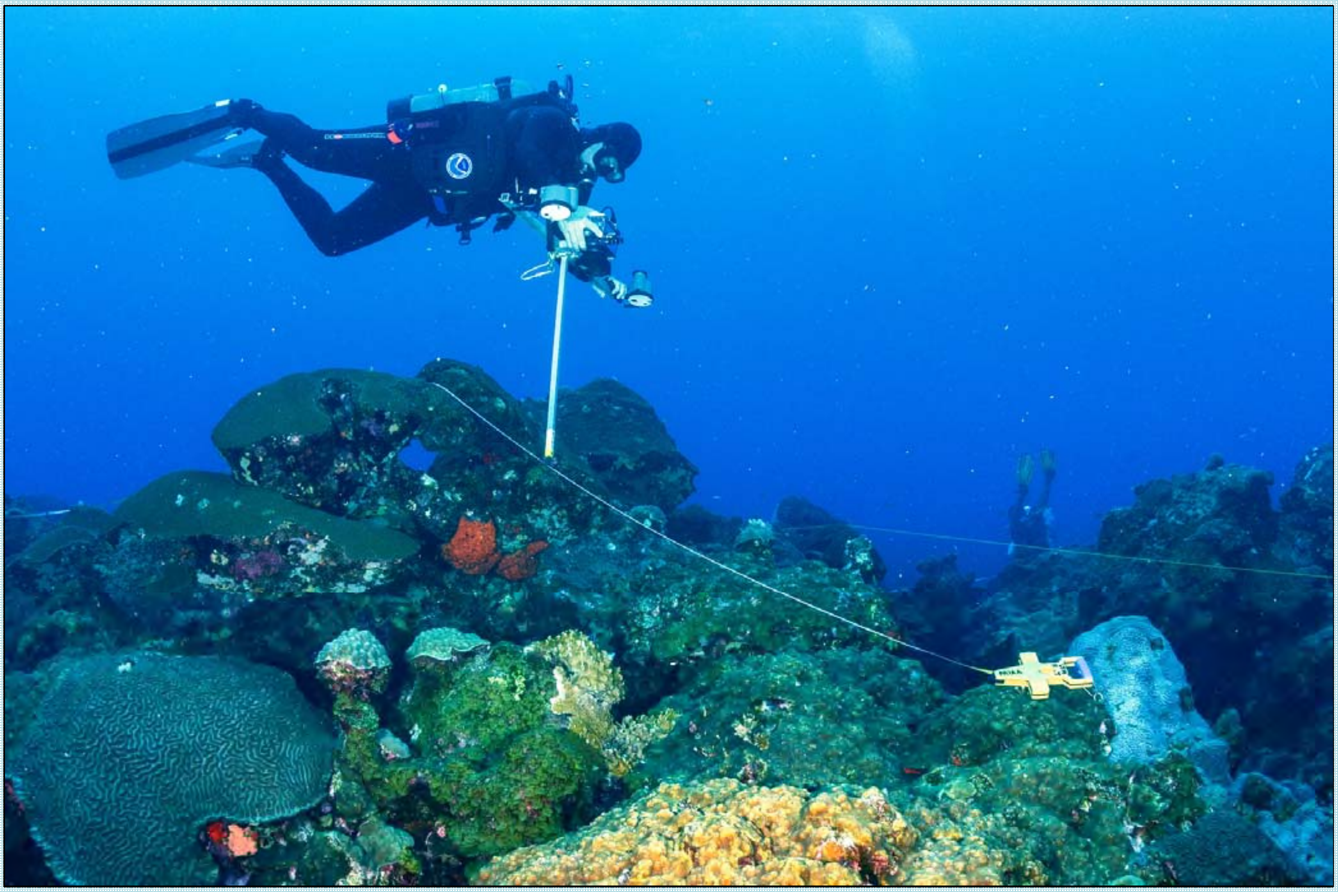
Office of National Marine Sanctuaries
National Oceanic and Atmospheric Administration

Long-Term Monitoring at East and West Flower Garden Banks: 2014 Annual Report



July 2015

http://flowergarden.noaa.gov

Suggested Citation:
Johnston, M.A., M.F. Nuttall, R.J. Eckert, and J.A. Embesi. 2015. Long-Term Monitoring at East and West Flower Garden Banks National Marine Sanctuary: 2014 Annual Report. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Flower Garden Banks National Marine Sanctuary, Galveston, TX. 63 pp.

Cover Photo:
NOAA dive master, John Embesi, photographing a repetitive quadrat photostation at the East Flower Garden Bank, 2014. Credit: NOAA FGBNMS/GP Schmahl

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Acknowledgments

We thank the individuals, listed below, who contributed their time and expertise to make this long-term monitoring effort successful. We are grateful to NOAA and BOEM staff for their invaluable institutional knowledge. In particular, we acknowledge Greg Boland and Matthew Johnson for their support and dedication to this project.

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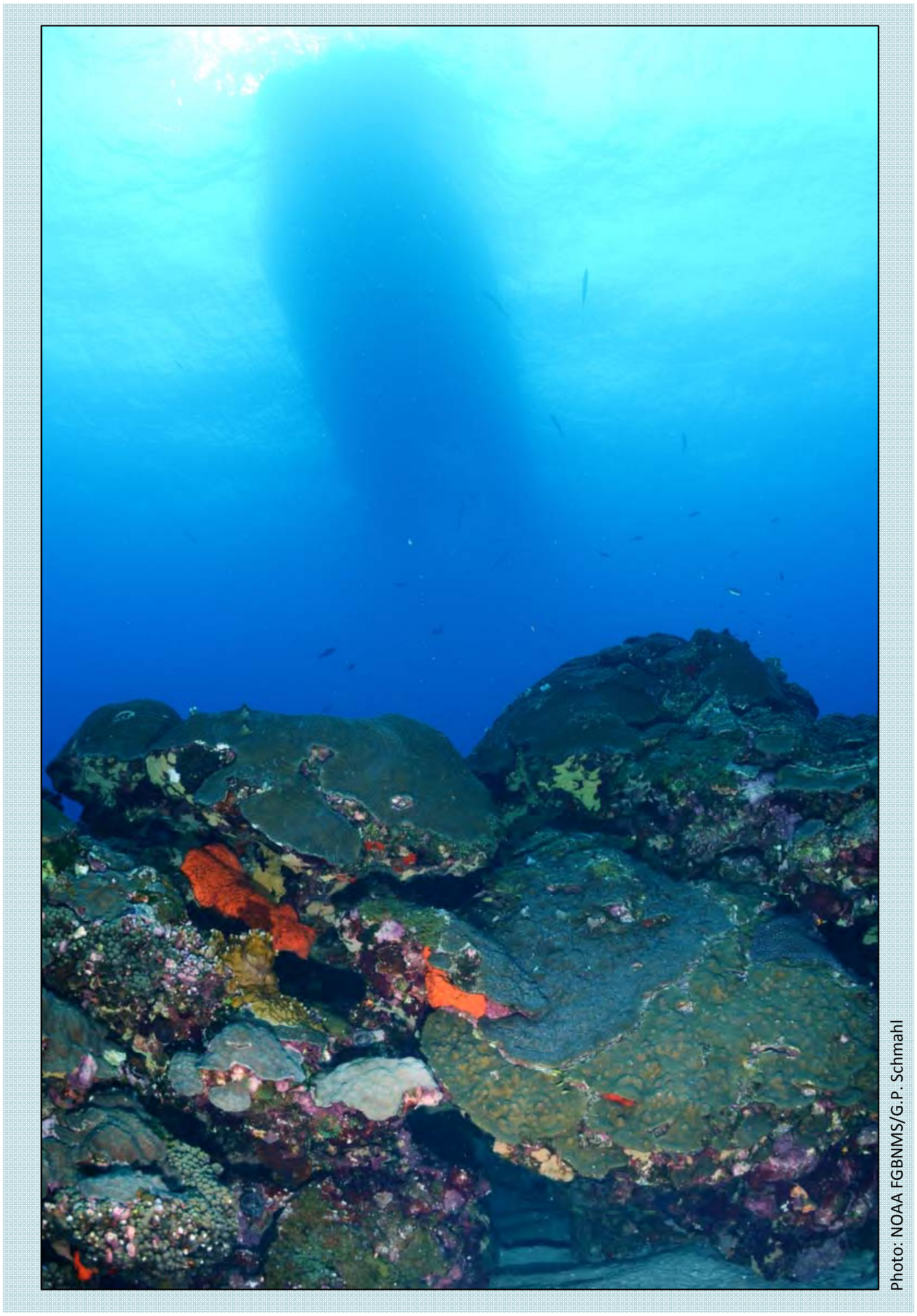


Photo: NOAA FGBNMS/G.P. Schmahl

RV Manta over the coral reef at West Flower Garden Bank, 2014.

In 26 years of continuous monitoring, the coral reefs of East and West Flower Garden Banks (EFGB and WFGB) have maintained levels of coral cover above 50% and have suffered minimally from hurricanes, coral bleaching, and disease, supporting relatively diverse and abundant benthic and fish populations in the northwestern Gulf of Mexico.

This report summarizes fish and benthic community observations from 2014 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 2014 monitoring period include:

Chapter 2: Random Transects

- *Benthic communities at EFGB and WFGB are dominated by coral, with approximately 60% mean coral cover 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 (27%).*
- *Pseudodiploria strigosa is the second most abundant species (11%).*
- *Despite continued mean coral cover above 50 percent, macroalgae mean cover has been 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 74%.*
- *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

- *Pomacentridae (damelfish), Serranidae (groupers), and Labridae (wrasses and parrotfish) are the dominant fish families at both banks.*
- *The most abundant species include Brown Chromis (Chromis multilineata), followed by Bluehead (Thalassoma bifasciatum).*
- *Mean fish density (abundance per 100* m^2*) is highest at WFGB.*
- *Mean fish biomass (100* g/m^2*) is greatest at EFGB, with piscivores comprising over half the biomass.*
- *First observed in 2011 at the FGB, lionfish (Pterois volitans/miles) were documented in the long-term monitoring dataset for the second consecutive year, with a sighting frequency of 35%.*

Chapter 6: Conclusions

- *The results are consistent with previous monitoring efforts of mean coral cover above 50% at the Flower Garden Banks, highlighting the coral stability at the study sites since the start of the monitoring program in 1989.*
- *The coral reef of the Flower Garden Banks continues to be healthy and stable compared to other reefs in the Caribbean, although macroalgae cover is increasing.*
- *The number of coral and fish species at EFGB and WFGB are lower than the most diverse areas of the Caribbean and western Atlantic; however, percent coral cover and fish abundance are greater.*
- *Continued monitoring will document long-term changes in condition and will be useful for management decisions and future research focused on the dynamics of the robust benthic communities and the fish populations they support.*

Chapter 1

LONG-TERM MONITORING AT EAST AND WEST FLOWER GARDEN BANKS


Photo: TAMUG/Amanda Sterne

A Christmas tree worm at East Flower Garden Bank, 2014.

Long-Term Monitoring Introduction

The coral reef-capped East and West Flower Garden Banks are part of a discontinuous arc of reef environments along the outer continental shelf in the northwestern Gulf of Mexico containing the northernmost coral reefs in North America (Bright et al. 1985; Rezak et al. 1985) (Figure 1.1). In the 1970s, because of concern about potential impacts of 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 East and West Flower Garden Banks (EFGB and WFGB). The purpose was to establish baseline data and determine if these reefs were impacted by nearby oil and gas exploration and production activities (Figure 1.2).

In 1988, DOI officially established a long-term monitoring program to evaluate the potential ongoing impacts of oil and gas development to EFGB and WFGB. The long-term monitoring effort evaluates changes in living coral and benthic community cover, coral growth rates, reef fish population dynamics, water quality, and other indices of reef vitality within designated 10,000 m^2 study sites on the coral reef of EFGB and WFGB.

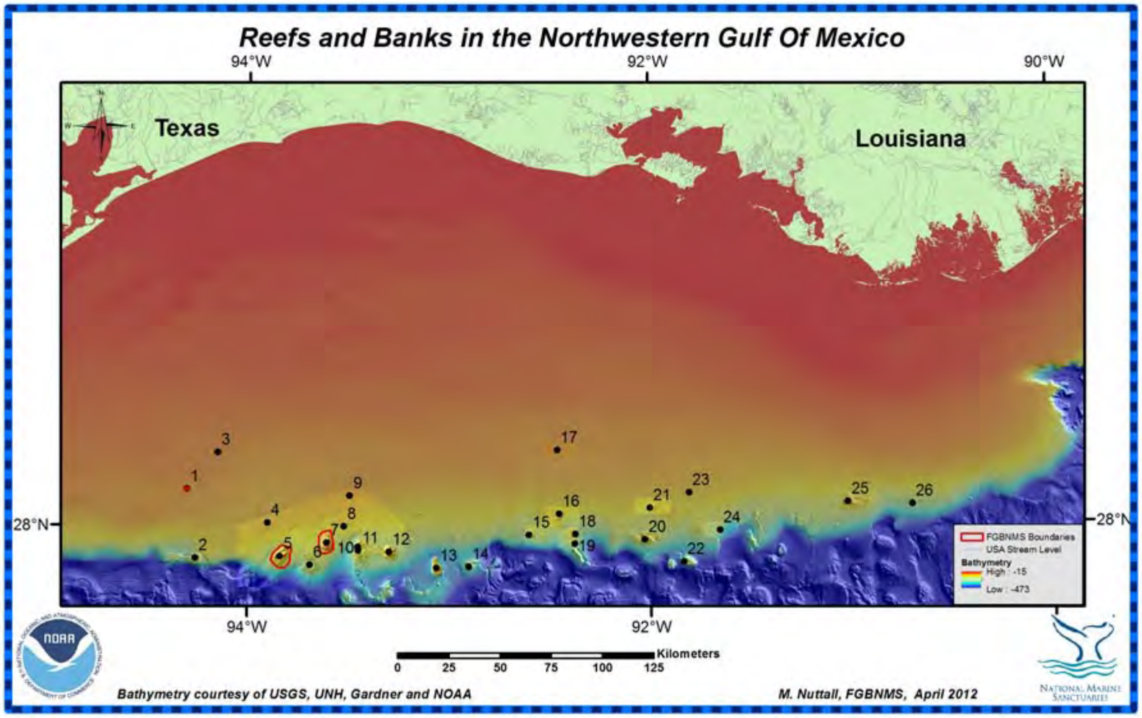


Figure 1.1. Map of EFGB, WFGB, and Stetson Bank (outlined in red) in relation to the Texas-Louisiana continental shelf and other topographic features of the northwestern Gulf of Mexico.

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.

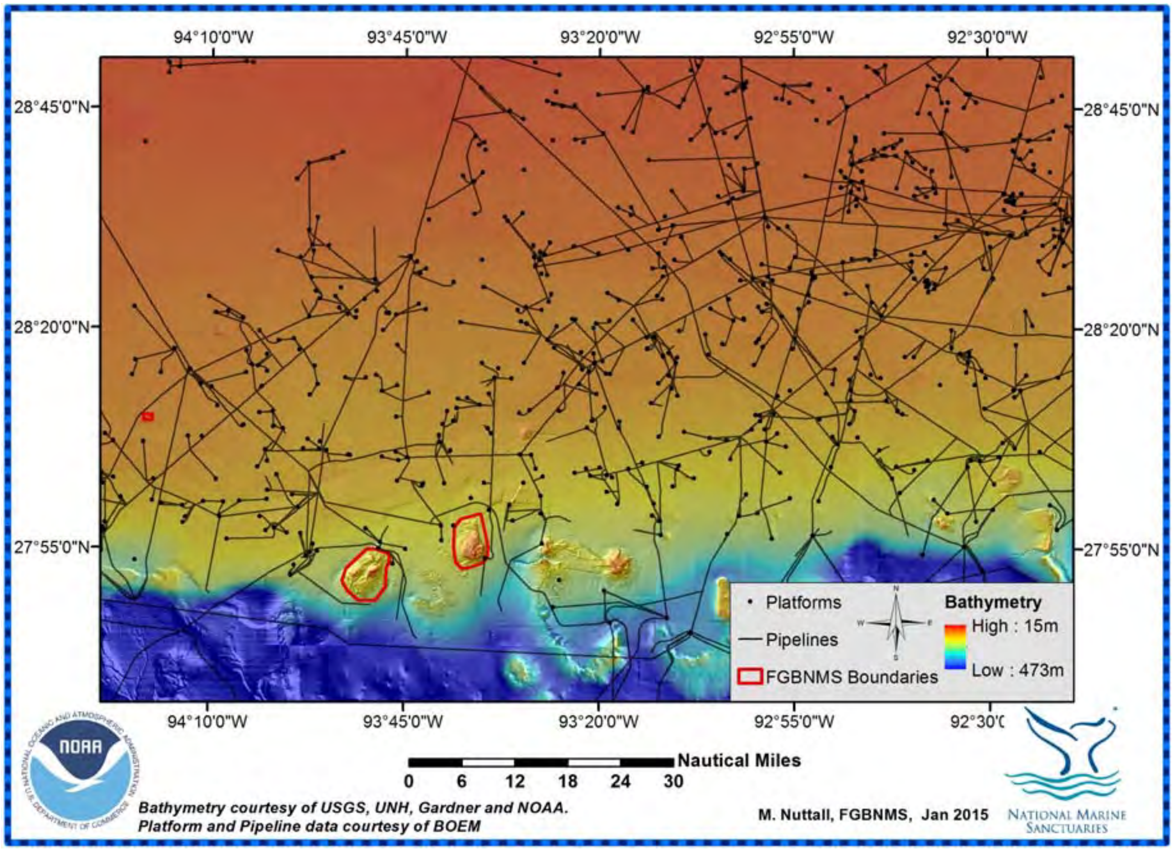


Figure 1.2. Map of oil and gas platforms and pipelines near EFGB, WFGB, and surrounding banks.

Though many coral reefs in the western Atlantic and Caribbean region have experienced significant declines in coral cover, the reefs of EFGB and WFGB, which are part of Flower Garden Banks National Marine Sanctuary (FGBNMS), support healthy coral and fish assemblages (Johnston et al. 2013; Clark et al. 2014). 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.

EFGB and WFGB are located roughly 190 km offshore and at a depth of at least 17 m. Total depth at EFGB ranges from 17–134 m, and 18–140 m at WFGB. All monitoring at both banks was conducted within the coral reef zone (Schmahl et al. 2008), which is the shallowest portion of the reef known as “the reef cap.” While abundant, coral species diversity at both banks is low; 31 species from 18 genera are represented, compared to 67 species found on some Caribbean reefs (Goreau and Wells 1967; Schmahl et al. 2008).

Long-Term Monitoring Study Sites

The monitoring effort was conducted from the NOAA *R/V Manta* during July 22–25, 2014. Data was collected within 10,000 m² (100 x 100 m or 1 hectare) study sites that were established in 1989 (hereafter referred to as “study sites”) and are located on the shallow reef cap at the Flower Garden Banks (FGB), and in deeper sites (40 m) that were later established outside the study sites.

The approximate centers of the study sites are 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). Within the locations of the study sites, depths ranged between 17–27m at EFGB, and 18–25 m at WFGB.

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

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

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. 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 the 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).

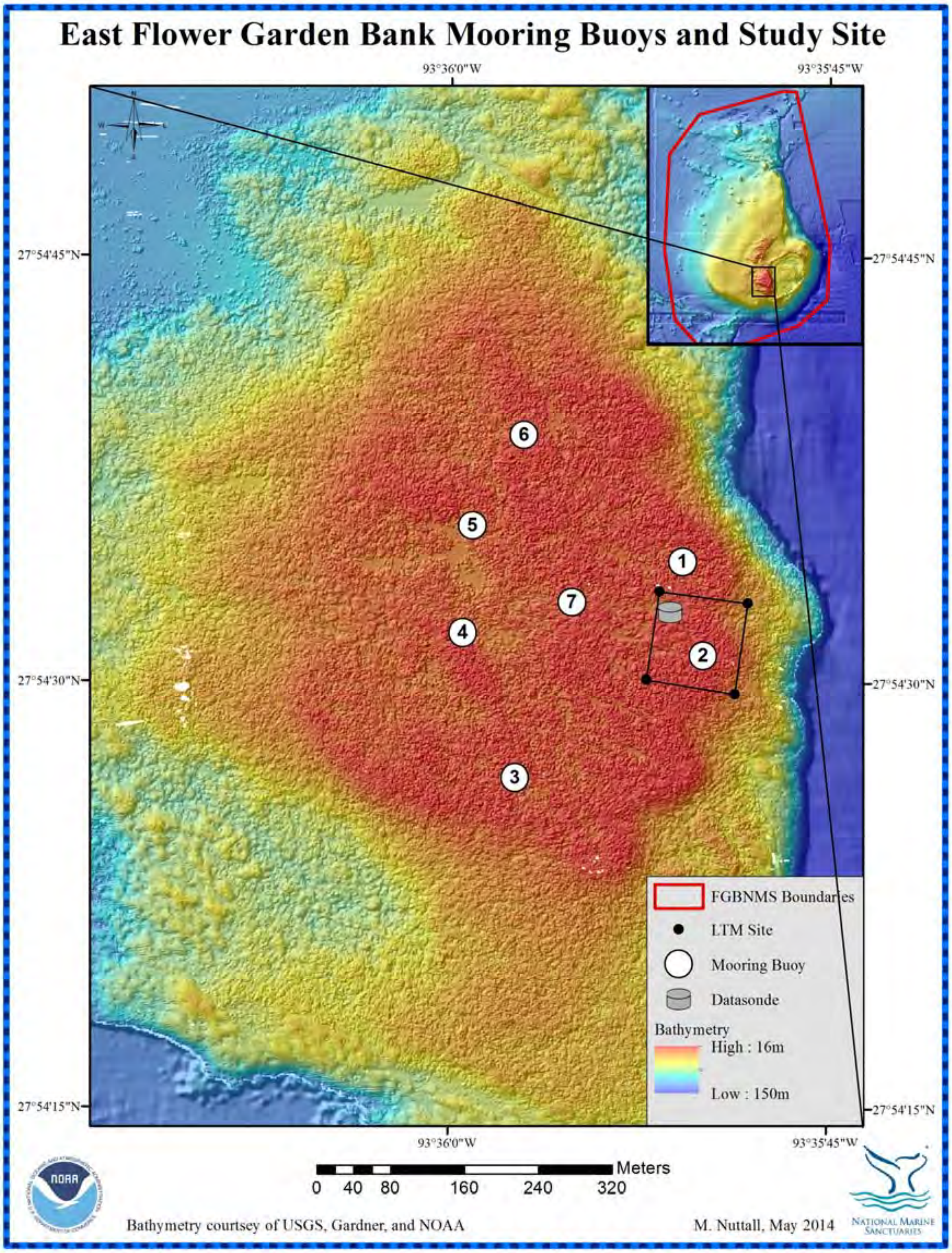


Figure 1.3. Bathymetric map of EFGB with long-term monitoring study site (LTM site), mooring buoy, and datasonde locations.

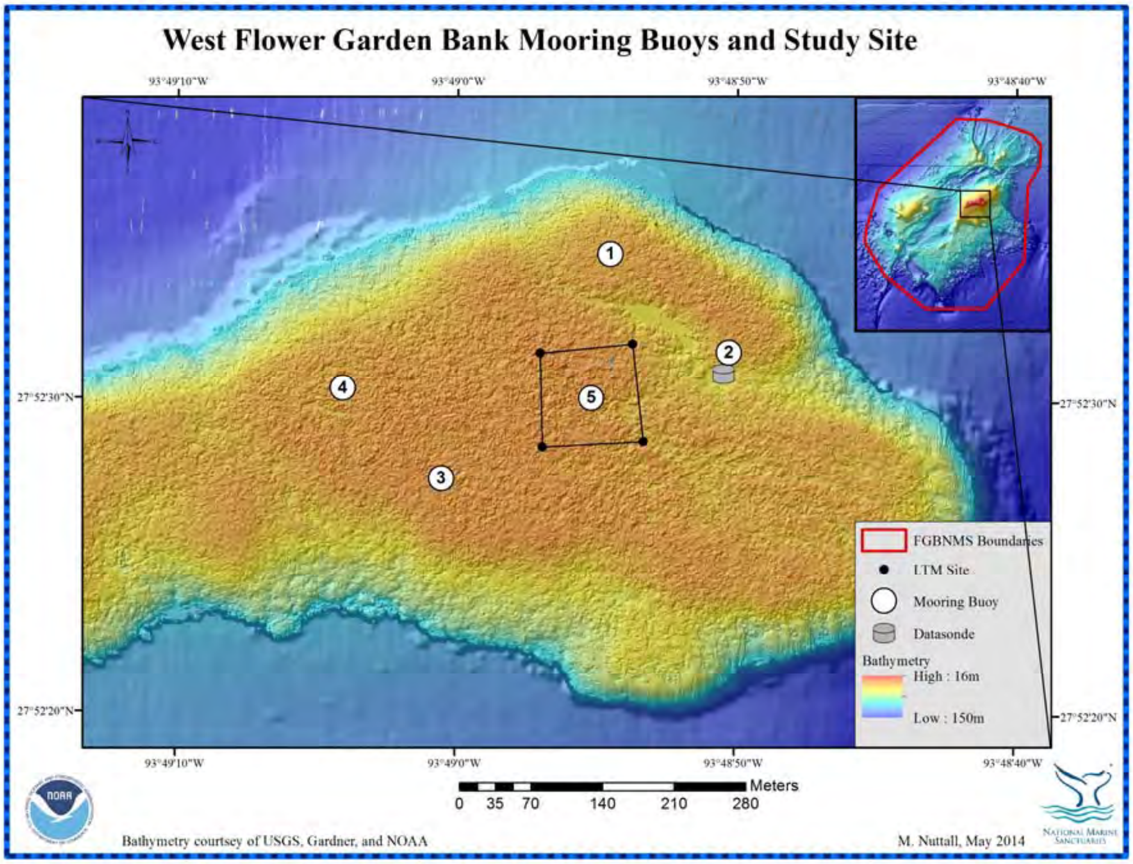


Figure 1.4. Bathymetric map of WFGB with long-term monitoring study site (LTM site), mooring buoy, and datasonde locations.

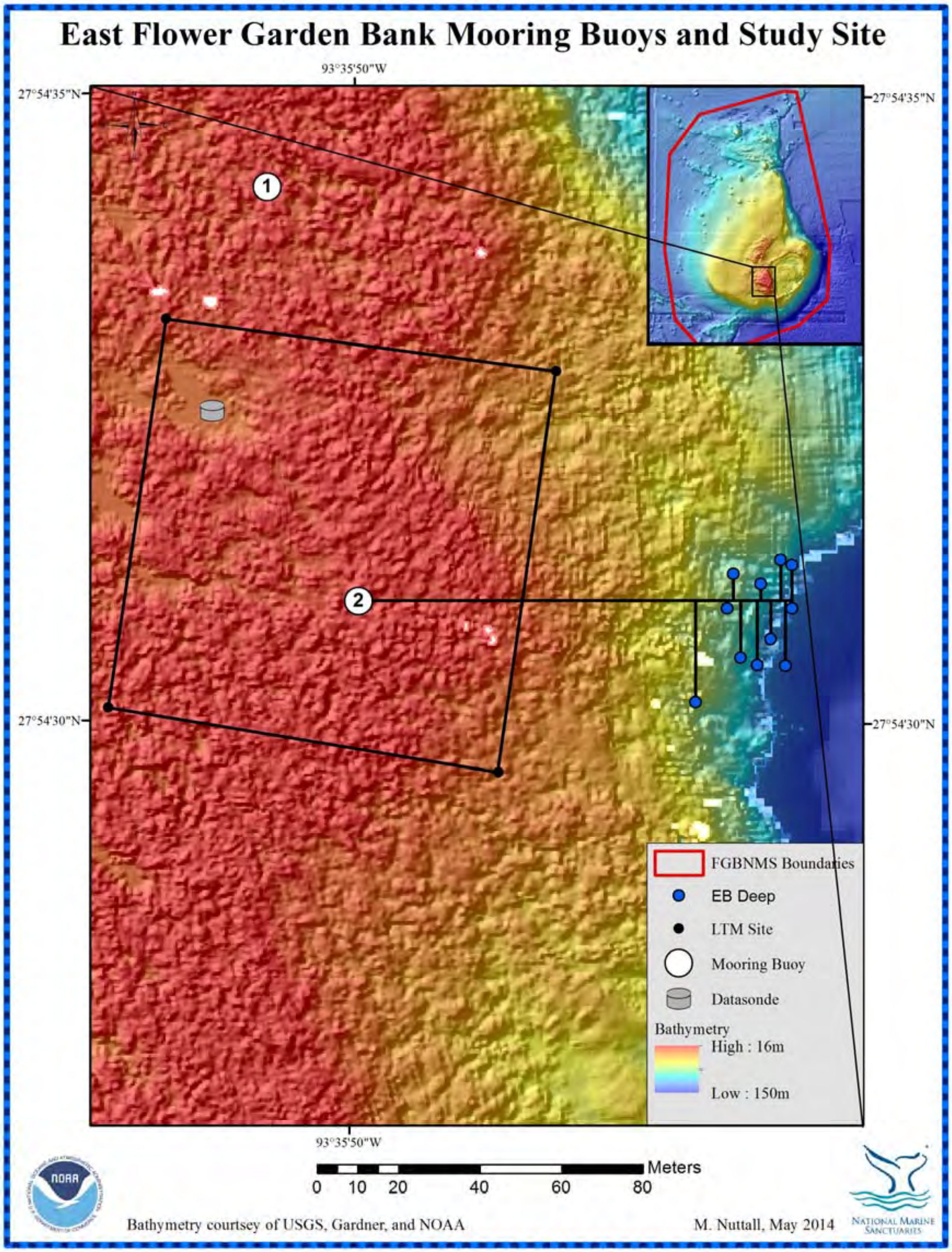


Figure 1.5. Bathymetric map of EFGB with long-term monitoring study site (LTM site), mooring buoy, and repetitive deep photostation locations (EB Deep).

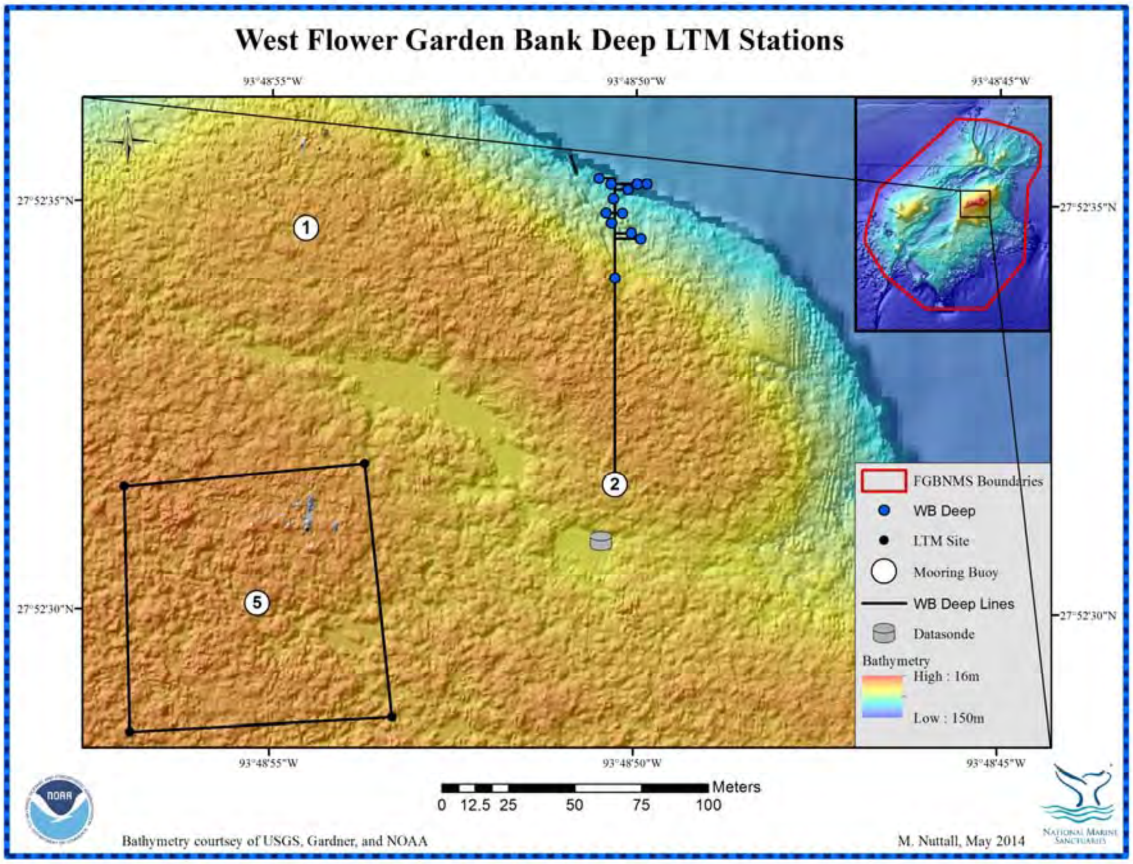


Figure 1.6. Bathymetric map of WFGB with long-term monitoring study site (LTM site), mooring buoy, and repetitive deep photostation locations (WB Deep).

For multi-year long-term monitoring reports (Rezak et al. 1985; 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. 2015 in review), 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.
- 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 to record salinity, temperature, and depth. Quarterly water sampling is conducted at both banks to test for chl *a*, ammonia, nitrate, nitrite, TKN, and phosphorous.

For the purposes of one-year annual reports, random transects, repetitive photostations, and fish surveys 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 (Rezak et al. 1985; 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. 2015 in review). It should be noted that an abbreviated data collection occurred during the 2014 long-term monitoring cruise due to funding limitations and only selected objectives (random transects, repetitive quadrat photos, and fish surveys as reported in this document) were completed.

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

To estimate the areal coverage of benthic components such as corals, sponges, and macroalgae, photographs along 10 m transect tapes were taken randomly within each study site. Conducted at random locations, the transect surveys were used to compare habitat between banks and provide information to document the benthic reef community of EFGB and WFGB in 2014.

Random Transect Methods

Random Transect Field Methods

Four random transects within each quadrant of both study sites, totaling 16 transects per bank, were completed. Each transect captures approximately 8 m^2 of benthic habitat. 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 non-overlapping images above the reef (Figure 2.1).

Photo: NOAA FGBNMS/G.P. Schmahl

Figure 2.1. A camera and strobes are mounted on an aluminum t-frame to take random transect photos.

A 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 intervals marked on a spooled, fiberglass, measuring tape at 55.88 cm apart producing 17 non-overlapping images along the 10 m transect. Each still frame image captured an 80 x 55 cm area. This produced a total photographed area of 8.36 m^2 per transect, or a minimum of 117.04 m^2 photographed per study site per year (for more detailed methods, see Johnston et al. 2013).

Random Transect Data Processing

Mean percent cover in the random transect images was analyzed using Coral Point Count with Microsoft® Excel® extensions (CPCe) (Kohler and Gill 2006). CPCe outputs included parameters of each species/substrate type (mean, standard deviation, standard error) and the calculation of the Shannon–Weaver diversity index for each species.

A total of 500 points was distributed evenly among all photos within a transect. Points were randomly overlaid on each image and benthic species lying under these points were identified. Organisms positioned beneath each random dot were identified as follows: corals, sponges, and macroalgae were identified to lowest possible taxonomic group (macroalgae included algae longer than approximately 3 mm and included thick algal turfs); and crustose coralline algae, fine turfs, and bare rock were grouped as “CTB” (Aronson and Precht 2000). 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. Percent cover of each functional group was used to calculate ecological distance via Bray-Curtis similarity matrices (Bray and Curtis 1957). 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).

For long-term trends (1978–2014), each functional group sample was averaged by year and compared using nonparametric analysis for non-normal data. Multidimensional scaling (Kruskal 1964) was used to visualize community dissimilarities between years, with time series trajectory to highlight community shifts over time. Cluster analyses were performed on 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 SIMPER.

Diversity indices including species richness, Margalef’s species richness (d), Pielou’s eveness (J’), and Shannon diversity (H’) were calculated to make comparisons between banks based on benthic diversity.

Random Transect Results

Random Transect Mean Percent Cover

The major benthic components of the 2014 random transects were coral cover (60%), followed by macroalgae cover (28%), CTB (10%), and sponge cover (1%) (Figure 2.2).

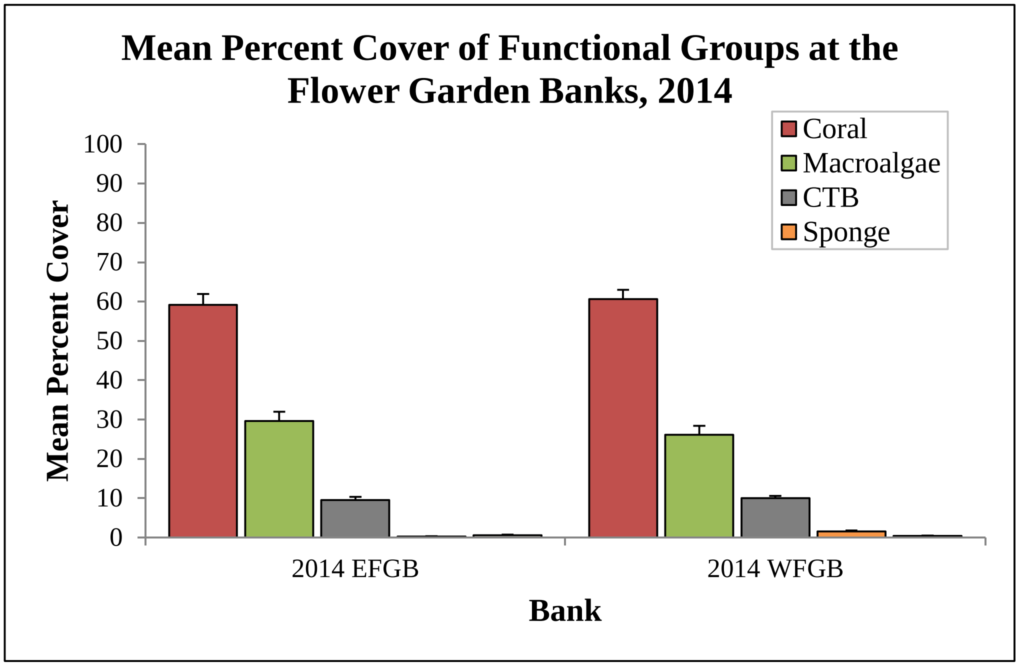


Figure 2.2. Mean percent cover + SE from random transect functional groups at the FGB.

Consistent with past monitoring results (Johnston et al. 2013; Johnston et al. 2014), EFGB mean (± standard error) coral cover was above 50% in 2014 (59.16% ± 2.80) and the sponge cover remained extremely low (0.28% ± 0.08). Mean macroalgae cover was 29.65% ± 2.34 and mean CTB cover was 9.55% ± 0.76. At WFGB, mean coral cover was above 50% (60.66% ± 2.30), followed by mean macroalgae (26.14% ± 2.23), CTB (10.05% ± 0.50), and sponge cover (1.53% ± 0.29). When using ANOSIM to compare for differences between banks based on functional groups, no significant dissimilarities were found, suggesting that EFGB and WFGB were similar in overall benthic community composition.

In the 2014 random transects less than 5% of the coral cover analyzed showed incidences of bleaching, paling, or fish biting. In addition, no incidences of coral disease were observed. It is important to note that bleaching as determined by the long-term monitoring methodology may be incomplete, as surveys usually occur in early summer months when weather is optimal (before signs of bleaching occur).

Orbicella franksi was the most abundant coral species observed in 2014 (27.53% ± 4.04) at EFGB. *Pseudodiploria strigosa* (10.21% ± 1. 27) was the next most abundant species. Corals that could not be differentiated (less than 0.2%) because of camera angle or camera distortion were labeled as "unidentified coral" (Figure 2.3). *Orbicella franksi* was also the most abundant coral species observed in 2014 (25.48% ± 2.34) at WFGB, followed by *Pseudodiploria strigosa* (11.78% ± 2.05) (Figure 2.3).

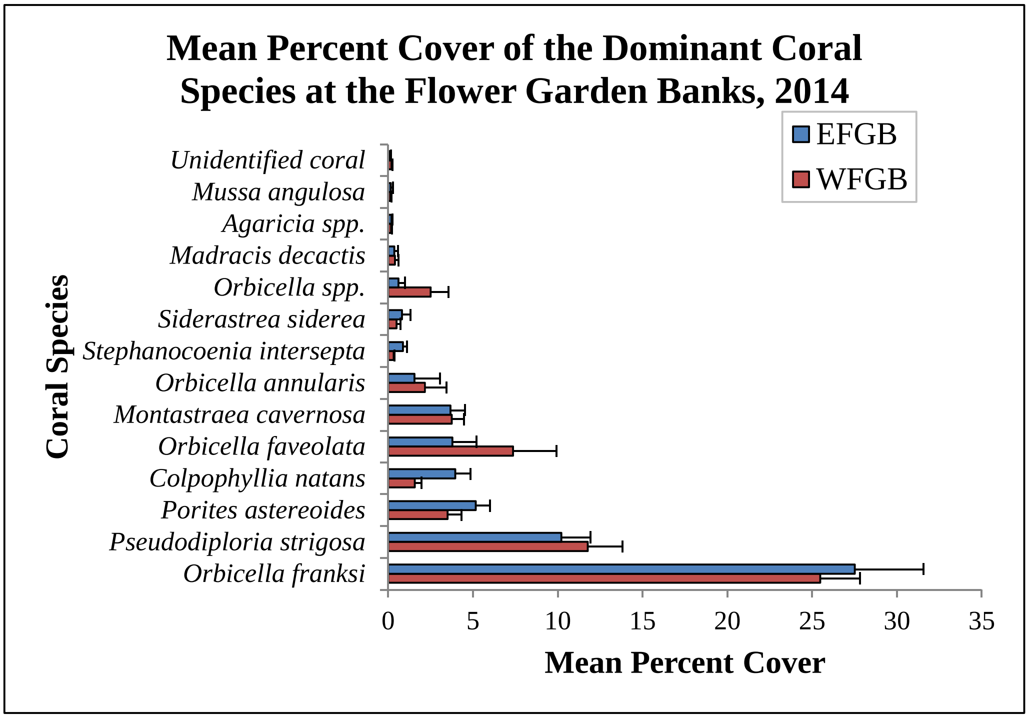


Figure 2.3. Mean percent cover + SE of observed dominant coral species from random transects.

Diversity measures were averaged between EFGB and WFGB over the year (Table 2.2). When compared for differences between banks based on diversity measures, no significant dissimilarities were found, suggesting that EFGB and WFGB were similar in overall species richness and evenness.

Table 2.2. Diversity measures presented as mean ± SE from 2014.

Random Transect Diversity Measures	EFGB	WFGB
Species Richness	98.64 ± 0.57	98.38 ± 0.44
Margalef's Species Richness (d)	0.59 ± 0.03	0.63 ± 0.02
Pielou's Eveness (J')	0.68 ± 0.03	0.68 ± 0.02
Shannon Diversity (H'(loge))	0.88 ± 0.03	0.92 ± 0.02

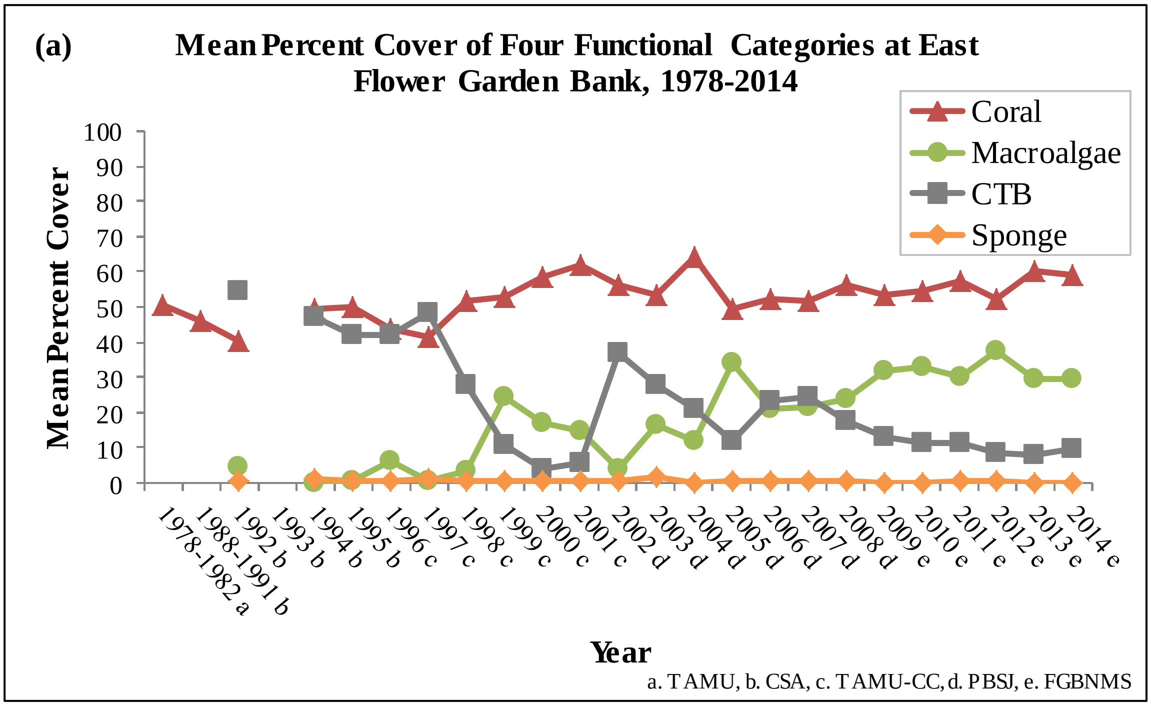
Random Transect Long-Term Trends

A historical comparison of dominant 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 functional categories from the random transects (coral, sponge, macroalgae, and CTB) were analyzed. Mean percent coral cover at EFGB and WFGB during the period from 1978–2014 ranged from 39–62% with a mean of approximately 53% cover over time. The highest coral cover recorded was in 2010 at WFGB (Figure 2.4).

Multivariate historical cover analysis from EFGB and WFGB was compared among years (1994–2014) to evaluate changes in the benthic community. Cluster and MDS analysis placed the mean percent cover from 1994–2014 in two significant clusters (85% similarity) (Figure 2.5). The data suggests communities were similar from 1994–1997; a significant shift in community composition occurred in 1998 to another that has persisted from 1999–2014. SIMPER analysis identified that for most comparisons from 1994–2014, the greatest contributors to the observed dissimilarity were CTB and macroalgae.

A noticeable trend is that macroalgae cover has increased since the beginning of the monitoring program (Figure 2.4). Macrolgae cover at the FGB remained relatively low until 1998, never exceeding approximately 6% at either bank. It increased dramatically in 1999 and, while fluctuating, has remained comparatively high when compared to previous years. A reciprocal relationship between macroalgae and CTB has been observed throughout the monitoring program. However after 2008, macroalgae dominated CTB cover, as macroalgae cover continued to increase.

These trends correspond to SIMPER results, suggesting that the greatest contributors to the observed dissimilarity over time were CTB and macroalgae. This also corresponds to the MDS analysis, suggesting that from 1994–1997 the community was stable, and in 1998 there was a shift due to changes in CTB and macroalgae cover, causing the community to stabilize once again from 1999–2014, but with higher macroalgae percent cover than ever recorded on both banks.



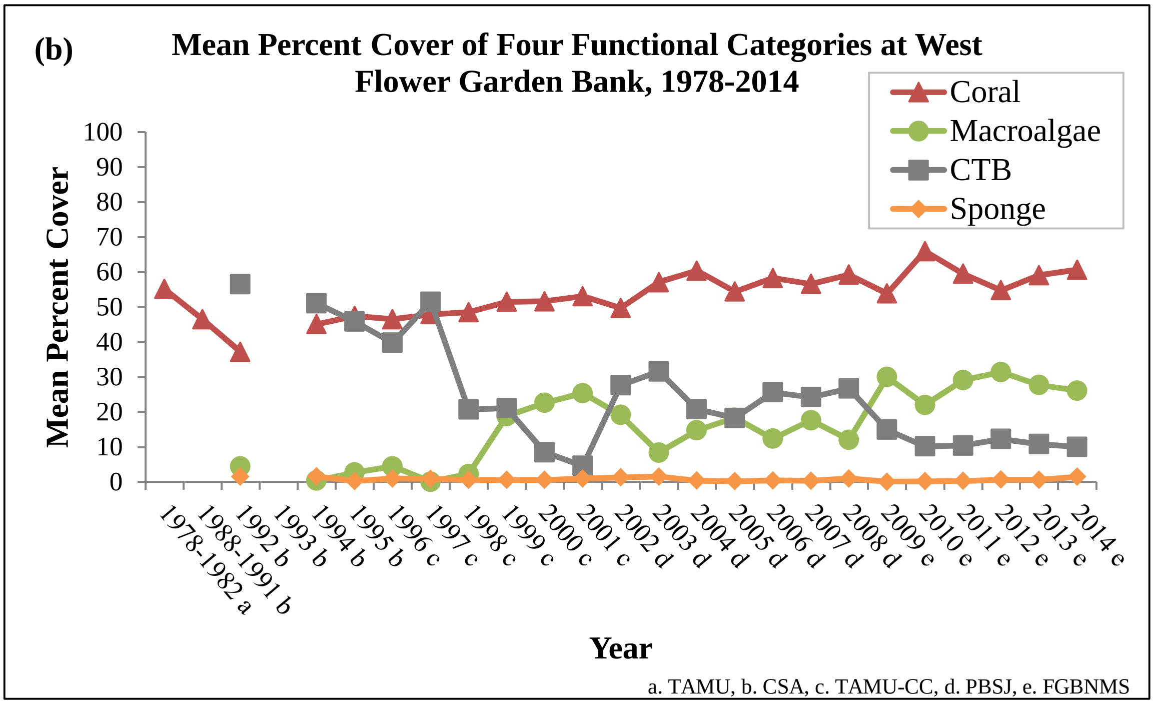


Figure 2.4. Mean percent cover of coral, sponge, macroalgae, and CTB at (a) EFGB and (b) WFGB.

No mean percent cover data were reported in 1993. Data for 1978–1982 from Gittings et al. (1992), who reported data from Kraemer (1982); for 1988–1991 from Gittings et al. (1992); for 1992–1995 from Continental Shelf Associates, Inc. (CSA 1996); for 1996–2001 from Dokken et al. (2003); 2002–2008 from PBS&J (Precht et al. 2006, 2008b); and FGBNMS for 2009–2010 (Johnston et al. 2013); 2011–2012 (Johnston et al. 2015 in review) and 2013 (Johnston et al. 2014).

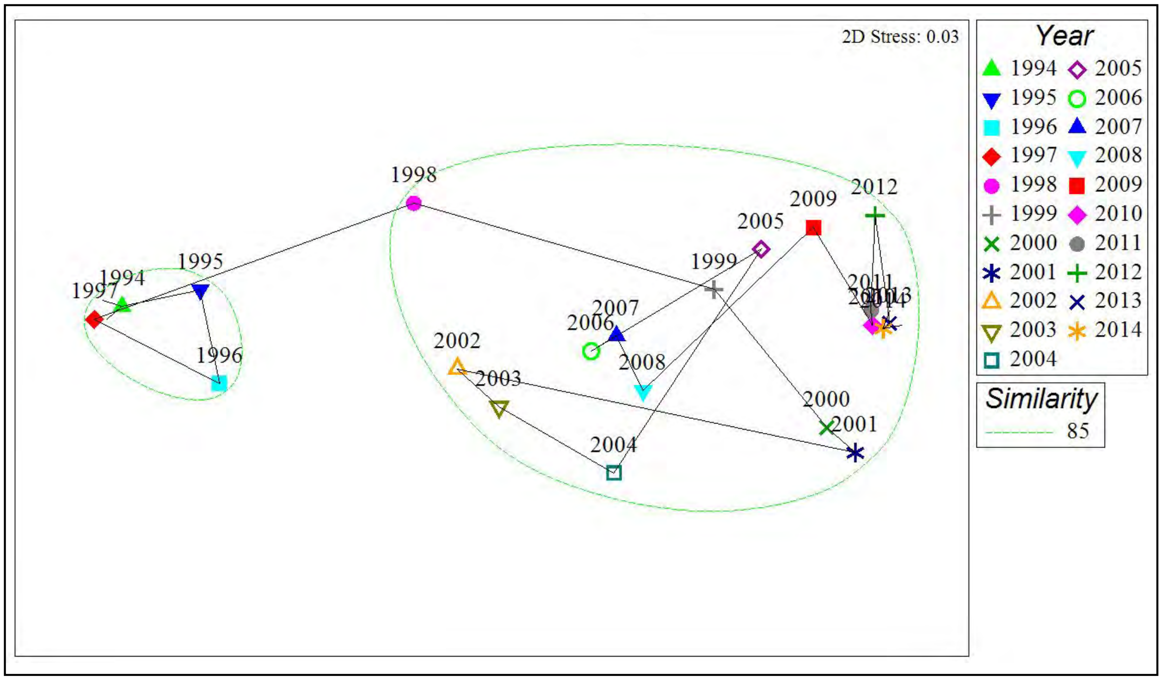


Figure 2.5. Two-dimensional MDS plot based on Bray-Curtis similarities comparing benthic cover analysis from 1994–2014 at the EFGB and WFGB.

The green circle groups surveys that are 85% similar.

Random Transect Discussion

In a global trend of declining coral reef health, the FGB continues to support high coral cover compared to reefs in the Caribbean region (Aronson et al. 1994, 2005; Gardner et al. 2003; AGRRA 2003; Pina Amargós et al. 2008; Steneck et al. 2011; Johnston et al. 2013). Gardner et al. (2003) reported the regional decline of corals across the Caribbean basin over the last three decades, with mean coral cover decreasing from approximately 50% to 10%. Natural and anthropogenic factors, including storms, temperature stress, disease, predation, overfishing, sedimentation, eutrophication, and habitat destruction have all played a part in the decline (Aronson and Precht 2001; Rogers and Beets 2001; Gardner et al. 2003). In Bonaire, live coral declined from a consistent 48% (from 1999–2009) to 38% in 2011 after a bleaching event (Steneck et al. 2011). Mean coral cover in Florida Keys National Marine Sanctuary decreased from 13% in 1996 to 7% in 2010 (ONMS 2011). In contrast, FGB coral cover 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 reasons for the condition of the FGB include 1) depth of water above the reefs; 2) the remote offshore location 3) presence of oligotrophic, oceanic waters; 3) healthy grazer populations; and 4) protective federal regulations (Aronson et al. 2005).

Chapter 3

REPETITIVE QUADRAT PHOTOSTATIONS

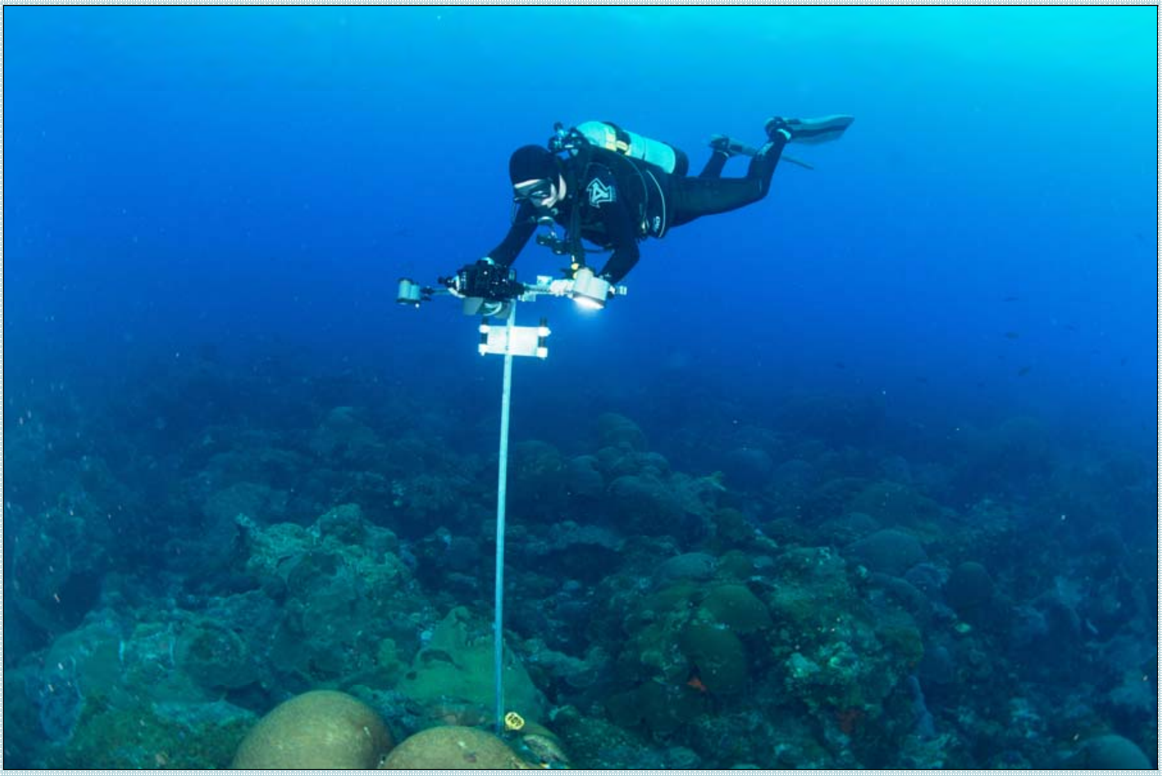


Photo: NOAA FGBNMS/G.P. Schmahl

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

Repetitive Quadrat Photostation Introduction

Permanent repetitive quadrat photostations covering 5 m^2 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 2014 using random-dot analysis.

Repetitive Quadrat Photostation Methods

Repetitive Quadrat Photostation Field Methods

In 2014, 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).

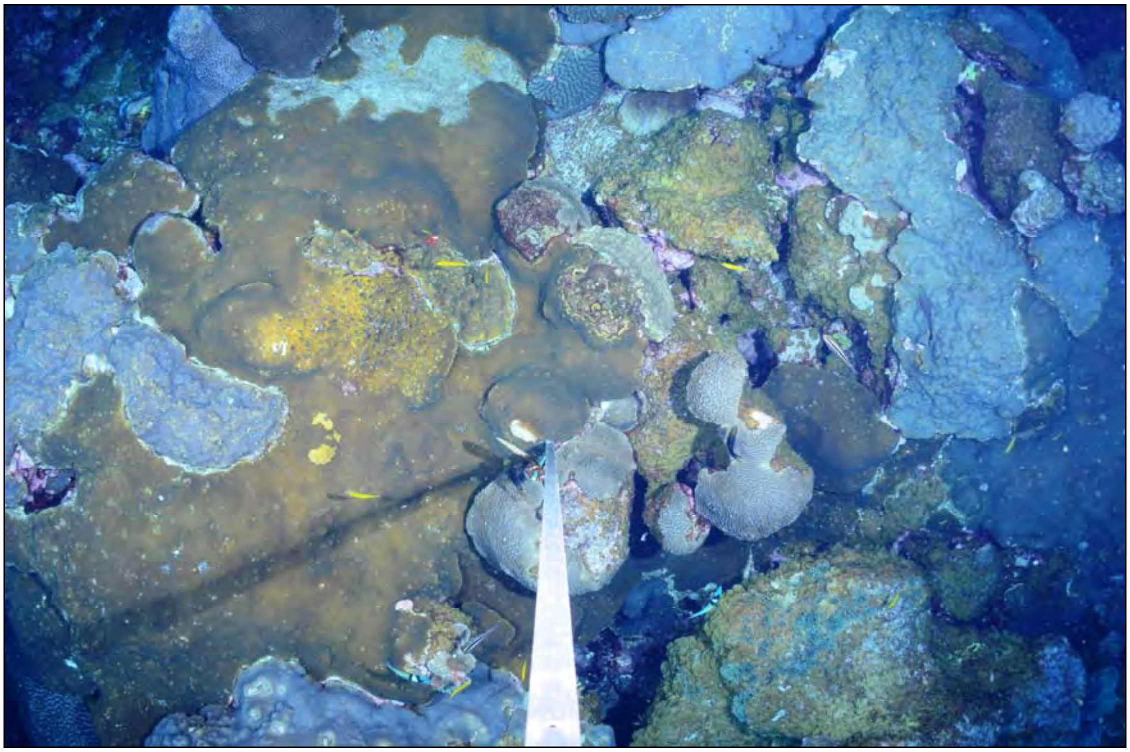


Photo: NOAA FGBNMS/G.P. Schmahl

Figure 3.1. Repetitive quadrat photostation #504 at WFGB in 2014.

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 same quadrats 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 2014 (63.64% ± 2.91), and the sponge cover was extremely low (0.28% ± 0.11). Mean macroalgae cover was 20.75% ± 1.92, and mean CTB cover was 14.63% ± 1.26. In repetitive quadrats at WFGB, mean coral cover was approximately 60% in 2014 (59.98% ± 1.94). The sponge cover was low at the WFGB (0.13% ± 0.07). Mean macroalgae cover was 24.20% ± 1.87 and CTB cover was 14.06% ± 0.79.

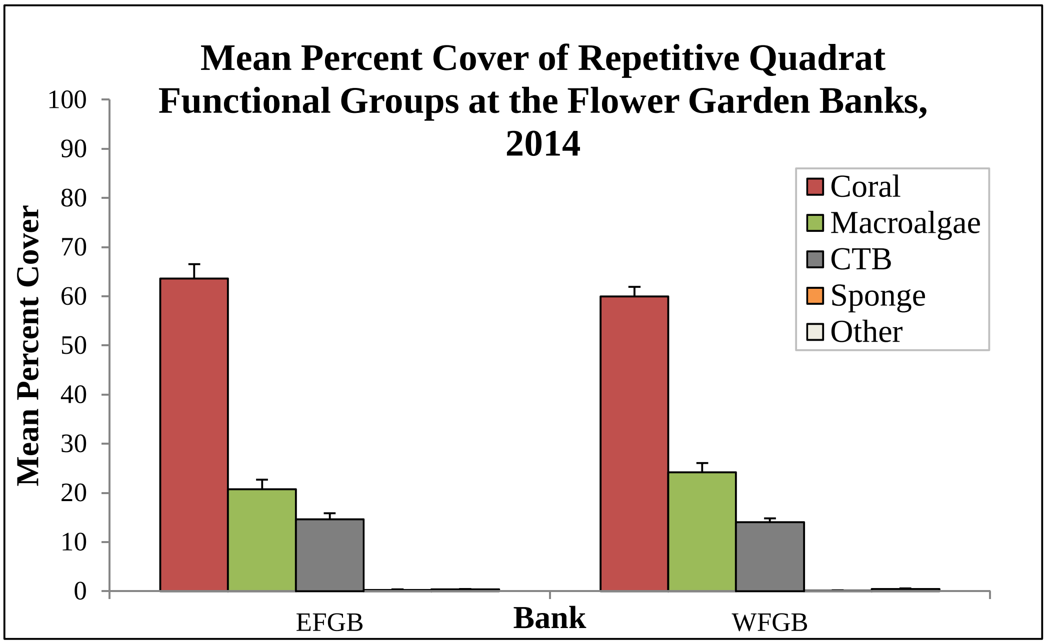


Figure 3.2. Repetitive quadrat photostation functional group mean percent cover + SE at the FGB, 2014.

Less than 1.0% of the coral cover analyzed was observed to bleach, pale, or show signs of isolated or concentrated fish biting. Minimal coral disease was observed (0.04%). 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.

Orbicella franksi was the dominant coral cover component at the 2014 EFGB repetitive quadrat photostations (31.42% ± 3.26). *Pseudodiploria strigosa* (11.02% ± 1.93) and *Orbicella faveolata* (7.57% ± 1.82) were the next most abundant species (Figure 3.3). *Orbicella franksi* was also the dominant coral cover component at the WFGB repetitive photostations (27.53% ± 2.29). *Pseudodiploria strigosa* (8.85% ± 1.29) and *Porites astereoides* (4.45% ± 0.57) were the next most abundant species (Figure 3.3).

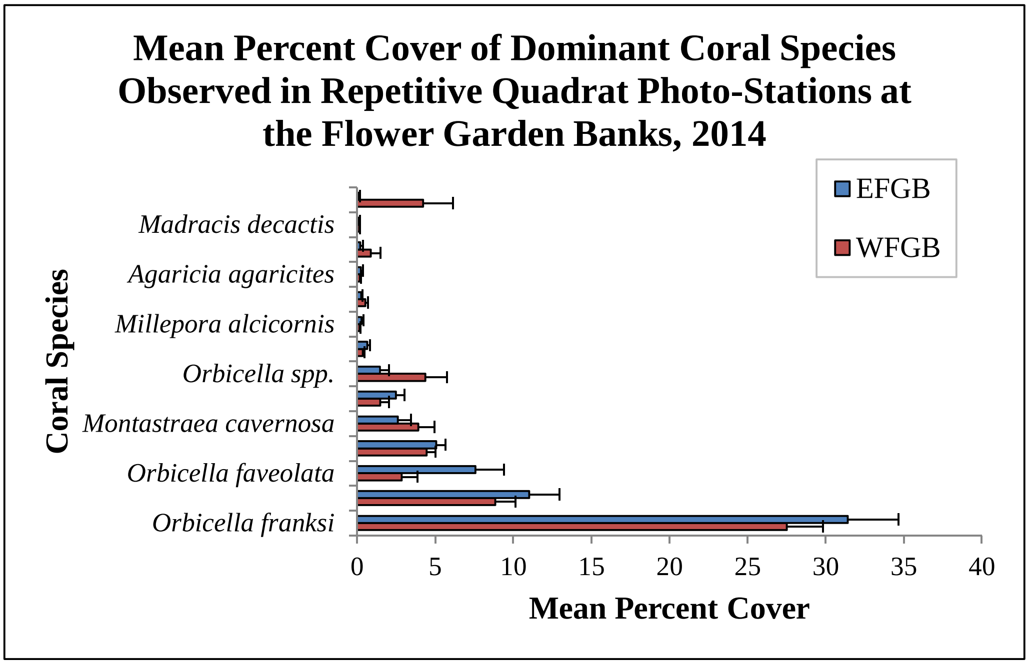


Figure 3.3. Dominant coral mean percent cover + SE observed in repetitive quadrat photostations.

Repetitive Quadrat Photostation Long-Term Trends

The mean percent benthic cover from the repetitive quadrat photostations was analyzed to measure changes over time. Mean percent coral cover showed an increase from 1992–2014, with a mean of approximately 61% overtime at both EFGB and WFGB. Periods of lower CTB cover generally coincided with increases in the macroalgae component (Figure 3.4).

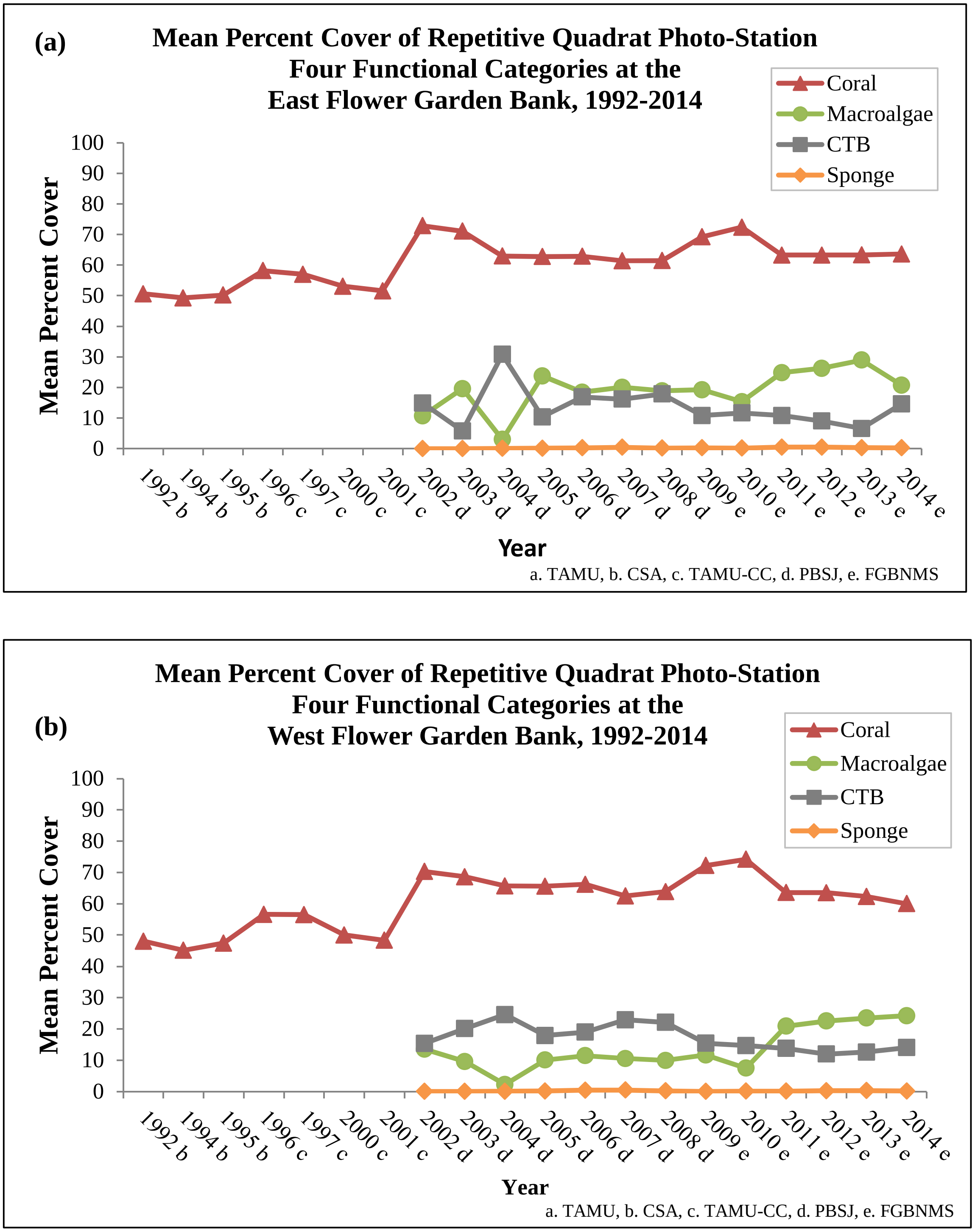


Figure 3.4. Mean percent cover of coral, sponge, macroalgae, and CTB at (a) EFGB and (b) WFGB.

Coral cover data was not collected at the stations until 1992, and the remaining categories did not begin until 2002. No mean percent cover data were reported in 1993. Data for 1992–1995 from Continental Shelf Associates, Inc. (CSA) (1996); for 1996–2001 from Dokken et al. (2003); 2002–2008 from PBS&J (Precht et al. 2006, 2008b); and FGBNMS for 2009–2010 (Johnston et al. 2013); 2011–2012 (Johnston et al. 2015 in review); and 2013 (Johnston et al. 2014).

Multivariate historical cover analysis among years (2002–2014) was used to evaluate changes in benthic community structure. SIMPER analysis identified that, for most comparisons from 2002–2014, the greatest contributors to the observed dissimilarity were CTB and macroalgae. Cluster analysis and MDS suggest that the plot placed the mean percent cover from 2002–2014 in one significant cluster (90% similarity), with the year 2004 as an outlier (Figure 3.5). After 2004, macroalgae cover increased. Three clusters were identified that were 95% similar. The cluster from 2011–2014 represents the highest macroalgae percent cover that has ever been recorded in repetitive photostations on both banks.

These trends correspond to SIMPER results, suggesting that the greatest contributors to the observed dissimilarity over time were CTB and macroalgae. This also corresponds to the MDS plot, suggesting that a significant shift in community composition occurred in 2004, which reorganized from 2005–2014, but with higher macroalgae percent cover than ever recorded in repetitive quadrat photostations.

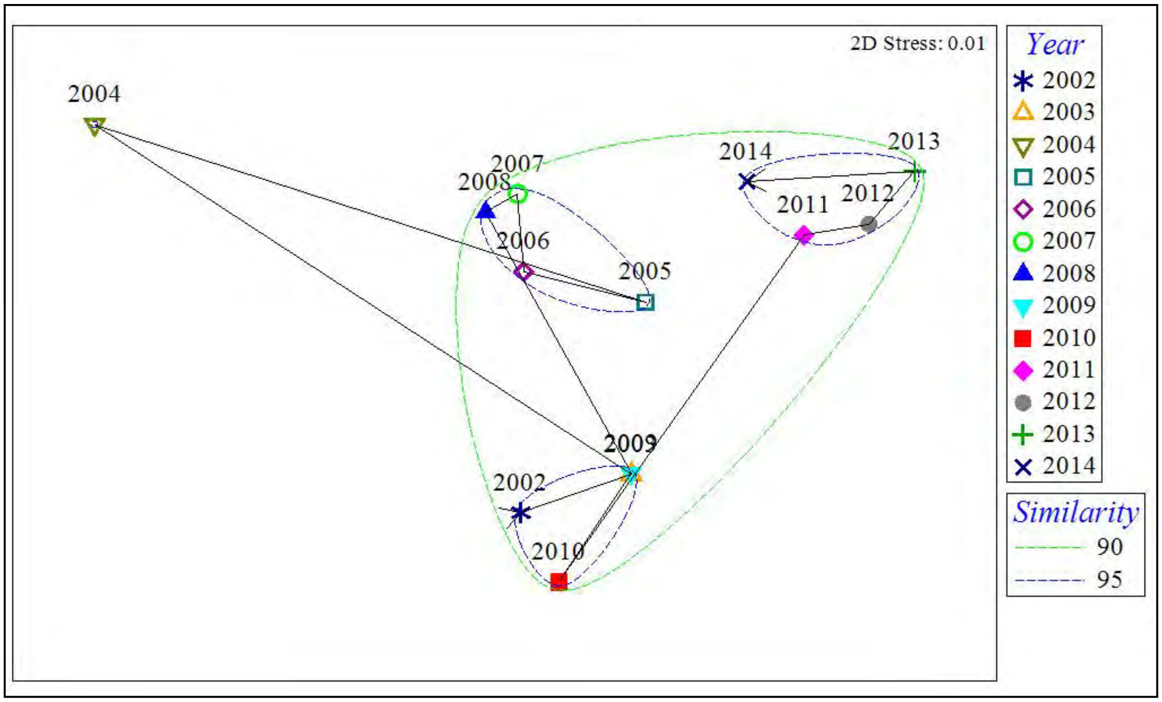


Figure 3.5. Two-dimensional MDS plot based on Bray-Curtis similarities comparing benthic cover analysis from 2002–2014 at EFGB and WFGB repetitive quadrat photostations.

The green line groups surveys that are 90% similar, and the blue line groups surveys that are 95% similar.

Repetitive Quadrat Photostation Discussion

Greater coral cover estimates (62%) were obtained from the repetitive quadrat photostations in comparison to the random transects (60%) 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 diverse habitat with high coral cover (large coral colonies).

The majority of the repetitive quadrat photostations have been in place since the beginning of the monitoring program, and display a time series from 1989–2014. Like most stations, in the example from EFGB station 102, overall coral cover increases from 1989–2014 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 *Pseudodiploria strigosa* and *Porites astereoides* colonies in the center of the photostations, and algal colonization on a *Pseudodiploria strigosa* head in the lower left corner in 2014, affecting approximately 50% of the colony.

Overall, the most noticeable patterns were: 1) inverse relationship between CTB and the macroalgae cover, 2) increasing macroalgae cover, and 3) stable/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.

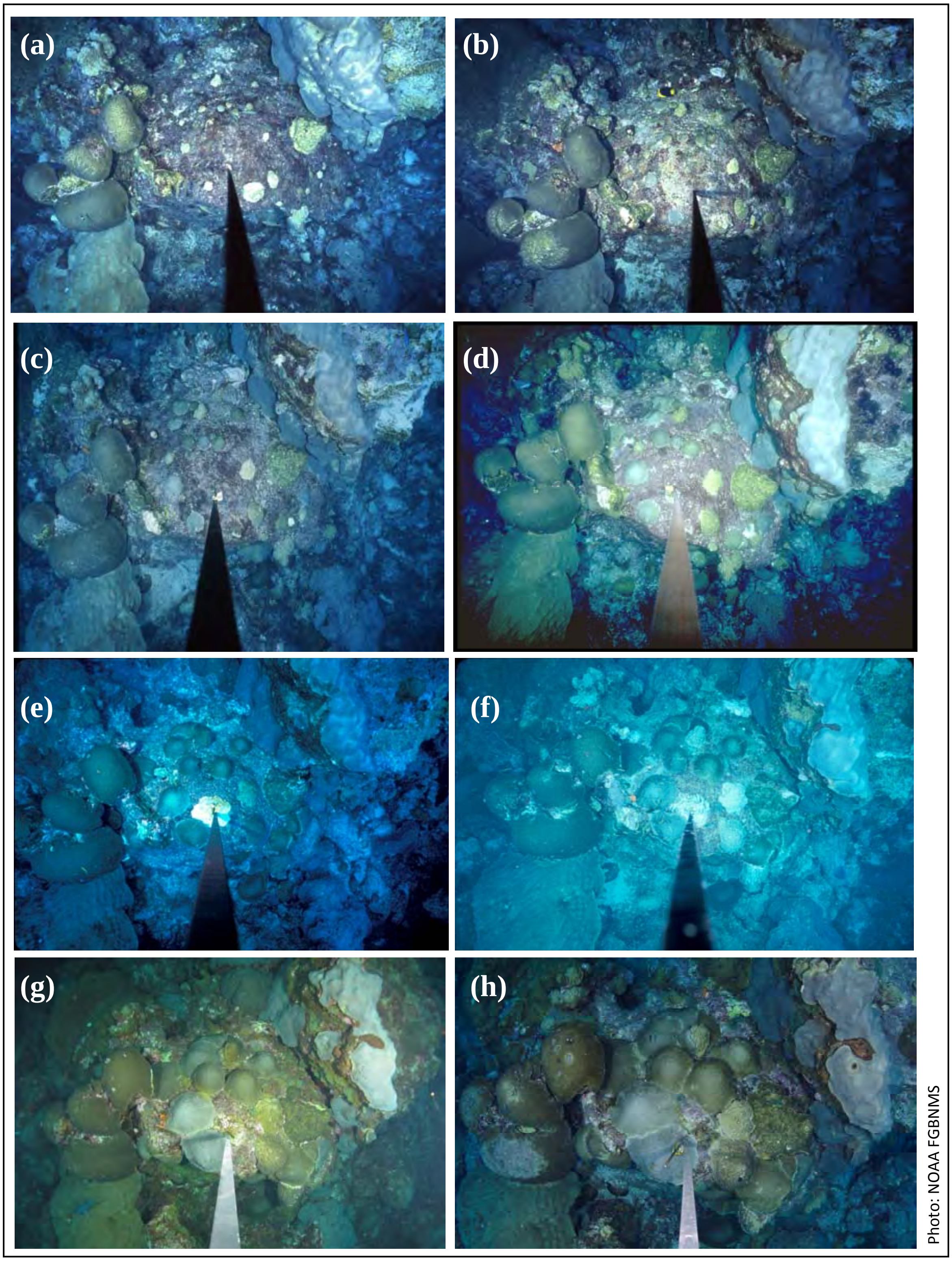


Figure 3.6. Repetitive quadrat photostation 102 from the EFGB in a time series showing a growing coral community from (a) 1989; (b) 1992; (c) 1995; (d) 1998; (e) 2002; (f) 2006; (g) 2010; (h) 2014.

Chapter 4

REPETITIVE DEEP PHOTOSTATIONS

Photo: NOAA FGBNMS/Ryan Eckert

Repetitive deep photostation #7at East Flower Garden Bank in 2014.

Repetitive Deep Photostation Introduction

Permanent repetitive deep photostations covering 5 m^2 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 2014 using random-dot analysis.

Repetitive Deep Photostation Methods

Repetitive Deep Photostation Field Methods

Eleven repetitive deep photostations were located outside the study site at EFGB near buoy#2. The photostations were located east of EFGB study site at depths between 32–40 m. Twelve repetitive deep photostations were located outside the study site at WFGB near buoy #2. The stations were located 78 m north of WFGB study site mooring at depths between 24–38 m. Each station 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 at these deep repetitive sites (Figure 4.1).

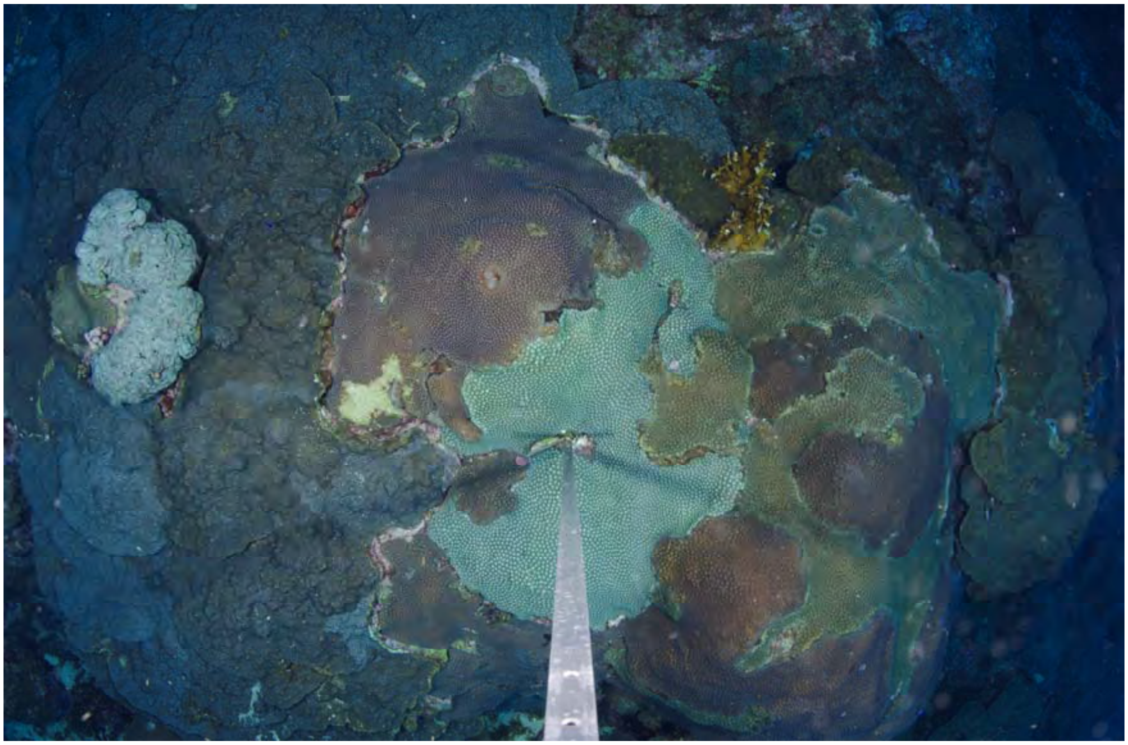


Photo: NOAA FGBNMS/Ryan Eckert

Figure 4.1. Repetitive deep photostation #4 at EFGB in 2014.

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 component of the repetitive deep photostations was coral cover (74%), followed by macroalgae (18%), CTB (7%), and sponge cover (0.5%) (Figure 4.2). The coral cover analyzed exhibited no signs of disease, and less than 0.3% was observed to pale.

At EFGB, mean coral cover was above 75% in 2014 (76.51% ± 3.77), and sponge cover was below 0.3% (0.21% ± 0.14). Macroalgae cover was 14.35% ± 2.09, and CTB cover was 8.83% ± 2.14 (Figure 4.2). At WFGB, mean coral cover was above 70% in 2014 (72.00% ± 5.32) and sponge cover was below 1% (0.80% ± 0.37). Mean macroalgae cover was 20.94% ± 5.30 and CTB cover was 2.14% ± 0.75 (Figure 4.2).

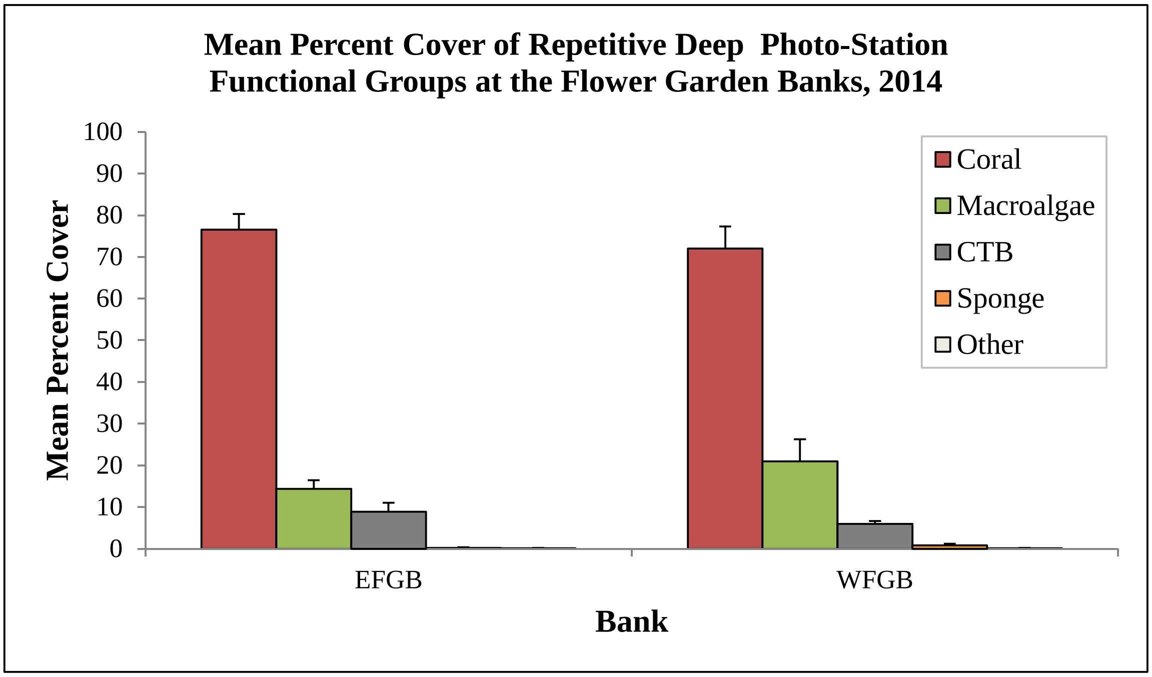


Figure 4.2. Repetitive deep photostation functional group mean percent cover +SE at the FGB.

When compared for differences between banks based on functional groups, no significant dissimilarities were found, suggesting that EFGB and WFGB repetitive deep photostations are similar in overall benthic community composition.

Similar to the random transects in the previous section and the shallow repetitive quadrat photostations, *Orbicella franksi* was the dominant mean coral cover component (35.48% ± 5.39) at EFGB. Different from the shallower repetitive quadrats and random transects, *Montastraea cavernosa* (16.32% ± 4.90) was the next dominant deep station coral at the EFGB. This was followed by *Colpophyllia natans* (7.78% ± 2.43) and *Orbicella* spp. (4.63% ± 1.85) (Figure 4.3).

At WFGB in 2014, *Orbicella franksi* was the main coral cover component (32.74% ± 6.73). *Montastraea cavernosa* (19.24% ± 4.98) was the next dominate repetitive deep photostation coral at WFGB, which was followed by *Stephanocoenia intersepta* (7.23% ± 3.47) and *Madracis aurentenra* (2.66% ± 2.20) (Figure 4.3).

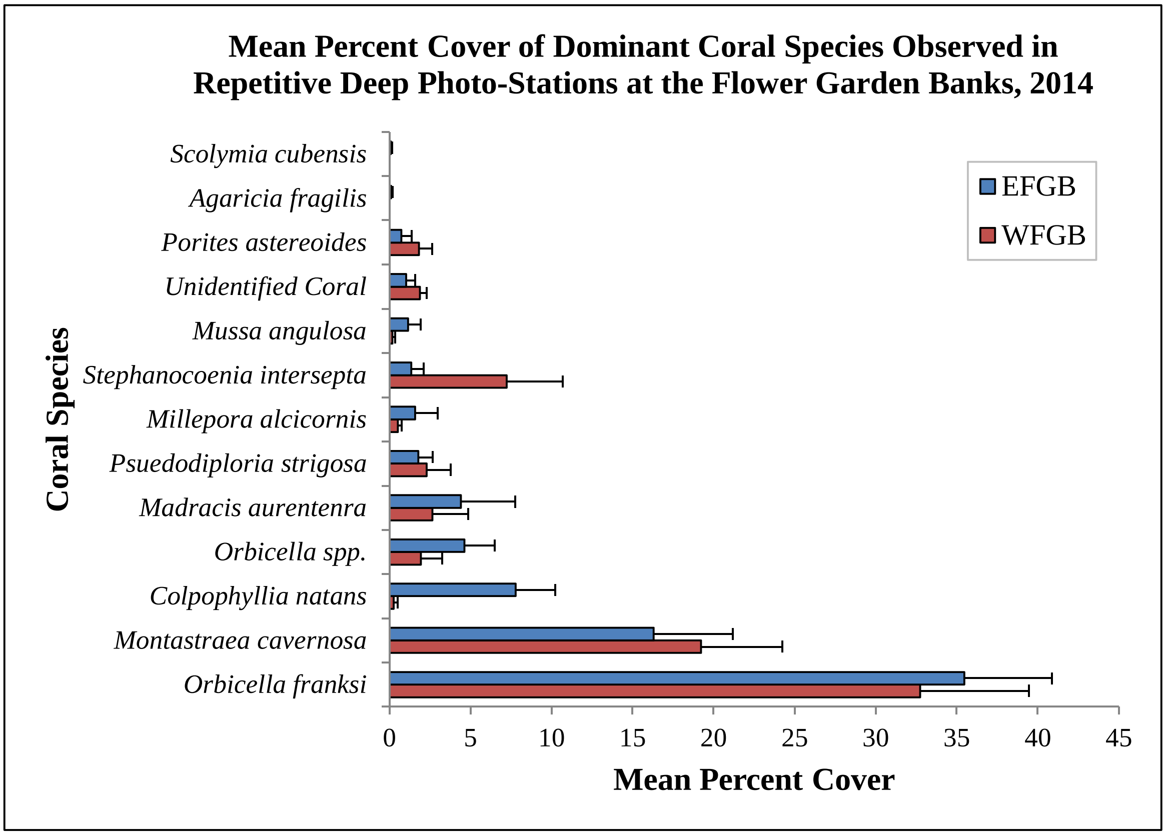


Figure 4.3. Mean percent cover + SE of dominant corals observed in repetitive deep photostations.

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 74% at the deep stations and 62% at the shallow repetitive quadrats in the study sites. Mean deep station macroalgae cover for both banks was 18%, while the shallow stations macroalgae cover was 23% in 2014. Mean percent CTB cover at the deep stations was 7% and the mean CTB cover at the repetitive shallow stations was 14%. Mean percent sponge cover was below 1% for both the deep and shallow repetitive stations (Figure 4.4).

When compared for differences between banks and depth based on community structure, a significant difference occurred between depths (Global R=0.15, p=1.7%), suggesting that EFGB and WFGB repetitive deep photostations are significantly different in overall benthic community composition than the shallow repetitive stations.

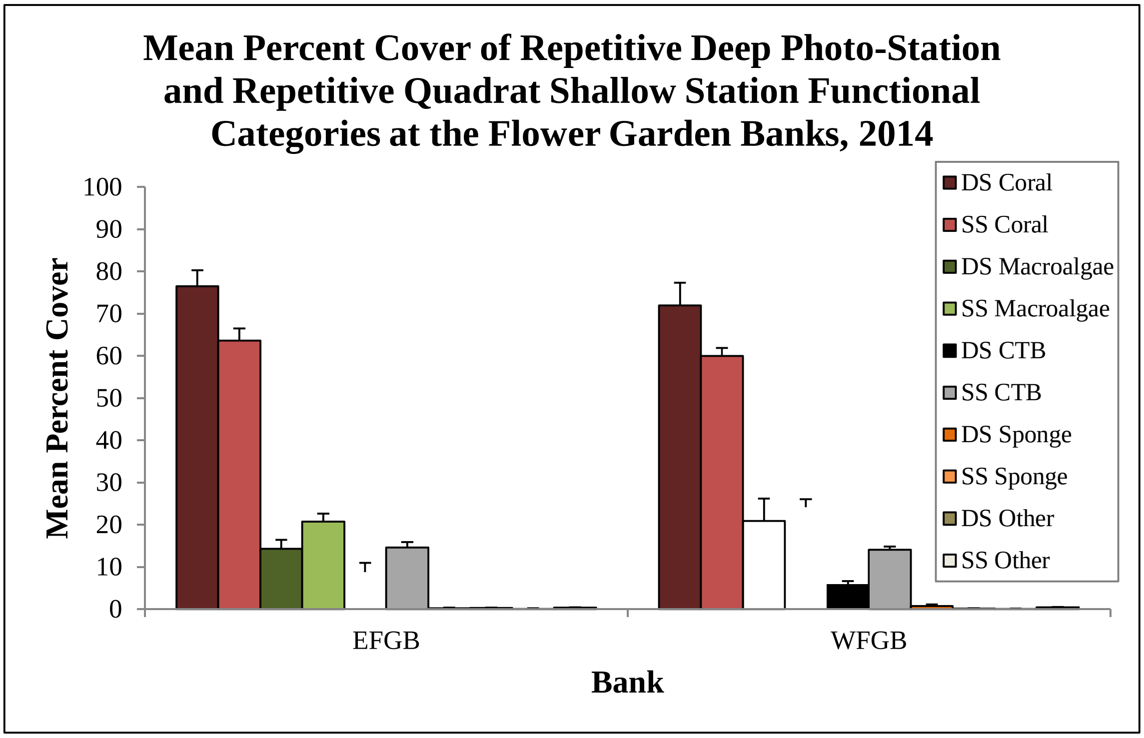


Figure 4.4. Repetitive deep photostation (DS) and repetitive quadrat shallow photostation (SS) functional group mean percent cover + SE at the FGB in 2014.

Repetitive Deep Photostation Long-Term Trends

Mean percent coral cover in the repetitive deep photostations was approximately 78% during the period from 2003–2014 at EFGB; the highest cover was recorded in 2004 (86%). In 2012, twelve deep stations were established at WFGB. The mean coral cover in WFGB deep station quadrats was 74% between 2012–2014.

At EFGB, increases in macroalgae cover generally coincided with decreases in CTB cover (Figure 4.5). Overall, the most noticeable pattern was the inverse relationship between CTB components and macroalgae cover, with increased algae cover starting in 2011, similar to the random transects and repetitive quadrats in the study sites on the shallower portion of the reef cap. At this time, the results suggest that algal overgrowth is not affecting estimates of underlying benthic coral cover. However, this is a general observation, because coral does not grow and die at the same rate as algae.

At WFGB, mean coral cover decreased from 77% in 2012 to 72% in 2014, while macroalgae increased from 14% to 21%. CTB (6%) and sponge (1%) remained stable from 2012 to 2014.

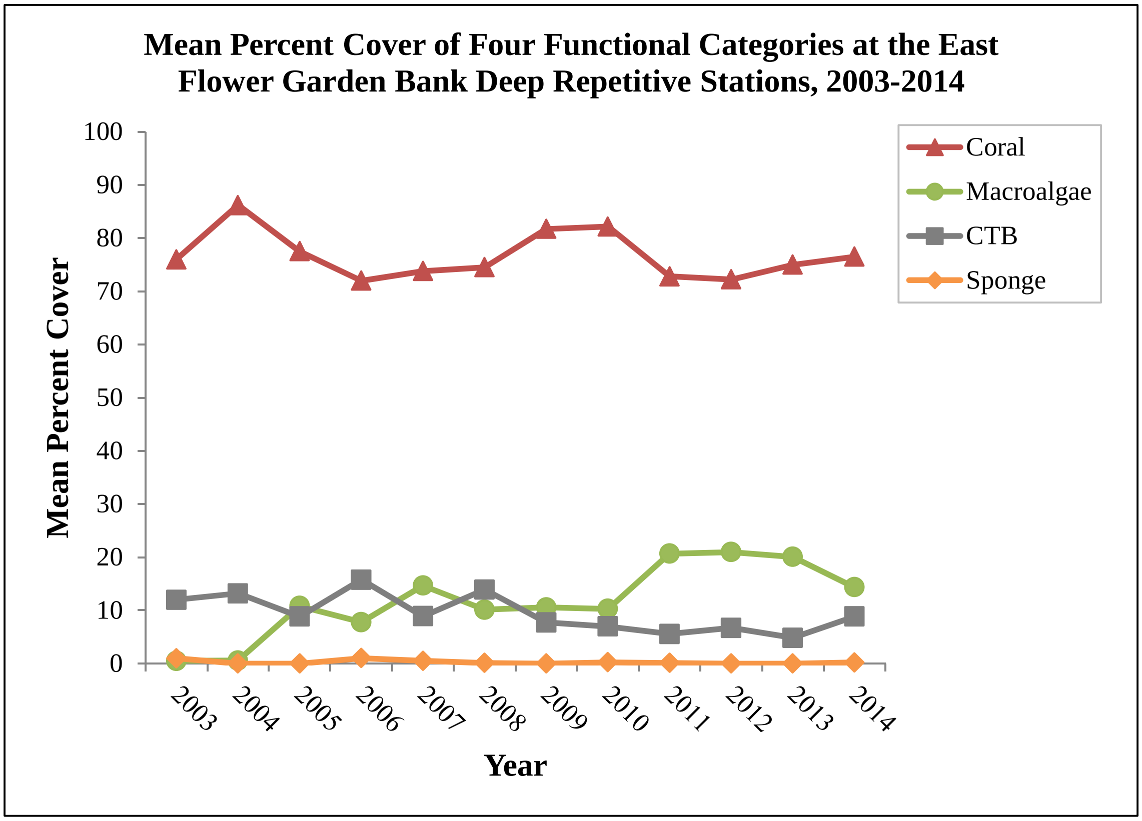


Figure 4.5. Repetitive deep photostation mean percent cover of coral, sponge, macroalgae, and CTB at EFGB in 2014.

Data for 2002–2008 from PBS&J (Precht et al. 2006, 2008b) and FGBNMS for 2009–2010 (Johnston et al. 2013); 2011–2012 (Johnston et al. 2015 in review); and 2013 (Johnston et al. 2014).

Repetitive Deep Photostation Discussion

Higher mean coral cover estimates (74%) were obtained from the repetitive deep photostations than were obtained from the shallower repetitive quadrats (62%) and the random transects (60%). 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. 2015 in review). The deep stations were dominated by *Orbicella franksi*; *Montastraea cavernosa* was the second-most dominant coral species, unlike the shallower study sites. A noticeable difference between EFGB and WFGB repetitive deep photostations and the shallower repetitive quadrat photostations was the lack of *Orbicella annularis* cover at the deep depths and decreased occurrence of *Pseudodiploria strigosa*. Macroalgae cover also appeared to differ, averaging 18% at the deep stations, and 23% at the shallow stations.

Repetitive quadrat photostations also display a time series from 2004–2014 (Figure 4.6). Like most repetitive deep photostations, in the example from EFGB station D7, the overall coral community appears to be stable from 2004–2014 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 as the year's progress, 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 well.

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 the macroalgae cover, 2) increasing macoalgae cover, and 3) stable coral cover over time, similar to the random transects and repetitive quadrat photostations.

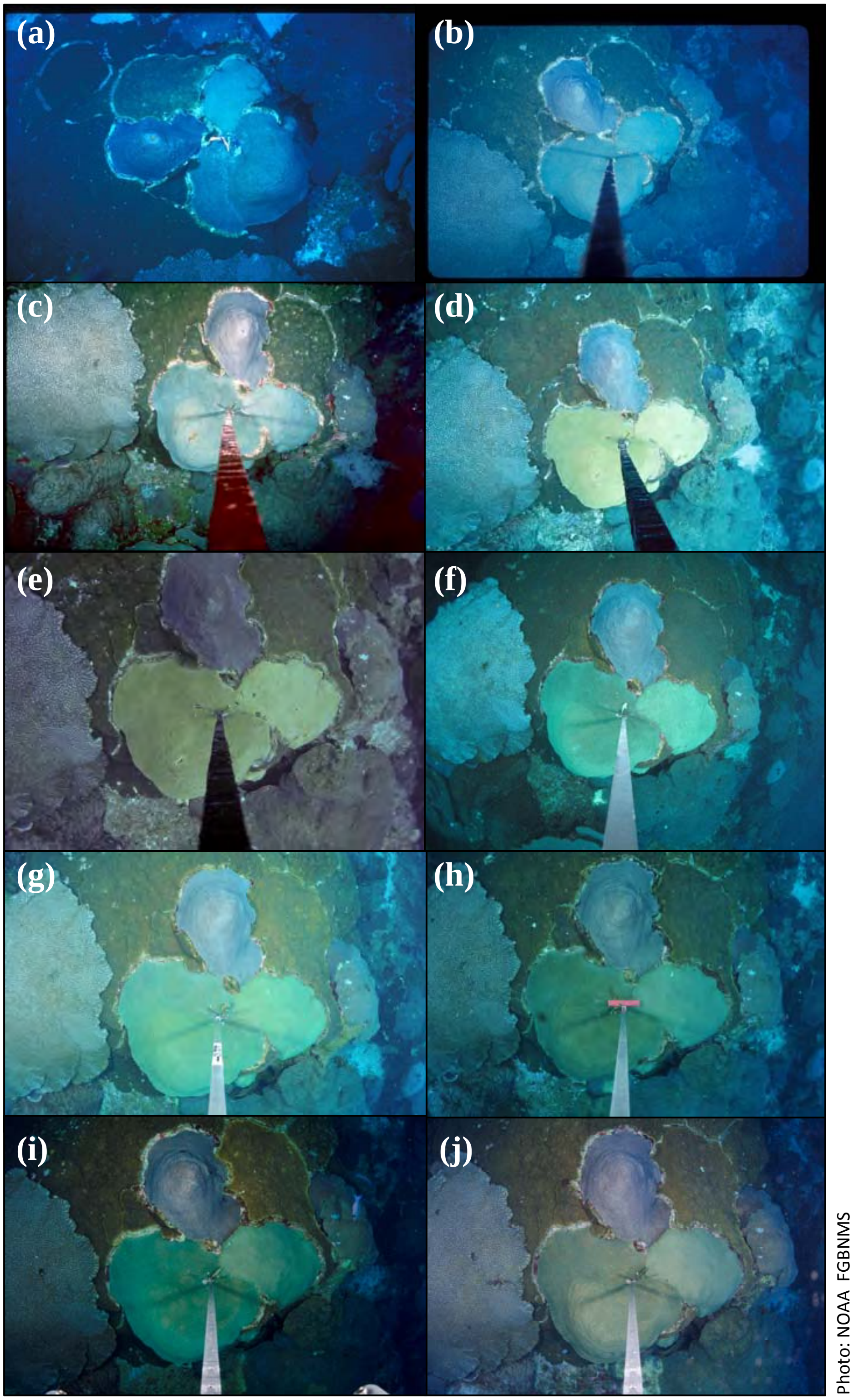


Figure 4.6. Repetitive deep photostation #D7 from EFGB in a time series showing a healthy and stable coral community from (a) 2004; (b) 2006; (c) 2007; (d) 2008; (e) 2009; (f) 2010; (g) 2011; (h) 2012; (i) 2013; and (j) 2014. No photos available for 2003 or 2005.

Chapter 5

FISH SURVEYS


Photo: NOAA FGBNMS/G.P. Schmahl

Creole Wrasse swim over the coral cap at East Flower Garden Bank.

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, a minimum of six surveys in each quadrant of the study sites. 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: TAMUG/ Amanda Sterne

Figure 5.1. A manta ray swims near NOAA diver, Michelle Johnston, while 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 10–15 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. Survey locations were stratified randomly within the study sites, and each survey represents one sample.

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 and sting rays 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. Species composition differences between banks were analyzed by converting to ecological distance using Bray-Curtis similarity matrices (Bray and Curtis 1957). SIMPER were 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 ($\alpha=0.05$) clusters within the data. MDS plots, 100 random starting configurations to minimize stress, were generated to examine for evidence of community differences between banks (Kruskal 1964). 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 JMP$^{\circledR}$ version 10.0.

Fish Surveys Results

A total of 28 families and 83 species were recorded in 2014 for all samples combined. Overall, mean species richness was 22.9 (±0.5 SE), and similar between banks, with 21.9 (±0.6 SE) at EFGB and 23.9 (±0.7 SE) at WFGB. Brown Chromis (*Chromis multilineata*) were the most abundant species overall, followed by Bluehead (*Thalassoma bifasciatum)* at both banks (Figure 5.2).

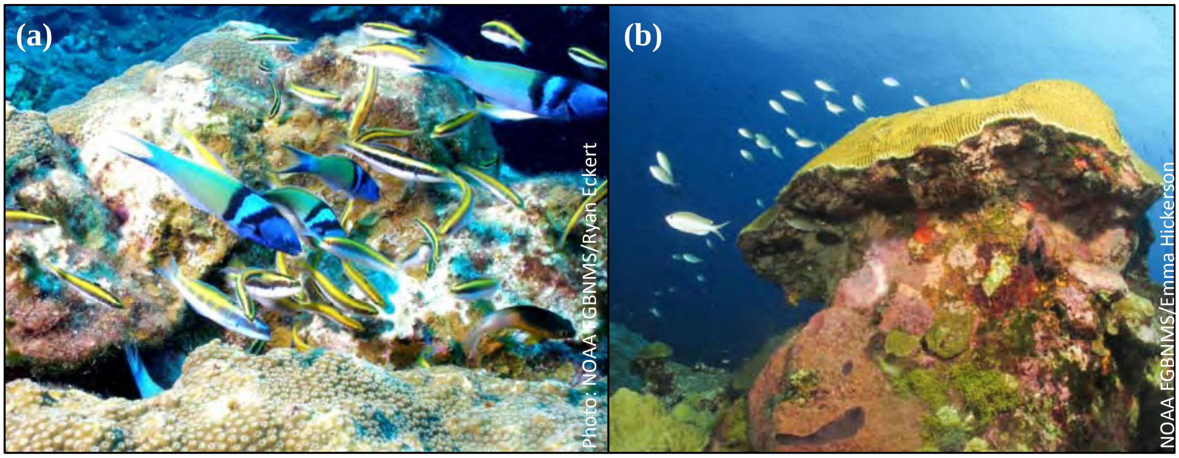


Figure 5.2. Most abundant fish species in 2014: (a) Bluehead and (b) Brown Chromis.

Sighting Frequency and Occurrence

The most frequently sighted species from both banks was the Atlantic Creolefish (*Paranthias furcifer*), observed in all surveys (Figure 5.3). Other frequently sighted species include Great Barracuda (*Sphyraena barracuda*), Sharpnose Puffer (*Canthigaster rostrate*), and Brown Chromis (Table 5.1). Most shark and ray species are considered "rare" (occur in <20% of all surveys) (REEF 2014). While no shark species were recorded, Giant Manta (*Manta birostris*) were observed in 10% of surveys at EFGB and none at WFGB.

Figure 5.3. Atlantic Creolefish displaying night coloration.

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 - Trophic Guild)**	**2014**		**All Surveys**
	EFGB	**WFGB**	
Epinephelidae: *Paranthias furcifer* (Atlantic Creolefish-PL)	100.0	100.0	100.0
Sphyraenidae: *Sphyraena barracuda* (Great Barracuda-P)	100.0	96.7	98.3
Tetraodontidae: *Canthigaster rostrata* (Sharpnose Puffer-I)	100.0	96.7	98.3
Pomacentridae*: Chromis multilineata* (Brown Chromis-I)	100.0	93.3	96.7
Labridae: *Thalassoma bifasciatum* (Bluehead-I)	96.7	93.3	95.0
Pomacentridae: *Stegastes partitus* (Bicolor Damselfish-H)	96.7	93.3	95.0
Pomacentridae: *Chromis cyanea* (Blue Chromis-PL)	93.3	93.3	93.3
Pomacentridae: *Stegastes planifrons* (Threespot Damselfish-I)	83.3	93.3	88.3
Acanthuridae: *Acanthurus coeruleus* (Blue Tang-H)	80.0	86.7	83.3
Labridae: *Bodianus rufus* (Spanish Hogfish-I)	70.0	90.0	80.0

Species Density

Mean fish density (abundance per 100 m^2) was greatest at WFGB (170 ± 18 SE) and lowest at EFGB (123 ± 10 SE). The high fish density at WFGB was caused by greater local abundance of Bonnetmouth (*Emmelichthyops atlanticus*), with a mean density of 13 ± 5 SE individuals per 100 m^2 at WFGB in comparison to zero at EFGB. Additionally, mean density of Bermuda Chub (*Kyphosus saltatrix/incisor*) was also greater at WFGB, with a mean density of 13 ± 5 SE individuals per 100 m^2 at WFGB in comparison to a mean density of 1 ± 0.4 SE individuals per 100 m^2 at EFGB.

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 (Johnston et al. 2013). Size-frequency distributions, using the relative abundance of species for each trophic guild, were graphed for each trophic guild. At both EFGB and WFGB, invertivores were dominated by smaller individuals and piscivores were dominated by larger individuals (Figure 5.4). Planktivores possessed a bell shaped distribution at both banks, with the majority of individuals of moderate size. Herbivore size distribution was variable, with a slight trend for larger individuals.

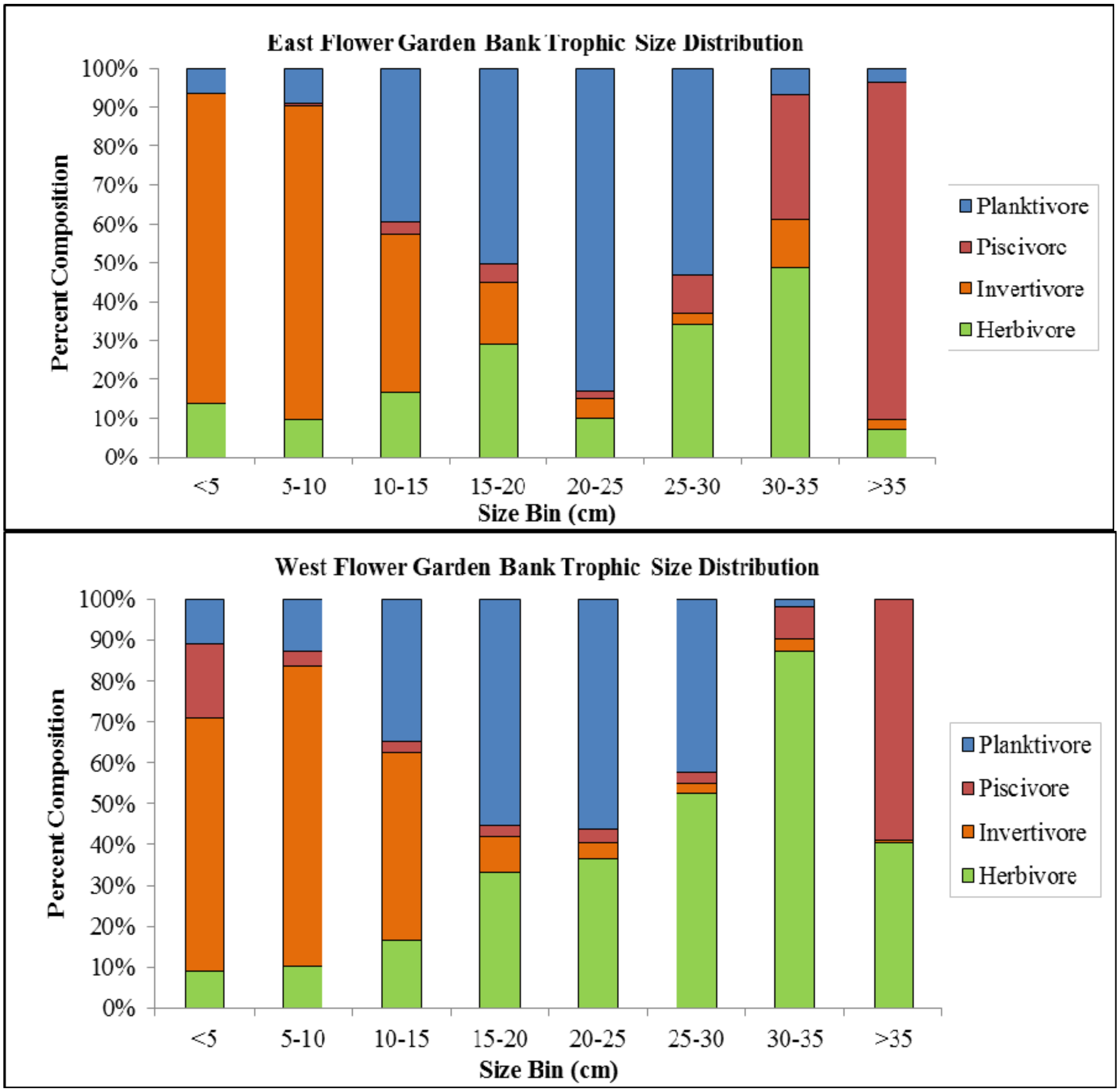


Figure 5.4. Size distribution of individuals by trophic guild, (a) EFGB and (b) WFGB.

Biomass Analysis

Mean biomass was calculated to be 12890.1 g/100 m^2 (±1419.0 SE) at EFGB and 27225.7 g/100 m^2 (±4642.8 SE) at WFGB. ANOSIM analysis indicates that while biologically significant, variation in biomass between banks was uninformative between surveys (Global R=0.126, p<0.1%). SIMPER analysis identified the greatest contributor to the observed dissimilarity between banks were Chub, Great Barracuda (*Sphyraena barracuda*), and Atlantic Creolefish.

When summed into trophic guilds, the piscivores possessed the highest mean biomass for all surveys, with 9201.5 g/100 m^2 (±1645.1 SE). The lowest mean biomass from all surveys was represented by the invertivores, with 950.1 g/m^2 (±101.1 SE) (Table 5.4, Figure 5.6). ANOSIM analysis indicates that while biologically significant, variation in trophic group biomass between banks was uninformative between surveys (Global R=0.089, p<0.5%).

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

Trophic Group	**2014**		**All Surveys**
	EFGB	**WFGB**	
Herbivore	2752.45 ± 356.56	11321.96 ± 3075.44	7037.21 ± 1633.07
Invertivore	1023.09 ± 158.05	877.01 ± 127.49	950.05 ± 101.12
Planktivore	60395.23 ± 32185.49	2555.41 ± 462.18	31475.32 ± 16395.58
Piscivore	5932.58 ± 1087.08	12471.35 ± 3015.55	9201.96 ± 1645.13

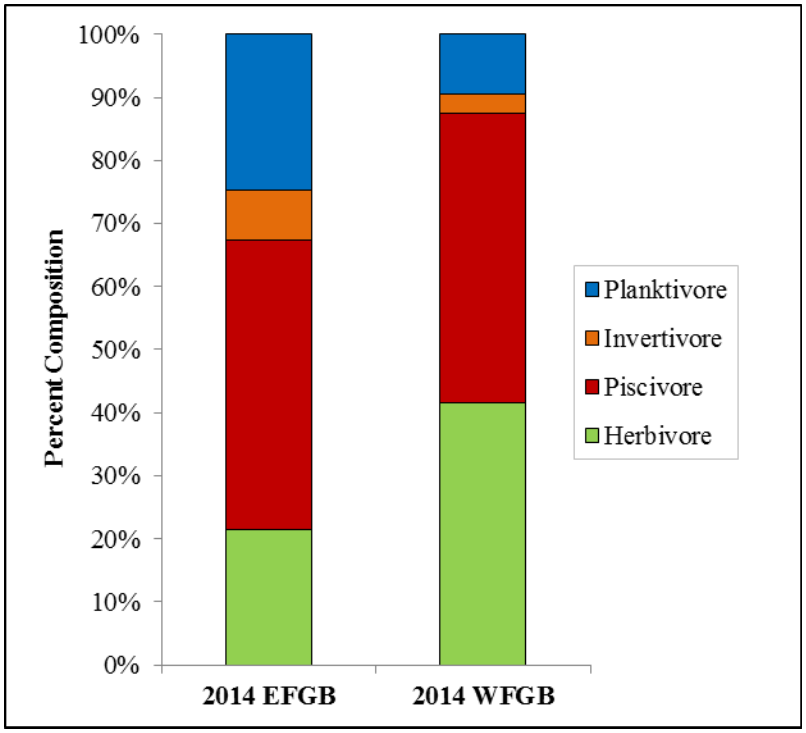


Figure 5.6. Percent composition of biomass for each trophic guild.

Within each trophic guild, average biomass for each species was calculated (Table 5.5). For the herbivore guild, 72.8% of the biomass was contributed by Chub. For the invertivore guild, the greatest contribution was from Brown Chromis, at 17.2% of all biomass. For the piscivore guild, Great Barracuda contributed the greatest biomass to all surveys, at 50.1%. For the planktivore guild, the greatest contribution was Atlantic Creolefish (80.9% of all biomass).

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

Trophic Guild	**Species ID (Family Name:Species Name (Common Name - Trophic Guild)**	**2014**		**All Surveys**
		EFGB	**WFGB**	
Herbivore	Kyphosidae: *Kyphosus saltatrix/incisor* (Chub (Bermuda/Yellow)-H)	831.7	9414.3	5123.0
	Balistidae: *Melichthys niger* (Black Durgon-H)	439.2	649.1	544.1
	Labridae: *Sparisoma viride* (Stoplight Parrotfish-H)	521.5	334.1	427.8
	Labridae: *Scarus vetula* (Queen Parrotfish-H)	210.9	308.3	259.6
	Acanthuridae: *Acanthurus coeruleus* (Blue Tang-H)	260.5	181.6	221.0
	Labridae: *Scarus taeniopterus* (Princess Parrotfish-H)	103.6	145.7	124.6
	Labridae: *Sparisoma aurofrenatum* (Redband Parrotfish-H)	117.4	99.0	108.2
	Acanthuridae: *Acanthurus chirurgus* (Doctorfish-H)	67.0	35.0	51.0
	Pomacentridae: *Stegastes partitus* (Bicolor Damselfish-H)	37.0	59.7	48.3
	Pomacentridae: *Microspathodon chrysurus* (Yellowtail Damselfish-H)	58.1	32.1	45.1
	Acanthuridae: *Acanthurus tractus* (Ocean Surgeonfish-H)	60.6	13.0	36.8
	Labridae: *Scarus iseri* (Striped Parrotfish-H)	30.8	16.9	23.8
	Pomacentridae: *Stegastes variabilis* (Cocoa Damselfish-H)	6.2	28.3	17.2
	Labridae: *Sparisoma atomarium* (Greenblotch Parrotfish-H)	7.4	4.2	5.8
	Labridae: *Sparisoma chrysopterum* (Redtail Parrotfish-H)	0.7	<0.1	0.4
	Pomacentridae: *Stegastes adustus* (Dusky Damselfish-H)	<0.1	0.5	0.2
	Blenniidae: *Ophioblennius macclurei* (Redlip Blenny-H)	0.1	0.2	0.1
	Gobiidae: *Gnatholepis thompsoni* (Goldspot Goby-H)	<0.1	<0.1	<0.1
Invertivore	Pomacentridae: *Chromis multilineata* (Brown Chromis-I)	170.9	155.4	163.1
	Labridae: *Bodianus rufus* (Spanish Hogfish-I)	95.1	99.5	97.3
	Pomacanthidae: *Pomacanthus paru* (French Angelfish-I)	90.9	53.7	72.3
	Diodontidae: *Diodon hystrix* (Porcupinefish-I)	58.2	72.3	65.3
	Labridae: *Thalassoma bifasciatum* (Bluehead-I)	63.5	65.2	64.4
	Pomacentridae: *Stegastes planifrons* (Threespot Damselfish-I)	36.7	81.7	59.2
	Balistidae: *Balistes vetula* (Queen Triggerfish-I)	105.5	<0.1	52.8
	Pomacanthidae: *Holacanthus ciliaris* (Queen Angelfish-I)	92.3	2.6	47.4
	Pomacanthidae: *Holacanthus tricolor* (Rock Beauty-I)	45.2	41.7	43.4
	Lutjanidae: *Lutjanus griseus* (Gray Snapper-I)	9.6	74.9	42.3
	Mullidae: *Mulloidichthys martinicus* (Yellow Goatfish-I)	68.7	15.8	42.2
	Chaetodontidae: *Chaetodon sedentarius* (Reef Butterflyfish-I)	38.6	36.8	37.7
	Ostraciidae: *Lactophrys triqueter* (Smooth Trunkfish-I)	46.3	23.0	34.6
	Ostraciidae: *Acanthostracion polygonius* (Honeycomb Cowfish-I)	11.6	21.6	16.6
	Tetraodontidae: *Canthigaster rostrata* (Sharpnose Puffer-I)	11.7	19.6	15.6

Trophic Guild	Species ID (Family Name:Species Name (Common Name - Trophic Guild)	2014		All Surveys
		EFGB	WFGB	
	Epinephelidae: *Epinephelus adscensionis* (Rock Hind-I)	25.9	3.3	14.6
	Chaetodontidae: *Chaetodon ocellatus* (Spotfin Butterflyfish-I)	16.5	8.4	12.4
	Pomacentridae: *Abudefduf saxatilis* (Sergeant Major-I)	2.7	16.0	9.4
	Chaetodontidae: *Prognathodes aculeatus* (Longsnout Butterflyfish-I)	2.0	15.2	8.6
	Holocentridae: *Holocentrus adscensionis* (Squirrelfish-I)	4.5	8.2	6.3
	Holocentridae: *Myripristis jacobus* (Blackbar Soldierfish-I)	<0.1	12.4	6.2
	Balistidae: *Canthidermis sufflamen* (Ocean Triggerfish-I)	2.2	9.3	5.8
	Monacanthidae: *Cantherhines macrocerus* (Whitespotted Filefish-I)	10.3	<0.1	5.1
	Labridae: *Halichoeres garnoti* (Yellowhead Wrasse-I)	1.2	8.8	5.0
	Diodontidae: *Diodon holocanthus* (Balloonfish-I)	<0.1	9.4	4.7
	Pomacanthidae: *Holacanthus bermudensis* (Blue Angelfish-I)	<0.1	9.0	4.5
	Monacanthidae: *Cantherhines pullus* (Orangespotted Filefish-I)	6.3	1.7	4.0
	Labridae: *Halichoeres bivittatus* (Slippery Dick-I)	<0.1	4.3	2.2
	Chaetodontidae: *Chaetodon striatus* (Banded Butterflyfish-I)	3.7	<0.1	1.9
	Labridae: *Halichoeres radiatus* (Puddingwife-I)	<0.1	3.2	1.6
	Gobiidae: *Elacatinus oceanops* (Neon Goby-I)	0.1	1.8	0.9
	Cirrhitidae: *Amblycirrhitus pinos* (Redspotted Hawkfish-I)	0.1	1.2	0.7
	Holocentridae: *Holocentrus rufus* (Longspine Squirrelfish-I)	<0.1	1.3	0.6
	Labridae: *Halichoeres maculipinna* (Clown Wrasse-I)	1.0	<0.1	0.5
	Muraenidae: *Gymnothorax miliaris* (Goldentail Moray-I)	0.8	<0.1	0.4
	Epinephelidae: *Cephalopholis fulva* (Coney-I)	0.6	<0.1	0.3
	Labridae: *Bodianus pulchellus* (Spotfin Hogfish-I)	0.3	<0.1	0.1
	Blenniidae: *Parablennius marmoreus* (Seaweed Blenny-I)	0.2	<0.1	0.1
	Pomacentridae: *Stegastes leucostictus* (Beaugregory-I)	<0.1	<0.1	<0.1
Piscivore	Sphyraenidae: *Sphyraena barracuda* (Great Barracuda-P)	3926.8	5300.7	4613.8
	Carangidae: *Caranx latus* (Horse-eye Jack-P)	378.5	4029.9	2204.2
	Epinephelidae: *Mycteroperca bonaci* (Black Grouper-P)	<0.1	1227.1	613.5
	Carangidae: *Caranx hippos* (Crevalle Jack-P)	863.0	<0.1	431.5
	Lutjanidae: *Lutjanus jocu* (Dog Snapper-P)	164.0	602.6	383.3
	Carangidae: *Seriola dumerili* (Greater Amberjack-P)	<0.1	663.0	331.5
	Carangidae: *Caranx lugubris* (Black Jack-P)	3.3	402.7	203.0
	Muraenidae: *Gymnothorax moringa* (Spotted Moray-P)	263.3	1.8	132.5
	Scorpaenidae: *Pterois volitans/miles* (Lionfish-P)	89.7	119.2	104.5
	Epinephelidae: *Cephalopholis cruentata* (Graysby-P)	40.6	56.6	48.6

Trophic Guild	Species ID (Family Name:Species Name (Common Name - Trophic Guild)	2014		All Surveys
		EFGB	WFGB	
	Serranidae: *Mycteroperca tigris* (Tiger Grouper-P)	96.4	<0.1	48.2
	Carangidae: *Caranx ruber* (Bar Jack-P)	72.1	5.1	38.6
	Epinephelidae: *Mycteroperca interstitialis* (Yellowmouth Grouper-P)	11.5	53.4	32.4
	Carangidae: *Seriola rivoliana* (Almaco Jack-P)	11.5	<0.1	5.8
	Haemulidae: *Emmelichthyops atlanticus* (Bonnetmouth-P)	<0.1	9.3	4.6
	Epinephelidae: *Mycteroperca venenosa* (Yellowfin Grouper-P)	8.6	<0.1	4.3
	Epinephelidae: *Mycteroperca phenax* (Scamp-P)	2.9	<0.1	1.4
	Aulostomidae: *Aulostomus maculatus* (Atlantic Trumpetfish-P)	0.3	<0.1	0.1
Planktivore	Epinephelidae: *Paranthias furcifer* (Atlantic Creolefish-PL)	2633.8	2004.9	2319.4
	Labridae: *Clepticus parrae* (Creole Wrasse-PL)	433.4	493.6	463.5
	Pomacentridae: *Chromis cyanea* (Blue Chromis-PL)	57.5	50.7	54.1
	Echeneidae: *Remora remora* (Remora-PL)	56.6	<0.1	28.3
	Pomacentridae: *Chromis scotti* (Purple Reeffish-PL)	0.5	3.0	1.7
	Opistognathidae: *Opistognathus aurifrons* (Yellowhead Jawfish-PL)	0.1	1.9	1.0
	Pomacentridae: *Chromis insolata* (Sunshinefish-PL)	<0.1	1.3	0.7

Abundance-Biomass Curves

For all samples, w values remained close to 0, indicating a balanced community, comprised of large and small species (Figure 5.7). Mean w values for EFGB were 0.116 (± 0.014 SE) and for WFGB were 0.157 (± 0.018 SE). Comparisons between banks were made using a one-way ANOVA, with no data transformation. No significant differences were observed between the abundance and biomass dominance plots between banks.

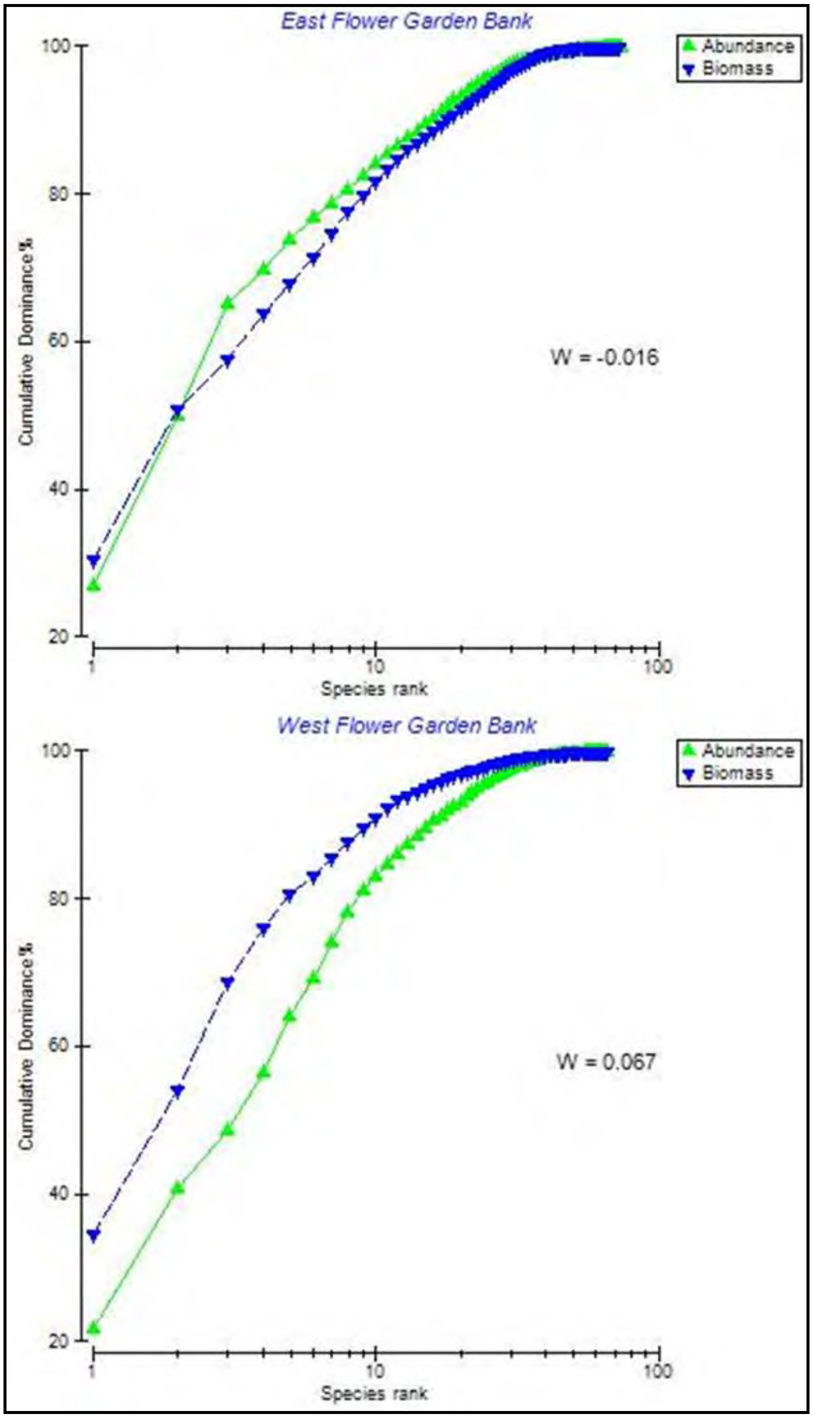


Figure 5.7. Abundance-Biomass curves for all surveys from EFGB and WFGB.

Family Level Analysis

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

The grouper family was comprised of 8 species from the *Mycteroperca*, *Cephalopholis* and *Epinephelus* generas: Graysby (*Cephalopholis cruentata*), Coney (*Cephalopholis fulva*), Rock Hind (*Epinephelus adscensionis*), 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 (13.5% for density, 80.1% for biomass) indicate that density data provided has good power to detect population changes, while biomass data provided has 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, and Rock Hind was 63.5 g/100 m^2 (± 12.9 SE), with similar means between EFGB and WFGB. Mean biomass of large bodied grouper, including Black Grouper, Yellowmouth Grouper, Yellowfin Grouper, Scamp, and Tiger Grouper was 699.9 g/100 m^2 (± 612.6 SE), with higher average biomass at WFGB (1280.4 g/100 m^2 ± 125.6 SE) than EFGB (119.4 g/100 m^2 ± 40.9 SE). Large bodied grouper size distributions were graphed for each species (Figure 5.8). Size at maturity was included, when available, for the species.

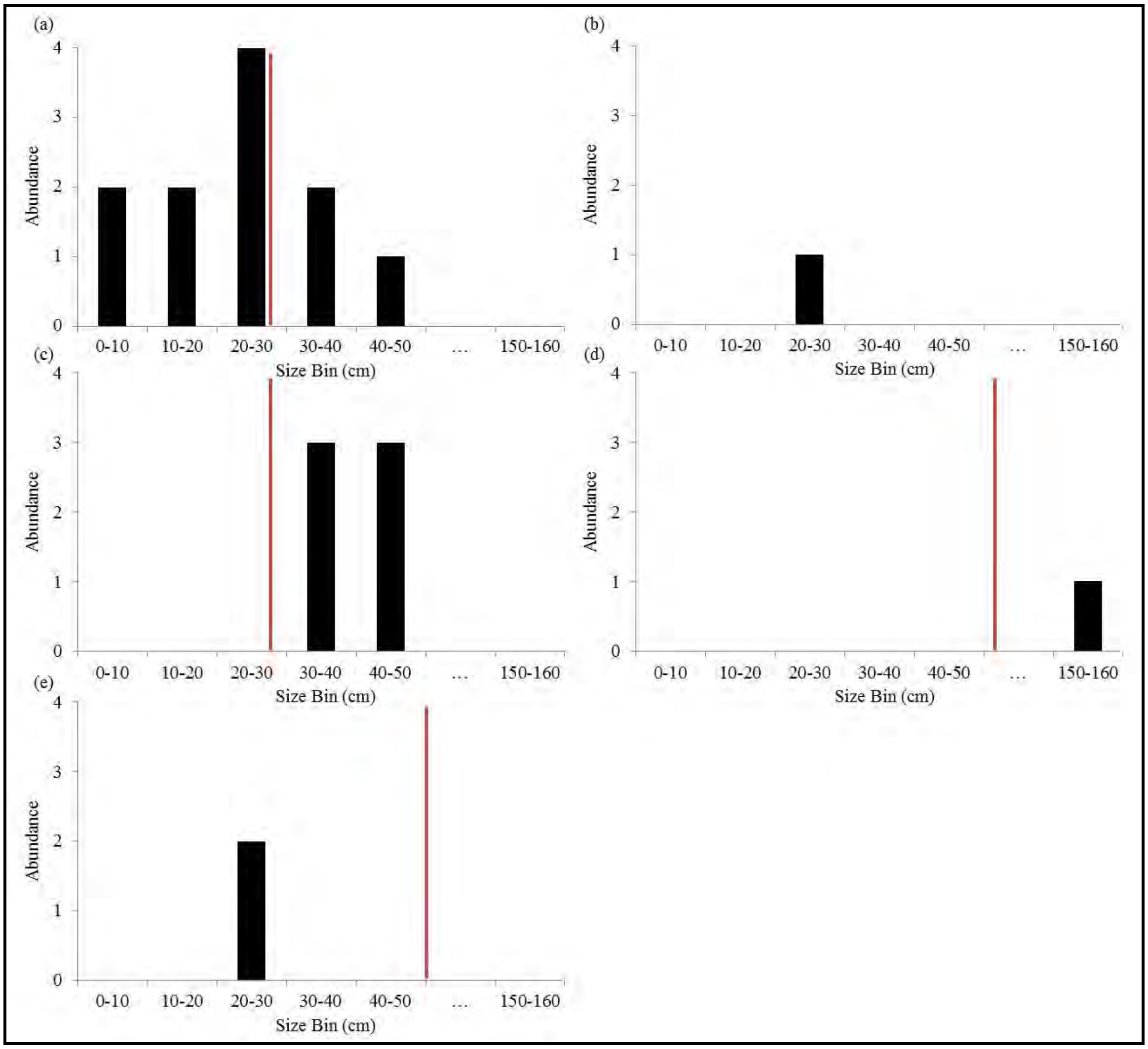


Figure 5.8. Size frequency of grouper species observed during 2014 includes (a) Yellowmouth Grouper, (b) Scamp, (c) Tiger Grouper, (d) Black Grouper, and (e) Yellowfin Grouper.

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*). While it should be noted that coefficient of variation percentages (25.7% for density, 31.4% for biomass) indicate that the data provided has poor power to detect population changes, ANOSIM results indicate a significant spatial variation in snapper community composition based on density (Global R=0.037, p<4%) and biomass (Global R=0.035, p<3.3%). The observed dissimilarity between banks was contributed to predominantly by Dog Snapper for both density (76.8%) and biomass (80.9%). WFGB had greater overall density and biomass of Dog Snapper.

Mean biomass of snapper was 424.6 g/100 m^2 (± 133.5 SE), with higher mean biomass at WFGB (677.6 g/100 m^2 ± 246.1 SE) than at EFGB (173.6 g/100 m^2 ± 87.0 SE). Snapper size distributions were graphed for each species (Figure 5.9), and size at maturity was included when available for the species.

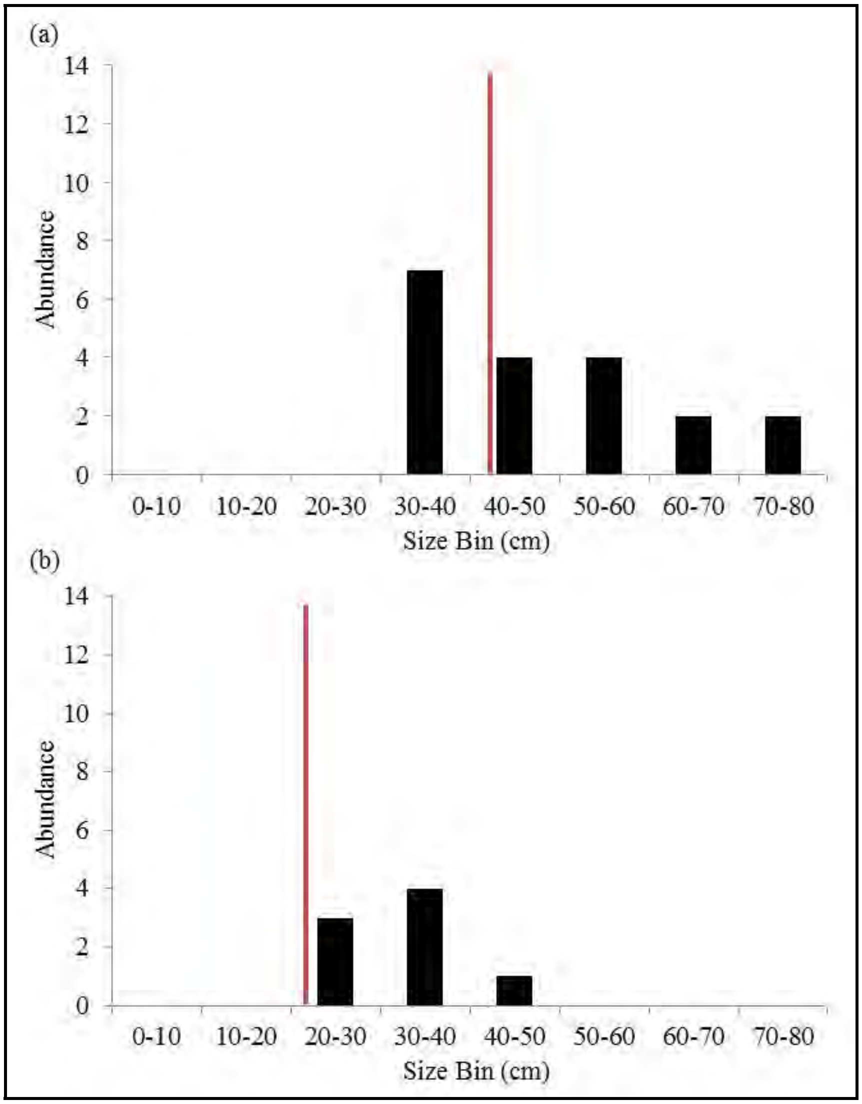


Figure 5.9. Size distribution of snapper species observed during 2014 includes (a) Dog Snapper and (b) Gray Snapper. Vertical solid red lines represent estimated size of female maturity (Garcia-Cagide et al. 1994).

Parrotfish fishes have been identified as an important species group on coral reefs (Jackson et al. 2014). Parrotfish at the FGB included 7 species: Striped Parrotfish (*Scarus iseri*), Princess Parrotfish (*Scarus taeniopterus*), Queen Parrotfish (*Scarus vetula*), Greenblotch Parrotfish (*Sparisoma atomarium*), Redband Parrotfish (*Sparisoma aurofrenatum*), Redtail Parrotfish (*Sparisoma chrysopterum*), and Stoplight Parrotfish (*Sparisoma viride*). While it should be noted that coefficient of variation percentages (7.7% for density, 10.0% for biomass) indicate that the data provided has good power to detect population changes, ANOSOM results indicate no significant temporal differences in community composition based on density or biomass.

Mean biomass of parrotfishes was 950.2 g/100 m^2 (± 95.1 SE), with similar mean biomasses at EFGB and WFGB. The parrotfish population at both EFGB and WFGB have wide size distributions, but are marginally dominated by smaller individuals (<20 cm) (Figure 5.10).

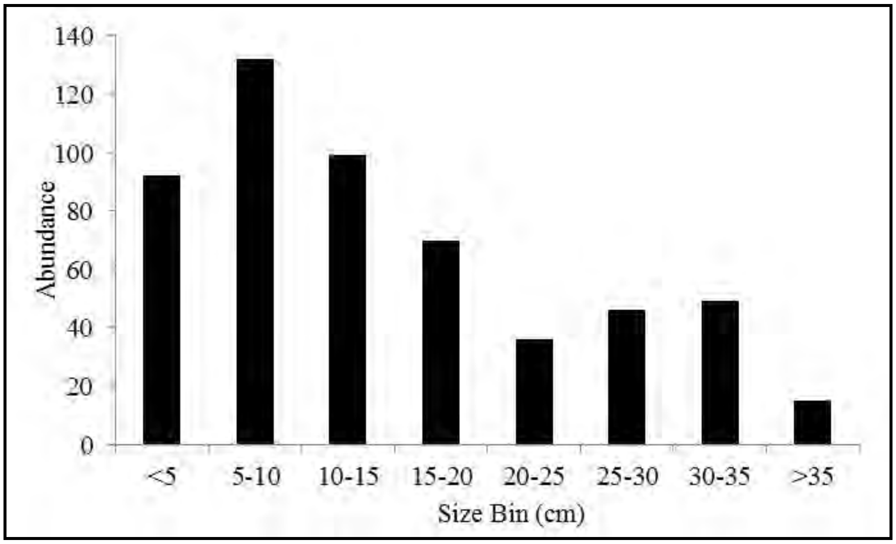


Figure 5.10. Size distribution of all parrotfish recorded in 2014.

This reporting year marks the second consecutive documentation of Lionfish (*Pterois volitans/miles*) in the long-term monitoring dataset. Lionfish are considered an invasive species, native to the Indo-Pacific. Sighting frequency for the species for all surveys in 2014 was 35%, with similar sighting frequencies between banks. Total Lionfish abundance at EFGB was 20 individuals and WFGB was 15 individuals. Mean density for all surveys was <1 per 100 m^2 (0.3) and mean biomass for all surveys was 104.5 g/100 m^2 (± 24.5 SE). Since the initial documentation of lionfish in the long-term monitoring dataset, density has increased by year (Figure 5.11) but size distribution remains similar between years (Figure 5.12).

While it should be noted that coefficient of variation percentages (21.3% for density, 23.4% for biomass) indicate that the data provided has moderate power to detect population changes, ANOSOM results indicate no significant temporal differences in community composition based on density or biomass.

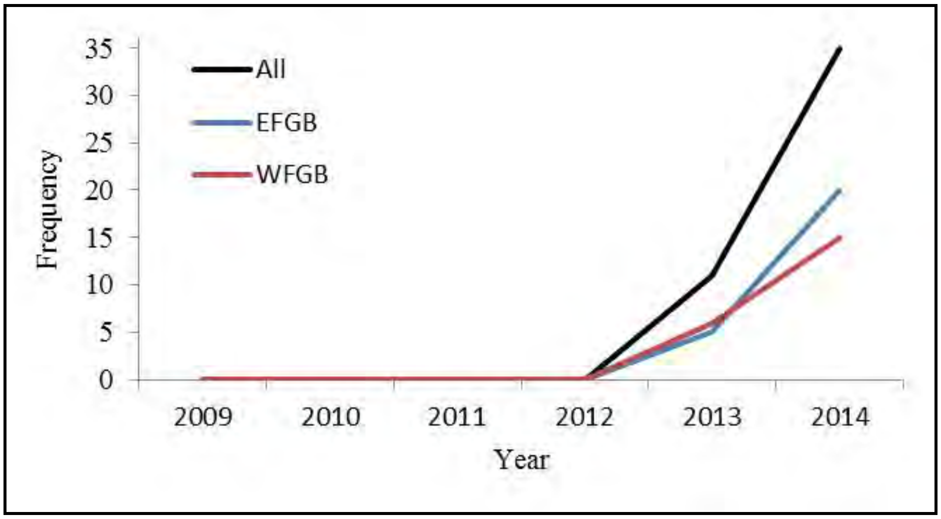


Figure 5.11. Lionfish abundance from 2012 to 2014 shows increasing abundance at both EFGB and WFGB.

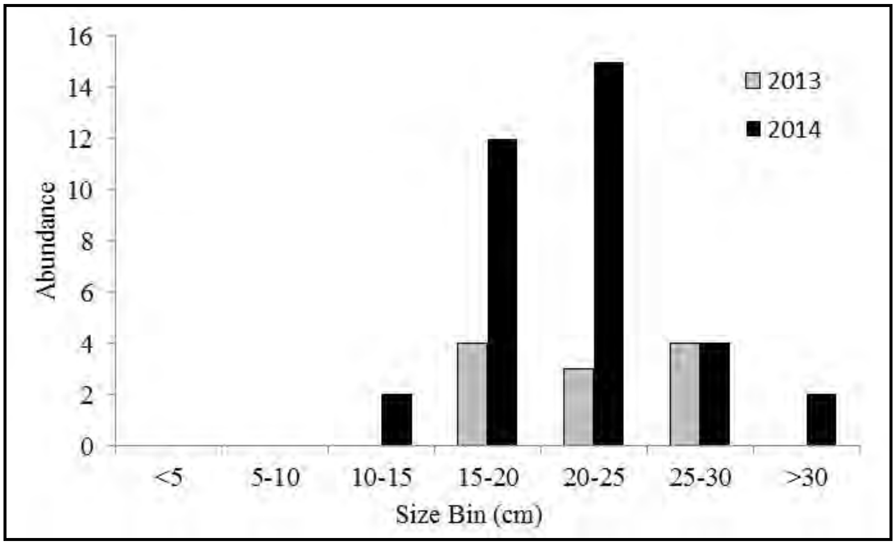


Figure 5.12. Lionfish size distribution from 2013 and 2014 show similar trends.

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, 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 lists for the FGBNMS are 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)	3830.25 ± 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)	6355.38 ± 172.60	20.70 ± 0.12
FGB (Clark et al. 2015a)	34570.87 ± 3517.95	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 promoted the dispersal of additional fish species and allowed some to reach the FGB, such as Yellowtail Snapper (*Ocyurus chrysurus*) (Boland et al. 1983; Rooker et al. 1997; Gittings 1998).

Fish surveys conducted in 2014 indicate an abundant and diverse reef fish community at both EFGB and WFGB, as observed in previous annual monitoring surveys (Precht et al. 2006; Zimmer et al. 2010; Johnston et al. 2013). Though some results indicate a significant spatial variation in community composition, statistical R values indicate that this difference is barely separable between 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.

The FGB is documented to have a lower species richness and overall abundance of herbivorous fishes than other Caribbean reefs (Rezak 1985; Dennis and Bright 1988). Historically, low macroalgae cover has been reported in the annual monitoring, while recent data suggested a gradual increase in macroalgae cover over time, 2014 results show a small decrease in macroalgae cover from 2013 results. During this study period, the herbivore guild possessed the second greatest mean biomass, contributing to over

35% of the total biomass. Within the herbivore guild, over 70% of the total biomass is attributed to Bermuda Chub. The piscivore guild had the greatest mean biomass, contributing over 45% of the total biomass. Within the piscivore guild, Great Barracuda contributed to over 50% of the total biomass. While the biomass of the herbivore and piscivore guilds a similar, 2013 was dominated by herbivores, while 2014 is dominated by piscivores. 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 (DeMartini et al. 2008; Friedlander and DeMartini 2002; 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 (DeMartini et al. 2008; Odum and Odum 1971; Wang et al. 2009).

Abundance-biomass curves have historically been used to infer community health, where a community dominated by few large species is considered “pristine” and a community dominated by many small species is considered “impacted” (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 Grouper consisted of individuals that are both immature and mature, and Tiger Grouper and Black Grouper possessed only sexually mature individuals. In contrast to the grouper population, the snapper community was dominated by few large species. Most of the snapper observed were considered of large enough size to be sexually mature. However, Dog Snapper density was much greater at WFGB than EFGB. It should be noted that at EFGB and WFGB, typical recruitment/nursery habitat for snappers (mangroves and sea grasses) are not present, and the mechanism for recruitment of this family to the area in unknown.

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; Randall 1961), 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)**
Flower Garden Banks	950
Belize	1200
Guatemala	670
Honduras	440
Mexico	1710

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

Lionfish were recorded in surveys for the second consecutive year in 2014, but have been observed by divers consistently on the reefs since 2011. Since their first observation, numbers have rapidly increased every year. Other monitoring efforts that studied the reef from 2010–2012 only documented lionfish in surveys in 2012, where a mean density of 0.44 individuals per 100 m^2 was observed (Clark et al. 2014). In LTM surveys, average lionfish density has doubled from 2013 to 2014 (0.32 per 100 m^2). While this recorded density is still lower than the Clark et al. (2014) study, this is not due to a decline in the lionfish population. It is likely due to the restricted habitat sampled in the LTM study: both LTM study sites are located on the shallow portions of the reef cap and do not encompass the deeper reef habitat included in the Clark et al. (2014) study. Additionally, the sighting frequency of Lionfish between 2013 and 2014 doubled, from 16.7% to 35%.

Chapter 6

CONCLUSIONS

Photo: NOAA FGBNMS/Emma Hickerson

A Spanish Hogfish and Yellowtail Damselfish hover over the reef cap at East Flower Garden Bank.

Conclusions

This report summarizes 2014 benthic and fish community observations as part of the annual long-term monitoring program conducted at EFGB and WFGB. In over 26 years of continuous monitoring, the coral reefs of EFGB and WFGB have maintained levels of coral cover above 50%. Even though coral cover remains above 50%, macroalgae cover has increased significantly since the beginning of the monitoring program. In some areas within the region, increased algae cover has driven coral decline; however, this has not yet happened at the FGB (ONMS 2011). The number of coral and fish species at EFGB and WFGB are lower than the most diverse areas of the Caribbean and western Atlantic; however, percent coral cover and fish abundance are greater.

The long-term monitoring program at EFGB and WFGB is one of the longest running monitoring programs of a coral reef anywhere in the world. The relatively stable conditions on the reef study locations since the beginning of the monitoring program, combined with the historical data collection and the proximity to oil and gas development, make the FGB an ideal sentinel site for continued support of a long-term monitoring program.

Problems that affect coral reefs throughout the region, including land-based sources of pollution and disease have not had a major impact at the FGB, partially due to their relative isolation and depth; however, increased impacts from climate change, excess nutrients, and invasive species, are reasons for increased vigilance and perhaps concern for the future of the resources. Continued monitoring will document long-term changes in condition and will be useful for management decisions and future research focused on the dynamics of the robust benthic communities and the fish populations they support.

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NATIONAL MARINE SANCTUARY SYSTEM

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

AMERICA'S UNDERWATER TREASURES