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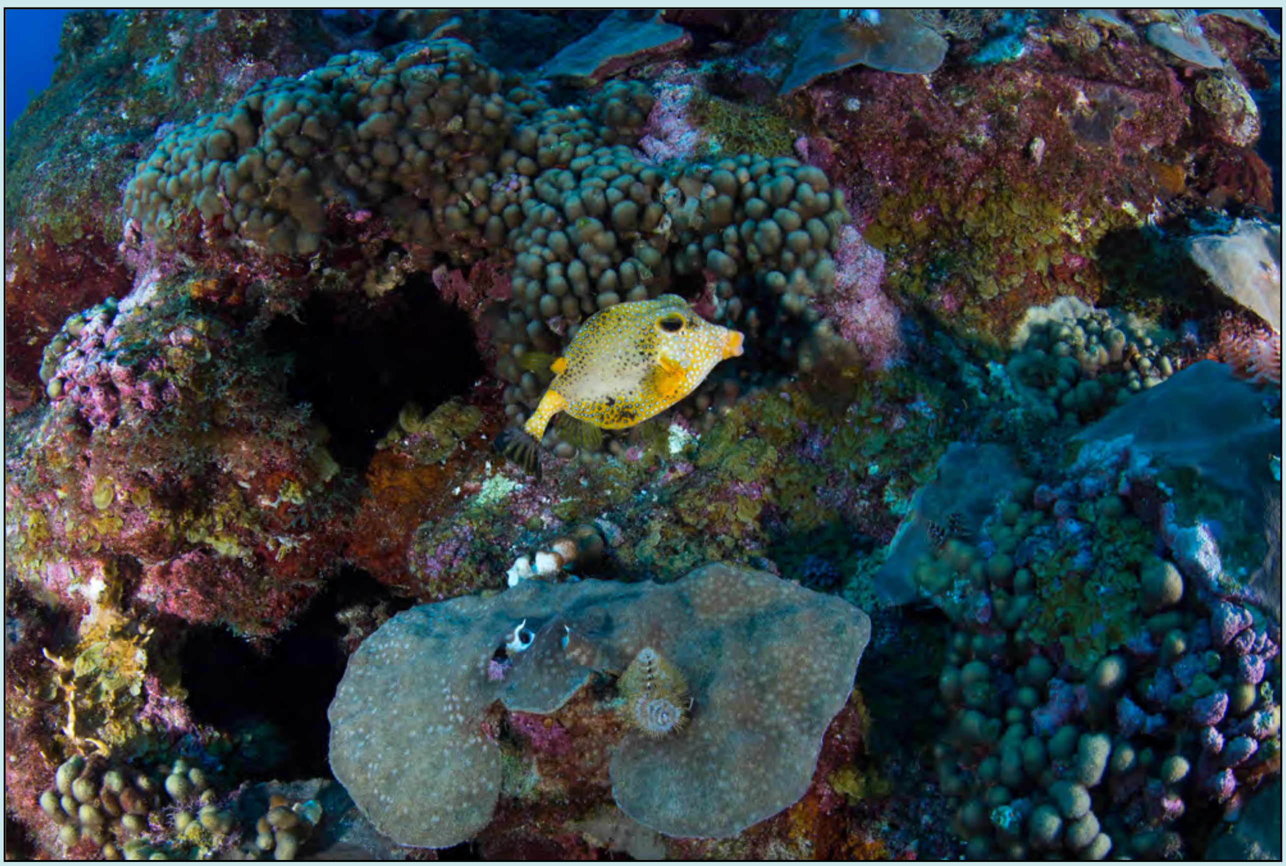
MARINE SANCTUARIES CONSERVATION SERIES ONMS-16-02

Long-Term Monitoring at East and West Flower Garden Banks: 2015 Annual Report



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Smooth Trunkfish (*Lactophrys triqueter*) in a golden color phase at East Flower Garden Bank, 2015. Credit: NOAA FGBNMS/G.P. Schmahl

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Acknowledgments

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Acronyms

BOEM – Bureau of Ocean Energy Management
CCL – Carbon Cycle Laboratory
Chl-*a – Chlorophyll-a*
CPCe – Coral Point Count® with Excel® extensions
CTB – Crustose coralline algae, fine turf algae, and bare rock
EFGB – East Flower Garden Bank
EPA – Environmental Protection Agency
FGBNMS – Flower Garden Banks National Marine Sanctuary
NOAA – National Oceanic and Atmospheric Administration
RV – Research Vessel
Texas A&M University Corpus Christi – TAMU-CC
TKN – Total Kjeldahl Nitrogen
WFGB – West Flower Garden Bank

EXECUTIVE SUMMARY


Photo: NOAA FGBNMS/ G.P. Schmahl

The *R/V Manta* moored over the coral reef at West Flower Garden Bank, 2015.

Since 1989 a federally supported long-term coral reef monitoring program has focused on two study sites atop East Flower Garden Bank and West Flower Garden Bank (EFGB and WFGB) in the northwestern Gulf of Mexico. In 27 years of continuous monitoring, mean coral cover was above 50% and represented a stable coral community. Despite global coral reef decline in recent decades, EFGB and WFGB have suffered minimally from hurricanes, coral bleaching, and disease, and the reef supports relatively diverse and abundant benthic and fish populations.

This report summarizes fish and benthic community observations and water quality data from 2015 as part of the annual long-term monitoring program jointly funded by NOAA's Flower Garden Banks National Marine Sanctuary and the Bureau of Ocean Energy Management. The benthic and fish community surveys were conducted by a team of multi-disciplinary scientists using random transects to document components of benthic cover, repetitive photostations to document changes in the composition of benthic assemblages in shallow and deep repetitive sites, and modified Bohnsack and Bannerot (1986) fish surveys to examine fish population composition within designated study sites at EFGB and WFGB.

Key findings from the 2015 monitoring period include:

Chapter 2: Random Transects

- *Benthic communities at EFGB and WFGB are dominated by coral, with approximately 56% mean coral cover within the study sites for both banks.*
- Orbicella franksi*, a threatened species as listed by the Endangered Species Act, is the principal component of mean percent coral cover at both banks (28%).*
- Pseudodiploria strigosa *is the second most abundant species (9%).*
- *Despite continued mean coral cover above 50 percent, macroalgae mean percent cover has been significantly increasing since 1999.*

Chapter 3: Repetitive Quadrat Photostations

- *Mean coral cover in the repetitive quadrat photostations is approximately 62% for both banks.*
- *Similar to the random transects, the coral assemblages remained consistent at both banks, with the dominant corals being* Orbicella franksi *followed by* Pseudodiploria strigosa.
- *Mean macroalgae cover shows an increasing trend since it was first measured at repetitive quadrat photostations in 2002.*
- *Incidences of bleaching, paling, and fish biting are rare (less than 1% of the area assessed), and there is little evidence of coral disease.*

Chapter 4: Repetitive Deep Photostations

- *In the 32–40 m repetitive deep photostations, mean coral cover is 73%.*
- *Dominant coral species composition changes slightly with depth, with* Orbicella franksi *and* Montastraea cavernosa *being the most abundant species in this depth range.*
- *Mean macroalgae cover has been increasing since it was first measured at the repetitive deep stations in 2003.*

Chapter 5: Fish Surveys

- *Labridae (wrasses and parrotfish), Pomacentridae (damselfish), and Serranidae (groupers) are the dominant fish families at both banks.*
- *The most abundant species include Bonnetmouth (*Emmelichthyops atlanticus*), followed by Bluehead (*Thalassoma bifasciatum*) and Brown Chromis (*Chromis multilineata*).*
- *Mean fish density (abundance/100 m^2) is highest at EFGB.*
- *Mean fish biomass (g/100 m^2) is greatest at EFGB, with piscivores comprising greater than 35% of the biomass.*
- *First observed in 2011 at the FGB, lionfish (*Pterois volitans/miles*) were documented in the long-term monitoring dataset for the third consecutive year, with sighting frequency significantly increasing to approximately 40%.*

Chapter 6: Water Quality

- *Temperature and salinity differed from historical averages in 2015.*
- *Cooler than normal temperatures were recorded in the late summer.*
- *Temperatures above the 30°C bleaching threshold were not sustained.*
- *Nutrient tests indicated no detectable levels of the nutrients tested throughout the year.*
- *Carbonate chemistry indicates that the FGB and surrounding area acts as a net CO_2 sink.*

Chapter 1

LONG-TERM MONITORING AT EAST AND WEST FLOWER GARDEN BANKS

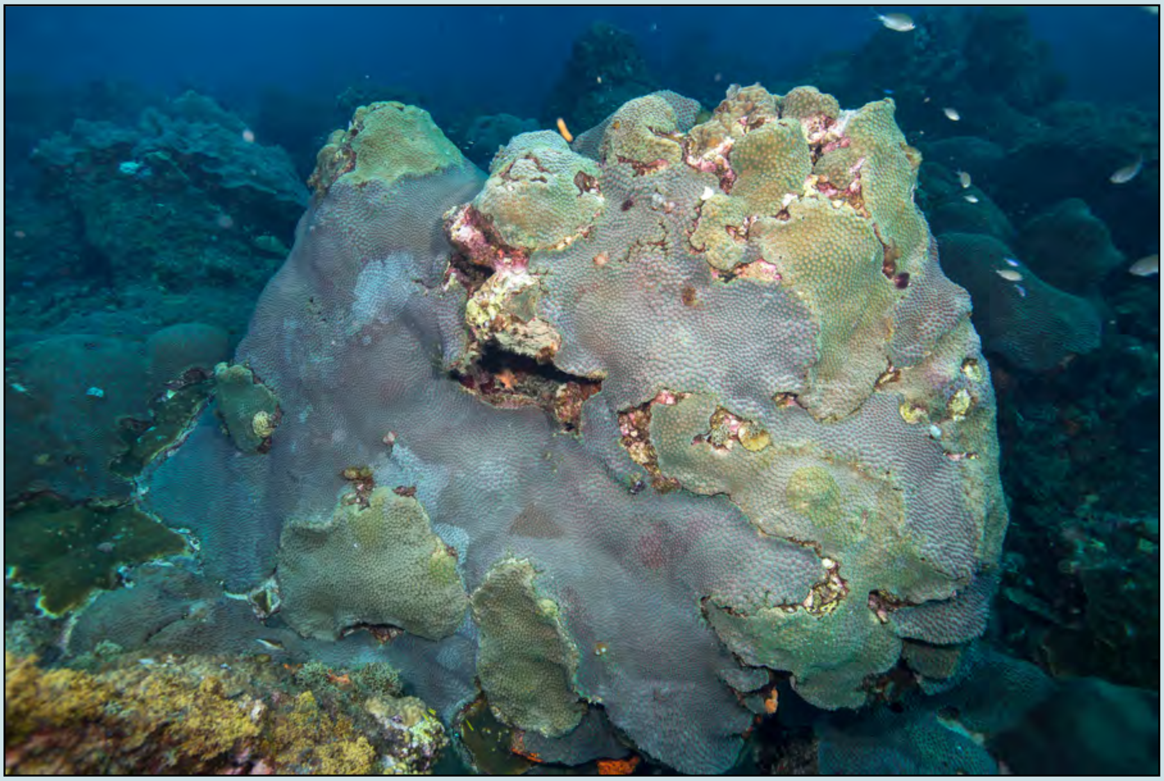


Photo: NOAA FGBNMS/G.P. Schmahl

Great star coral, *Montastraea cavernosa*, at East Flower Garden Bank, 2015.

Long-Term Monitoring Introduction

The coral reef-capped East Flower Garden Bank and West Flower Garden Bank (EFGB and WFGB) are part of a discontinuous arc of reef environments along the outer continental shelf in the northwestern Gulf of Mexico (Bright et al. 1985) (Figure 1.1). They are located approximately 190 km south of the Texas and Louisiana border, containing several distinct habitats ranging in depth from 17–140 m. EFGB and WFGB provide favorable conditions for hermatypic corals and support abundant fish and invertebrate populations (Goreau and Wells 1967; Schmahl et al. 2008; Clark et al. 2014; Johnston et al. 2015a). The shallowest portions of each bank are topped by well-developed coral reefs, in depths ranging from 17–50 m.

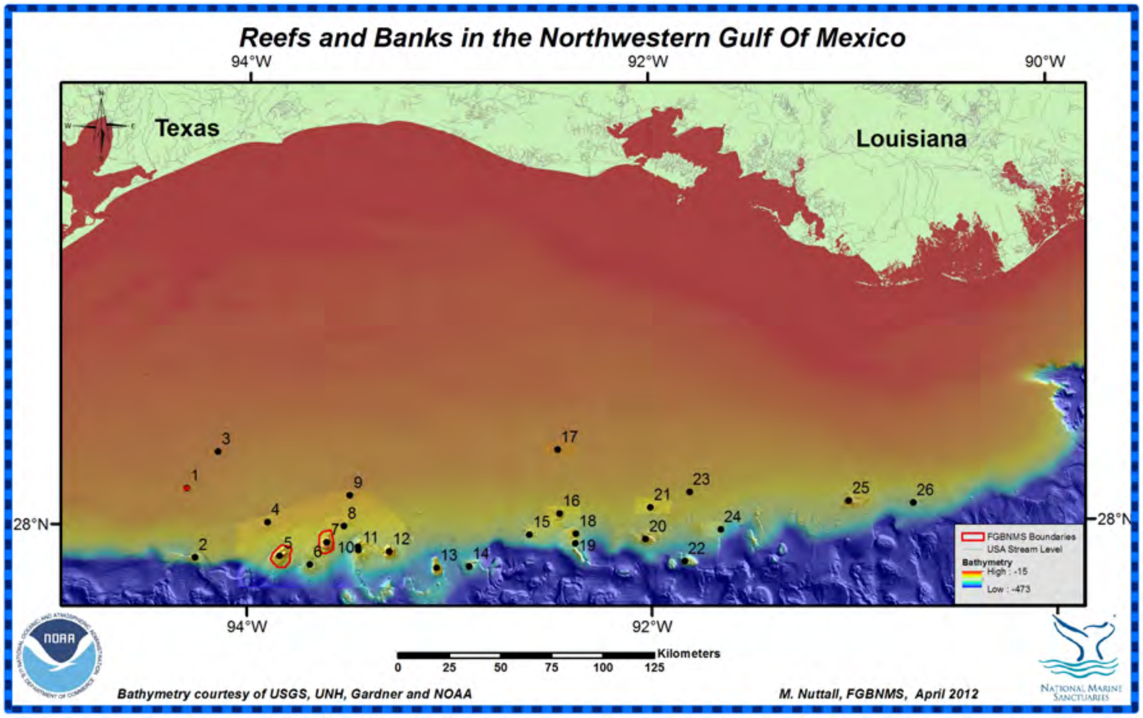


Figure 1.1. Map of EFGB, WFGB, and Stetson Bank (outlined in red) in relation to the Texas-Louisiana continental shelf and other topographic features of the northwestern Gulf of Mexico.

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

In the 1970s, due to concerns about potential impacts from offshore oil and gas development, the Department of Interior (DOI) (initially through the Bureau of Land Management, then the Minerals Management Service, and now the Bureau of Ocean Energy Management [BOEM]) started monitoring EFGB and WFGB to establish baseline data and determine if these reefs were impacted by nearby oil and gas activities (Figure 1.2).

Though many coral reefs in the western Atlantic and Caribbean region have experienced significant declines in coral cover due to environmental and anthropogenic stressors, the reefs of EFGB and WFGB, which are part of Flower Garden Banks National Marine Sanctuary (FGBNMS), continue to flourish (Gardner et al. 2003; Mumby and Steneck 2011; DeBose et al. 2012; Clark et al. 2014; Jackson et al. 2014; Johnston et al. 2015a; Johnston et al. 2016b). Administered through an interagency agreement, the monitoring program is important to NOAA and BOEM, who share the responsibility of protecting and monitoring these important marine resources.

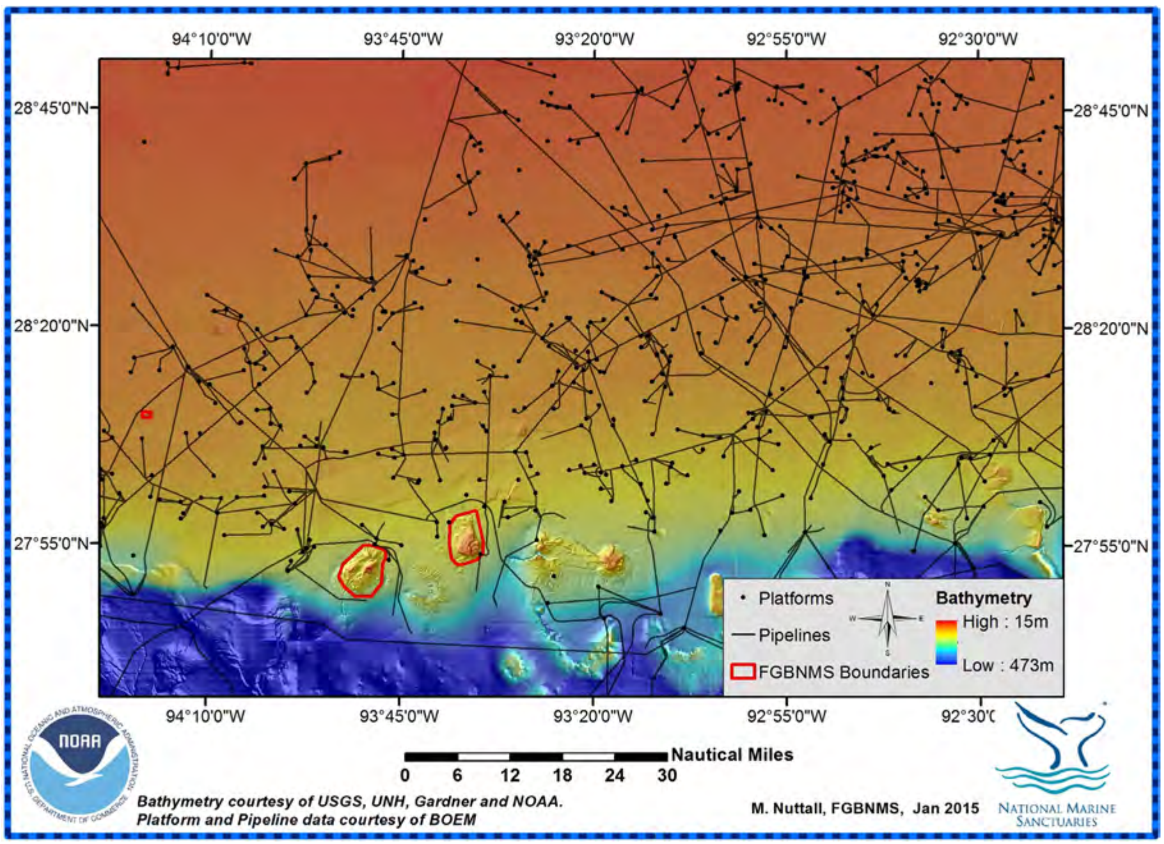


Figure 1.2. Map of oil and gas platforms and pipelines near EFGB, WFGB, and surrounding banks.

Long-Term Monitoring Study Sites

Data has been collected annually during summer months since 1989 at permanent 10,000 m^2 study sites (100 x 100 m or 1 hectare) (hereafter referred to as "study sites") on each bank. Within the study sites, depths ranged from 17–27 m, and at deeper sites (later established outside the study site boundaries), depths ranged from 30–40 m. The approximate centers of the study sites are currently marked by permanent mooring buoys: FGBNMS permanent mooring #2 at EFGB and mooring #5 at WFGB (Table 1.1; Figure 1.3 and 1.4). The monitoring effort was conducted from the NOAA *R/V Manta* during September 07–11, 2015.

Table 1.1. Coordinates and depths for the study site permanent moorings.

Study Site Mooring Buoy Locations			
Mooring	**Lat (DDM)**	**Long (DDM)**	**Depth (m)**
EFGB Mooring #2	27° 54.516 N	-93° 35.831 W	19.2
WFGB Mooring #5	27° 52.501 N	-93° 48.918 W	20.7

In 2015, the benthic community was examined along random 10 m transects and in stationary repetitive photostations. Fish surveys were conducted at randomly located points within the study sites, and water samples were collected quarterly. Within each study site at EFGB and WFGB, stationary repetitive photostations were established at the beginning of the monitoring program in 1989. The centers of these repetitive quadrat photostations are marked by 0.5 m tall rods or eyebolts. Historically, 40 repetitive quadrat photostations have been maintained over time at each bank.

Eleven repetitive deep photostations are located outside the study site at EFGB. The deep photostations were established in April 2003 for comparison with the shallower repetitive photostations already in place, and are located east of the EFGB study site at depths between 32–40 m (Figure 1.5).

Twelve repetitive deep photostations are located outside the study site at WFGB. These deep photostations 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 mooring buoy #2 at depths between 24–38 m (Figure 1.6).

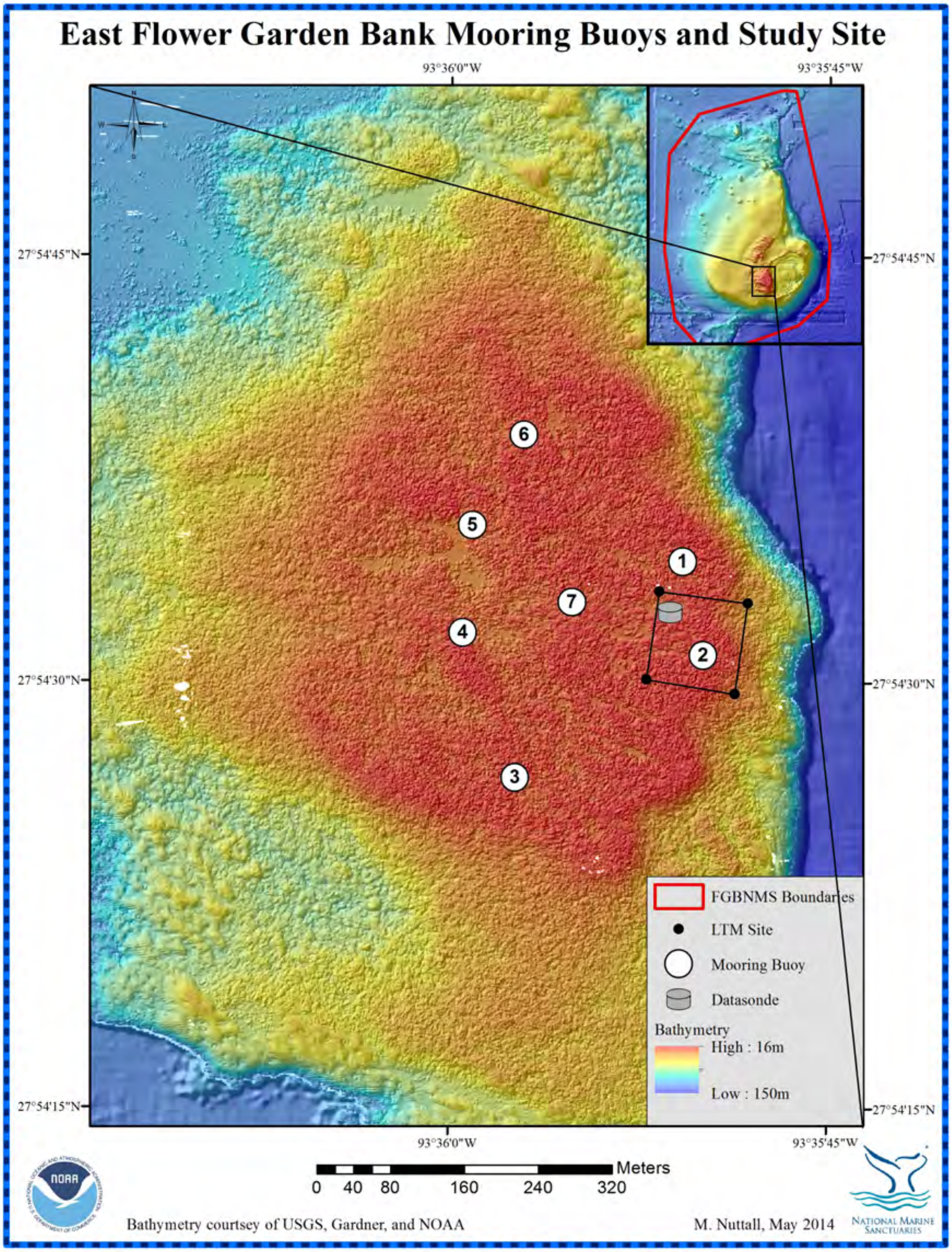


Figure 1.3. Bathymetric map of EFGB with long-term monitoring study site (LTM site), mooring buoy, and water quality datasonde locations.

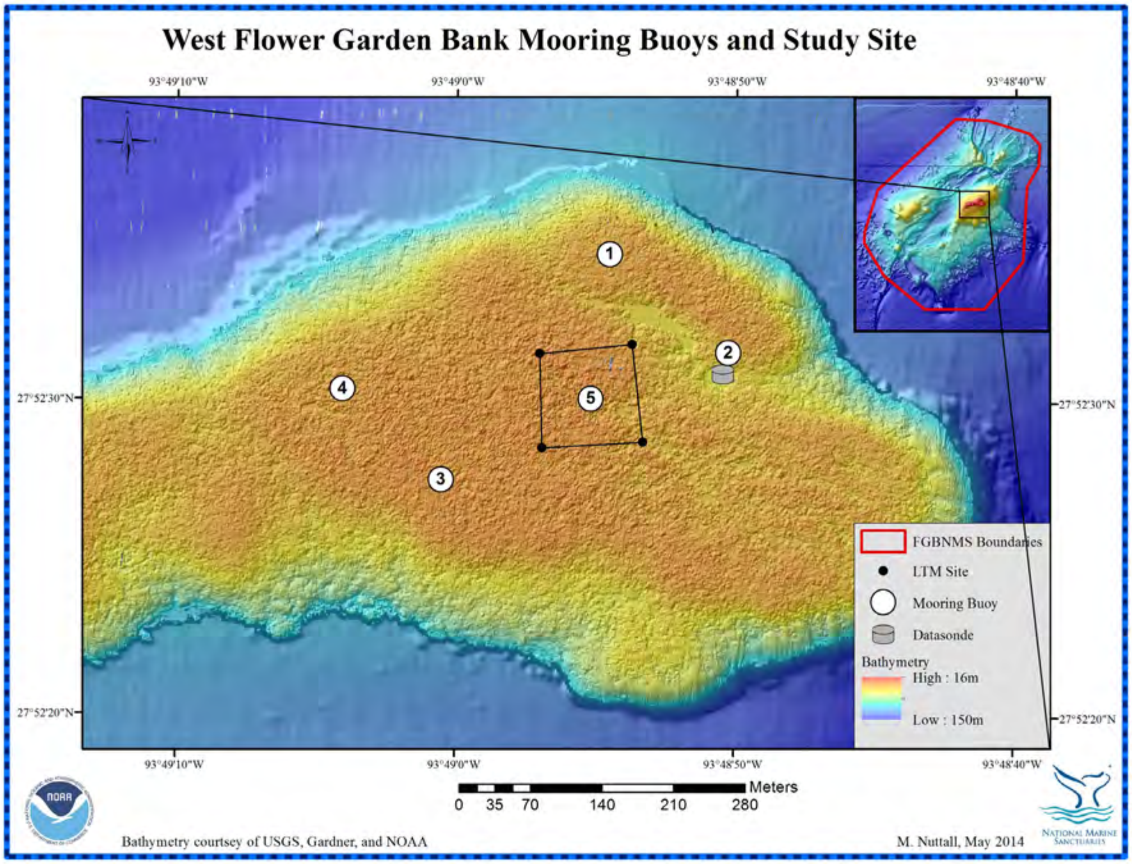


Figure 1.4. Bathymetric map of WFGB with long-term monitoring study site (LTM site), mooring buoy, and water quality datasonde locations.

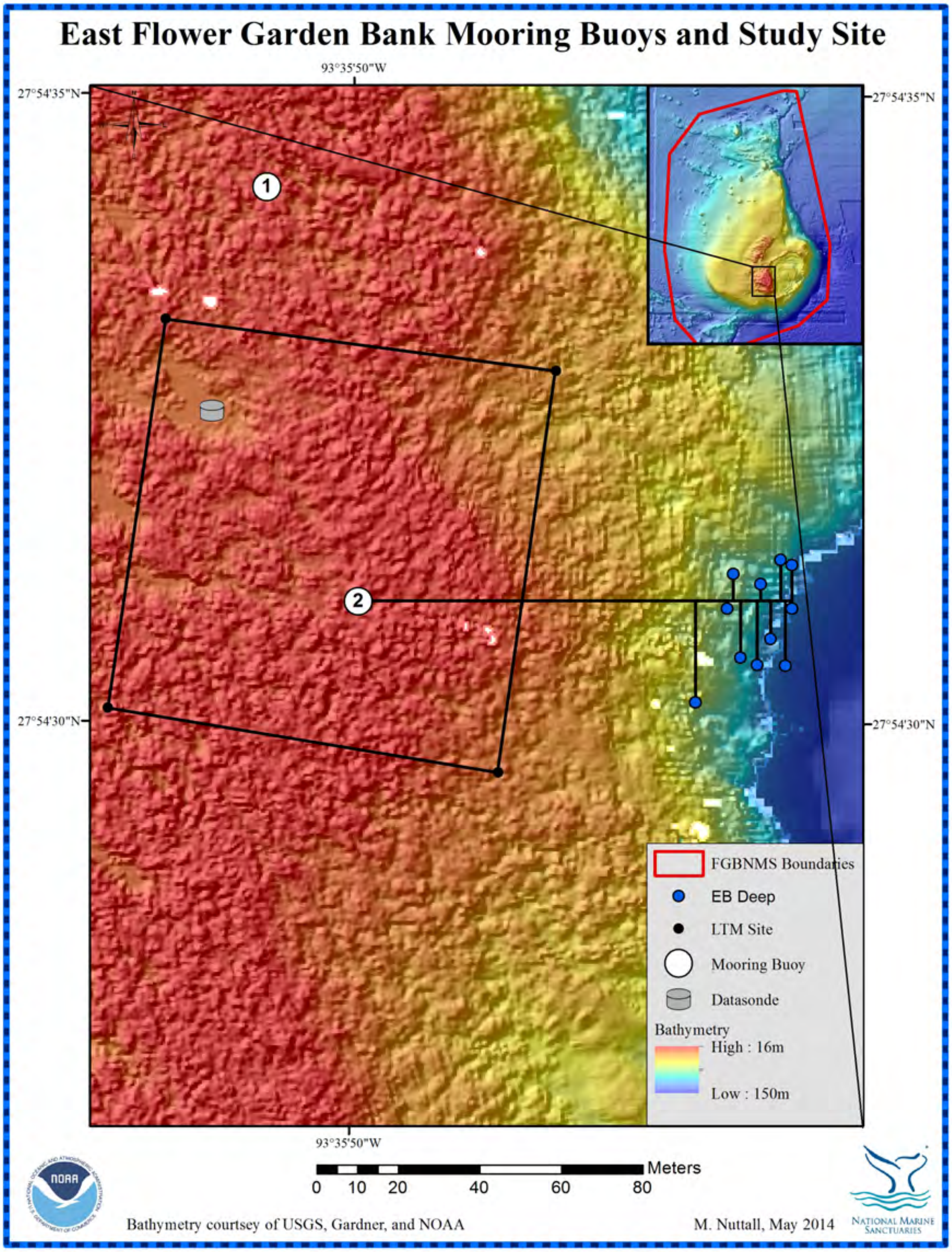


Figure 1.5. Bathymetric map of EFGB with long-term monitoring study site (LTM site), mooring buoy, and repetitive deep photostation locations (EB Deep).

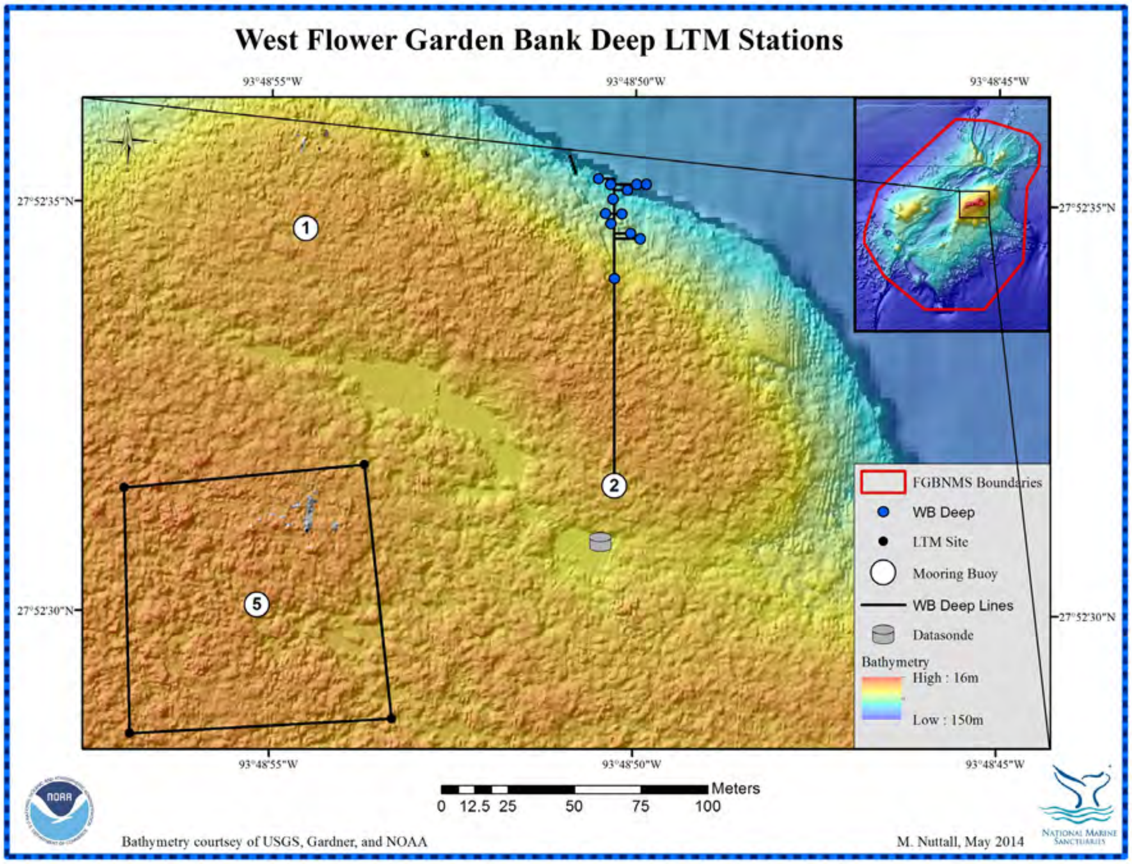


Figure 1.6. Bathymetric map of WFGB with long-term monitoring study site (LTM site), mooring buoy, and repetitive deep photostation locations (WB Deep).

For multi-year long-term monitoring reports (Gittings et al. 1992; CSA 1996; Dokken et al. 1999, 2003; Precht et al. 2006; Zimmer et al. 2010; Johnston et al. 2013; Johnston et al. 2015a), the following techniques listed below are used to evaluate coral reef diversity, growth rates, and coral reef community health:

- Thirty-two random photographic transects 10 m in length are analyzed to evaluate parameters of the coral community.
- Eighty repetitive photostations and twenty-three repetitive deep photostations are maintained to detect and evaluate long-term changes at the stations and in individual coral colonies. Planimetry is used to measure percent change in area of living tissue of selected coral colonies.
- Sixteen coral demographic surveys are conducted to assess coral colony size along random transects.
- Sixty permanent stations for monitoring marginal growth rates of *Psuedodiploria strigosa* is conducted using comparisons of repetitive close-up photographs of coral margins.
- Eight cores of *Orbicella faveolata* colonies are taken during the third year of four-year monitoring periods. All cores are sectioned and x-rayed to measure accretionary growth rates.
- Two videotaped 100 m transects are conducted at each study site to document the general conditions of reef health.
- Forty-eight fish counts are conducted using a modified Bohnsack & Bannerot (1986) technique for quantitatively assessing community structure of coral reef fishes.
- *Diadema antillarum* (long spined sea urchin) surveys are conducted to establish current population levels as a basis for comparison with future observations.
- One Sea-Bird® Electronics, Inc. (SBE) 37-SMP MicroCAT water quality instrument is stationed on each bank (24 m) to record salinity, temperature, and depth. Deeper HOBO® loggers at 30 m and 40 m record temperature. Quarterly water sampling is conducted at each bank to measure chlorophyll-*a*, ammonia, nitrate, nitrite, total Kjeldahl nitrogen, and phosphorous.

For the purpose this one-year annual report, random transects, repetitive photostations, fish surveys, and water quality results will be evaluated and discussed. Multi-year monitoring reports from previous long-term monitoring periods can be referenced for detailed methods, additional techniques and analyses, and historical data (Gittings et al. 1992; CSA 1996; Dokken et al. 1999, 2003; Precht et al. 2006; Zimmer et al. 2010; Johnston et al. 2013; Johnston et al. 2015a).

Chapter 2

RANDOM TRANSECTS

Photo: NOAA FGBNMS/G.P. Schmahl

NOAA diver, Ryan Eckert, with camera and strobes mounted on aluminum t-frame taking random transect photographs at East Flower Garden Bank.

Random Transect Introduction

Benthic cover, including components such as corals, sponges, substrates, and macroalgae, was determined through analysis of a series of non-overlapping randomly located 10-m photo transects. The random photo transect surveys were used to compare habitat between banks and provide information to document the benthic reef community of EFGB and WFGB in 2015.

Random Transect Methods

Random Transect Field Methods

A total of sixteen non-overlapping random transects within each study site were completed in 2015. A Canon Power Shot® G11 digital camera in an Ikelite® housing and 28-mm equivalent wet mount lens adaptor, mounted on a 0.65-m t-frame with bubble level and two Inon® Z240 strobes was used to capture images along the transects. The bubble level mounted to the t-frame center ensured images were taken in a vertical orientation to standardize the area captured. The mounted camera was placed at marked intervals 80 cm apart on a spooled 15 m measuring tape producing 17 non-overlapping images along the transect (Figure 2.1). Each still frame image captured a 0.8 x 0.6 m area (0.48 m^2). This produced a total photographed area of 8.16 m^2 per transect, and a minimum of 130.56 m^2 photographed area per study site per year (for detailed methods, see Johnston et al. 2015a).

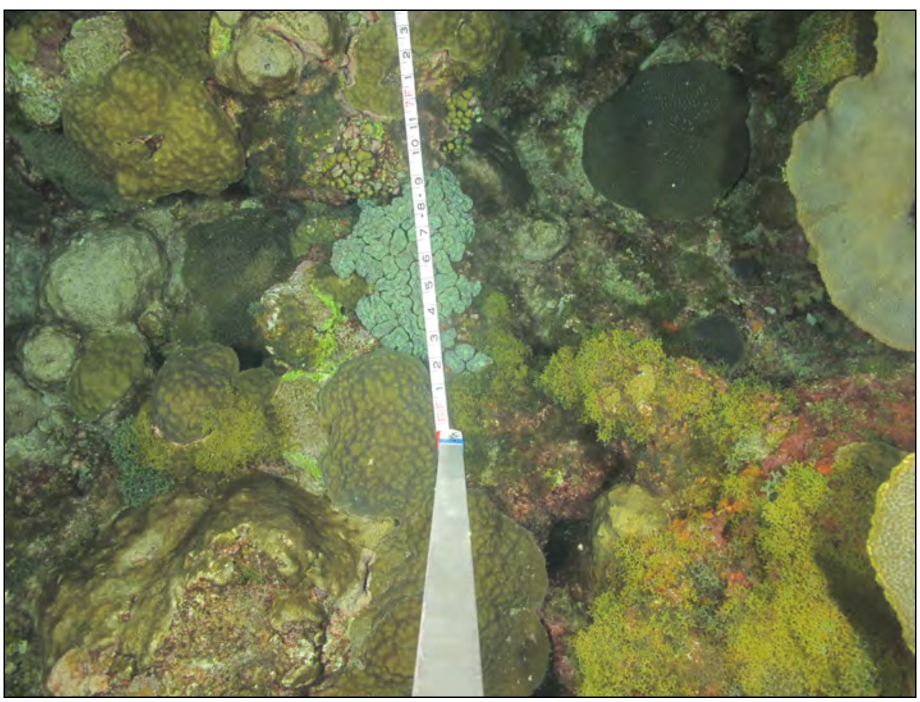


Photo: NOAA FGBNMS/R.J. Eckert

Figure 2.1. Photo taken at marked interval along random transect with camera mounted to aluminum t-frame.

Random Transect Data Processing

Mean percent benthic cover from random transect images was analyzed using Coral Point Count with Microsoft® Excel® extensions (CPCe) version 4.1 with a 500 point overlay randomly distributed among all images within a transect (Aronson et al. 1994; Kohler and Gill 2006). Organisms positioned beneath each random point were identified to the lowest possible taxonomic level, and grouped into four primary functional groups: 1) coral, 2) sponge, 3) macroalgae and 4) "CTB," a composite substrate category that includes crustose coralline algae, fine turf algae, and bare rock (Aronson and Precht 2000; Aronson et al. 2005). Macroalgae included algae longer than approximately 3 mm and thick algal turfs. Point count analysis was conducted for photos within a transect and mean percent cover for all groups was determined by averaging all transects per bank. Additional categories included other live components (ascidians, fish, serpulids, etc.), sand, rubble, and unknown. The coverages of coral bleaching, paling, concentrated and isolated fish biting, and disease were also recorded.

Random Transect Analysis

Based on benthic mean percent cover, comparisons in community differences between the banks were made using nonparametric analysis for non-normal data with Primer® version 6.0 (Anderson et al. 2008). Percent cover of each functional group was used to calculate ecological distance via Bray-Curtis similarity matrices. Significant dissimilarities were tested using analysis of similarity (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).

Significant long-term trends in mean percent cover data were detected using the Mann-Kendall trend test in R® version 3.2.0 (Hipel and McLeod 1994). Functional group means by year and bank were compared using multidimensional scaling with a time series trajectory in Primer® version 6.0 (Anderson et al. 2008). Cluster analyses were performed on Bray-Curtis similarity matrices with similarity profile (SIMPROF) tests to identify significant (α=0.05) clusters within the data. Ordinations were run using 100 random starting configurations to determine the best fit model and minimize stress. Species contributing to the observed dissimilarities were identified using similarity percentages (SIMPER). It should be noted that the range of data collected has varied slightly over the years. From 1989–1991 only mean percent coral cover was collected; other major functional groups were added in 1992. No data were collected in 1993 due to poor weather.

Diversity indices including Margalef's species richness (d), Pielou's evenness (J'), and Shannon diversity (H') were calculated using Primer® version 6.0 to make comparisons between banks based on benthic diversity.

Random Transect Results

Random Transect Mean Percent Cover

The major benthic components of the 2015 random transects were coral cover (56%), followed by macroalgae cover (34%), CTB (9%), and sponge cover (1%) (Figure 2.2).

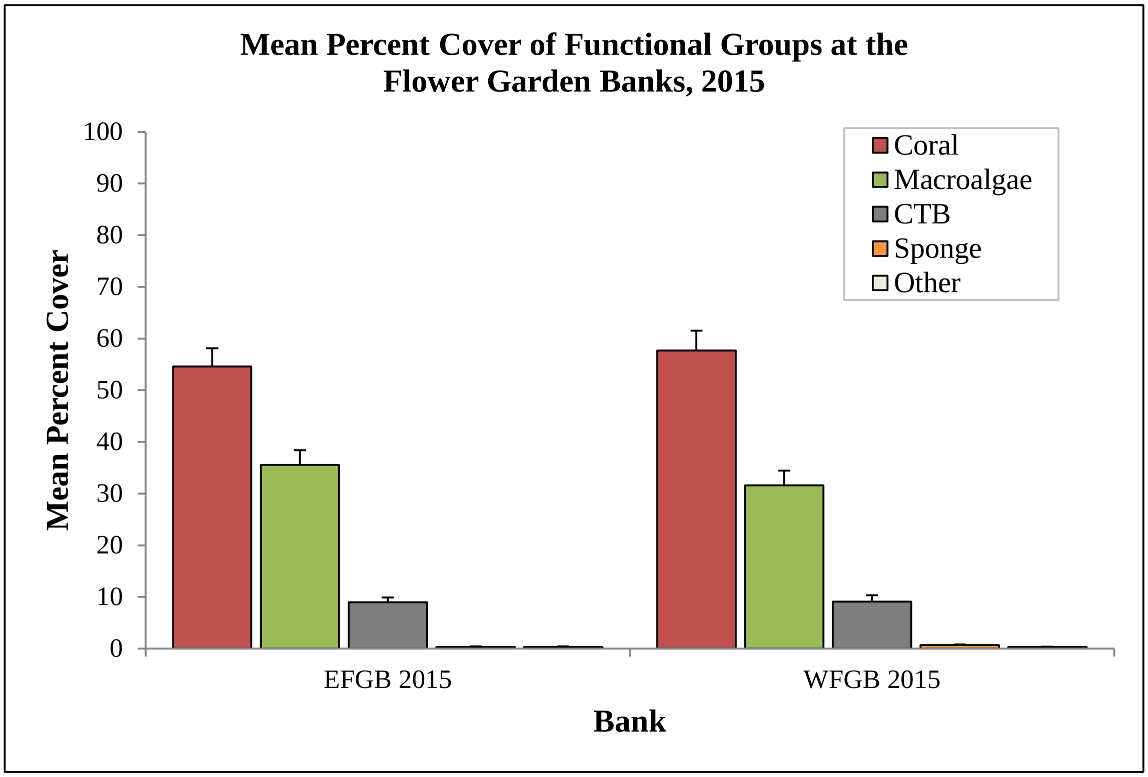


Figure 2.2. Mean percent cover + SE from random transect functional groups at EFGB and WFGB in 2015.

Consistent with past monitoring results (Johnston et al. 2014; Johnston et al. 2015a, b), EFGB mean (± standard error) coral cover was above 50% in 2015 (54.61% ± 3.54) and the sponge cover was 0.34% ± 0.09. Mean macroalgae cover was 35.54% ± 2.87 and mean CTB cover was 8.95% ± 0.92. At WFGB, mean coral cover was above 50% (57.70% ± 3.83), followed by mean macroalgae (31.60% ± 2.85), CTB (9.09% ± 1.24), and sponge cover (0.67% ± 0.16). ANOSIM results comparing the bank functional groups revealed no significant dissimilarities, suggesting that EFGB and WFGB were similar to each other in overall benthic community composition in 2015.

In the 2015 random transects less than 1% of the coral cover analyzed showed incidences of bleaching and paling. In addition, no incidences of fish biting or coral disease were observed. It is important to note that reported bleaching may be incomplete, as monitoring surveys usually occur in early summer months when water temperatures are usually lower than what is required to trigger a bleaching event.

A total of 17 species of coral were observed between EFGB and WFGB. *Orbicella franksi* was the most abundant coral species observed in 2015 (25.57% ± 3.47) at EFGB. *Pseudodiploria strigosa* (8.53% ± 1. 71) was the next most abundant species. *Orbicella franksi* was also the most abundant coral species observed in 2015 (30.15% ± 3.38) at WFGB, followed by *Pseudodiploria strigosa* (8.81% ± 1.37) (Figure 2.3). Corals that could not be identified (less than 0.6%) because of camera angle or camera distortion were labeled as "unidentified coral." There were no significant differences in coral species composition between banks.

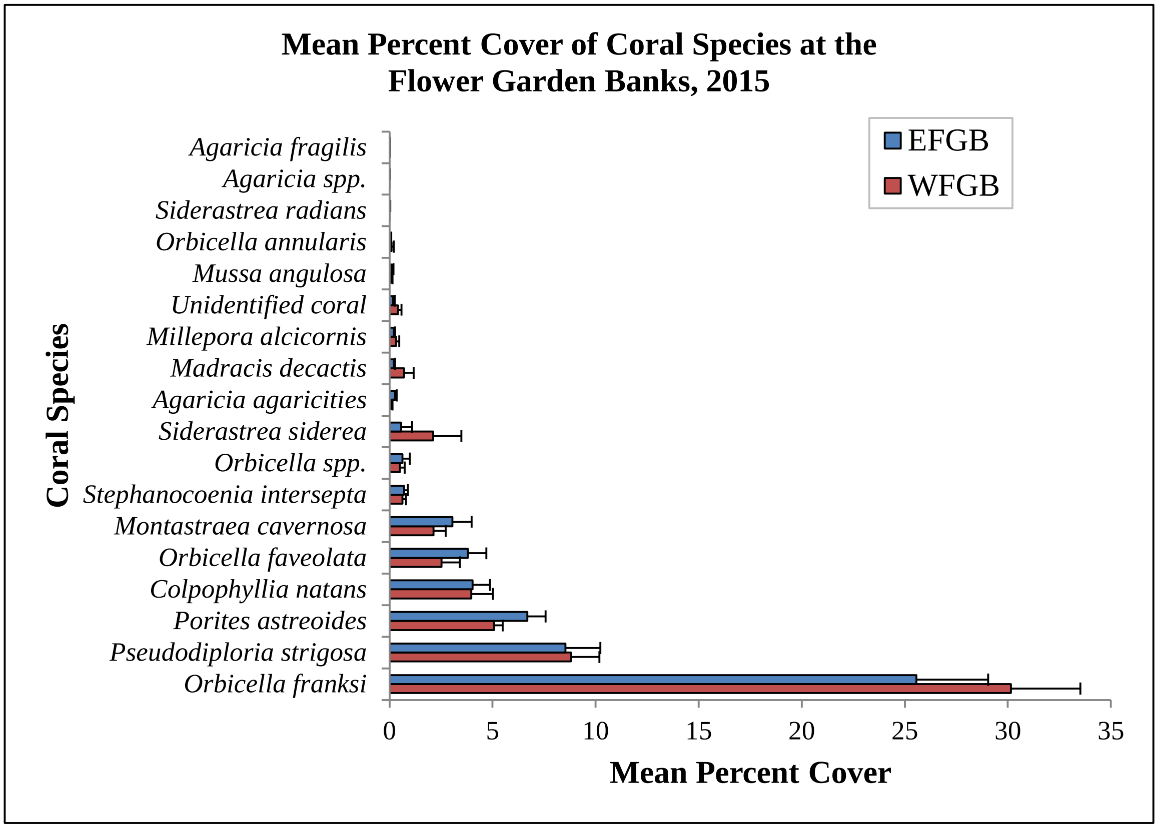


Figure 2.3. Mean percent cover + SE of observed coral species from random transects in 2015.

Coral species diversity measures were averaged between EFGB and WFGB for 2015 (Table 2.2). No significant dissimilarities were found from ANOSIM results comparing diversity measures between bank communities, suggesting that EFGB and WFGB were similar in overall coral species richness and evenness.

Table 2.2. Diversity measures presented as mean ± SE from 2015.

Random Transect Coral Diversity Measures	EFGB	WFGB
Margalef's Species Richness (d)	2.11 ± 0.13	2.03 ± 0.08
Pielou's Evenness (J')	0.67 ± 0.02	0.63 ± 0.02
Shannon Diversity (H'(loge))	1.48 ± 0.07	1.39 ± 0.06

Random Transect Long-Term Trends

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 main random transect functional categories (coral, sponge, macroalgae, and CTB) were analyzed. Like many long-term monitoring programs, a variety of underwater camera setups were used to capture benthic cover as technology advanced from 35-mm slides (1989–2001), digital videography using video still frame grabs (2002–2009), and digital still images (2010–2015) (Gittings et al. 1992; CSA 1996; Dokken et al. 1999, 2003; Precht et al. 2006; Zimmer et al. 2010; Johnston et al. 2014; Johnston et al. 2015a, b). Prior to the use of CPCe, percent cover was calculated with myler traces and a calibrated planimeter from 1989–1995 (Gittings et al. 1992; CSA 1996). From 1996–2003, random dot layers were generated manually in photo software programs (Dokken et al. 1999, 2003).

Mean percent coral cover at EFGB and WFGB during the period from 1989–2015 ranged from 39–62%, significantly increasing over time (τ=0.55, p<0.001) (Figure 2.4). Dominant coral species with the greatest mean percent cover were the *Orbicella* species group (31.15%) (primarily *Orbicella franksi*), followed by *Pseudodiploria strigosa* (7.91%) (Figure 2.5). There were no significant differences in coral species composition between banks from 1989–2015. Macroalgae and CTB cover generally varied inversely, with macroalgae significantly increasing (τ=0.67, p<0.001) and CTB significantly decreasing (τ=-0.58, p<0.001) over time (Figure 2.4). ANOSIM results comparing the bank communities revealed no significant dissimilarities, suggesting that EFGB and WFGB were similar to each other in overall benthic community composition from 1989–2015.

Prior to 1999, macroalgae cover was consistently below 5%; however, in 1999, macroalgae cover increased to approximately 20% and has remained high, peaking above 30% in 2012 and remaining near 30% since 2013. Multivariate historical percent cover analysis was compared among years when appropriate data was available (1994–2015) to evaluate benthic cover change over time. SIMPROF tests from cluster analysis resulted in two significant (π=3.34, p<0.001) clusters (90% similar) corresponding to the shift in increased macroalgae. The data suggests benthic communities were similar from 1994–1998; a significant shift in community composition occurred in 1999 to another that has persisted from 1999–2015 (Figure 2.6). SIMPER analysis identified that for most comparisons from 1994–2014, the greatest contributor to the observed dissimilarity was macroalgae.

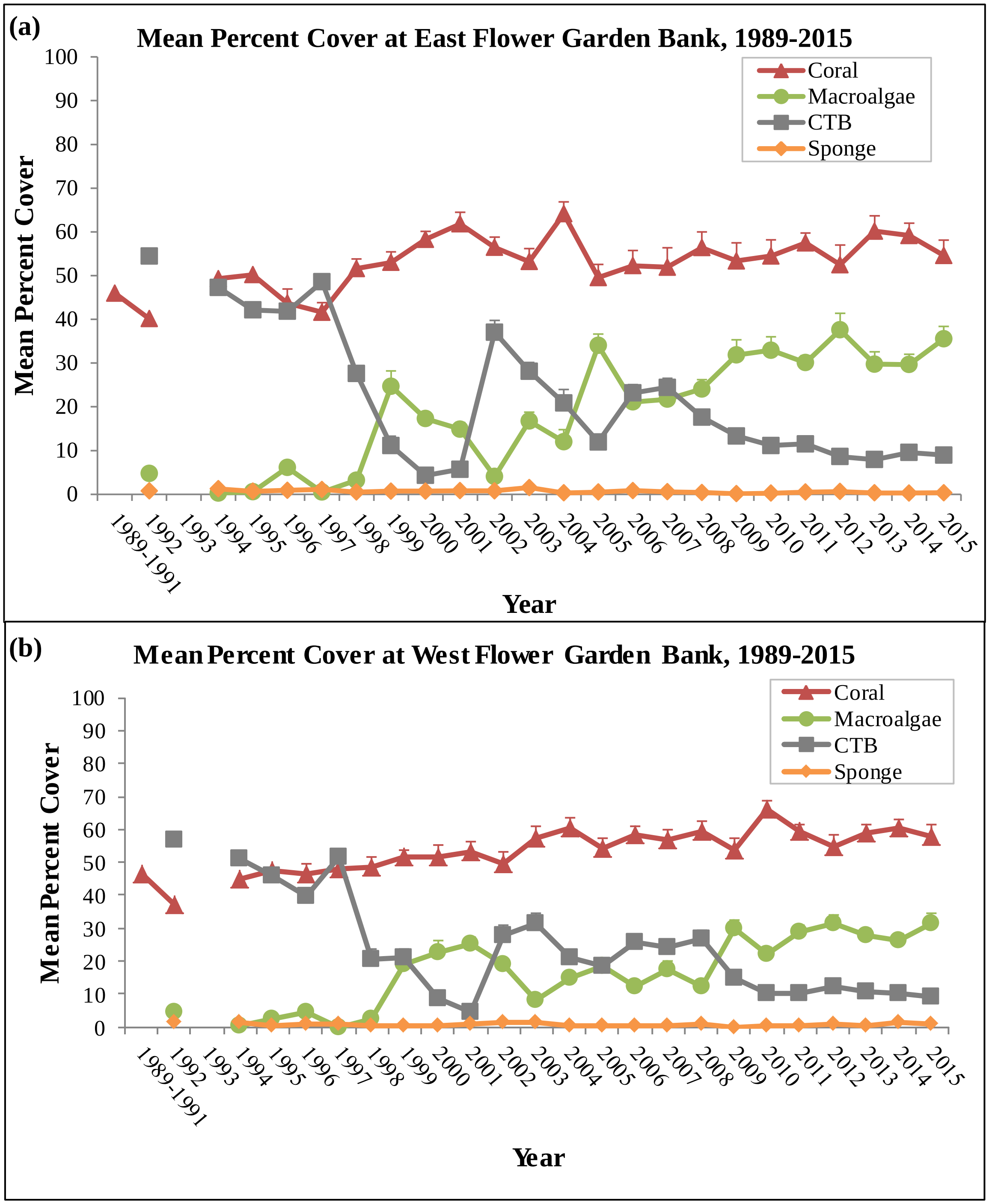


Figure 2.4. Mean percent cover + SE of coral, sponge, macroalgae, and CTB at (a) EFGB and (b) WFGB from 1989 to 2015.

No mean percent cover data were reported in 1993. Data for 1989–1991 from Gittings et al. (1992); 1992–1995 from Continental Shelf Associates, Inc. (CSA 1996); 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); 2011–2012 (Johnston et al. 2015a); 2013 (Johnston et al. 2014); and 2014 (Johnston et al. 2015b).

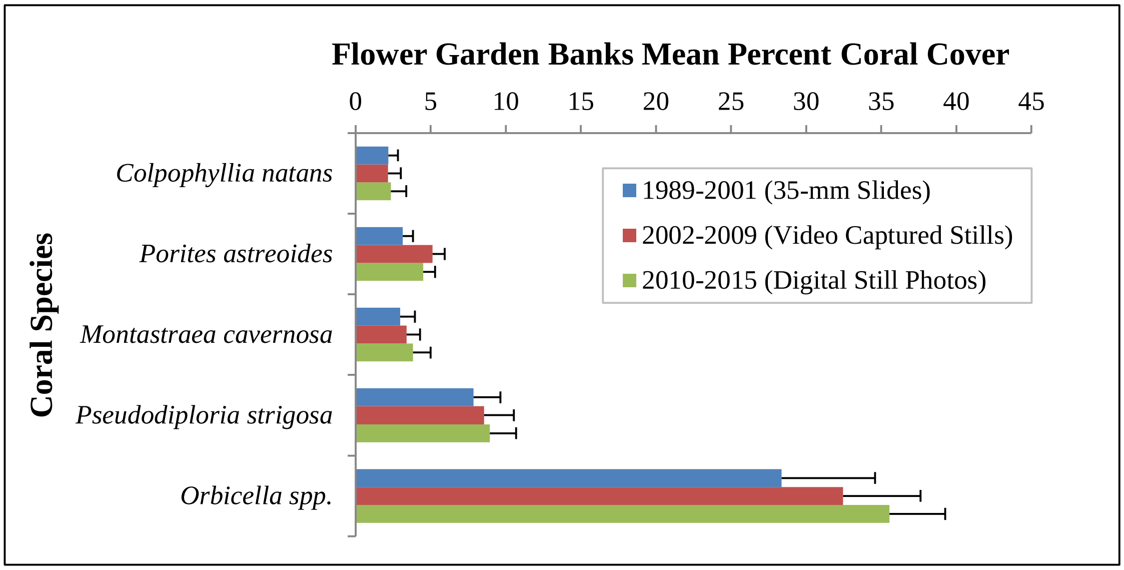


Figure 2.5. Percent cover of dominant coral species at EFGB and WFGB from 1989 to 2015.

The *Orbicella* species group combines *O. franksi*, *O. faveolata*, and *O. annularis*. These separate species have been recognized in recent years, but are grouped to compare with historical data collection methods.

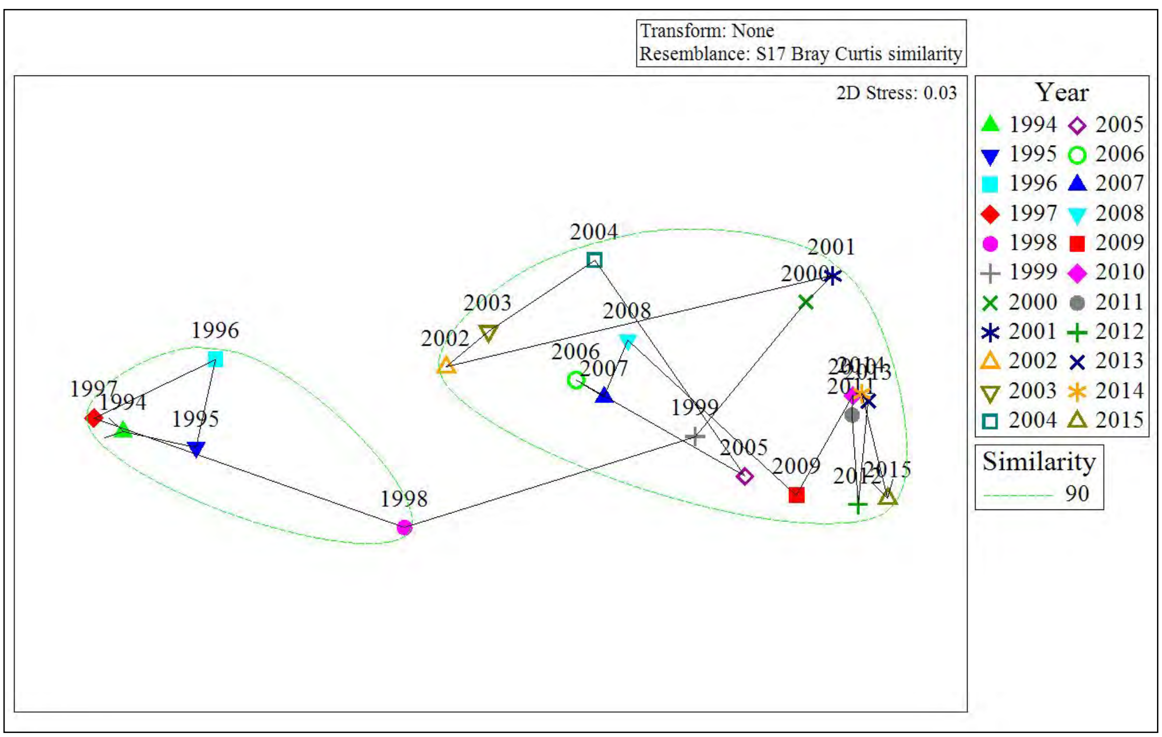


Figure 2.6. Two-dimensional MDS plot based on Bray-Curtis similarities comparing benthic cover analysis from 1994 to 2015 at EFGB and WFGB.

The green circle groups surveys that are 90% similar.

Random Transect Discussion

Despite global coral reef decline in recent decades, mean coral cover at EFGB and WFGB was above 50% for the combined 26 years of continuous monitoring, and represented a stable coral community. However, mean macroalgae percent cover increased significantly between 1998 and 1999, rising from approximately 5% to 20%, and reaching a maximum above 30% in 2012. An inverse relationship between macroalgae and CTB has been observed throughout the monitoring program. However, after 2008 macroalgae was greater than CTB cover, continuing to increase until 2012. These trends suggest that from 1994–1998 the reef community was stable and beginning in 1999 there was a shift as CTB declined and macroalgae cover increased, causing the community to change due to significantly higher macroalgae percent cover. In contrast to other shallow water reefs in the Caribbean region, increases in mean macroalgae cover have not been concomitant with coral cover decline at the Flower Garden Banks (Gardner et al. 2003; Mumby and Steneck 2011; DeBose et al. 2012; Jackson et al. 2014; Johnston et al. 2016b).

This shift in macroalgae cover is consistent with other reefs in the Gulf of Mexico and Caribbean region. Stetson Bank, a series of claystone and siltstone pinnacles covered by a diverse coral and sponge community located 48 km northwest of WFGB, has shown a similar but more pronounced trend (DeBose et al. 2012). Prior to 1999 mean percent coral cover on high relief pinnacles at Stetson Bank ranged from 23–32%, mean sponge cover ranged from 27–39%, and mean macroalgae cover ranged from 13–20%. After 1999, coral and sponge cover decreased to 7% and 16% respectively, while macrolagae increased to 62%, presumably from river nutrient discharge flowing offshore, hurricanes, and thermal stress leading to bleaching events (DeBose et al. 2012). Toth et al. (2014) reported increased macroalgae cover and significant coral decline at study sites in Florida Keys National Marine Sanctuary where mean coral cover had declined from 5% in 1998 to 2% by 2011, likely due to disease, hurricane damage, and thermal stress. Other reefs in the wider Caribbean region are also showing declines largely due to algae competition, overfishing, bleaching, and coral disease (Gardner et al. 2003; Steneck et al. 2011; Jackson et al. 2014).

In contrast, EFGB and WFGB have not shown a decline in coral cover, despite periodic hurricanes and bleaching events (Hagman and Gittings 1992; Dudgeon et al. 2010). In fact, coral cover at the FGB is between 6 to 11 times higher than values estimated for other locations in the Caribbean region (Caldow et al. 2009; Clark et al. 2014). Some possible reasons for the relatively stable condition of the banks include: 1) deep water (17–25 m) that provides a more stable environment than shallow reefs; 2) the remote offshore location (190 km offshore), limiting anthropogenic stressors from coastal runoff; 3) oligotrophic oceanic conditions, and 4) protective federal regulations (Aronson et al. 2005; Johnston et al. 2015a). It should be noted the FGB coral community lacks acroporid corals that contribute to regional decline in coral cover (Aronson et al. 2005).

Despite their remoteness, EFGB and WFGB are not immune to impacts. Climate change, invasive species, storms, and water quality degradation are potential threats (ONMS 2008; Nuttall et al. 2014). As the Gulf of Mexico environment continues to change (Karnauskas et al. 2015), ongoing monitoring will be critical to document ecosystem variation. The relatively high percent coral cover conditions since the beginning of the monitoring program make EFGB and WGB ideal for protection and conservation. Continued monitoring will document changes in the reef community condition compared to the historical baseline, and enable resource managers to make decisions regarding management and research activities focused on the dynamics of the benthic communities and the biota they support.

Chapter 3

REPETITIVE QUADRAT PHOTOSTATIONS

Photo: NOAA FGBNMS/G.P. Schmahl

NOAA diver, Ryan Eckert, photographs a repetitive quadrat photostation at East Flower Garden Bank.

Repetitive Quadrat Photostation Introduction

Permanent repetitive quadrat photostations were photographed to monitor changes in the composition of benthic assemblages in repetitive sites at EFGB and WFGB study sites. The photographs were analyzed to measure percent benthic cover components in 2015 using random-dot analysis.

Repetitive Quadrat Photostation Methods

Repetitive Quadrat Photostation Field Methods

In 2015, thirty-seven and forty-one repetitive quadrats were photographed at EFGB and WFGB, respectively. Each repetitive quadrat photostation was located by SCUBA divers using detailed study site maps and the stations were photographed to document changes in the composition of benthic assemblages at these repetitive sites (Figure 3.1).

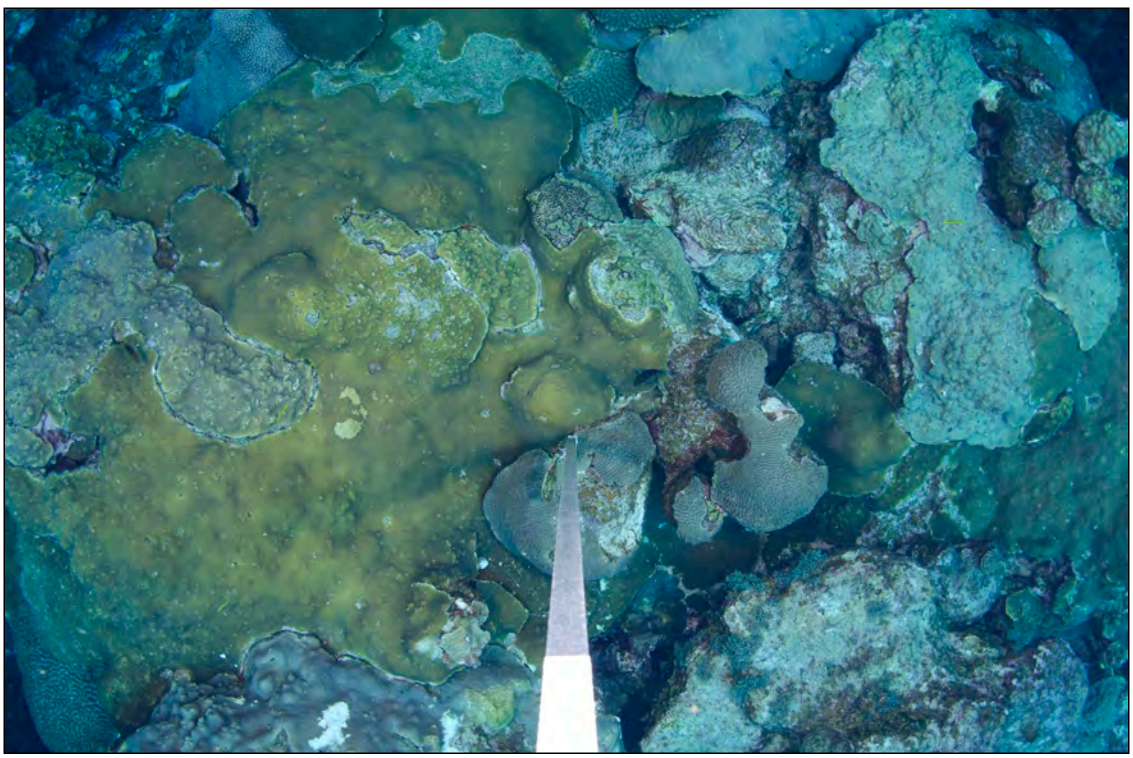


Photo: NOAA FGBNMS/R.J. Eckert

Figure 3.1. Repetitive quadrat photostation #504 at WFGB in 2015.

Stations were photographed using a Nikon® D7000® SLR camera with 16 mm lens in Sea&Sea® housing with small dome port and two Inon Z240® strobes. The camera was mounted in the center of a T-shaped camera frame, at a distance of 2 m from the substrate. To ensure that the repetitive stations were photographed in the same manner each year, the frame was oriented in a north-facing direction and kept vertical using an attached bulls-eye bubble level. This set-up produced images with a coverage of 5 m^2.

Repetitive Quadrat Photostation Data Processing

A total of 100 random dots were overlaid on each photograph and benthic species lying under these points were identified using CPCe, as described in Chapter 2.

Repetitive Quadrat Photostation Analysis

All nonparametric analysis for non-normal data were carried out using Primer® version 6.0, as described in Chapter 2.

Repetitive Quadrat Photostation Results

Repetitive Quadrat Photostation Mean Percent Cover

At EFGB, mean coral cover was recorded above 60% in 2015 (61.50% ± 2.68), and the sponge cover was 0.41% ± 0.14 in all photostations. Mean macroalgae cover was 26.39% ± 2.03, and mean CTB cover was 10.84% ± 0.89. In repetitive quadrat photostations at WFGB, mean coral cover was recorded above 60% in 2015 (63.32% ± 2.07). The sponge cover was 0.26% ± 0.11, mean macroalgae cover was 24.65% ± 1.72, and CTB cover was 10.45% ± 0.81.

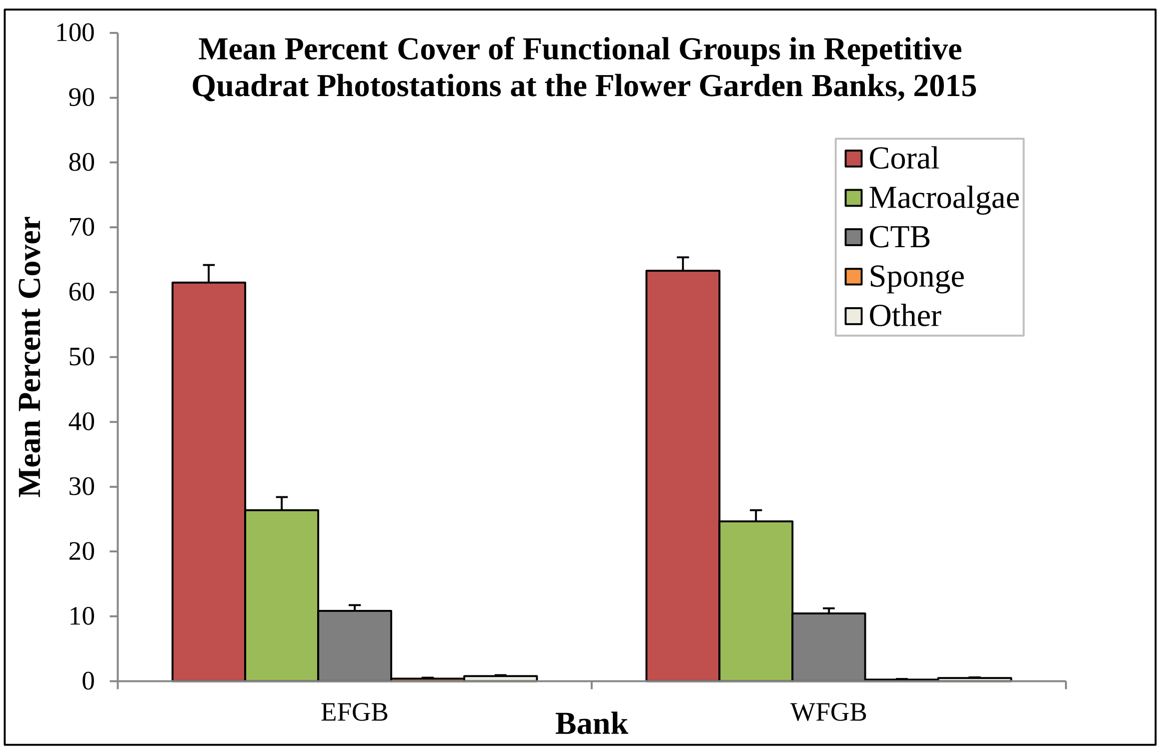


Figure 3.2. Mean percent cover + SE from repetitive quadrat photostation functional groups at EFGB and WFGB in 2015.

Less than 0.1% of the coral cover analyzed was observed to bleach or pale. No signs of isolated or concentrated fish biting were observed and minimal coral disease was observed (0.07%). When compared for differences between banks based on functional groups, no significant dissimilarities were found, suggesting that repetitive photostations at EFGB and WFGB were similar in overall benthic community composition.

A total of 15 species of coral were observed between EFGB and WFGB repetitive quadrat photostations. *Orbicella franksi* was the dominant coral cover component at EFGB (33.36% ± 2.85). *Pseudodiploria strigosa* (10.07% ± 1.92) and *Orbicella faveolata* (6.38% ± 1.46) were the next most abundant species (Figure 3.3). *Orbicella franksi* was also the dominant coral cover component at the WFGB photostations (32.59% ± 2.53). *Pseudodiploria strigosa* (7.87% ± 1.29) and *Porites astreoides* (5.23% ± 0.64) were the next most abundant species (Figure 3.3). Corals that could not be identified (less than 0.4%) because of camera angle or camera distortion were labeled as "unidentified coral." There were no significant differences in coral species composition between banks in the repetitive quadrat photostations.

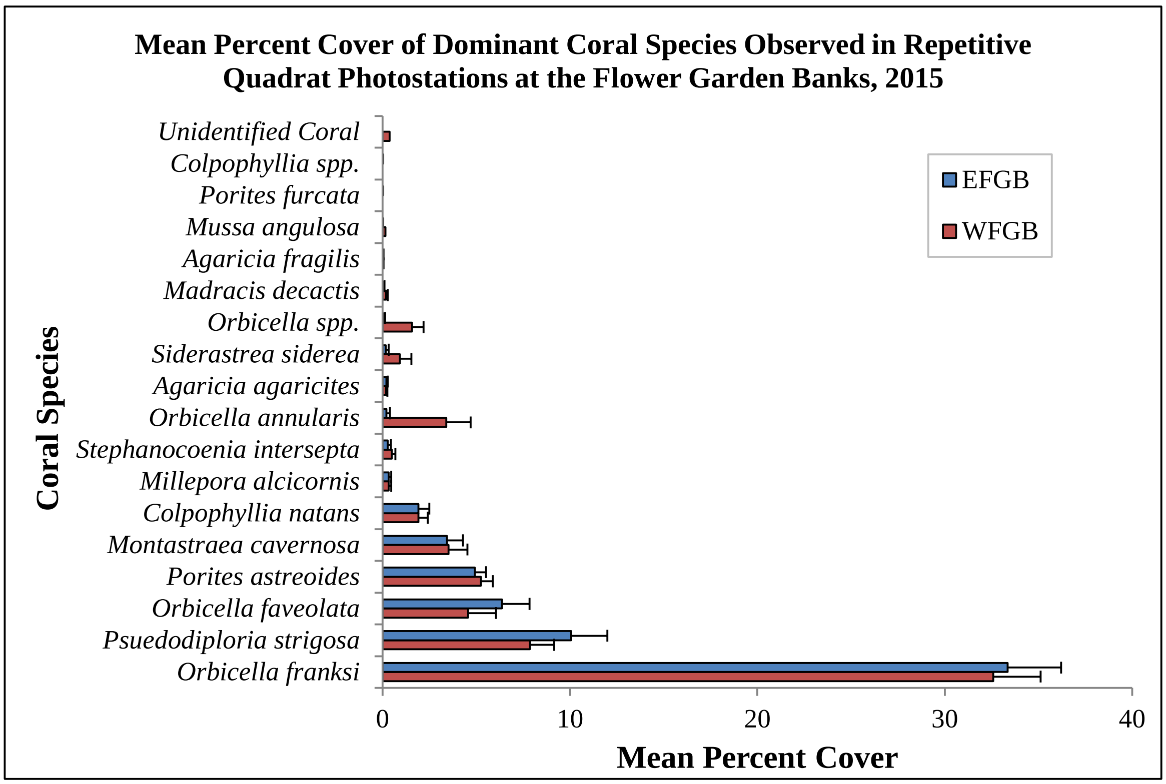


Figure 3.3. Mean percent cover + SE of observed coral species from repetitive quadrat photostations in 2015.

Repetitive Quadrat Photostation Long-Term Trends

The mean percent benthic cover from the repetitive quadrat photostations was analyzed to measure changes over time. Like many long-term monitoring programs, underwater camera setups used to capture benthic cover changed as technology advanced from 35-mm slides and film (1989–2007) to digital still images (2008–2015) (Gittings et al. 1992; CSA 1996; Dokken et al. 1999, 2003; Precht et al. 2006; Zimmer et al. 2010; Johnston et al. 2014; Johnston et al. 2015a, b). From 1989–2009, photographs for each repetitive quadrat photostations encompassed an 8 m^2 area, but changed in 2009 to 5 m^2 due to updated camera equipment.

Mean percent coral cover at EFGB and WFGB repetitive quadrat photostations during the period from 1989–2015 ranged from 45–74%, significantly increasing over time (τ=0.35, p=0.024) (Figure 3.4). Overall mean percent coral cover was approximately 60% at both EFGB and WFGB, and periods of lower CTB cover generally coincided with increases in the macroalgae component (Figure 3.4).

Similar to the random transects, dominant coral species with the greatest mean percent cover were the *Orbicella* species group (43.10%) (primarily *Orbicella franksi*), followed by *Pseudodiploria strigosa* (9.50%) in the repetitive quadrat stations when species level data became available in 2000 (Figure 3.5). There were no significant differences in coral species composition between banks from 2000–2015.

Sponge, macroalgae, and CTB data became available in 2002. Macroalgae, and CTB data cover generally varied inversely, with macroalgae significantly increasing (τ=0.75, p<0.001) over time (Figure 3.4). ANOSIM results comparing benthic cover in repetitive quadrat photostations revealed no significant dissimilarities, suggesting that photostations at EFGB and WFGB were similar to each other in overall benthic community composition from 2002–2015.

Multivariate historical percent cover analysis was compared among years for which appropriate data was available (2002–2015) to evaluate benthic cover change over time. No significant clusters were found in the data. Similar to random transects, increased macroalgae cover was not concomitant with coral cover decline in repetitive quadrat photostations from 2002–2015.

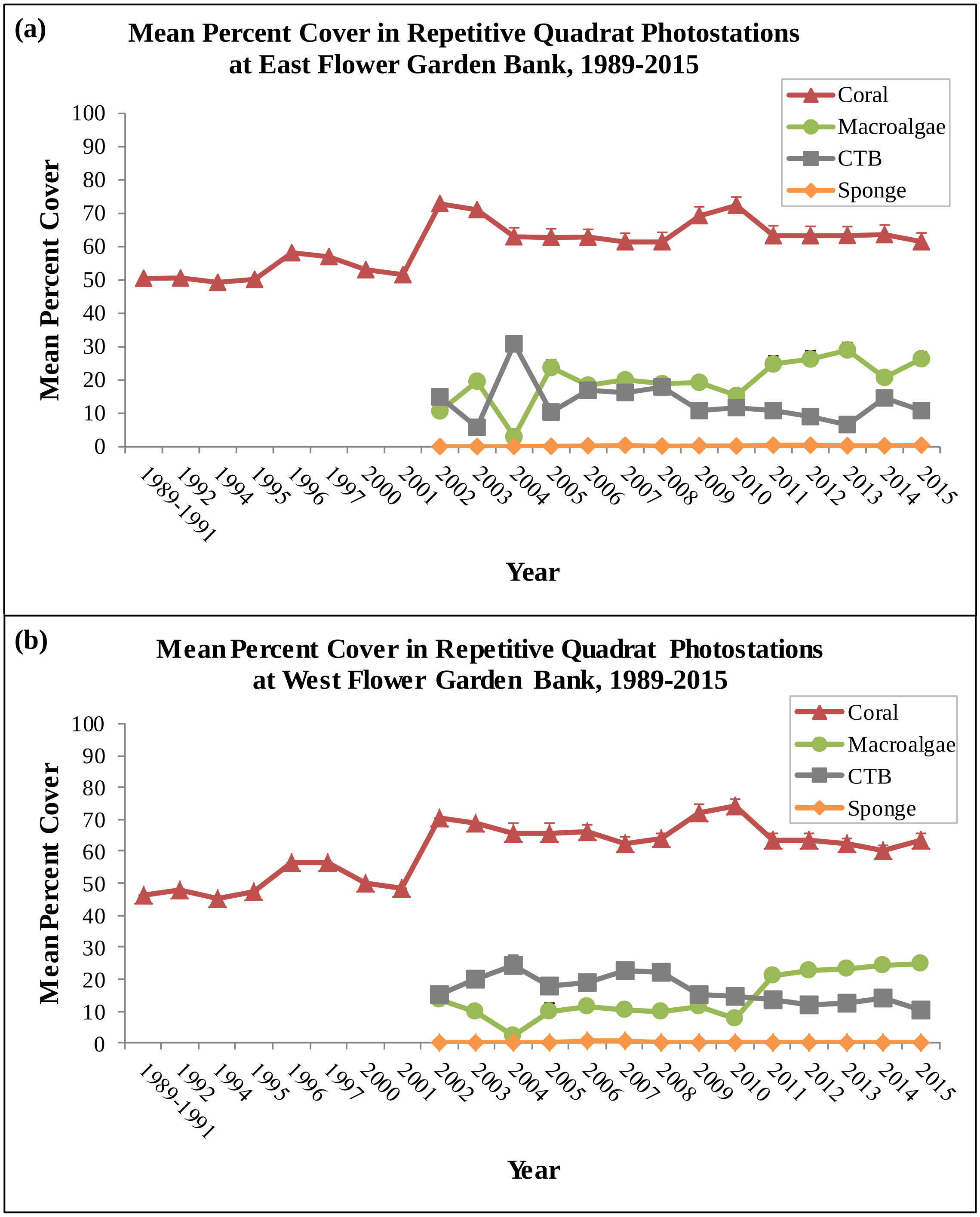


Figure 3.4. Mean percent cover +SE of coral, sponge, macroalgae, and CTB in repetitive quadrat stations at (a) EFGB and (b) WFGB from 1989 to 2015.

Sponge, macrolage, and CTB categories did not begin until 2002. No mean percent cover data were reported in 1993. Data for 1989–1991 from Gittings et al. (1992); 1992–1995 from Continental Shelf Associates, Inc. (CSA) (1996); 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); 2011–2012 (Johnston et al. 2015a); 2013 (Johnston et al. 2014); and 2014 (Johnston et al. 2015b).

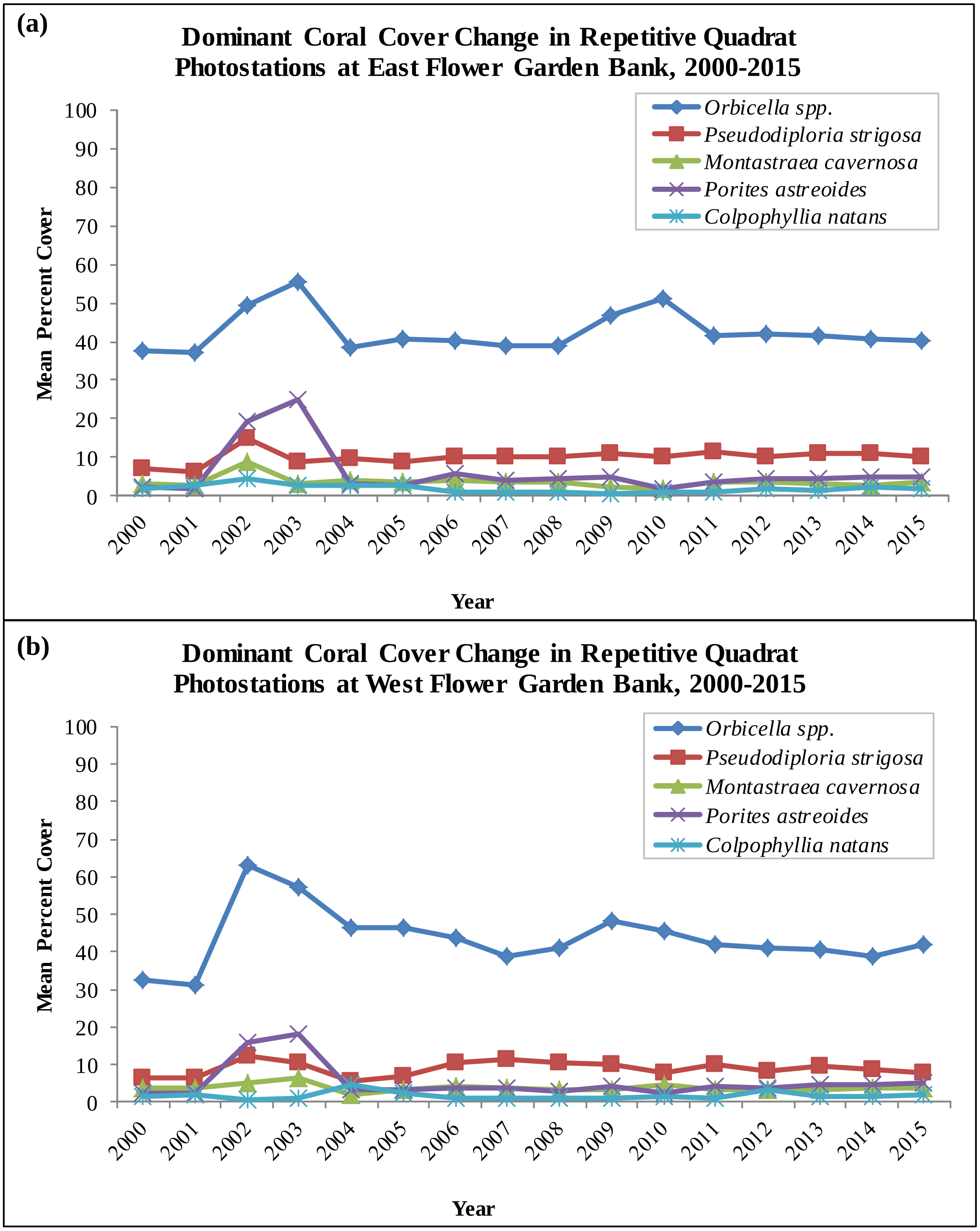


Figure 3.5. Percent cover of dominant coral species in repetitive quadrat photostations at (a) EFGB and (b) WFGB from 2000 to 2015.

The *Orbicella* species group combines *O. franksi*, *O. faveolata*, and *O. annularis*. These separate species have been recognized in recent years, but are grouped to compare with historical data collection methods.

Repetitive Quadrat Photostation Discussion

Greater coral cover estimates were obtained from the repetitive quadrat photostations in comparison to the random transects (62% vs. 56%) at both EFGB and WFGB. 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 habitat with large coral colonies to monitor individual corals.

The majority of the repetitive quadrat photostations have been in place since the beginning of the monitoring program, and display a time series from 1989–2015. Like most stations, in the example from EFGB station 102, overall coral cover increases from 1989–2015 and is in good health during all years (Figure 3.6). Some colonies may appear paler in certain years due to variations in photographic equipment (e.g., 35 mm slides, 35 mm film, and digital photography), because all photos are subject to varying degrees of differing camera settings, lighting, etc., from year to year. Changes include bare substrate to colonization and growth of *Pseudodiploria strigosa* and *Porites astreoides* colonies in the center of the photostations, and algal colonization on a *Pseudodiploria strigosa* head in the lower left corner in 2015, affecting approximately 50% of the colony.

Overall, in repetitive quadrat photostations the most evident patterns were: 1) inverse relationship between CTB and the macroalgae cover, 2) increasing macroalgae cover, and 3) increasing coral cover over time. Despite the higher coral cover in the repetitive quadrats, these stations showed similar trends observed in the random transects, suggesting that monitoring these specific stations may give a representative view of the dynamics of the overall study site, with an increasing trend in algal cover.

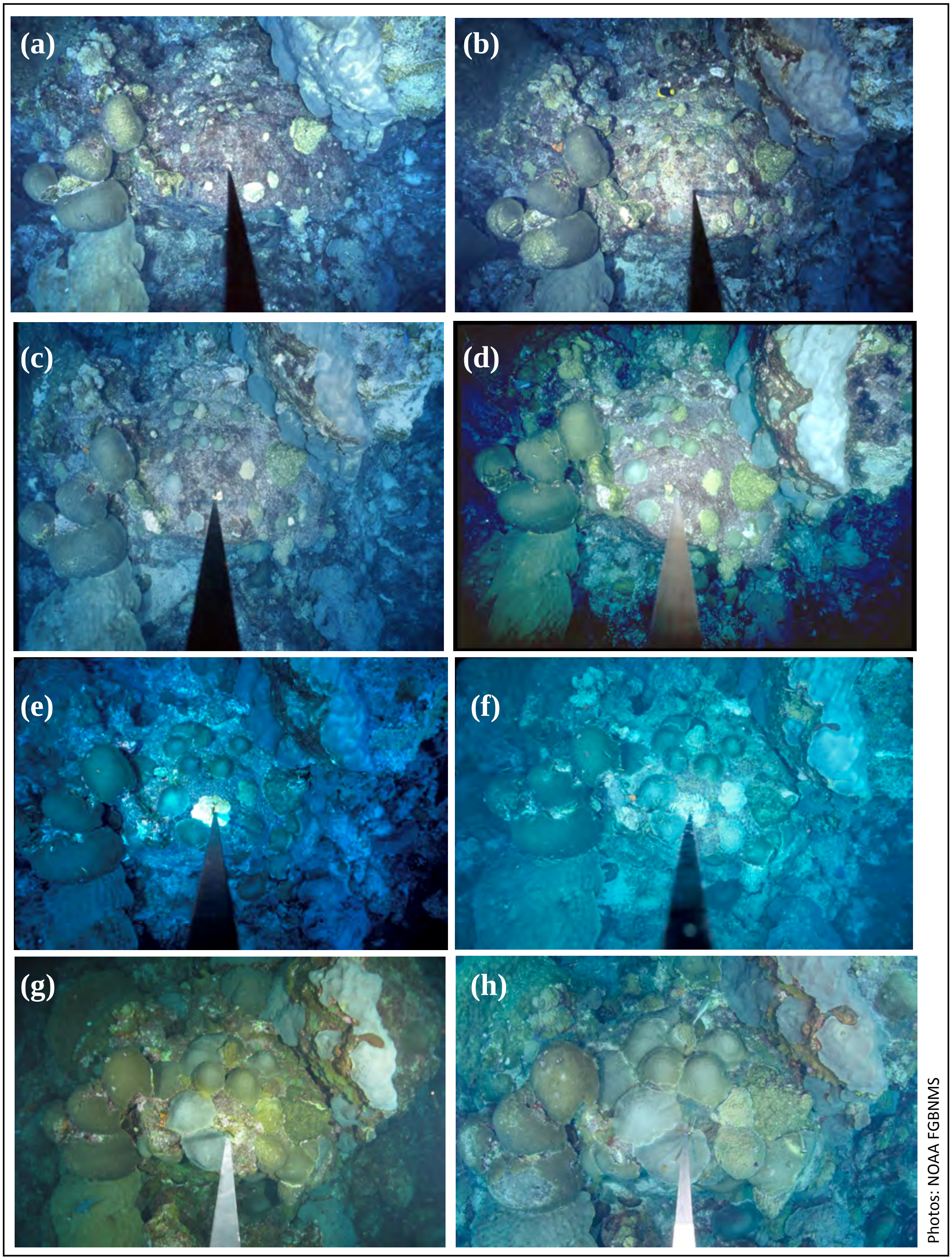


Figure 3.6. Repetitive quadrat photostation #102 from EFGB in a time series showing a growing coral community from (a) 1989; (b) 1992; (c) 1995; (d) 1998; (e) 2002; (f) 2006; (g) 2010; (h) 2015.

Chapter 4

REPETITIVE DEEP PHOTOSTATIONS

Photo: NOAA FGBNMS/R.J. Eckert

Repetitive deep photostation #7 at East Flower Garden Bank in 2015.

Repetitive Deep Photostation Introduction

Permanent repetitive deep photostations were photographed to compare to the benthic composition of the shallower repetitive quadrat photostations. The deep repetitive photostations were located outside the EFGB and WFGB study sites, ranging from 24–40 m depths. EFGB deep repetitive stations were established in 2003 and WFGB deep repetitive stations were established in 2012. The photographs were analyzed to measure percent benthic cover components in 2015 using random-dot analysis.

Repetitive Deep Photostation Methods

Repetitive Deep Photostation Field Methods

Eleven repetitive deep photostations at EFGB were located outside the study site (east of buoy#2), ranging in depth from 32–40 m 9 (Figure 1.5). Twelve repetitive deep photostations were located outside the study site at WFGB near buoy #2. The stations were located 78 m north of the mooring at depths between 24–38 m (Figure 1.6). Each deep photostation was located by SCUBA divers using detailed maps and photographed annually (see methods in Chapter 3) to monitor changes in the composition of benthic assemblages (Figure 4.1).

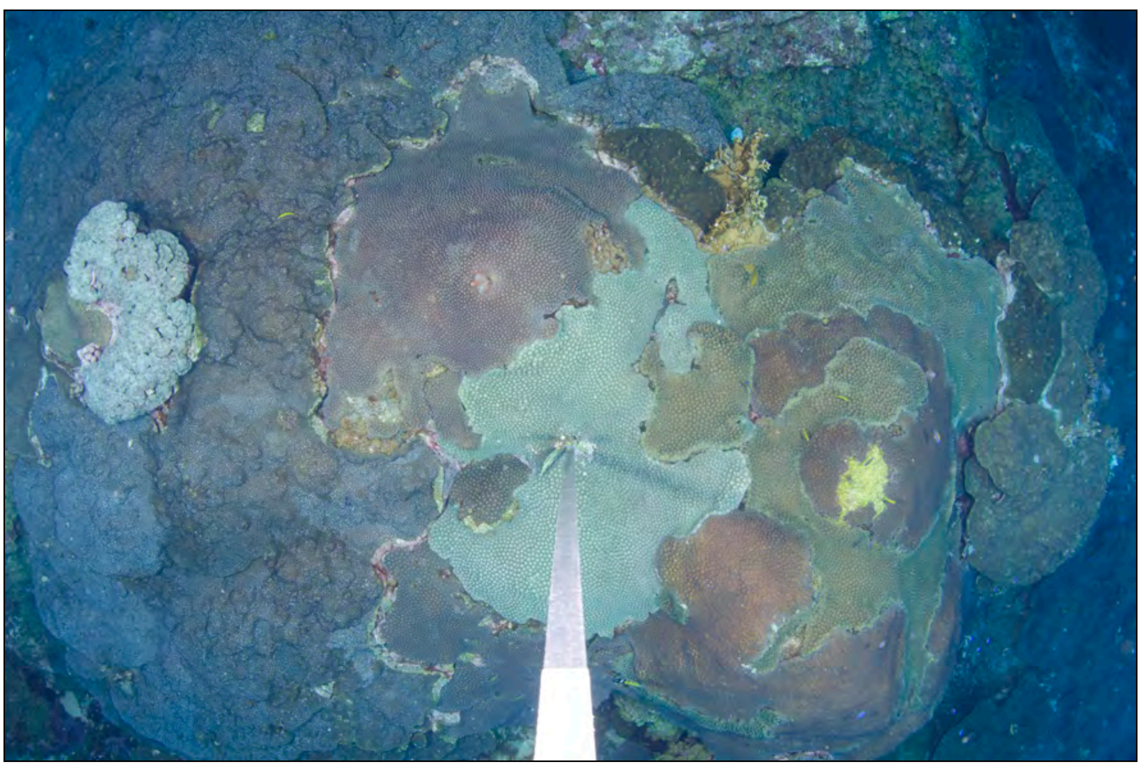


Photo: NOAA FGBNMS/R.J. Eckert

Figure 4.1. Repetitive deep photostation #4 at EFGB in 2015.

Repetitive Deep Photostation Data Processing

A total of 100 random dots were overlaid on each photograph and benthic species lying under these points were identified using CPCe, as described in Chapter 2.

Repetitive Deep Photostation Analysis

All nonparametric analysis for non-normal data were carried out using Primer® version 6.0, as described in Chapter 2.

Repetitive Deep Photostation Results

Repetitive Deep Photostation Mean Percent Cover

The major benthic cover component of the repetitive deep photostations was coral (73%), followed by macroalgae (20%), CTB (6%), and sponge cover (0.4%) (Figure 4.2). The coral cover analyzed exhibited no signs of disease, and less than 0.5% was observed to pale. At EFGB, mean coral cover was 72.42% ± 3.67, and sponge cover was 0.49% ± 0.22. Macroalgae cover was 19.76% ± 3.19 and CTB cover was 7.03% ± 0.94 (Figure 4.2). At WFGB, mean coral cover was 74.27% ± 5.06 and sponge cover was 0.29% ± 0.15. Mean macroalgae cover was 19.68% ± 4.92 and CTB cover was 4.74% ± 0.57 (Figure 4.2). When compared for differences between banks based on functional groups, no significant dissimilarities were found, suggesting that EFGB and WFGB repetitive deep photostations were similar in overall benthic community composition.

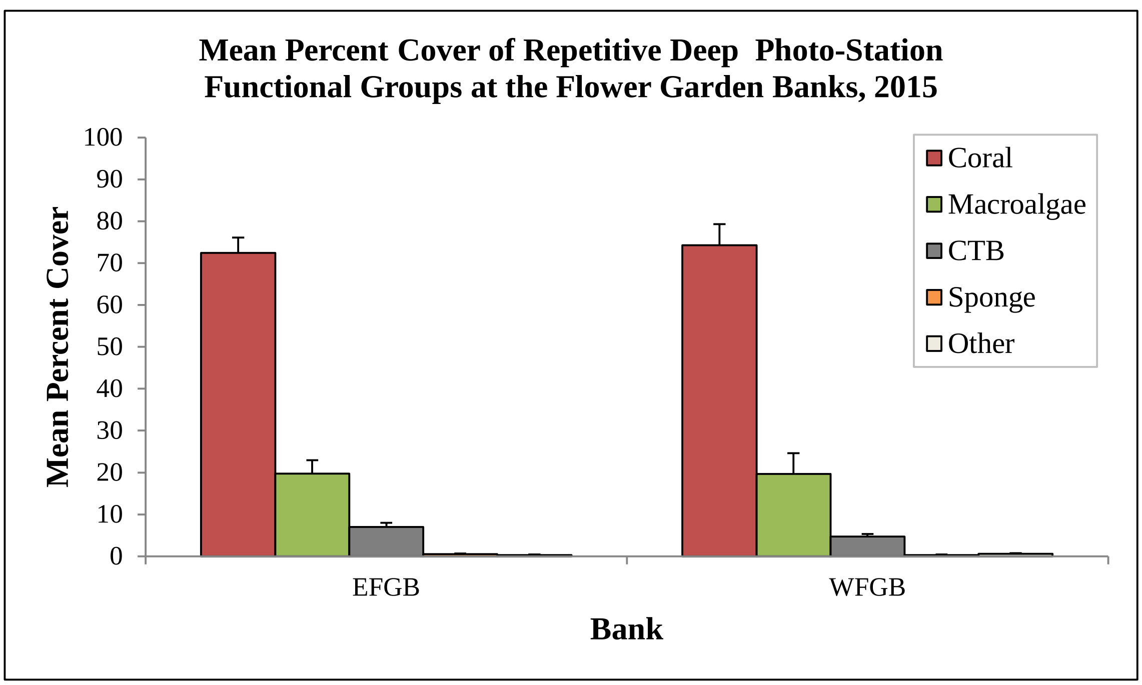


Figure 4.2. Repetitive deep photostation functional group mean percent cover +SE at the FGB in 2015.

Orbicella franksi was the dominant mean coral cover component (36.68% ± 4.65) at the EFGB repetitive deep photostations, and *Montastraea cavernosa* (16.00% ± 4.58) was the next dominant deep station coral species at EFGB. This was followed by *Colpophyllia natans* (8.42% ± 3.18) and *Madracis auretenra* (3.22% ± 2.40) (Figure 4.3).

At the WFGB repetitive deep photostations in 2015, *Orbicella franksi* was the main coral cover component (35.59% ± 7.08). *Montastraea cavernosa* (18.77% ± 4.69) was the next dominate repetitive deep photostation coral at WFGB, which was followed by *Stephanocoenia intersepta* (8.30% ± 3.33) and *Madracis auretenra* (4.29% ± 2.91) (Figure 4.3). There were no significant differences in coral species composition between banks in the repetitive deep photostations.

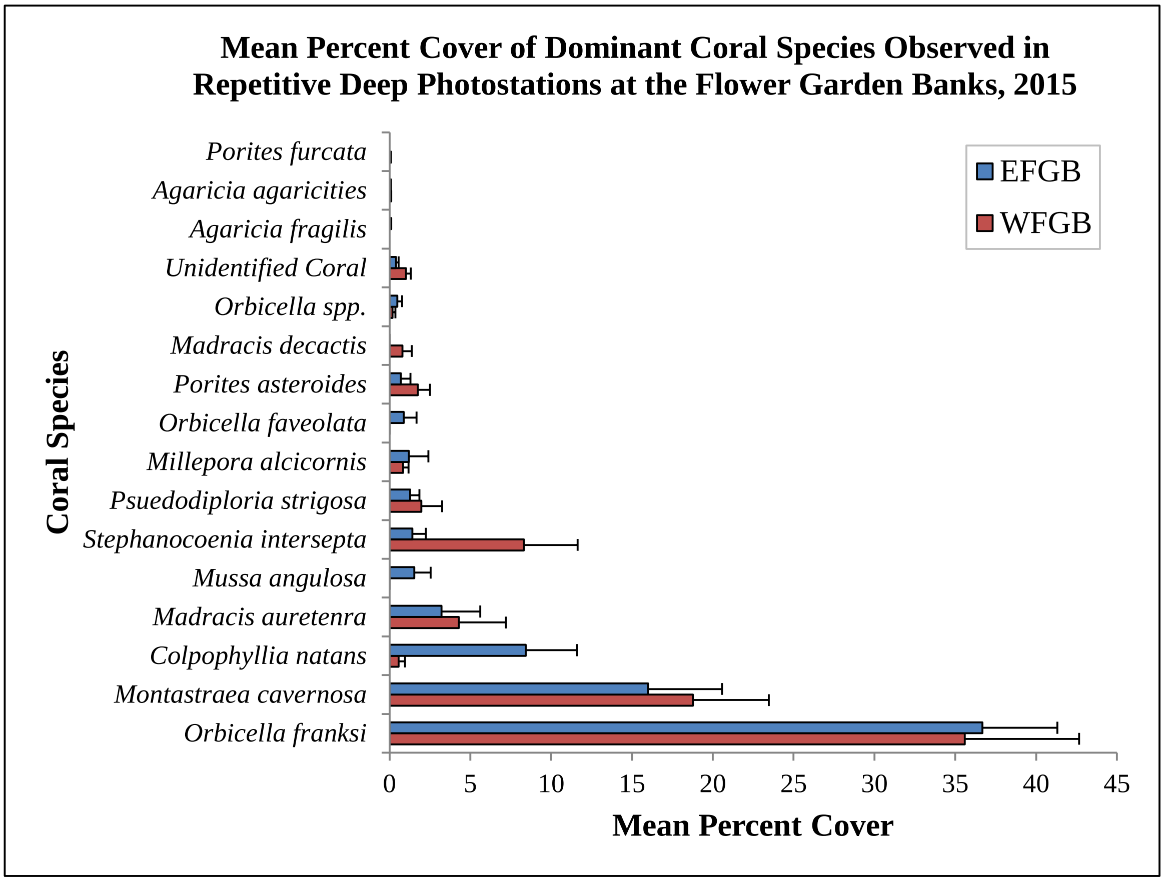


Figure 4.3. Mean percent cover + SE of dominant corals observed in repetitive deep photostations at EFGB and WFGB in 2015.

Repetitive Deep Photostation and Repetitive Quadrat Shallow Station Comparison

The mean percent coral cover was higher in the repetitive deep photostations (Deep Stations, or DS) when compared to the repetitive quadrat shallow photostations (Shallow Stations, or SS); averaging 73% at the deep stations and 60% at the shallow stations in the study sites. Mean deep station macroalgae cover for both banks was 20%, while the shallow station macroalgae cover was 26% in 2015. Mean percent CTB cover at the deep stations was 6% and the mean CTB cover at the repetitive shallow stations was 11%. Mean percent sponge cover was below 0.5% for both the deep and shallow repetitive stations (Figure 4.4).

When compared for differences between banks and depth based on percent cover, a significant difference occurred between depths (*Global R*=0.134, *p*=3.2%), suggesting that EFGB and WFGB repetitive deep photostations are significantly different in overall benthic community composition than the shallow repetitive quadrat stations.

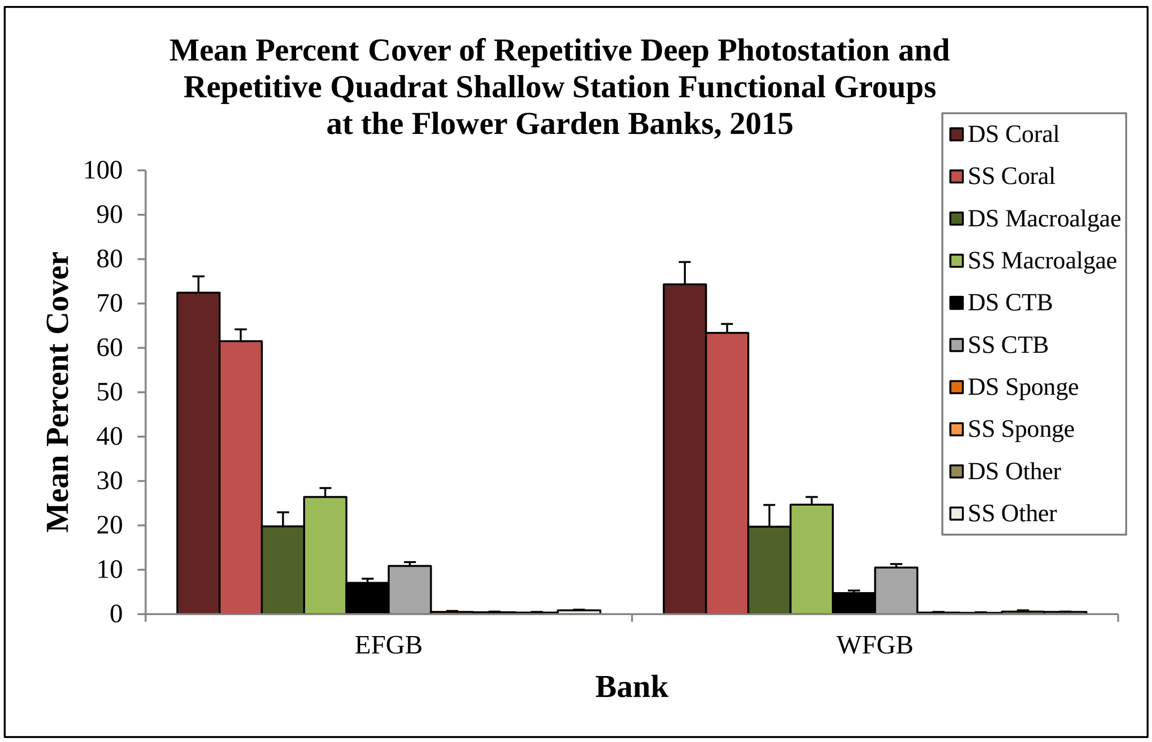


Figure 4.4. Repetitive deep photostation (DS) and repetitive quadrat shallow photostation (SS) functional group mean percent cover + SE at the FGB in 2015.

Repetitive Deep Photostation Long-Term Trends

The mean percent benthic cover from the repetitive deep photostations was analyzed to measure changes over time. Like many long-term monitoring programs, underwater camera setups used to capture benthic cover changed as technology advanced from 35-mm film (2003–2007) to digital still images (2008–2015) (Precht et al. 2006; Zimmer et al. 2010; Johnston et al. 2014; Johnston et al. 2015a, b). From 2003–2009, photographs for each repetitive deep photostation encompassed an 8 m^2 area, but changed in 2009 to 5 m^2 due to updated camera equipment.

Mean percent coral cover in the repetitive deep photostations was approximately 76% during the period from 2003–2015 at EFGB; ranging from 72–86% (Figure 4.5). CTB significantly decreased over time (τ=-0.513, p=0.017), coinciding with macroalgae that significantly increased over time (τ=0.564, p=0.009). Overall, the most noticeable pattern was the inverse relationship between CTB components and macroalgae cover, with increased macroalgae cover starting in 2011, and remaining approximately 20% until 2015. This pattern between CTB and macrolagae is similar to the random transects and repetitive quadrats in the study sites on the shallower portion of the reef cap.

Multivariate historical percent cover analysis was compared among years when appropriate data was available (2003–2015) to evaluate benthic cover change over time at EFGB. SIMPROF tests from cluster analysis resulted in two significant (π=0.577, p=3.7%) clusters (90% similar). The data suggests benthic communities at the EFGB repetitive deep stations were similar from 2003–2004; a significant shift in community composition occurred in 2005 that has persisted to 2015 (Figure 4.6). SIMPER analysis identified that for most comparisons from 2003–2015, the greatest contributors to the observed dissimilarity were macroalgae and coral. Similar to random transects, increased macroalgae cover was not concomitant with significant coral cover decline in repetitive quadrat photostations from 2003–2015.

In 2012, twelve deep stations were established at WFGB. The mean coral cover in WFGB deep station quadrats was 74% from 2012–2015, ranging from 72–77% (Figure 4.5). Since 2012, macroaglae has ranged from 14–21% and CTB has ranged from 5–7%. Sponge cover was approximately 1% from 2012–2015. No significant clusters were found in the data, suggesting that the benthic communities in the WFGB repetitive deep stations were similar from 2012–2015.

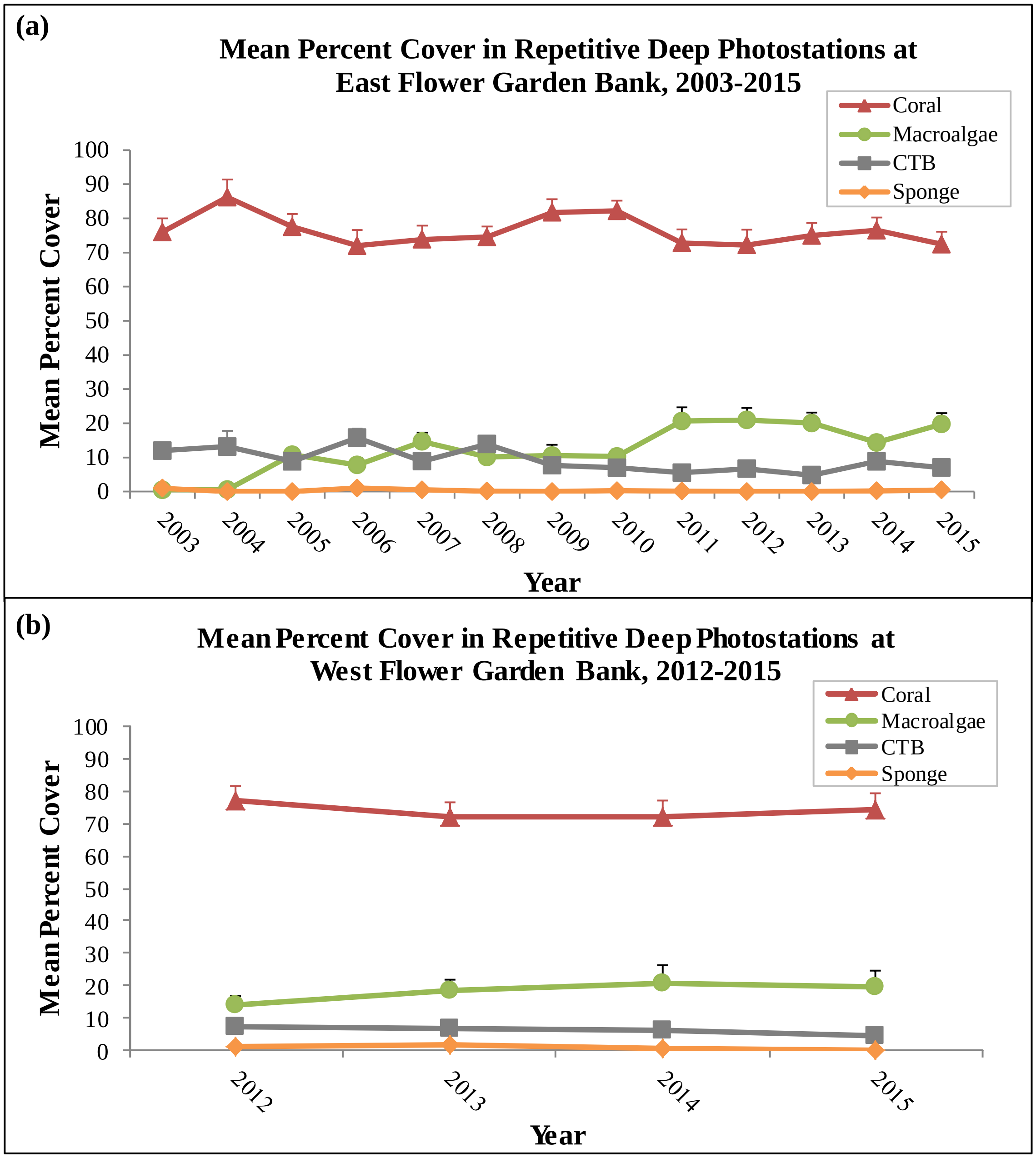


Figure 4.5. Repetitive deep photostation mean percent cover of coral, sponge, macroalgae, and CTB at (a) EFGB and (b) WFGB in 2015.

Data for 2003–2008 from PBS&J (Precht et al. 2006, 2008b) and FGBNMS for 2009–2010 (Johnston et al. 2013); 2011–2012 (Johnston et al. 2015a); 2013 (Johnston et al. 2014), and 2014 (Johnston et al. 2015b).

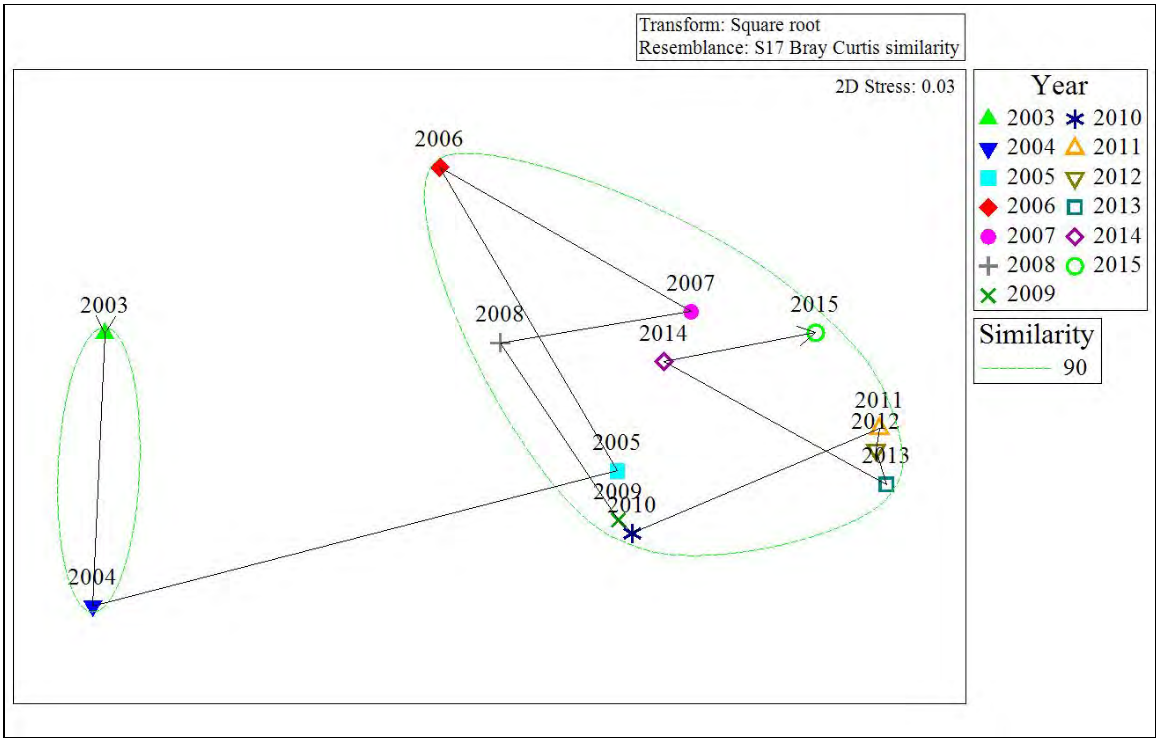


Figure 4.6. Two-dimensional MDS plot based on Bray-Curtis similarities comparing benthic cover analysis from 2003 to 2015 at EFGB.

The green circle groups surveys that are 90% similar.

The dominant coral species with the greatest mean percent cover over time were the *Orbicella* species group (primarily *Orbicella franksi*) in the repetitive deep stations at EFGB and WFGB (Figure 4.7). Differing from the random transects and shallow repetitive quadrat photostations, *Montastraea cavernosa* was the second most dominant species over time. SIMPROF tests from cluster analysis resulted in several significant (π=2.04, p=0.1%) clusters (90% similar) at EFGB (Figure 4.8). SIMPER analysis identified that for most comparisons from 2003–2015, the greatest contributor to the observed dissimilarity was the *Orbicella* species group, which decreased significantly over time (τ=-0.564, p=0.009). One cluster resulted at WFGB, suggesting that coral community did not change over time.

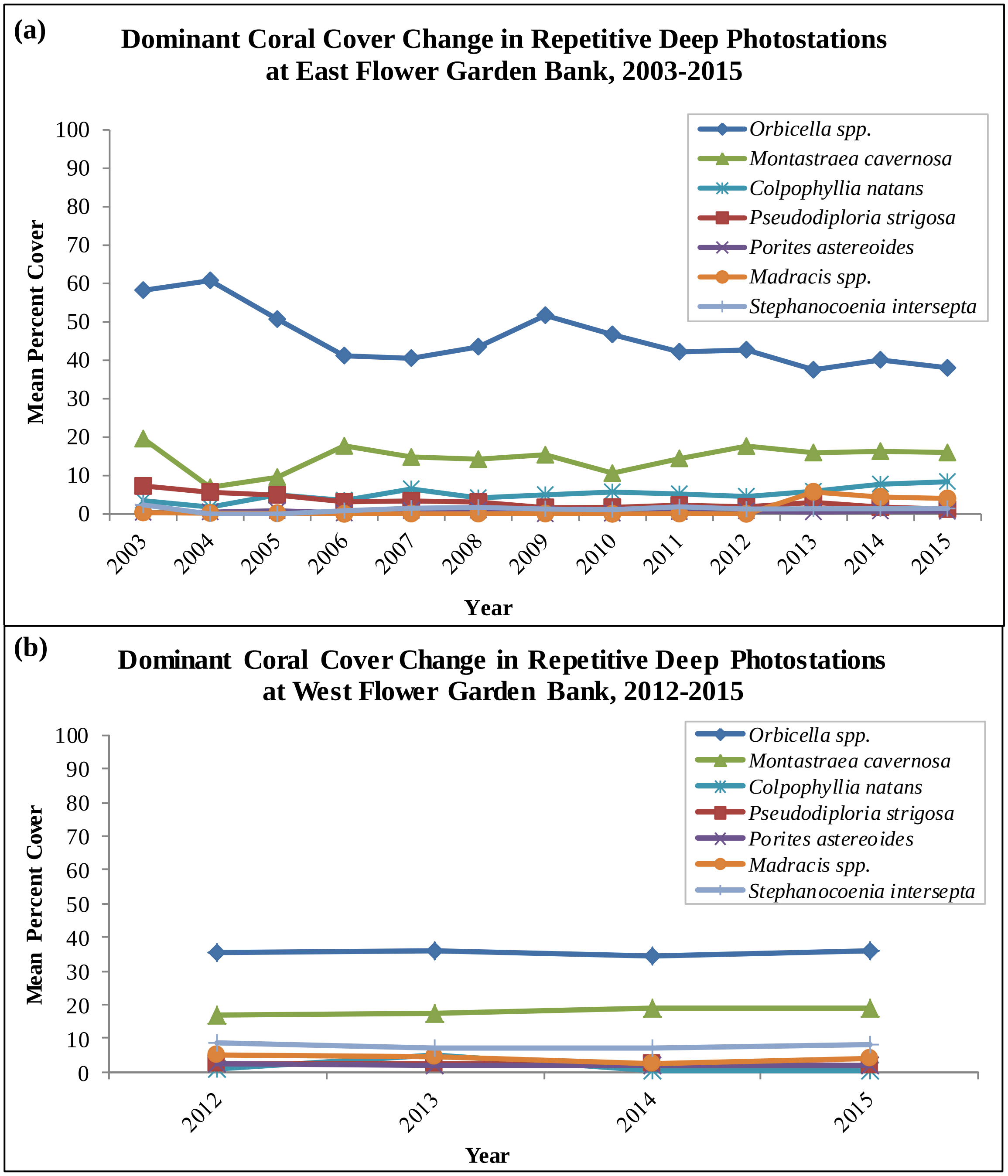


Figure 4.7. Percent cover of dominant coral species in repetitive deep photostations at (a) EFGB and (b) WFGB over time.

The *Orbicella* species group combines *O. franksi*, *O. faveolata*, and *O. annularis*. These separate species have been recognized in recent years, but are grouped to compare with historical data collection methods.

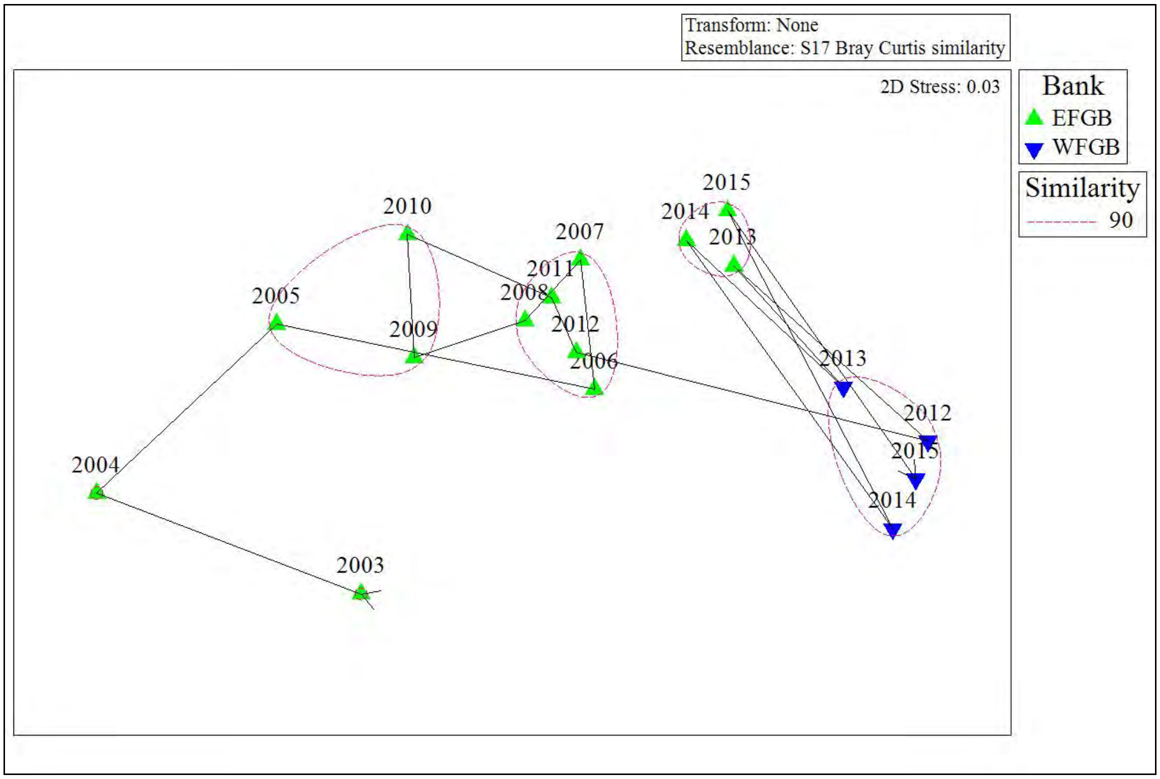


Figure 4.8. Two-dimensional MDS plot based on Bray-Curtis similarities comparing coral cover analysis from 2003 to 2015 at EFGB and 2012 to 2015 at WFGB.

The pink circle groups surveys that are 90% similar.

Repetitive Deep Photostation Discussion

Higher mean coral cover estimates (73%) were obtained from the repetitive deep photostations than were obtained from the shallower repetitive quadrats (60%) and the random transects (56%). Higher percent mean coral cover in the repetitive deep photostations relative to repetitive quadrats and random transects has also been documented in previous reports (Precht et al. 2006, 2008b; Zimmer et al. 2010; Johnston et al. 2013; Johnston et al. 2015a, b). The deep stations were dominated by *Orbicella franksi* (similar to the random transects and shallow repetitive photostations); however, *Montastraea cavernosa* was the second-most dominant coral species, unlike the shallower study sites.

A noticeable difference between EFGB and WFGB repetitive deep photostations and the shallower repetitive quadrat photostations was the lack of *Orbicella annularis* cover at the deeper depths and decreased occurrence of *Pseudodiploria strigosa*. *Stephanocoenia intersepta* and *Madracis* species were also more abundant in the repetitive deep stations compared to shallower sites. Macroalgae cover, while still less than shallower sites, increased over time following a similar pattern to the increasing macroalgae cover in the repetitive quadrat photostations and random transects.

Repetitive quadrat photostations display a time series from 2004–2015 (Figure 4.9). Like most repetitive deep photostations, in the example from EFGB station D7, the overall coral community appears to be stable from 2004–2015 and in good health during all years (Figure 4.9). Some colonies may appear paler in certain years due to variations in photographic equipment, because all photos are subject to varying degrees of differing camera settings, lighting, etc. The first photo from 2004 was taken in a different orientation than the rest of the photographs. The large *Montastraea cavernosa* colonies in the center of the photographs appear to gain tissue over the years, and the margin of the *Colpophyllia natans* colony on the left side of the photographs appears to grow closer to the *Montastraea cavernosa* colonies.

As with both the repetitive quadrat photostations and random transects, periods of increased algae cover generally coincided with decreases in the CTB category. Overall, the most noticeable patterns were: 1) inverse relationship between CTB and macroalgae cover, 2) increasing macroalgae cover, and 3) mean coral cover above 70% over time.

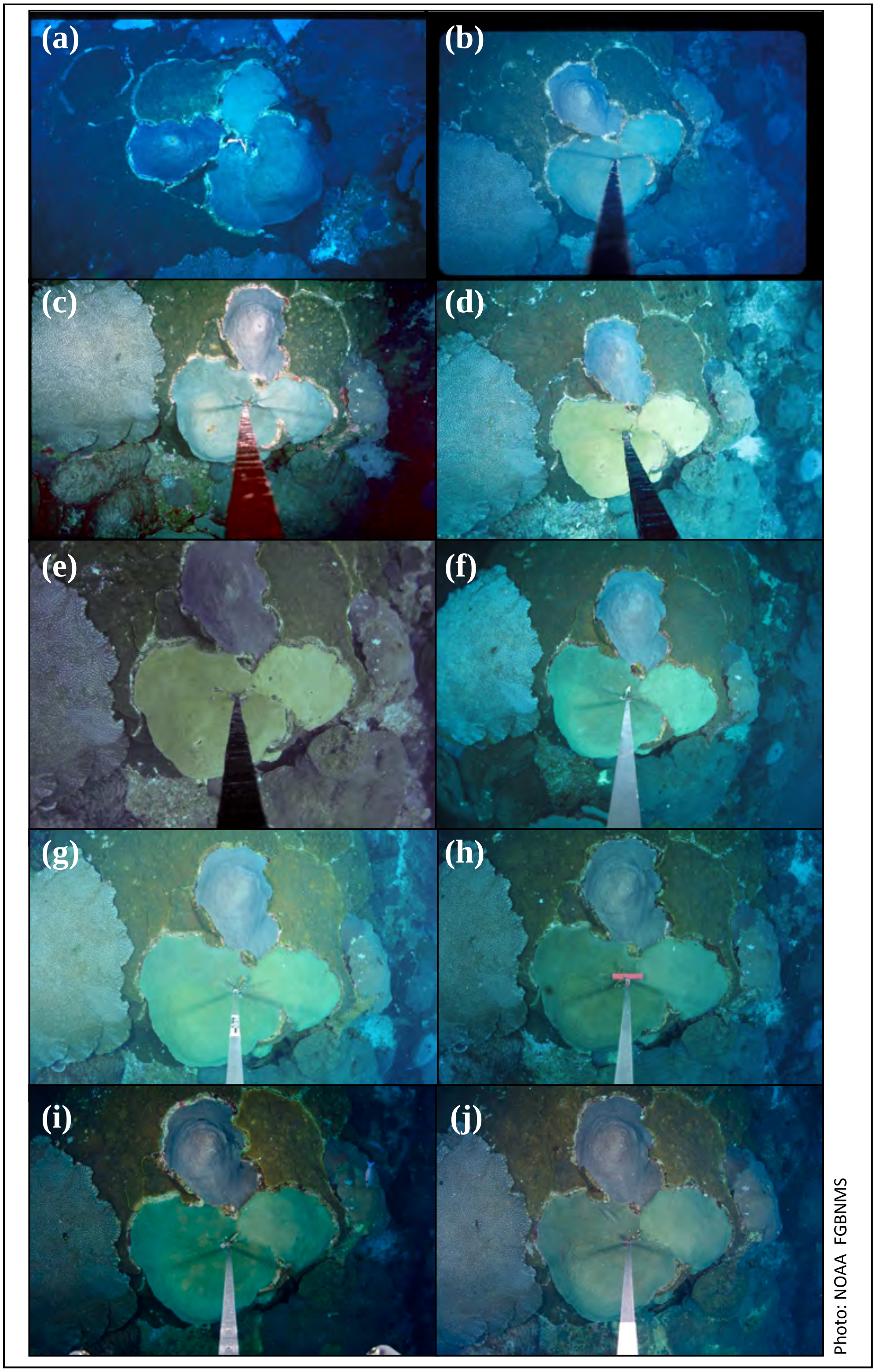


Figure 4.9. Repetitive deep photostation #D7 from EFGB in a time series showing a healthy and stable coral community from (a) 2004; (b) 2006; (c) 2007; (d) 2008; (e) 2009; (f) 2010; (g) 2011; (h) 2012; (i) 2013; and (j) 2015. No photos available for 2003 or 2005.

Chapter 5

FISH SURVEYS

Photo: NOAA FGBNMS/M.F. Nuttall

A Giant Manta and schooling Bonnetmouth swim over the coral reef at East Flower Garden Bank, 2015.

Fish Surveys Introduction

To examine fish population composition and changes over time, stationary visual fish surveys were conducted in the study sites at EFGB and WFGB. These surveys are used to characterize and compare fish assemblages between habitat types and years. Fish surveys were added to the long-term monitoring protocol in 2002.

Fish Surveys Methods

Fish Surveys Field Methods

Fishes were visually assessed by SCUBA divers using a modified Bohnsack and Bannerot (1986) stationary visual fish survey technique. Twenty-four randomly located surveys were conducted at both EFGB and WFGB, and each survey represents one sample. Observations of fishes were restricted to an imaginary cylinder with a radius 7.5 m from the diver, extending to the surface (Figure 5.1).

Photo: NOAA FGBNMS/G.P. Schmahl

Figure 5.1. NOAA diver, Marissa Nuttall, conducting a fish survey at East Flower Garden Bank.

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 size bins). Size was binned into eight groups; 0–5 cm, 5–10 cm, 10–15 cm, 15–20 cm, 20–25 cm, 25–30 cm, 30–35 cm, and >35 cm, where each individuals estimated total length was recorded. Each survey required 15–20 minutes to complete. 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. Fish survey dives began in the early morning (after 0700 CDT), and were repeated throughout the day until dusk.

Fish Surveys Data Processing

Fish survey data was entered into a Microsoft® Excel® database by the surveyor. Entered data was checked for quality and accuracy prior to processing. For each entry, fish family, trophic guild, and biomass were recorded. Species were classified into 'primary' trophic guilds: herbivores (H), piscivores (P), invertivores (I), and planktivores (PL).

Fish Surveys 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. 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. Species accumulation curves were generated, 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 biomass was computed by converting length data to weights using the allometric length-weight conversion formula:

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

where W = individual weight (grams), L = length of fish (cm), and α and β are constants for each species generated from the regression of its length and weight, derived from Froese and Pauly (2014) and Bohnsack and Harper (1988). Because lengths for every individual fish were not recorded, mean total lengths for each species size categories were used. A mean species-biomass per unit area estimate (g/100 m^2) was calculated. Biomass and species accumulation plots were generated to make overall assessments of the fish community at EFGB and WFGB. Observations of manta rays, sting rays, and eels were removed from all biomass analyses due to their rare nature and large size.

Statistical analyses were conducted on square root transformed density and biomass data using Primer® version 6.0 (Anderson et al. 2008). Species composition differences between banks were analyzed by converting to ecological distance using Bray-Curtis similarity matrices. SIMPER was used to analyze community dissimilarity between banks and highlight species that contributed greatly to the observed dissimilarity. Cluster analyses were performed on similarity matrices, with SIMPROF tests, to identify significant (α=0.05) clusters within the data. MDS plots, 100 random starting configurations to minimize stress, were generated to examine for evidence of community differences between banks. Community differences were then compared for significant differences using ANOSIM. The R statistic, typically ranging between 0 and 1, indicates between and within group dissimilarities, where small R values (<0.25) indicate that similarities between sites and within sites are indistinguishable (Clarke & Warwick 2001).

For family analysis, percent coefficient of variation (CV%) was calculated to determine the power of the analyses. CV% was calculated using the following formula:

$$CV\% = SE/\bar{\bar{X}}$$

where SE = standard error and $\bar{\bar{X}}$ = population mean. A CV% of 20% or lower is considered good, as it would be able to statistically detect a minimum change of 40% in the population within the survey period.

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 for parametric data, including w-values. Students t-test were used for pair-wise comparisons with the statistical software R version 3.2.0.

Fish Surveys Results

A total of 27 families and 77 species were recorded in 2015 for all samples combined. Overall, mean species richness (± standard error) was 20.13 ± 0.66, and similar between banks, with 20.21 ± 0.84 at EFGB and 20.04 ± 1.06 at WFGB. In 2015, Bonnetmouth (*Emmelichthyops atlanticus*) were the most abundant species overall, followed by Bluehead (*Thalassoma bifasciatum),* Brown Chromis (*Chromis multilineata*), and Creole Wrasse (*Clepticus parrae*) at both banks (Figure 5.2).

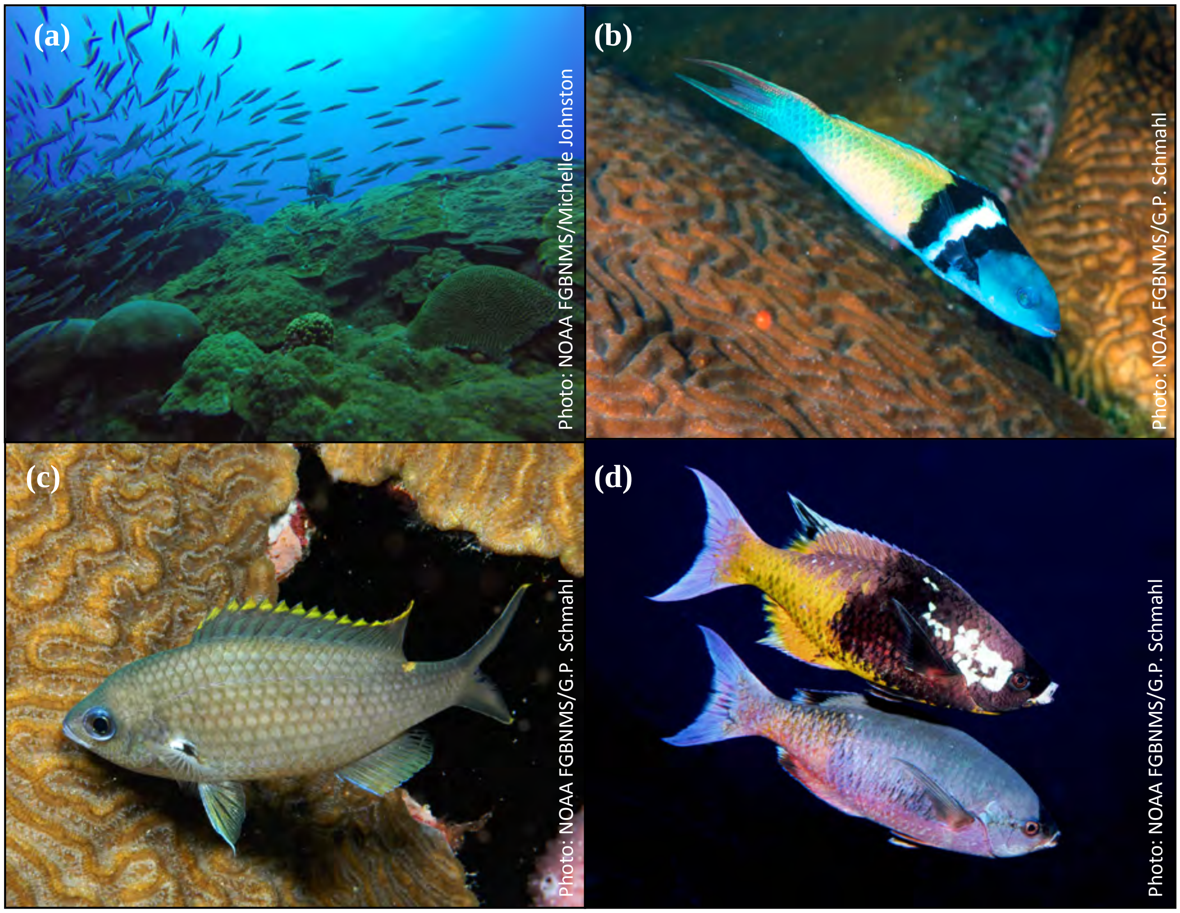


Figure 5.2. Most abundant fish species in 2015: (a) Bonnetmouth, (b) Bluehead, (c) Brown Chromis, and (b) Creole Wrasse.

Sighting Frequency and Occurrence

The most frequently sighted species from both banks was the Brown Chromis, observed in 98% of all surveys. Other frequently sighted species include Bicolor Damselfish (*Stegastes partitus*), Bluehead, and Blue Tang (*Acanthurus coeruleus*) (Table 5.1). Most shark and ray species were considered "rare" (occur in <20% of all surveys) (REEF 2014). While no shark species were recorded, manta rays (*Manta spp.*) were observed in 8% of surveys at EFGB. No sharks or mantas were observed at WFGB.

Table 5.1. Top 10 most frequently sighted species by bank, including sighting frequency for all surveys.

Species ID **Family Name: Species Name (Common Name)**	**2015**		**All Surveys**
	EFGB	**WFGB**	
Pomacentridae*: Chromis multilineata* (Brown Chromis)	100.00	95.83	97.92
Pomacentridae: *Stegastes partitus* (Bicolor Damselfish)	95.83	95.83	95.83
Labridae: *Thalassoma bifasciatum* (Bluehead)	87.50	100.00	93.75
Acanthuridae: *Acanthurus coeruleus* (Blue Tang)	83.33	87.50	85.42
Tetraodontidae: *Canthigaster rostrata* (Sharpnose Puffer)	87.50	79.17	83.33
Epinephelidae: *Paranthias furcifer* (Atlantic Creolefish)	62.50	100.00	81.25
Balistidae: *Melichthys niger* (Black Durgon)	66.67	83.33	75.00
Labridae: *Sparisoma viride* (Stoplight Parrotfish)	66.67	79.17	72.92
Pomacentridae: *Stegastes planifrons* (Threespot Damselfish)	66.67	70.83	68.75
Pomacentridae: *Chromis cyanea* (Blue Chromis)	83.33	54.17	68.75

Species Density

Mean fish density (abundance/100 m^2 ± standard error) was 302.04 ± 41.36 at EFGB and 256.51 ± 34.54 at WFGB. The higher fish density at EFGB was caused by greater local abundance of Bonnetmouth.

Trophic Group Analysis

Species were grouped by trophic guild into four major categories, as defined by NOAA's Center for Coastal Monitoring and Assessment (CCMA) BioGeography Branch fish-trophic level database: herbivores, piscivores, invertivores, and planktivores (Caldow et al. 2009). Size-frequency distributions, using the relative abundance, were graphed for each trophic guild. At both EFGB and WFGB, invertivores were dominated by smaller individuals (<5 cm and 5-10 cm). Piscivores were dominated by either small (<5 cm and 5-10 cm) or large individuals (>35 cm) (Figure 5.3). Planktivores displayed a normal distribution at both banks, with the majority of individuals of moderate size (15-25 cm). Herbivore size distribution was variable, with a slight trend for larger (25-35 cm) individuals (Figure 5.3).

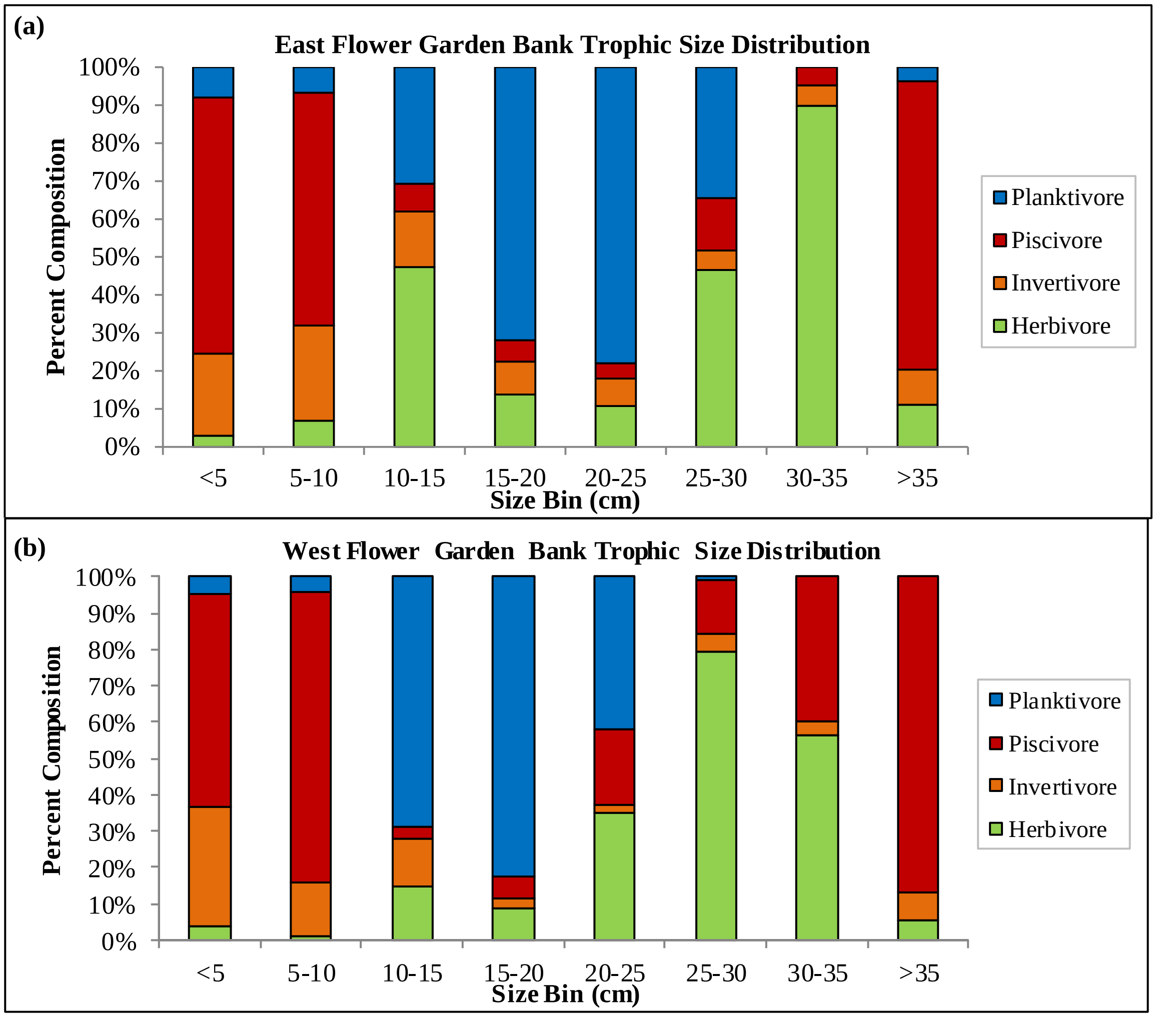


Figure 5.3. Size distribution of individuals by trophic guild from (a) EFGB and (b) WFGB in 2015.

Biomass Analysis

Mean biomass was calculated to be 12,174.47 g/100 m^2 ± 2,943.00 SE at EFGB and 7,972.50 g/100 m^2 ± 1,042.96 at WFGB in 2015. ANOSIM analysis indicates that while biologically significant, variation in biomass between banks was uninformative among surveys (Global R=0.062, p=1.1%). SIMPER analysis identified the greatest contributor to the observed dissimilarity between banks were Atlantic Creolefish (*Paranthias furcifer*) (24.50%), Bermuda Chub (*Kyphosus saltatrix/incisor*) (24.26%), and Great Barracuda (*Sphyraena barracuda*) (19.46%).

When classified by trophic guild, piscivores possessed the highest mean biomass for all surveys, with 3,524.26 g/100 m^2 ± 1,054.74. The lowest mean biomass from all surveys was represented by the invertivores, with 1,478.26 g/m^2 ± 1,044.17 (Table 5.4, Figure 5.4). ANOSIM results comparing the trophic guilds revealed no significant dissimilarities between banks, suggesting that EFGB and WFGB trophic communities were similar in 2015.

Table 5.4. Mean biomass ± SE, in g/100 m^2, for each trophic guild by bank and between all surveys.

Trophic Group			All Surveys
	EFGB	WFGB	
Herbivore	4,081.28 ± 1,922.11	2,730.18 ± 649.61	3,405.73 ± 1,426.14
Invertivore	2,458.42 ± 1,460.56	498.09 ± 105.88	1,478.26 ± 1,044.17
Planktivore	1,855.91 ± 633.02	1,475.83 ± 249.64	1,665.87 ± 477.63
Piscivore	3,780.12 ± 1,257.02	3,268.40 ± 829.18	3,524.26 ± 1,054.74

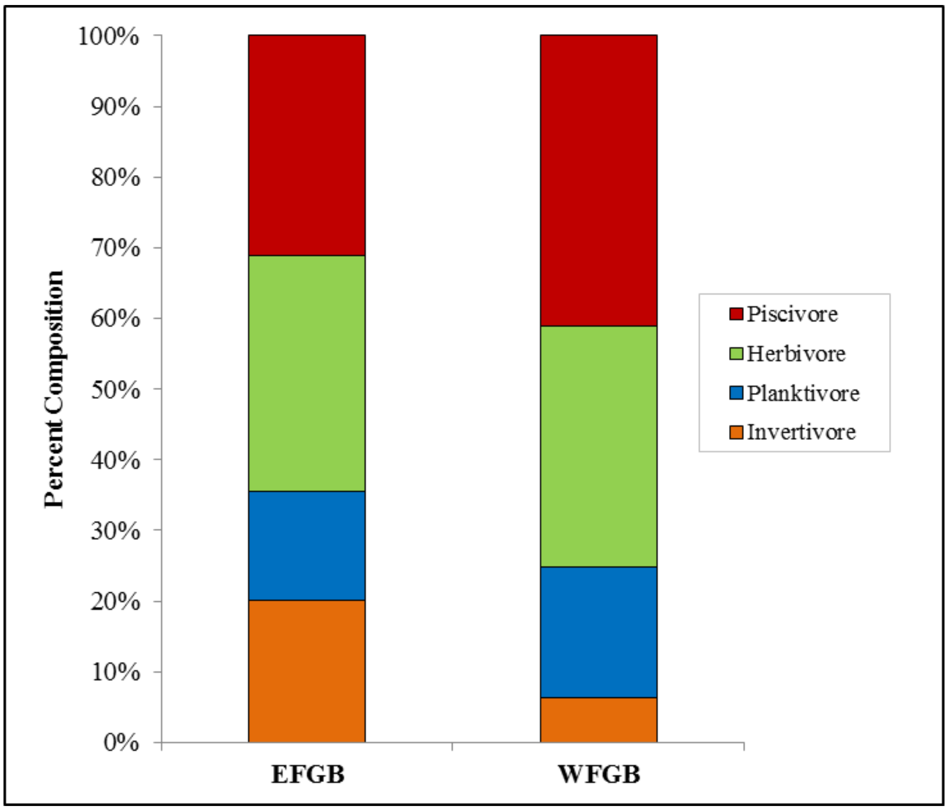


Figure 5.4. Percent composition of biomass for each trophic guild in 2015.

Within each trophic guild, average biomass for each species was calculated (Table 5.5). For the herbivore guild, 62.24% of the biomass was contributed by Bermuda Chub. For the invertivore guild, the greatest contribution was from Ocean Triggerfish (*Canthidermis sufflamen*), at 65.23% of all biomass. For the piscivore guild, Great Barracuda contributed the greatest biomass to all surveys, at 35.50%. For the planktivore guild, the greatest contribution was Atlantic Creolefish (60.98% of all biomass).

Table 5.5. Biomass, in g/100 m^2, of each species, grouped by trophic guild (herbivores, piscivores, invertivores, and planktivores).

Trophic Guild	Species ID Family Name: Species Name (Common Name)	2015 EFGB	2015 WFGB	All Surveys
Herbivore	Kyphosidae: *Kyphosus saltatrix/incisor* (Chub (Bermuda/Yellow)	2,637.40	1,602.15	2,119.77
	Balistidae: *Melichthys niger* (Black Durgon)	466.90	237.07	351.99
	Labridae: *Sparisoma viride* (Stoplight Parrotfish)	246.56	289.83	268.20
	Labridae: *Scarus vetula* (Queen Parrotfish)	253.52	274.36	263.94
	Acanthuridae: *Acanthurus coeruleus* (Blue Tang)	130.01	129.05	129.53
	Labridae: *Scarus taeniopterus* (Princess Parrotfish)	93.43	89.70	91.57
	Labridae: *Sparisoma aurofrenatum* (Redband Parrotfish)	96.37	41.44	68.91
	Acanthuridae: *Acanthurus chirurgus* (Doctorfish)	92.26	17.68	54.97
	Labridae: *Scarus iseri* (Striped Parrotfish)	3.10	33.10	18.10
	Pomacentridae: *Stegastes partitus* (Bicolor Damselfish)	26.22	6.31	16.27
	Pomacentridae: *Stegastes adustus* (Dusky Damselfish)	17.43	0.57	9.00
	Pomacentridae: *Microspathodon chrysurus* (Yellowtail Damselfish)	7.37	7.11	7.24
	Labridae: *Sparisoma atomarium* (Greenblotch Parrotfish)	7.90	0.00	3.95
	Pomacentridae: *Stegastes variabilis* (Cocoa Damselfish)	2.05	1.78	1.91
	Blenniidae: *Ophioblennius macclurei* (Redlip Blenny)	0.60	0.03	0.31
	Gobiidae: *Gnatholepis thompsoni* (Goldspot Goby)	0.17	0.00	0.08
Invertivore	Balistidae: *Canthidermis sufflamen* (Ocean Triggerfish)	1,866.97	61.44	964.21
	Monacanthidae*: Cantherhines macrocerus* (Whitespotted Filefish)	148.05	0.00	74.03
	Mullidae: *Mulloidichthys martinicus* (Yellow Goatfish)	124.62	22.62	73.62
	Diodontidae: *Diodon holocanthus* (Balloonfish)	64.55	64.55	64.55
	Pomacentridae: *Chromis multilineata* (Brown Chromis)	45.55	55.52	50.54
	Labridae: *Thalassoma bifasciatum* (Bluehead)	31.57	34.45	33.01
	Pomacentridae: *Stegastes planifrons* (Threespot Damselfish)	52.37	12.03	32.20
	Pomacanthidae: *Holacanthus ciliaris* (Queen Angelfish)	32.52	30.36	31.44
	Diodontidae: *Diodon hystrix* (Porcupinefish)	0.00	55.66	27.83
	Labridae: *Bodianus rufus* (Spanish Hogfish)	27.85	20.10	23.97
	Pomacanthidae: *Holacanthus tricolor* (Rock Beauty)	8.90	23.52	16.21
	Lutjanidae: *Lutjanus griseus* (Gray Snapper)	0.00	29.24	14.62
	Ostraciidae: *Acanthostracion polygonius* (Honeycomb Cowfish)	0.00	21.56	10.78
	Chaetodontidae: *Chaetodon sedentarius* (Reef Butterflyfish)	2.91	14.33	8.62
	Ostraciidae: *Lactophrys triqueter* (Smooth Trunkfish)	8.79	6.94	7.87
	Tetraodontidae: *Canthigaster rostrata* (Sharpnose Puffer)	10.81	3.55	7.18
	Epinephelidae: *Epinephelus adscensionis* (Rock Hind)	6.93	5.52	6.22

Trophic Guild	Species ID Family Name: Species Name (Common Name)	2015		All Surveys
		EFGB	WFGB	
	Pomacanthidae: *Holacanthus townsendi* (Townsend Angelfish)	0.00	11.53	5.76
	Labridae: *Halichoeres maculipinna* (Clown Wrasse)	6.90	2.05	4.47
	Labridae: *Halichoeres garnoti* (Yellowhead Wrasse)	5.74	2.37	4.06
	Pomacentridae: *Abudefduf saxatilis* (Sergeant Major)	2.12	5.73	3.93
	Epinephelidae: *Epinephelus guttatus* (Red Hind)	2.87	4.23	3.55
	Pomacanthidae: *Holacanthus bermudensis* (Blue Angelfish)	6.26	0.00	3.13
	Chaetodontidae: *Chaetodon ocellatus* (Spotfin Butterflyfish)	0.61	5.63	3.12
	Monacanthidae: *Cantherhines pullus* (Orangespotted Filefish)	0.00	2.47	1.24
	Chaetodontidae: *Prognathodes aculeatus* (Longsnout Butterflyfish)	0.02	1.31	0.66
	Holocentridae: *Holocentrus adscensionis* (Squirrelfish)	0.96	0.00	0.48
	Labridae: *Bodianus pulchellus* (Spotfin Hogfish)	0.00	0.94	0.47
	Labridae: *Halichoeres radiatus* (Puddingwife)	0.28	0.28	0.28
	Epinephelidae: *Cephalopholis fulva* (Coney)	0.17	0.00	0.09
	Cirrhitidae: *Amblycirrhitus pinos* (Redspotted Hawkfish)	0.06	0.07	0.06
	Sciaenidae: *Equetus punctatus* (Spotted Drum)	0.00	0.06	0.03
	Gobiidae: *Elacatinus oceanops* (Neon Goby)	0.02	0.01	0.02
	Gobiidae: *Coryphopterus glaucofraenum* (Bridled Goby)	0.01	0.00	0.00
	Blenniidae: *Parablennius marmoreus* (Seaweed Blenny)	0.00	0.00	0.00
	Pomacentridae: *Chromis enchrysura* (Yellowtail Reeffish)	0.00	0.01	0.00
	Labridae: *Halichoeres bivittatus* (Slippery Dick)	0.00	0.00	0.00
Piscivore	Sphyraenidae: *Sphyraena barracuda* (Great Barracuda)	1,168.47	1,332.88	1,250.67
	Carangidae: *Caranx latus* (Horse-eye Jack)	1,680.54	68.63	874.58
	Haemulidae: *Emmelichthyops atlanticus* (Bonnetmouth)	194.81	705.80	450.30
	Serranidae: *Mycteroperca tigris* (Tiger Grouper)	410.95	57.61	234.28
	Epinephelidae: *Mycteroperca bonaci* (Black Grouper)	45.35	354.82	200.09
	Scorpaenidae: *Pterois volitans/miles* (Lionfish)	44.64	251.29	147.96
	Lutjanidae: *Lutjanus jocu* (Dog Snapper)	0.00	179.76	89.88
	Carangidae: *Caranx ruber* (Bar Jack)	18.05	150.54	84.29
	Muraenidae: *Gymnothorax funebris* (Green Moray)	83.85	0.00	41.92
	Carangidae: *Caranx crysos* (Blue Runner)	0.00	81.98	40.99
	Epinephelidae: *Mycteroperca phenax* (Scamp)	59.12	0.00	29.56
	Carangidae: *Seriola rivoliana* (Almaco Jack)	0.00	57.88	28.94
	Epinephelidae: *Mycteroperca interstitialis* (Yellowmouth Grouper)	33.07	9.12	21.10
	Epinephelidae: *Cephalopholis cruentata* (Graysby)	11.92	16.07	13.99
	Carangidae: *Caranx lugubris* (Black Jack)	13.12	0.00	6.56

Trophic Guild	Species ID Family Name: Species Name (Common Name)	2015 EFGB	2015 WFGB	All Surveys
	Muraenidae: *Gymnothorax moringa* (Spotted Moray)	9.73	0.00	4.86
	Epinephelidae: *Mycteroperca venenosa* (Yellowfin Grouper)	4.17	0.00	2.08
	Aulostomidae: *Aulostomus maculatus* (Atlantic Trumpetfish)	0.00	2.03	1.02
Planktivore	Epinephelidae: *Paranthias furcifer* (Atlantic Creolefish)	1,249.22	783.19	1,016.20
	Labridae: *Clepticus parrae* (Creole Wrasse)	602.80	691.54	647.17
	Pomacentridae: *Chromis cyanea* (Blue Chromis)	3.57	1.01	2.29
	Haemulidae: *Haemulon vittatum* (Boga)	1.09	0.00	0.54
	Pomacentridae: *Chromis insolata* (Sunshinefish)	0.31	0.03	0.17
	Pomacentridae: *Chromis scotti* (Purple Reeffish)	0.02	0.06	0.04

Abundance-Biomass Curves

For all samples, w values remained close to 0, suggesting a balanced community, comprised of large and small species (Figure 5.5 and 5.6). Mean w values for EFGB were 0.04 ± 0.03 and for WFGB were 0.05 ± 0.03. No significant differences were observed between the abundance and biomass dominance plots between banks.

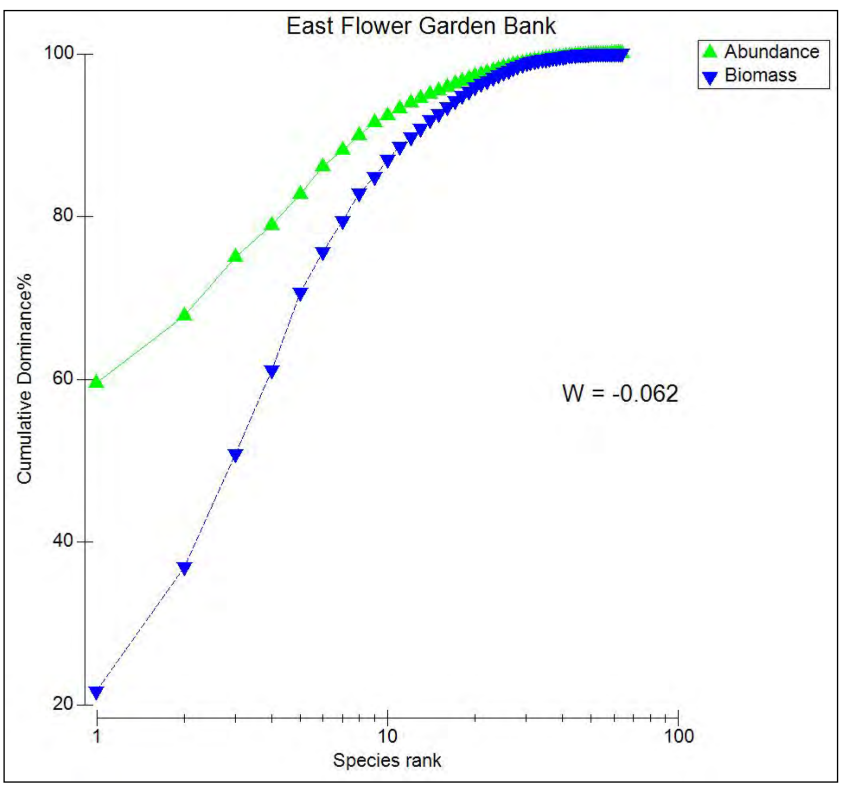


Figure 5.5. Abundance-Biomass curves for all surveys from EFGB in 2015.

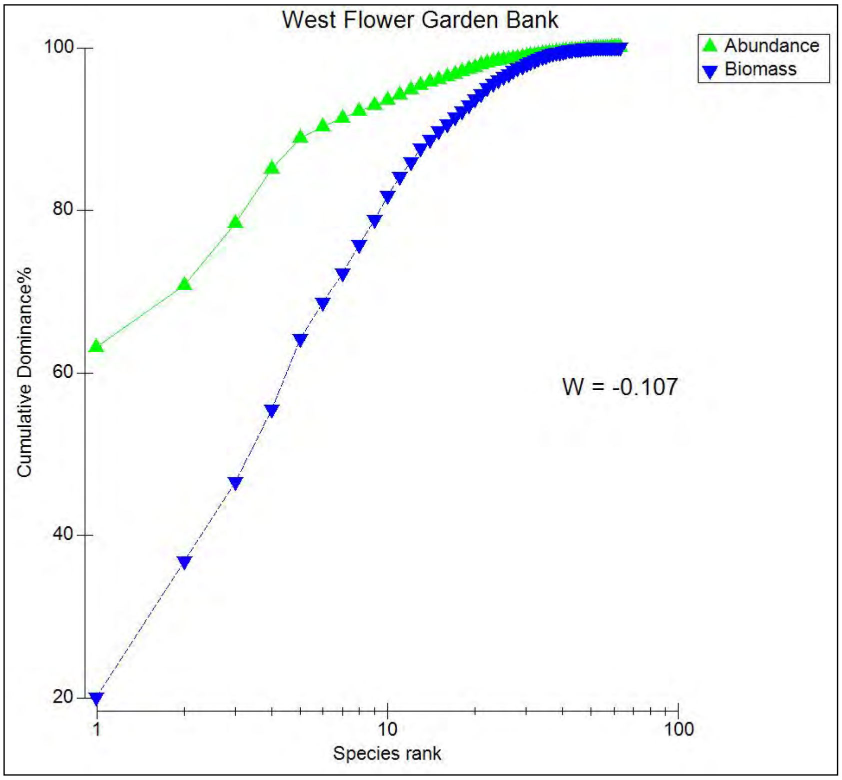


Figure 5.6. Abundance-Biomass curves for all surveys from WFGB in 2015.

Family Level Analysis

Due to particular concerns for species from the grouper (including *Mycteroperca*, *Cephalopholis* and *Epinephelus* genera only), snapper (*Lutjanidae* genus only), and parrotfish (including *Sparisoma* and *Scarus* genera only) families, additional analyses were conducted on these families to determine size frequency distributions.

The grouper family was comprised of 9 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*), Yellowfin Grouper (*Mycteroperca venenosa*), Scamp (*Mycteroperca phenax*), and Tiger Grouper (*Mycteroperca tigris*). While it should be noted that coefficient of variation percentages (18.58% for density, 52.51% for biomass) indicate that the density data provided had good power to detect population changes, the biomass data provided had poor power to detect population changes. ANOSIM results indicate no significant differences in community composition based on density or biomass.

Mean biomass of small bodied grouper, including Graysby, Coney, Red Hind, and Rock Hind was 23.85 g/100 m^2 ± 5.61, with similar means between EFGB (21.87 g/100 m^2 ±

6.76) and WFGB (25.82 g/100 m^2 ± 9.09). Mean biomass of large bodied grouper, including Black Grouper, Yellowmouth Grouper, Yellowfin Grouper, Scamp, and Tiger Grouper was 487.11 g/100 m^2 ± 268.80, with higher average biomass at EFGB (552.66 g/100 m^2 ± 387.87) than WFGB (421.55 g/100 m^2 ± 380.10). Large bodied grouper size distributions were graphed for each species and size at maturity was included, when available (Figure 5.7).

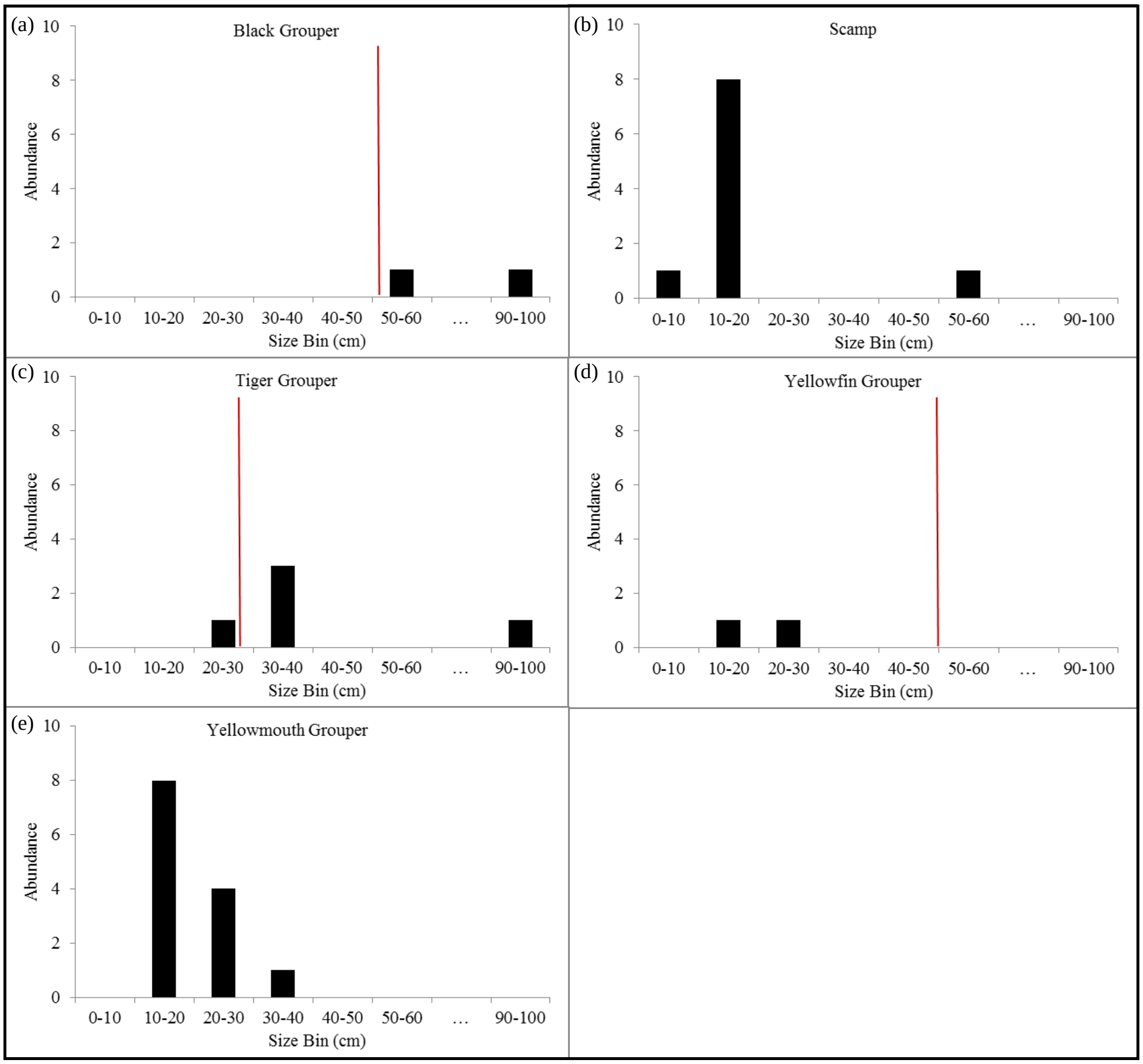


Figure 5.7. Size frequency of large bodied grouper species observed during 2015 includes (a) Black Grouper, (b) Scamp, (c) Tiger Grouper, (d) Yellowfin Grouper, and (e) Yellowmouth Grouper.

Vertical solid red lines represent estimated size of female maturity, when available, (a) SAFMC 2005, (c) Heemstra and Randall 1993, (d) Brule et al. 2003, and (e) Froese and Pauly 2014.

The snapper family was comprised of 2 species from the *Lutjanidae* genus: Gray Snapper (*Lutjanus griseus*) and Dog Snapper (*Lutjanus jocu*). Mean biomass at WFGB was 209.01 g/100 m^2 ± 130.28. No snapper were observed at EFGB. Snapper size distributions were graphed for each species (Figure 5.8), and size at maturity was included when available for the species.

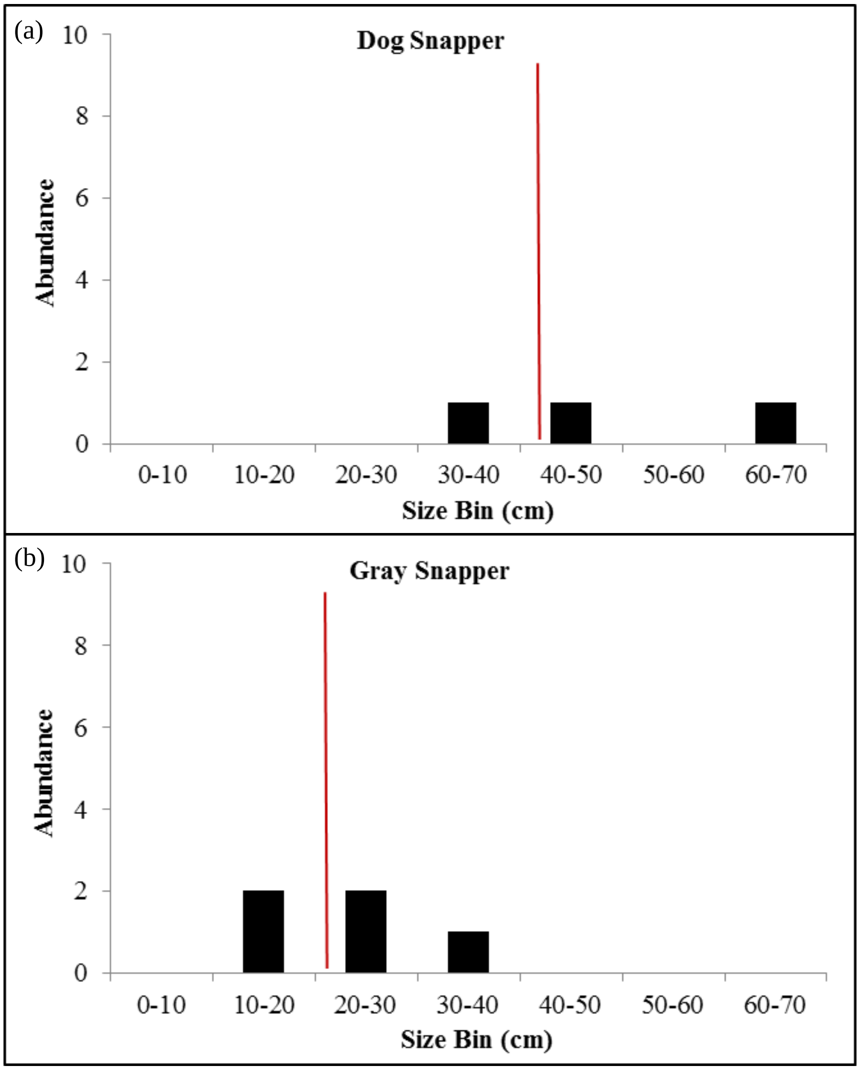


Figure 5.8. Size distribution of snapper species observed during 2015 includes (a) Dog Snapper and (b) Gray Snapper. Vertical solid red lines represent estimated size of female maturity (Garcia-Cagide et al. 1994).

Parrotfishes have been identified as an important herbivore on coral reefs by Jackson et al. (2014) because they are the most effective grazers on Caribbean reefs. Parrotfish at the FGB included 6 species: Striped Parrotfish (*Scarus iseri*), Princess Parrotfish (*Scarus taeniopterus*), Queen Parrotfish (*Scarus vetula*), Greenblotch Parrotfish (*Sparisoma atomarium*), Redband Parrotfish (*Sparisoma aurofrenatum*), and Stoplight Parrotfish (*Sparisoma viride*). Coefficient of variation percentages (9.08% for density, 14.55% for biomass) indicated that the data provided had good power to detect population changes. ANOSIM results indicated no significant differences in community composition based on biomass; however, there was a significant spatial variation in parrotfish community composition based on density (*Global R*=0.064, *p*=2.3%). The observed dissimilarity between banks was contributed predominantly by Stoplight Parrotfish (23.70%), with EFGB having greater overall density of Stoplight Parrotfish.

Mean biomass of parrotfishes was 714.66 g/100 m^2 ± 104.01, with similar mean biomasses at EFGB (700.88 g/100 m^2 ± 162.01) and WFGB (728.44 g/100 m^2 ± 133.91). The parrotfish population at both EFGB and WFGB have wide size distributions, but are marginally dominated by smaller individuals (<20 cm) (Figure 5.9).

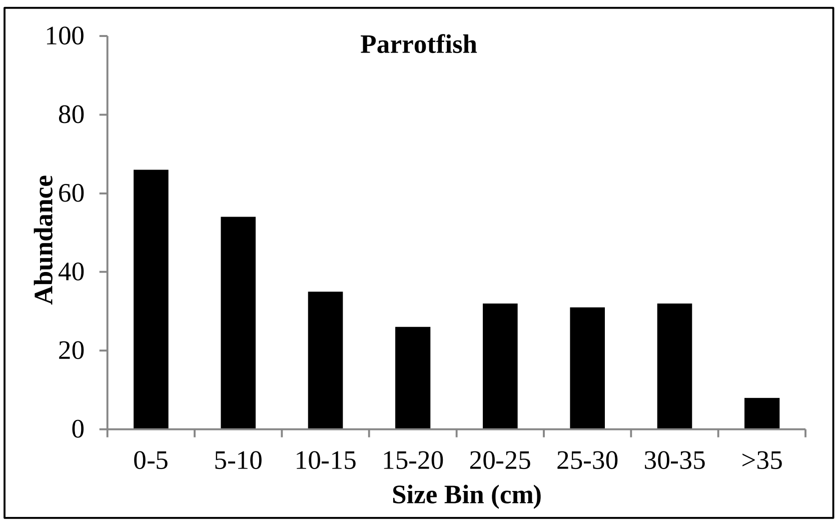


Figure 5.9. Size distribution of all parrotfish recorded in 2015.

This reporting year marks the third consecutive documentation of lionfish (*Pterois volitans/miles*) in the long-term monitoring study sites. Lionfish are an invasive species, native to the Indo-Pacific. Sighting frequency for lionfish at EFGB was 16.67% and 62.50% at WFGB in 2015. Total lionfish abundance at EFGB was 4 individuals and WFGB was 15 individuals. Mean density for all surveys was <1/100 m^2 (0.55) and mean biomass for all surveys was 147.96 g/100 m^2 ± 38.70. Since the initial documentation of lionfish in the long-term monitoring dataset, overall density increased from 2013 to 2014, but decreased in 2015 (Figure 5.10). Size distribution remained similar between years (Figure 5.11).

Coefficient of variation percentages (29.09% for density and 26.15% for biomass) indicated that the data provided had moderate power to detect population changes. ANOSIM results indicated a significant spatial variation in community composition based on density (*Global R*=0.182, *p*=0.3%) and biomass (*Global R*=0.179, *p*=0.3%).

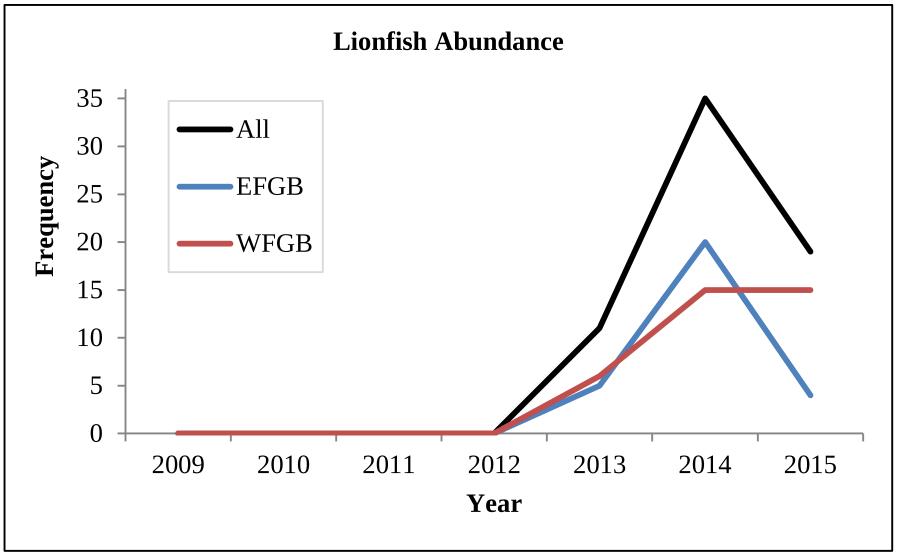


Figure 5.10. Lionfish abundance from 2012 to 2015 shows increasing abundance at both EFGB and WFGB through 2014, and a decrease in 2015.

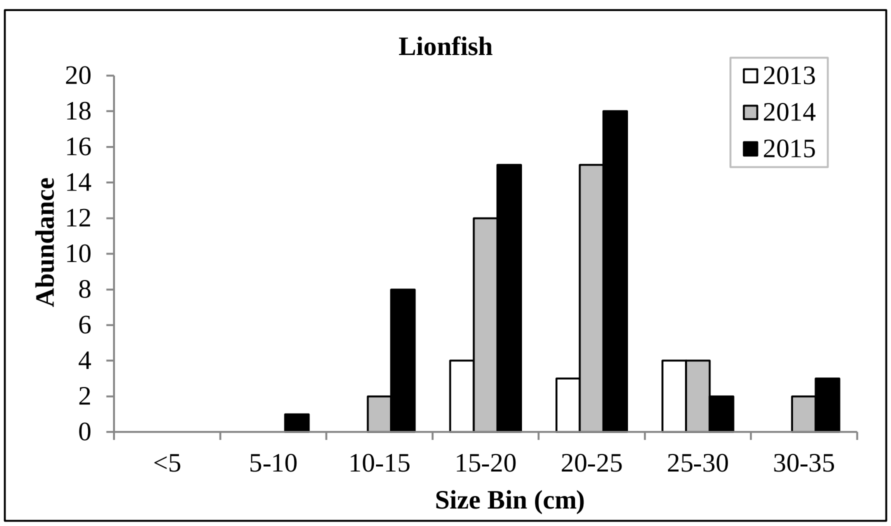


Figure 5.11. Lionfish size distribution from 2013 to 2015.

Fish Surveys Long-Term Trends

Fish communities are considered indicators of ecosystem health (Sale 1991) and are therefore an important component to long-term monitoring programs. Fish surveys were added to the long-term monitoring protocol in 2002. Monitoring fish community changes over extended periods of time is valuable in detecting changes from normal variations in the community.

Since 2002, fish density has been variable at EFGB and WFGB (Figure 5.12). Density ranged from 52.70–302.00 individuals/100 m^2 at EFGB, and 64.80–313.40 individuals/100 m^2 at WFGB. There were no significant differences in overall density between banks from 2002–2015 and no significant trends were detected.

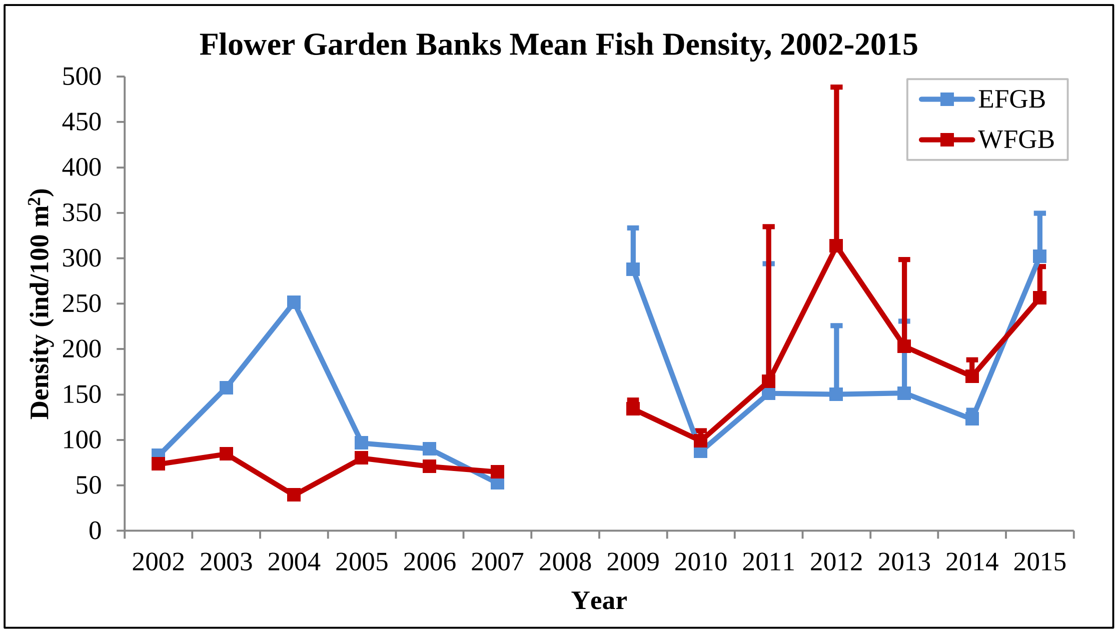


Figure 5.12. Mean fish density +SE from 2002 to 2015 at EFGB and WFGB.

No data were collected in 2008. SE not available before 2009.

Biomass data was first collected in 2006, and has been variable at EFGB and WFGB (Figure 5.13). Biomass ranged from 51.44–242.70 g/100 m^2 at EFGB, and 24.58–272.26 g/100 m^2 at WFGB. There were no significant differences in overall biomass between banks from 2006–2015 and no significant trends were detected.

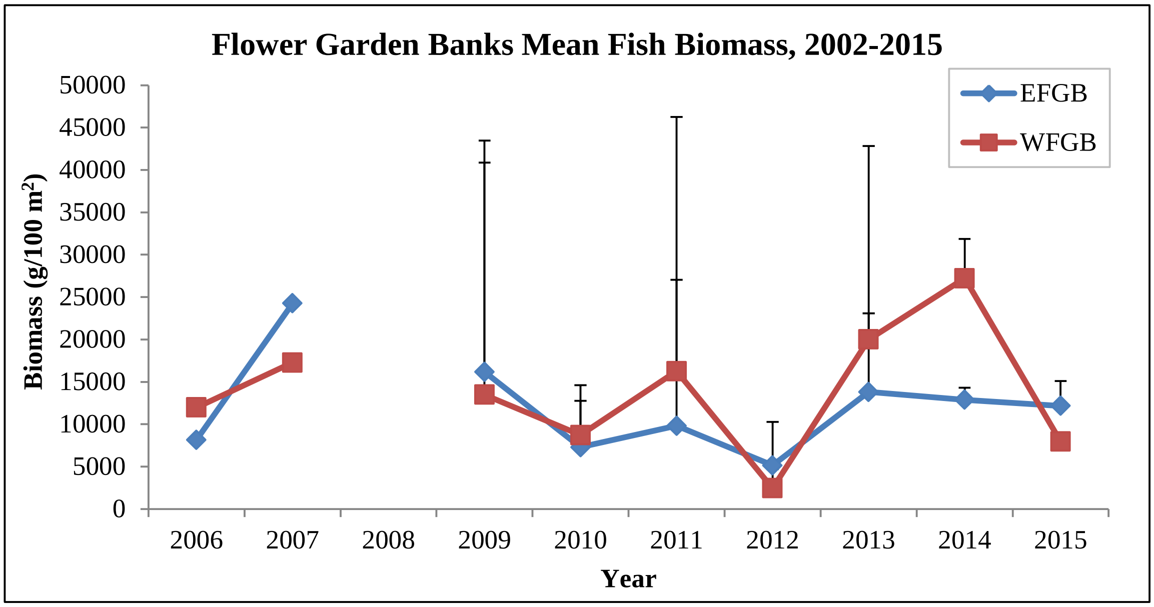


Figure 5.13. Mean fish biomass +SE from 2006 to 2015 at EFGB and WFGB.

No data were collected in 2008. SE not available before 2009.

Fish Surveys Discussion

Historically, the fish communities at EFGB and WFGB have been considered to be low in species diversity but high in biomass (Zimmer et al. 2010); possessing 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). However, additional studies conducted by NOAA's BioGeography Branch in Puerto Rico, US Virgin Islands, and FGB suggest that while average biomass is much greater at FGB and subsequently variability in biomass is also greater, average species richness is greater at FGB in comparison to these other reefs (Table 5.6). While overall fish species diversity for the FGBNMS is reduced in comparison to other Caribbean reefs, the average number of species observed in a defined area is greater at the FGB.

Table 5.6. Comparison of other Caribbean reef biomass and species richness to FGB.

Region	Average Biomass (g/100 m^2)	Average Richness (Richness/100 m^2)
Puerto Rico (Caldow et al. 2015; Bauer et al. 2015a; Bauer et al. 2015b)	3,830.25 ± 188.51	18.19 ± 0.19
US Virgin Islands (Roberson et al. 2015; Pittman et al. 2015; Clark et al. 2015b; Bauer et al. 2015c)	6,355.38 ± 172.60	20.70 ± 0.12
Flower Garden Banks (Clark et al. 2015a)	34,570.87 ± 3,517.95	24.60 ± 0.36

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, in addition to the mooring buoys located at the banks from 1990 onward, may have helped promote the dispersal of additional fish species and allowed some to reach the FGB, such as Yellowtail Snapper (*Ocyurus chrysurus*), Sergeant Majors (*Abudefduf saxatilis*) (Boland et al. 1983; Rooker et al. 1997; Gittings 1998; Pattengill 1998), and lionfish (Dahl and Patterson 2013). Lionfish densities on northern Gulf of Mexico artificial reefs are among the highest densities reported in the western Atlantic (10 – 100 lionfish/100 m^2), which may negatively impact native fishes due to the voracious appetitive and generalist feeding preferences of lionfish (Dahl and Patterson 2013).

Fish surveys conducted in 2015 indicate an abundant and diverse reef fish community at EFGB and WFGB, as observed in previous annual monitoring surveys (Precht et al. 2006; Zimmer et al. 2010; Johnston et al. 2013; Johnston et al. 2015a, b). Though some results indicate a significant spatial variation in community composition, statistical R values indicate that this difference is small among groups, and is therefore considered uninformative. With this in mind, no distinct differences were observed between banks, suggesting that, despite small variations, EFGB and WFGB fish communities are similar within study site habitat.

The FGB is documented to have a lower species richness and overall abundance of herbivorous fishes than other Caribbean reefs (Dennis and Bright 1988). Historically, low macroalgae cover has been reported in the annual monitoring, while recent data suggest a gradual increase in macroalgae cover over time. During this study period, the herbivore guild possessed the second greatest mean biomass, contributing to over 33% of the total biomass. Within the herbivore guild, over 60% of the total biomass is attributed to Bermuda Chub. The piscivore guild had the greatest mean biomass, contributing approximately 35% of the total biomass. Within the piscivore guild, Great Barracuda contributed to over 36% of the total biomass. Large schools of Bonnetmouth were observed at both EFGB and WFGB in 2015, contributing to over 12% of the piscivore biomass, and also resulting in the most abundant species.

Piscivore dominated biomass indicates that the ecosystem maintains an inverted biomass pyramid. The inverted biomass pyramid has been documented in reef ecosystems, where piscivore dominance is associated with minimal impacts, particularly from fishing (Friedlander and DeMartini 2002; DeMartini et al. 2008; Knowlton and Jackson 2008; Sandin et al. 2008; Singh et al. 2012). Typically, inverted biomass pyramids are associated with healthy reef systems with high coral cover, due to the availability of refugees, rapid turnover rates of prey items, slow growth rates of predators, and potential food subsidies from the surrounding pelagic environment (Odum and Odum 1971; DeMartini et al. 2008; Wang et al. 2009).

Abundance-biomass curves have historically been used to infer community health on shallow-water coral reefs, where a community dominated by few large species is considered “pristine” and a community dominated by many small species is considered “impacted” (DeMartini et al. 2008; SOKI Wiki 2014). Results indicate that FGB fish communities are evenly distributed, meaning that the population can be considered moderately disturbed, and somewhat lacking in density of large fishes.

From the large bodied groupers observed, Yellowfin Grouper consisted of only immature individuals, Yellowmouth and Tiger Grouper consisted of immature and mature individuals, and Black Grouper possessed only sexually mature individuals. In contrast to the grouper population, the snapper community was dominated by immature and mature individuals. 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 is unknown.

Parrotfish have been identified as key reef species, with their abundance and biomass being positively correlated with coral cover (Jackson et al. 2014). The mean biomass of parrotfish at the FGB is considered low (Jackson et al. 2014) and similar to other Caribbean reefs (Table 5.7). However, low parrotfish biomass is frequently associated with high fishing pressure and low coral cover, neither of which is apparent at the FGB.

Table 5.7 Mean biomass (g/100 m^2) for parrotfish at other Caribbean reefs.

Location	**Biomass (g/100 m^2)**
Mexico	1,710
Belize	1,200
Flower Garden Banks	715
Guatemala	670
Honduras	440

All data, with the exception of the FGB data, is from AGRRA 2012.

Lionfish were recorded in surveys for the third consecutive year in 2015, but have been observed by divers consistently on the reefs since 2011. Since their first observation, numbers have rapidly increased every year, with the exception of 2015 (Johnston et al. 2016a). In LTM surveys, average lionfish density doubled from 2013 to 2014 (0.32 per 100 m^2), and increased to 0.55 per 100 m^2 in 2015. The sighting frequency of lionfish between 2013 and 2014 doubled, from 16.7% to 35%, and was recorded at 40% in 2015.

It should be noted that the staff of FGBNMS currently works to remove lionfish when possible in attempts to suppress potential impacts to the native fish community from predation-induced declines; however, divers are limited to the upper portion of the reef crest (< 40 m) (Green et al. 2014; Johnston et al. 2016a). Within the long-term monitoring study sites, removals do not take place during LTM field operations, ensuring sighting frequency, density, and biomass data are not affected. However, because lionfish are opportunistically removed by permitted divers throughout the rest of the year, data are likely to be the minimum estimates for these parameters, as they would presumably be higher if lionfish were not removed from the system.

Chapter 6

WATER QUALITY

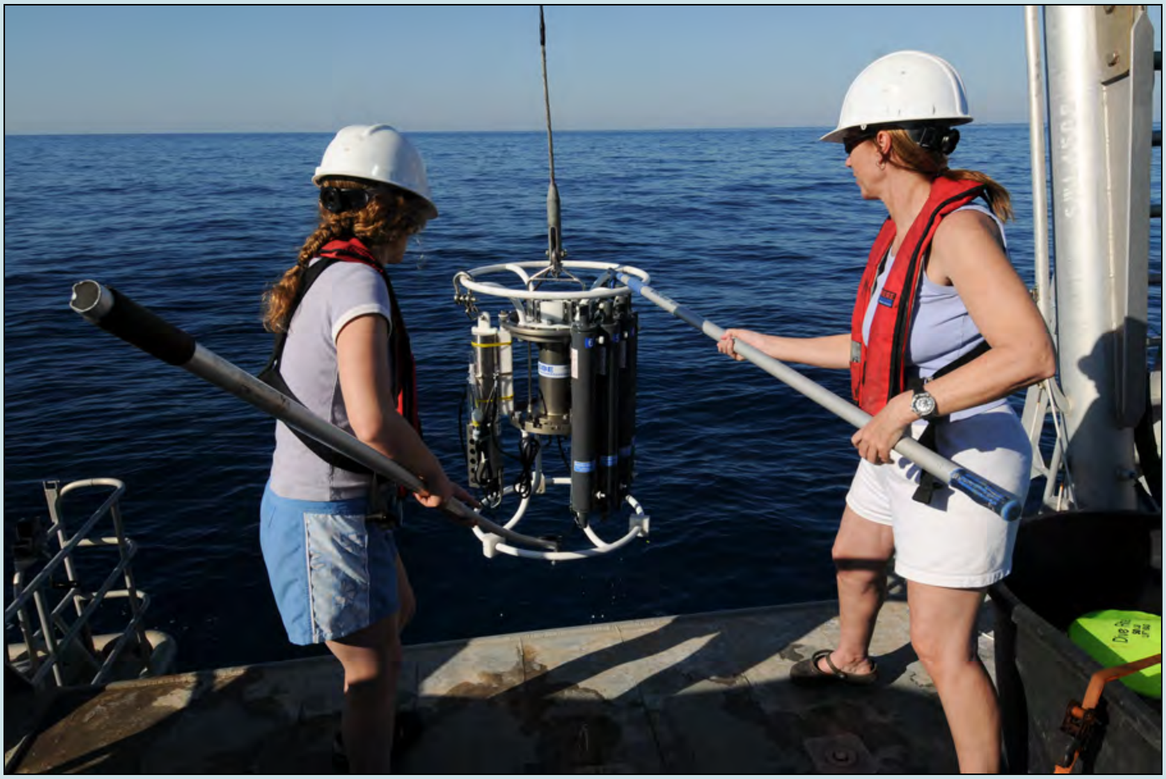


Photo: NOAA FGBNMS/G.P. Schmahl

Flower Garden Banks National Marine Sanctuary researchers deploy a water quality sampling carousel off the back deck of the NOAA *R/V Manta*.

Water Quality Introduction

Several water quality parameters were continually or periodically recorded at EFGB and WFGB in 2015. At a minimum, salinity and temperature were recorded every hour by data loggers permanently installed near the study sites at depths of 24 m and temperature loggers collected temperature data every hour at 30 m and 40 m depths at each bank.

Water samples were collected quarterly throughout the year at three different depth ranges, and analyzed by an Environmental Protection Agency certified laboratory for select nutrient levels and ocean carbonate measurements.

This chapter presents data from the instruments at EFGB and WFGB from January 1–December 31, 2015.

Water Quality Methods

Water Quality Field Methods

Temperature and Salinity Loggers

The primary instrument for recording salinity and temperature was a Sea-Bird® Electronics, Inc. MicroCAT® 37 logger at a 24 m depth. The logger was installed on a large railroad wheel located in sand flats at each bank. The instrument recorded temperature and salinity hourly throughout the year. Each quarter year, the instrument was exchanged by SCUBA divers for downloading and maintenance. It was immediately exchanged with an identical instrument to avoid any gaps in the data collection. Prior to re-installation, all previous data were removed from the instrument and battery life checked. Maintenance and factory service of each instrument was performed annually.

Onset® Computer Corporation HOBO® Pro v2 U22-001 thermographs were used to record temperature levels on an hourly basis. These instruments provide a highly reliable temperature backup for the primary logging instrument and are located at a 24 m station. These were the only loggers deployed at a 30 m and 40 m station, and recorded temperature hourly. The loggers were also downloaded, maintained and replaced on a quarterly basis. The instruments were either attached directly to the primary instrument at the 24 m station or to permanent photostations at the 30 m and 40 m stations. Prior to re-installation, all previous data were removed from the instrument and battery levels were checked.

Water Samples

Water samples were collected quarterly during the year using a sampling carousel equipped with a Sea-Bird® Electronics *19plus* V2 CTD and six OceanTest® Corporation 2.5 liter Niskin bottles. The carousel was attached to NOAA *R/V Manta* with a scientific winch cable. The winch cable allows the operator to activate the bottles to sample at specific depths. A total of six samples were collected each quarter. Two 2.5 liter water samples were collected near the reef cap on the seafloor (approximately 18 m depth), midwater (10 m depth) and near the surface (1 m depth).

Water samples were analyzed for chlorophyll-*a* (chl-*a*) and nutrients including ammonia, nitrate, nitrite, phosphorous and Total Kjeldahl Nitrogen (TKN). 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 total nitrogen samples were collected in 1000 ml bottles with a sulfuric acid preservative. An additional blind duplicate water sample was taken at one of the sampling depths 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 for processing at an Environmental Protection Agency (EPA) certified laboratory. The samples were transported and delivered to A&B Laboratories in Houston, TX, within twenty four hours of being collected for analysis. In 2015, water samples were obtained on February 11th, May 1st, September 1st, and November 4th.

Water samples for ocean carbonate measurements were collected following methods provided by the Carbon Cycle Laboratory (CCL) at Texas A&M University – Corpus Christi (TAMU-CC) (Hu 2015). Samples were collected in Pyrex 250ml borosilicate bottles with polypropylene caps. Two replicates were collected at each depth. Bottles were filled using a 30cm plastic tube that connected from the spout of the Niskin. Bottles were rinsed three times using the sample water, filled carefully to reduce bubble formation, and overflowed by at least 200ml. 100µl of $HgCl_2$ was added to each bottle before inverting vigorously. Samples were then stored at 4°C. Samples and CTD profile data were sent to CCL at TAMU-CC, in Corpus Christi, TX. Samples were obtained on February 11th, May 1st, and November 4th.

Water Quality Data Processing and Analysis

Temperature and salinity data obtained from loggers were downloaded and processed each quarter. The twenty four hourly readings obtained each day were averaged into one daily value and recorded in a database. Each calendar day was assigned a value in the database. Separate databases were maintained for each type of logger. For temperature data, a historical average of data from the previous 24 years (1990–2014) was used for comparison. For salinity data, a historical average of data from the previous 7 years (2008–2014) was used for comparison.

Chlorophyll-*a* and nutrient analyses results were obtained quarterly from A&B Laboratories and compiled into an excel table. Ocean carbonate analyses results were compiled and received as an annual report from the CCL at TAMU-CC (Hu 2015).

Water Quality Results

Temperature and Salinity Loggers

At the EFGB 24 m station, the minimum temperature logged was 20.20^{o}C, recorded on February 24, 2015 (Figure 6.1). The maximum temperature, recorded on August 22, 2015, was 29.81^{o}C. At the 30 m station, no data was available for January or February 2015 due to a HOBO logger that disappeared from the fixed station. The data from February 11–September 7, 2015 was corrupt due logger malfunction and therefore lacking minimum winter temperature data. A new logger was replaced at the 30 m depth station in September. The maximum temperature, recorded on October 9–10, 2015, was 28.25^{o}C; however, maximum temperatures probably occurred before the logger was replaced. At the 40 m station, the minimum temperature logged was 20.30^{o}C, recorded on February 24, 2015. The maximum temperature, recorded on August 22, 2015, was 29.72^{o}C.

At the WFGB 24 m station, the minimum temperature logged was 19.62^{o}C, recorded on March 14, 2015 (Figure 6.1). The maximum temperature, recorded on August 21, 2015, was 29.97^{o}C. At the 30 m station, the minimum temperature logged was 19.73^{o}C, recorded on March 14, 2015 as well. The maximum temperature, recorded on August 31, 2015, was 30.07^{o}C. At the 40 m station, the minimum temperature logged was 19.67^{o}C, recorded on March 14, 2015. The maximum temperature, recorded on August 21, 2015, was 29.48^{o}C.

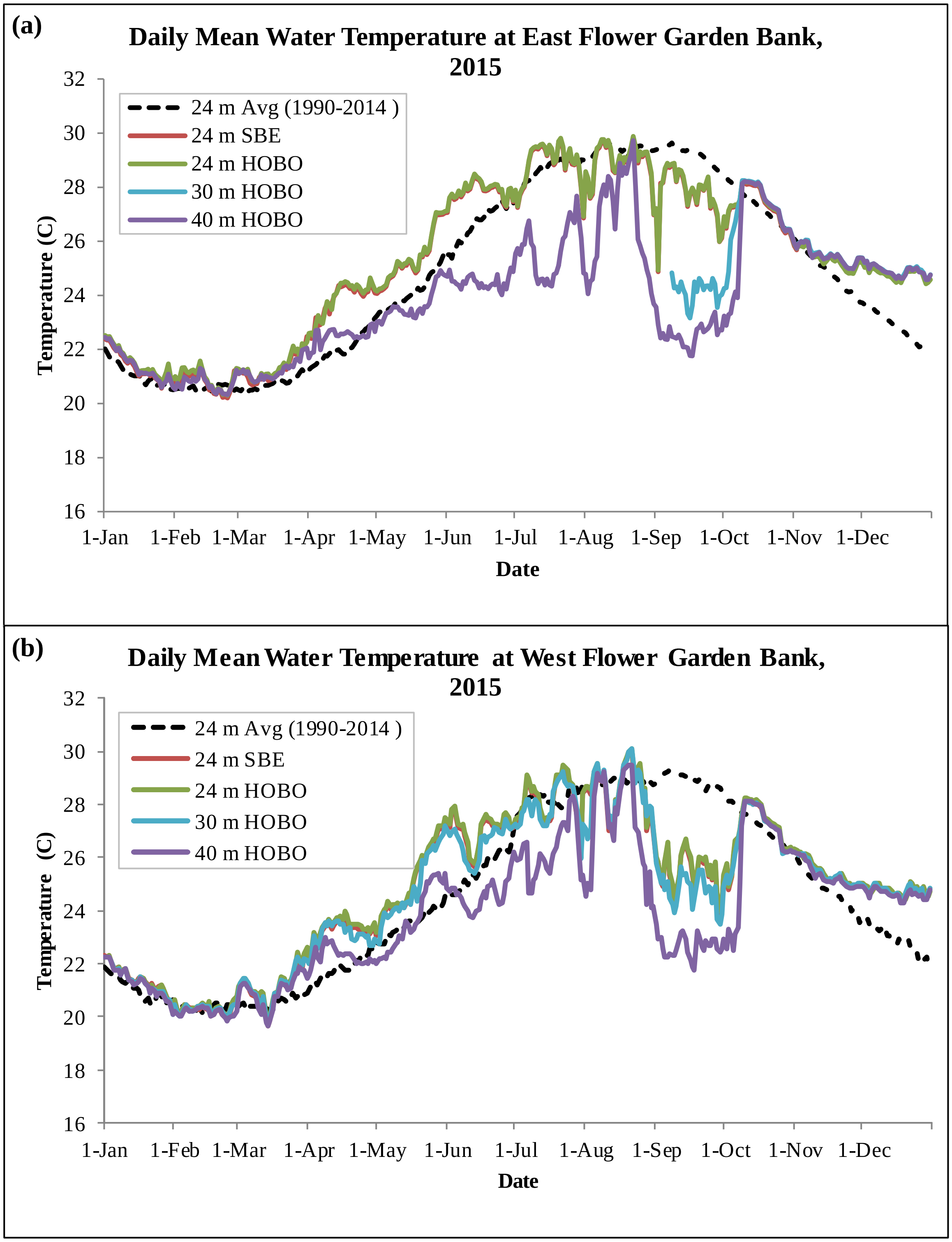


Figure 6.1. Daily mean water temperature (^{o}C) at (a) EFGB and (b) WFGB in 2015 with 24-year average temperature.

Based on data from HOBO thermographs, the coolest temperatures were typically observed at the deeper stations year round. On average, the temperature difference between the 24 m and 40 m stations was 1.52^{o}C at EFGB. The maximum difference recorded was 6.46^{o}C on September 6, 2016, where the deeper station recorded the coldest temperature. No comparisons to the 30 m station were made due to corrupt data for the majority of 2015. At WFGB, the average temperature difference between the 24 m and 30 m stations was minor (0.10^{o}C). The average temperature difference between the 24 m and 40 m stations was 1.0^{o}C. The maximum difference recorded was 4.21^{o}C on September 6, 2016, where the deeper station recorded the coldest temperature.

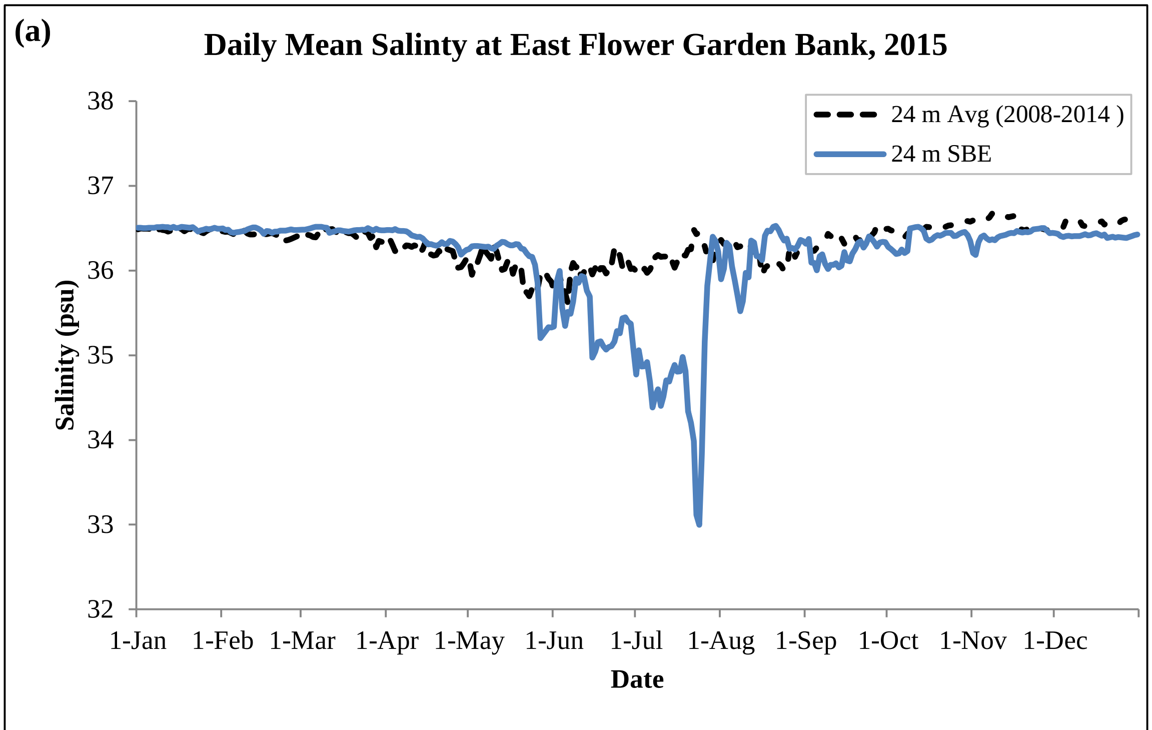
When compared to daily mean water temperature from the past 24 years, water temperatures where warmer than the historic average from March–July in 2015 then colder than average in September 2015 (Figure 6.1).

The minimum salinity level recorded in 2015 at EFGB was 33.00 psu on July 24, 2015 and the maximum salinity level was 36.53 psu on August 21, 2015 (Figure 6.2). When compared to the daily mean salinity observed over the last 7 years at EFGB, the 2015 data showed greater fluctuation over the summer months from June-August. The minimum salinity level recorded at WFGB was 34.30 psu on July 23, 2015 and the maximum salinity level was 36.57 psu on August 20, 2015 (Figure 6.2). When compared to the daily mean salinity observed over the last 7 years at WFGB, the 2015 data showed greater fluctuation over the summer months from June-August.

Water Samples

Nutrient analyses indicate that ammonia, chl-*a*, nitrate, nitrite, phosphorus, and nitrogen levels for all samples in 2015 were below detectable levels. The first chl-*a* and nutrient samples were taken 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 spikes in chl-*a*, ammonia, and TKN (Figures 6.3 and 6.4).

Carbonate samples taken throughout the year included pH (on total scale), alkalinity, and total dissolved CO_2 (DIC) (Table 6.1 and 6.2). Derived carbonate system parameters, including carbonate saturate state with respect to aragonite ($\Omega_{aragonite}$) and CO_2 fugacity (fCO_2), were calculated using the program CO2SYS with DIC and lab-measured pH and input parameters and carbonic acid dissociation constants in Dickson and Millero (1987). pH varied in a relatively narrow range throughout the year. The lowest fCO_2 values, where the air-sea fCO_2 gradients were greatest, were observed in February 2015. The lowest $\Omega_{aragonite}$ values and highest DIC were also observed in February 2015, but aragonite saturation states suggested the seawater was well buffered across all survey times (Hu 2015).



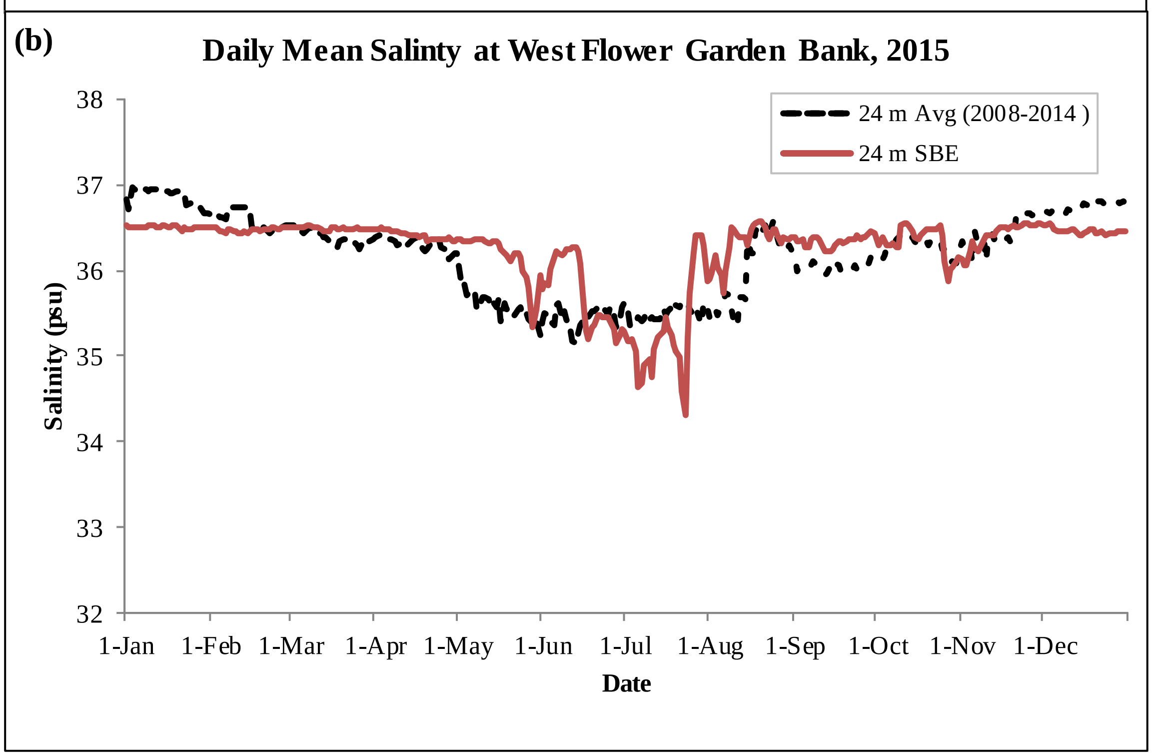


Figure 6.2. Daily mean salinity (psu) at the 24 m station depth at (a) EFGB and (b) WFGB in 2015 compared to the 7-year daily salinity mean.

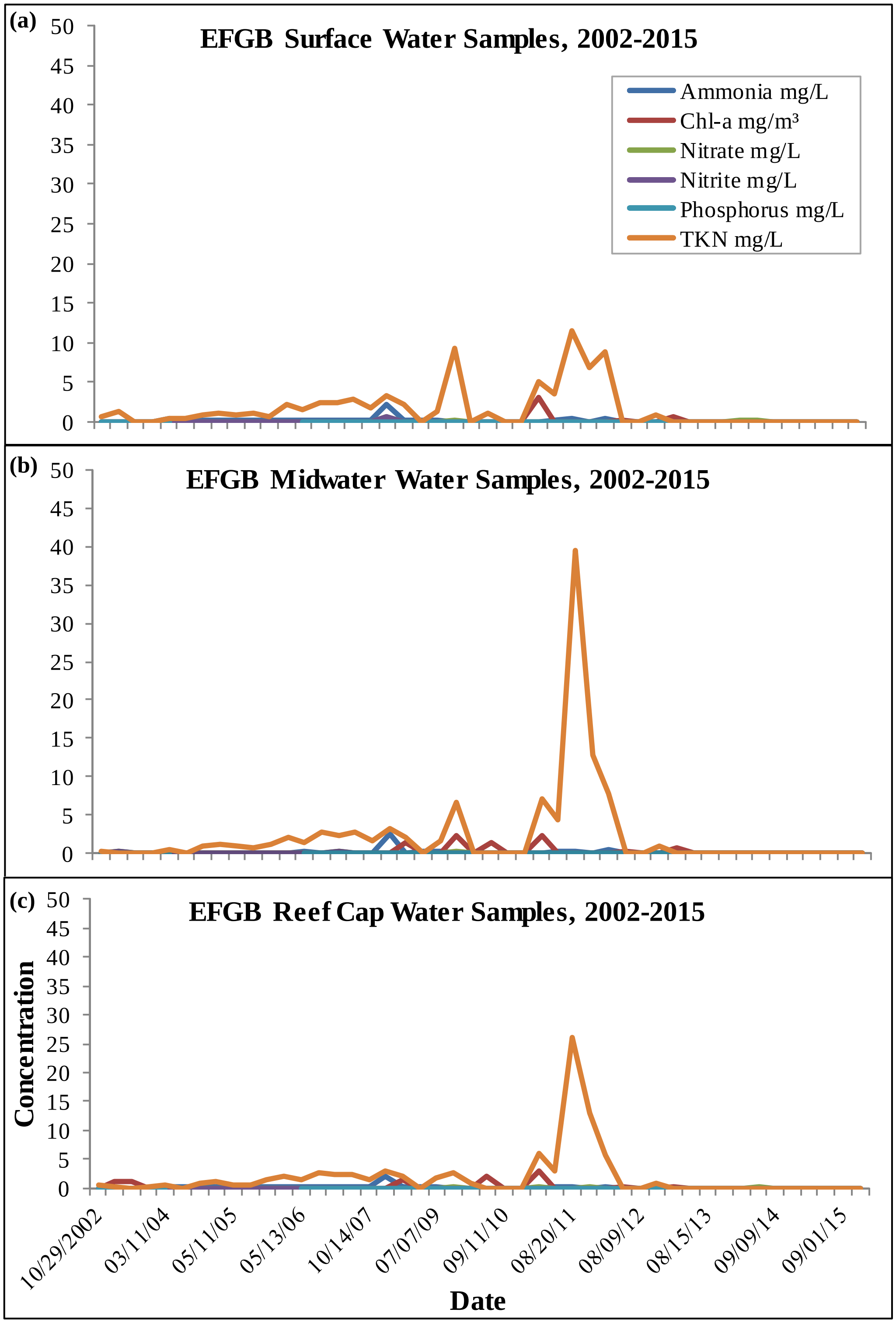


Figure 6.3. EFGB water samples and nutrient analysis taken at the (a) surface, (b) midwater, (c) and reef cap from 2002-2015.

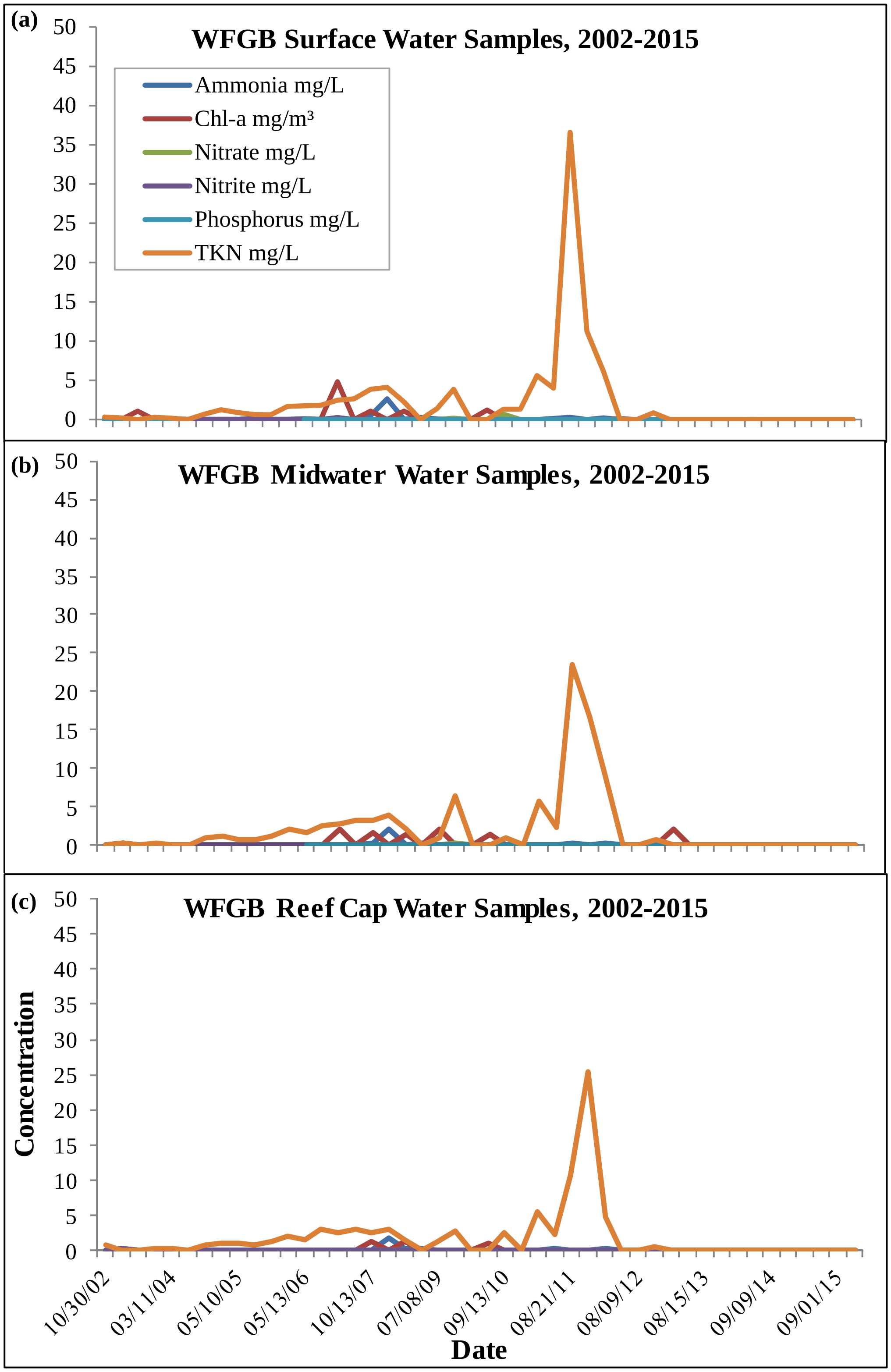


Figure 6.4. WFGB water samples and nutrient analysis taken at the (a) surface, (b) midwater, (c) and reef cap from 2002-2015.

Table 6.1. EFGB carbonate sample results for 2015.

EFGB Date	Depth (m)	Salinity (ppt)	Temp (^oC)	pH Total	Alkalinity (mmol/kg)	DIC (mmol/kg)	pH *in situ*	$\Omega_{aragonite}$	fCO_2 (matm)
2/10/2015	20	36.67	20.19	8.0398	2400.3	2062.4	8.1113	3.46	341.8
2/10/2015	10	36.71	20.73	8.0422	2400.4	2078.5	8.1058	3.49	347.3
2/10/2015	1	36.50	21.00	8.0429	2401.1	2083.7	8.1027	3.50	351.4
5/01/2015	20	36.22	24.08	8.0497	2387.8	2066.4	8.0497	3.57	387.5
5/01/2015	10	36.19	24.16	8.0538	2392.7	2066.1	8.0538	3.60	384.7
5/01/2015	1	36.11	24.29	8.0535	2392.2	2067.1	8.0535	3.60	387.3
11/04/2015	20	36.32	26.08	8.0717	2381.1	2041.4	8.0550	3.73	391.8
11/04/2015	10	36.30	26.14	8.0746	2382.5	2044.1	8.0574	3.76	390.4
11/04/2015	1	36.29	26.19	8.0762	2381.1	2042.5	8.0584	3.78	389.4

Table 6.2. WFGB carbonate sample results for 2015.

WFGB Date	Depth (m)	Salinity (ppt)	Temp (^oC)	pH Total	Alkalinity (mmol/kg)	DIC (mmol/kg)	pH *in situ*	$\Omega_{aragonite}$	fCO_2 (matm)
2/10/2015	20	36.59	19.91	8.0365	2399.4	2081.2	8.1123	3.43	341.2
2/10/2015	10	36.51	20.19	8.0396	2402.4	2082.2	8.1114	3.46	342.8
2/10/2015	1	36.49	20.30	8.0387	2402.2	2080.5	8.1091	3.46	345.3
5/01/2015	20	36.40	24.00	8.0534	2396.1	2072.0	8.0534	3.62	383.2
5/01/2015	10	36.26	24.32	8.0539	2396.3	2075.1	8.0539	3.62	388.6
5/01/2015	1	36.47	24.67	8.0537	2396.7	2069.9	8.0537	3.63	393.0
11/04/2015	20	36.43	25.82	8.0602	2384.6	2055.1	8.0474	3.67	401.7
11/04/2015	10	36.38	25.86	8.0759	2395.1	2057.6	8.0628	3.80	387.1
11/04/2015	1	36.37	25.93	8.0760	2396.1	2055.7	8.0621	3.80	387.8

Discussion

EFGB and WFGB water temperature readings were warmer than averaged historical data in the winter and spring; however, late summer and fall temperatures reached lower than average temperatures, which may be resultant from the effects of El Nino and the least active hurricane season recorded in decades (Klotzbach and Gray 2015). While temperatures reached maximum highs of 28.25^oC at EFGB on the reef crest, they did not exceed the 30^oC bleaching threshold. Temperatures at WFGB reached a maximum of 30.07^oC for one day in August 2015.

Salinity levels at EFGB and WFGB were similar to historical averages for most of the study period, with the exception of an extended event in July 2015, where salinity was reduced by approximately 2 psu. However, the data collected were still within the accepted limits of salinity for coral reefs located in the Western Atlantic (31–38 PSU; Coles and Jokiel 1992). The most probable source of low salinity water at the FGB is a nearshore river-seawater mix that reaches the outer continental shelf, emanating principally from the Mississippi and Atchafalaya River watersheds, and subjecting the FGB occasionally to nearshore processes and to regional river runoff.

Laboratory analyses indicated that nutrient levels at EFGB and WFGB were below detectable levels, indicating low nutrient waters in 2015. However, a historical trend that was apparent at EFGB and WFGB was the increases 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. 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).

Carbonate analysis indicate a thermal control on carbonate systems in this region. After controlling for temperature, surface seawater fCO_2 does not appear to significantly deviate from the atmospheric value, and may have a seasonal pattern with a peak $nfCO_2$ occurring in late winter to early spring (February-March) and lowest $nfCO_2$ in late summer (August-September). The distribution of ΔfCO_2 on an annual basis suggested that this area had a small net air-sea CO_2 flux. Seasonal and spatial distribution of seawater carbonate chemistry in 2015 demonstrates that seawater in the FGBNMS area (including East Bank, West Bank, and Stetson Bank), despite its relative proximity to the land, behaved like an open ocean setting (such as the Bermuda Atlantic Time-series Study, or BATS) (Bates et al. 2012) in terms of its annual fCO_2 fluctuation and minimal terrestrial influence. This data serves as a baseline, offering a reference for future studies in the water column as a result of either man-made or naturally occurring petroleum leakage in the northwestern Gulf of Mexico (Hu 2015).

Chapter 7

CONCLUSIONS

Photo: NOAA FGBNMS/G.P. Schmahl

A bioeroded star coral on the coral cap at West Flower Garden Bank, 2015.

Conclusions

Despite global coral reef decline in recent decades, mean coral cover at EFGB and WFGB was above 50% for the combined 27 years of continuous monitoring, and represented a stable coral community within the study sites. However, mean macroalgae percent cover increased significantly between 1998 and 1999, rising from approximately 3% to 20%, and reaching a maximum above 30% in 2012. In contrast to many other shallow water reefs in the Caribbean region, increases in mean macroalgae cover have not been concomitant with coral cover decline at EFGB or WFGB.

Repetitive quadrat stations at shallow and deep depths ranged in percent coral cover from 60-70%, and contained stable coral communities over time. Macroalgae cover increased over time following a similar pattern to the increasing macroalgae cover in the random transects.

Fish surveys conducted in 2015 indicate an abundant and diverse reef fish community at both EFGB and WFGB. The piscivore guild had the greatest mean biomass, contributing approximately 35% of the total biomass, followed by the herbivore guild. Invasive lionfish were documented in fish surveys for the third consecutive year.

Although water column temperatures warmed quickly early in the year, there were no sustained water temperatures on the reef crest exceeding the 30^{o}C bleaching threshold. While salinity declines in July may indicate potential runoff events, all nutrient samples in 2015 were below detectable limits. Carbonate chemistry indicates that this area acts as a net CO_2 sink.

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 impacts from climate change, storms, changes in water quality, and invasive species, are reasons for increased vigilance and perhaps concern for the future of the resources.

The relatively high percent coral cover conditions since the beginning of the monitoring program make EFGB and WGB ideal for protection and conservation. Continued monitoring will document changes in the reef community condition compared to the historical baseline, and enable resource managers to make decisions regarding management and research activities focused on the dynamics of the benthic communities and the biota they support.

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NATIONAL MARINE SANCTUARY SYSTEM

Scale varies in this perspective. Adapted from National Geographic Maps.

AMERICA'S UNDERWATER TREASURES