dot were identified as corals, sponges, macroalgae, or CTB, as described in section 3.2. Additional categories included other live components (ascidians, fish, serpulids, etc.), sand, rubble, and unknown (Volume II Appendix 4). After each image was analyzed, the data were entered into project-specific Microsoft® Excel® spreadsheets. QA/QC for the photographic methods consisted of multiple, scientific divers all trained on the same camera systems for correct camera operation. Divers were able to practice camera setup and operation with mock corals in a swimming pool before field work began. Statistical comparisons of identifications by multiple investigators were conducted to confirm the same identifications in the photographs to ensure that they agreed on species identifications within the frames. Each investigator was given sample photographs from EFGB and WFGB and identified all benthic components in each photograph. We found that identification of benthic components agreed 95% of the time with no significant difference (α=0.05) between the benthic components identified in the identical photographs by different investigators.

4.2.2.2. Planimetry Analysis

Planimetry was used to measure percent change in area of living tissue of selected coral colonies (i.e., *Orbicella* spp., *Pseudodiploria strigosa*, *Colpophyllia natans*, *Montastraea cavernosa*, *Porites astreoides*, *Siderastrea siderea*, and *Stephanocoenia intersepta)* at repetitive quadrat stations in successive years. For the 2011–2012 interval, it was possible to compare 32 quadrat photographs at EFGB and 39 quadrat photographs at WFGB. For EFGB deep stations, all nine quadrats were compared for the interval.

Planimetry results were calculated by taking areal measurements of some coral colonies whose lateral margins were contained entirely within the image frame from 2011 and 2012. Colonies close to the center of the image, with a complete lateral margin, were selected. The live tissue cover of each colony was traced in Adobe® Illustrator® CS2 using a Wacom® Cintiq® 12WX Tablet. A mask was then created of the live tissue and areal measurements were calculated using ImageJ®. The percent change in area for each colony was calculated by comparing the area of 2011 to the area of 2012. The change (positive=growth, or negative=retreat) in pixels was divided by the area (pixels) from 2011 to determine proportional growth or loss of tissue area.

4.2.3. Repetitive Quadrat Statistical Analyses

Mean percent cover was calculated for each photo from the 100 analyzed points for each of the taxa and four benthic categories. Factor plots were produced in CPCe to compare the mean percent cover of major benthic categories and coral species between banks and through time. CPCe spreadsheet contents included header information, statistical parameters of each species/substrate type (mean, standard deviation, standard error) and the calculation of the Shannon–Weaver diversity index for each species (Kohler and Gill 2006). Results are presented as mean percent cover ± standard error.

ANOVA was performed to test the null hypotheses that the response variables of univariate benthic cover did not differ by year (2011 and 2012) and bank (EFGB and WFGB). ANOVAs were calculated for each variable with the statistical software JMP® version 10.0. Data were tested for normality and square root transformed as necessary to assume a normal distribution to meet the assumptions of parametric statistical tests (Zimmer et al. 2010). However, the ANOVA procedure is robust enough to perform calculations on data that deviate from normal assumptions (Zar 1984).

A two-tailed t-test was performed to test the null hypotheses that the response variables of univariate margin cover did not differ between banks for the planimtery analysis. T-tests were calculated to identify differences in marginal percent change of dominant corals with the statistical software JMP® version 10.0. Data were tested for normality to meet the assumptions of parametric statistical tests.

Multivariate statistical techniques were used to compare how the two banks may differ in benthic composition. Based on benthic mean percent cover, comparisons in community differences between the two banks were made using nonparametric analysis for non-normal data. Significant dissimilarities were tested using ANOSIM with square root transformation and Bray-Curtis similarity resemblance measure. Cluster analyses were performed on similarity matrices, and MDS was used to visualize community dissimilarities by bank. Ordinations were run using 100 random starting configurations to determine the best fit model and minimize stress. SIMPER was used to analyze community dissimilarity between year and bank and highlight species that contributed to the observed dissimilarity. The R statistic, typically ranging between 0 and 1, indicates between and within group dissimilarities, where R values less than 0.3 indicate that similarities between sites and within sites are the same (Clarke & Warwick 2001). All analyses were all carried out using Primer® version 6.0.

For long-term trends, each functional group sample was averaged by year and compared using nonparametric analysis for non-normal data. Mean percent cover data of each functional group were used to calculate ecological distance via Bray-Curtis similarity matrices. Data were square root transformed to minimize the impacts of extremely dominant members of the community. Cluster analyses were performed on similarity matrices, and MDS plots were used to visualize community dissimilarities between years, with time series trajectory to highlight community shifts over time. SIMPER identified the greatest contributors to the observed dissimilarity.

4.3. REPETITIVE QUADRAT RESULTS

4.3.1. Repetitive Quadrat Analysis

4.3.1.1. Repetitive Quadrat Percent Cover

The point count data from the repetitive quadrats in the 10,000 m^2 study sites were expressed as mean percent cover ± standard error (SE), the same way the random transect data were displayed in section 3.4. In general, repetitive quadrat results from 2011 and 2012 revealed higher mean percent coral cover (63%) than random transects (56%), followed by macroalgae cover (24%), CTB cover (11%), and very low coverage of sponges (including encrusting sponges) (0.3%) (Figure 4.3.1). Macroalgae cover increased at both banks over both years. The higher mean coral cover at repetitive stations, when compared to random transect coral cover (56%) was to be expected, because the stations were originally selected as premium monitoring sites with high coral cover to track individual sites and colonies over time. They were not selected to be representative of average benthic percent cover. Volume II Appendix 8 of this report contains the repetitive quadrat data for 2011 and 2012 at the FGB.

At EFGB, mean coral cover remained above 60 percent from 2011–2012 (63.29% ± 2.97 to 63.29% ± 2.83), while the sponge cover remained extremely low for both years (0.46% ± 0.18 to 0.47% ± 0.22) (Figure 4.3.1 and Table 4.3.1). Macroalgae cover (mainly *Dictyota* spp. and fleshy algae) increased from 2011–2012 (24.85% ± 2.40 to 26.27% ± 2.53), and CTB cover remained stable (10.83% ± 0.91 to 9.02% ± 0.82) as well.

In quadrats at WFGB, mean coral cover remained above 60% from 2011 (63.54% ± 2.30) to 2012 (63.50% ± 2.09). The sponge cover remained extremely low for both years at WFGB (0.11% ± 0.09 to 0.22% ± 0.15) (Figure 4.3.1 and Table 4.3.1). Macroalgae cover increased from 2011–2012 (20.90% ± 1.76 to 22.54% ± 1.80) and CTB cover remained stable (13.79% ± 1.12 to 11.98% ± 1.08) between both years.

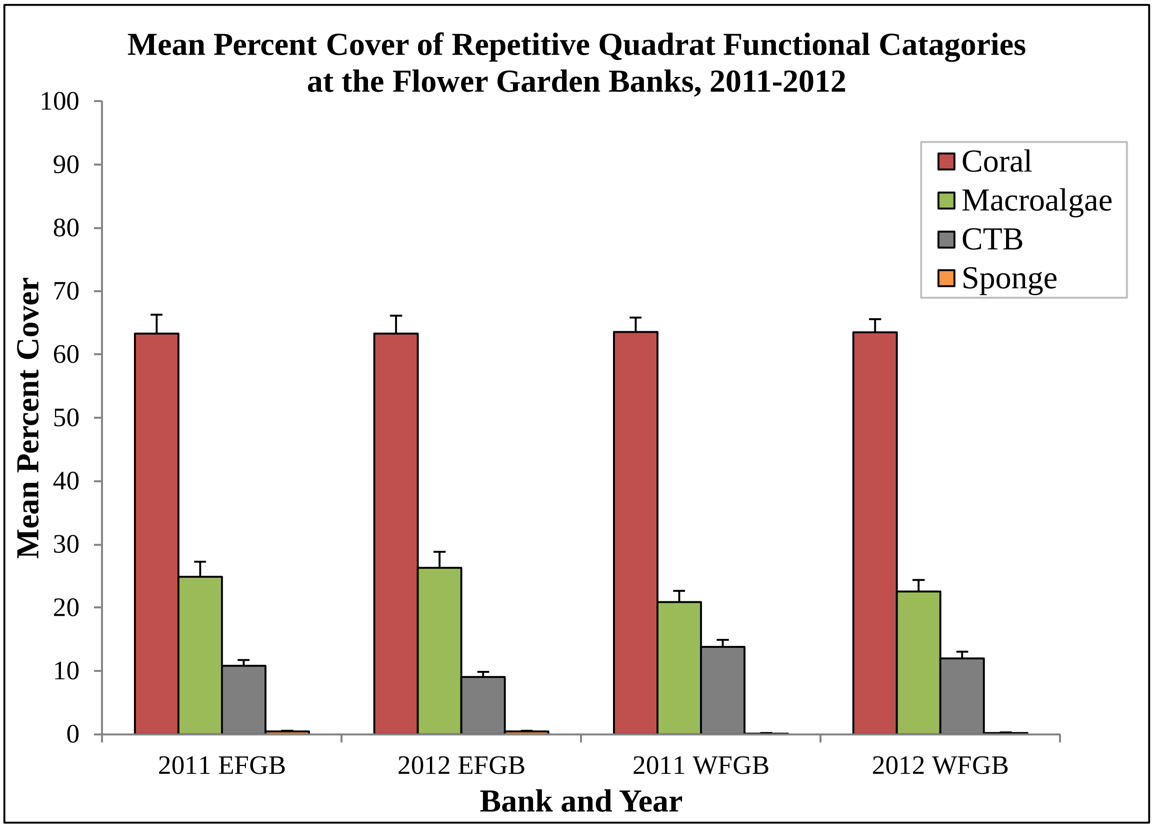


Figure 4.3.1. Mean percent cover + SE of four functional benthic categories at the FGB in 2011 and 2012.

Values calculated from repetitive quadrat photographs.

Table 4.3.1.

Mean Percent Cover ± SE of Benthic Categories in Repetitive Quadrats at EFGB and WFGB in 2011 and 2012 (listed from most to least abundant).

Cover Category	**2011 EFGB**	**2012 EFGB**	**2011 WFGB**	**2012 WFGB**
Coral				
Orbicella franksi	30.72 ± 3.11	30.94 ± 3.11	28.81 ± 2.62	29.35 ± 2.49
Pseudodiploria strigosa	11.39 ± 1.82	9.95 ± 1.60	9.87 ± 1.66	8.42 ± 1.42
Unidentified OASC (*Orbicella* spp.)	5.95 ± 1.40	4.92 ± 1.55	7.92 ± 2.31	7.25 ± 1.90
Orbicella faveolata	4.48 ± 1.42	5.73 ± 1.51	3.41 ± 1.39	1.72 ± 0.92
Porites astereoides	3.72 ± 0.48	4.35 ± 0.54	4.36 ± 0.59	3.71 ± 0.44
Montastraea cavernosa	3.52 ± 1.05	3.75 ± 1.05	3.40 ± 1.02	3.37 ± 0.93
Colpophyllia natans	0.91 ± 0.29	1.78 ± 0.48	1.20 ± 0.46	3.33 ± 0.71
Unidentified Coral	1.53 ± 0.48	0.85 ± 0.25	0.91 ± 0.22	1.68 ± 0.38
Agaricia agaricites	0.10 ± 0.07	0.09 ± 0.07	0.08 ± 0.05	0.05 ± 0.04
Orbicella annularis	0.31 ± 0.18	0.18 ± 0.18	1.77 ± 0.87	2.63 ± 1.14
Millepora alcicornis	0.23 ± 0.09	0.21 ± 0.08	0.17 ± 0.08	0.18 ± 0.09
Stephanocoenia intersepta	0.19 ± 0.08	0.13 ± 0.08	0.66 ± 0.24	0.46 ± 0.16
Madracis decactis	0.07 ± 0.07	0.07 ± 0.05	0.16 ± 0.09	0.17 ± 0.10
Mussa angulosa	0.06 ± 0.04	0.03 ± 0.03	0.08 ± 0.05	0.11 ± 0.07
Porites furcata	0.06 ± 0.04	0.00	0.03 ± 0.03	0.00
Leptoseris cucullata	0.03 ± 0.03	0.00	0.00	0.00
Siderastrea siderea	0.03 ± 0.03	0.32 ± 0.29	0.56 ± 0.44	1.00 ± 0.85
Madracis auretenra	0.00	0.00	0.06 ± 0.04	0.03 ± 0.03
Agaricia spp.	0.00	0.00	0.00	0.00
Scolymia cubensis	0.00	0.00	0.00	0.03 ± 0.03
Total Mean Coral	63.29 ± 2.97	63.29 ± 2.83	63.54 ± 2.30	63.50 ± 2.09
Sponge				
Unknown Sponge	0.22 ± 0.16	0.12 ± 0.09	0.03 ± 0.03	0.03 ± 0.03
Aiolochroia (Pseudoceratina) crassa	0.13 ± 0.07	0.03 ± 0.03	0.00	0.00
Ircinia felix	0.06 ± 0.06	0.06 ± 0.04	0.06 ± 0.04	0.00
Xestospongia muta	0.03 ± 0.03	0.00	0.00	0.03 ± 0.03
Encrusting sponge	0.03 ± 0.03	0.25 ± 0.18	0.03 ± 0.03	0.08 ± 0.06
Agelas clathrodes	0.00	0.00	0.00	0.08 ± 0.06
Total Mean Sponge	0.46 ± 0.18	0.47 ± 0.22	0.11 ± 0.09	0.22 ± 0.15
CTB				
Bare Substrate	4.99 ± 0.51	3.12 ± 0.38	7.30 ± 0.62	4.89 ± 0.49
Fine Turf	3.96 ± 0.63	4.93 ± 0.63	3.04 ± 0.49	5.39 ± 0.76
Crustose Coralline Algae	1.75 ± 0.38	0.90 ± 0.24	2.93 ± 0.58	1.11 ± 0.23
Total Mean CTB	10.83 ± 0.91	9.02 ± 0.82	13.79 ± 1.12	11.98 ± 1.08
Macroalgae				
Dictyota spp.	10.56 ± 1.45	12.25 ± 1.60	1.39 ± 0.40	1.96 ± 0.39
Fleshy Algae	9.05 ± 1.00	8.87 ± 1.00	9.10 ± 0.93	9.76 ± 1.15

Cover Category	**2011 EFGB**	**2012 EFGB**	**2011 WFGB**	**2012 WFGB**
Lobophora variegata	3.66 ± 0.66	2.21 ± 0.41	8.24 ± 1.06	6.84 ± 0.90
Thick Turf Algae	1.58 ± 0.29	2.68 ± 0.53	2.06 ± 0.28	3.97 ± 0.49
Filamentous Algae	0.00	0.26 ± 0.15	0.11 ± 0.07	0.00
Total Mean Macroalgae	24.85 ± 2.40	26.27 ± 2.53	20.90 ± 1.76	22.54 ± 1.80

Orbicella franksi was the dominant coral cover component at the EFGB repetitive stations in 2011 (30.72% ± 3.11) and 2012 (30.94% ± 3.11). *Pseudodiploria strigosa* (11.39% ± 1.82 and 9.95% ± 1.60 in 2011 and 2012, respectively) and *Orbicella* spp. that could not be differentiated were the next most abundant taxa (5.95% ± 1.40 in 2011 and 4.92% ± 1.55 in 2012), followed by *Orbicella faveolata*, *Porites astereodes*, and *Montastrea cavernosa* (Figure 4.3.2 and Table 4.3.1). The remaining coral cover was made up of thirteen species, none of which exceeded 2.0% in either year (Table 4.3.1). Corals that could not be differentiated (less then 2%) because of camera angle or camera distortion were labeled as “unidentified coral.” Shannon-Wiener diversity values remained consistent at EFGB (H’= 0.84 and H’= 0.83 in 2011 and 2012, respectively).

As with EFGB, *Orbicella franksi* was the dominant coral cover component at WFGB repetitive stations in 2011 (28.81% ± 2.62) and 2012 (29.35% ± 2.49). *Pseudodiploria strigosa* (9.87% ± 1.66 and 8.42% ± 1.42 in 2011 and 2012, respectively) and *Orbicella* spp. that could not be differentiated (7.92% ± 2.31 in 2011 and 7.25% ± 1.90 in 2012) were the next most abundant taxa, followed by *Porites astereodes*, *Montastrea cavernosa*, and *Orbicella faveolata* (Figure 4.3.3 and Table 4.3.1). The remaining coral cover was made up of thirteen species, none of which exceeded 4.0% in either year (Table 4.3.1). Corals that could not be differentiated (less then 2%) because of camera angle or camera distortion were labeled as “unidentified coral.” Shannon-Wiener diversity values remained consistent at WFGB (H’=0.86 and H’=0.87 in 2011 and 2012, respectively).

In the repetitive quadrats in 2011 and 2012, the incidences of bleaching, paling, disease, and fish biting were extremely low at both banks (Table 4.3.2). The mean percentage of corals impacted by isolated or concentrated fish biting at EFGB and WFGB ranged from 0.00 to 0.17%. Less than 0.3% of the coral cover analyzed in the repetitive quadrats exhibited signs of disease, and less than 1% of the coral cover analyzed showed signs of bleaching or paling at EFGB and WFGB in either year. It is important to note that bleaching as determined by the long-term monitoring methodology may be incomplete, as surveys usually occur when weather is optimal (e.g., before hurricane season) in earlier summer months before signs of bleaching occur.

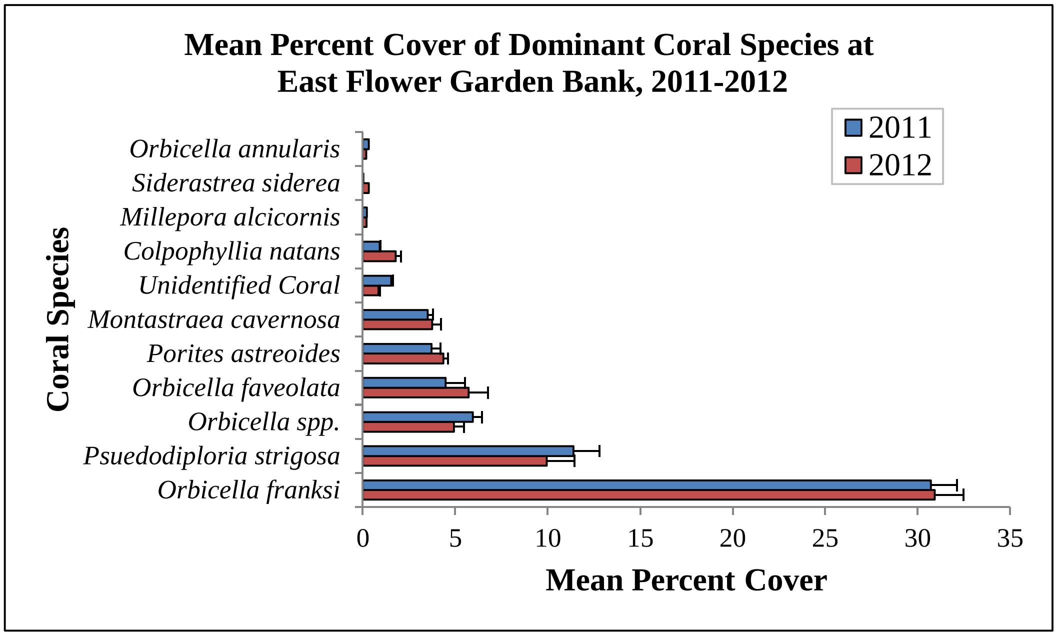


Figure 4.3.2. Mean percent cover + SE of dominant observed coral species in repetitive quadrats at EFGB in 2011 and 2012.

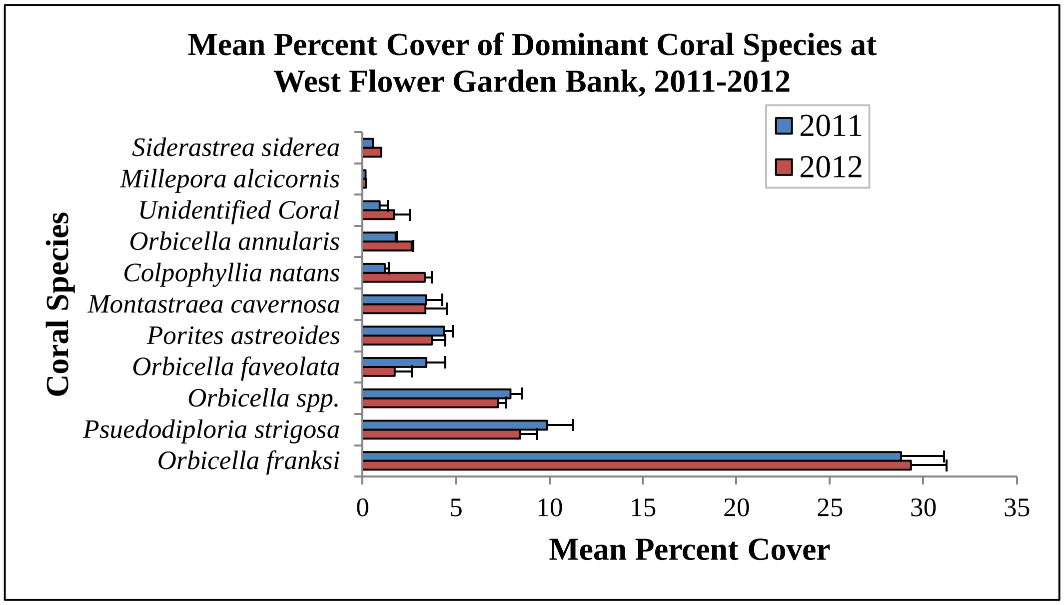


Figure 4.3.3. Mean percent cover + SE of dominant observed coral species in repetitive quadrats at WFGB in 2011 and 2012.

Table 4.3.2.

Mean Percent Cover ± SE of Coral Condition Categories in Repetitive Quadrats at EFGB and WFGB from 2011 and 2012.

Cover Category	2011 EFGB	2012 EFGB	2011 WFGB	2012 WFGB
Coral Condition (occurrences in coral)				
Bleached Coral	0.00	0.05 ± 0.04	0.00	0.00
Paling Coral	0.20 ± 0.11	0.22 ± 0.10	0.63 ± 0.26	0.00
Isolated Fish Biting	0.00	0.03 ± 0.03	0.03 ± 0.03	0.00
Concentrated Fish Biting	0.00	0.11 ± 0.08	0.00	0.17 ± 0.10
Disease	0.00	0.14 ± 0.10	0.00	0.02 ± 0.02

In summary, the combined data collected in 2011 and 2012 showed persistence of *Orbicella franksi* as the dominant coral species in the repetitive quadrats at EFGB and WFGB (Table 4.3.1). *Pseudodiploria strigosa* was the second-most prevalent coral species during this time period. *Orbicella* spp. corals that could not be differentiated, along with *Orbicella faveolata*, *Porites astreoides,* and *Montastraea cavernosa* were consistently the third, fourth, and fifth most abundant corals observed. The mean percent coral cover in the repetitive quadrats at both banks was 63.41 ± 2.55 for the reporting period. This was higher than the random transect mean percent cover for both banks (56.07%), but, as explained previously, the coral in the repetitive stations were selected partly because of their high coral cover.

4.3.1.2. Repetitive Quadrat Univariate Analysis

The repetitive quadrat point count data expressed as mean percent cover was analyzed by one-way ANOVA, with bank and year as fixed factors with an experimentwise error rate of $\alpha=0.05$. The data on proportional cover were non-normal, so categories were square root transformed. The one-way ANOVA showed no significant difference between bank or year for coral or macroalgae. A two-way ANOVA displaying the bank by year interaction was also not significant for coral and macroalgae (Table 4.3.3).

A one-way ANOVA on the proportional cover of CTB and sponges showed no significant difference between years; however, the effects of bank on sponges (P-value=0.02) and CTB (P-value=0.01) were significant. The two-way ANOVA displaying the bank by year interaction were significant for sponges (P-value=0.04) and CTB (P-value=0.02) as well in the repetitive quadrats (Table 4.3.3). Overall, CTB cover was higher at WFGB than EFGB during the study period, and sponge cover was higher at EFGB. Tukey–Kramer *a posteriori* comparisons showed that CTB cover was significantly higher (P-value=0.03) at WFGB than EFGB, and sponge cover was significantly higher at EFGB (P-value=0.03).

Table 4.3.3.

Results of ANOVA on Mean Percent Cover Estimates from Repetitive Quadrats from 2011 and 2012

Source	Sum of Squares	df	Mean Square	F-ratio	P-value
(A) Corals					
Bank	0.16	1	0.16	0.07	0.79
Year	0.01	1	0.01	0.01	0.98
Bank*Year	0.17	2	0.08	0.03	0.97
Error	382.85	162	2.36		
Total	383.01	164			
(B) Sponges					
Bank	1.07	1	1.07	5.88	**0.02**
Year	0.09	1	0.09	0.51	0.47
Bank*Year	1.17	2	0.58	3.20	**0.04**
Error	29.48	162	0.05		
Total	30.65	164			
(C) Macroalgae					
Bank	4.77	1	4.77	2.50	0.12
Year	1.32	1	1.32	0.69	0.41
Bank*Year	6.06	2	3.03	1.59	0.21
Error	309.07	162	0.09	1.27	0.28
Total	315.13	164			
(D) CTB					
Bank	7.45	1	7.45	8.52	**0.01**
Year	3.14	1	3.14	3.49	0.06
Bank*Year	10.53	2	5.26	6.12	**0.02**
Error	139.45	162	0.08		
Total	149.98	164			

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

4.3.1.3. Repetitive Quadrat Multivariate Analysis

The point counts for the repetitive quadrats were further analyzed by using multivariate techniques. Multivariate cover analysis was compared between bank and year using ANOSIM. There were no significant differences between years, and there were no significant differences between banks, resulting in no multivariate interaction. These results differ from the ANOVA, which detected individually significant sponge and CTB differences. However, these within group dissimilarities may not have been significant enough to detect an overall community difference between banks in the ANOSIM analysis.

Cluster analysis and MDS plot placed the repetitive quadrat cover between bank and year in two tight clusters trending to the right of the ordination (80% similarity), with three outlier groups. The stress level of the MDS was 0.07, indicating good goodness-of-fit in a two-dimensional scale, suggesting high confidence in the pattern displayed (Figure 4.3.4). These results agree with the ANOSIM quadrats were similar between years and banks.

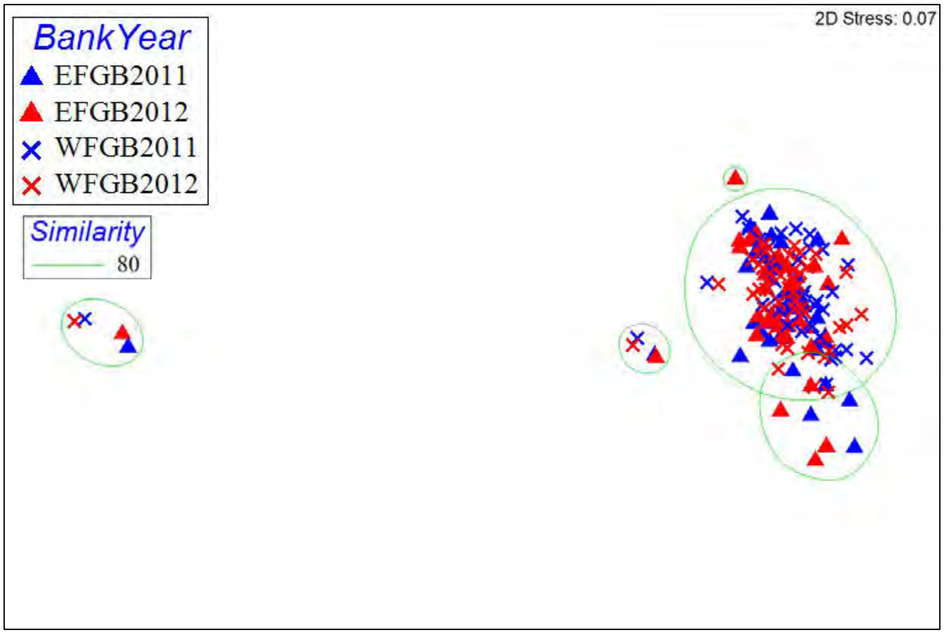


Figure 4.3.4. Two-dimensional MDS plot based on Bray-Curtis similarities showing the spatial representation of repetitive quadrat benthic community cover similarities between EFGB and WFGB for 2011 and 2012.

The green circles group surveys that are 80% similar.

4.3.1.4. Historical Comparison of Repetitive Quadrat Benthic Cover

The mean percent benthic cover from the four functional categories from the repetitive quadrats was analyzed to measure changes over time at the repetitive quadrat photostations. Mean percent coral cover was not collected at the repetitive quadrat stations until 1992, and the remaining three categories did not begin until 2002. No data were collected in 1993 due to poor weather, and cover data were not calculated in 1998 or 1999.

Mean percent coral cover in the repetitive quadrats showed an overall increase in benthic cover during the period from 1992–2012 at EFGB; highest cover was recorded in 2002 and the mean was of approximately 61% cover over time. Coral cover in the repetitive quadrats at WFGB showed an overall increase from 1992–2012; the highest cover was recorded in 2010 and the mean was of approximately 60% overtime (Figure 4.3.5 and Table 4.3.4). Periods of lower CTB cover generally coincided with increases in the algal component, and led to a reciprocal relationship between macroalgae and CTB cover.

The increase in coral cover at both banks from 2001–2002 may be a result of the monitoring program being awarded to a different contract company in 2002, with new staff and different expertise analyzing the monitoring data. It should also be noted that slight increases in coral cover from 2009–2010 most likely were due to changing camera systems. The camera system from 2009 captured a smaller area than the system in 2010, resulting in the necessary cropping of 2010 photos for comparison. This resulted in coral colonies in the center of the photostations comprising a larger percentage of the captured photos than in past monitoring periods, inflating coral cover for both years in CPCe (Johnston et al. 2013). Updated camera systems corrected for this in 2011 and 2012, and captured an area of 5 m^2.

The historical cover from repetitive quadrats was further analyzed by using multivariate techniques. Multivariate historical cover analysis from EFGB and WFGB was compared between years (complete dataset from 2002–2012) to calculate mean benthic cover change over a large time scale. SIMPER analysis identified that, for most comparisons between 2002 and 2012, the greatest contributors to the observed dissimilarity were CTB and macroalgae.

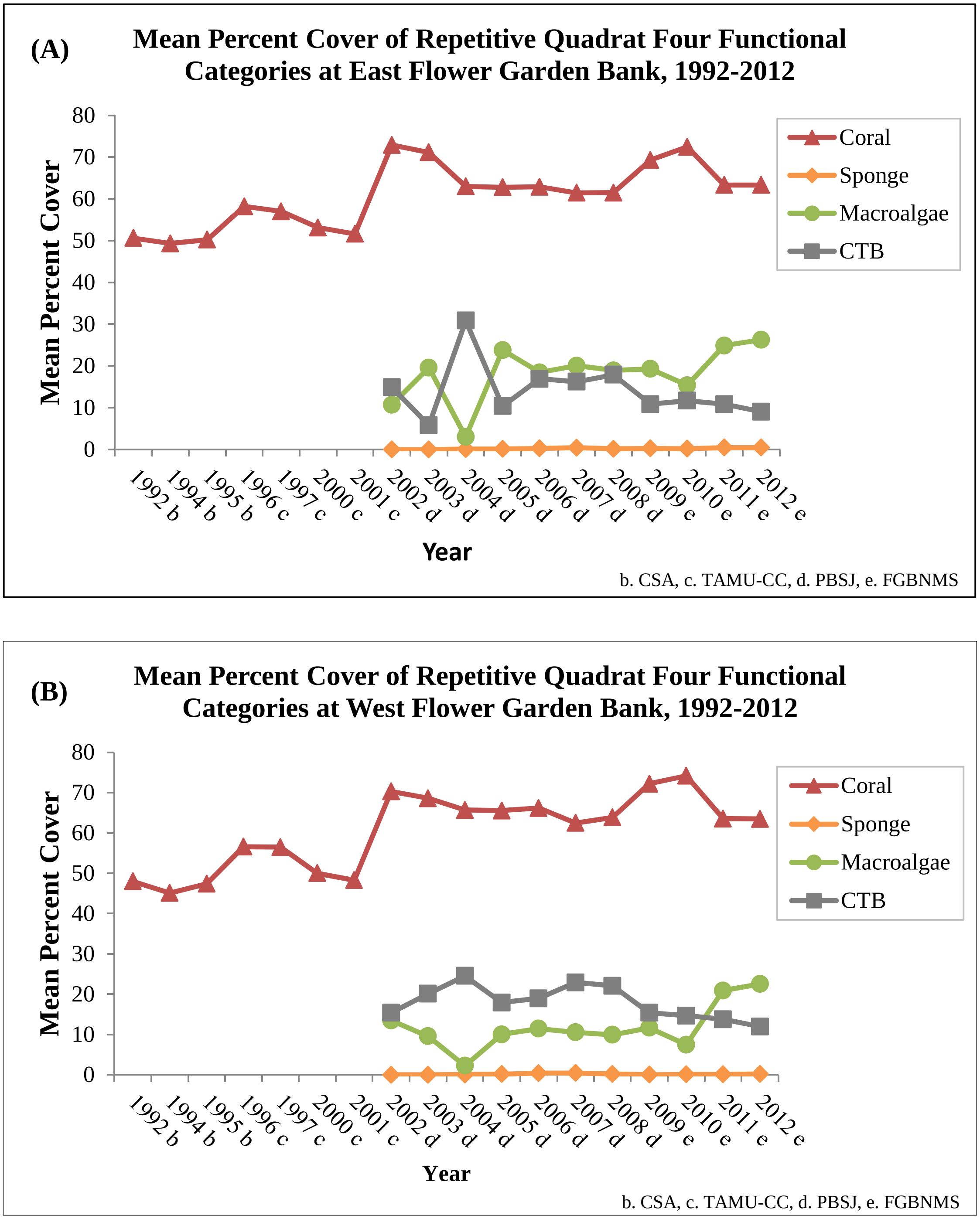


Figure 4.3.5. Historical representation of mean percent cover of coral, sponge, macroalgae, and CTB in repetitive quadrats at (A) EFGB and (B) WFGB.

No percent cover data were reported in 1993. Data for 1992–1995 was reported from Continental Shelf Associates, Inc. (CSA) (1996); for 1996–2001 from Dokken et al. (2003); 2002–2008 from PBS&J (Precht et al. 2006, 2008b); and FGBNMS for 2009–2010 (Johnston et al. 2013).

Table 4.3.4.

EFGB and WFGB Repetitive Quadrat Data for Dominant Cover Categories from 1992–2012.

EFGB Repetitive Quadrat Data				
Year	**Coral**	**Sponge**	**Macroalgae**	**CTB**
1992	50.6	NA	NA	NA
1994	49.3	NA	NA	NA
1995	50.2	NA	NA	NA
1996	58.2	NA	NA	NA
1997	57	NA	NA	NA
2000	53.1	NA	NA	NA
2001	51.6	NA	NA	NA
2002	72.9	NA	10.7	14.9
2003	71.1	NA	19.6	5.8
2004	62.98 ± 2.72	0.09 ± 0.04	3.00 ± 0.58	30.83 ± 2.52
2005	62.78 ± 2.60	0.12 ± 0.06	23.78 ± 2.13	10.39 ± 1.16
2006	62.87 ± 2.32	0.26 ± 0.13	18.45 ± 1.36	16.91 ± 1.24
2007	61.43 ± 2.64	0.42 ± 0.13	20.04 ± 1.62	16.21 ± 1.10
2008	61.46 ± 2.82	0.16 ± 0.08	18.92 ± 1.69	17.89 ± 1.52
2009	69.27 ± 2.69	0.24 ± 0.11	19.27 ± 1.98	10.83 ± 0.94
2010	72.41 ± 2.56	0.19 ± 0.08	15.37 ± 1.71	11.69 ± 1.14
2011	63.29 ± 2.97	0.46 ± 0.18	24.85 ± 2.40	10.83 ± 0.91
2012	63.29 ± 2.83	0.47 ± 0.22	26.27 ± 2.53	9.02 ± 0.82

WFGB Repetitive Quadrat Data				
Year	**Coral**	**Sponge**	**Macroalgae**	**CTB**
1992	48	NA	NA	NA
1994	45.1	NA	NA	NA
1995	47.4	NA	NA	NA
1996	56.6	NA	NA	NA
1997	56.5	NA	NA	NA
2000	50	NA	NA	NA
2001	48.3	NA	NA	NA
2002	70.3	NA	13.5	15.4
2003	68.6	NA	9.6	20.1
2004	65.68 ± 3.09	0.08 ± 0.09	2.23 ± 0.66	24.54 ± 3.04
2005	65.57 ± 3.38	0.16 ± 0.12	10.04 ± 2.36	17.91 ± 1.86
2006	66.17 ± 1.98	0.42 ± 0.12	11.45 ± 1.00	18.97 ± 1.41
2007	62.47 ± 2.06	0.45 ± 0.15	10.54 ± 0.97	22.91 ± 1.55
2008	63.86 ± 1.86	0.19 ± 0.08	9.92 ± 1.02	22.07 ± 1.35
2009	72.19 ± 2.49	0.03 ± 0.03	11.65 ± 1.53	15.41 ± 1.51
2010	74.19 ± 2.07	0.11 ± 0.06	7.46 ± 1.01	14.69 ± 1.21
2011	63.54 ± 2.30	0.11 ± 0.09	20.90 ± 1.76	13.79 ± 1.12
2012	63.50 ± 2.09	0.22 ± 0.15	22.54 ± 1.80	11.98 ± 1.08

Values listed in the table are mean percent covers. Standard errors (± SE) are reported from 2002–2012. 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 Continental Shelf Associates, Inc. (CSA) (1996); for 1996–2001 from Dokken et al. (2003); 2002–2008 from PBS&J (Precht et al. 2006, 2008b); and FGBNMS for 2009–2012 (Johnston et al. 2013).

Cluster analysis and MDS plot placed the cover analysis from 2002–2012 in one tight cluster (90% similarity), with the year 2004 as an outlier. The low stress level (0.01) indicated good goodness-of-fit in a 2-dimensional scale, suggesting high confidence in the pattern displayed (Figure 4.3.6). Overall, these results agree with the ANOSIM (no significant differences of bank or year occur between EFGB and WFGB), and make the banks similar in terms of benthic composition for the repetitive quadrats.

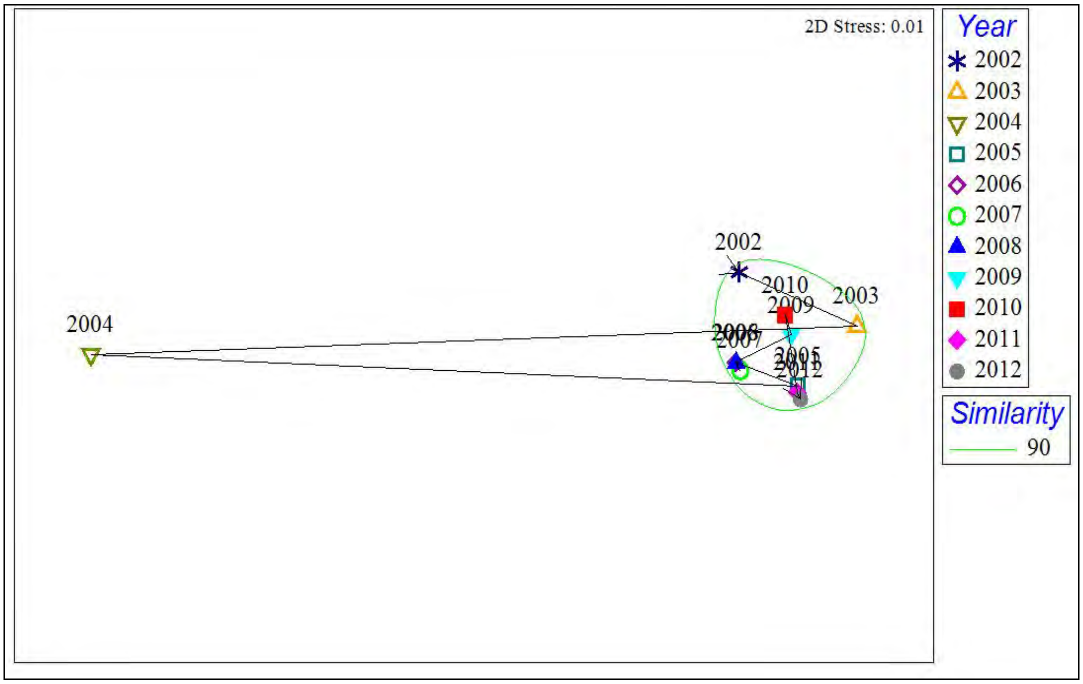


Figure 4.3.6. Two-dimensional MDS plot based on Bray-Curtis similarities comparing benthic cover analysis from 2002–2012 in repetitive quadrats at EFGB and WFGB.

The green circle groups years that are 90% similar.

The coral cover increases generally coincided with lower macroalgal cover, and periods of lower coral cover generally coincided with increases in the algal component and decreases in the CTB category (Figure 4.3.5. and Table 4.3.4). In 2004 macroalgae cover decreased, but in 2005, macroalgae cover was observed to increase, which led to a reciprocal relationship between macroalgae and CTB cover until 2010. After 2010, macroalgae was greater than CTB cover, as macroalgae cover continued to increase. These trends correspond to SIMPER results, and suggest that the greatest contributors to the observed dissimilarity over time were CTB and macroalgae. This also corresponds to the MDS analysis, and suggests that 2002–2012 the community was stable, with the exception of 2004 when algae declined. These results are similar to the random transects: stable coral cover but with increasing macroalgae percent cover throughout the monitoring program.

4.3.2. Repetitive Deep Station Percent Cover

All EFGB deep photostations were photographed in 2011 (nine stations) and 2012 (twelve stations) and analyzed for benthic cover using random dot analysis. Twelve WFGB deep photostations were installed and photographed in 2012. The point count data were grouped into four functional categories and expressed as mean percent covers, the same way the random transect point counts and repetitive quadrats were displayed. Mean percent coral cover ranged from 72–77% between 2011 and 2012, and sponge cover was extremely low (0.00–0.93%). Mean coral cover was followed by macroalgae (19%) and CTB cover (7%) (Figure 4.3.7). Volume II Appendix 8 of this report contains the repetitive deep station data for 2011 and 2012.

At WFGB, 2012 was the first year deep repetitive photographs were taken and analyzed. Coral cover (76.96% ± 4.77) was above 70 percent in 2012 and sponge cover was very low (0.93% ± 0.49). Macroalgae cover was lower at WFGB (13.87% ± 3.00) while CTB cover (7.29% ± 2.09) was comparable to EFGB (Figure 4.3.7 and Table 4.3.5).

At EFGB, mean coral cover remained above 70 percent from 2011–2012 (72.81% ± 3.99 to 72.22% ± 4.43). Sponge cover was very low in 2011 (0.12% ± 0.12) and not detected in 2012. Macroalgae cover (mainly fleshy algae, *Lobophora variegata*, and *Dictyota spp*.) remained stable from 2011–2012 (20.66% ± 3.99 to 20.97% ± 3.52), as did CTB cover (5.54% ± 0.93 to 6.70% ± 1.09) (Figure 4.3.7 and Table 4.3.5).

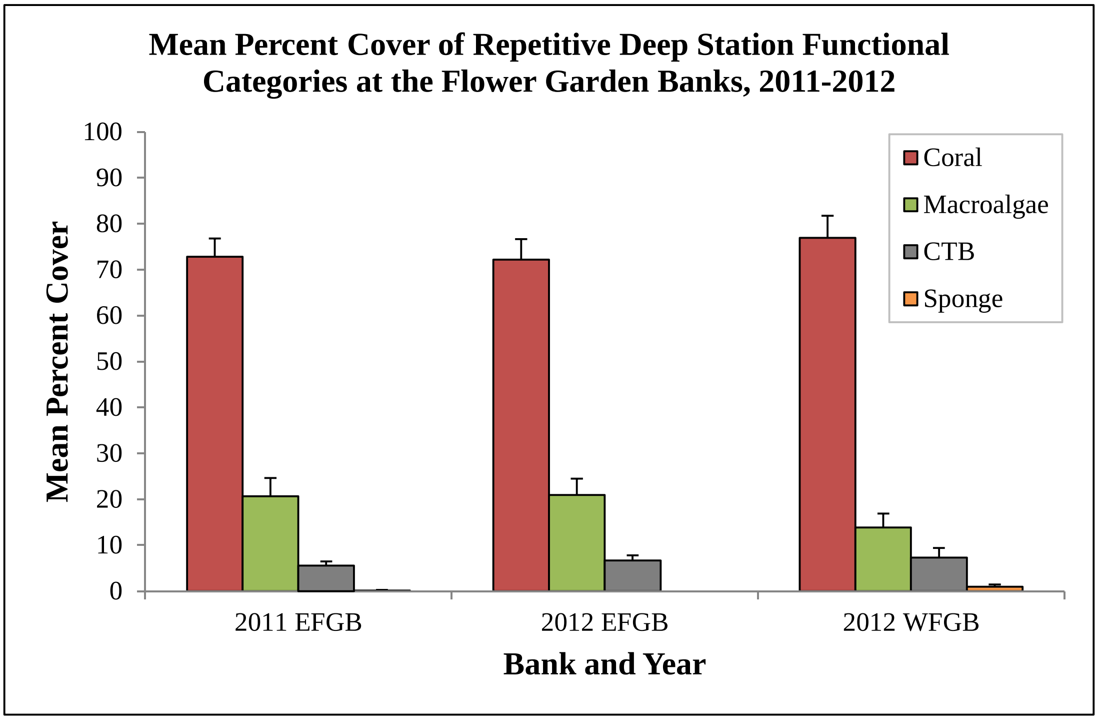


Figure 4.3.7. Mean percent cover + SE of four functional benthic categories at the FGB repetitive deep stations in 2011 and 2012.

Table 4.3.5.

Mean Percent Cover ± SE of Benthic Categories in Repetitive Deep Stations at EFGB from 2011 and 2012, and at WFGB in 2012 (listed from most to least abundant).

Cover Category	**2011 EFGB Deep Stations**	**2012 EFGB Deep Stations**	**2012 WFGB Deep Stations**
Coral			
Orbicella franksi	34.82 ± 4.77	38.79 ± 5.14	30.00 ± 6.19
Montastraea cavernosa	14.44 ± 3.54	17.68 ± 4.78	17.13 ± 4.43
Orbicella spp.	7.07 ± 3.85	3.35 ± 1.12	4.44 ± 2.78
Colpophyllia natans	5.22 ± 2.89	4.56 ± 1.85	0.94 ± 0.54
Pseudodiploria strigosa	2.29 ± 1.52	1.85 ± 0.83	2.41 ± 1.27
Unidentified Coral	2.44 ± 0.92	0.57 ± 0.46	3.68 ± 0.81
Millepora alcicornis	2.07 ± 1.27	1.15 ± 0.80	0.66 ± 0.28
Stephanocoenia intersepta	1.86 ± 0.95	1.27 ± 0.63	8.91 ± 3.63
Mussa angulosa	1.28 ± 0.70	1.15 ± 0.63	0.00
Porites astereoides	0.64 ± 0.52	0.81 ± 0.68	2.53 ± 1.15
Orbicella faveolata	0.34 ± 0.34	0.58 ± 0.35	1.15 ± 0.62
Agaricia spp.	0.23 ± 0.23	0.11 ± 0.11	0.09 ± 0.09
Madracis decactis	0.00	0.00	1.54 ± 1.16
Madracis auretenra	0.12 ± 0.12	0.00	3.26 ± 2.31
Madracis spp.	0.00	0.00	0.12 ± 0.12
Orbicella annularis	0.00	0.00	0.10 ± 0.10
Scolymia cubensis	0.00	0.35 ± 0.25	0.00
Total Coral	72.81 ± 3.99	72.22 ± 4.43	76.96 ± 4.77
Sponge			
Encructing sponge	0.00	0.00	0.19 ± 0.13
Ircinia strobilina	0.00	0.00	0.10 ± 0.10
Agelas clathrodes	0.00	0.00	0.09 ± 0.09
Total Sponge	0.12 ± 0.12	0.00	0.93 ± 0.49
Macroalgae			
Fleshy algae	10.71 ± 2.46	14.01 ± 2.27	9.09 ± 1.87
Lobophora variegata	6.90 ± 1.48	5.12 ± 1.52	1.42 ± 0.54
Dictyota spp.	2.19 ± 0.80	1.27 ± 0.51	1.15 ± 0.35
Thick turf algae	0.73 ± 0.36	0.57 ± 0.35	2.21 ± 1.21
Filamentous Algae	0.13 ± 0.13	0.00	0.00
Total Macroalgae	20.66 ± 4.00	20.97 ± 3.52	13.87 ± 3.00
CTB			
Bare Substrate	2.29 ± 0.57	3.34 ± 0.78	1.51 ± 0.51
Fine Turf	1.68 ± 0.56	2.07 ± 0.79	3.92 ± 1.65

Cover Category	**2011 EFGB Deep Stations**	**2012 EFGB Deep Stations**	**2012 WFGB Deep Stations**
Crustose Coralline Algae	1.09 ± 0.18	1.17 ± 0.60	1.07 ± 0.53
Total CTB	5.54 ± 0.93	6.70 ± 1.09	7.29 ± 2.09
Other			
Shadow	7.78 ± 1.62	2.11 ± 0.72	10.83 ± 1.65
Wand	1.22 ± 0.43	1.44 ± 0.41	2.17 ± 0.42
Sand	0.48 ± 0.36	0.00	0.56 ± 0.29
Fish	0.26 ± 0.17	0.00	0.00
Invertebrate	0.12 ± 0.12	0.11 ± 0.11	0.19 ± 0.13
Tag	0.11 ± 0.11	0.11 ± 0.11	0.00

Consistent with past monitoring results, *Orbicella franksi* continued to dominate the EFGB repetitive deep stations in 2011 and 2012; it increased from 2011–2012 (34.82% ± 4.77 to 38.79% ± 5.14). Different from the shallower repetitive quadrats and random transects, *Montastraea cavernosa* (14.44% ± 3.54 and 17.68% ± 4.78 in 2011and 2012) was the next dominant deep station coral at EFGB. This was followed by *Orbicella* spp. that could not be differentiated (7.07% ± 3.85 to 3.34% ± 1.12), *Colpophyllia natans* (5.22% ± 2.89 to 4.56% ± 1.85), and *Pseudodiploria strigosa* (2.29% ± 1.52 to 1.85% ± 0.82) in 2011 and 2012. The remaining coral cover was made up of 10 species, none of which exceeded more than 3.0% in either year (Table 4.3.5). Corals that could not be differentiated due to camera angle or camera distortion were labeled as “unidentified coral” (Figure 4.3.8).

At WFGB in 2012, *Orbicella franksi* was the main component (30.00% ± 6.19). *Montastraea cavernosa* (17.13% ± 4.43) was the next dominate deep station coral at WFGB. This was followed by *Stephanocoenia intersepta* (8.91% ± 3.63) and *Orbicella* spp. components that could not be differentiated (4.44% ± 2.78). The remaining coral cover was made up of 10 species, none of which exceeded more than 4% of the total cover (Table 4.3.5). Corals that could not be differentiated due to camera angle or camera distortion were labeled as “unidentified coral” (Figure 4.3.9).

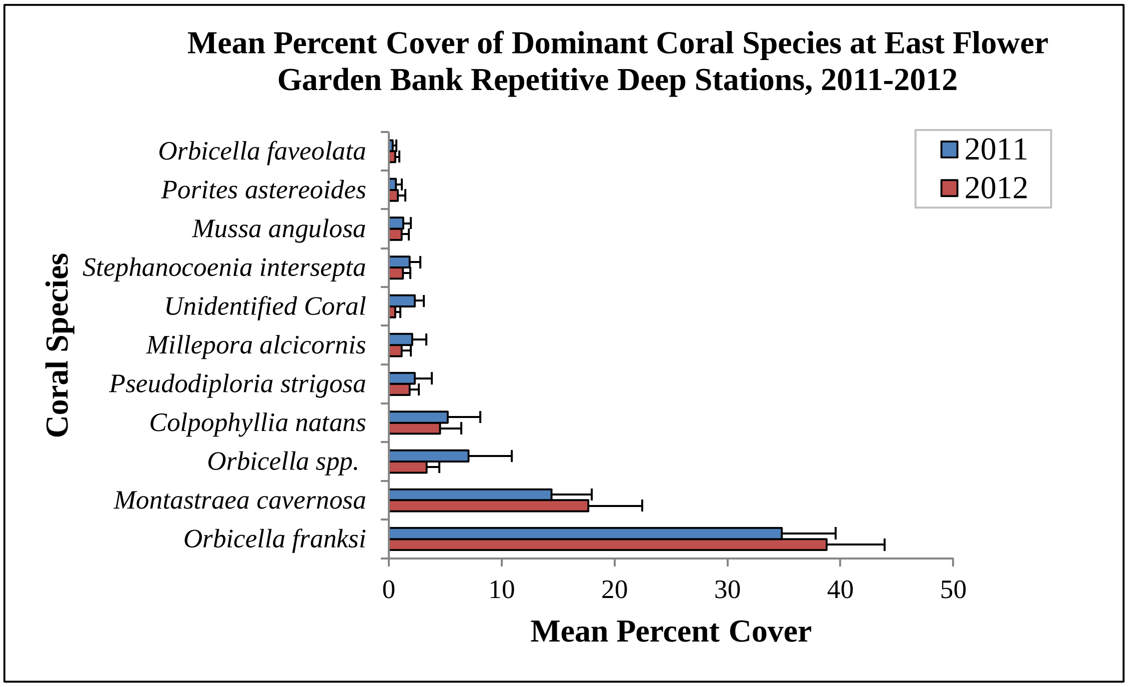


Figure 4.3.8. Mean percent cover + SE of the observed dominant coral species at EFGB repetitive deep stations in 2011 and 2012.

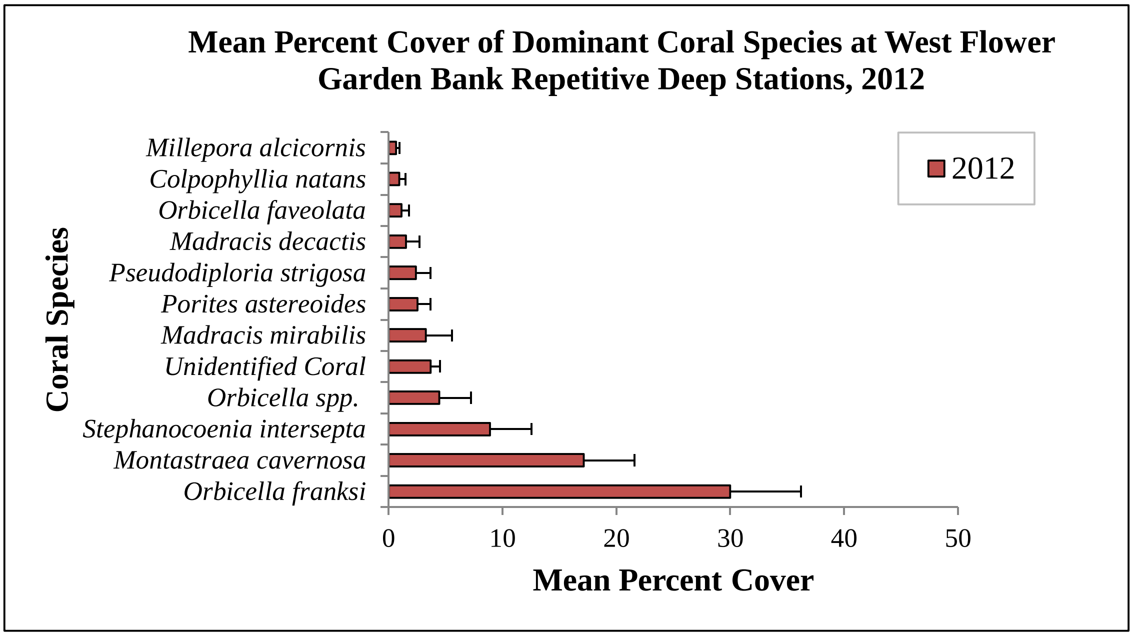


Figure 4.3.9. Mean percent cover + SE of the observed dominant coral species at WFGB repetitive deep stations in 2012.

In EFGB repetitive deep stations in 2011 and 2012, the incidences of bleaching, paling, disease, and fish biting were extremely low. The percentage of corals impacted by isolated or concentrated fish biting ranged from 0.00 to 0.11%. The coral cover analyzed in the deep repetitive quadrats exhibited no signs of disease or bleaching; only 2% of the mean coral cover analyzed showed signs of paling at EFGB in 2011 and 0.11% in 2012. There were no signs of bleaching, paling, disease, or fish biting at WFGB deep stations (Table 4.3.6).

Table 4.3.6.

Mean Percent Cover ± SE of Coral Condition Categories in Repetitive Deep Stations at EFGB from 2011 and 2012, and at WFGB in 2012.

Cover Category	2011 EFGB Deep Stations	2012 EFGB Deep Stations	2012 WFGB Deep Stations
Coral Condition (occurrences in coral)			
Bleached Coral	0.00	0.00	0.00
Paling Coral	2.00 ± 1.76	0.11 ± 0.11	0.00
Concentrated Fish Biting	0.11 ± 0.11	0.00	0.00
Isolated Fish Biting	0.00	0.00	0.00
Other Disease	0.00	0.00	0.00

4.3.2.1. Repetitive Deep Station Univariate Analysis

EFGB deep repetitive station point count data grouped into four major functional categories and expressed as mean percent covers were analyzed by one-way ANOVA with year as a fixed factor and an experimentwise error rate of $\alpha=0.05$. The 2012 EFGB and WFGB deep station point count mean percent cover data were analyzed by one-way ANOVA, with bank as a fixed factor. The data on proportional cover for sponges and CTB were non-normal, so categories were square root transformed.

A one-way ANOVA on the proportional cover of all observed corals, sponge, macroalgae, and CTB at EFGB deep stations showed no significant difference between years (Table 4.3.7). A one-way ANOVA on the proportional cover of all observed corals, sponge, macroalgae, and CTB between EFGB and WFGB deep stations showed no significant difference between banks (Table 4.3.8).

Table 4.3.7.

Results of ANOVA on Mean Percent Cover Estimates from EFGB Repetitive Deep Stations from 2011 and 2012

Source	Sum of Squares	df	Mean Square	F-ratio	P-value
(A) Corals					
Year	0.01	1	0.01	0.01	0.90
Error	9.62	16	0.60		
(B) Sponges					
Year	0.06	1	0.06	1.00	0.33
Error	0.96	16	0.06		
(C) Macroalgae					
Year	0.05	1	0.05	0.03	0.85
Error	24.19	16	1.51		
(D) CTB					
Year	0.22	1	0.22	0.61	0.45
Error	5.74	16	0.36		

Table 4.3.8.

Results of ANOVA on Mean Percent Cover Estimates between EFGB and WFGB Repetitive Deep Stations from 2012

Source	Sum of Squares	df	Mean Square	F-ratio	P-value
(A) Corals					
Bank	0.33	1	0.33	0.37	0.55
Error	17.21	19	0.91		
(B) Sponges					
Bank	1.47	1	1.47	3.60	0.07
Error	7.75	19	0.41		
(C) Macroalgae					
Bank	5.17	1	5.17	3.10	0.09
Error	31.73	19	1.67		
(D) CTB					
Bank	0.08	1	0.08	0.07	0.80
Error	22.03	19	1.16		

4.3.2.2. Repetitive Deep Station Multivariate Analysis

The point counts for the deep stations were further analyzed by using multivariate techinques. Multivariate cover analysis was compared between bank and year using ANOSIM. There were no significant differences between years, and there were no significant differences between banks, which resulted in no multivariate interaction.

Cluster analysis and MDS plot placed EFGB deep station cover in a loosely clustered group (80% similarity), while WFGB 2012 stations appeared to be more varied. However, the stress level of the MDS was low at 0.05, which indicates good goodness-of-fit in a two-dimensional scale, which suggests high confidence in the pattern displayed (Figure 4.3.10). These results agree with both the ANOVA and ANOSIM that no significant differences of bank or year occur between EFGB and WFGB deep stations; this makes the banks similar in terms of deep repetitive photostation composition.

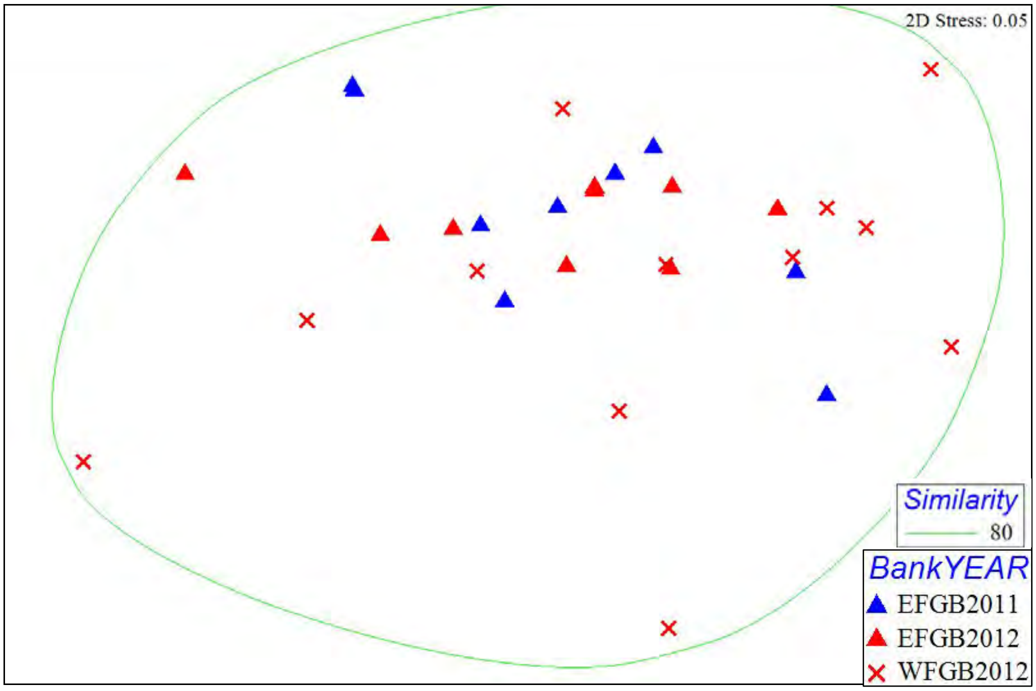


Figure 4.3.10. Two-dimensional MDS plot based on Bray-Curtis similarities showing the spatial representation of benthic community similarities between the 2011 and 2012 EFGB and 2012 WFGB repetitive deep stations.

The green circle groups surveys that are 80% similar.

4.3.2.3. Repetitive Deep Station and Shallow Station Comparison

The point count data from the repetitive deep stations (DS) and the shallow station (SS) quadrats in the 10,000 m^2 study sites were compared. The 2011 WFGB shallow station repetitive quadrat data were not included in this comparison (deep stations were not installed until 2012). The mean percent coral cover was higher in the repetitive deep stations when compared to the shallower repetitive quadrats; it averaged 73% from 2011–2012 at the deep stations and 63% at the shallow repetitive quadrats in the study sites. Macroalgae cover for both banks averaged 18% for the deep stations, and the shallow stations macroalgae cover was 24% from 2011 and 2012. Mean percent CTB cover at the deep stations was 7% and the mean CTB cover at the repetitive shallow stations was 11%. Mean percent sponge cover was below 1% for both the deep and shallow repetitive stations (Table 4.3.9 and Figure 4.3.11).

Table 4.3.9.

Mean Percent Cover ± SE of Benthic Categories in Repetitive Deep Stations and Shallow Repetitive Quadrats at EFGB and WFGB from 2011 and 2012

Cover Category	2011 EFGB	2012 EFGB	2011 WFGB	2012 WFGB
Shallow Station Coral	63.29 ± 2.97	63.29 ± 2.83	63.54 ± 2.30	63.50 ± 2.09
Deep Station Coral	72.81 ± 3.99	72.22 ± 4.43	NA	76.96 ± 4.77
Shallow Station Macroalgae	24.85 ± 2.40	26.27 ± 2.53	20.90 ± 1.76	22.54 ± 1.80
Deep Station Macroalgae	20.66 ± 4.00	20.97 ± 3.52	NA	13.87 ± 3.00
Shallow Station CTB	10.83 ± 0.91	9.02 ± 0.82	13.79 ± 1.12	11.98 ± 1.08
Deep Station CTB	5.54 ± 0.93	6.70 ± 1.09	NA	7.29 ± 2.09
Shallow Station Sponge	0.46 ± 0.18	0.47 ± 0.22	0.11 ± 0.09	0.22 ± 0.15
Deep Station Sponge	0.12 ± 0.12	0.00	NA	0.93 ± 0.49

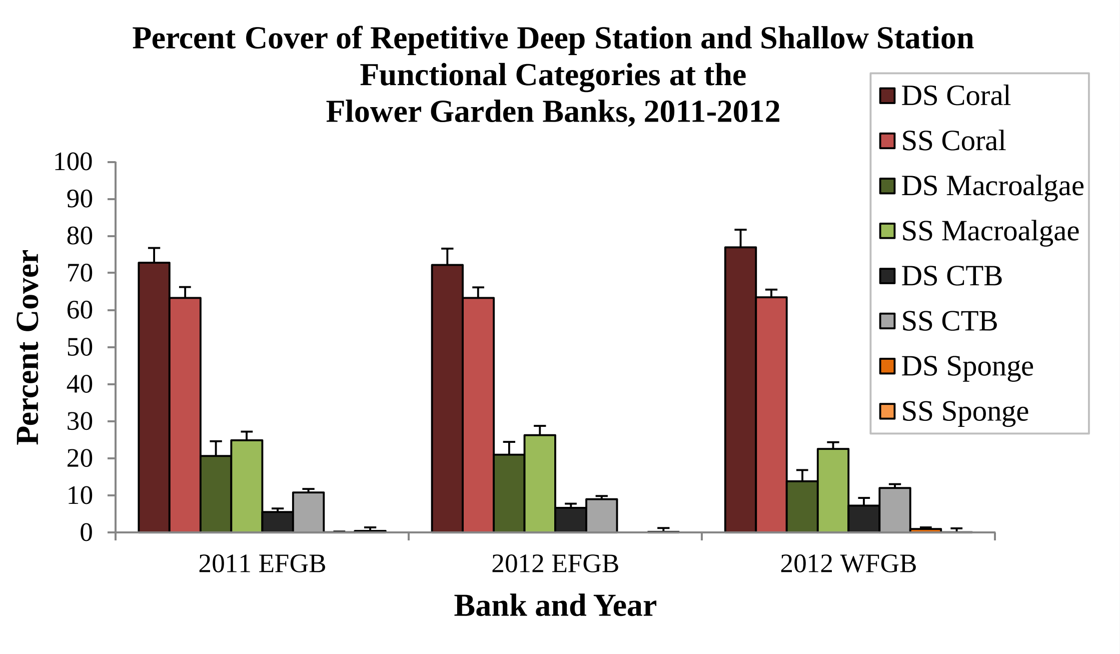


Figure 4.3.11. Mean percent cover + SE of four functional benthic categories at the FGB repetitive deep stations (DS) and shallow station (SS) repetitive quadrats in 2011 and 2012.

The deep repetitive station and shallow repetitive quadrat point count data grouped into four major functional categories and expressed as mean percent covers were analyzed by one-way ANOVA with depth (deep and shallow) as a fixed factor and an experimentwise error rate of α=0.05. The data on proportional cover for sponges and CTB were non-normal, so categories were square root transformed.

A one-way ANOVA on the proportional cover of all observed sponges and macroalgae showed no significant difference between depths; however, corals (P-value>0.01) and CTB (P-value>0.01) were significantly different (Table 4.3.10). High error was reported for all categories because there were more shallow stations than deep stations in the analysis and this resulted in an uneven sample size.

Table 4.3.10.

Results of ANOVA on Proportional Mean Cover Estimates from Repetitive Deep Stations and Shallow Station Repetitive Quadrats from 2011 and 2012

Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**	**P-value**
(A) Corals					
Depth	22.02	1	22.02	10.50	>**0.01**
Error	404.72	193	2.10		
(B) Sponges					
Depth	0.11	1	0.11	0.56	0.45
Error	41.07	193	0.21		
(C) Macroalgae					
Depth	7.26	1	7.26	3.80	0.06
Error	368.43	193	1.91		
(D) CTB					
Depth	15.84	1	15.84	17.50	>**0.01**
Error	174.69	193	0.91		

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

4.3.2.4. Historical Comparison of Repetitive Deep Station Benthic Cover

Mean percent coral cover in the repetitive deep photostations was 77% during the period from 2003–2012 at EFGB; the highest cover was recorded in 2004 with a mean of approximately 86% (Table 4.3.11). In 2003, the mean coral cover in EFGB deep stations was 76.5% Data from 2003–2008 was collected by Precht et al (2006 and 2008b). From 2004–2010, the mean ranged from 72–86%. In 2012, twelve deep stations were established at WFGB. The mean coral cover in WFGB deep station quadrats was 77% in 2012.

Periods of lower coral cover generally coincided with increases in the algal component and decreases in the CTB category. Coral and CTB cover increases generally coincided with lower macroalgal cover (Figure 4.4.12). At this time, the results suggest that algal overgrowth is not affecting estimates of underlying benthic coral cover. Overall, the most noticeable pattern was the inverse relationship between coral and CTB components and the macroalgae cover, with an increasing trend in algae cover, similar to the random transects and repetitive quadrats in the study sites on the shallower portion of the reef cap. However, this is a general observation, because coral does not grow and die at the same rate as algae.

Table 4.3.11.

EFGB and WFGB Repetitive Deep Station Data for Dominant Cover Categories from 2003–2012.

EFGB Repetitive Deep Stations				
Year	**Coral**	**Sponge**	**Macroalgae**	**CTB**
2003	76.00 ± 4.00	1.00 ± 0.20	0.50 ± 0.10	12.00 ± 1.00
2004	86.20 ± 5.18	0.00	0.57 ± 0.62	13.18 ± 4.62
2005	77.51 ± 3.77	0.00	10.82 ± 1.89	8.84 ± 1.85
2006	72.00 ± 4.60	1.02 ± 0.46	7.77 ± 2.07	15.76 ± 2.75
2007	73.80 ± 4.09	0.51 ± 0.25	14.67 ± 2.62	8.90 ± 1.66
2008	74.52 ± 3.14	0.13 ± 0.09	10.11 ± 1.47	13.92 ± 2.42
2009	81.73 ± 3.90	0.00	10.56 ± 3.12	7.72 ± 1.39
2010	82.18 ± 3.01	0.25 ± 0.25	10.28 ± 2.06	6.98 ± 1.53
2011	72.81 ± 3.99	0.12 ± 0.12	20.66 ± 4.00	5.54 ± 0.93
2012	72.22 ± 4.43	0.00	20.97 ± 3.52	6.70 ± 1.09
WFGB Repetitive Deep Stations				
Year	**Coral**	**Sponge**	**Macroalgae**	**CTB**
2012	76.96 ± 4.77	0.93 ± 0.49	13.87 ± 3.00	7.29 ± 2.09

Values listed in table are mean percent covers. Standard errors (± SE) are reported from 2003–2012. Data for 2003–2008 from PBS&J (Precht et al. 2006, 2008b); and FGBNMS for 2009–2012 (Johnston et al. 2013).

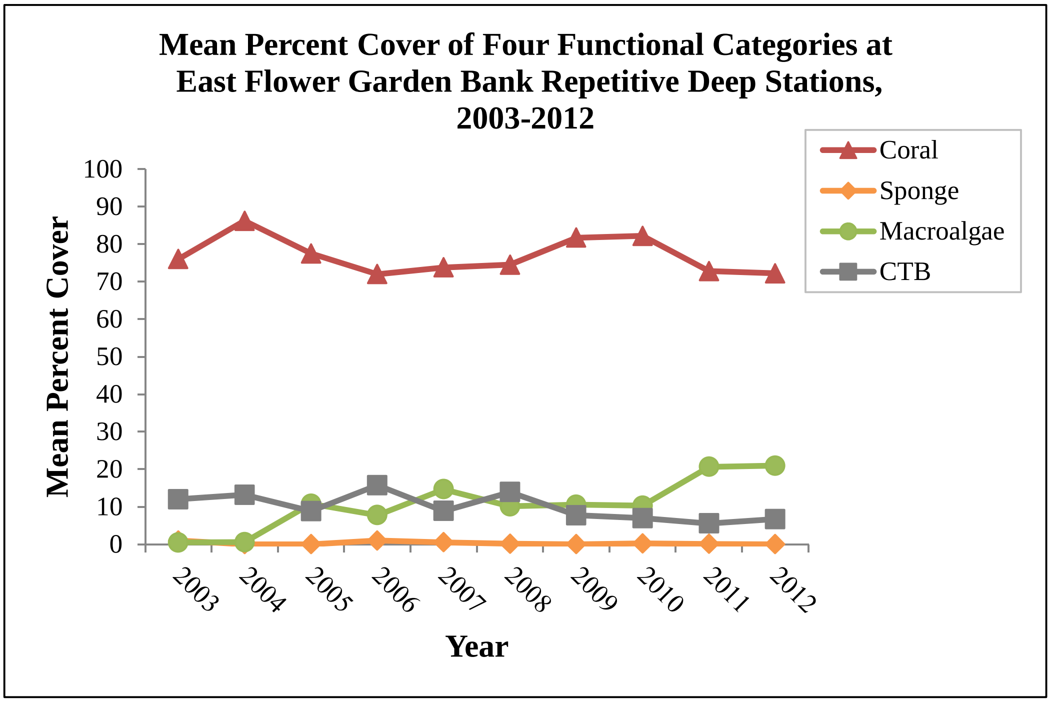


Figure 4.3.12. Repetitive deep station mean percent cover from 2003–2012 of coral, sponge, macroalgae, and CTB at EFGB.

4.3.3. Repetitive Quadrat Planimetric Analysis

Selected corals in repetitive quadrat photographs were analyzed using planimetry. Measurements of the amount of change in living area on selected coral colonies were conducted to document the dynamics of particular coral colonies at EFGB repetitive quadrats, including EFGB repetitive deep stations and WFGB repetitive quadrats. Colonies with discernable margins close to the center of the photograph were measured for planar areal change from 2011–2012. In each frame, one to four colonies of framework-building corals, where the margins were clearly defined, were chosen for analysis. *Orbicella* spp., the main contributors to coral cover at the FGB, and *Pseudodiploria strigosa* and *Porites astreoides* colonies were the most common colonies selected. A complete list of repetitive quadrat photostation coral colonies selected for planimetric analysis and their percent change from 2011 and 2012 are listed in Volume II Appendix 7 of this report.

On average, coral colonies selected for analysis at EFGB and WFGB were found to increase in area from 2011–2012. While retreat in specific colonies was measured, overall percent change was positive in the coral colonies measured in EFGB repetitive quadrats (13.51%), EFGB repetitive deep stations (9.17%), and WFGB repetitive quadrats (6.42%) (Figure 4.3.13).

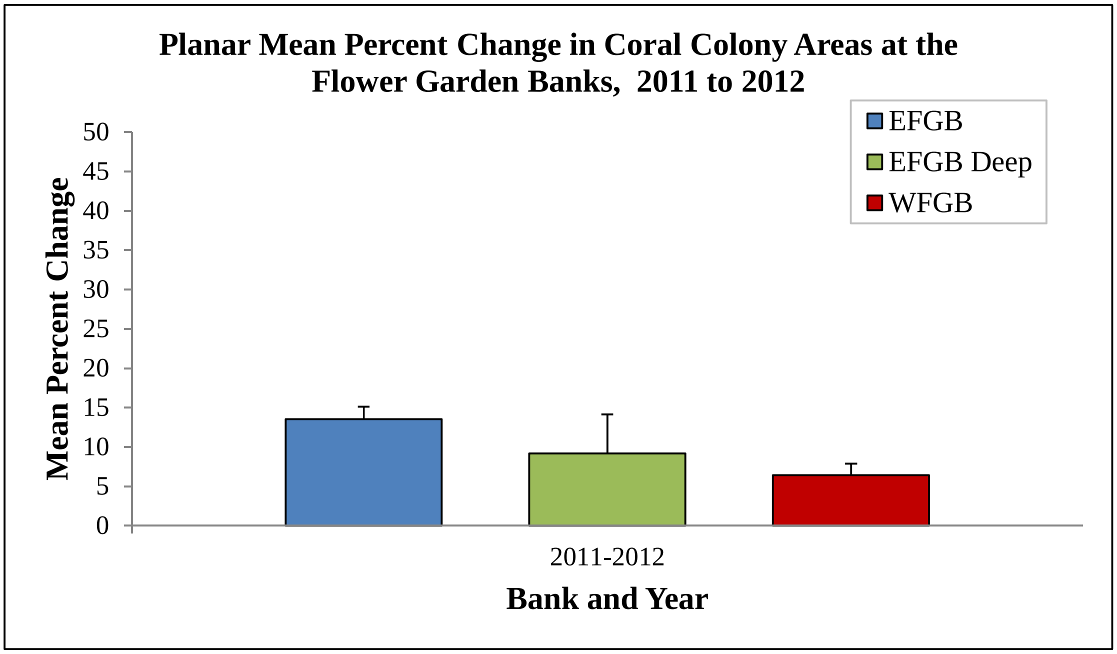


Figure 4.3.13. Mean percent change from repetitive quadrat planimetry analysis for 2011 and 2012 at EFGB and WFGB repetitive quadrats and EFGB repetitive deep stations (EFGB Deep).

When comparing complete individual colonies for planimetry analysis, *Porites astreoides* was the dominant coral taxon that exhibited proportional growth from 2011–2012, most likely because it is small and fits the criteria for selection. This was followed by *Colpophylia natans* at WFGB repetitive quadrats and EFGB repetitive deep stations, and *Orbicella franksi* at EFGB repetitive quadrats. Several colonies exhibited tissue loss from 2011–2012, including *Stephanocoenia intersepta* at EFGB repetitive deep stations, and *Siderastrea siderea* and *Montastraea cavernosa* at WFGB. The mean percent change in tissue results (change in planar area) for coral colonies measured from EFGB was approximately 10%, 4% in WFGB repetitive quadrats, and 11% in EFGB repetitive deep stations (Figure 4.3.14).

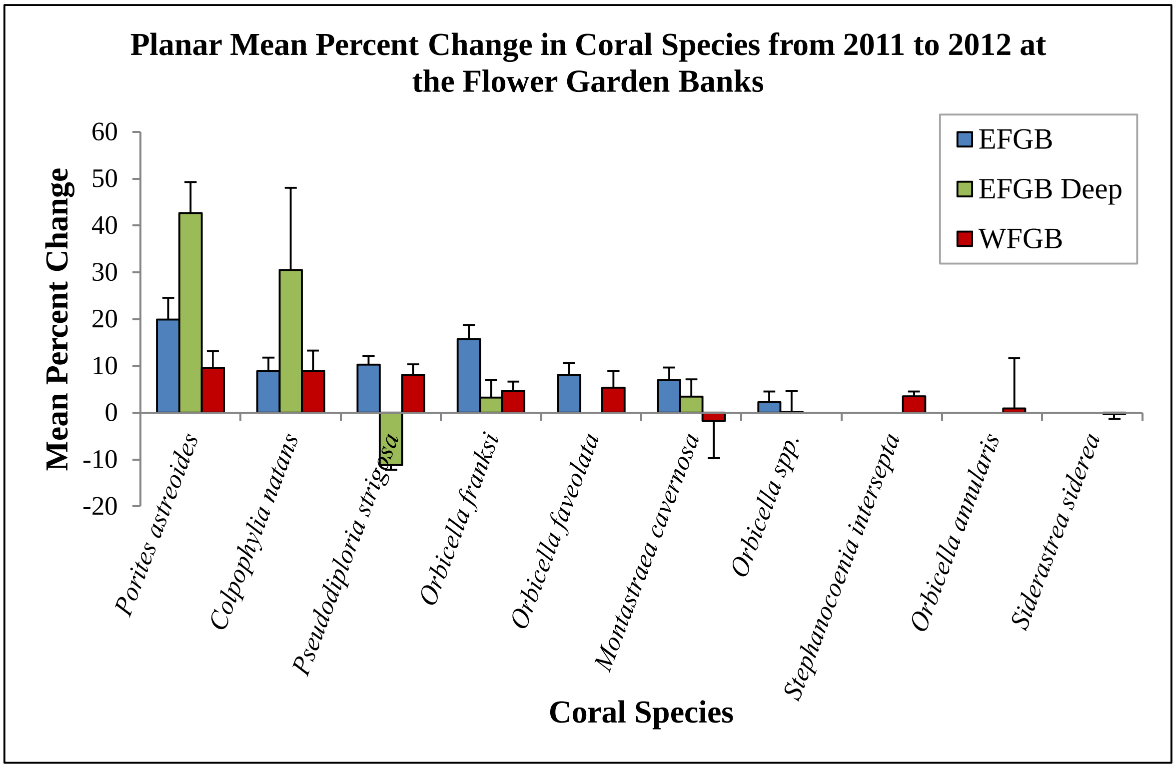


Figure 4.3.14. Mean percent change from coral species from repetitive quadrat planimetry analysis for 2011 and 2012 at EFGB and WFGB repetitive quadrats and EFGB repetitive deep stations (EFGB Deep).

Sample size for *Porites astreoides*: EFGB n=30, WFGB n=33, EFGB Deep n=2; *Colpophylia natans*: EFGB n=9, WFGB n=10, EFGB Deep n=4; *Pseudodiploria strigosa*: EFGB n=29 WFGB n=32, EFGB Deep n=1; *Orbicella franksi*: EFGB n=24, WFGB n=24, EFGB Deep n=9; *Orbicella faveolata*: EFGB n=9, WFGB n=13; *Montastraea cavernosa*: EFGB n=7, WFGB n=11, EFGB Deep n=10; *Orbicella spp.*: EFGB n=1, EFGB Deep n=2; *Stephanocoenia intersepta*: WFGB n=1; *Orbicella annularis*: WFGB n=5; *Siderastrea siderea*: WFGB n=1.

A two-sample t-test was performed to compare the percent change of dominant coral species (*Porites astreoides, Colpophylia natans, Orbicella franksi, Orbicella faveolata,* and *Pseudodiploria strigosa*) from EFGB to WFGB quadrats to examine variations by bank with an experimentwise error rate of α=0.05. The percent change data were non-normal. Transformation did not correct for normality, so data were left untransformed.

The two-tailed t-test revealed that percent colony change differences were not significant for *Colpophylia natans, Orbicella faveolata,* and *Pseudodiploria strigosa* between the two banks. However, percent colony change for *Porites astreoides* (P-value=0.04) and *Orbicella franksi* (P-value>0.01) were significantly different between WFGB and EFGB (Table 4.3.12). Overall, both *Porites astreoides* and *Orbicella franksi* percent change was higher at EFGB than WFGB from 2011–2012. EFGB repetitive deep stations were not included in this analysis due to the small sample size and lack of a WFGB repetitive deep station comparison in 2011.

Table 4.3.12.

Results of t-test on Percent Colony Change for Dominant Coral Species from Repetitive Quadrat Planimetry Analysis for 2011 and 2012 at EFGB and WFGB

Source	**Difference**	**df**	**Standard Error Difference**	**T-ratio**	**P-value**
(A) ***Porites astreoides***					
Bank	-10.38	61	5.81	-1.79	**0.04**
(B) ***Colpophylia natans***					
Bank	0.01	17	5.37	0.002	0.50
(C) ***Orbicella franksi***					
Bank	-11.07	46	3.57	-3.10	**>0.01**
(D) ***Orbicella faveolata***					
Bank	-0.33	20	4.66	-0.07	0.47
(E) ***Pseudodiploria strigosa***					
Bank	-2.18	59	2.91	-0.76	0.23

4.4. REPETITIVE QUADRAT DISCUSSION

4.4.1. Study Site Repetitive Quadrats

Repetitive quadrats were analyzed for mean percent cover of benthic components, including coral species, sponge, macroalgae, and CTB, and to identify coral health indicators (bleaching, paling, concentrated fish biting, isolated fish biting, and disease) in 2011 and 2012. Higher coral cover estimates (63%) were obtained from the repetitive quadrats in comparison to the random transects (56%) at both EFGB and WFGB. Higher percent coral cover in repetitive quadrats relative to random transects has also been documented in previous reports (Dokken et al. 2003; Precht et al. 2006, 2008b; Zimmer et al. 2010; Johnston et al. 2013). It should be noted that this does not provide a comprehensive view of the dominant species at EFGB and WFGB, because repetitive photostations are biasedly placed on diverse habitat with high coral cover (large coral colonies). They were not intended to be representative of mean benthic cover.

Repetitive photostations also display a unique time series from 2006–2012 (Figure 4.4.1). Like most stations, in the example from EFGB station 102, the overall coral community appears to be stable from 2006–2012 and in good health during all years. Some colonies may appear paler in certain years due to variations in photographic equipment (e.g., note large *Montastraea cavernosa* in upper right corner in 2010), because all photos are subject to varying degrees of differing camera settings, lighting, etc. Small changes include concentrated fish biting (bright white patch in the center of the frame) in 2011, and a damselfish garden that appeared on a *Pseudodiploria strigosa* head in the lower left corner in 2011 and 2012, affecting approximately 25% of the colony.

Species composition at repetitive stations was similar to that in the random transects; the dominant corals were *Orbicella franksi*, *Pseudodiploria strigosa*, *Orbicella* spp., and *Orbicella faveolata*. Coral disease was virtually absent from analyzed quadrats at both banks in 2011 and 2012. Paling and bleaching were also rare, and concentrated and isolated fish biting.

In the repetitive quadrats, mean percent coral cover showed an overall increase in benthic cover during the period from 1992–2012 at EFGB and WFGB. EFGB mean coral cover was approximately 61% over time. WFGB mean coral cover was approximately 60% over time. Macroalgae mean percent cover at EFGB and WFGB both increased in 2011 and 2012 when compared to previous years (Figure 4.3.5.).

A similar pattern was observed in the random transects in section 3.4, where coral cover showed an overall increase from 1992–2012. At EFGB and WFGB, coral cover averaged approximately 52% cover over time. Macrolagae cover in the random transects at both EFGB and WFGB increased from 2008 to 2012, when compared to previous years.

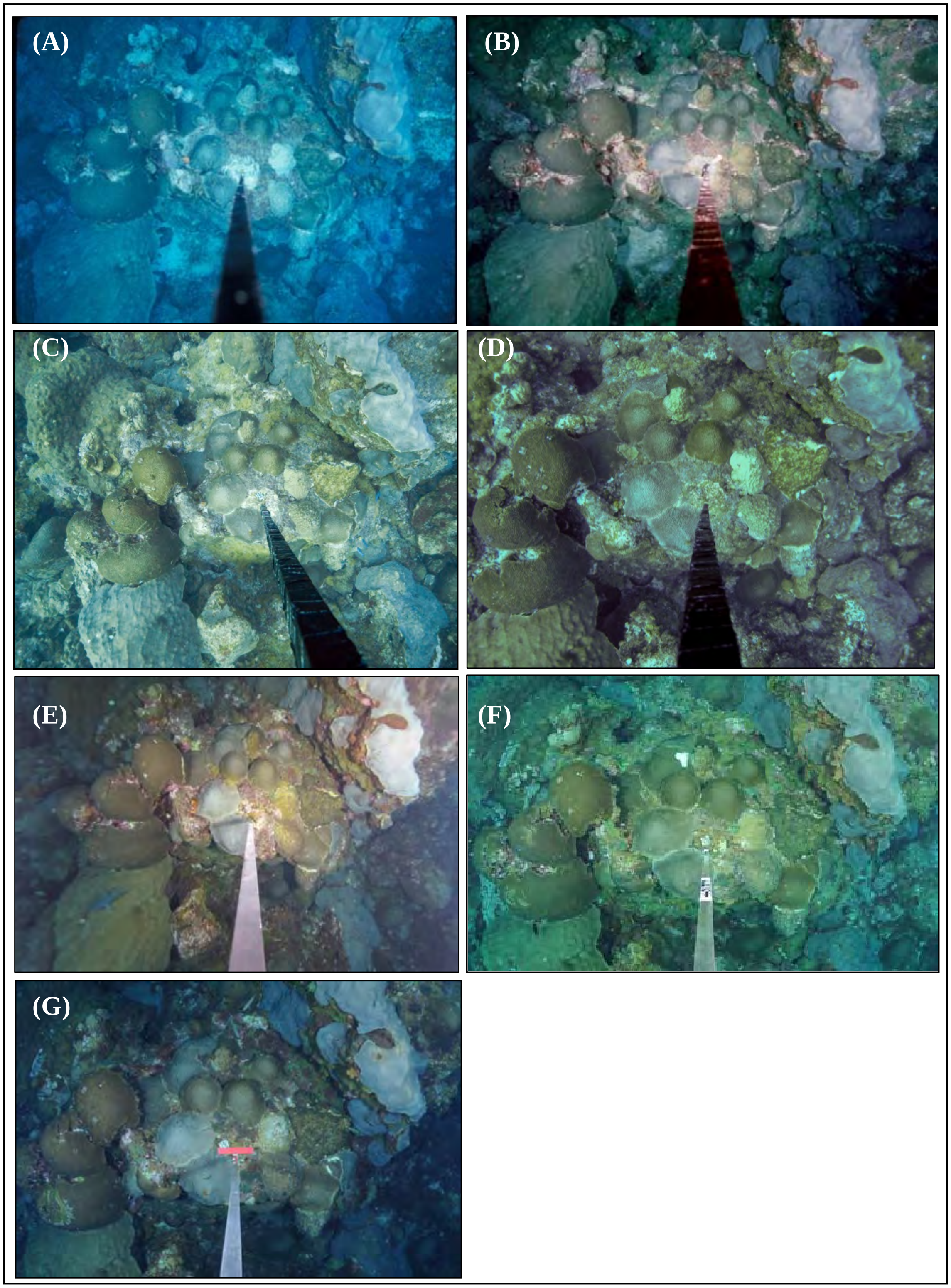


Figure 4.4.1. Repetitive photostation 761 (re-named 102 in 2012) from EFGB in a time series from 2006–2012, showing a healthy and stable coral community: (A) 2006; (B) 2007; (C) 2008; (D) 2009; (E) 2010; (F) 2011; (G) 2012 (NOAA/FGBNMS).

In the repetitive quadrats and random transects, periods of lower coral cover generally coincided with increases in the algal component and decreases in the CTB category. Overall, the most noticeable patterns were: 1) inverse relationship between CTB and the macroalgae cover, 2) increasing macroalage cover, and 3) stable coral cover over time. Despite the higher coral cover in the repetitive quadrats, these stations showed similar trends observed in the random transects, which suggests that monitoring these specific stations also gives a representative view of the dynamics of the overall study site, and an increasing trend in algal cover.

4.4.2. Repetitive Deep Stations

At EFGB, nine deep stations located at 32–40 m depths were established in April of 2003 to monitor the deeper benthic coral community, and two more stations were added in 2012. The coral cover was significantly higher in the deep stations, and averaged 74% in 2011 and 2012, when compared to the shallower repetitive quadrats (63%).

Higher percent coral cover in the deep station quadrats relative to random transects has also been documented in previous reports (Precht et al. 2006, 2008b; Zimmer et al. 2010; Johnston et al. 2013). The deep stations were dominated by *Orbicella franksi*; *Montastraea cavernosa* was the second-most dominant coral species, unlike the shallower study sites. A noticeable difference between EFGB and WFGB deep repetitive stations and the shallow repetitive quadrat stations was the lack of *Orbicella annularis* cover at the deep stations and decreased occurrence of *Pseudodiploria strigosa*. The coral community observed in the deep station photographs appears to be both healthy and stable from 2003 to 2012, with consistent percent cover above 70% when compared to past monitoring periods.

4.4.3. Planimetry

To document the growth dynamics of particular coral colonies at the FGB, repetitive quadrats were analyzed using planimetry by taking areal measurements of coral colonies whose lateral margins were contained entirely within the image frame from 2011 and 2012. Planimetric analysis at repetitive stations generally revealed tissue growth with limited living tissue loss.

Orbicella franksi, followed by *Pseudodiploria strigosa*, were the dominant coral cover species in the repetitive quadrats. However, even though *Orbicella franksi* and *Pseudodiploria strigosa* were the dominant frame building corals in the repetitive quadrat percent cover analysis, *Porites astreoides* was the dominant coral to exhibit proportional growth from selected corals analyzed from 2011–2012. It should be noted that *Porites astreoides* colonies were not the dominant corals in the repetitive quadrats, but were selected because of their clearly defined margins. For example, even though large *Orbicella franksi* and *Pseudodiploria strigosa* colonies dominate the coral cover at EFGB repetitive quadrat station #10 (Figure 4.4.2), smaller *Colpophylia natans*, *Porites astreoides*, and *Pseudodiploria strigosa* colonies were selected for analysis because their lateral margins were within the image frame.

Orbicella franksi and *Pseudodiploria strigosa* also exhibited tissue growth, but many of these colonies contained margins outside of the photographs, and their large size most likely exhibits slower growth rates than smaller colonies, such as *Porites astreoides*.

A total of 267 colonies were compared between 2011 and 2012 from EFGB, WFGB, and EFGB deep stations; only 18% of the colonies exhibited tissue loss. Similar to the *Pseudodiploria strigosa* colonies documented in the lateral growth stations in section 6.1, *Pseudodiploria strigosa* colonies in the planimetric analysis also revealed tissue growth.

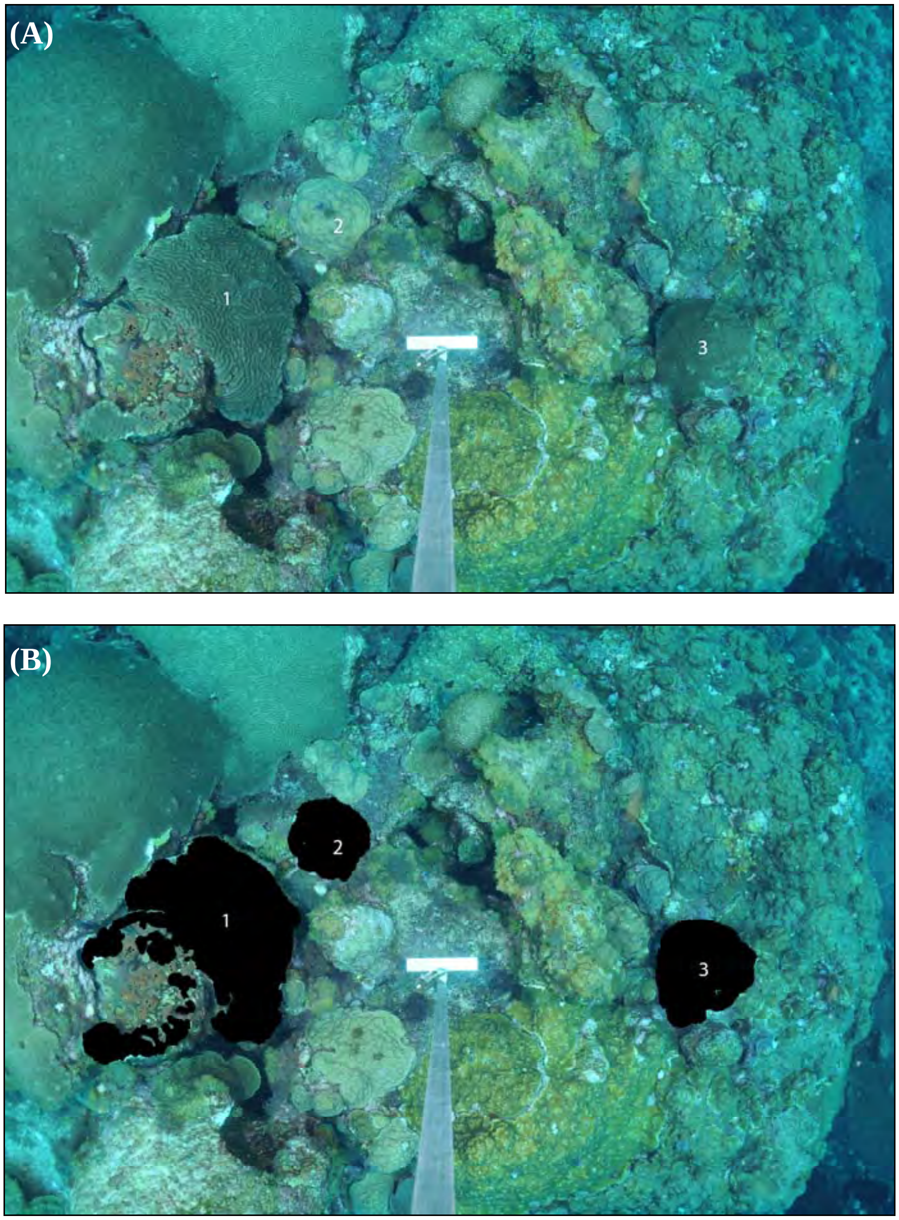


Figure 4.4.2. An example of colonies selected for planimetric analysis include 1) *Colpophylia natans*, 2) *Porites astreoides*, and 3) *Pseudodiploria strigosa* in photo (A), and colony planar outlines in (B), at repetitive quadrat station #10 at EFGB in 2012.

CHAPTER 5.0: LATERAL GROWTH

5.1. LATERAL GROWTH METHODOLOGICAL RATIONALE

Pseudodiploria strigosa is the second largest contributor to coral cover at the FGB, after *Orbicella franksi* (Bright et al. 1984; USDOI, MMS 1998; Dokken et al. 2003; Gittings et al. 1992; Precht et al. 2006; Precht et al. 2008b; Zimmer et al. 2010; Johnston et al. 2013). The lateral margins of selected *Pseudodiploria strigosa* colonies were monitored and photographed annually to detect any incipient changes over time and space. *Pseudodiploria strigosa* is more suitable for marginal comparisons than other coral species because of the conspicuous patterns and grooves that, when photographed, can be matched when repetitive annual photographs are overlaid.

5.2. LATERAL GROWTH METHODS

5.2.1. Lateral Growth Field Methods

At the beginning of the monitoring program in the late 1980s, sixty lateral growth stations, located on the margins of *Pseudodiploria strigosa* colonies, were established at each bank to assess coral margin growth rates. In 2003, 12 new stations at EFGB and 17 new stations at WFGB were established to replace old stations that had been lost or were overgrown. With few exceptions, this method is not common among coral reef monitoring programs and has proved to be extremely problematic throughout the FGB monitoring program (section 5.4).

Rates of coral advance (tissue gain) and retreat (tissue loss) were determined through photographic analysis of these permanent stations. Lateral growth stations are located along a margin of live *Pseudodiploria strigosa* adjacent to bare substrate or reef rock. The stations contain two bolts that are embedded into the substrate in such a manner that the growth margin of the coral bisects a close-up photograph of the station. Each station is identified by a uniquely numbered plastic tag secured to one of the station bolts.

Lateral growth stations are located and marked by SCUBA divers using underwater maps (Volume II, Appendix 2), and then divers photograph each station. Divers were equipped with a camera, a close-up framer, and strobe. In 2011 and 2012, a Canon Power Shot G11® in a Fisheye Fix® housing with a standard flatport and Inon® strobe was used. The camera was set at auto exposure, ISO 200, on macro and autofocus settings, and strobe set to TTL. The framer was placed on corner bolts at each station, with the intention to obtain a repeated image of the station (Figure 5.2.1). Some stations were missing identification tags. Those stations that did have tags were photographed with the tag in the frame. For stations without tags, the current photographs were matched with past photographs using the ridge patterns of the *Pseudodiploria strigosa* colonies.

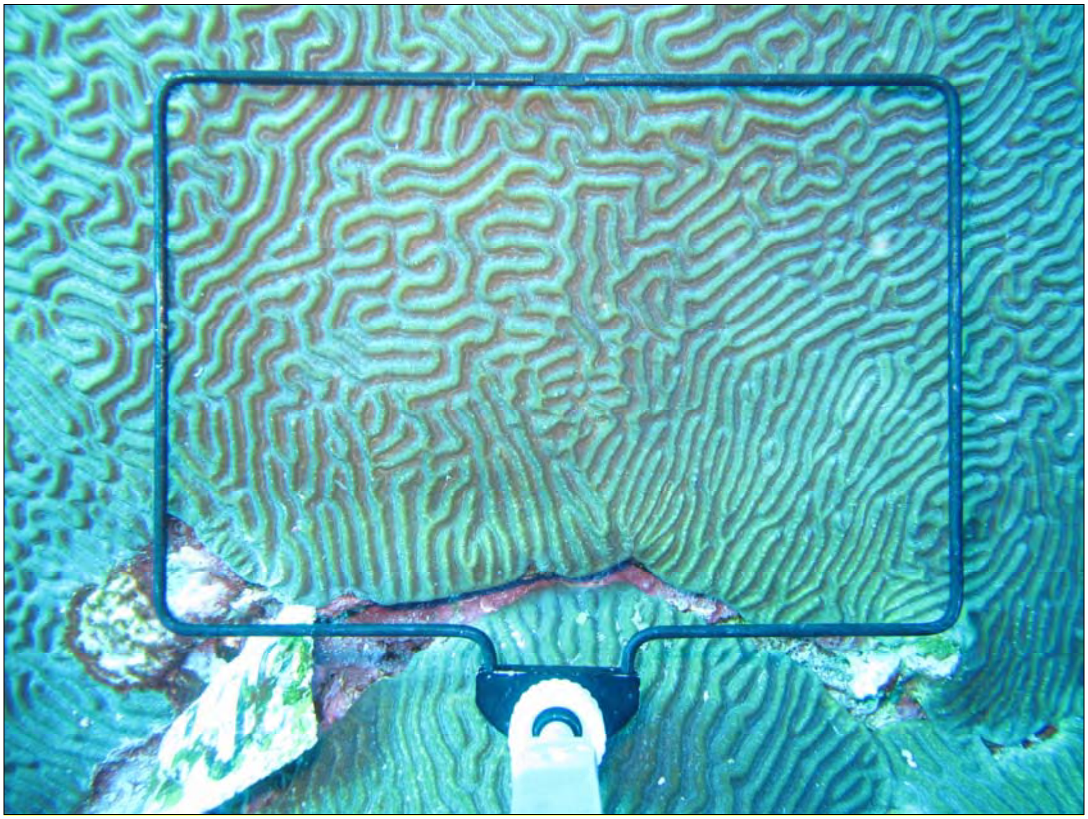


Figure 5.2.1. Lateral growth station #108 on a *Pseudodiploria strigosa* colony with close-up framer at WFGB in 2011 (NOAA/FGBNMS).

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

5.2.2. Lateral Growth Data Processing

Images corresponding to a specific lateral growth station were compared between consecutive years (2010–2011 and 2011–2012). Lateral differences in the margins of the *Pseudodiploria strigosa* colonies were evaluated by overlaying the pairs of photographs, using Photoshop CS5®, and dividing the lateral growth edge of the colony vertically into areas categorized as "growth," "retreat," "stable," and "not available" (for areas that were dark, shadowed, or out of focus). Using ImageJ® (a public domain, Java-based image processing program developed at the National Institutes of Health), the entire horizontal width of the frame was set to 100 units, then the horizontal distances of growth, retreat, and stability were measured (Figure 5.2.2). These values were then combined to obtain an overall percentage of growth, retreat, and stability for each image. Successive photographs of a given colony were aligned using the colony's ridge patterns.

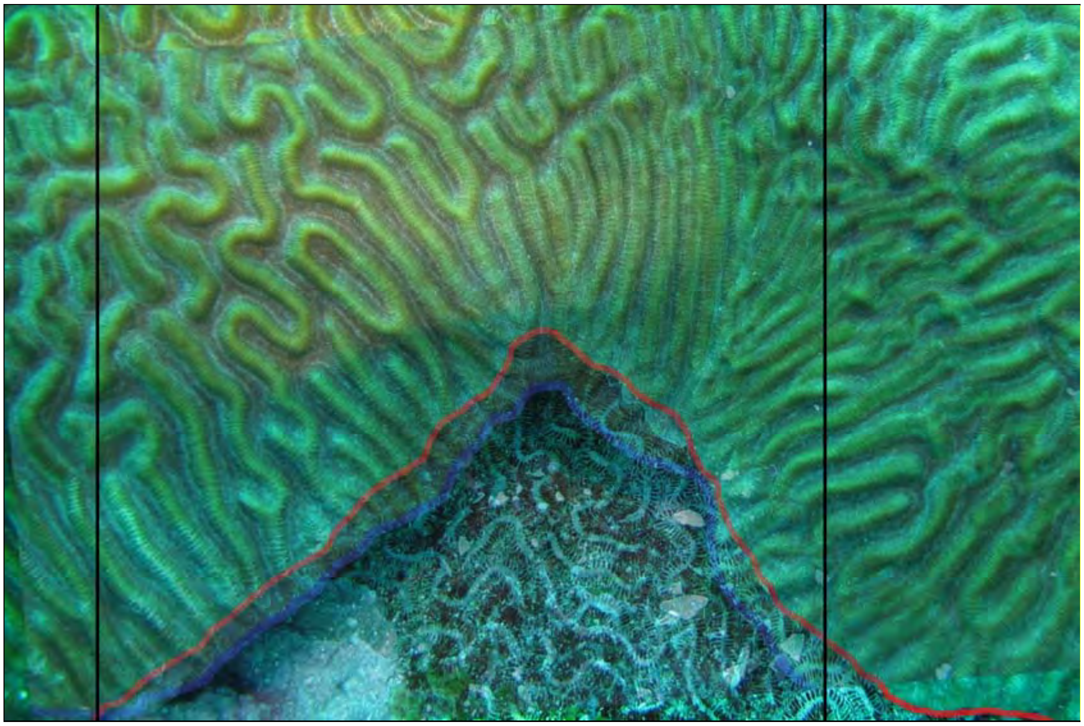


Figure 5.2.2. Image analysis of *Pseudodiploria strigosa* lateral growth margin at EFGB (NOAA/FGBNMS).

The red line is the 2010 margin and the blue line is the 2011 margin demonstrating tissue growth from 2010–2011.

5.2.3. Lateral Growth Data Presentation and Analysis

Proportional annual change in the lateral margin of individual *Pseudodiploria strigosa* colonies, whether positive or negative, was examined. A percent change value was calculated for each comparable image margin, and each image margin was assigned an overall designation category of growth, retreat, or stability from 2010–2011 and 2011–2012. Lateral growth data can be found in Volume II Appendix 3.

The growth, retreat, and stability of colony margin tissue were calculated by subtracting the linear distance for each category measured for each station margin for the current year from the linear distance for each category measured during the previous year. Areas of the image that were not distinguishable during analysis were not included in the total percentage. Percent changes were calculated by determining the linear margin gained or lost and dividing by the total units of the photographed colony margin and multiplying by 100. A two-tailed t-test was performed to test the null hypotheses that the marginal growth did not differ between banks (EFGB and WFGB) with an experimentwise error rate of $\alpha=0.05$. All analyses were calculated with the statistical software JMP® version 10.0.

5.3. LATERAL GROWTH RESULTS

In 2011, 29 colonies of *Pseudodiploria strigosa* were photographed at EFGB and 31 in 2012. In 2011, 19 lateral growth stations were photographed at WFGB and 40 in 2012. However, as in previous years, most of these photographs were not usable for analysis. Of the photographs taken, 21 photos of the same station were taken in 2010–2011 and 20 photos of the same station from 2011–2012 for EFGB. However, only four pairs generated successful matches from 2010–2011 and only one photo pair generated a successful match from 2011–2012. Of the photos taken at WFGB, 13 photos from the same station were taken in 2010–2011, and 17 from the same stations were taken from 2011–2012. However, only three pairs generated successful matches from 2010–2011 and no pairs generated a successful match from 2011–2012 (Table 5.3.1).

Table 5.3.1.

Comparable Lateral Growth Station Photographs from 2009–2012

Year	EFGB			WFGB		
	Number of Photos Collected	Photos Matched to Station from Previous Year	Number of Successful Photo Matches to Station from Previous Year	Number of Photos Collected	Photos Matched to Station from Previous Year	Number of Successful Photo Matches to Station from Previous Year
2009	30	0	0	41	0	0
2010	29	20	5	32	9	9
2011	29	21	4	19	13	3
2012	31	20	1	40	17	0

Lateral growth data was not collected during the 2008 annual monitoring cruise due to the constraints of weather; therefore, there was no comparable data from 2009 to 2008.

Several factors contribute to the great discrepancy in the number of photographs collected compared to the number of "successful matches" for analysis. These factors include: 1) some stations no longer have margins to measure in a photograph because of colony growth or death and 2) photographs are not taken in the same position or orientation each year because of bolts overgrown by coral, missing bolts, photographer error, and changes in the rugosity of some colonies. Though numerous stations may have been photographed in two consecutive years, because of the reasons listed above, far fewer photo comparisons were possible.

The proportion of annual change in marginal tissue growth or retreat was examined by bank (EFGB and WFGB) and by year (2010–2011 and 2011–2012). There was a high degree of variability between progression/regression percentages among years for both EFGB and WFGB (Table 5.3.2). On average, the proportions of marginal growth from 2010–2012 were advancing. For each station, a single estimate of each measure (growth, retreat, and stability), was calculated, regardless of the number of areas of progression or regression present. Greater than 33% of all the marginal length analyzed was advancing and exhibiting positive growth. At EFGB, there was an overall increase in marginal growth from 2010–2011, and from 2011–2012, the marginal growth retreated. WFGB also showed an increase in *Pseudodiploria strigosa* marginal growth from 2010–2011. There were no comparable stations during 2011–2012. Volume II Appendix 6 of this report contains the lateral growth data from 2011 and 2012.

Table 5.3.2.

Pseudodiploria strigosa Lateral Growth Stations and Percent of Margin Growing, Retreating, or Remaining Stable of Coral Tissue at EFGB and WFGB from 2010–2011 and 2011–2012

Site	**Percent Change from 2010–2011**		
EFGB Station	**Growth**	**Retreat**	**Stable**
EFGB 12	100.0	0.0	0.0
EFGB 13	67.3	8.9	23.8
EFGB 29	0.0	100.0	0.0
EFGB 49	53.2	25.6	21.2
WFGB Station	**Growth**	**Retreat**	**Stable**
WFGB 69	77.4	22.6	0.00
WFGB 73	100.0	0.0	0.0
WFGB 99	45.1	15.1	39.8
Site	**Percent Change from 2011–2012**		
EFGB Station	**Growth**	**Retreat**	**Stable**
EFGB 49	12.7	87.3	0.0

5.3.1. Historical Comparison of Lateral Growth Results

A historical comparison of percent change in *Pseudodiploria strigosa* colonies was made from year 2001–2012. Although lateral growth measurements have been collected since the beginning of the monitoring program, variations in methods over the monitoring years only allowed comparisons to be made for this time frame.

There was a high degree of variability between advance/retreat percentages among all years for both EFGB and WFGB (Figure 5.3.1). However, greater than 13% of all the marginal length analyzed was advancing and exhibiting positive growth from 2001–2012. At EFGB, there was an overall 4% increase in marginal growth from 2001–2012. WFGB also showed an increase (23%) in *Pseudodiploria strigosa* marginal growth from 2001–2011 (there were no comparable WFGB stations during 2011–2012). A two-tailed t-test revealed no significant difference in *Pseudodiploria strigosa* marginal growth between EFGB and WFGB from 2011–2012 (df=15, Std Error= 15.91, t-ratio=1.35, P-value=0.90).

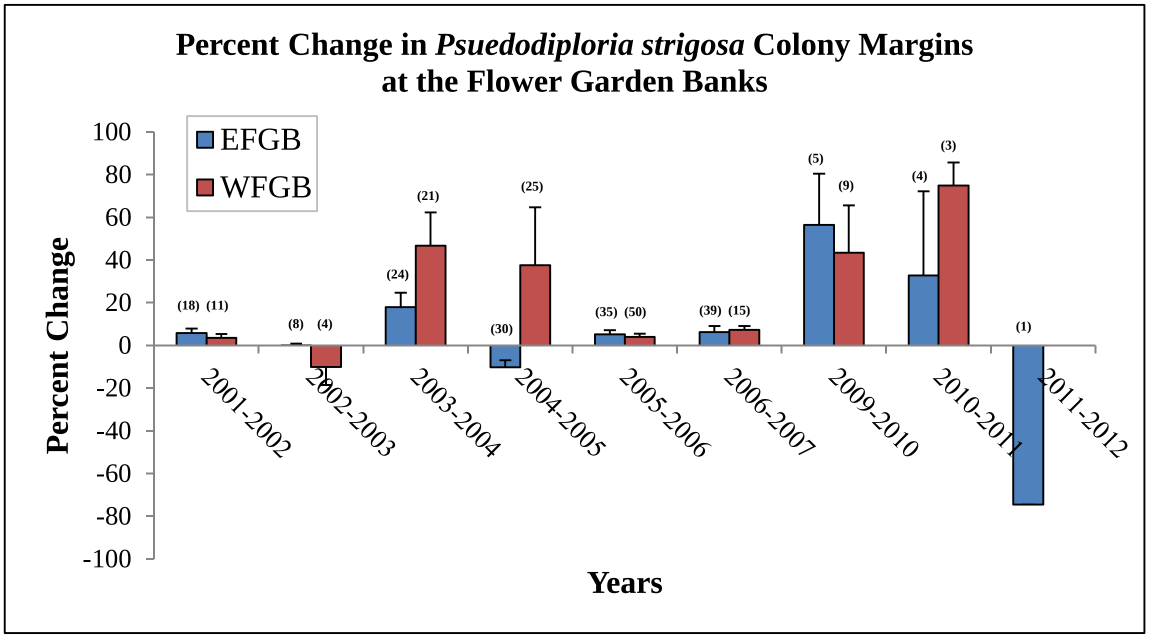


Figure 5.3.1. Percent change ± SE in *Pseudodiploria strigosa* colonies at EFGB and WFGB during intervals from 2001–2012.

No ± SE value for 2011–2012 at EFGB and no comparison for WFGB from 2011–2012. Sample size for each bank in parentheses above corresponding bar on graph. Note declining sample size number as photo station matches decline over time.

5.4. LATERAL GROWTH DISCUSSION

Lateral growth measurements have been used for much of the monitoring history of the FGB. However, this is not a common method, and does not allow for comparison to other coral reef monitoring programs in the region.

Many factors have affected the quality of lateral growth data from the long-term monitoring study for many years. The stations appear to have a short useful life because the colonies can overgrow the small area within the station in a short period of time, causing coral to grow beyond the margin and over the station bolts (Figure 5.4.1). It is a laborious task to keep the stations maintained, because they have to be re-established or repaired frequently. The stations can also retreat or become overgrown with algae (Figure 5.4.2). The margins on many colonies can also become irregular by overgrowing on one side, thus making the station no longer usable because the margin can no longer be measured and compared to previous photos from past years (Figure 5.4.3). Previous researchers have encountered problems with locating overgrown lateral growth photostations and photographing the stations in a consistent way (e.g., at the same angle every time) due to bolts shifting from coral overgrowth, which results in a different orientation from one year to the next (Figure 5.4.4). As of the 2012 research season, few comparable stations remained at either bank.

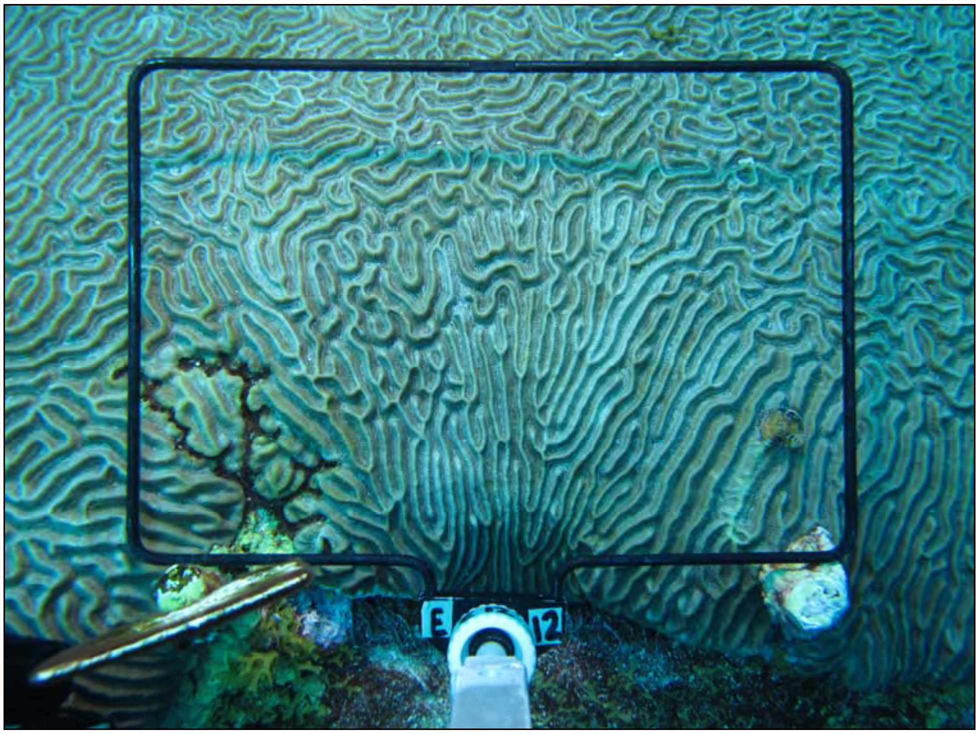


Figure 5.4.1. Lateral growth station #10 on a *Pseudodiploria strigosa* colony with close-up framer at EFGB in 2012 displaying an overgrown margin and bolts (NOAA/FGBNMS).

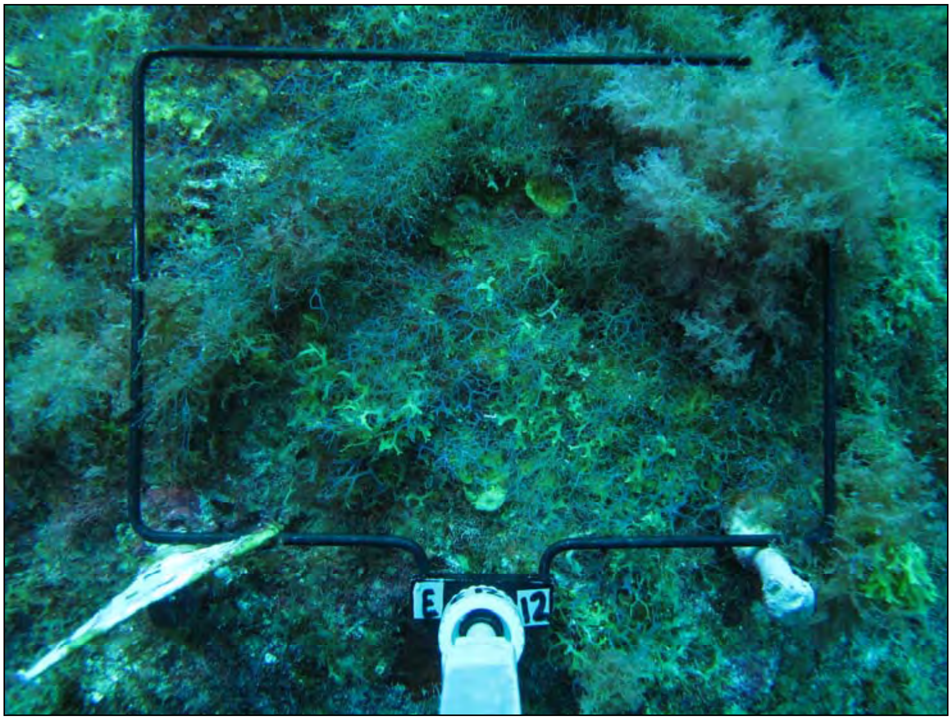


Figure 5.4.2. Lateral growth station #15 on a *Pseudodiploria strigosa* colony with close-up framer at EFGB in 2012 displaying algae overgrowth (NOAA/FGBNMS).

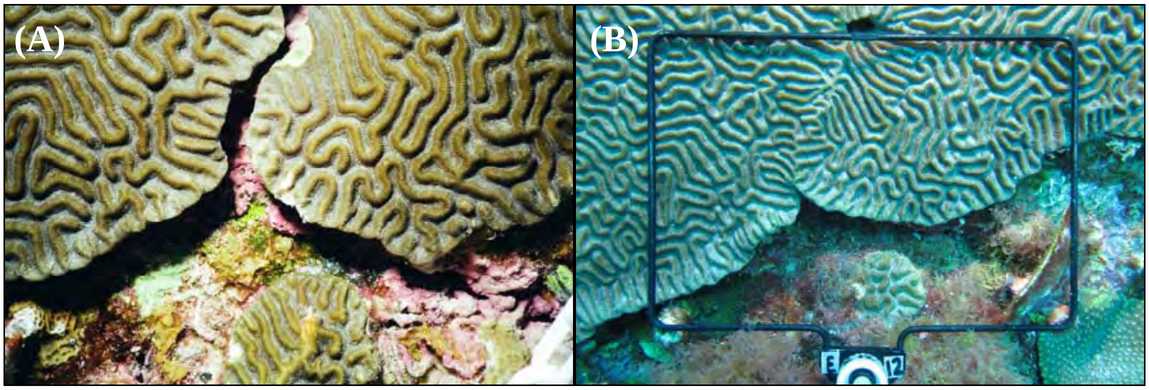


Figure 5.4.3. Lateral growth station #10 on a *Pseudodiploria strigosa* colony with close-up framer at EFGB in (A) 2009 displaying a measurable margin, and (B) in 2012 displaying an overgrown irregular margin that can no longer provide a comparable measurement (NOAA/FGBNMS).

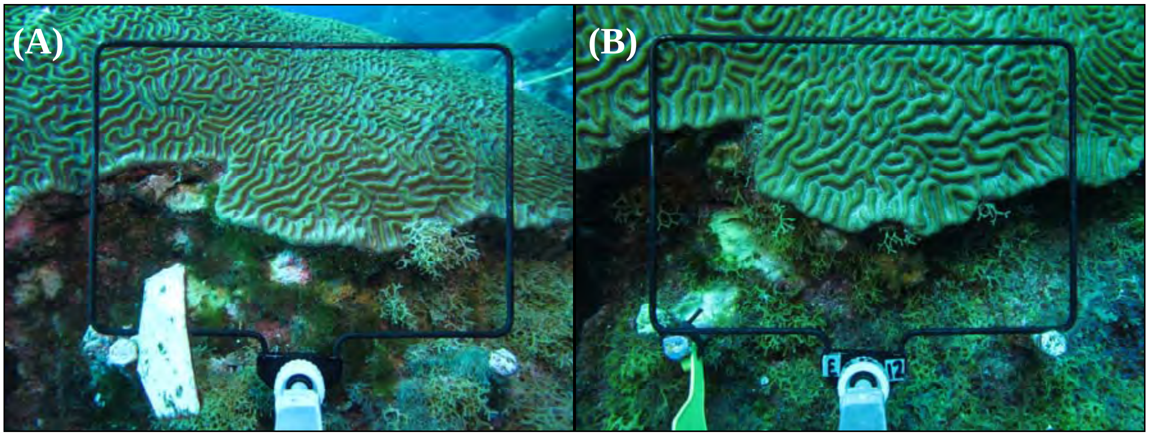


Figure 5.4.4. Lateral growth station #34 on a *Pseudodiploria strigosa* colony with close-up framer at EFGB in (A) 2011 where the framer was not placed in the correct orientation, and (B) in 2012 displaying the correct orientation and bolt placement; however, the photo is no longer comparable to the previous year (NOAA/FGBNMS).

In 2012, many of the stations established years ago were completely overgrown by coral (Volume II Appendix 6.B.), which resulted in the loss of many stations. When FGBNMS began conducting the long-term monitoring in 2009, many of the lateral growth stations could not be located because of colony over growth or inaccurate mapping of the stations from previous years. Also, the frequent loss of marker pins and great changes in stations resulted in photographs being taken in different orientations, which made analysis difficult or impossible. In many instances, the framer used in the technique prevents exact replication of the sample area because the subject area is not two-dimensional and the framer cannot be laid “flat” on the coral surface. Because of the direct contact, the effects of increased rugosity and the changing orientation of margins caused by bioerosion, and accretionary growth also hinders repetitive photography.

In an attempt to summarize the status of the lateral growth stations since FGBNMS began the long-term monitoring, lateral growth stations were compared from 2009 to 2012; over time the majority of the stations have become overgrown by coral or algae (Volume II Appendix 3B). At EFGB, 89% of the stations had been overgrown with coral by 2012, and 84% of the stations at WFGB had been overgrown with coral by 2012. Though these stations no longer create comparable photos for analysis, it should be noted that they are displaying positive growth.

This method has proved to be extremely problematic throughout the FGB monitoring program. Originally, both *Pseudodiploria strigosa* and *Montastreaea annularis* colonies were measured for lateral growth. However, *Montastreaea annularis* stations were eliminated in 1992 after stations were unsuitable for analysis. Throughout the years, different methods have been used to analyze lateral growth (e.g., cm/6 months, cm/year, cm^2/year, cm^2/year percent change, and positive or negative percent change), and a variety of analyses have been conducted (net growth, advance/retreat rates, advance/retreat ratios, marginal stability, percent change) that are not consistent among reporting periods; this makes historical comparisons problematic. A full analysis of varying methods used throughout the monitoring program shows inconsistencies among techniques and analyses (Table 5.4.1).

Improvements in methodology and a separate cruise to allow time to establish new stations are necessary. A new method, replacing the current framer bolts with a small “key and keyhole” plate is currently being tested (Figure 5.4.5). A thick plastic plate bolted to the bare substrate will act as a keyhole next to the *Pseudodiploria strigosa* margin. The new camera “key” pole locks into the plate, allowing for precise and consistent photographic repeatability. The “key and keyhole” mechanism prevents improper orientation, which has caused issues with data analyses in past years. The “key holes” will be plugged to prevent biofouling. Thirty test stations at each bank have custom numbers based on bank and quadrant with new Y-Tex tags. The distance and heading to each lateral station has been incorporated into a new master map; this gives divers more accurate location information for each station from a known location. Comparisons for the updated method will be available from 2014–2015.

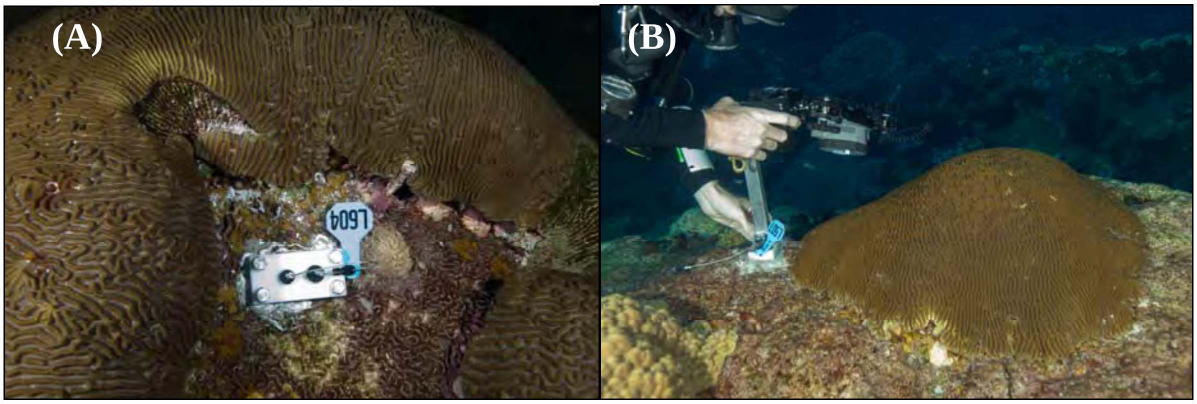


Figure 5.4.5. New lateral growth test station on a *Pseudodiploria strigosa* colony margin (A), and lateral photograph taken by placing the framer in the key hole plate (B) (NOAA/FGBNMS).

Table 5.4.1.

Historical Review of *Pseudodiploria strigosa* Lateral Growth Methods and Analyses Throughout the Monitoring Program

Years	**1989–1991**	**1992, 1994–1995**	**1996–1997**	**1998–1999**	**1998–2001**	**2002–2003**	**2004–2005**	**2004–2008**	**2009–2010**	**2011–2012**
Report	Gittings et al. TAMU 1992	Continental Shelf Associates 1996	Dokken et al. TAMUCC 1999	Dokken et al. TAMUCC 2001	Dokken et al. TAMUCC 2003	Precht et al. PBS&J 2006	Precht et al. PBS&J 2008	Zimmer et al. PBS&J 2010	Johnston et al. FGBNMS 2013	this report
Growth Units	cm/6 months	cm/yr	cm/yr	cm²/station	% change: cm²/station	% change - positive/negative	% change - cm²/station	% change - cm²/station	% change - positive/negative	% change - positive/negative
Growth rate	0.10	EFGB: 0.05, WFGB: 0.2	EFGB: 0.06, WFGB 0.14	EFGB: -0.14, WFGB: -0.54	NR	NR	NR	NR	NR	NR
EFGB Lateral Photos	60 *P. strigosa*, 60 *M. annularis*	60 photographed, number analyzed not reported.	60 *P. strigosa*	46 (1998), 50 (1999)	13 (2000), 29 (2001)	54 photographed, 18 "matches" (2002), 62 photographed, 8 "matches" (2003)	36 photographed, 24 "matches" (2004), 60 photographed, 30 "matches" (2005)	52 photographed, 35 "matches" (2006), 58 photographed, 39 "matches" (2007)	41 photographed (2009), 29 photographed (2010), 5 "matches"	21 photographed (2011), 20 photographed (2012), 1 "match"
WFGB Lateral Photos	60 *P. strigosa*, 60 *M. annularis*	60 photographed, number analyzed not reported.	60 *P. strigosa*	1998 not recorded, 47 (1999)	25 (2000), 24 (2001)	43 photographed, 11 "matches" (2002), 64 photographed, 4 "matches" (2003)	27 photographed, 21 "matches" (2004), 58 photographed, 25 "matches" (2005)	60 photographed, 50 "matches" (2006), 18 photographed, 15 "matches" (2007)	40 photographed (2009), 34 photographed in (2010), 9 "matches"	13 photographed (2011), 17 photographed (2012), 0 "match"
Methods and Analysis	Nails used to mark stations. Number of stations actually analyzed/sampled throughout study not reported. Variety of analyses conducted (net growth, advance/retreat rates, advance/retreat ratios, marginal stability).	Previously installed stations unsuitable. New stations established in 1994. Of photographed stations, **60% could not be analyzed. *M. annularis* stations eliminated after 1992.**	Of 60 stations established on each bank, approximately 20 on each bank were suitable. New stations were established in 1996. Ternary diagrams used to display advance/retreat ratios.	A substantial number of stations were unsutiable for analysis in 1998. Ternary diagrams used to display advance/retreat ratios.	Data are used for descriptive purposes only because the pins and markers are constantly being lost, rendering data unsuitable for analysis.	Unusuable photographs in 2002 (too dark). New stations established in 2003, so could not compare with previous year. Very little usable data so only generalizations made.	Poor weather conditions in 2004 limited sampling.	Stations not sampled in 2008 due to weather. Digital photography "tested" in 2007. High variability of data over time prevented statistical analysis	Most lateral growth stations unsuitable for analysis due to overgrowth by coral or algae.	Most lateral growth stations unsuitable for analysis due to overgrowth by coral or algae.

Despite improved methods for collecting comparable lateral stations, it should be evaluated whether lateral growth data is a valuable measure for monitoring. These stations have proved to be problematic throughout the program history, as stated above and noted in previous reports, and lateral growth data is not comparable to other coral reef monitoring programs because other programs do not collect this data.

CHAPTER 6.0: SCLEROCHRONOLOGY

6.1. SCLEROCHRONOLOGY METHODOLOGICAL RATIONALE

Sclerochronology involves the study of coral growth by the measurement of the accretionary growth bands deposited by corals in their calcium carbonate skeletons. One commonly measured coral growth parameter is skeletal extension rate. The skeletons of many corals, including *Orbicella* spp., contain a consistent sequence of high- and low-density bands, comparable to tree rings. Annual growth is represented by each couplet of adjacent high- and low-density bands (Figure 6.1.1). Thus, the rate of skeletal extension can be determined by measuring the combined width of two adjacent growth bands along the length of a corallite. The skeletons of long-lived corals therefore record the histories of coral growth, and it is possible to examine how current rates compare with those of the past (Dodge and Kohler 1984).

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

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

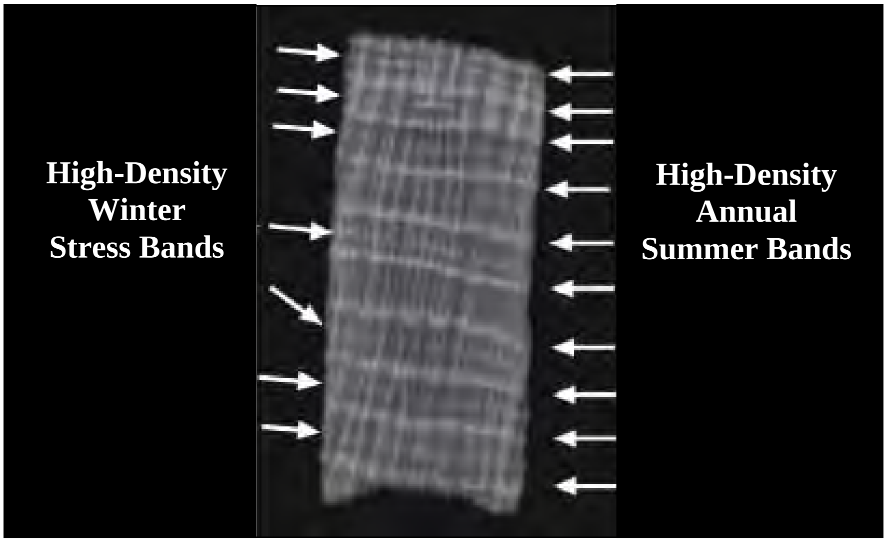


Figure 6.1.1. Example X-radiograph of *Orbicella faveolata* skeletal material from the FGB showing density banding (Slowey/TAMU).

6.2. SCLEROCHRONOLOGY METHODS

6.2.1. Why *Orbicella faveolata*?

The determination of coral skeletal extension rate has been identified as one of the best quantitative measures of 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 *Orbicella* spp. show relatively little response in growth rate to varying environmental conditions compared to other species. However, studies have shown significant suppression of *Orbicella faveolata* growth may occur if a coral is disturbed, for example, by short-term exposure to high concentrations of drilling mud (Hudson and Robbin 1980) or by changes in environmental parameters when a coral is transferred from an offshore location to an inshore site (Hudson 1981b).

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

Previous research on sclerochronology on the *Orbicella* spp. has been extensive (Dustan 1975; Hudson et al. 1976; Emiliani et al. 1978; Foster 1980; Hudson 1981a, 1981b; Graus and Macintyre 1982; Dodge and Lang 1983; Dodge and Brass 1984; Leder et al. 1991; Slowey and Crowley 1995). It has been shown that accelerated growth in *Orbicella* spp. 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 *Orbicella* spp. appeared to be deposited for only short periods of time, whereas the low-density bands were generally produced for a greater part of the year.

6.2.2. Sclerochronology Field Methods

Random *Orbicella faveolata* core samples from each quadrant of EFGB and WFGB study sites were collected every two years. In July 2012, four cores were taken from robust *Orbicella faveolata* corals living within the northeast (NE), northwest (NW), southeast (SE) and southwest (SW) quadrants of the study site, for a total of eight cores. The quality of the initial SW and SE cores recovered from WFGB was not certain, so replicate cores were taken. The NW core from EFGB did not produce clearly recognizable growth bands and was therefore not used in the analysis.

A pneumatic drill, fitted with a diamond-tipped 35 mm lapidary bit, was used to extract short cores of skeletal material from the apex of the *Orbicella faveolata* colonies. Corals were sampled at their apex because growth rate is known to vary across the surface of an individual coral colony and it is at the apex where the maximum rate typically occurs. The longitudinal axis of each core was oriented as closely as possible to the direction that the corallites appeared to grow, that is, along the main growth axis of the coral. The cores were about 30 mm in diameter and their lengths ranged from 5 to 17 cm long. The holes left from core extraction were filled with pre-drilled coral skeleton plugs and coral rubble (obtained from coral cores extracted previously during mooring drilling) that were fixed in place using LiquidRoc 500® adhesive to prevent subsequent bioerosion and mortality of the sampled colony.

The cores were placed in padded sections of plastic pipe that were filled with 95% ethanol solution, and refrigerated to preserve the coral skeletal material and reduce disturbance during storage and transport. For processing and analysis, the coral cores were transferred to the laboratory of Dr. Niall Slowey at the Department of Oceanography at Texas A&M University.

6.2.3. Sclerochronology Data Processing

Comparable images of the coral cores collected in 2012 were obtained using the computerized tomography (CT) scanner approach (Brooks and Hounsfield 1973; DiChiro 1976; and Wellington and Vinegar 1987). The process of determining the coral extension rates involved several steps. First, a Siemens® CT scanner at Texas A&M University’s College of Veterinary Medicine and Biomedical Sciences was used to generate a three-dimensional matrix of X-ray attenuation coefficients that correspond to adjacent 0.6 × 0.6 × 0.6 mm volumes of the skeletal material in each coral core section. Matrix values were expressed in CT number notation, where variations in CT number largely reflect variations in skeletal bulk density.

To create and analyze digital images of the coral cores, the CT numbers were associated with grayscale values where smaller CT values (lower densities) correspond to smaller grayscale values (darker gray). Next, the images generated by the CT scanner were loaded into OsiriX® medical image processing software (Rosset et al. 2004). For each image, the pixel grayscale values of 14 adjacent 0.6 mm thick "slices" of CT scanner data were averaged, simulating the image that would have been obtained if an 8.4- mm-thick "slab" of skeletal material had actually been cut from the core section and then X-rayed in the traditional fashion. The resultant slab images revealed variations in skeletal density, and allowed annual bands and stress bands to be identified. Ages for the annual band couplets were assigned by counting backwards from the most recently deposited colony surface at the top of each core toward older skeletal material at depths within the each core. Finally, the slab images were loaded into the ImageJ® software package (Schneider et al. 2012). Three straight transect lines were drawn to measure the changes of grayscale corresponding to the annual density band couplets, with each transect line following the apparent corallite walls while remaining as perpendicular as possible to the growth bands. For each transect, pixel grayscale compared with distance was determined and the distance between summertime high-density bands indicates the annual extension rate of the coral for specific time periods. An average extension rate value for each year was obtained by averaging the values from the three transects.

For each core of *Orbicella faveolata* skeletal material, slab images were generated at three or four different orientations about the core's longitudinal axis. Results from the orientation that yielded the most accurate extension rates for each coral core are presented in this report. A thorough analysis of the potential influence of "slab" orientation on extension rate values is presented elsewhere (Yudelman 2014).

6.2.4. Sclerochronology Data Presentation and Analysis

After the annual accretionary growth (extension) rates were determined for each coral core, the means and standard errors were calculated for each bank and year. ANOVA was performed to compare differences in extension rates between banks (EFGB and WFGB) with an experimentwise error rate of $\alpha=0.05$. Analyses were calculated with the statistical software JMP® version 10.0.

6.3. SCLEROCHRONOLOGY RESULTS

X-ray images of skeletal material in the *Orbicella faveolata* coral cores obtained in 2012 revealed two types of distinct high-density bands: annual bands presumably deposited during late summer, and stress bands deposited during periods of otherwise rapid growth. The spatial patterns of corallite development within the cores were such that it was possible to determine reliable annual extension rates from eight of the cores (Figures 6.3.1 and 6.3.2; Table 6.3.1). Mean extension rates and standard error values were calculated for each bank and year when comparable measurements were available. Extension rates were not determined for the time period extending from the summer 2011–2012 because clearly recognizable high-density growth bands corresponding to the summer of 2012 were not evident. The 2012 sclerochronology data is in Volume II Appendix 5 of this report.

Annual extension rate records are presented for three *Orbicella faveolata* corals at EFGB (Table 6.3.1). The longest time period spanned by these records was from 1995 to 2012 (>16 years). During this period, annual extension rates ranged from 4.6 to 9.6 mm/yr; the maximum value occurred from 2004 to 2005, and the minimum value occurred from 2010 to 2011. From 1996 and 2010, the mean annual extension rate of EFGB corals was 6.5 mm/yr.

Annual extension rate records are presented for five *Orbicella faveolata* corals at WFGB (Table 6.3.1). The longest time period spanned by these records was from 1997 to 2012 (>14 years). WFGB corals displayed a greater range of annual extension rates than the corals at EFGB; they ranged from 3.3 to 10.3 mm/yr, with the maximum value occurred from 2007 and 2008 and the minimum value occurred from 2010 and 2011. Corals at WFGB extended at a mean rate of 5.6 mm/yr during the period from 1997 to 2012.

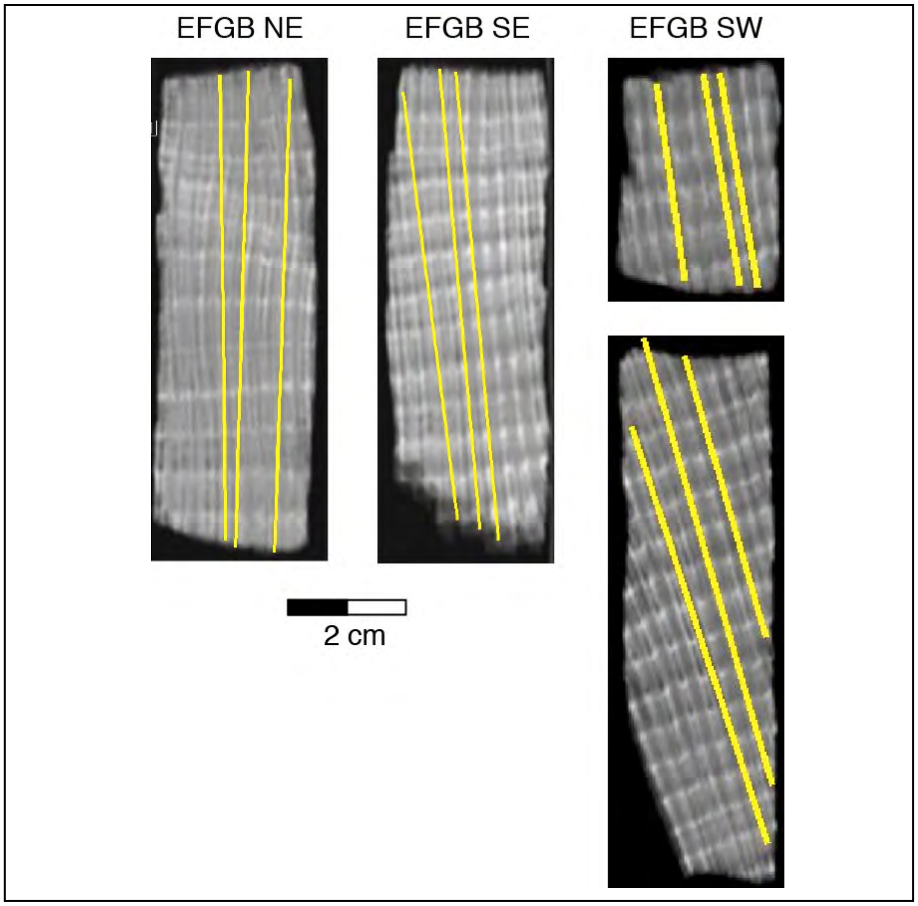


Figure 6.3.1. Digitally created slab X-radiographs of *Orbicella faveolata* skeletal structure in the plane of corallite growth from coral cores taken in EFGB study site quadrants (NE=northeast, SE=southeast, SW=southwest) (Yudelman 2014).

Yellow lines across each image indicate transects along which coral extension was measured to obtain values in Table 6.3.1.

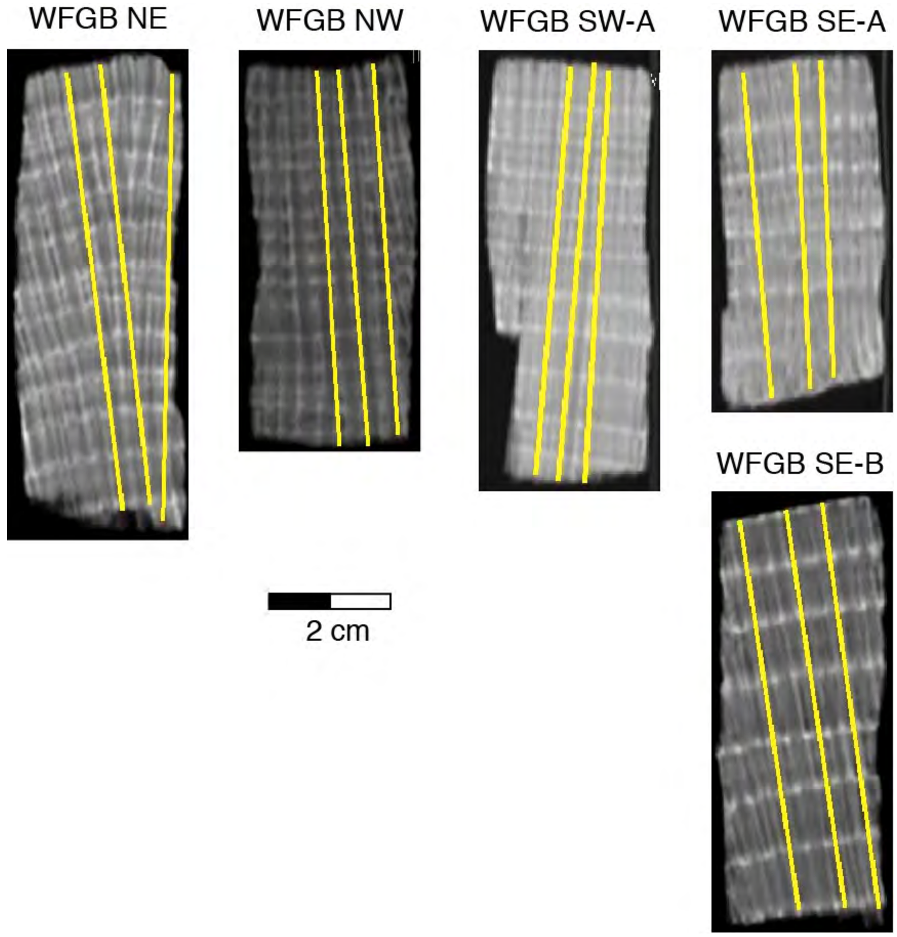


Figure 6.3.2. Digitally created slab X-radiographs of *Orbicella faveolata* skeletal structure in the plane of corallite growth from coral cores taken in WFGB study site quadrants (NW=northwest, NE=northeast, SE=southeast, SW=southwest) (Yudelman 2014).

Yellow lines across each image indicate transects along which coral extension was measured to obtain values in Table 6.3.1.

Table 6.3.1.

Coral Growth at the FGB Determined from Cores Taken in 2012

***Orbicella faveolata* Extension Rate (mm/yr)**												
Year	***East Flower Garden Bank***					***West Flower Garden Bank***						
	NE	**SE**	**SW**	**Mean**	***Std. Error***	**NE**	**NW**	**SW**	**SE-A**	**SE-B**	**Mean**	***Std. Error***
2012 - 2011	↓	↓	↓	–	–	↓	↓	↓	↓	↓	–	–
2011 - 2010	4.6	4.9	6.3	**5.3**	**0.5**	6.5	3.3	5.7	8.0	8.4	**6.4**	**0.9**
2010 - 2009	7.6	5.4	6.8	**6.6**	**0.6**	5.7	3.9	6.3	9.5	9.0	**6.9**	**1.1**
2009 - 2008	6.8	5.2	7.1	**6.4**	**0.6**	5.6	4.6	6.1	9.6	10.0	**7.2**	**1.1**
2008 - 2007	5.1	5.9	7.4	**6.1**	**0.7**	6.0	3.5	6.5	7.5	10.3	**6.8**	**1.1**
2007 - 2006	6.4	6.2	6.4	**6.3**	**0.1**	6.1	3.7	4.0		8.3	**4.4**	**1.1**
2006 - 2005	8.6	5.7	6.9	**7.1**	**0.8**	6.9	5.0	5.1		10.0	**5.4**	**1.2**
2005 - 2004	9.6	5.8	6.8	**7.4**	**1.1**	6.0	4.0	6.0			**5.4**	**0.7**
2004 - 2003	7.4	6.5	6.9	**7.0**	**0.3**	6.5	4.1	6.1			**5.6**	**0.8**
2003 - 2002	7.5	5.6	7.2	**6.8**	**0.6**	7.6	4.4	6.2			**6.1**	**0.9**
2002 - 2001		5.6	6.8	**6.2**	**0.6**	7.7	4.2				**5.9**	**1.7**
2001 - 2000		5.4	7.0	**6.2**	**0.8**		5.9				**5.9**	
2000 - 1999			7.0	**7.0**			5.4				**5.4**	
1999 - 1998			6.2	**6.2**			4.2				**4.2**	
1998 - 1997			6.8	**6.8**			3.3				**3.3**	
1997 - 1996			6.2	**6.2**								
1996 - 1995			6.2	**6.2**								
	Mean All Years			**6.5**	**0.6**	**Mean All Years**					**5.6**	**1.0**

Each value is an average of measurements made on three transects across digitally created slab X-radiographs of coral cores (yellow lines on Figure 6.3.1 and Figure 6.3.2). Extension rates were not determined for 2011–2012 because clearly recognizable high-density growth bands were not evident. Cores are designated by quadrant in each study site: NW=northwest, NE=northeast, SE=southeast, SW=southwest. Data from Yudelman (2014).

EFGB cores indicate more similar extension rates than WFGB cores (Figure 6.3.3 and Figure 6.3.4). No apparent correlation exists between average annual extension rate and the water depth where the corals lived (all cores are from water depths between 18 and 22 m). Other factors may cause the differences in extension rates between the cores (i.e., genetic variability, temperature, food availability, surrounding organisms and habitat, current locations, predation, etc).

Extension rates also depend on two other factors: 1) where on the surface of the coral head a core is taken, and 2) the overall size and vitality of a coral. When divers sampled *Orbicella faveolata* coral heads for this study in 2012, they chose robust corals for sampling and attempted to take the cores from apex of the coral heads where the maximum rate typically occurs. Slight variations in the nature of the coral heads and the relative positions of the cores could nevertheless introduce biases.

To determine if the growth rates differed significantly between banks, a simple one-way ANOVA was performed to compare extension rates between EFGB and WFGB from 2012-1995 with an experimentwise error rate of α=0.05. The data were normally distributed, so no transformation was necessary. The extension rates for the period of comparison were not significantly different between EFGB and WFGB (df=1, SS=1.67, F-ratio=0.65, P-value=0.42).

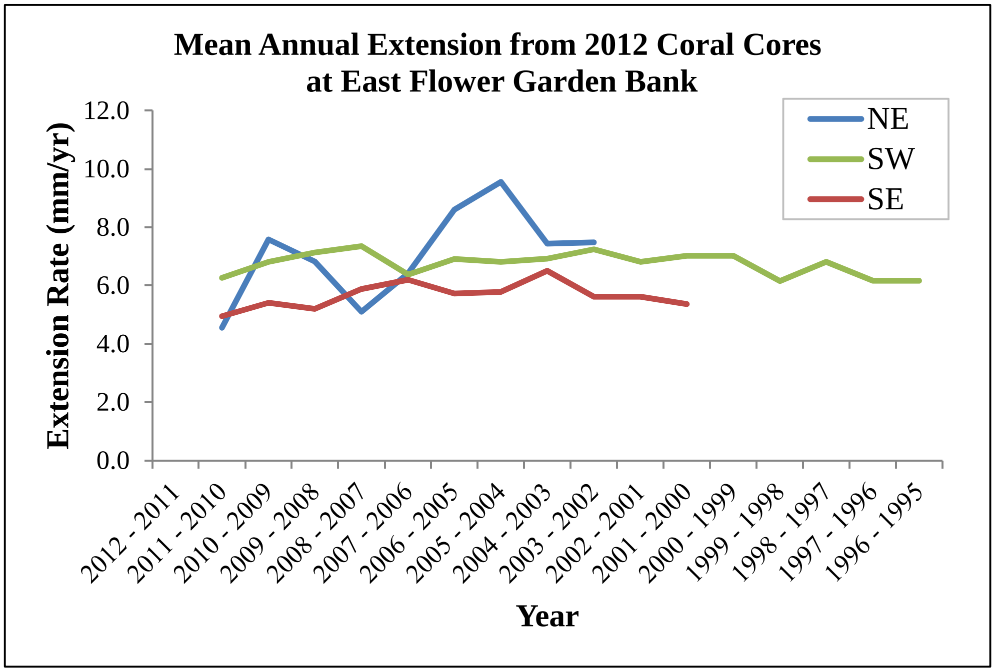


Figure 6.3.3. Mean annual extension rates determined from cores collected in 2012 at EFGB (Yudelman 2014).

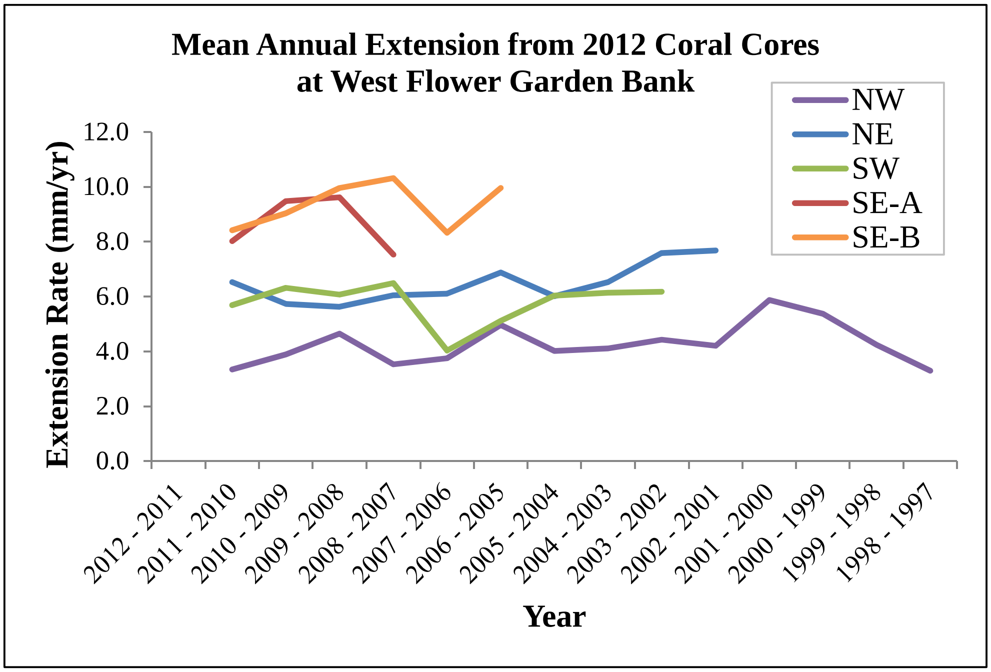


Figure 6.3.4. Mean annual extension rates determined from cores collected in 2012 at WFGB (Yudelman 2014).

6.4. SCLEROCHRONOLOGY DISCUSSION

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

Accretionary rates of *Orbicella annularis* documented over a wide geographic range throughout the Caribbean vary from 3.0 to 12.0 mm/yr (Weber and White 1977). Growth rates have been shown to vary with depth, with faster growth rates generally occurring in shallower water (Weber and White 1977). Hudson (1981a) reported growth rates of *Orbicella 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. Hudson and Robbin (1980) and Deslarzes (1992) reported annual growth rates for 16 colonies of *Orbicella annularis* at the FGB. The mean was 7.9 mm/yr from 1886–1907, 8.8 mm/yr from 1907–1957, 7.0 mm/yr from 1957–1988, and 9.0 mm/yr during 1988–1989 (the last year they had data).

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

Cores taken during the 2012 sampling period indicate that, for at least the decade leading up to and including the summer of 2011, *Orbicella faveolata* extension rates ranged from 4.6 to 9.6 mm/yr at EFGB and 3.3 to 10.3 mm/yr at WFGB. These ranges are quite similar to those found from cores taken during the 2009–2010 sampling period (3.0 to 7.6 mm/yr at EFGB and 3.3 to 9.7 mm/yr at WFGB) and the growth rates reported by Zimmer et al. (2010) for the 2004–2008 long-term monitoring reporting period, but differed slightly from the growth rates reported by Precht et al. (2006) and the past work by Dokken et al. (2003), who reported a wider range of growth rates at EFGB and WFGB. Growth rates for *Orbicella faveolata* at WFGB, and less so at EFGB, continued to be in the middle to upper range of FGB growth rates as recorded by Hudson and Robbin (1980).

The fact that the range of values found during the past three monitoring efforts displays a decrease in range of values, when compared to previous monitoring efforts, may reflect two factors. First, the divers collecting the monitoring cores have greater awareness of the need to consistently take cores from the apexes of similarly-sized, robust coral heads, reducing variability associated with differences in coral growth associated with coral head geometry and coral head vitality. Second, natural interdecadal variations in environmental factors do occur. Because coral cores taken for monitoring purposes are relatively short, the effects of interdecadal variations in environmental conditions on coral extension become more apparent when data from monitoring efforts associated with different time periods are compared.

For example, of long-term growth studies of *Orbicella faveolata* corals at the FGB, Hudson and Robbin (1980) and Deslarzes (1992) observed that a late 1950s growth decline is a prominent feature of the records. Studies first hypothesized this decline could be caused by lower light levels due to bank subsidence that resulted from salt dome dissolution (Rezak and Bright 1981), or local variations in water temperature or outflow from the Atchafalaya River (Dodge and Lang 1983; Szmant-Froelich 1984) with a positive correlation between and winter/spring temperature and growth, and a negative correlation between Atchafalaya River discharge and growth. The analysis by Slowey and Crowley (1995) supported the temperature explanation and fit it into a large-scale climatic context. They compared meteorologic and coral growth records and found that during the past century changes in coral growth at the FGB correspond to changes in the winter climate of the Gulf of Mexico and southeastern U.S. Slowey and Crowley (1995) found that recent decadal scale variability in both coral growth and regional wintertime climate are closely linked to changes to the orientation of the mid-latitude atmospheric jet stream over North America. When the jet stream has a more north-south orientation, wintertime temperatures in the Gulf of Mexico and southeastern U.S. are colder and the corals exhibit slower growth and possess more winter stress bands. Variations in the orientation of the jet stream and wintertime climate are among the dominant modes of extratropical climate variability in the Northern Hemisphere (Wallace and Gutzler 1981; Simmons et al. 1983; Wallace et al. 1993).

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

In the summer of 2010, the FGB experienced an unusual warming of the water column and coral bleaching, which were reflected in the data at WFGB. As described in the random transect data, approximately 7% of the corals at WFGB were bleached and 11% were paling. Seven of the eight coral cores collected during 2012 do indicate a slight decline in extension rate from about 2008–2009 to 2010–2011. However, though this correspondence is intriguing, the available environmental and coral skeletal information is insufficient to ascertain whether this decline is statistically significant and a consequence of bleaching and paling. Though valuable growth rate information is collected from cores, it should be evaluated whether coral cores should be taken every two years during monitoring periods. Due to the slow nature of coral growth rates, it may be more appropriate to take longer cores once every five years.

CHAPTER 7.0: PERIMETER VIDEOGRAPHY

7.1. PERIMETER VIDEOGRAPHY METHODOLOGICAL RATIONALE

Portions of the perimeter lines were videotaped each year at EFGB and WFGB to document change at known locations along the perimeter of the study sites. General aspects of coral condition were documented and compared year to year. The perimeter surveys are intended to provide a visual long-term dataset and general overview of coral reef health and are particiularly useful for documenting effects from natural events, such as bleaching and hurricanes on large areas of the reef.

7.2. PERIMETER VIDEOGRAPHY METHODS

Divers videotaped two 100 m segments of the perimeter lines at EFGB (north and east margins) and WFGB (south and west margins) in 2011 and 2012. At EFGB, divers began at the northwest corner of the 10,000 m^2 study site and videotaped the north line to the northeast corner, then the east line to the southeast corner. At 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 distance above the bottom by attaching a weighted 2 m line to the bottom of the camera housing to assist with consistency of distance from the substrate. The line was kept to the left of the perimeter. The camera was aimed downward at a 45° angle to capture the substratum. In both years, a 360° panoramic view of the reef was videotaped at the three corners documented during the perimeter video. In 2011, a Sony® Handicam® DCR-TRV950 video camera in a Light and Motion® Bluefin® housing with Light and Motion® Sunray® video lights was used with a red filter for color correction. In 2012, a Canon® VIXIA® HF G10 HD video camera in a Light and Motion® Stingray® housing with Light and Motion® SOLA® 4000 lights was used with a red filter for color correction.

The video footage was reviewed to record the general condition of corals along the perimeter of the study sites. Individual coral colonies displaying possible disease, bleaching, paling, or other notable conditions on the reef were identified and recorded. Affected coral colonies were compared in 2011 and 2012. Changes in coral colony condition were recorded. The perimeter surveys are intended to provide a visual long-term dataset and general overview of coral reef health. Because the analyses were qualitative, no statistical analyses were conducted.

7.3. PERIMETER VIDEOGRAPHY RESULTS

The perimeter video was reviewed for a qualitative analysis of the general condition of corals along the perimeter of the study sites. The review of the 2011 and 2012 perimeter videos suggests that, in general, the coral community along the perimeter lines at EFGB and WFGB study sites displayed low levels of stress and healthy corals. The limited bleaching and paling observed were similar to random transect and repetitive quadrat data. Furthermore, no evidence of disease was observed at either bank. The use of the HD video camera in 2012 greatly improved the quality of the video and ability to differentiate coral species and conditions.

7.3.1. EFGB Perimeter Lines

In 2011, the perimeter video was taken at 1800 CDT; in 2012, it was taken at 1700 CDT. Three incidences of paling were observed at EFGB in 2011. Two were *Montastraea cavernosa* colonies and the other was an *Orbicella* spp. colony. In 2012, one *Montastraea cavernosa* colony displayed signs of paling. No bleaching was observed in 2011 or 2012 at EFGB.

A seismic cable used for oil and gas exploration penetrates part of the EFGB study site boundary. In 2011 it was observed to scour and create a scar on a *Pseudodiploria strigosa* colony, but in 2012, the cable had shifted and the scar on the colony had healed (Figure 7.3.1). Seismic cables had been observed on both EFGB and WFGB before the banks were designated a national marine sanctuary. These seismic cables may be left over from surveys decades ago. The cables have been observed to be degrading over time, and are now considered marine debris.

7.3.2. EFGB 360° Panoramic Views

At the northwest corner, corals appeared to be healthy in both 2011 and 2012. In 2011, there was a paling *Porites astreoides* colony. In 2012, it appeared there was higher turf algal cover than in 2011; however, this may have been more visible due to the HD camera used in 2012. At the northeast and southeast corners, the corals appeared to be in good condition, with no evidence of bleaching stress or disease in 2011 or 2012.

7.3.3. WFGB Perimeter Lines

In 2011, the perimeter video was taken at 0800 CDT; in 2012, it was taken at 1000 CDT. In 2011, bleaching occurred on two colonies (*Montastraea cavernosa* and *Porites astreoides*). In 2012 at WFGB, one *Pseudodiploria strigosa* colony was covered with algal over growth. No signs of disease were observed in either year. The *Montastraea cavernosa* colony that was observed to bleach in 2011 was recovered by 2012 (Figure 7.3.2). Along the south line in 2011, a cleaning station was observed that included a tiger grouper (*Mycteroperca tigri*) with neon gobies (*Elacatinus oceanops*) and Spanish hogfish (*Bodianus rufus*).

7.3.4. WFGB 360° Panoramic Views

Corals in the southeast corner showed no signs of bleaching, paling, or fish biting in 2011 and 2012. In 2012, it appeared there was higher turf algal cover than in 2011; however, this may have been more visible due to the HD camera used in 2012. At the southwest and northwest corners, the corals appeared to be in good condition, with no evidence of bleaching stress or fish biting.

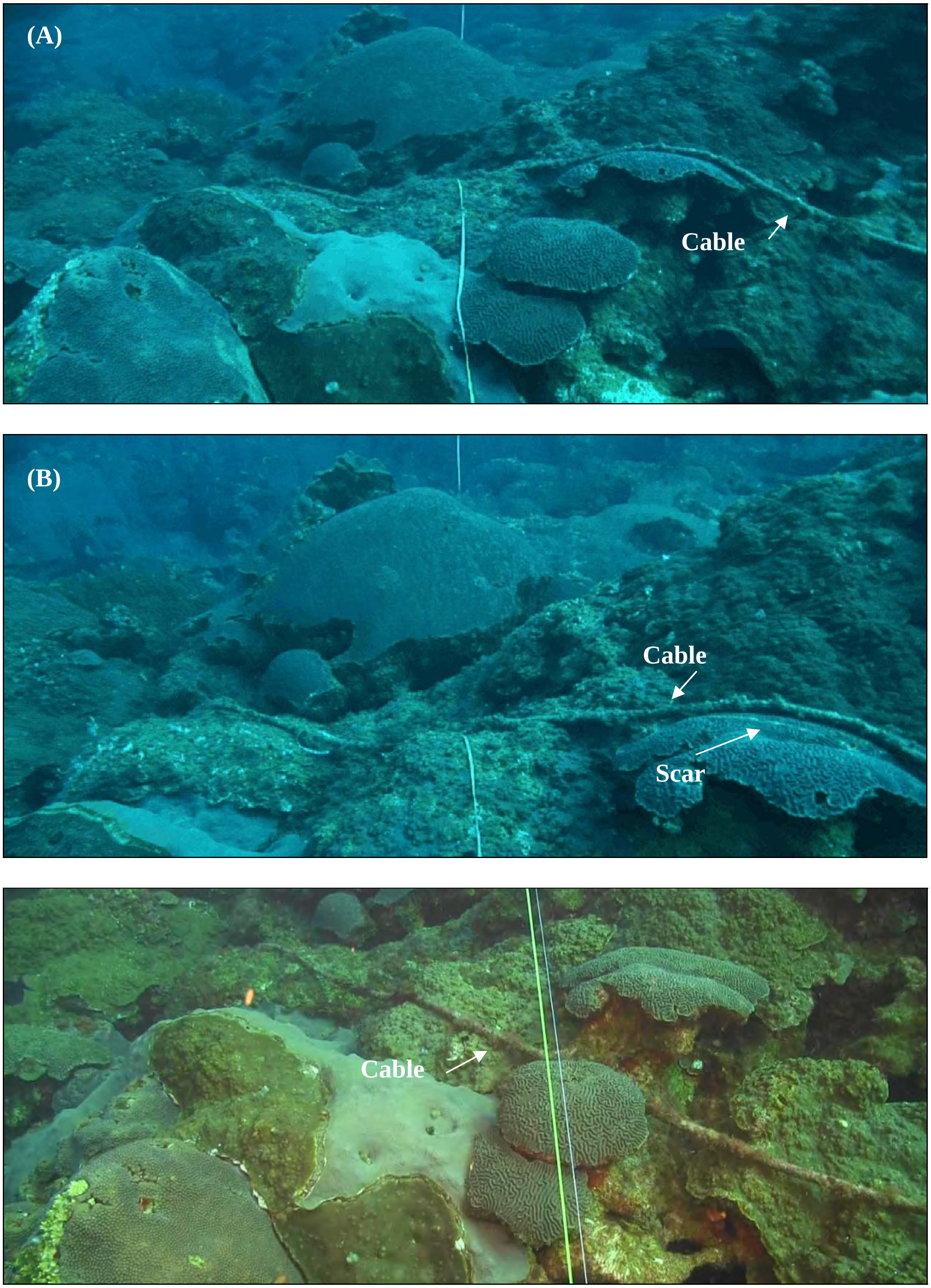


Figure 7.3.1. A seismic cable draped over a *Colpophyllia natans* coral head in 2011 (A), the cable and scar in 2011 (B), and the recovered colony and shifted cable in 2012 (C) at EFGB (NOAA/FGBNMS).

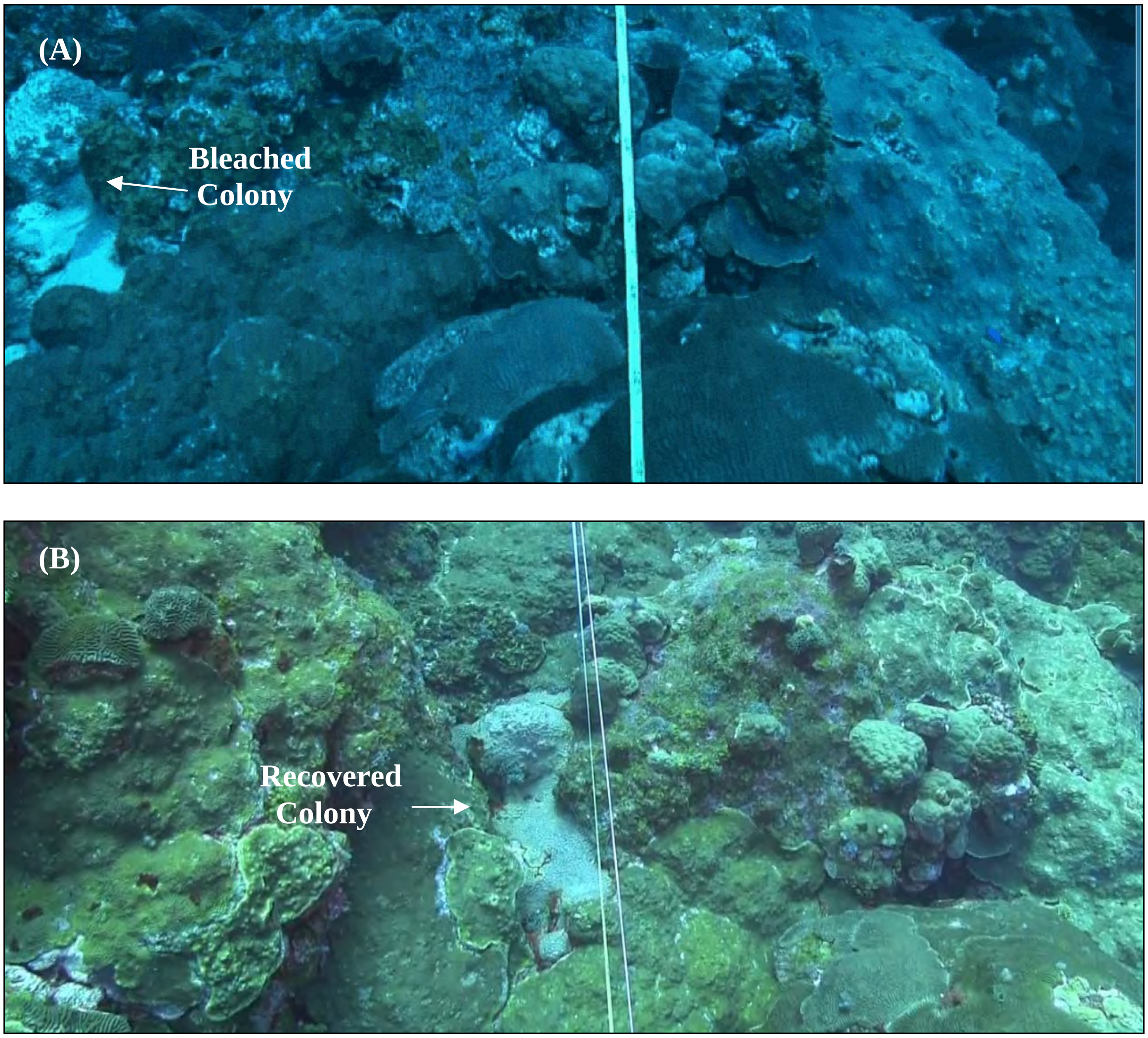


Figure 7.3.2. A bleached *Montastraea cavernosa colony* in 2011 (A), and the same recovered colony in 2012 (B) at WFGB (note shift in line between years) (NOAA/FGBNMS).

7.4. PERIMETER VIDEOGRAPHY DISCUSSION

Videography of the perimeter lines and 360° panoramic views of the corner markers at EFGB and WFGB provided a general overview of coral condition at the study sites from 2011–2012. Similar to the findings from the random transects, in both years coral condition appeared to be in relatively good health at both banks and there were no signs of coral disease. There were few incidences of bleaching and paling. The use of the HD camera in 2012 made corals and fish much easier to discern, due to the higher resolution and sharper image of the upgraded system, which provided clear images of both the perimeter lines and 360° panoramic views of the reef at each corner marker.

It is important to note that the perimeter lines did shift between years on both banks (Figure 7.4.1), as the study sites were refurbished in 2012. Due to the effect of currents and surge on the flexible perimeter lines between the fixed corner markers, which are 100-m apart, mid-transect eye bolts were installed in 2012 to help improve repeatability so that transect lines can be attached to eye bolts to avoid shifting lines with the current.

Missing corner markers were also replaced with permanent eyebolts, and installed to make the study site a 10,000 m^2 area. In the past, shifting perimeter lines and corner marker positions resulted in a lack of overlapping video footage and fewer available coral comparisons. Now that corner markers and mid transect eyebolts are permanent, transect lines should be repeatable and allow for more coral colony comparisons.

CHAPTER 8.0: DIVER OBSERVATIONS

8.1. DIVER OBSERVATIONS METHODOLOGICAL RATIONALE

In addition to the annual data collection protocol, other biologically relevant information is documented within the study sites at EFGB and WFGB. During each annual monitoring cruise, observations of general coral reef health and notable biological and oceanographic events (e.g., spawning, animal behavior) were qualitatively assessed.

8.2. DIVER OBSERVATIONS METHODS

As divers traversed the FGB study sites during the 2011 and 2012 annual monitoring cruises, they noted and photographically documented any biologically relevant observations and events.

8.3. DIVER OBSERVATION RESULTS

8.3.1. Wildlife Observations

8.3.1.1. Elasmobranch Sightings

During the 2011 EFGB annual monitoring cruise, two mantas (*Manta* spp.*)* were sighted during diving operations. Each manta has a unique set of markings and color patterns on its ventral side. These can be used to identify individual rays. The two sighted were newly recorded mantas and were added to the FGBNMS manta sighting catalog. A Caribbean reef shark (*Carcharhinus perezi*) and dusky shark (*Carcharhinus obscurus*) were also observed in the EFGB study site. Mantas were not sighted at WFGB in 2011 during the monitoring period, however a sicklefin devil ray (*Mobula tarapacana*) was observed in the study site. In 2012, no mantas were observed at EFGB. At WFGB, two mantas and a devil ray were observed within the study site.

8.3.1.2. Fish Sightings

In 2011 at WFGB, a marbled grouper *(Dermatolepis inermis*) visited divers on a sand flat near the water quality instrumentation (Figure 8.3.1) and a large loggerhead sea turtle (*Caretta caretta*) was observed surfacing near the R/V *Manta*. A large green moray (*Gymnothorax funebris*), a rarely seen species at the FGB, was observed in the study site, and several queen conch (*Lobatus gigas*) were observed in the sand flat.

At EFGB repetitive deep stations in 2012, a rare barred hamlet (*Hypoplectrus puella*) was seen by divers. This was the first documented sighting of this species within sanctuary boundaries. Divers also observed a lionfish (*Pterios* spp.), and an adult female loggerhead sea turtle at the EFGB repetitive deep stations. In 2012 at WFGB, a yellowmouth grouper (*Mycteroperca interstitiali*) was seen at a cleaning station, and a large loggerhead sea turtle was observed in the study site. A nesting sergeant major (*Abudeduf saxatilis*) damselfish with eggs was observed by divers. At the WFGB repetitive deep stations, a lionfish and hawksbill sea turtle (*Eretmochelys imbricata*) were also observed at WFGB (Figure 8.3.2). These observations are anecdotal and quantitative fish surveys are reported in Chapter 10.

Figure 8.3.1. Marbled grouper (*Dermatolepis inermis*) visits diver at WFGB (NOAA/FGBNMS).

Figure 8.3.2. Hawksbill sea turtle (*Eretmochelys imbricata*) at WFGB (NOAA/FGBNMS).

8.3.2. Coral Health Observations

During the 2011 and 2012 annual monitoring cruises, scientific divers made qualitative observations of coral colonies exhibiting signs of disease or other coral health issues. During the 2011 and 2012 monitoring cruises, divers experienced 30 m visibility and water temperatures near 29°C. There were no unusual observations at EFGB in 2011; however, Xestospongia "wasting disease" was observed in a giant barrel sponge (*Xestospongia muta*) and "false bleaching" was observed at WFGB in 2011 (Figure 8.3.3).

Occasionally, a syndrome that has been called "false bleaching" is seen in coral colonies at the FGB, especially in large polyped coral species, such as *Monastraea cavernosa* (Figure 8.3.3). This syndrome appears very similar to that reported by Kramarsky-Winter et al. (2006), and is not bleaching at all, but coral surfaces covered by a layer of aggregate-like protist microorganisms embedded in the mucus and surface coral tissue in patchy distributions. The role of protists in the marine environment is not well understood, but it is thought that corals may benefit from the protist association through protist nutrient production, actually helping massive corals survive bleaching events better than branching corals. Further study of this syndrome at the FGB should be conducted.

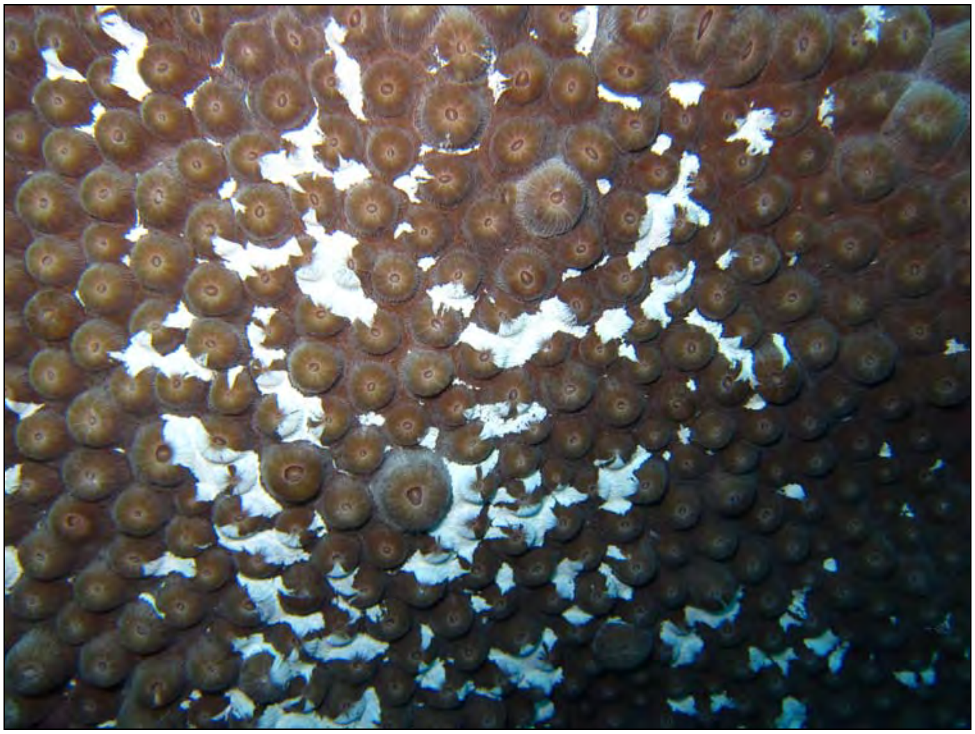


Figure 8.3.3. *Montastraea cavernosa* "false bleaching" at WFGB (NOAA/FGBNMS).

In 2012, divers observed fluorescent orange algae growth at EFGB (Figure 8.3.4). This was also observed in 2010 in the previous reporting period. The orange alga was very noticeable in the crevices of the reef, and has been identified as *Martensia pavonia*, a delicate net-forming alga that is a member of the Delesseriaceae family and exhibits a bright orange color in its deteriorating state (Fredericq, University of Louisiana at Lafayette, pers. comm.). Algal blooms are classic indicators of high nutrient levels on coral reefs, and tend to expand in the warm season and during the rainy season when more nutrients are flushed offshore from land.

Figure 8.3.4. Fluorescent orange algae, *Martensia pavonia*, observed at EFGB in 2012 (NOAA/FGBNMS).

There were no unusual observations at WFGB in 2012, but divers did observe sponge spawning in the northwest corner of the study site at 0911 CDT on 27 July 2012 (Figure 8.3.5).

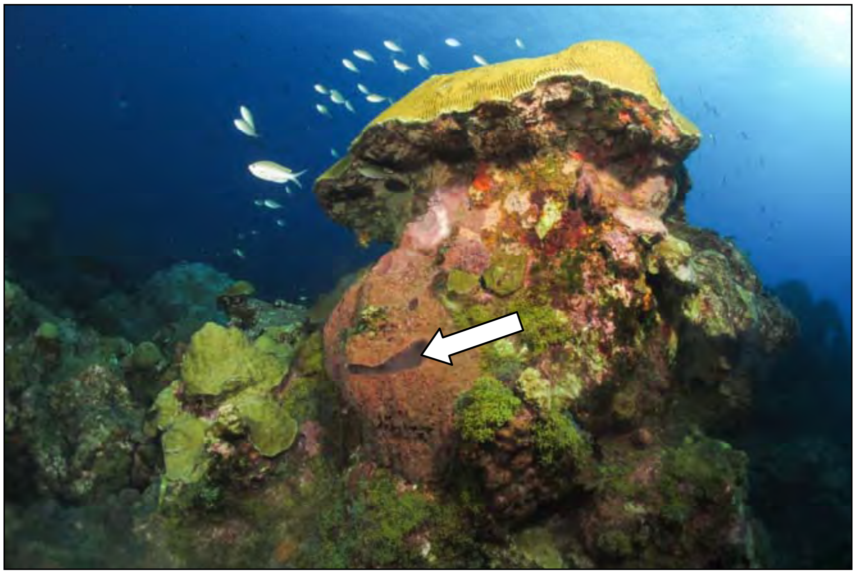


Figure 8.3.5. Arrow points to spawn leaving the barrel of the sponge at WFGB in 2012 (NOAA/FGBNMS).

8.3.3. Invasive Species Sightings

In 2002, orange cup coral (*Tubastraea coccinea*) was first documented at EFGB. It is native to the Indo-Pacific and may have entered the South Atlantic and Caribbean by attaching to a ship's hull, having its larvae discharged in ballast water, or being transported on reused structures such as drilling rigs or production platforms. This species is now common on oil and gas platforms in the Gulf of Mexico, and it is suspected that platforms played a role in the spread of this species (Fenner and Banks 2004). It is the most common coral species on High Island A389A, the only oil and gas production platform inside sanctuary boundaries. This platform is located about one mile from the coral cap at EFGB. In 2011 and 2012, sporadic colonies were observed on the reefs near the EFGB and WFGB study sites, and were also observed in previous monitoring periods (Figure 8.3.8). As of this time, *Tubastraea coccinea* has been documented along the south perimeter line near the southwest corner of the WFGB study site.

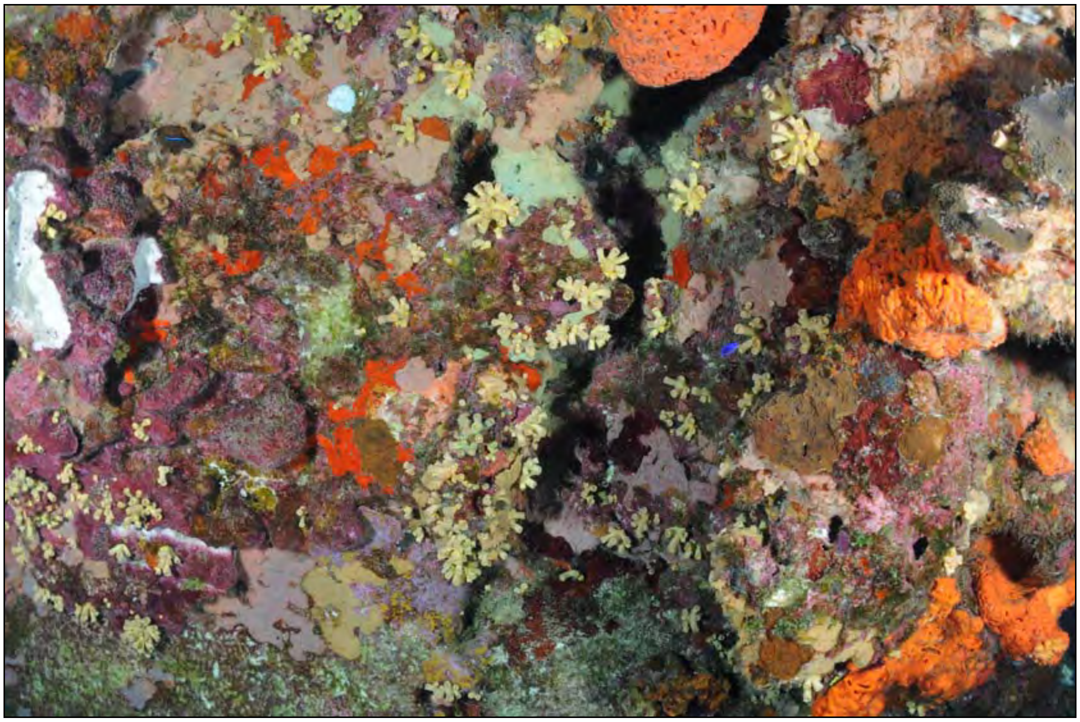


Figure 8.3.6. Patches of orange cup coral (*Tubastraea coccinea)*, an invasive species from the Pacific, at WFGB (NOAA/FGBNMS).

Lionfish (*Pterois miles/volitans*), an invasive species known for their voracious appetites, venomous spines and rapid reproduction, first invaded in the southern Gulf of Mexico off the northern Yucatan Peninsula in December 2009. In September 2010, two lionfish were sighted at Sonnier Bank by Texas A&M University Galveston researcher divers. These were the first confirmed sightings of lionfish at the natural banks in the northwestern Gulf of Mexico, about 60 miles east of EFGB. In July 2011, no lionfish were observed in the long-term monitoring study site, but in 2012, Lionfish were observed at EFGB and WFGB repetitive deep stations and within the WFGB study site (Figure 8.3.9). Overall, a total of four were observed at EFGB and two at WFGB in 2011. In 2012, lionfish sightings increased, with 40 observed at EFGB and 105 at WFGB. Reported sightings are from recreational and FGBNMS divers.

Figure 8.3.7. Invasive lionfish (*Pterois* spp.) at WFGB in 2012 (NOAA/FGBNMS).

8.4. DIVER OBSERVATIONS DISCUSSION

8.4.1. Wildlife Observations

8.4.1.1. Elasmobranch Sightings

Sanctuary staff and volunteers have been collecting photos and videos of mantas sighted in the sanctuary over many years. These photos are the basis of a FGBNMS Manta Photo Catalog, identifying each of the known individuals and the additional of new individuals. The catalog can be viewed on the FGBNMS website and downloaded as a poster. Of the four mantas observed during 2011 and 2012, one could be positively identified as having been seen in the past.

8.4.2. Coral Health Observations

In 2011 and 2012, divers observed minimal bleaching in the FGB study sites. This varied from the previous monitoring period, where divers observed a higher than normal number of bleached coral colonies (primarily *Montastraea cavernosa* and *Millepora alcicornis*) at WFGB in 2010.

It should be noted that monitoring at EFGB and WFGB was conducted in July in both 2011 and 2012, before signs of bleaching are normally observed. In the Gulf of Mexico region, bleaching tends to occur in the late fall after sustained peak temperatures and beaching is significantly visible. In July of 2011 and 2012, NOAA's Coral Reef Watch Program's satellite data provided near-real time data on the reef environmental conditions in the Gulf of Mexico to quickly identify areas at risk for coral bleaching. Areas near and inside FGBNMS boundaries were coded at bleaching alert “No Stress” levels and “Watch” in July of 2011. Areas near and inside FGBNMS boundaries were coded at bleaching alert “Watch” in July of 2012. In September of 2011 and 2012, there was no risk of bleaching near the FGB. Therefore, even though monitoring was not done in the late fall when signs of bleaching peak from warm sea surface water temperatures exceed the 30°C coral bleaching threshold, the temperatures were not sustained in the 2011 and 2012 monitoring seasons to create a bleaching threat.

In 2012, divers also observed the fluorescent orange algae, *Martensia pavonia*, at EFGB. Algal growth often indicates excessive levels of nutrients moving from the coastal zone into offshore habitats, stimulating production. Coral reef ecosystems are sensitive to high concentrations of nitrogen and phosphorus, which promote algal overgrowth. Besides algal cover, reefs with high levels of nutrients in the water may be more susceptible to coral diseases. Along developed coastlines excess nutrients come from human sources, such as human sewage, livestock manures, and agricultural runoff. Nutrients carried offshore act as fertilizers for marine plants growth. Algae can be considered an early warning of changes in water quality and potential impacts to coral health.

8.4.3. Invasive Species Sightings

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

Tubastraea coccinea is a zooxanthellate scleractinian coral that is an exotic, invasive species within the Caribbean and western Atlantic (Fenner 1999, 2001; Fenner and Banks 2004). Native to the tropical Indo-Pacific and the eastern Atlantic (Cairns 2000), *Tubastraea coccinea* was first reported in the Caribbean in 1943 (Fenner and Banks 2004). No fossil evidence of this species has been found within the Caribbean (Cairns

1999). *Tubastraea coccinea* is typically located on the undersides of rocks or massive corals, in caves, and on rock walls (Glynn et al. 2008). It appears to compete particularly well on artificial substrates, which may account for its widespread dispersal. It is a hermaphroditic brooding coral that releases planula larvae year round (Cairns 2000; Glynn et al. 2008) and has a mean growth rate of approximately 3 cm^2/year (Vermeij 2006). This species reaches reproductive maturity at a small size (from as small as 2–10 polyps; Glynn et al. 2008) and at an early age (reproductively viable at approximately 1.5 years; Vermeij 2006). *Tubastraea coccinea* has the ability to compete effectively by forming thin tissue outgrowths (“runners”) that extend over the substrate until suitable substrate is encountered, at which time a new polyp forms (Vermeij 2005). These competitive mechanisms may put native benthos at risk.

This species was first observed in the Caribbean in 1943 by Vaughn and Wells, and has since spread throughout the Caribbean and Bahamas (IUCN 2007; 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 and ship hulls, ballast water, transport of marine structures and machinery (e.g., oil platforms; Ferriera 2003; Fenner and Banks 2004). *Tubastraea coccinea* has colonized many of the oil and gas platforms in the northwestern Gulf of Mexico (Sammarco et al. 2006). The probability that oil and gas platforms are playing a role in the colonization of this invasive species should be of interest to BOEM.

Over the last five years, one of the world’s most popular ornamental aquarium fish, the native Indo-Pacific lionfish (*Pterios* spp.), has invaded much of the western Atlantic and Caribbean region (Morris and Whitfield 2009) (Figure 8.4.2). The proliferation of this species has occurred quickly due to early sexual maturation, high fecundity, ability to invade many habitats, and effectiveness in competing for food (they are voracious predators that have no known predators in the region) (Mumby et al. 2011). Lionfish subject small-bodied and juvenile reef fish to greatly elevated predation, and coral reefs are at risk of phase shifts mediated by secondary effects of changes in fish trophic structure (e.g. increasing algal cover caused by the loss of herbivores). The long-term consequences on reef biodiversity and function are not yet clear, but are a matter of grave concern to resource managers.

The FGBNMS will continue to monitor the sanctuary for this invasive species. FGBNMS staff has worked with other staff at sanctuary sites to develop a National Marine Sanctuary Lionfish Response Plan (Johnston et al. 2015). Though there is little scientific evidence to support using biocontrol as a natural means to slow the lionfish invasion, EFGB and WFGB provides a unique opportunity to conduct an experiment to measure the effectiveness of natural predation, and the influence of fishing on this natural control mechanism. The managers of FGBNMS are currently in the process of investigating the use of an experimental research area to assess these questions.

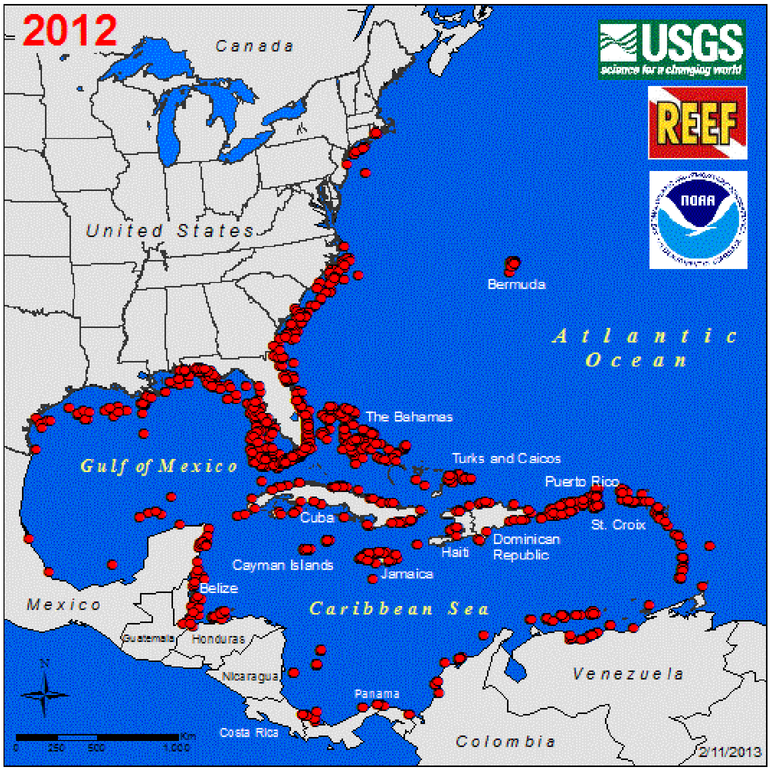


Figure 8.4.1. Lionfish sightings from 1985–2012 (USGS).

CHAPTER 9.0: WATER QUALITY

9.1. WATER QUALITY METHODOLOGICAL RATIONALE

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

Hereafter, "water quality" will refer to the physical (temperature) and biological (Chl-*a*), and chemical (salinity and nutrients) characteristics of the seawater overlying the FGB. This report presents the results of the water quality monitoring at EFGB and WFGB conducted from February 2011 to November 2012, and temperature and salinity profiles collected from January 2011 to December 2012.

9.2. WATER QUALITY METHODS

9.2.1. Sea-Bird Conductivity and Temperature Recorder

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

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

9.2.1.1. Specific Conductance (Salinity)

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

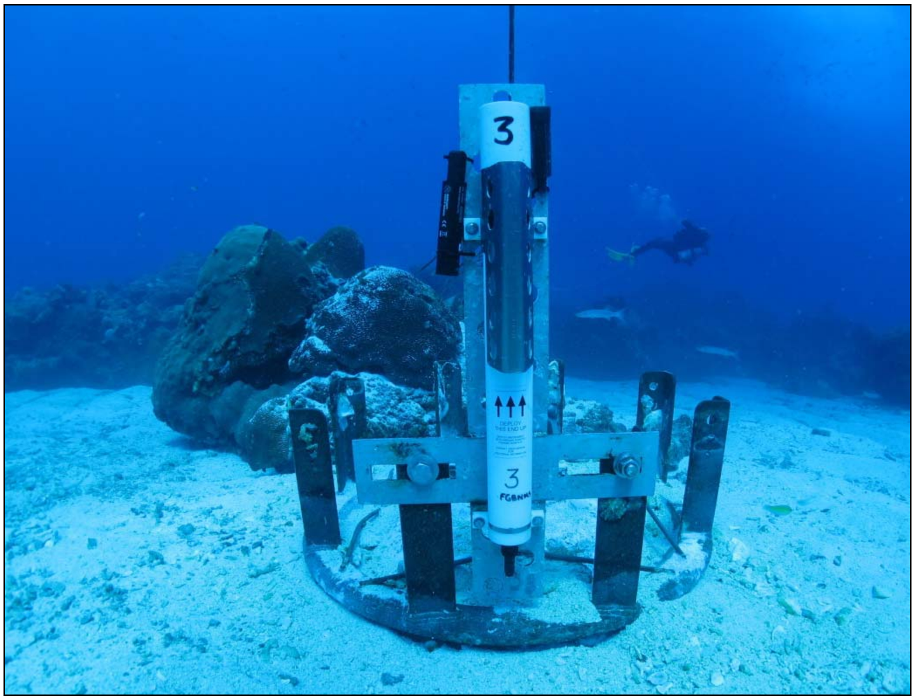


Figure 9.2.1. Sea-Bird 37-SMP MicroCAT water quality instrument at EFGB (NOAA/FGBNMS).

9.2.1.2. Temperature

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

9.2.2. HoboTemp Thermographs

One HOBO Pro v2 Water Temperature Data Logger (HoboTemp) was attached to each of the Sea-Bird instruments as backup recorders of seawater temperature. HoboTemp recorders have an accuracy of ± 0.2°C and resolution is 0.02°C at 25°C. They are designed with a durable streamlined case for extended deployment in fresh or salt water, and equipped with an Optic USB interface for data offload in the field. The data loggers were deployed in a water depth of 23 m at EFGB and in at 27 m at WFGB and recorded every 30 min. Recorders were also located at EFGB and WFGB deep stations at 30.5 m and 39.6 m.

9.2.3. YSI Probe

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

9.2.4. Chlorophyll *a* and Nutrients

Surface (<1 m), midwater (10 m), and near bottom (20 m) water samples were acquired eight different times at EFGB and WFGB between February 2011 and November 2012 (Table 9.2.1). During each sampling event, water was collected twice at each depth using a vertical 10 liter sampling bottle (Niskin®). Water samples were immediately transferred into pre-cleaned polyethylene and glass containers (tested monthly using nanopure water) provided by an independent, U.S. Environmental Protection Agency (USEPA) certified analytical laboratory (Anacon, Inc. in Houston, TX). Water samples were analyzed for Chl-*a*, ammonia, nitrate, nitrite, TKN, and soluble reactive phosphorous. Water samples for Chl-*a* analyses were collected in 1000 ml glass containers with no preservatives. Samples for reactive soluble phosphorous were placed in 250 ml bottles with no preservatives. Ammonia, nitrate, nitrite, and TKN samples were collected in 1000 ml bottles with sulphuric acid (H_2SO_4) as a preservative. One blind duplicate seawater sample was taken at one of the sampling depths on one of the banks for each sampling period. Within minutes of sampling, labeled sample containers were stored on ice at 4°C and a chain of custody was initiated. Once back onshore, the samples were sent to Anacon, Inc. for analysis using standard USEPA methods (Table 9.2.2) to assess concentrations of Chl-*a* and nutrients (ammonia, nitrate and nitrite, TKN, soluble reactive phosphorous).

Table 9.2.1.

Water Sampling Schedule, Depth, and Number of Samples Taken at EFGB and WFGB in 2011 and 2012

EFGB			WFGB		
Sampling Date	**Depth**	**Samples**	**Sampling Date**	**Depth**	**Samples**
02/15/2011	1, 10, 20 m	6	02/15/2011	1, 10, 20 m	6
05/15/2011	1, 10, 20 m	6	05/17/2011	1, 10, 20 m	6
08/20/2011	1, 10, 20 m	6	08/21/2011	1, 10, 20 m	6
10/24/2011	1, 10, 20 m	6	10/25/2011	1, 10, 20 m	6
03/25/2012	1, 10, 20 m	6	03/25/2012	1, 10, 20 m	6
05/29/2012	1, 10, 20 m	6	05/29/2012	1, 10, 20 m	6
08/09/2012	1, 10, 20 m	6	08/09/2012	1, 10, 20 m	6
11/09/2012	1, 10, 20 m	6	11/09/2012	1, 10, 20 m	6

Dates represent month/day/year.

Table 9.2.2.

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

Parameter	Method	Detection Limit
Chlorophyll-*a*	10200HPLC	1-mg/m³
Ammonia	M4500 NH3 D	0.10–mg/l
Nitrate	E353.3	0.15–mg/l
Nitrite	E353.2	0.15–mg/l
Soluble reactive phosphorous	SM 4500 P E	0.02–mg/l
Total Kjeldahl nitrogen (TKN)	SM 4500 NH3 C	0.55–mg/l

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

9.3. WATER QUALITY RESULTS

9.3.1. Sea-Bird Temperature and Salinity

9.3.1.1. Temperature

Seawater temperature was simultaneously measured at EFGB (23 m) and WFGB (27 m) using a Sea-Bird 37-SMP MicroCAT datasonde from January 2011 to December 2012. The seawater temperature records were complete, with the exception of a gap from 08 November 2012 to 31 December 2012 at EFGB and 9 August 2012 to 31 December 2012 at WFGB due to a sensor malfunction. The gaps in these Sea-Bird records were supplemented with backup HoboTemp logger data. The temperature records include the winter minimum and summer maximum, and daily average temperatures were calculated. Water quality data from 2011 and 2012 at the FGB is found in Volume II Appendix 9 of this report.

At EFGB, temperature ranged from a minimum of 18.62°C to a maximum of 30.30°C in 2011. The annual mean temperature was 24.85°C. In 2012, the temperature ranged from 20.41°C to 30.49°C. The 2012 mean temperature was 25.50°C (Table 9.3.1).

Overall, 2012 was a warmer year than 2011; however, several thermal anomalies were recorded at EFGB. There were episodes of low temperature in the summer (June) of 2012 ranging from 24.91–25.20°C on the reef cap of the EFGB study site, as well as a decreases in temperature (to 28.51°C) in late August 2011 at EFGB, with a spike in temperature in September 2011 (to 29.93°C). Winter and early spring temperatures in 2011 (January–April) were lower than in 2012, and the temperatures on the reef cap in late summer through early winter in 2011 (September–December) were also lower than in 2012. Both the maximum temperatures in 2011 and 2012 exceeded 30°C. In 2011, temperature exceeded 30°C for eight days, and in 2012, temperature exceeded 30°C for 23 days. This is considered the coral bleaching threshold for the FGB (Hagman and Gittings 1992); however, because only limited time was spent above this temperature, the risk of bleaching was low (Figure 9.3.1).

Table 9.3.1.

Summary of Sea-Bird Seawater Temperature Parameters from 2011–2012

Measurement	2011		2012	
	EFGB	WFGB	EFGB	WFGB
Annual Mean Temperature (°C)	24.85	24.84	25.50	25.49
Annual Minimum Temperature (°C)	18.62	17.92	20.41	20.41
Annual Maximum Temperature (°C)	30.30	30.44	30.49	30.55

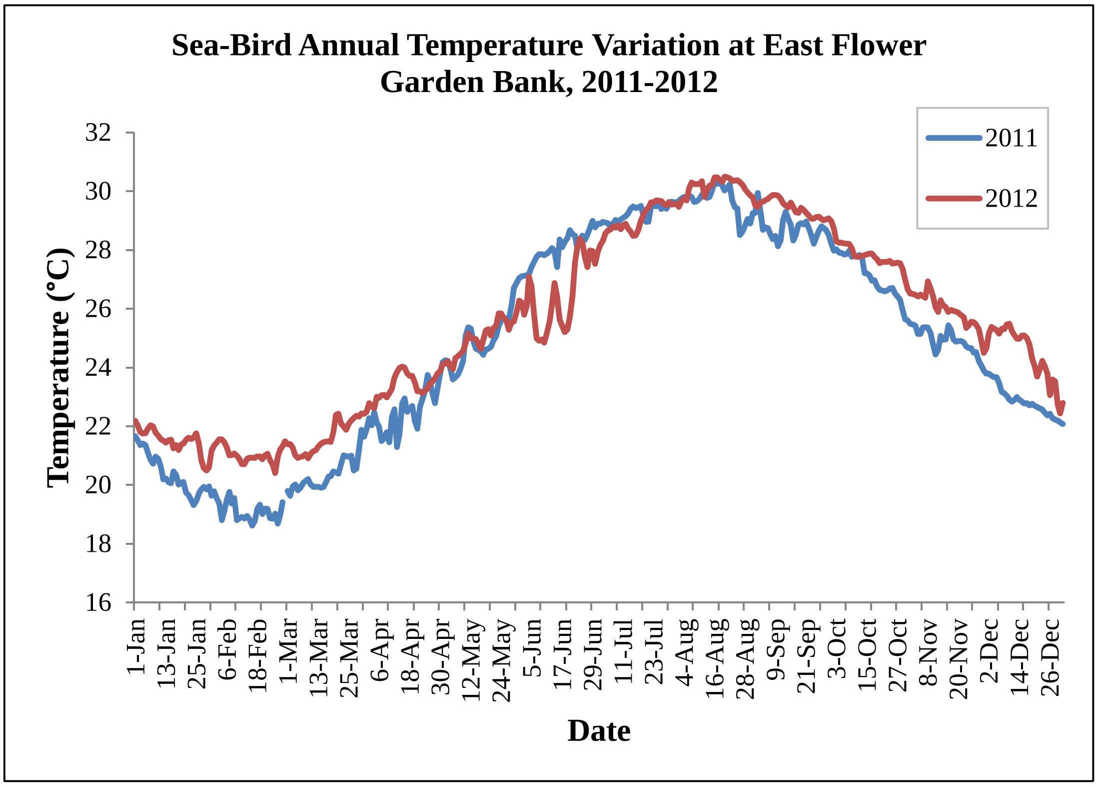


Figure 9.3.1. Sea-Bird datasonde daily mean seawater temperature measured near the reef cap at EFGB from 2011–2012.

At WFGB, the annual daily mean temperature ranged from a minimum of 17.92°C to a maximum of 30.44°C in 2011. The annual mean temperature was 24.84°C. In 2012, temperature ranged from 20.41°C to 30.55°C. The annual mean temperature was 25.49°C (Table 9.3.1).

Overall, 2012 was a warmer year than 2011; however, several thermal anomalies were recorded at WFGB. Winter and early spring temperatures in 2011 (January–April) were lower than in 2012, and the temperatures on the reef cap in the fall through early winter in 2011 (October–December) were also lower than in 2012. In September 2011, a sharp temperature decline was recorded (24.31°C), beginning September 22, 2011 and ending September 24, 2011. The temperature stayed below 27°C for 40 hours. Like EFGB, both the maximum temperatures in 2011 and 2012 exceeded 30°C. In 2011, temperature exceeded 30°C for 12 days and in 2012, temperature exceeded 30°C for 24 days. However, only limited time was spent above this temperature, reducing the risk of bleaching (Figure 9.3.2).

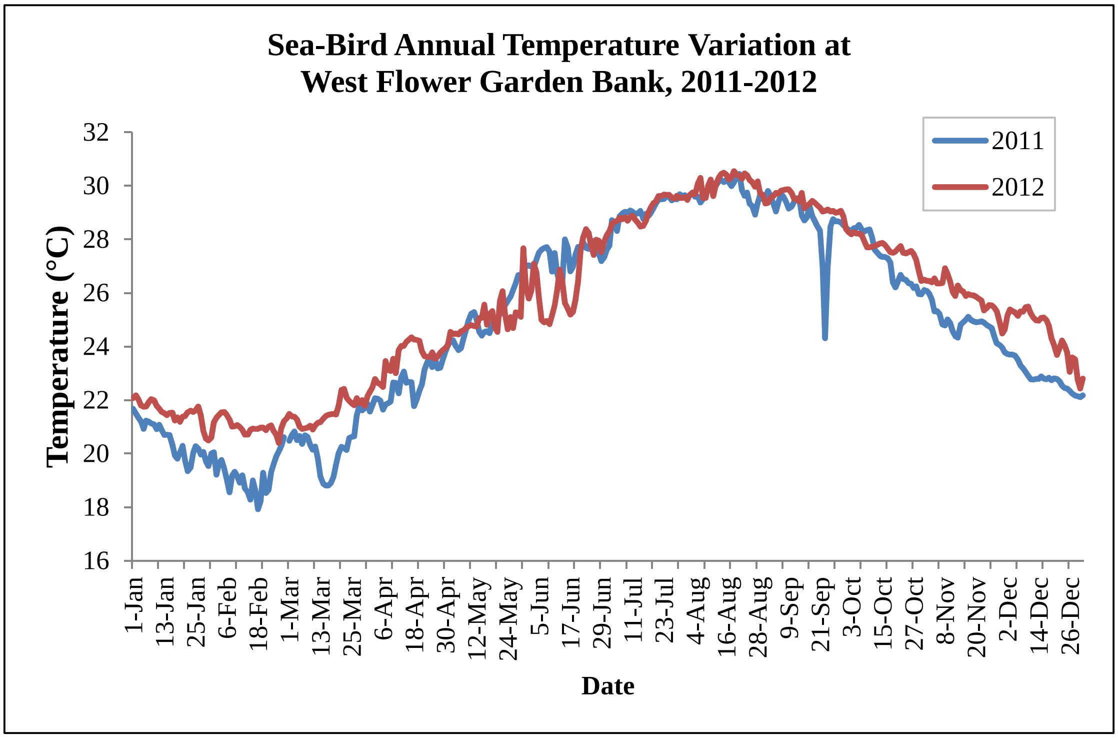


Figure 9.3.2. Sea-Bird datasonde daily mean seawater temperature measured near the reef cap at WFGB from 2011–2012.

9.3.1.2. Salinity

Salinity records at EFGB and WFGB were complete between January 2011 and December 2011. At EFGB, there were data gaps from 08 November 2012 to 31 December 2012 and 9 August 2012 to 31 December 2012 at WFGB due to a sensor malfunctions. The annual daily mean salinity ranged from 35.02 PSU to 36.66 PSU in 2011 at EFGB. The annual mean salinity was 36.27 PSU. In 2012, salinity ranged from 34.58 PSU to 36.65 PSU. The annual mean salinity was 36.09 PSU (Table 9.3.2). At WFGB, the annual range was 34.76 to 37.80 PSU in 2011. The annual mean salinity was 36.51 PSU. In 2012, salinity ranged from 34.58 to 36.65 PSU. The annual mean was 36.14 PSU (Table 9.3.2).

Table 9.3.2.

Summary of Sea-Bird Salinity Parameters from 2011–2012

Measurement	2011		2012	
	EFGB	WFGB	EFGB	WFGB
Annual Mean PSU	36.27	36.51	36.09	36.14
Annual Minimum PSU	35.02	34.76	34.58	34.58
Annual Maximum PSU	36.66	37.80	36.65	36.65

Practical salinity unit (PSU)

EFGB and WFGB experienced periods of salinity in July of 2011 averaging approximately 35 PSU. WFGB exhibited sharp salinity declines in May 2011 (34.76 PSU) and June 2012 (34.58 PSU). Salinity at WFGB in January and February of 2011 averaged 37.7 PSU, and then experienced a sharp decline in March 2011. This may have been a sensor malfunction. For the remainder of the 2011–2012 monitoring period, salinity remained stable at approximately 36 PSU (Figure 9.3.3).

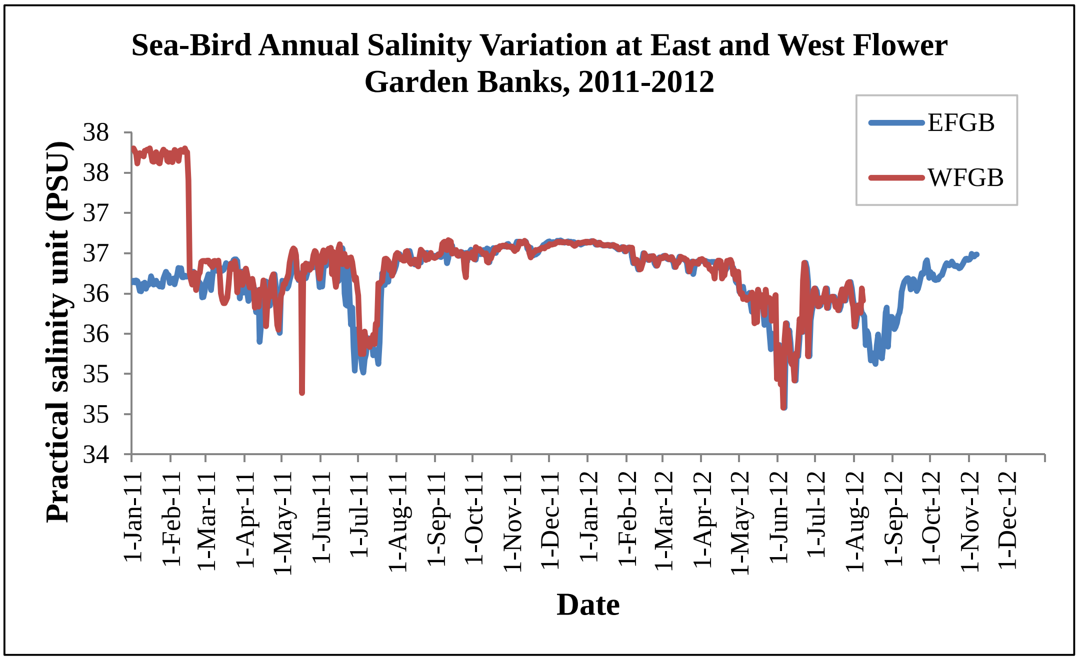


Figure 9.3.3. Sea-Bird datasonde daily mean salinity measured near the reef cap at EFGB and WFGB from 2011 and 2012.

9.3.2. HoboTemp Thermograph Data

HoboTemp thermographs were attached to each of the Sea-Bird instruments at both banks from January 2011 through December 2012. The HoboTemp record provided similar data to that captured by the Sea-Bird datasondes: low average temperatures in 2011, and higher fall temperatures in 2012 (Table 9.3.3).

At EFGB, the HoboTemp temperature ranged from 17.85°C to 30.65°C in 2011. The annual mean was 24.78°C. In 2012, the annual mean ranged from 20.37°C to 30.21°C. The annual mean was 25.35°C. At WFGB, it ranged from 18.63°C to 30.32°C in 2011, with a mean of 24.91°C. In 2012, the range was 19.96°C to 30.55°C. The mean was 25.45°C (Table 9.3.3).

Table 9.3.3.

Summary of HoboTemp Seawater Temperature Parameters from 2011–2012

Measurement	2011		2012	
	EFGB	WFGB	EFGB	WFGB
Annual Mean Temperature (°C)	24.78	24.91	25.35	25.45
Annual Minimum Temperature (°C)	17.85	18.63	20.37	19.96
Annual Maximum Temperature (°C)	30.65	30.32	30.21	30.55

HoboTemp thermographs were also located at the EFGB repetitive deep stations at 30.5 m and 40 m from July 2011 through December 2012; however, due to a lost logger at the 30.5 m depth, there was a data gap from 20 August 2011 to 24 July 2012. HoboTemp thermographs were also placed at WFGB deep stations at 30.5 m and 40 m when they were installed in 2012, for a short data record from November through December 2012.

In a similar trend, when compared to the shallower temperature records, temperatures peaked in late summer (August-September) and were lowest in the winter (January-February). At EFGB, the HoboTemp temperature ranged from 28.34°C to 30.38°C in 2011 at the 30.5 m depth, and 22.04°C to 30.27°C at the 40 m depth. In 2012, temperature ranged from 22.38°C to 29.85°C in 2011 at the 30.5 m depth, and 20.41°C to 29.55°C at the 40 m depth (Table 9.3.4). As expected, the longer, more complete data records were lower in temperature when compared to the records on the shallower section of the reef, with maximum temperatures not exceeding the 30°C bleaching threshold.

Table 9.3.4.

Summary of HoboTemp Seawater Temperature Parameters from 2011–2012 at EFGB and WFGB Repetitive Deep Stations

Measurement	2011		2012			
	EFGB 30.5 m	EFGB 40 m	EFGB 30.5 m	EFGB 40 m	WFGB 30.5 m	WFGB 40 m
Annual Mean Temperature (°C)	29.48	26.37	27.35	24.44	25.19	24.73
Annual Minimum Temperature (°C)	28.34	22.04	22.38	20.41	23.11	22.76
Annual Maximum Temperature (°C)	30.38	30.27	29.85	29.55	26.57	26.08

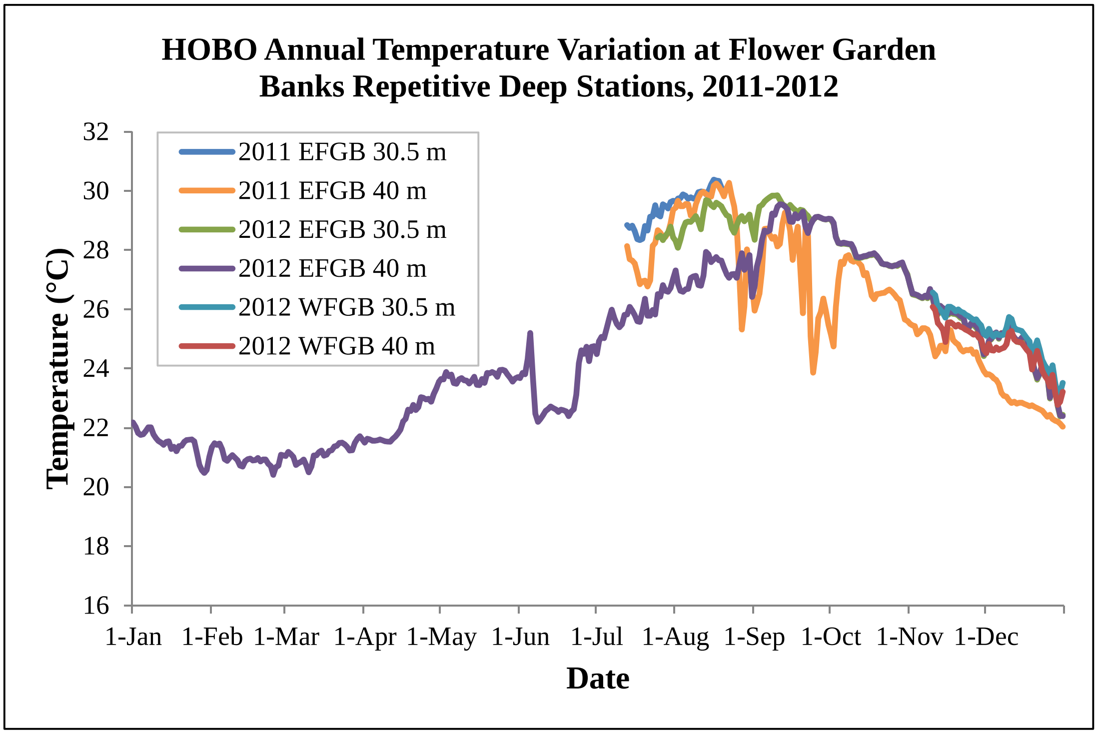


Figure 9.3.4. HoboTemp thermographs daily mean seawater temperature measured at the EFGB and WFGB repetitive deep stations from 2011–2012.

9.3.3. YSI Vertical Profiles

During each cruise, opportunistic seawater temperature profiles were measured using an YSI probe deployed by hand. Temperature and salinity were recorded at 20 m, 15 m, 10 m, 5 m, 4 m, 3 m, 2 m, and 1 m increments, as well as at the water surface (Table 9.3.5). These data complement the data collected by the stationary water quality instruments on the sea floor at each bank by giving additional information, if needed, about the conditions at the surface and throughout the water column. YSI profiles corroborated the high water temperatures in the summer of 2011 and 2012. They also indicate the lack of a pronounced thermocline between the surface and 20 m during any times of the year. The majority of the time, there was less than one degree difference (°C) between the temperature on the surface and the temperature on the reef.

Table 9.3.5.

Summary of Opportunistic YSI Seawater Temperature Vertical Profiles from 2011–2012 at EFGB and WFGB.

				Temperature (°C)								
				Depth (m)								
Bank	**Buoy**	**Date**	**Time**	**0.0**	**1.0**	**2.0**	**3.0**	**4.0**	**5.0**	**10.0**	**15.0**	**20.0**
EFGB	2	5/15/2011	19:50	24.7	24.7	24.7	24.7	24.7	24.7	24.7	24.7	24.6
EFGB	2	5/16/2011	19:03	24.8	24.8	24.8	24.8	24.8	24.7	24.6	24.6	24.6
WFGB	2	5/17/2011	20:19	24.7	24.7	24.7	24.7	24.7	24.8	24.8	24.9	24.9
EFGB	2	7/11/2011	14:05	30.4	30.4	30.4	30.3	30.3	30.2	30.1	29.9	29.7
EFGB	2	7/12/2011	10:30	30.4	30.3	30.2	30.2	30.1	30.1	30.1	30.1	30.1
WFGB	5	7/13/2011	10:13	30.2	30.2	30.2	30.2	30.2	30.2	30.0	29.9	29.8
WFGB	5	7/14/2011	9:25	29.8	29.8	29.8	29.8	29.8	29.8	29.8	29.8	29.9
EFGB	2	7/21/2011	19:18	30.3	30.3	30.2	30.2	30.2	30.2	29.8	29.8	29.3
EFGB	2	7/22/2011	8:42	29.8	29.8	29.8	29.8	29.8	29.8	29.8	29.8	29.7
EFGB	3	8/3/2011	6:58	30.1	30.1	30.1	30.1	30.1	30.1	30.1	30.0	29.7
EFGB	5	8/19/2011	16:43	**31.2**	**31.2**	**31.2**	**31.1**	**31.0**	**30.9**	**30.4**	**30.1**	**30.1**
EFGB	4	8/20/2011	19:03	30.9	30.9	30.9	30.8	30.8	30.8	30.4	30.2	30.1
WFGB	2	8/21/2011	8:49	30.3	30.3	30.3	30.3	30.3	30.3	30.3	30.3	30.3
EFGB	1	9/15/2011	17:40	29.5	29.5	29.4	29.4	29.4	29.2	29.2	29.2	29.1
WFGB	4	9/16/2011	12:35	29.9	29.7	29.7	29.7	29.7	29.6	29.6	29.6	29.0
EFGB	3	10/24/2011	20:30	26.7	26.7	26.8	26.7	26.7	26.7	26.7	26.7	26.7
WFGB	2	10/25/2011	20:10	26.5	26.5	26.5	26.5	26.5	26.5	26.4	26.4	26.4
EFGB	5	3/25/2012	17:25	**23.2**	**23.1**	**22.5**	**22.3**	**22.3**	**22.3**	**22.1**	**22.1**	**22.1**
WFGB	2	3/25/2012	19:30	**23.0**	**23.3**	**23.1**	**23.1**	**22.8**	**22.7**	**22.6**	**22.6**	**21.8**
EFGB	5	5/29/2012	11:00	27.0	26.9	26.9	26.9	26.9	26.8	26.6	26.3	26.1
WFGB	2	5/29/2012	12:47	**27.7**	**27.7**	**27.7**	**27.7**	**27.5**	**27.2**	**26.8**	**26.6**	**25.6**
WFGB	5	6/27/2012	19:25	**30.0**	**30.0**	**29.9**	**29.9**	**29.8**	**29.6**	**28.8**	**28.7**	**27.8**
WFGB	5	6/28/2012	14:45	**30.2**	**30.2**	**30.1**	**30.0**	**29.8**	**29.7**	**28.9**	**28.7**	**27.7**
WFGB	5	6/29/2012	20:08	**29.3**	**29.3**	**29.3**	**29.3**	**29.3**	**29.3**	**29.0**	**28.6**	**28.0**
EFGB	3	7/18/2012	20:20	**30.0**	**30.0**	**30.0**	**30.0**	**29.9**	**29.7**	**29.3**	**29.3**	**28.8**
EFGB	3	7/19/2012	6:30	29.6	29.5	29.5	29.5	29.6	29.7	29.9	29.4	29.2
WFGB	2	7/19/2012	11:27	**29.9**	**29.9**	**29.9**	**29.9**	**29.9**	**29.8**	**29.7**	**29.3**	**27.6**
EFGB	6	9/3/2012	16:20	30.2	30.2	30.1	30.0	29.7	29.7	29.6	29.6	29.6
EFGB	6	9/4/2012	18:50	30.5	30.4	30.4	30.2	30.0	29.7	29.7	29.7	29.7
WFGB	2	9/6/2012	18:00	30.5	30.5	30.4	30.0	29.9	30.0	30.0	29.9	29.8
EFGB	3	9/21/2012	20:10	29.1	29.1	29.1	29.1	29.1	29.1	29.1	28.9	28.9
EFGB	1	11/9/2012	6:40	26.6	26.6	26.6	26.6	26.6	26.6	26.6	26.6	26.6
WFGB	2	11/9/2012	10:20	26.4	26.4	26.4	26.4	26.4	26.4	26.4	26.4	26.4

Rows in bold highlight more than one degree difference from top to bottom

9.3.4. Water Samples

9.3.4.1 Chlorophyll a and Nutrients

Surface (<1 m), midwater (10 m), and near bottom (20 m) water samples were acquired at 8 different times at both EFGB and WFGB for the 2011 and 2012 monitoring periods. Water samples were analyzed for Chl-*a* and nutrients (ammonia, nitrate, nitrite, soluble reactive phosphorous, and TKN). Nitrite and soluble reactive phosphorus were not detected in any of the tested samples.

Approximately 3% of the water samples collected contained concentrations of Chl-*a* that were above detectable limits (>1 mg/m^3). These samples were collected in February 2011, specifically those from the surface and at the reef cap at EFGB. The highest concentration detected was 2.94 mg/m^3 of Chl-*a* (Table 9.3.6).

Table 9.3.6.

Chl-*a* Concentrations (mg/m^3) in Water Samples at EFGB and WFGB from 2011–2012

Chl-*a* (Detection limit: 1 mg/m^3)	**2011**				**2012**			
	2/15/11 – 2/16/11	**5/15/11 – 5/17/11**	**8/20/11 – 8/21/11**	**10/24/11 – 10/25/11**	**3/25/12**	**5/29/12**	**8/9/12**	**11/9/12**
EFGB Surface A	**2.94**	ND	ND	ND	ND	0.2	ND	ND
EFGB Surface B	ND	ND	ND	ND	ND	0.1	ND	ND
EFGB Midwater A	**2.14**	ND	ND	ND	ND	ND	ND	ND
EFGB Midwater B	ND	ND	ND	ND	ND	0.2	ND	ND
EFGB Reef Cap A	**2.94**	ND	ND	ND	ND	0.1	ND	ND
EFGB Reef Cap B	ND	ND	ND	ND	ND	0.1	ND	ND
WFGB Surface A	ND	ND	ND	ND	ND	0.1	ND	ND
WFGB Surface B	ND	ND	ND	ND	ND	ND	ND	ND
WFGB Midwater A	ND	ND	ND	ND	ND	ND	ND	ND
WFGB Midwater B	ND	ND	ND	ND	ND	0.1	ND	ND
WFGB Reef Cap A	ND	ND	ND	ND	ND	0.1	ND	ND
WFGB Reef Cap B	ND	ND	ND	ND	ND	ND	ND	ND

ND=Not detected at reporting limit. Concentrations above detectable limits (>1 mg/m^3) in bold. Dates represent month/day/year.

Approximately 38% of water samples contained concentrations of ammonia above detectable limits. Ammonia was detected in all samples taken from 15-17 May 2011, 20-21 August 2011, and 25 March 2012 at EFGB and WFGB. Ammonia concentrations ranged from 0.10 to 0.34 mg/l (Table 9.3.7). The modal value for ammonia levels was 0.10 mg/l. Samples containing the greatest amount of ammonia were obtained at EFGB on 25 March 2012.

Table 9.3.7.

Concentrations of Ammonia (mg/l) in Water Samples at EFGB and WFGB from 2011–2012

Ammonia (Detection limit: 0.10 mg/l)	**2011**				**2012**			
	2/15/11 – 2/16/11	**5/15/11 – 5/17/11**	**8/20/11 – 8/21/11**	**10/24/11 – 10/25/11**	**3/25/12**	**5/29/12**	**8/9/12**	**11/9/12**
EFGB Surface A	ND	**0.10**	**0.20**	ND	**0.26**	ND	ND	ND
EFGB Surface B	ND	**0.20**	**0.30**	ND	**0.25**	ND	ND	ND
EFGB Midwater A	ND	**0.20**	**0.30**	ND	**0.34**	ND	ND	ND
EFGB Midwater B	ND	**0.10**	**0.20**	ND	**0.28**	ND	ND	ND
EFGB Reef Cap A	ND	**0.20**	**0.20**	ND	**0.19**	ND	ND	ND
EFGB Reef Cap B	ND	**0.10**	**0.30**	ND	**0.24**	ND	ND	ND
WFGB Surface A	ND	**0.10**	**0.30**	ND	**0.21**	ND	ND	ND
WFGB Surface B	ND	**0.20**	**0.30**	ND	**0.24**	ND	ND	ND
WFGB Midwater A	ND	**0.10**	**0.30**	ND	**0.22**	ND	ND	ND
WFGB Midwater B	ND	**0.10**	**0.30**	ND	**0.23**	ND	ND	ND
WFGB Reef Cap A	ND	**0.10**	**0.20**	ND	**0.19**	ND	ND	ND
WFGB Reef Cap B	ND	**0.30**	**0.10**	ND	**0.20**	ND	ND	ND

ND=Not detected at reporting limit. Concentrations at or above detectable limits (>0.10 mg/l) in bold. Dates represent month/day/year.

In approximately 2% of water samples, the nitrate concentrations were above detection limits (0.15 mg/l). The only samples that contained detectable levels were those collected on the EFGB reef cap in February 2011 and October 2011 (Table 9.3.8).

Table 9.3.8.

Concentrations of Nitrate in Water Samples at EFGB and WFGB from 2011–2012

Nitrate (Detection limit: 0.15 mg/l)	**2011**				**2012**			
	2/15/11 – 2/16/11	**5/15/11 – 5/17/11**	**8/20/11 – 8/21/11**	**10/24/11 – 10/25/11**	**3/25/12**	**5/29/12**	**8/9/12**	**11/9/12**
EFGB Surface A	ND	ND	ND	ND	ND	ND	ND	ND
EFGB Surface B	ND	ND	ND	ND	ND	ND	ND	ND
EFGB Midwater A	ND	ND	ND	ND	ND	ND	ND	ND
EFGB Midwater B	ND	ND	ND	ND	ND	ND	ND	ND
EFGB Reef Cap A	ND	ND	ND	ND	ND	ND	ND	ND
EFGB Reef Cap B	**0.31**	ND	ND	**0.31**	ND	ND	ND	ND
WFGB Surface A	ND	ND	ND	ND	ND	ND	ND	ND
WFGB Surface B	ND	ND	ND	ND	ND	ND	ND	ND
WFGB Midwater A	ND	ND	ND	ND	ND	ND	ND	ND
WFGB Midwater B	ND	ND	ND	ND	ND	ND	ND	ND
WFGB Reef Cap A	ND	ND	ND	ND	ND	ND	ND	ND
WFGB Reef Cap B	ND	ND	ND	ND	ND	ND	ND	ND

ND=Not detected at reporting limit. Concentrations above detectable limits (>0.15 mg/l) in bold. Dates represent month/day/year.

TKN was detectable in 75% of all water samples collected at EFGB and WFGB. It was detected in all of the 2011 samples, and half of the 2012 samples. Concentrations ranged from 0.60 to 45.20 mg/l, both of which were collected at EFGB on 09 November 2012 and 21 August 2011, respectively (Table 9.3.9).

Table 9.3.9.

Concentrations of TKN in Water Samples at EFGB and WFGB from 2011–2012

TKN (Detection limit: 0.55 mg/l)	**2011**				**2012**			
	2/15/11 – 2/16/11	**5/15/11 – 5/17/11**	**8/20/11 – 8/21/11**	**10/24/11 – 10/25/11**	**3/25/12**	**5/29/12**	**8/9/12**	**11/9/12**
EFGB Surface A	**2.90**	**4.60**	**15.20**	**4.40**	**7.90**	ND	ND	**0.60**
EFGB Surface B	**7.30**	**2.30**	**7.60**	**9.30**	**9.40**	ND	ND	**0.90**
EFGB Midwater A	**7.90**	**2.10**	**34.10**	**8.10**	**6.80**	ND	ND	**1.00**
EFGB Midwater B	**6.40**	**6.50**	**45.20**	**17.4**	**8.70**	ND	ND	**1.10**
EFGB Reef Cap A	**7.60**	**3.60**	**15.90**	**2.20**	**5.30**	ND	ND	**0.80**
EFGB Reef Cap B	**4.40**	**1.90**	**36.40**	**24.0**	**6.30**	ND	ND	**0.90**
WFGB Surface A	**6.90**	**1.30**	**38.90**	**20.70**	**4.80**	ND	ND	**1.00**
WFGB Surface B	**4.30**	**6.80**	**34.30**	**1.80**	**7.50**	ND	ND	**0.70**
WFGB Midwater A	**5.70**	**2.10**	**15.40**	**14.70**	**8.10**	ND	ND	**0.70**
WFGB Midwater B	**5.70**	**2.70**	**31.60**	**18.60**	**9.90**	ND	ND	**0.70**
WFGB Reef Cap A	**5.80**	**2.50**	**8.40**	**30.40**	**3.80**	ND	ND	**0.60**
WFGB Reef Cap B	**5.00**	**2.00**	**13.10**	**20.60**	**5.70**	ND	ND	**0.70**

ND=Not detected at reporting limit. Concentrations above detectable limits (>0.55–mg/l) in bold.
Dates represent month/day/year.

9.4. WATER QUALITY DISCUSSION

9.4.1. Water Quality Parameters

Water quality parameters investigated at EFGB and WFGB from January 2011 through December 2012 were temperature, salinity, Chl-*a*, and nutrients (ammonia, nitrate, nitrite, soluble reactive phosphorous, and TKN).

9.4.1.1. Sea-Bird versus Hobo Temperature Records

HoboTemp thermographs were attached to each of the Sea-Bird 37-SMP MicroCAT datasondes as backup records of seawater temperature, and data were acquired at the both banks from January 2011 through December 2012. Concurrent Sea-Bird and Hobo data could be compared to evaluate accuracy. Overall, both methods provided reliable temperature records. Statistical comparisons were conducted to compare daily means from 2011–2012 using a two-sample t-test with an experimentwise error rate of $\alpha=0.05$. Although differences were seen in July and August in 2012, potentially due to uncalibrated instruments, overall no significant differences were found. However, one or both of the sensors at EFGB began to provide slightly different readings during mid-June through July of 2012, as the Sea-Bird datasonde recorded higher temperatures than the HoboTemp thermographs (Figure 9.4.1). WFGB Sea-Bird and Hobo temperature data had only slight differences at WFGB (Figure 9.4.2). Interestingly, the HoboTemp thermograph at WFGB and the Sea-Bird datasonde at WFGB both recorded the low temperature drop below 27°C in late September of 2011. Both instruments were functioning properly, so it is unknown what caused this sudden decrease in temperature. Both the Sea-Bird and Hobo Temp thermographs will continue to be used at the FGB to enhance long-term monitoring of temperature on the reef cap, as well as provide reliable backup records if one sensor fails.

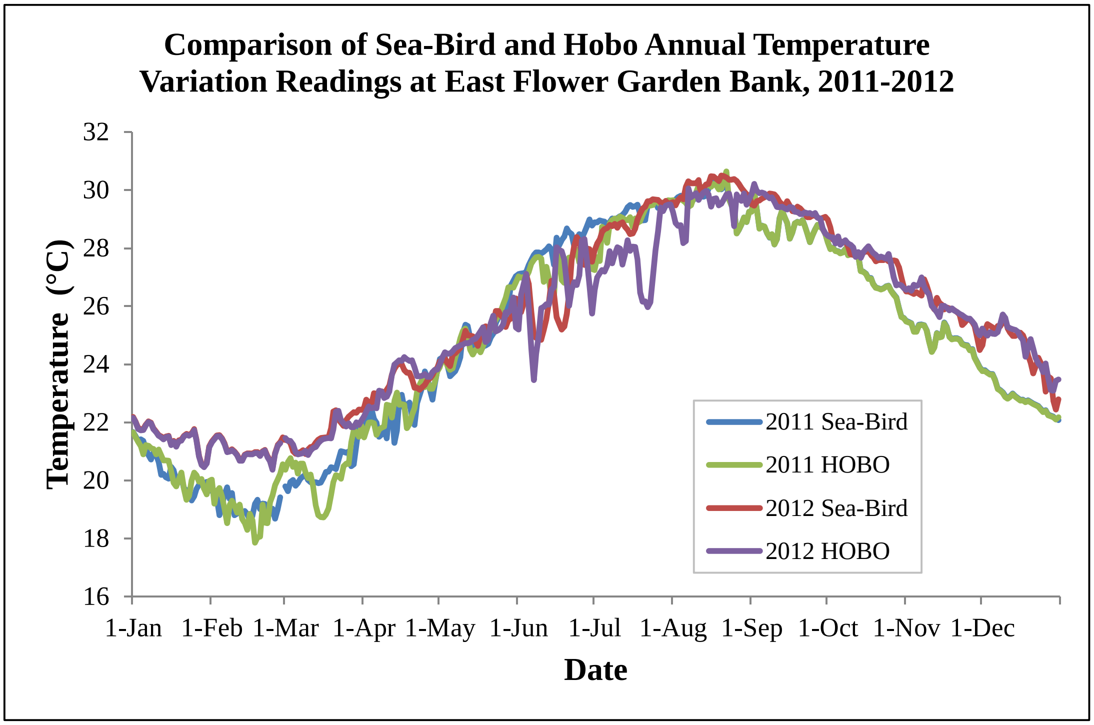


Figure 9.4.1. Comparison of Sea-Bird and Hobo daily mean seawater temperature readings measured near the reef cap at EFGB from 2011–2012.

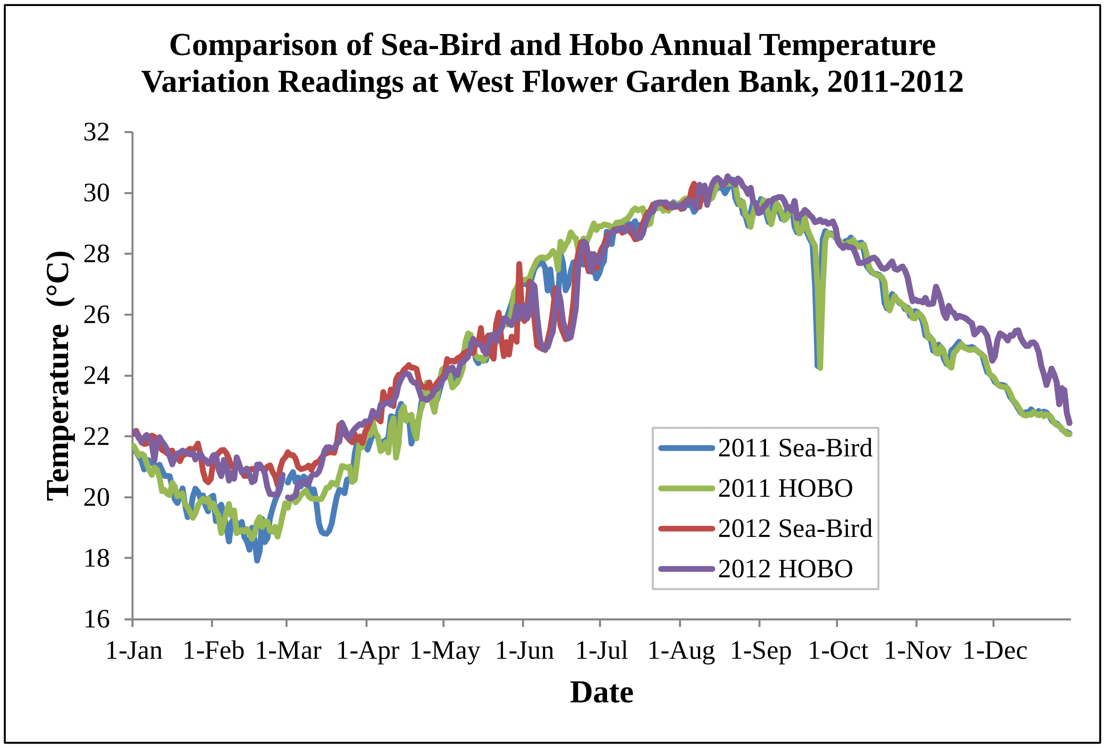


Figure 9.4.2. Comparison of Sea-Bird and Hobo daily mean seawater temperature readings measured near the reef cap at the WFGB from 2011–2012.

9.4.1.2. Temperature

Historical long-term averages derived from past monitoring periods show that the temperature minimum on the reef cap typically occurs from January to mid-March and the temperature maximum from mid-August through mid-September (Figures 9.4.3 and 9.4.4). The temperature on the EFGB reef cap was typically warmer than that on WFGB, especially during the summer months. This may be due to WFGB proximity to the shelf edge, which is more likely to subject the reef cap to cooler water. EFGB is slightly farther up on the continental shelf, perhaps subjecting it more regularly to warmer water masses. The mean daily temperature range on the EFGB reef cap from 1990 to 2012 was 20.0 to 29.8°C. The mean daily temperature range on the WFGB reef cap from 1990 to 2012 was 19.8 to 29.5°C.

Trends in seasonal thermal changes over the reef caps of EFGB and WFGB are apparent (Figures 9.4.3 and 9.4.4). From a winter minimum, the temperature gradually rises through the end of March and reaches a maximum during mid-August through mid-September. The temperature decreases gradually starting around October and reaches an annual minimum by mid-February through mid-March. During the 2011–2012 monitoring period, there were several thermal anomalies (both positive and negative). The most notable was temperature dips below the mean in June of 2012 at EFGB and temperature dips below the mean at WFGB in February and September of 2011. Overall, both EFGB and WFGB show warming trends of temperatures above the historical mean temperatures.

As expected, the mean temperatures recorded within the study site were warmer than the temperatures recorded at the repetitive deep stations. At EFGB, the annual mean temperature was 24.85°C in 2011 and 25.50°C in 2012. At WFGB, the annual mean temperature was 24.84°C and 25.49°C in 2012. At the deepest 40 m depth, the annual mean temperature was 24.44°C at EFGB and 24.73°C at WFGB in 2012.

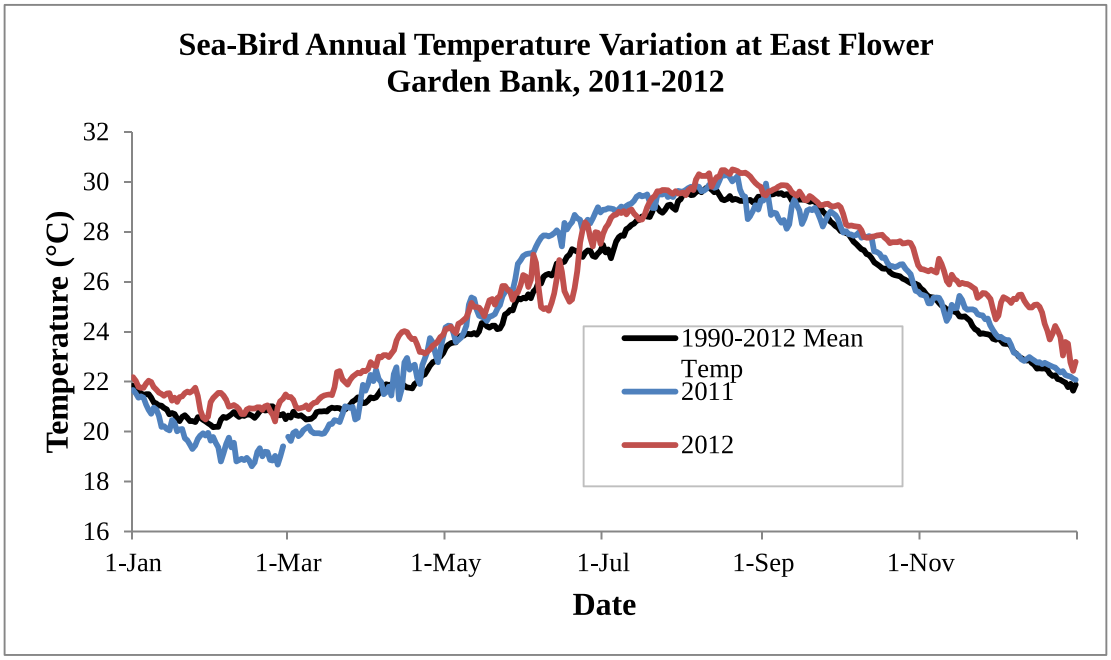


Figure 9.4.3. Seawater temperature measured using Sea-Bird datasonde near the reef cap at EFGB in 2011 and 2012, and the historical long-term mean temperature from past monitoring periods.

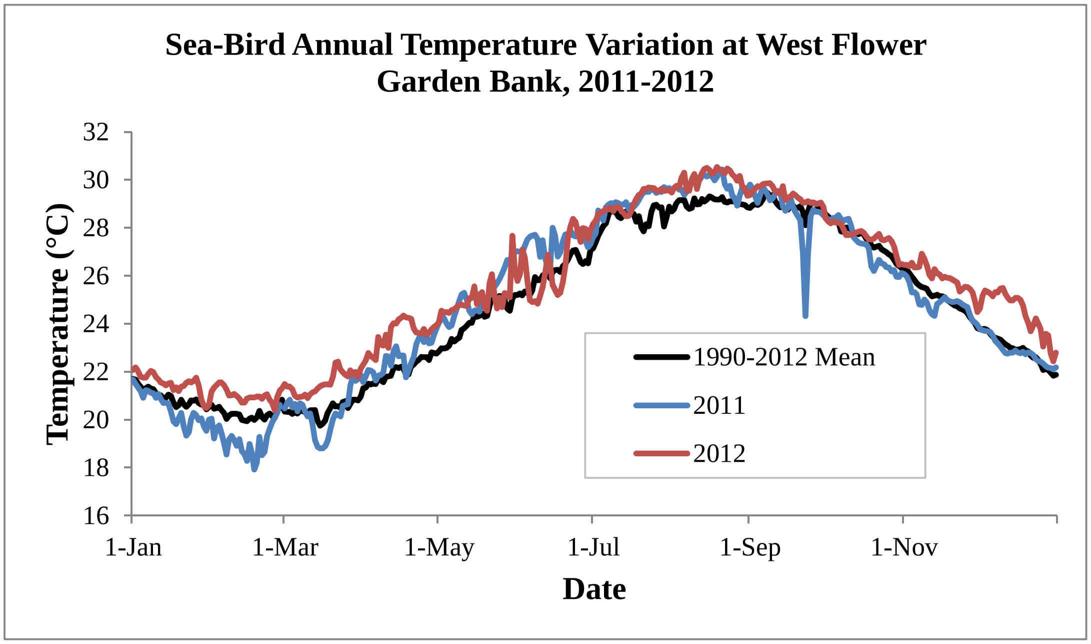


Figure 9.4.4. Seawater temperature measured using Sea-Bird datasonde near the reef cap at WFGB in 2011 and 2012, and the historical long-term mean temperature from past monitoring periods.

9.4.1.3. Salinity

Salinity data were obtained from the Sea-Bird MicroCAT for January 2011 to December 2012, ranging from approximately 34.6 to 37.8 PSU at EFGB and WFGB with a mean of approximately 36 PSU. The data indicated lower salinity in summer months, a pattern consistent on both banks. During 2011, there were two events of low salinity on the reef caps of the FGB: one in May and another, more pronounced event from July through August. During 2012, there were also two events of low salinity: one in July and another, less pronounced event in August at EFGB. The data collected appear to be within the accepted limits of salinity for coral reefs located in the Western Atlantic (31–38 PSU; Coles and Jokiel 1992).

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

9.4.2. Chlorophyll *a* and Nutrients

Chl-*a* concentrations in 2011 and 2012 revealed that the water column overlying the FGB reef caps could occasionally contain as much as 2.94 mg/m^3. Not all water samples contained detectable levels of Chl-*a* (>1 mg/m^3), and 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 expected in the summer (July–August; Nowlin et al. 1998). The relatively high values of Chl-*a* (by FGB standards) observed on 15 February 2011 may be indicative of an algal bloom, or a pulse of inshore water rapidly pushed offshore.

In a recent study, Bell et al. (2013) suggest that coral cover reduction on the Great Barrier Reef is attributable largely to chronic eutrophication, and that threshold Chl-*a* values need to be decreased to 0.2 mg/m^3 to sustain healthy reef communities. Though most FGB values were below this range, some water samples contained values above this threshold. Unfortunately no oceanographic satellite data were available through NOAA's CoastWatch Program to examine the occurrence of an algal bloom at the FGB in February 2011, because the use of CoastWatch to monitor changes in Chl-*a* in the area of the FGB is certainly more useful than spot checks alone.

Ammonia values were typically less than 1 mg/l from the sea surface to the reef cap, with the exception of samples taken on 15–17 May 2011, 20–21 August 2011, and 25 March 2012 at EFGB and WFGB. While high levels of ammonia can be toxic to aquatic life and indicate pollution, the levels of ammonia reported ranged between 0.10–0.34 mg/l, just above the 0.10 mg/l reporting limit. Seasonal fluctuations in ammonia concentrations are natural due to varying rates of organic loading and biological decay.

Nitrate levels were not detected, with the exception of two samples above the reporting limit (0.15 mg/l). Nitrite and soluble reactive phosphorus were not detected in any of the samples.

TKN (organic nitrogen and ammonia) was detected in all water samples collected at the banks in 2011, with concentrations ranging from 1.3–45.2 mg/l (above the 0.55 mg/l detection threshold). In 2012, 50% of the samples contained TKN concentrations above the detectable threshold ranging from 0.6–9.9 mg/l. TKN is a portion of the total nitrogen measurement and tests for the presence of nitrogen through the subtraction of ammonia nitrogen to give organic nitrogen. Organic nitrogen consists mainly of protein substances and their byproducts. The presence of nitrogenous compounds at abnormal levels in surface water generally indicates pollution and can lead to excess algae growth.

The first Chl-*a* and and nutrient concentration samples were taken at the FGB as part of the long-term monitoring program in 2002. Since that time, most nutrients have been recorded below detectable limits, with the exception of the occasional spike in Chl-*a* and ammonia (Figure 9.4.5 and Figure 9.4.6). However, the one historical trend that is apparent at EFGB and WFGB is the increase in TKN since the first measurements were made in 2002. Organic nitrogen and ammonia that contributes to TKN is typically formed within the water column by phytoplankton and bacteria and cycled within the food chain, and is subject to seasonal fluctuations in the biological community, but can be affected by both point and non-point sources. It is possible that high levels of TKN may be correlated with the increased levels of macroaglae cover at both banks. Nowlin et al. (1998) showed that shelf edge waters in the northwestern Gulf of Mexico are typically stripped of nutrients. When present, the probable sources of nutrients in the water column at the FGB are nearshore waters (Nowlin et al. 1998), sediments (Entsch et al. 1983), or benthic and planktonic organisms (D’Elia and Wiebe 1990). More frequent sampling is required to understand nutrient dynamics over the reef caps.

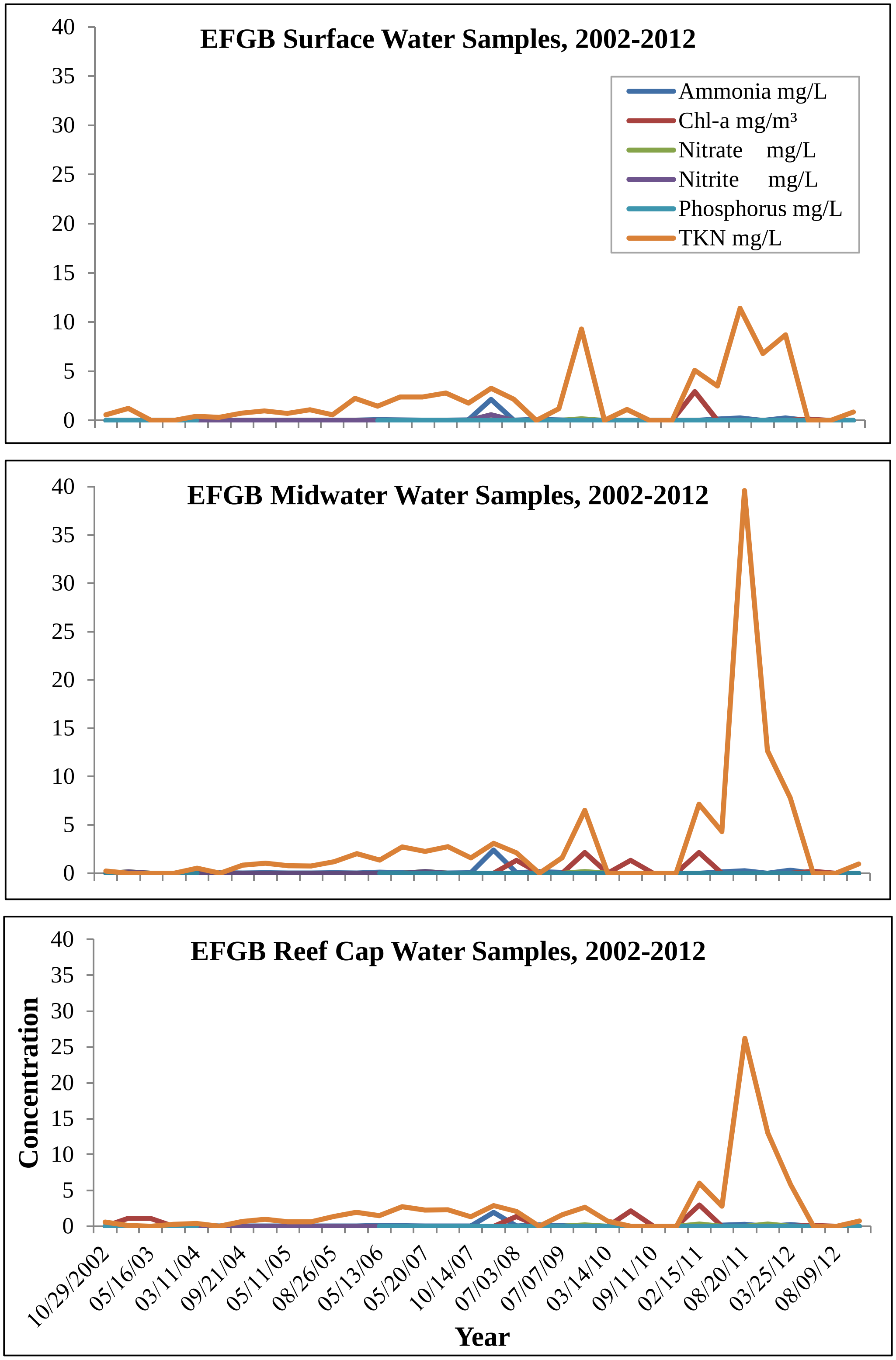


Figure 9.4.5. Water samples taken at the surface, midwater, and on the reef cap at EFGB from 2002–2012.

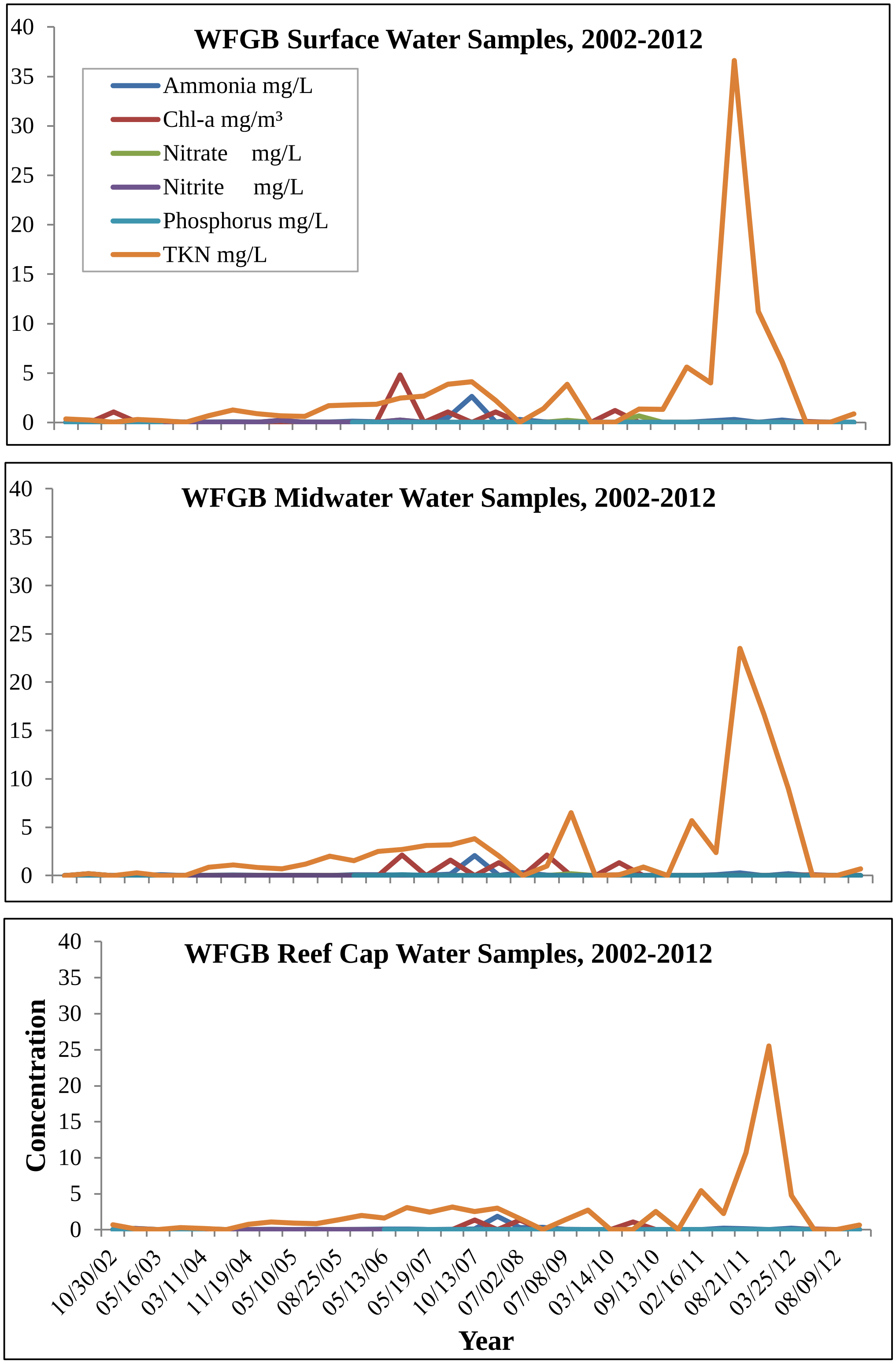


Figure 9.4.6. Water samples taken at the surface, midwater, and on the reef cap at WFGB from 2002–2012.

9.4.3. Sea State

During the 2011–2012 monitoring period, three tropical storms and one hurricane occurred in the Northern Gulf of Mexico. In the past, up to 11 tropical cyclones have affected the Gulf of Mexico in one year (Precht et al. 2006). In 2008, Hurricane Ike crossed over EFGB (eventually making landfall in Galveston, Texas), damaging coral in the long-term monitoring study site. However, the 2011 and 2012 storms were located in other areas of the Gulf of Mexico and did not impact the FGB. Tropical Storm Lee in 2011 and Hurricane and Tropical Storm Isaac in 2012 were the two cyclones that came closest to the FGB during the monitoring period; however, both storms were still over 200 km east of the FGB. A list of all tropical cyclones that have occurred in the Northern Gulf of Mexico since 2002 can be found in Volume II Appendix 11.

CHAPTER 10.0: FISH SURVEYS

10.1. FISH SURVEYS METHODOLOGICAL RATIONALE

Surveys of fish assemblages have been conducted at the FGB since the early 1980s; however, these surveys have not been part of the long-term monitoring study (Boland et al. 1983; Rezak et al. 1985; Dennis and Bright 1988; Pattengill 1998). Fish surveys were officially added to the long-term monitoring protocol in 2002. The fish assemblages of the coral reef zone at EFGB and WFGB are composed of Caribbean reef species; however, the total number of species is lower in comparison (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 also been investigated (Rooker et al. 1997). Continued monitoring of the FGB is vital to increasing the understanding of this unique habitat in light of the ongoing, as well as the changing, natural and anthropogenic pressures on fish populations.

10.2. FISH SURVEYS METHODS

Twenty-four stationary visual fish surveys were conducted at both EFGB and WFGB in 2011 and 2012, six surveys in each quadrant of the study sites. Fishes were visually assessed by SCUBA divers using a modified Bohnsack and Bannerot (1986) stationary visual fish census technique. Observations of fishes were restricted to an imaginary cylinder with a radius 7.5 m from the diver, extending to the surface. All fish species observed within the first five minutes of the survey were recorded while the diver slowly rotated in place. Immediately following this five minute observation period, one rotation was conducted for each species noted in the original five minute period to record abundance (number of individuals per species) and total length (within eight categories). Each survey required 10 to 15 minutes. Transitory or schooling species were counted and measured at the time the individuals moved through the cylinder during the initial five-minute period. After the initial five-minute period, additional species were recorded but marked as observed after the official survey period. These observations were excluded from the analysis, unless otherwise stated.

For each quadrant, a random number between 0 and 50 was generated to indicate the starting location along the first boundary line encountered (e.g., if the random number is 27 m and the corner of the transect tape is 0, the transect is started at 27 m along the transect tape, and if the lowest corner of the transect tape is 50 m, the transect is started at 77 m along the transect tape). A second random number was generated between 0 and 40 to determine the number of fin kicks perpendicular from the boundary line into the study site. It takes approximately 40 fin kicks to swim 50 m, the length of the quadrant, if there is not a strong current. A third random number was generated to provide a random heading, between 0° and 359°, providing a direction to swim the random distance. Those criteria provided the starting location for the first fish count, with a fourth number to provide a random heading, between 0° and 359°, along which to lay the tape marking the radius of the survey.

Subsequent survey starting points were determined with a second set of randomly generated numbers with the first number providing a heading, between 0° and 359°, and the second providing the number of fin kicks, between 12 and 40, to ensure the starting point was at least 15 m away from the previous location. A third number was generated to provide a random heading, between 0° and 359°, in which to lay the tape marking the 7.5 m radius of the survey.

Fish survey dives began in the early morning (0700 CDT), and were repeated throughout the day until dusk. Surveys were binned into five time groupings: early morning (0700 to 0900), later morning (0901 to 1200), early afternoon (1201 to 1500), late afternoon (1501 to 1800), and early evening (1801 to dusk) to document differences throughout the day. Survey locations stratified randomly within the 10,000 m^2 study site, and occurred within depths of 20–24 m.

10.3. FISH SURVEYS DATA AND STATISTICAL ANALYSIS

Summary statistics of fish census data include abundance, density, sighting frequency, richness, diversity, and evenness. Fish densities are expressed as the number of fish per 100 m^2, where densities were calculated by dividing the number of individuals per survey by the horizontal area of the survey cylinder (176.7 m^2), then multiplying by 100 to provide fish densities per 100 m^2. Sighting frequency for each species is expressed as the percentage of the total number of times the species was recorded out of the total number of surveys for the site (Bank and Year). Relative abundance is expressed as the number of individuals of one species divided by the total number of all species observed. Species richness is the total number of species for each site (Bank and Year). Diversity was calculated using the Shannon-Wiener diversity index, H':

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

where k is the number of species present and p_i is the relative abundance of each species, calculated as the proportion of individuals of a given species to the total number of individuals observed.

Species evenness (J') was determined for each site and year using the following calculation:

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

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

Species accumulation curves were generated in PRIMER-E®, showing species accumulation as the increasing total number of species observed (S_{obs}) and Chao's estimator, based on the number of rare species (Chao1).

Fish total length was recorded as size-classes: <5 cm, 5-10 cm, 10-15 cm, 15-20 cm, 20-25 cm, 25-30 cm, 30-35 cm and >35 cm. Species were classified into four trophic guilds: herbivores, piscivores, invertivores, and planktivores. Size-frequency distributions for the four trophic guilds were calculated for each bank and year by dividing the number of herbivores, piscivores, invertivores, and planktivores in each size class by the total number observed in each trophic guild.

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

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

where W = individual weight (grams), L = length of fish (cm), and α and β are constants for each species generated from the regression of its length and weight, derived from Froese and Pauly (2009) and Bohnsack and Harper (1988). Mean length for each species (to the nearest 5 cm) was used to estimate size. A mean 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). Biomass and species accumulation plots were generated to make overall assessments of the fish community at EFGB and WFGB. Observations of mantas and sting rays were removed from all biomass analyses due to their rare nature and large size.

The software package Primer® version 6.0 was used to conduct statistical analyses on square root transformed density and biomass data. Species composition changes between years and banks were analyzed by converting to ecological distance using Bray-Curtis similarity matrices (Bray and Curtis, 1957):

$S'_{jk} = 1 – (\Sigma_{ni}=1\ X_{ij} - X_{ik}) / (\Sigma_{ni}=1\ X_{ij} + X_{ik})$

where n is the number of species and X_{ij} is the abundance of the i^{th} species in the j^{th} sample and where there are n species overall. Where required, a dummy variable (value=1) was included in the analysis. SIMPER were used to analyze community dissimilarity between year and bank and highlight species that contributed greatly to the observed dissimilarity. MDS plots, 100 random starting configurations to minimize stress, were generated to examine for evidence of community differences by year and bank (EFGB and WFGB). Community differences were then compared for significant differences using non-parametric ANOSIM. The R statistic, typically ranging between 0 and 1, indicates between and within group dissimilarities, where small R values (<0.3) indicate that similarities between sites and within sites are the same (Clarke & Warwick 2001).

Dominance plots were generated for species abundance and biomass. W-values (difference between the biomass and abundance) were calculated for each survey. The difference between abundance and biomass curves, w, can range between -1<w>1. Where w=1 indicates that the population has an evenly distributed abundance, but that biomass is dominated by few species, and where w=-1 indicates that the converse is true.

Two-sample t-tests (two-tailed) were used to analyze parametric data, including diversity indices and w-values. Students t-test were used for pair-wise comparisons with the statistical software JMP® version 10.0.

Trend analysis of biomass and density data over time was conducted using the nonparametric Mann-Kendall trend test. This analysis was conducted using R (R Developent Core Team 2012), with the Kendall package (McLeod 2011).

10.4. FISH SURVEYS RESULTS

Fish surveys were conducted at both banks during July 2011 and 2012 monitoring cruises. During this monitoring period, a total of 96 surveys were conducted, with 24 surveys conducted at each bank. Each survey represents one sample. Each sample covered 176.7 m^2, resulting in a coverage of 42% of the 10,000 m^2 study sites during 2011 and 2012. A complete list of species observed and their abundance per 100 m^2 by year and bank is seen in Table 10.4.1. All fish survey data from 2011 and 2012 can be found in Volume II Appendix 10 of this report.

Table 10.4.1.

Complete Species List for 2011 and 2012 at EFGB and WFGB Showing Abundance per 100 m^2 by Year and Bank

Species ID:	**EFGB**		**WFGB**	
(Family Name: Species Name (Common Name - Trophic Guild)	**2011**	**2012**	**2011**	**2012**
Pomacentridae: *Chromis multilineata* (brown chromis - I)	88.24	61.69	108.05	169.14
Serranidae: *Paranthias furcifer* (creolefish - PL)	14.88	10.33	7.45	6.11
Labridae: *Thalassoma bifasciatum* (bluehead - I)	9.48	10.78	12.31	13.30
Labridae: *Clepticus parrae* (creole wrasse - PL)	4.86	6.74	4.53	36.22
Labridae: *Bodianus rufus* (Spanish hogfish - I)	2.95	1.89	2.59	3.09
Tetraodontidae: *Canthigaster rostrata* (sharpnose puffer - I)	2.57	2.08	1.98	4.17
Pomacentridae: *Stegastes partitus* (bi-color damselfish - H)	2.36	7.31	2.69	15.35
Pomacentridae: *Stegastes planifrons* (threespot damselfish - I)	2.24	2.52	2.99	3.09
Acanthuridae: *Acanthurus coeruleus* (blue tang - H)	2.12	2.19	1.30	2.15
Kyphosidae: *Kyphosus sectatrix* (chub [Bermuda/yellow] - H)	1.96	3.65	4.41	7.29
Pomacentridae: *Chromis cyanea* (blue chromis - PL)	1.56	2.66	2.50	3.80
Pomacentridae: *Stegastes variabilis* (cocoa damselfish - H)	1.56	4.98	1.23	5.05
Sphyraenidae: *Sphyraena barracuda* (barracuda - P)	1.39	3.25	2.95	1.89
Labridae: *Sparisoma atomarium* (greenblotch parrotfish - H)	1.27	0.38	0.17	0.38
Belonidae: *Belonidae spp*. (needlefish spp. - P)	1.18	0.00	0.00	0.00
Labridae: *Scarus taeniopterus* (princess parrotfish - H)	1.18	2.15	0.19	5.35
Balistidae: *Melichthys niger* (black durgon - H)	0.97	1.11	0.66	1.63
Labridae: *Scarus vetula* (queen parrotfish - H)	0.97	2.62	1.20	1.96
Gobiidae: *Elacatinus oceanops* (neon goby - I)	0.92	1.11	0.28	2.59
Labridae: *Sparisoma aurofrenatum* (redband parrotfish - H)	0.68	1.84	0.42	2.10

Species ID: **(Family Name: Species Name (Common Name - Trophic Guild)**	**EFGB**		**WFGB**	
	2011	**2012**	**2011**	**2012**
Pomacentridae: *Microspathodon chrysurus* (yellowtail damselfish - H)	0.66	0.52	0.59	0.33
Labridae: *Sparisoma viride* (stoplight parrotfish - H)	0.61	1.13	0.83	1.41
Carangidae: *Caranx latus* (horse-eye jack - P)	0.57	0.14	0.14	0.05
Blenniidae: *Ophioblennius macclurei* (redlip blenny - H)	0.54	0.19	0.17	0.40
Chaetodontidae: *Chaetodon sedentarius* (reef butterflyfish - I)	0.42	0.85	0.71	0.85
Serranidae: *Cephalopholis cruentata* (graysby - P)	0.40	0.52	0.26	0.57
Carangidae: *Carangoides ruber* (bar jack - P)	0.31	6.91	0.28	1.72
Pomacentridae: *Abudefduf saxatilis* (sergeant major - I)	0.28	0.12	0.24	0.17
Pomacentridae: *Stegastes adustus* (dusky damselfish - H)	0.28	0.47	0.05	3.16
Serranidae: *Mycteroperca interstitialis* (yellowmouth grouper - P)	0.28	0.33	0.05	0.09
Pomacentridae: *Chromis scotti* (purple reeffish - PL)	0.26	1.27	0.83	5.54
Acanthuridae: *Acanthurus chirurgus* (doctorfish - H)	0.24	0.61	0.07	0.26
Blenniidae: *Parablennius marmoreus* (seaweed blenny - I)	0.24	2.05	0.00	3.44
Chaetodontidae: *Prognathodes aculeatus* (Longsnout butterflyfish - I)	0.24	0.14	0.33	0.33
Acanthuridae: *Acanthurus bahianus* (ocean surgeonfish - H)	0.21	0.73	0.02	0.85
Pomacanthidae: *Holacanthus tricolor* (rock beauty - I)	0.21	0.31	0.07	0.75
Labridae: *Halichoeres garnoti* (yellowhead wrasse - I)	0.19	1.44	0.09	0.97
Mullidae: *Mulloidichthys martinicus* (yellow goatfish - I)	0.19	0.73	0.17	0.07
Chaetodontidae: *Chaetodon ocellatus* (spotfin butterflyfish - I)	0.17	0.38	0.00	0.07
Lutjanidae: *Lutjanus griseus* (gray snapper - I)	0.17	0.14	0.14	0.14
Pomacentridae: *Chromis insolata* (sunshinefish - PL)	0.17	0.35	0.26	1.23
Ostraciidae: *Lactophrys triqueter* (smooth trunkfish - I)	0.12	0.14	0.19	0.24
Acanthuridae: *Acanthurus spp*. (surgeonfish spp. - H)	0.09	0.00	0.00	0.00
Holocentridae: *Holocentrus adscensionis* (squirrelfish - I)	0.09	0.05	0.00	0.00
Serranidae: *Cephalopholis fulva* (coney - I)	0.09	0.07	0.00	0.00
Serranidae: *Epinephelus adscensionis* (rock hind - I)	0.09	0.21	0.00	0.02
Balistidae: *Canthidermis sufflamen* (ocean triggerfish- I)	0.07	0.14	0.09	0.02
Chaetodontidae: *Chaetodon striatus* (banded butterflyfish - I)	0.07	0.00	0.02	0.05
Cirrhitidae: *Amblycirrhitus pinos* (redspotted hawkfish - I)	0.07	0.02	0.09	0.09
Apogonidae: *Apogon maculatus* (flamefish - I)	0.05	0.00	0.00	0.00
Balistidae: *Balistes vetula* (queen triggerfish - I)	0.05	0.00	0.00	0.00
Carangidae: *Caranx lugubris* (black jack - P)	0.05	0.02	0.00	0.00
Lutjanidae: *Lutjanus jocu* (dog snapper - P)	0.05	0.12	0.12	0.28
Pomacanthidae: *Pomacanthus paru* (French angelfish - I)	0.05	0.00	0.05	0.05
Labridae: *Scarus iseri* (striped parrotfish - H)	0.05	0.42	0.12	1.23
Tetraodontidae: *Sphoeroides spengleri* (bandtail puffer - I)	0.05	0.00	0.00	0.00
Carangidae: *Caranx hippos* (Crevalle jack - P)	0.02	0.00	0.00	0.00
Labridae: *Bodianus pulchellus* (spotfin hogfish - I)	0.02	0.00	0.02	0.00

Species ID: **(Family Name: Species Name (Common Name - Trophic Guild)**	**EFGB**		**WFGB**	
	2011	**2012**	**2011**	**2012**
Lutjanidae: *Ocyurus chrysurus* (yellowtail snapper - PL)	0.02	0.00	0.00	0.00
Monacanthidae: *Cantherhines macrocerus* (whitespotted filefish - I)	0.02	0.00	0.02	0.00
Monacanthidae: *Cantherhines pullus* (orange spotted filefish - I)	0.02	0.12	0.02	0.07
Serranidae: *Mycteroperca bonaci* (black grouper - P)	0.02	0.00	0.00	0.09
Serranidae: *Mycteroperca phenax* (scamp - P)	0.02	0.02	0.00	0.00
Serranidae: *Mycteroperca tigris* (tiger grouper - P)	0.02	0.05	0.09	0.05
Carangidae: *Caranx crysos* (blue runner - P)	0.00	0.00	0.00	0.54
Carangidae: *Seriola dumerili* (greater amberjack - P)	0.00	0.00	0.00	0.07
Chaenopsidae: *Acanthemblemaria aspera* (roughhead blenny - PL)	0.00	0.00	0.00	0.02
Diodontidae: *Diodon hystrix* (porcupinefish - I)	0.00	0.00	0.00	0.07
Gobiidae: *Gnatholepis thompsoni* (goldspot goby - H)	0.00	0.02	0.00	0.00
Holocentridae: *Holocentrus rufus* (longspine squirrelfish - I)	0.00	0.05	0.05	0.05
Labridae: *Halichoeres bivittatus* (slippery dick - I)	0.00	0.02	0.14	0.00
Labridae: *Halichoeres maculipinna* (clown wrasse - I)	0.00	0.09	0.00	1.98
Labridae: *Halichoeres radiatus* (pudding wife - I)	0.00	0.05	0.00	0.12
Lutjanidae: *Lutjanus cyanopterus* (Cubera snapper - P)	0.00	0.00	0.00	0.05
Mullidae: *Pseudupeneus maculatus* (spotted goatfish - I)	0.00	0.00	0.12	0.00
Muraenidae: *Gymnothorax miliaris* (goldentail moray - I)	0.00	0.02	0.02	0.05
Muraenidae: *Gymnothorax moringa* (spotted moray - P)	0.00	0.00	0.05	0.00
Ostraciidae: *Acanthostracion polygonius* (honeycomb cowfish - I)	0.00	0.00	0.05	0.07
Ostraciidae: *Lactophrys bicaudalis* (spotted trunkfish - I)	0.00	0.00	0.02	0.00
Pomacanthidae: *Holacanthus bermudensis* (blue angelfish - I)	0.00	0.02	0.02	0.02
Pomacanthidae: *Holacanthus ciliaris* (queen angelfish - I)	0.00	0.07	0.05	0.07
Pomacanthidae: *Holacanthus townsendi* (townsend angelfish - I)	0.00	0.00	0.02	0.00
Pomacentridae: *Stegastes leucostictus* (beaugregory - I)	0.00	0.00	0.00	1.04
Labridae: *Sparisoma radians* (bucktooth parrotfish - H)	0.00	0.00	0.00	0.05

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

Total fish abundance at EFGB in 2011 and 2012 was 6,411 and 6,376, respectively. At WFGB, total fish abundance in 2011 and 2012 was 6,979 and 12,556, respectively.

Species accumulation curves indicate that current sample size adequately captures species richness for the study period (Figure 10.4.1).

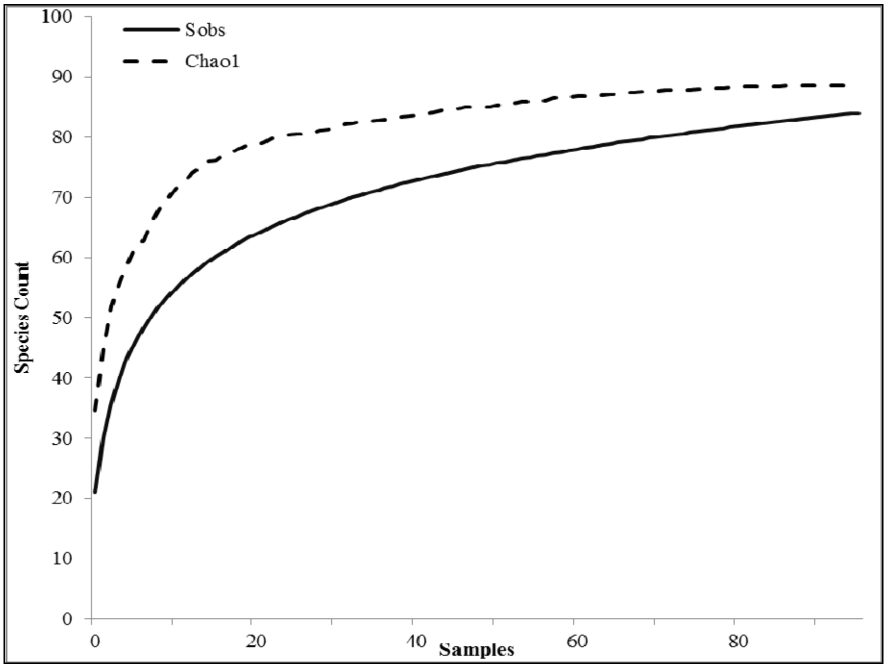


Figure 10.4.1. Tropical species accumulation curve.

S_{obs} represents species accumulation with increasing total number of species observed and Chao1 represents Chao's estimator accounting for the number of rare species.

10.4.1. Population Diversity

A total of 26 families and 84 species were recorded during this survey period for all samples combined. Family richness ranged between 21 (EFGB 2012 and WFGB 2011) and 24 (WFGB 2012). Species richness varied between 59 (WFGB 2011) and 65 (WFGB 2012) (Table 10.4.2). In 2011, an average of 11 ± 2 fish families per sample was recorded at EFGB and 11 ± 2 at WFGB. In 2012, an average of 11 ± 2 fish families per sample was recorded at EFGB and 13 ± 2 at WFGB. For species richness in 2011, an average of 20 ± 4 fish species per sample was recorded at EFGB, and 19 ± 3 at WFGB. In 2012, an average of 22 ± 4 fish species per sample was recorded at EFGB, and 23 ± 5 at WFGB.

Table 10.4.2.

Species and Family Richness by Year and Bank

	EFGB		**WFGB**	
	2011	**2012**	**2011**	**2012**
Species Richness	64	60	59	65
Mean Species Richness/Survey	20±4	22±4	19±3	23±5
Family Richness	22	21	21	24
Mean Family Richness/Survey	11±2	11±2	11±2	13±2

Values expressed as richness ± SD

When species richness was compared using a two-way ANOVA with an experimentwise error rate of α=0.05, a significant difference was observed between 2011 and 2012 (P-value=0.0006), but not between banks. The interaction of year and bank was also not significant. Analysis of each pair using a Students t-test showed a significant difference in species richness between 2011 and 2012 at WFGB (P-value=0.0009), but not at EFGB. No significant difference was seen in species richness between EFGB and WFGB in 2011 or 2012.

Species richness within families was calculated overall and between years and banks. Overall, the families containing the greatest number of species were the wrasses and parrotfishes (Labridae), damselfishes (Pomacentridae), and groupers and seabasses (Serranidae), represented by 15, 11, and 8 species, respectively (Table 10.4.3).

Table 10.4.3.

Species Richness within Families between Years and Banks, and between all Surveys

Family	**EFGB**		**WFGB**		**All Surveys**
	2011	**2012**	**2011**	**2012**	
Labridae	11	13	11	13	15
Pomacentridae	10	10	10	11	11
Serranidae	8	7	7	6	8
Pomacanthidae	2	3	2	4	5
Carangidae	4	3	2	3	5
Acanthuridae	4	3	3	3	4
Lutjanidae	3	2	3	3	4
Chaetodontidae	4	3	4	4	4
Balistidae	3	2	3	2	3
Ostraciidae	1	1	1	2	3
Tetraodontidae	2	1	2	1	2
Gobiidae	1	2	1	1	2
Blenniidae	2	2	2	2	2
Mullidae	1	1	1	1	2
Holocentridae	1	2	1	1	2
Monacanthidae	2	1	1	1	2
Muraenidae	0	1	0	1	2
Sphyraenidae	1	1	1	1	1
Kyphosidae	1	1	1	1	1
Belonidae	1	0	1	0	1
Cirrhitidae	1	1	1	1	1
Apogonidae	1	0	1	0	1
Chaenopsidae	0	0	0	1	1
Diodontidae	0	0	0	1	1

Diversity and evenness was measured between banks and years by calculating Shannon-Wiener diversity indices (Table 10.4.4). Diversity varied between banks and years; the greatest diversity occurred at WFGB in 2012. The lowest diversity was calculated for WFGB in 2011. Evenness between banks and years remained relatively stable; the least variation in communities occurred at EFGB in 2012.

Table 10.4.4.

Shannon-Wiener Diversity and Evenness Indices for Each Bank and Year

	EFGB		**WFGB**	
	2011	**2012**	**2011**	**2012**
Diversity (H’)	0.83	1.11	0.71	0.89
Evenness (J’)	0.46	0.62	0.40	0.49

When compared between banks using a two-way ANOVA, a significant difference was only observed between 2011 and 2012 for species diversity (P-value=0.0083). In pair-wise Students t-tests, only the comparison of species diversity between WFGB in 2011 and EFGB in 2012 were found to be significantly different (P-value=0.0165), suggesting a significantly greater species diversity at EFGB in 2012 than WFGB in 2011.

10.4.2. Sighting Frequency and Occurrence

The most frequently sighted species from all years and locations was the brown chromis (*Chromis multilineata*), observed in 91% of all surveys. Other frequently sighted species included Spanish hogfish (*Bodianus rufus*), bluehead (*Thalassoma bifasciatum*), sharpnose puffer (*Canthigaster rostrata*), blue tang (*Acanthurus coeruleus*), bi-color damselfish (*Stegastes partitus*), and great barracuda (*Sphyraena barracuda*), with sighting frequencies of 90%, 90%, 88%, 85%, 83%, and 80%, respectively (Table 10.4.5)

Table 10.4.5.

Percent Sighting Frequency for Species by Year and Bank, Including Sighting Frequency for All Surveys Conducted during the 2011–2012 Reporting Period

Species ID: (Family Name: Species Name (Common Name - Trophic Guild)	**EFGB**		**WFGB**		**All Surveys**
	2011	**2012**	**2011**	**2012**	
Acanthuridae: *Acanthurus bahianus* (ocean surgeonfish)	20.8	20.8	4.2	29.2	18.0
Acanthuridae: *Acanthurus chirurgus* (doctorfish)	20.8	45.8	8.3	20.8	23.0
Acanthuridae: *Acanthurus coeruleus* (blue tang)	95.8	79.2	91.7	87.5	85.0
Acanthuridae: *Acanthurus spp*. (surgeonfish spp.)	4.2	0.0	0.0	0.0	1.0
Apogonidae: *Apogon maculatus* (flamefish)	4.2	0.0	0.0	0.0	1.0
Balistidae: *Balistes vetula* (queen triggerfish)	8.3	0.0	0.0	0.0	2.0
Balistidae: *Canthidermis sufflamen* (ocean triggerfish)	8.3	20.8	16.7	4.2	12.0
Balistidae: *Melichthys niger* (black durgon)	58.3	66.7	58.3	62.5	59.0
Belonidae: *Belonidae spp*. (needlefish spp.)	4.2	0.0	0.0	0.0	1.0

Species ID: **(Family Name: Species Name (Common Name - Trophic Guild)**	**EFGB**		**WFGB**		**All Surveys**
	2011	**2012**	**2011**	**2012**	
Blenniidae: *Ophioblennius macclurei* (redlip blenny)	41.7	16.7	25.0	29.2	27.0
Blenniidae: *Parablennius marmoreus* (seaweed blenny)	20.8	25.0	0.0	45.8	22.0
Carangidae: *Carangoides ruber* (bar jack)	29.2	45.8	16.7	12.5	25.0
Carangidae: *Caranx crysos* (blue runner)	0.0	0.0	0.0	4.2	1.0
Carangidae: *Caranx hippos* (Crevalle jack)	4.2	0.0	0.0	0.0	1.0
Carangidae: *Caranx latus* (horse-eye jack)	12.5	16.7	16.7	8.3	13.0
Carangidae: *Caranx lugubris* (black jack)	4.2	4.2	0.0	0.0	2.0
Carangidae: *Seriola dumerili* (greater amberjack)	0.0	0.0	0.0	4.2	1.0
Chaenopsidae: *Acanthemblemaria aspera* (roughhead blenny)	0.0	0.0	0.0	4.2	1.0
Chaetodontidae: *Chaetodon ocellatus* (spotfin butterflyfish)	12.5	20.8	0.0	8.3	10.0
Chaetodontidae: *Chaetodon sedentarius* (reef butterflyfish)	33.3	62.5	54.2	58.3	50.0
Chaetodontidae: *Chaetodon striatus* (banded butterflyfish)	8.3	0.0	4.2	4.2	4.0
Chaetodontidae: *Prognathodes aculeatus* (longsnout butterflyfish)	25.0	20.8	37.5	41.7	30.0
Cirrhitidae: *Amblycirrhitus pinos* (redspotted hawkfish)	8.3	4.2	16.7	16.7	11.0
Diodontidae: *Diodon hystrix* (porcupinefish)	0.0	0.0	0.0	12.5	3.0
Gobiidae: *Elacatinus oceanops* (neon goby)	33.3	54.2	20.8	62.5	41.0
Gobiidae: *Gnatholepis thompsoni* (goldspot goby)	0.0	4.2	0.0	0.0	1.0
Holocentridae: *Holocentrus adscensionis* (squirrelfish)	12.5	8.3	0.0	0.0	5.0
Holocentridae: *Holocentrus rufus* (longspine squirrelfish)	0.0	8.3	4.2	8.3	5.0
Kyphosidae: *Kyphosus sectatrix* (chub (Bermuda/yellow))	70.8	54.2	70.8	79.2	66.0
Labridae: *Bodianus pulchellus* (spotfin hogfish)	4.2	0.0	4.2	0.0	2.0
Labridae: *Bodianus rufus* (Spanish hogfish)	95.8	91.7	91.7	95.8	90.0
Labridae: *Clepticus parrae* (creole wrasse)	66.7	50.0	54.2	75.0	59.0
Labridae: *Halichoeres bivittatus* (slippery dick)	0.0	4.2	20.8	0.0	6.0
Labridae: *Halichoeres garnoti* (yellowhead wrasse)	25.0	16.7	8.3	12.5	15.0
Labridae: *Halichoeres maculipinna* (clown wrasse)	0.0	8.3	0.0	50.0	14.0
Labridae: *Halichoeres radiatus* (pudding wife)	0.0	8.3	0.0	12.5	5.0
Labridae: *Thalassoma bifasciatum* (bluehead)	87.5	100.0	87.5	100.0	90.0
Labridae: *Scarus iseri* (striped parrotfish)	4.2	16.7	8.3	12.5	10.0
Labridae: *Scarus taeniopterus* (princess parrotfish)	41.7	37.5	16.7	45.8	34.0
Labridae: *Scarus vetula* (queen parrotfish)	58.3	95.8	66.7	75.0	71.0
Labridae: *Sparisoma atomarium* (greenblotch parrotfish)	70.8	29.2	20.8	25.0	35.0
Labridae: *Sparisoma aurofrenatum* (redband parrotfish)	41.7	54.2	29.2	58.3	44.0
Labridae: *Sparisoma radians* (bucktooth parrotfish)	0.0	0.0	0.0	8.3	2.0
Labridae: *Sparisoma viride* (stoplight parrotfish)	45.8	62.5	66.7	58.3	56.0
Lutjanidae: *Ocyurus chrysurus* (yellowtail snapper)	4.2	0.0	0.0	0.0	1.0
Lutjanidae: *Lutjanus cyanopterus* (Cubera snapper)	0.0	0.0	0.0	4.2	1.0
Lutjanidae: *Lutjanus griseus* (gray snapper)	20.8	4.2	16.7	12.5	13.0

Species ID: **(Family Name: Species Name (Common Name - Trophic Guild)**	**EFGB**		**WFGB**		**All Surveys**
	2011	**2012**	**2011**	**2012**	
Lutjanidae: *Lutjanus jocu* (dog snapper)	8.3	12.5	20.8	37.5	19.0
Monacanthidae: *Cantherhines macrocerus* (whitespotted filefish)	4.2	0.0	4.2	0.0	2.0
Monacanthidae: *Cantherhines pullus* (orange spotted filefish)	4.2	12.5	4.2	8.3	7.0
Mullidae: *Mulloidichthys martinicus* (yellow goatfish)	12.5	20.8	20.8	12.5	16.0
Mullidae: *Pseudupeneus maculatus* (spotted goatfish)	0.0	0.0	16.7	0.0	4.0
Muraenidae: *Gymnothorax moringa* (spotted moray)	0.0	0.0	8.3	0.0	2.0
Muraenidae: *Gymnothorax miliaris* (goldentail moray)	0.0	4.2	4.2	4.2	3.0
Ostraciidae: *Acanthostracion polygonius* (honeycomb cowfish)	0.0	0.0	8.3	12.5	5.0
Ostraciidae: *Lactophrys bicaudalis* (spotted trunkfish)	0.0	0.0	4.2	0.0	1.0
Ostraciidae: *Lactophrys triqueter* (smooth trunkfish)	16.7	20.8	25.0	33.3	23.0
Pomacanthidae: *Holacanthus bermudensis* (blue angelfish)	0.0	4.2	4.2	4.2	3.0
Pomacanthidae: *Holacanthus ciliaris* (queen angelfish)	0.0	12.5	8.3	12.5	8.0
Pomacanthidae: *Holacanthus townsendi* (townsend angelfish)	0.0	0.0	4.2	0.0	1.0
Pomacanthidae: *Holacanthus tricolor* (rock beauty)	20.8	33.3	12.5	50.0	28.0
Pomacanthidae: *Pomacanthus paru* (French angelfish)	8.3	0.0	8.3	8.3	6.0
Pomacentridae: *Abudefduf saxatilis* (sergeant major)	12.5	12.5	20.8	16.7	15.0
Pomacentridae: *Chromis cyanea* (blue chromis)	29.2	70.8	54.2	70.8	54.0
Pomacentridae: *Chromis insolata* (sunshinefish)	12.5	16.7	20.8	37.5	21.0
Pomacentridae: *Chromis multilineata* (brown chromis)	95.8	100.0	95.8	87.5	91.0
Pomacentridae: *Chromis scotti* (purple reeffish)	16.7	41.7	29.2	62.5	36.0
Pomacentridae: *Microspathodon chrysurus* (yellowtail damselfish)	54.2	37.5	33.3	20.8	35.0
Pomacentridae: *Stegastes adustus* (dusky damselfish)	20.8	33.3	8.3	45.8	26.0
Pomacentridae: *Stegastes leucostictus* (beaugregory)	0.0	0.0	0.0	20.8	5.0
Pomacentridae: *Stegastes partitus* (bi-color damselfish)	75.0	95.8	87.5	87.5	83.0
Pomacentridae: *Stegastes planifrons* (threespot damselfish)	66.7	54.2	83.3	50.0	61.0
Pomacentridae: *Stegastes variabilis* (cocoa damselfish)	58.3	75.0	45.8	58.3	57.0
Serranidae: *Cephalopholis cruentata* (graysby)	50.0	45.8	25.0	41.7	39.0
Serranidae: *Cephalopholis fulva* (coney)	8.3	8.3	0.0	0.0	4.0
Serranidae: *Epinephelus adscensionis* (rock hind)	12.5	16.7	0.0	4.2	8.0
Serranidae: *Mycteroperca bonaci* (black grouper)	4.2	0.0	0.0	16.7	5.0
Serranidae: *Mycteroperca interstitialis* (yellowmouth grouper)	41.7	33.3	8.3	8.3	22.0
Serranidae: *Mycteroperca phenax* (scamp)	4.2	4.2	0.0	0.0	2.0
Serranidae: *Mycteroperca tigris* (tiger grouper)	4.2	8.3	12.5	8.3	8.0
Serranidae: *Paranthias furcifer* (creolefish)	83.3	70.8	100.0	58.3	75.0
Sphyraenidae: *Sphyraena barracuda* (barracuda)	66.7	83.3	95.8	87.5	80.0
Tetraodontidae: *Canthigaster rostrata* (sharpnose puffer)	100.0	83.3	87.5	95.8	88.0
Tetraodontidae: *Sphoeroides spengleri* (bandtail puffer)	4.2	0.0	0.0	0.0	1.0

Species were considered “rare” if they were recorded in less than 20% of all surveys. “Prevalent” species were recorded in ≥20% of surveys. A total of 50 species were characterized as “rare” and 34 species were characterized as “prevalent.”

Each survey was transformed to presence/absence for each species, and analyzed for differences in community composition based on species occurrence between years and banks. The greatest dissimilarity was observed between EFGB in 2011 and WFGB in 2012 (46.82%); the smallest dissimilarity was seen between EFGB in 2012 and WFGB in 2012 (43.66%). No single species was identified as contributing predominately to the observed dissimilarity; all species made small, incremental contributions.

MDS ordination had a high 2-dimenstional stress value (0.3), indicating poor goodness-of-fit in a 2-dimensional scale (Figure 10.4.2). A slight data cluster was observed, with 2011 data trending more to the left of the ordination and 2012 data to the right.

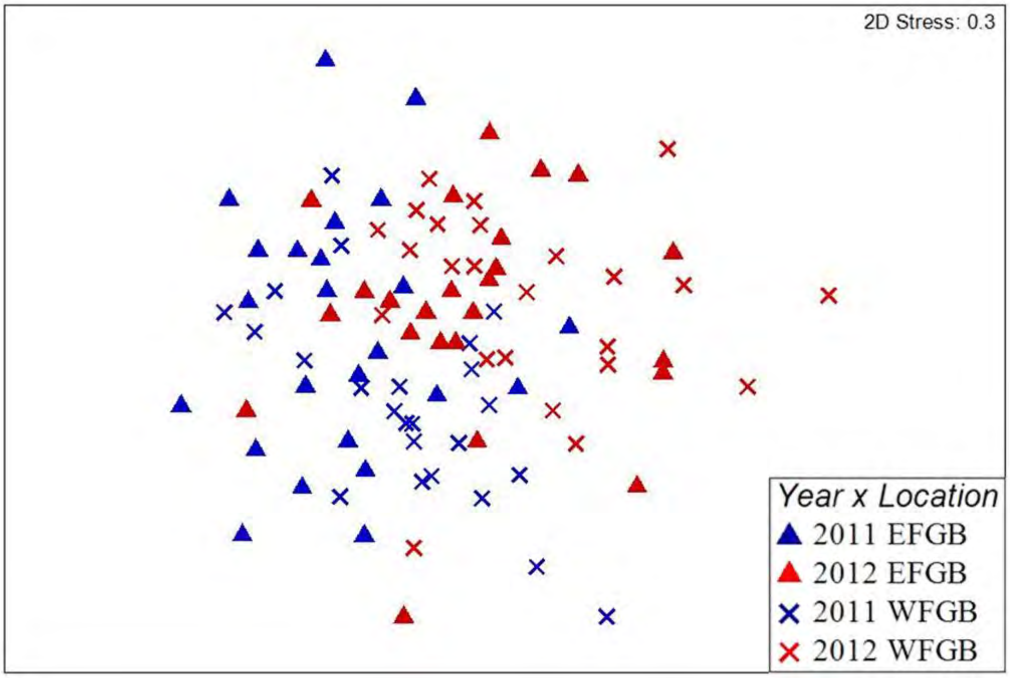


Figure 10.4.2. MDS plot displaying two-dimensional fish occurrence similarity between years and banks.

ANOSIM results indicate a significant, but small, spatial and temporal variations are occurring, with significant differences between year (Global R=0.15, p<0.1%) and bank (Global R=0.094, p<0.1%). While these differences are biologically significant, the very small R values indicate that the dissimilarities between groups are less than some of the within-group dissimilarities and are therefore uninformative.

10.4.3. Species Density

Mean fish density (abundance 100 m^{-2}) was highest at WFGB in 2012 (313 ± 318 SD) and lowest at EFGB in 2012 (150 ± 75 SD). The high fish density at WFGB in 2012 was caused by high local abundance of brown chromis, with an average density of 169 ± 233 SD individuals per 100 m^2. Brown chromis were the most abundant fish recorded at both banks for both years. Variations in fish densities between years and banks are predominantly attributed to the presence or absence of dense schooling fish species, including brown chromis, creolefish (*Paranthias furcifer*), and creole wrasse (*Clepticus parrae*).

Using SIMPER, greatest dissimilarity was observed between EFGB in 2011 and EFGB in 2012 (54.61%), while the smallest dissimilarity was observed between EFGB in 2012 and WFGB in 2012 (46.99%). The greatest contributor of dissimilarity for all comparisons was the density of brown chromis. The final MDS ordination had a moderate stress value (0.24), indicating moderate goodness-of-fit in a two-dimensional scale (Figure 10.4.3), with no apparent data clusters.

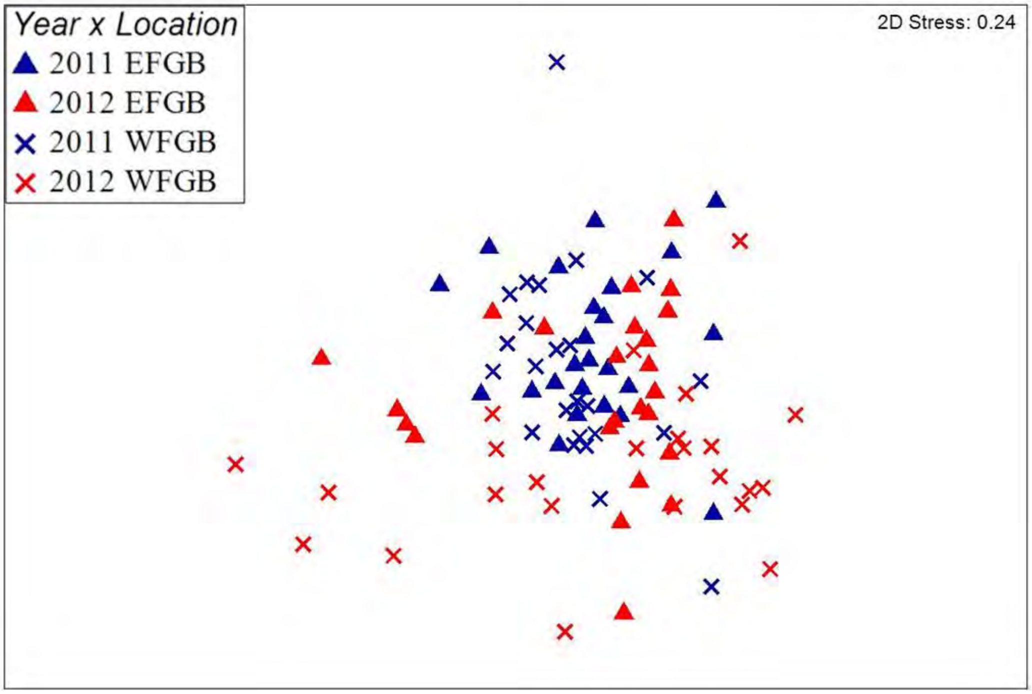


Figure 10.4.3. MDS plot displaying two-dimensional fish density similarity between years and banks.

ANOSIM results indicate a significant, but small, spatial and temporal variations are occurring, with significant differences between year (Global R=0.196, p<0.1%) and bank (Global R=0.115, p<0.1%). Though these differences are biologically significant, the small R values indicate that the dissimilarities between groups are less than some of the within-group dissimilarities and are therefore uninformative.

10.4.4. Trophic Group Analysis

Species were grouped by trophic guild into four major categories: herbivores, piscivores, invertivores, and planktivores. It should be noted that parrotfish, once belonging to the Scaridae family, have been reclassified and are part of the Labridae family (Westneat and Alfaro 2005; AFS 2013). Volume II Appendix 11 of this report contains all species groupings by trophic guild, as defined by NOAA's Center for Coastal Monitoring and Assessment (CCMA) BioGeography Branch fish-trophic level database.

Species richness and family richness within trophic guilds was calculated between years and banks (Table 10.4.6). Overall, the trophic guild containing the greatest number of species was the invertivores, with 42 species and 18 families, and the guild containing the fewest number of species was the planktivores, with 7 species and 5 families.

Table 10.4.6.

Species Richness within Trophic Guilds between Years and Banks, and between all Surveys

Trophic Group	EFGB		WFGB		All Surveys
	2011	2012	2011	2012	
Herbivore	17 (6)	17 (7)	16 (6)	17 (6)	19 (7)
Invertivore	29 (16)	29 (17)	30 (14)	31 (17)	42 (18)
Planktivore	6 (4)	5 (3)	5 (3)	6 (4)	7 (5)
Piscivore	13 (5)	9 (4)	8 (5)	11 (5)	16 (7)

The number in parenthesis represents family richness

The density was greatest for the invertivore guild, with an average of 133 individuals per 100 m^2, while the density was smallest for the piscivore guild, with an average of 6 individuals per 100 m^2 (Table 10.4.7).

Table 10.4.7.

Average Density per 100 m² of Individuals from each Trophic Guild by Year and Bank, ± Standard Deviation

Trophic Group	EFGB		WFGB		All Surveys
	2011	2012	2011	2012	
Herbivore	16±1	30±2	14±1	49±3	27±2
Invertivore	109±4	87±3	131±6	206±7	133±5
Planktivore	22±2	21±2	16±2	53±4	28±3
Piscivore	4±1	11±2	4±1	5±1	6±1

SIMPER analysis identified the greatest dissimilarity was between 2011 and 2012 at WFGB (31.89%), and the smallest dissimilarity was observed between 2011 and 2012 at EFGB (22.82%). For all comparisons, the greatest contributor to the observed dissimilarity was the invertivore trophic guild. The MDS ordination had a low stress value (0.13), indicating good goodness-of-fit in a two-dimensional scale (Figure 10.4.4). No clusters were apparent.

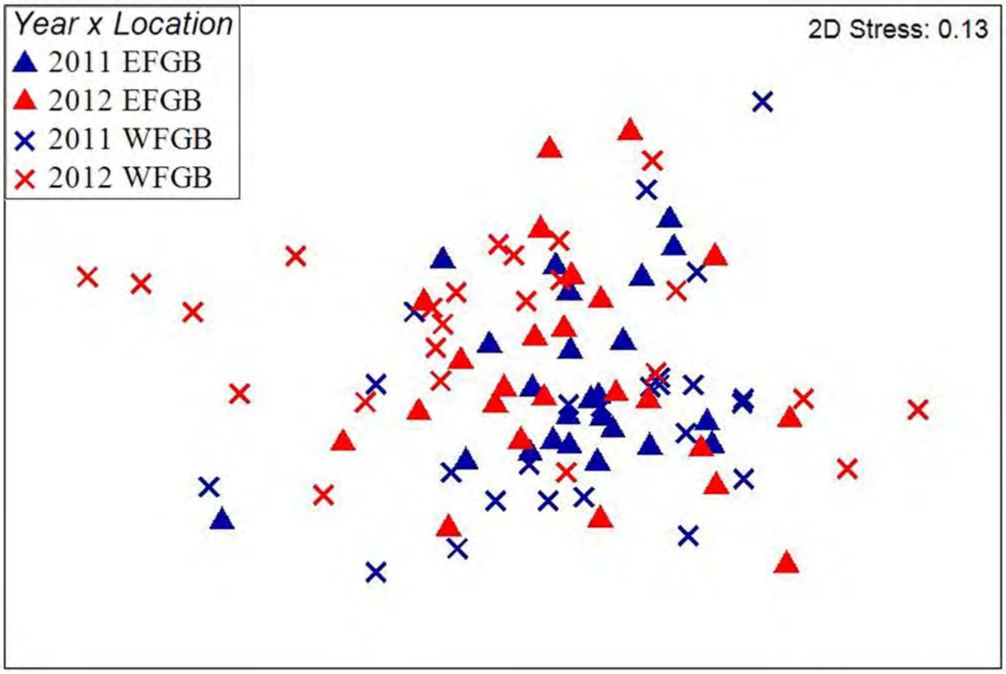


Figure 10.4.4. MDS plot displaying two-dimensional trophic guild density similarity between years and banks.

ANOSIM results indicate a significant, but small, spatial and temporal variations are occurring, with significant differences between year (Global R=0.12, p<0.1%) and bank (Global R=0.066, p<0.4%). All R statistic values were small, indicating that the dissimilarities between groups are less than some of the within-group dissimilarities and are therefore uninformative.

Size-frequency distributions, using the relative abundance of species for each trophic guild, were graphed for each trophic guild by year and bank. At both EFGB and WFGB, herbivores, invertivores, and planktivores were dominated by smaller individuals, whereas piscivores were dominated by larger individuals (Figures 10.4.5 and 10.4.6).

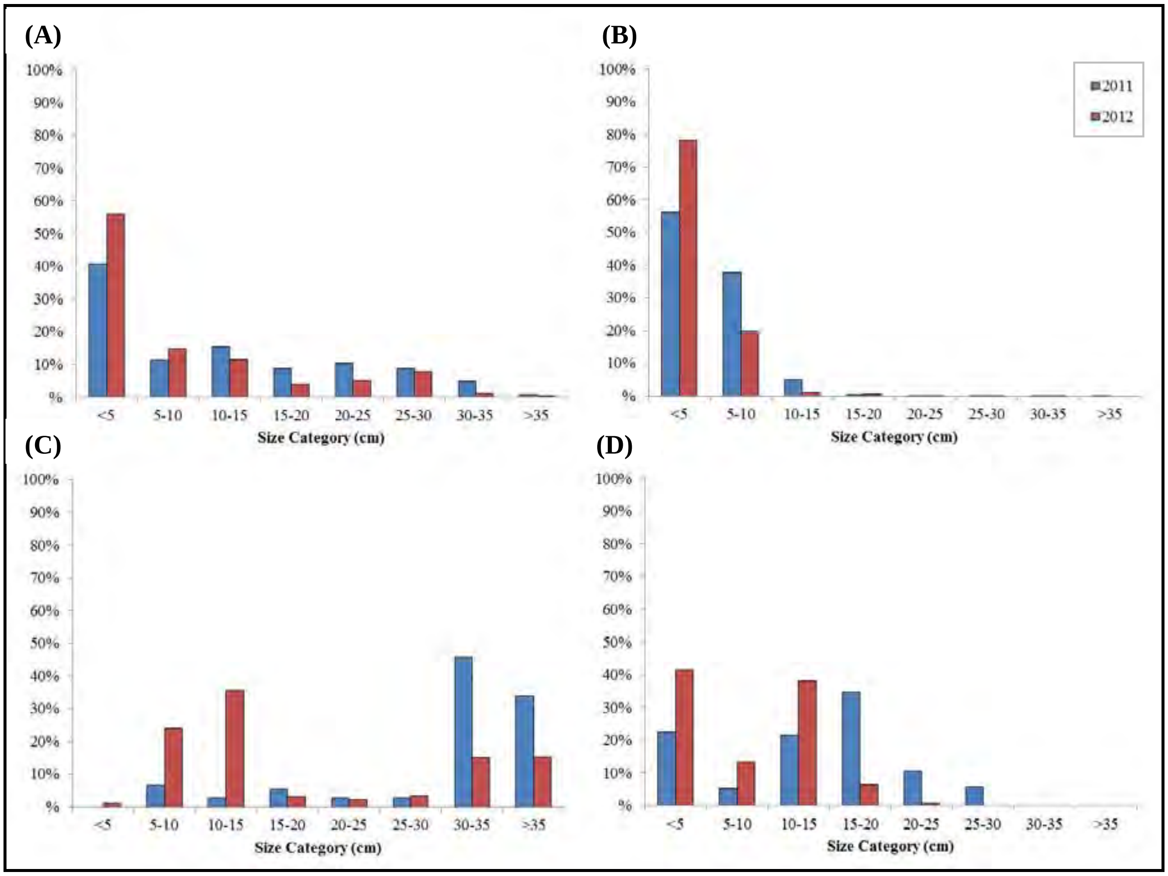


Figure 10.4.5. EFGB size distribution by trophic guild.

Blue columns represent year 2011 and red columns represent year 2012, (A) Herbivores, (B) Invertivores, (C) Piscivores, and (D) Planktivores.

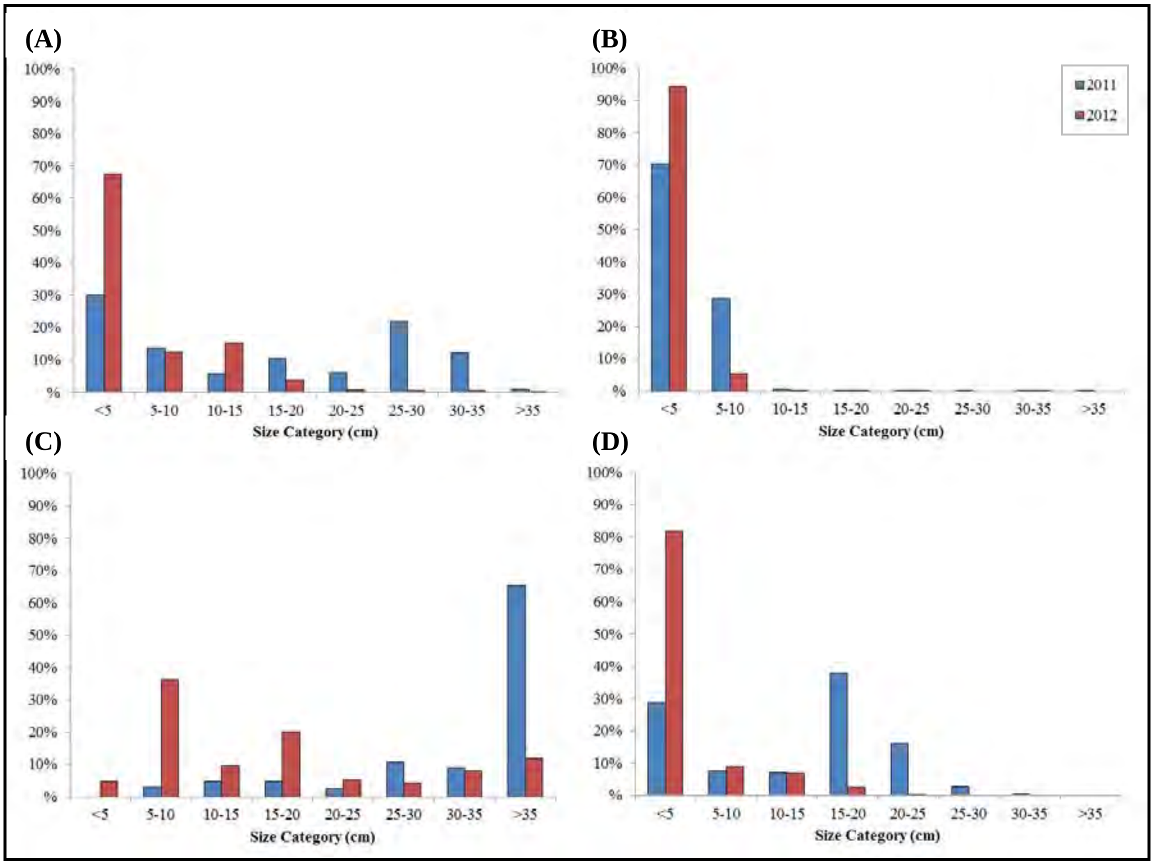


Figure 10.4.6. WFGB size distribution by trophic guild.

Blue columns represent year 2011 and red columns represent year 2012, (A) Herbivores, (B) Invertivores, (C) Piscivores, and (D) Planktivores.

10.4.5. Biomass Analysis

Average biomass for all surveys was calculated to be 118.18 g/m^2 ±233.07 SD). The greatest average biomass was seen at WFGB in 2011 (162.58 g/m^2 ±360.08 SD), while the lowest average biomass was seen at WFGB in 2012 (24.58 g/m^2 ± 22.58 SD) (Table 10.4.8).

Table 10.4.8.

Total and Average Biomass, in g/m², by Year and Bank, ± Standard Deviation

	EFGB		WFGB	
	2011	2012	2011	2012
Total Biomass (g/m^2)	2357.63	1234.58	3901.63	590.03
Average Biomass/Survey (g/m^2)	98.23±172.02	51.44±51.16	162.57±360.08	24.58±22.58

SIMPER analysis identified the greatest dissimilarity was between 2011 and 2012 at WFGB (68.08%); the smallest dissimilarity was observed between WFGB in 2011 and EFGB in 2012 (62.62%). For all comparisons, the greatest contributor to the observed dissimilarity was great barracuda, except for the comparison between EFGB in 2011 and WFGB in 2012, in which the greatest contributor to the observed dissimilarity was creolefish.

The MDS ordination had a moderate stress value (0.25), indicating moderate goodness-of-fit in a two-dimensional scale (Figure 10.4.7). A slight data cluster was observed, with 2011 data trending more to the left of the ordination and 2012 data to the right.

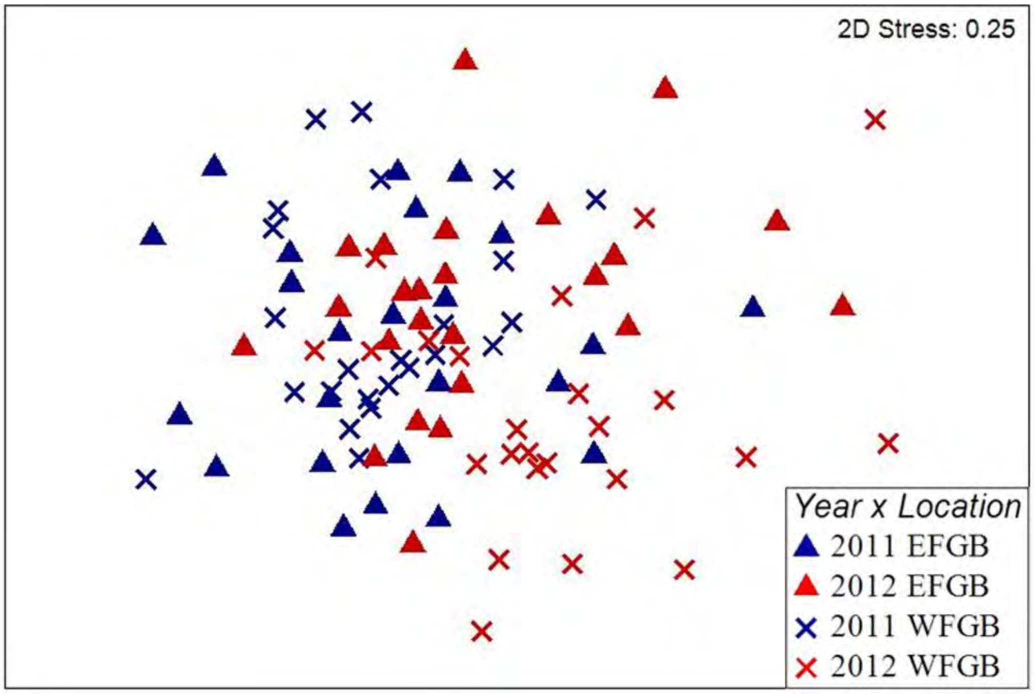


Figure 10.4.7. MDS plot displaying two-dimensional biomass similarity between years and banks.

ANOSIM results indicate a significant, but small, spatial and temporal variations are occurring, with significant differences between year (Global R=0.178, p<0.1%) and bank (Global R=0.126, p<0.1%). All R statistic values were small, indicating that the dissimilarities between groups are less than some of the within-group dissimilarities are therefore uninformative.

When summed into trophic guilds, the piscivores possessed the highest average biomass for all surveys, with 45.73 g/m^2 (±186.51 SD), over 50% of total biomass. However, when averaged between year and bank, the piscivores represented the only greatest average biomass at EFGB and WFGB in 2011. In 2012, at both EFGB and WFGB, the herbivores represented the greatest average biomass. The lowest average biomass from all surveys was represented by the invertivores with 7.46 g/m^2 (±11.25 SD). However, when averaged between year and bank, the invertivores represented the only lowest average biomass at EFGB and WFGB in 2011. In 2012, the lowest average biomass for both EFGB and WFGB was the planktivores (Table 10.4.9 and Figure 10.4.8). The reduced biomass of piscivores between 2011 and 2012 is primarily due to fewer horse-eye jack (*Caranx latus*) recorded during the 2012 study period.

Table 10.4.9.

Average Biomass, in g/m², for each Trophic Guild by Year and Bank and between all Surveys, ± Standard Deviation

Trophic Guild	EFGB		WFGB		All Surveys
	2011	2012	2011	2012	
H	23.07 ± 20.61	20.30 ± 37.18	34.45 ± 39.91	16.97 ± 38.16	22.67 ± 30.98
I	13.81 ± 18.66	3.64 ± 4.43	8.67 ± 6.86	3.28 ± 5.36	7.46 ± 11.25
PL	15.63 ± 22.93	3.53 ± 5.28	11.25 ± 21.96	2.34 ± 4.94	8.34 ± 16.94
P	45.72 ± 155.70	17.42 ± 29.10	108.20 ± 334.97	8.34 ± 10.99	45.73 ± 186.51

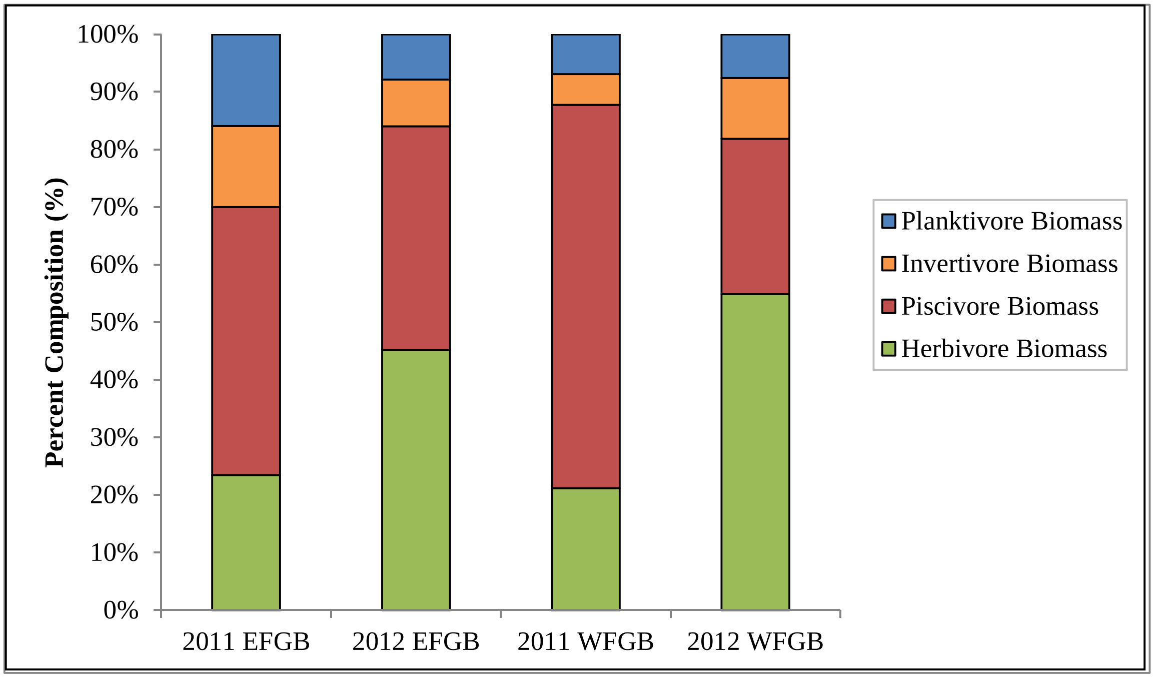


Figure 10.4.8. FGB size distribution by trophic guild: (A) herbivores, (B) invertivores, (C) piscivores, and (D) planktivores.

SIMPER analysis identified the greatest dissimilarity was between EFGB in 2011 and WFGB in 2012 (44.32%) and the smallest dissimilarity was observed between WFGB in 2011 and EFGB in 2012 (38.20%). For all comparisons, the greatest contributor to the observed dissimilarity was the piscivore guild.

The MDS ordination had a low stress value (0.14), which indicates good goodness-of-fit in a two-dimensional scale (Figure 10.4.9). No clusters were observed.

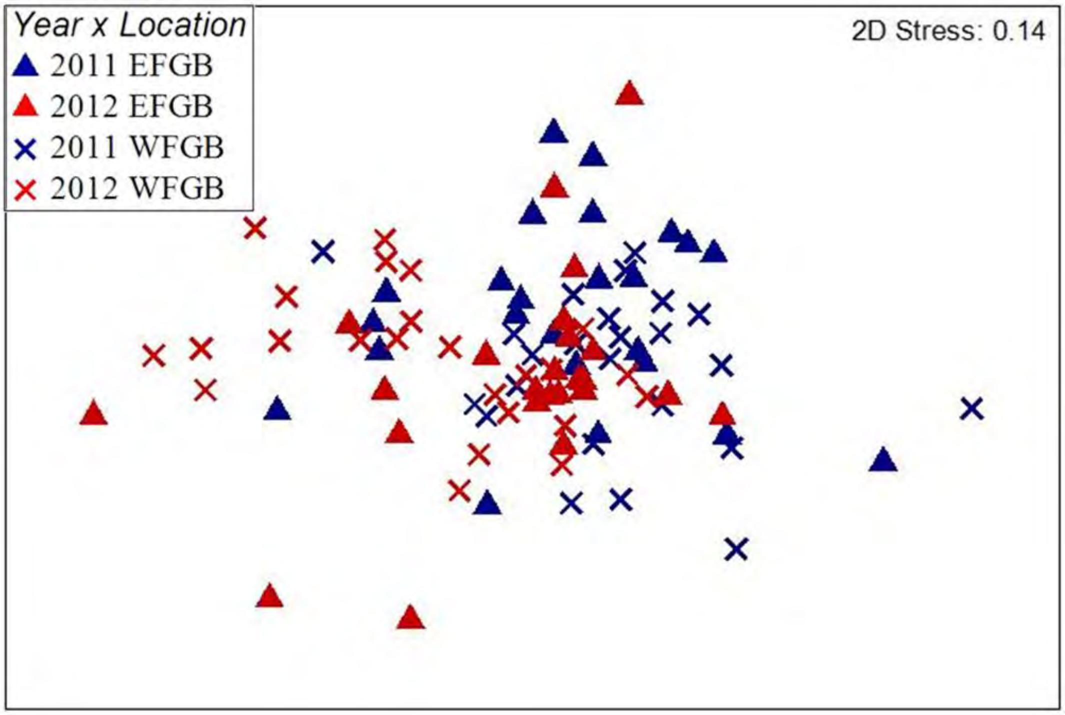


Figure 10.4.9. MDS plot displaying two-dimensional trophic guild similarity between years and banks.

ANOSIM results indicate a significant, but small, spatial, and temporal variations are occurring, with significant differences between year (Global R=0.156, p<0.1%) and bank (Global R=0.063, p<0.6%). All R statistic values were small, indicating that the dissimilarities between groups are less than some of the within-group dissimilarities.

For each trophic guild, the percent contribution each species made to the total biomass was calculated (Table 10.4.10). For the herbivore guild, 53.8% of the biomass was contributed by Bermuda chub (*Kyphosus sectatrix*). For the invertivore guild, the greatest contribution was brown chromis, contributing 59.5% of all biomass. For the piscivore guild, great barracuda contributed the greatest biomass to all surveys, 85.9%. For the planktivore guild, the greatest contribution was creolefish, contribution 78.5% of all biomass.

Table 10.4.10.

Percent Contribution of Each Species to the Average Biomass of Each Trophic Guild

Trophic Guild	**Species ID:** **(Family Name:Species Name (Common Name - Trophic Guild))**	**EFGB**		**WFGB**		**All Surveys**
		2011	**2012**	**2011**	**2012**	
Herbivore	Kyphosidae: *Kyphosus sectatrix* (chub (bermuda/yellow))	35.2	54.2	66.0	53.6	53.8
	Labridae: *Sparisoma viride* (stoplight parrotfish)	12.6	21.8	11.1	19.4	15.1
	Labridae: *Scarus vetula* (queen parrotfish)	8.8	9.2	12.1	10.0	10.3
	Balistidae: *Melichthys niger* (black durgon)	20.5	6.6	4.8	6.2	9.4
	Acanthuridae: *Acanthurus coeruleus* (blue tang)	14.8	3.4	2.8	5.2	6.3
	Labridae: *Scarus taeniopterus* (princess parrotfish)	3.5	0.8	0.7	1.1	1.5
	Labridae: *Sparisoma aurofrenatum* (redband parrotfish)	1.3	1.7	1.4	0.9	1.4
	Acanthuridae: *Acanthurus chirurgus* (doctorfish)	0.8	0.9	0.4	1.3	0.7
	Pomacentridae: *Microspathodon chrysurus* (yellowtail damselfish)	0.9	0.5	0.6	0.2	0.6
	Acanthuridae: *Acanthurus bahianus* (ocean surgeonfish)	0.4	0.4	<0.1	0.8	0.3
	Pomacentridae: *Stegastes partitus* (bi-color damselfish)	0.3	0.3	0.2	0.7	0.3
	Acanthuridae: *Acanthurus* spp. (surgeonfish spp.)	0.6	0.0	0.0	0.0	0.2
	Pomacentridae: *Stegastes variabilis* (cocoa damselfish)	0.1	0.2	<0.1	0.3	0.1
	Labridae: *Sparisoma atomarium* (greenblotch parrotfish)	0.1	0.1	<0.1	<0.1	0.1
	Blenniidae: *Ophioblennius macclurei* (redlip blenny)	<0.1	<0.1	<0.1	<0.1	<0.1
	Gobiidae: *Gnatholepis thompsoni* (goldspot goby)	0.0	<0.1	0.0	0.0	<0.1
	Pomacentridae: *Stegastes adustus* (dusky damselfish)	0.1	<0.1	<0.1	0.2	<0.1
	Labridae: *Scarus iseri* (striped parrotfish)	<0.1	<0.1	<0.1	<0.1	<0.1
	Labridae: *Sparisoma radians* (bucktooth parrotfish)	0.0	0.0	0.0	<0.1	<0.1
Invertivore	Pomacentridae: *Chromis multilineata* (brown chromis)	63.6	51.6	56.1	60.8	59.5
	Lutjanidae: *Lutjanus griseus* (gray snapper)	13.2	2.9	4.8	1.7	8.1
	Balistidae: *Canthidermis sufflamen* (ocean triggerfish)	3.8	9.3	10.1	0.8	6.0
	Pomacanthidae: *Pomacanthus paru* (French angelfish)	2.1	0.0	5.9	3.5	3.1

Trophic Guild	**Species ID:** **(Family Name:Species Name (Common Name - Trophic Guild))**	**EFGB**		**WFGB**		**All Surveys**
		2011	**2012**	**2011**	**2012**	
	Mullidae: *Mulloidichthys martinicus* (yellow goatfish)	1.3	10.6	1.0	0.9	2.4
	Pomacentridae: *Stegastes planifrons* (threespot damselfish)	1.4	1.3	3.8	1.8	2.1
	Ostraciidae: *Acanthostracion polygonius* (honeycomb cowfish)	0.0	0.0	3.3	8.8	2.0
	Labridae: *Bodianus rufus* (Spanish hogfish)	0.9	4.3	1.9	3.2	1.9
	Chaetodontidae: *Chaetodon sedentarius* (reef butterflyfish)	1.5	2.0	2.0	1.2	1.7
	Pomacanthidae: *Holacanthus ciliaris* (queen angelfish)	0.0	2.0	3.0	3.3	1.5
	Pomacanthidae: *Holacanthus tricolor* (rock beauty)	1.9	2.1	0.6	0.6	1.4
	Balistidae: *Balistes vetula* (queen triggerfish)	3.0	0.0	0.0	0.0	1.4
	Serranidae: *Epinephelus adscensionis* (rock hind)	1.5	3.5	0.0	<0.1	1.2
	Labridae: *Thalassoma bifasciatum* (bluehead)	0.6	2.4	1.0	1.1	1.0
	Monacanthidae: *Cantherhines macrocerus* (whitespotted filefish)	0.6	0.0	1.6	0.0	0.7
	Tetraodontidae: *Canthigaster rostrata* (sharpnose puffer)	0.5	0.8	1.3	0.4	0.7
	Holocentridae: *Holocentrus adscensionis* (squirrelfish)	1.3	0.7	0.0	0.0	0.7
	Diodontidae: *Diodon hystrix* (porcupinefish)	0.0	0.0	0.0	6.2	0.7
	Ostraciidae: *Lactophrys triqueter* (smooth trunkfish)	0.3	1.0	0.5	0.6	0.5
	Serranidae: *Cephalopholis fulva* (coney)	0.4	1.9	0.0	0.0	0.5
	Chaetodontidae: *Chaetodon striatus* (banded butterflyfish)	0.6	0.0	0.5	0.2	0.4
	Pomacentridae: *Abudefduf saxatilis* (sergeant major)	0.2	0.3	0.4	0.4	0.3
	Pomacentridae: *Stegastes leucostictus* (beaugregory)	0.0	0.0	0.0	2.6	0.3
	Chaetodontidae: *Chaetodon ocellatus* (spotfin butterflyfish)	0.2	1.3	0.0	0.3	0.3
	Holocentridae: *Holocentrus rufus* (longspine squirrelfish)	0.0	0.4	0.5	0.3	0.2
	Chaetodontidae: *Prognathodes aculeatus* (longsnout butterflyfish)	0.2	<0.1	0.4	0.2	0.2
	Monacanthidae: *Cantherhines pullus* (orange spotted filefish)	0.2	0.5	0.1	0.3	0.2
	Cirrhitidae: *Amblycirrhitus pinos* (redspotted hawkfish)	0.4	<0.1	<0.1	<0.1	0.2
	Pomacanthidae: *Holacanthus bermudensis* (blue angelfish)	0.0	0.3	0.3	0.1	0.1

Trophic Guild	**Species ID:** **(Family Name:Species Name (Common Name - Trophic Guild))**	**EFGB**		**WFGB**		**All Surveys**
		2011	**2012**	**2011**	**2012**	
	Labridae: *Halichoeres garnoti* (yellowhead wrasse)	0.1	0.1	0.1	<0.1	0.1
	Blenniidae: *Parablennius marmoreus* (seaweed blenny)	<0.1	0.3	0.0	0.2	0.1
	Mullidae: *Pseudupeneus maculatus* (spotted goatfish)	0.0	0.0	0.2	0.0	0.1
	Gobiidae: *Elacatinus oceanops* (neon goby)	0.1	<0.1	<0.1	0.1	0.1
	Apogonidae: *Apogon maculatus* (flamefish)	<0.1	0.0	0.0	0.0	<0.1
	Labridae: *Bodianus pulchellus* (spotfin hogfish)	<0.1	0.0	0.1	0.0	<0.1
	Labridae: *Halichoeres bivittatus* (slippery dick)	0.0	<0.1	0.1	0.0	<0.1
	Labridae: *Halichoeres maculipinna* (clown wrasse)	0.0	0.1	0.0	0.3	<0.1
	Labridae: *Halichoeres radiatus* (pudding wife)	0.0	<0.1	0.0	0.2	<0.1
	Muraenidae: *Gymnothorax miliaris* (goldentail moray)	0.0	<0.1	0.1	<0.1	<0.1
	Ostraciidae: *Lactophrys bicaudalis* (spotted trunkfish)	0.0	0.0	0.2	0.0	<0.1
	Pomacanthidae: *Holacanthus townsendi* (townsend angelfish)	0.0	0.0	0.1	0.0	<0.1
	Tetraodontidae: *Sphoeroides spengleri* (bandtail puffer)	<0.1	0.0	0.0	0.0	<0.1
Piscivore	Sphyraenidae: *Sphyraena barracuda* (great barracuda)	74.2	76.4	94.5	62.5	85.9
	Carangidae: *Caranx latus* (horse-eye jack)	17.3	7.0	3.6	2.0	7.3
	Lutjanidae: *Lutjanus jocu* (dog snapper)	1.9	3.1	1.1	14.0	2.2
	Serranidae: *Mycteroperca tigris* (tiger grouper)	0.2	6.3	0.3	0.2	0.9
	Serranidae: *Mycteroperca interstitialis* (yellowmouth grouper)	2.6	1.6	0.1	0.1	0.9
	Carangidae: *Carangoides ruber* (bar jack)	0.2	3.9	<0.1	0.5	0.5
	Serranidae: *Cephalopholis cruentata* (graysby)	0.8	0.5	0.3	1.3	0.5
	Carangidae: *Seriola dumerili* (greater amberjack)	0.0	0.0	0.0	8.3	0.4
	Belonidae: *Belonidae* spp. (needlefish spp.)	1.5	0.0	0.0	0.0	0.4
	Carangidae: *Caranx crysos* (blue runner)	0.0	0.0	0.0	7.1	0.3
	Serranidae: *Mycteroperca bonaci* (black grouper)	0.2	0.0	0.0	3.9	0.2
	Carangidae: *Caranx lugubris* (black jack)	0.5	0.6	0.0	0.0	0.2

Trophic Guild	Species ID: (Family Name:Species Name (Common Name - Trophic Guild))	EFGB		WFGB		All Surveys
		2011	2012	2011	2012	
	Carangidae: *Caranx hippos* (crevalle jack)	0.4	0.0	0.0	0.0	0.1
	Serranidae: *Mycteroperca phenax* (scamp)	0.1	0.5	0.0	0.0	0.1
	Muraenidae: *Gymnothorax moringa* (spotted moray)	0.0	0.0	0.1	0.0	0.1
	Lutjanidae: *Lutjanus cyanopterus* (Cubera snapper)	0.0	0.0	0.0	0.1	<0.1
Planktivore	Serranidae: *Paranthias furcifer* (creolefish)	82.1	82.1	68.1	61.0	75.8
	Labridae: *Clepticus parrae* (creole wrasse)	17.6	16.7	31.0	36.8	23.5
	Pomacentridae: *Chromis cyanea* (blue chromis)	0.3	1.1	0.8	0.8	0.6
	Pomacentridae: *Chromis scotti* (purple reeffish)	<0.1	0.1	0.1	0.9	0.1
	Pomacentridae: *Chromis insolata* (sunshinefish)	<0.1	0.1	0.1	0.5	0.1
	Chaenopsidae: *Acanthemblemaria aspera* (roughhead blenny)	0.0	0.0	0.0	<0.1	<0.1
	Lutjanidae: *Ocyurus chrysurus* (yellowtail snapper)	<0.1	0.0	0.0	0.0	<0.1

10.4.6. Diurnal Density Patterns

Fish abundance may change throughout the day due to fish behavior, resulting in disparate data on morning dives compared to afternoon dives. Community composition was compared for all years and location between five time groups: early morning (0700 to 0900), later morning (0901 to 1200), early afternoon (1201 to 1500), late afternoon (1501 to 1800), and early evening (1801 to dusk). Over all surveys, the most samples were collected in the late afternoon (32), while the fewest samples were collected in the early evening (12) (Table 10.4.11).

SIMPER analysis identified that the highest dissimilarity occurred between late morning and early evening surveys, with a dissimilarity of 53.64%, and the smallest dissimilarity occurred between late afternoon and early evening surveys, with a dissimilarity of 50.02%. For most comparisons, the greatest contributors to the observed dissimilarity were brown chromis, creole wrasse, and creolefish.

Table 10.4.11.

Number of Surveys Conducted During Various Times of the Day

Time of Day	EFGB		WFGB		All Surveys
	2011	2012	2011	2012	
Early Morning (0700-0900)	4	4	4	8	20
Late Morning (0901-1200)	1	4	8	4	17
Early Afternoon (1201-1500)	7	4	4	0	15
Late Afternoon (1501-1800)	10	6	4	12	32
Early Evening (1801-dusk)	2	6	4	0	12

The final MDS ordination had a moderate stress value (0.24), indicating moderate goodness-of-fit in a two-dimensional scale (Figure 10.4.10). No clusters were observed.

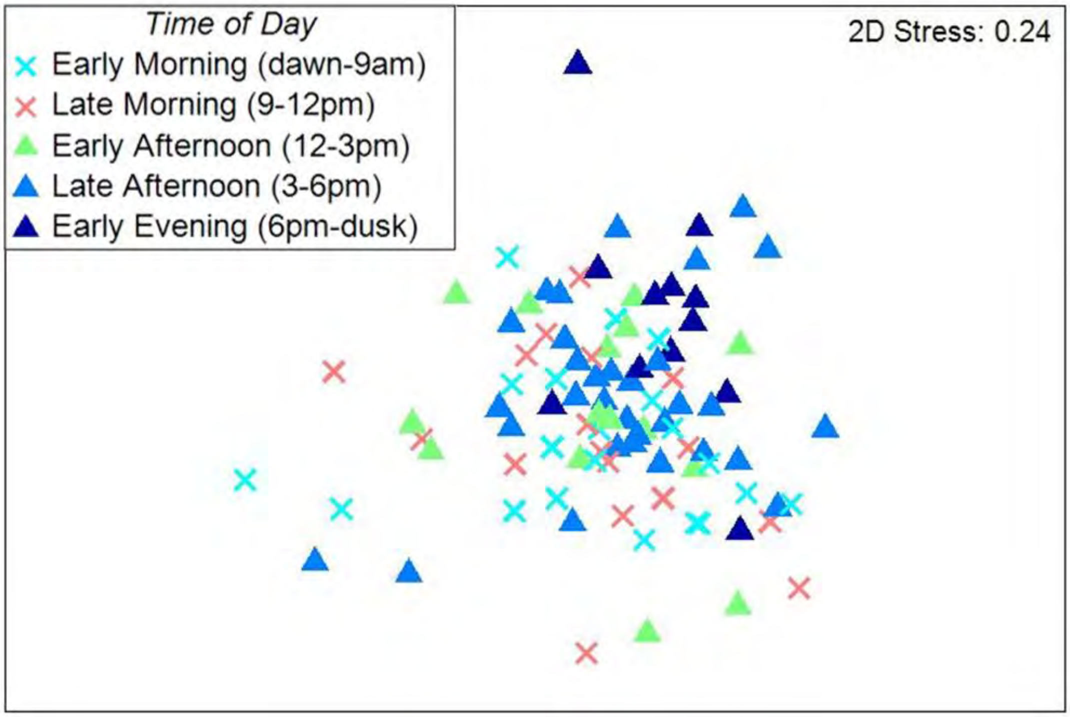


Figure 10.4.10. MDS plot displaying two-dimensional similarity between morning and afternoon surveys.

ANOSIM results indicate a significant, but small, difference between fish communities observed in each time bracket (Global R=0.074, p<2.8%). Pair-wise analysis indicate significant differences between early morning and early evening surveys (Global R=0.178, p<1.5%), later morning and early evening surveys (Global R=0.197, p<0.1%), and early afternoon and early evening surveys (Global R=0.198, p<0.3%). However, all significant comparisons possess small R values.

The top three species contributing to the observed dissimilarity were identified as brown chromis, creole wrasse, and creolefish. Comparisons were made between the densities of these individual species at each time bracket using ANOSIM. No significant differences were observed between creolefish densities or brown chromis densities. However, creole wrasse showed a significant difference in density by time of day (Global R=0.202, p<0.1%). Pair-wise tests indicate significant differences of density exist between the late afternoon and all other time brackets, except the early evening, and significant differences exist between the early evening and all other time brackets, except the late afternoon (Table 10.4.12).

Table 10.4.12.

ANOSIM Results for Pair-Wise Comparisons of Creole Wrasse Density in Each Time Bracket

Pair-Wise Comparisons	R Statistic	Significance Level %
Late Afternoon (1501-1800), Early Morning (0700-0900)	0.289	0.1
Late Afternoon (1501-1800), Late Morning (0901-1200)	0.38	0.1
Late Afternoon (1501-1800), Early Afternoon (1201-1500)	0.443	0.1
Late Afternoon (1501-1800), Early Evening (1801-dusk)	-0.051	72.3
Early Morning (0700-0900), Late Morning (0901-1200)	-0.02	69.1
Early Morning (0700-0900), Early Afternoon (1201-1500)	-0.016	53
Early Morning (0700-0900), Early Evening (1801-dusk)	0.126	3.7
Late Morning (0901-1200), Early Afternoon (1201-1500)	-0.028	96.8
Late Morning (0901-1200), Early Evening (1801-dusk)	0.329	0.2
Early Afternoon (1201-1500), Early Evening (1801-dusk)	0.527	0.1

10.4.7. Abundance-Biomass Curves

For all samples, w values remained close to 0, indicating a balanced community of both large and small species (Table 10.4.13; Figure 10.4.11). W ranged from a maximum of 0.121 ± 0.109 SD (EFGB 2012) to a minimum of 0.059 ± 0.089 SD (EFGB 2011). Comparisons between year and bank were made using an ANOVA, with no data transformation. No significant differences were observed between the abundance and biomass dominance plots between years or banks, or their interaction.

Table 10.4.13.

Average w values by Bank and Year, ± Standard Deviation

EFGB		WFGB		All Surveys
2011	2012	2011	2012	
0.059 ± 0.089	0.121 ± 0.109	0.087 ± 0.139	0.113 ± 0.161	0.095 ± 0.126

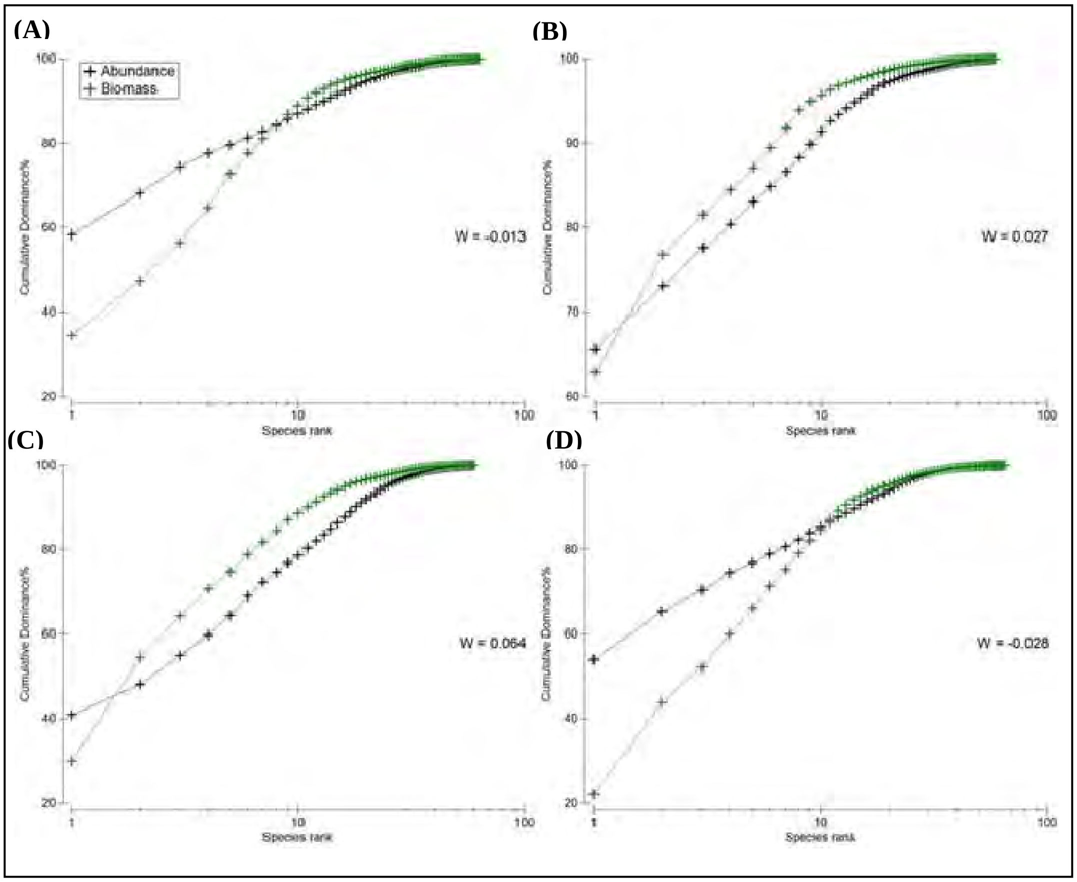


Figure 10.4.11. Abundance-Biomass curves for (A) EFGB 2011, (B) WFGB 2011, (C) EFGB 2012, and (D) WFGB 2012, with average w values for all surveys at the year and location.

10.4.8. Family Level Analysis

Due to particular concerns for species from the grouper (including *Mycteroperca, Cephalopholis* and *Epinephelus* generas only) and snapper (*Lutjanidae* genus only) families, additional analyses, on both density and biomass, were conducted on these families.

The grouper family comprised eight species from the *Mycteroperca*, *Cephalopholis* and *Epinephelus* genera: graysby (*Cephalopholis cruentata*), coney (*Cephalopholis fulva*), rock hind (*Epinephelus adscensionis*), red hind (*Epinephelus guttatus*), black grouper (*Mycteroperca bonaci*), yellowmouth grouper (*Mycteroperca interstitialis*), scamp (*Mycteroperca phenax*), and tiger grouper (*Mycteroperca tigris*). While ANOSIM results indicate no significant temporal differences in community composition based on density or biomass, a significant spatial difference, with small R values, was observed in density (Global R=0.083, p<0.5%) and biomass (Global R=0.07, p<0.4%). The observed dissimilarity between banks (86.31% with density, 91.61% with biomass), was contributed to predominantly by graysby.

Abundance-biomass plots for the grouper family were generated for each year and bank. The highest w value was observed in 2012 at WFGB (w=0.214), while the lowest w value was observed in 2011 at WFGB (w= -0.071) (Table 10.4.14).

Table 10.4.14

Average w Values by Bank and Year for the Grouper Family

EFGB		**WFGB**		**All Surveys**
2011	**2012**	**2011**	**2012**	
0.031	-0.007	-0.071	0.214	-0.062

The snapper family comprised four species from the *Lutjanidae* genus: yellowtail snapper (*Ocyurus chrysurus*), Cubera snapper (*Lutjanus cyanopterus*), gray snapper (*Lutjanus griseus*), and dog snapper (*Lutjanus jocu*). ANOSIM results indicate no significant spatial or temporal variations in snapper community composition based on density and biomass.

Abundance-biomass plots for the grouper family were generated for each year and bank. The highest w value was observed in 2012 at WFGB (w=0.214) and the lowest w value was observed in 2011 at WFGB (w= -0.071) (Table 10.4.15).

Table 10.4.15.

Average w Values by Bank and Year for the Snapper Family

EFGB		**WFGB**		**All Surveys**
2011	**2012**	**2011**	**2012**	
0.209	0.355	0.21	0.442	0.228

10.4.9. Long-Term Trends

To visualize trends in biomass and density over time, yearly means were graphed with exponential trends lines. Though biomass showed a declining trend over time at both banks, trends were not found to be significant (Figure 10.4.12). Density showed a marginally increasing relationship over time at both banks, but only density at WFGB was found to be significant (T=0.56, P-value=0.019) (Figure 10.4.13). Historical 2002–2012 fish data at the FGB can be found in Volume II Appendix 12 of this report.

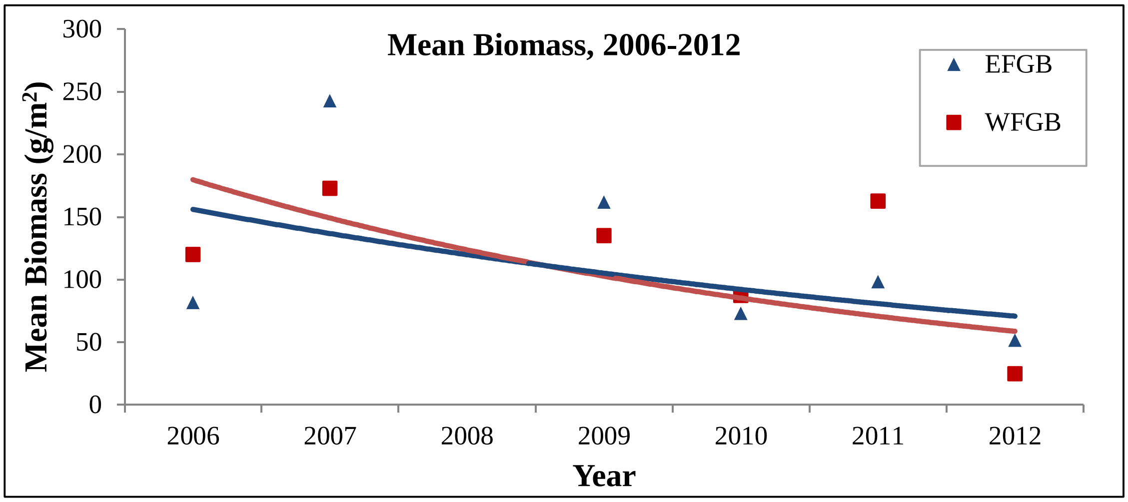


Figure 10.4.12. Mean biomass (g/m^2) of the fish community at EFGB and WFGB from 2006–2012.

Biomass not recorded until 2006. No data in 2008. Blue represents EFGB and red WFGB.

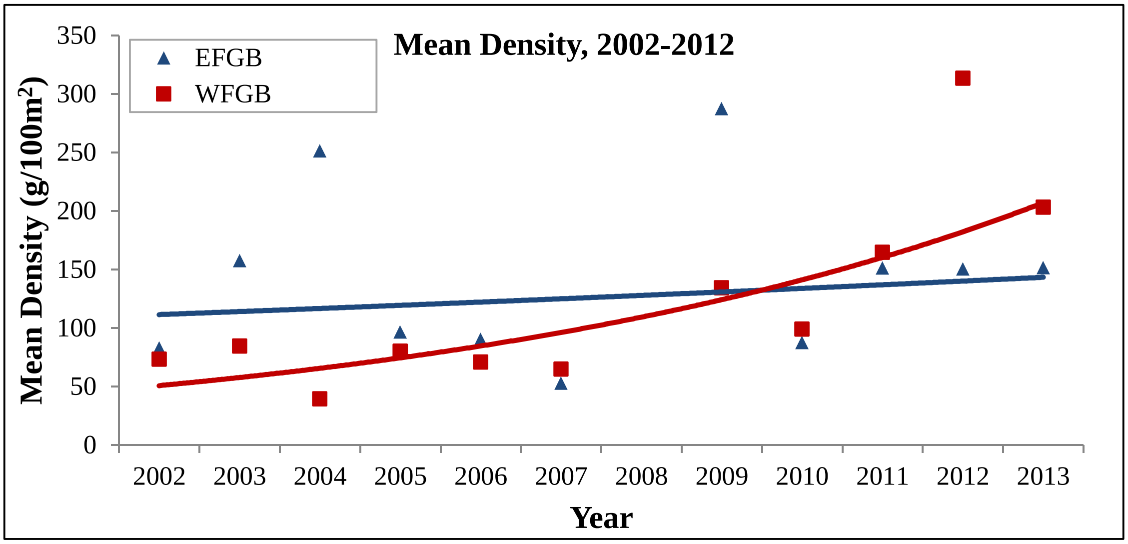


Figure 10.4.13. Mean fish density (g/100m^2) at EFGB and WFGB from 2002–2012.

Density first recorded in 2002. No data in 2008. Dots represent actual data points. Blue represents EFGB and red WFGB.

10.5. FISH SURVEYS DISCUSSION

The fish communities at EFGB and WFGB are considered to be low in species diversity but high in biomass (Pattengill-Semmens and Gittings 2003; Zimmer et al. 2010); they have significantly different fish assemblages compared to other reef systems in the Caribbean, primarily due to the limited presence of lutjanids and haemulids (Rooker et al. 1997). The observed fish assemblages of EFGB and WFGB occur near the northern latitudinal limit of coral reefs and are remote from other tropical reefs. The high number of oil and gas production platforms in the Gulf of Mexico may have promoted the dispersal of additional fish species and allowed some to reach the FGB and establish themselves (Boland et al. 1983; Rooker et al. 1997; Gittings 1998).

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

Fish surveys conducted during this study period (from 2011–2012) indicate a healthy reef fish community at both EFGB and WFGB, as observed in previous annual monitoring surveys between years (Precht et al. 2006; Zimmer et al. 2010; Johnston et al. 2013). However, this does not include long-term trends. A total of six additional species, and two fewer families, were recorded during the 2011–2012 study period in comparison to the 2009–2010 study period. Species richness was found to be similar between banks, but significantly different between years, with a greater species richness observed in 2012 than 2011. Similar to findings of previous annual monitoring efforts, these findings indicate that three families possessed the greatest species richness, including the damselfishes (Pomacentridae), groupers and seabasses (Serranidae), and wrasses and parrotfish (Labridae). Diversity and evenness indices were similar between years and banks, and to previous annual monitoring efforts, with the exception of a significantly lower species diversity observed in 2011 at WFGB in comparison to the diversity in 2012 at EFGB.

Numerous other approaches have been used over the years to collect fish data from the FGB. Extensive surveys conducted in 1980–1982 by Boland et al. (1983) used, among other things, remote video to collect data on fish assemblages. A decade later, when the Reef Environmental Education Foundation began surveys at the FGB, the roving diver technique (RDT) was used (Pattengill-Semmens and Gittings 2003). Rooker et al. (1997) and Pattengill et al. (1998) were the first to use the stationary visual census technique of Bohnsack and Bannerot (1986) at the FGB. Each of the techniques used have strengths and weaknesses. For example, comparisons of visual census techniques (e.g., Bortone et al. 1989) have revealed, that the RDT produces good data on diversity and sighting frequency, but is not as well suited as stationary surveys for recording fish counts, sizes, or densities.

Some species were likely underestimated because of the techniques used. Many blenny and goby species, for example, are small and cryptic. The stationary counting technique used here would underestimate their abundance and perhaps the number of species. Furthermore, surveys also intentionally excluded sand-covered bottom areas, so diver surveys were less likely to have recorded species associated with that habitat. It is suggested that multiple fish survey techniques, including both belt transect and stationary counting surveys, should be used to obtain more comprehensive data, particularly improving data on richness, cryptic species, and fish biomass.

The most frequently-sighted species on surveys during this study period were brown chromis, closely followed by Spanish hogfish and bluehead. All of these species are considered prevalent on other northwestern Caribbean and Gulf of Mexico coral reefs (REEF 2014) and have been documented with the highest abundance in other studies (Caldow et al. 2009). Most shark and ray species are considered rare (occur in <20% of all surveys) (REEF 2014), and none were recorded in fish surveys at the FGB during this study period. However, species were observed by divers as noted in the General Observations Section of this report. Another species that was frequently sighted was the great barracuda, but it is possible that this is an artifact of the proximity of the vessel, as these fish tend to aggregate below the vessel or close by.

One species that was not observed on fish surveys was the invasive Indo-Pacific Lionfish. Although they were not recorded on fish surveys, they were first observed by divers in FGBNMS in 2011 and seen in the study site in 2012 as stated in Chapter 8. Lionfish have become established throughout the southeast U.S., the Caribbean Sea, and much of the Gulf of Mexico. The range of these invasive predators is still expanding, and they are capable of causing significant impacts to biodiversity and recovery of coral reefs, a result of their high densities and predation rates on native fish communities. Lionfish are also well-known for their venomous spines, rapid colonization rate, and generalist preferences for both habitat and diet. This monitoring report is a milestone, because it documents baseline, or at least pre-invasion, ecosystem conditions on the reef.

Though some results indicate a significant spatial and temporal variation in community composition, statistical values indicate that this difference is barely separable, and it is therefore considered uninformative. No distinct significant differences were observed between years and banks, which suggests that, despite small variations, EFGB and WFGB fish communities are similar and stable over time.

At the FGB, the invertivore guild possessed the greatest species diversity and density, and variations in the density of this group contributed greatly to observed differences between samples. Data from previous study periods have also indicated that invertivores are the dominant trophic guild in terms of species diversity and density (Caldow et al. 2009; Johnston et al. 2013). Though the herbivore guild is not the dominant trophic guild in terms of density at the FGB, changes occurring in this community are important to the health and stability of the reef ecosystem. In this study period, less than 21% of all observed variation between banks was due to variations in the herbivore guild, indicting a similar and stable herbivore population. Though the FGB is documented to have a lower species richness and overall abundance of herbivorous fishes than other Caribbean reefs (Rezak 1985; Dennis and Bright 1988), the percentages of acanthurids and scarids is similar to deep and fore reefs of far western Cuba and Akumal, Yucatan, Mexico (Table 10.5.1.; Claro and Cantelar Ramos 2003; Steneck and Lang 2003). Historically, low algal cover has been reported in the annual monitoring, but recent data suggest a gradual increase in algal cover over time. This increase in algal cover was not reflected by changes in herbivore density during this study period.

Table 10.5.1.

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

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

During this monitoring period, the piscivore guild possessed the greatest average biomass, and was the greatest contributor to the observed variations between samples. This guild contributed to over 50% of the total biomass, which indicates a limitedly impacted ecosystem where apex predators are dominant (Friedlander and DeMartini 2002). Piscivore dominated biomass indicates that the ecosystem maintains an inverted biomass pyramid. However, when analyzed by year and bank, this pattern was observed only in 2011, and piscivores and herbivores both evenly dominated the biomass pyramid in 2012. Traditionally, a stable environment is thought to be dominated by the lowest trophic guild (herbivores), the inverted biomass pyramid has been documented in reef ecosystems, where piscivore dominance is associated with “pristine” habitats with minimal fishing impacts (Friedlander and DeMartini 2002; DeMartini et al. 2008; Knowlton and Jackson 2008; Sandin et al. 2008; Singh et al. 2012). Typically, these inverted biomass pyramids are associated with healthy reef systems with high coral cover, as observed at the FGBs. However, the shift from pisicivore dominated biomass at both EFGB and WFGB in 2011 to a more evenly dominated biomass between herbivores and piscivores (each contributing approximately 40% of the biomass) in 2012 is of interest and should be monitored for long term trends in future reports.

Great barracuda contributed to over 85% of the total biomass of the piscivore guild, with a much greater observed average biomass than the 2009 and 2010 study period. The majority of these observed individuals were considered too small to be sexually mature and none exceeded the average documented length for the species (Froese and Pauly 2014). Though these species are commonly documented as solitary, many of the observations made during this study period indicate they were observed in small aggregations of up to 30 individuals, which again may be an artifact of vessel presence.

Abundance-biomass curves have historically been used to infer community health, where a community dominated by few large species is considered "pristine" and a community dominated by many small species is considered "impacted." Results indicate that the fish communities of the FGB are evenly distributed, which means that the population can be considered mildly disturbed, and lacking in density of large fishes.

The grouper community exhibits an even population of grouper abundance to size; the average density of small bodied groupers (graysby, rock hind, and coney) double that of the large bodied groupers. From the large bodied groupers observed, all black grouper and tiger grouper were considered too small to be sexually mature, except for two large tiger grouper observed at EFGB in 2012 (Heemstra and Randall 1993; Froese and Pauly 2014). All black grouper observed were below the minimum recreational and commercial catch size limits. A previous report, by Caldow et al. (2009), documented a distinct correlation between large-bodied grouper size and proximity to the edge of the reef. The apparent predominance of small grouper is likely due to the restricted habitat sampled in this study: both study sites are located on the shallower portions of the reef cap and do not encompass deeper reef edge habitat.

In contrast to the grouper population, the snapper community was dominated by few large species. The largest snappers seen in the study area were typically smaller than the average known size for the species (dog snapper, yellowtail snapper, and Cubera snapper). Approximately half of the gray snapper observed, and all of the yellowtail snapper observed, were considered too small to be sexually mature (Garcia-Cagide et al. 1994; Froese and Pauly 2014). It should be noted that at EFGB and WFGB, typical recruitment/nursery habitat for snappers (mangroves and sea grasses) are not present, and the mechanism for recruitment of this family to the area in unknown.

As fish behavior changes throughout the day, the density of species may also change. When the top three species that contribute to the observed variation (brown chromis, creole wrasse, and creolefish) were analyzed individually, Creole wrasse were found to have a significantly higher density from 1501 to dusk. This information highlights the importance of distributing surveys evenly between times of day to accurately capture the fish community.

When analyzing biomass and density for long term trends, it should be noted that both measures show high variability between individual surveys, years, and banks. Historical analysis in this report found no significant long-term trends fish biomass (2006 – 2012) or density (2001-2012) at EFGB, despite trendline indications. However, density (2002-2012) at WFGB was found to have a significant trend in increasing density between years. While this data supports the finding of a stable fish community over the monitoring period at EFGB, it suggests the fish density at WFGB may be increasing. Continued monitoring of these trends is warrented, and should be expanded to include trends in abundance-biomass curves when additional data points (i.e. years of data) are available.

CHAPTER 11.0: SEA URCHIN AND LOBSTER SURVEYS

11.1. SEA URCHIN AND LOBSTER SURVEYS METHODOLOGICAL RATIONALE

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

Lobsters are commercially important species throughout much of the Caribbean and Gulf of Mexico; however, population dynamics of Caribbean Spiny Lobster (*Panulirus argus*) and Spotted Spiny Lobster (*Panulirus guttatus*) in the FGB are not well understood.

11.2. SEA URCHIN AND LOBSTER SURVEYS METHODS

Due to the nocturnal nature of these species, visual surveys were conducted at night, a minimum of 1.5 hours after sunset. In 2011 and 2012, surveys for *Diadema antillarum*, *Panulirus argus*, and *Panulirus guttatus* were conducted along the northern and eastern perimeter lines at EFGB and along the southern and western boundaries at WFGB. Two belt transects 2 m wide and 100 m long were surveyed by diver teams on each bank, thus totaling 400 m^2 per bank each year. Surveys began with the northeast corner at the EFGB study site and the southeast corner at the WFGB study site. All observed species were recorded.

11.3. STATISTICAL ANALYSES OF THE SEA URCHIN AND LOBSTER DATA

The software package Primer® version 6.0 was used to create similarity matrices and MDS plots using square-root transformed data. A SIMPER was conducted on the abundance data to determine the differences observed within and among groups.

11.4. SEA URCHIN AND LOBSTER SURVEYS RESULTS

The number of individuals recorded during each survey in 2011 and 2012 are listed in Table 11.4.1. One *Panulirus argus* was observed at EFGB in 2011 (0.25 per 100 m^2). No other lobsters were observed in 2011 or 2012.

At EFGB, no *Diadema antillarum* were observed in 2011 or 2012 along the selected EFGB study site perimeter lines. In 2011, 15 *Diadema antillarum* (3.75 per 100 m^2) were documented at WFGB. In 2012, 50 (12.5 per 100 m^2) were found along selected study site lines. This correlates to higher densities at WFGB in both 2011 and 2012 when compared to EFGB (Table 11.4.1).

Table 11.4.1.

Number of Individual Sea Urchins and Lobsters Observed During Surveys in 2011 and 2012

No. of Individuals Observed	Sea Urchins	Lobsters	
	Diadema antillarum	*Panulirus argus*	*Panulirus guttatus*
EFGB 2011	0	1	0
EFGB 2012	0	0	0
WFGB 2011	15	0	0
WFGB 2012	50	0	0

11.4.1. Historical Comparison of Sea Urchin and Lobster Surveys

Since 2004, lobster counts on surveys have ranged from zero to two. They are, however, occasionally encountered by divers at other times, so they do occur on the banks in low abundance. Since 2004, sea urchin counts on surveys have ranged from zero to fifty-five. A higher number of *Diadema antillarum* were observed during the surveys at WFGB in 2004 and 2012 (Figure 11.4.1).

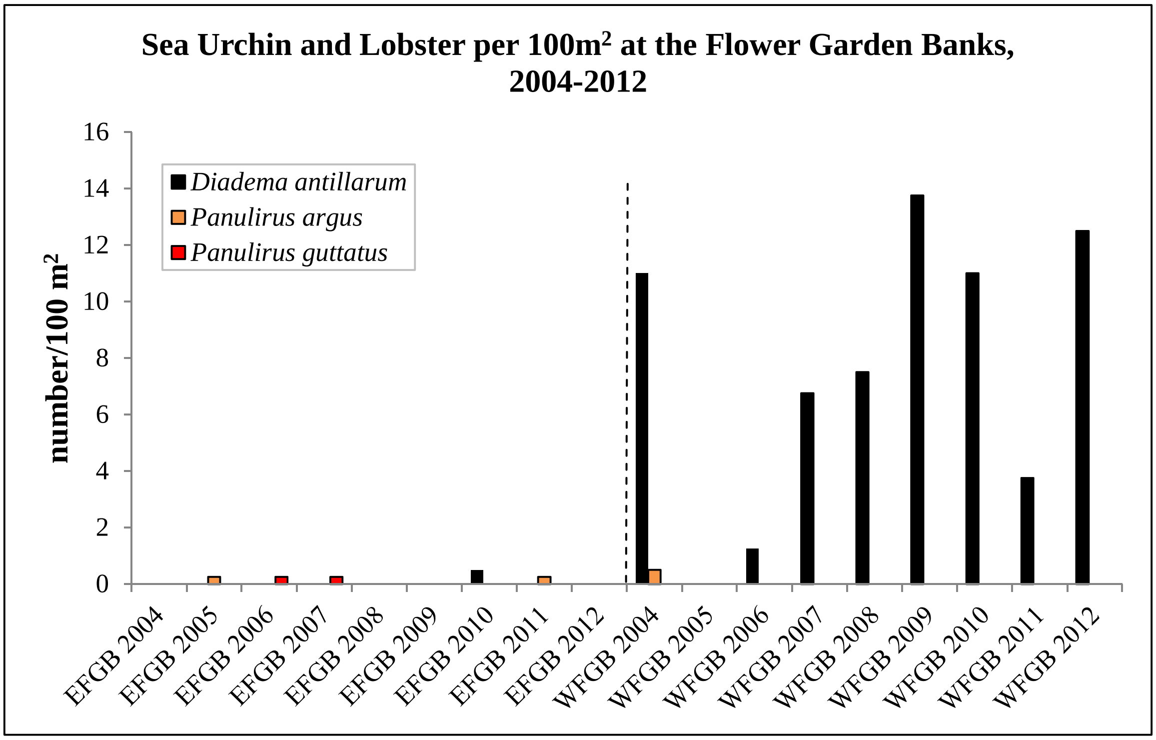


Figure 11.4.1. Sea urchin and lobster densities at the FGB from 2004–2012.

Data for 2004 to 2008 from PBS&J (Precht et al. 2006, 2008b); and FGBNMS for 2009 and 2010 (Johnston et al. 2013).

MDS analysis was performed on the *Diadema antillarum* abundance data at EFGB and WFGB using the 2004-2012 data. The MDS plot (Figure 11.4.2) highlights the dissimilarity between banks with EFGB abundance data clustering differently from WFGB abundance data (80% similarity). This dissimilarity was due to the abundance of *Diadema antillarum.* The low stress level indicates a high confidence in the relationships displayed. The MDS plot also revealed three outliers obtained at EFGB in 2008, 2011, and 2012 when no *Diadema antillarum* were observed, separating these values from all others by bank and year.

Groups were too small to run an ANOSIM; however, a SIMPER revealed a strong average dissimilarity of 68.74% between EFGB and WFGB. Results show that *Diadema antillarum* community composition differed between the banks during 2004 to 2012, and *Diadema antillarum* densities were significantly higher on WFGB than EFGB. Due to low sample sizes, no such determinations could be made by year.

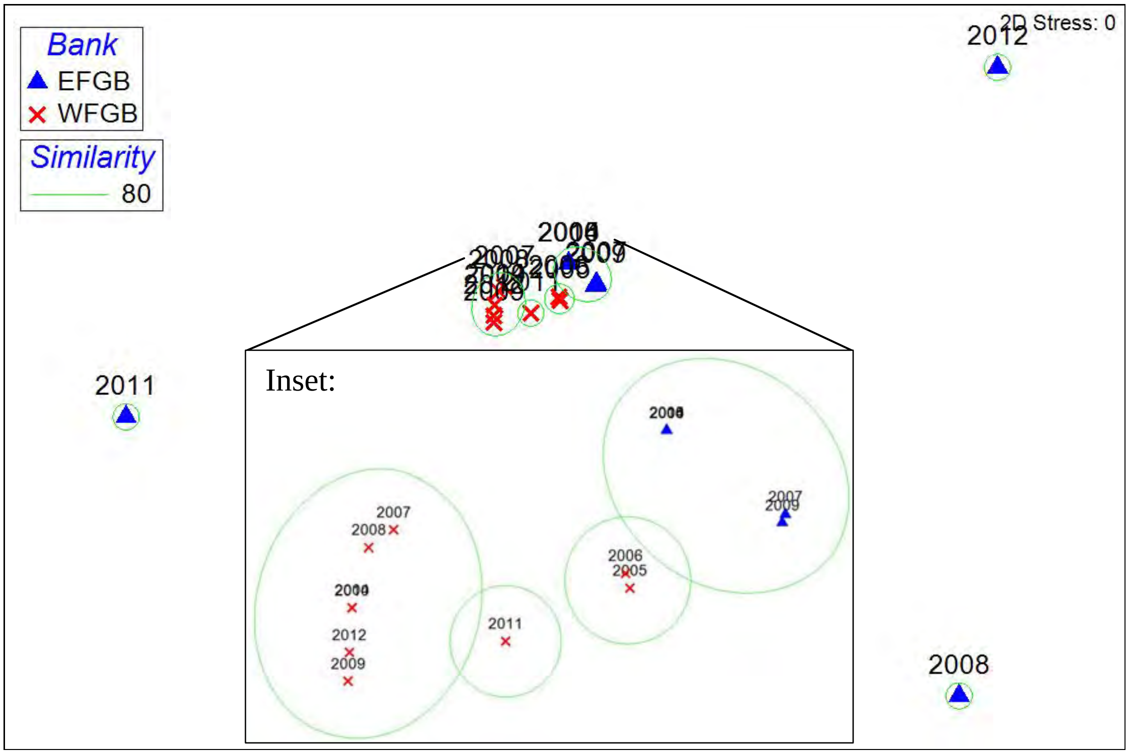


Figure 11.4.2. Two-dimensional MDS plot based on Bray-Curtis similarities comparing *Diadema antillarum* densities from 2004–2012.

The green circles group years that are 80% similar.

11.5. SEA URCHIN AND LOBSTER SURVEYS DISCUSSION

After the mass die off in 1983, *Diadema antillarum* populations have not recovered to pre-1983 levels, which were at least 140 individuals/100 m² at EFGB and 50 individuals/100 m² at WFGB (Gittings et al. 1998). Post-1984 sea urchin densities dropped to near zero (Gittings and Bright 1987). *Diadema antillarum* populations at EFGB remained low during this monitoring period and were similar to those reported in previous studies (Zimmer et al. 2010). Populations at WFGB have been consistently higher than EFGB. Both 2009 and 2012 had abundances among the higest recorded at WFGB since the die off. The previous fluctuations in annual density estimates suggest caution in declaring a recovering *Diadema antillarum* population on the FGB; continued monitoring will be required to track and compare temporal changes at both banks. It is suggested that the entire study site (all perimeter lines and crosshairs) be surveyed for lobster and *Diadema antillarum* instead of the same single transect every year.

CHAPTER 12.0: RECOMMENDATIONS

The following are recommendations for improving the monitoring protocols and increasing the scientific value of the monitoring program, as adjustments would improve the efficiency and quality of data collection efforts.

Operational Changes

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

- Evaluate lateral station methodology to remove comparison inconsistencies from year to year (a refurbishment cruise to establish new stations with updated methods took place July 2014). Based on updated methods, determine the value of lateral growth data as a monitoring tool.
- Evaluate the frequency of coral coring events and the use of schleronconology as a monitoring tool.
- Use multiple fish survey techniques, including belt transect and stationary surveys, to obtain more comprehensive data, particularly improving data on richness, cryptic species, and fish biomass. This was implemented during the 2013 monitoring period.
- Increase the number of lobster and sea urchin surveys instead of the same single transect every year. This was implemented during the 2013 monitoring period.
- Conduct a separate assessment to complete bleaching surveys in the late fall months when bleaching is most likely to occur.
- Add survey for coral size class distribution and for coral recruits. This was implemented during the 2013 monitoring period.
- Determine if great barracuda aggregations are an artifact of vessel presence.

Additional Recommendations

- Continue and increase the number of presentations and peer-reviewed publications resulting from this work.
- Create a monitoring quality assurance/quality control methods and procedures manual to ensure consistency in field procedures and data analysis (a procedures manual is being compiled).

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The Department of the Interior Mission

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

The Bureau of Ocean Energy Management Mission

The Bureau of Ocean Energy Management (BOEM) promotes energy independence, environmental protection, and economic development through responsible, science-based management of offshore conventional and renewable energy.