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National Oceanic and Atmospheric Administration
Marine Conservation Science Series

LONG-TERM MONITORING AT EAST AND WEST FLOWER GARDEN BANKS: 2016 ANNUAL REPORT

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Cover Photo:
A Spotfin Butterflyfish (*Chaetodon ocellatus*) swims within the West Flower Garden Bank long-term monitoring study site, 2016. Credit: NOAA FGBNMS/G.P. Schmahl

About the Marine Sanctuaries Conservation Series

The Office of National Marine Sanctuaries, part of the National Oceanic and Atmospheric Administration, serves as the trustee for a system of underwater parks encompassing more than 620,000 square miles of ocean and Great Lakes waters. The 13 national marine sanctuaries and two marine national monuments within the National Marine Sanctuary System represent areas of America's ocean and Great Lakes environment that are of special national significance. Within their waters, giant humpback whales breed and calve their young, coral colonies flourish, and shipwrecks tell stories of our maritime history. Habitats include beautiful coral reefs, lush kelp forests, whale migration corridors, spectacular deep-sea canyons, and underwater archaeological sites. These special places also provide homes to thousands of unique or endangered species and are important to America's cultural heritage. Sites range in size from less than one square mile to more than 582,000 square miles and serve as natural classrooms, cherished recreational spots, and are home to valuable commercial industries.

Because of considerable differences in settings, resources, and threats, each marine sanctuary has a tailored management plan. Conservation, education, research, monitoring and enforcement programs vary accordingly. The integration of these programs is fundamental to marine protected area management. The Marine Sanctuaries Conservation Series reflects and supports this integration by providing a forum for publication and discussion of the complex issues currently facing the sanctuary system. Topics of published reports vary substantially and may include descriptions of educational programs, discussions on resource management issues, and results of scientific research and monitoring projects. The series facilitates integration of natural sciences, socioeconomic and cultural sciences, education, and policy development to accomplish the diverse needs of NOAA's resource protection mandate. All publications are available on the Office of National Marine Sanctuaries website (http://www.sanctuaries.noaa.gov).

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Table of Contents

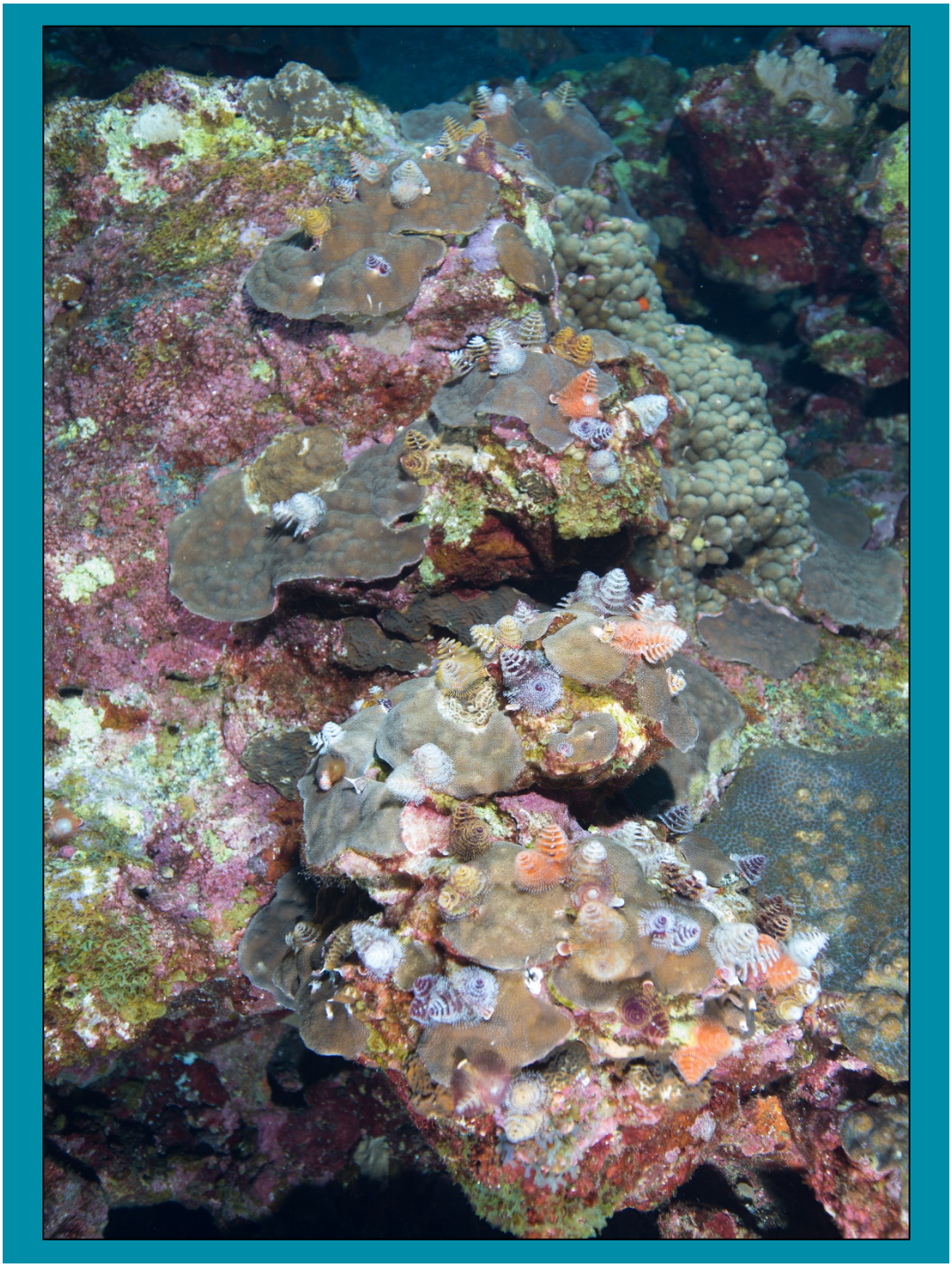
Abstract

This report summarizes fish and benthic community observations and water quality data collected from East Flower Garden Bank and West Flower Garden Bank long-term monitoring study sites in 2016. East Flower Garden Bank and West Flower Garden Bank are part of the Flower Garden Banks National Marine Sanctuary and located in the northwestern Gulf of Mexico. The annual long-term monitoring program officially began in 1989, and is funded by NOAA's Flower Garden Banks National Marine Sanctuary, the Bureau of Ocean Energy Management, and the National Marine Sanctuary Foundation. In 2016, mean coral cover was 49.92% within the East Flower Garden Bank study site and 58.54% within the West Flower Garden Bank study site. Mean macroalgae cover was 37.15% within the East Flower Garden Bank study site and 25.69% within the West Flower Garden Bank study site. Percent coral cover within repetitive study site photostations and at deep repetitive photostations ranged from 60-75%. The *Orbicella* species complex, listed as threatened under the Endangered Species Act, accounted for the majority of the coral cover within the study sites. Fish surveys conducted in 2016 indicated an abundant and diverse reef fish community, predominated by Labridae and Pomacentridae families. Water column temperatures warmed quickly in 2016, leading to the most severe coral bleaching event recorded at both banks. A localized mortality event was also documented and studied at East Flower Garden Bank. Decreased salinity, high temperatures, and low oxygen levels may have been contributing factors to the event. Bleached corals recovered after water temperatures dropped below threshold levels.

Key Words

Benthic Community, Bleaching, Coral Ecosystem, Coral Mortality, Coral Reef, Fish Community, Long-Term Monitoring, Flower Garden Banks National Marine Sanctuary, Gulf of Mexico, Marine Protected Area, Water Quality.

Executive Summary



Since 1989 a federally supported long-term coral reef monitoring program has focused on two study sites on East Flower Garden Bank (EFGB) and West Flower Garden Bank (WFGB) in the northwestern Gulf of Mexico. Despite global coral reef decline in recent decades, EFGB and WFGB have long been recognized as suffering minimally from hurricanes, coral bleaching, and disease, while supporting a relatively diverse and abundant benthic and fish population within monitoring sites. However, 2016 was an unprecedented year, with a mortality event affecting a localized portion of the coral reef at EFGB, along with a bleaching event affecting corals at both banks. The majority of bleached corals have recovered reef wide, and corals killed during the mortality event will be monitored over time to document recovery and future recruitment in the area.

This report summarizes fish and benthic community observations and water quality data from 2016, as well as historical data resulting from 27 years of nearly continuous monitoring. 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, surveys for sea urchins and lobster, and modified reef fish visual census surveys (Bohnsack and Bannerot 1986) to examine fish population composition within designated study sites at EFGB and WFGB. The annual long-term monitoring program was jointly funded by NOAA's Flower Garden Banks National Marine Sanctuary (FGBNMS) and the Bureau of Ocean Energy Management.

Key findings from data collected within long-term monitoring study sites in 2016 include:

Chapter 2: Random Transects

- Percent cover of the benthic community was dominated by coral within EFGB (49.92%) and WFGB (58.54%) study sites.
- *Orbicella franksi* was the principal component of mean percent coral cover within EFGB (20.38%) and WFGB (29.29%) study sites.
- *Pseudodiploria strigosa* was the second greatest contributor to mean percent coral cover within the study sites at EFGB (9.30%) and WFGB (8.81%).
- The *Orbicella annularis* species complex including *Orbicella franksi, Orbicella faveolata, Orbicella annularis* (all of which are listed as threatened species under the Endangered Species Act) made up 50.99% of the observed coral species within EFGB study sites and 61.67% of the observed coral species within WFGB study sites.
- Macroalgae mean percent cover (31.42%) has significantly increased since 1999 within the study sites at both banks.

Chapter 3: Repetitive Study Site Photostations

- Mean coral cover in the repetitive photostations was 62.23% at EFGB and 65.06% at WFGB.

- Similar to the random transects, *Orbicella franksi* was the predominant mean percent coral cover species followed by *Pseudodiploria strigosa.*
- Mean macroalgae percent cover (25.82%) has significantly increased since it was first measured at repetitive photostations in 2002 at EFGB and WFGB.

Chapter 4: Repetitive Deep Photostations

- In the 32–40 m depth range, repetitive deep photostation mean coral cover was 72.61% at EFGB and 75.84% at WFGB.
- Coral species composition changed slightly with depth, with *Orbicella franksi* (34.76%) and *Montastraea cavernosa* (16.03%) being the most abundant species in this depth range in photostations at both banks.
- Mean macroalgae percent cover (19.79%) has significantly increased since installation of the EFGB repetitive deep photostations in 2003.
- Mean percent coral cover was significantly higher in repetitive deep photostations (74%) compared to the shallower repetitive study site photostations (64%).

Chapter 5: Coral Demographic Surveys

- *Orbicella franksi* covered the greatest total area (58,615,875 cm^3) within EFGB study site surveys and *Orbicella faveolata* covered the greatest total area within WFGB (36,290,058 cm^3) study site surveys.
- *Porites astreoides* was the most abundant coral recruit species observed within EFGB and WFGB study sites.

Chapter 6: Sea Urchin and Lobster Surveys

- After the mass die off in 1983, long-spined sea urchin (*Diadema antillarum*) populations within the EFGB study site have remained low (1.50 per 100 m^2), but densities within the WFGB study site (21.25 per 100 m^2) were significantly higher than EFGB in 2016.
- Since surveys began in 2004, lobster counts have ranged from zero to two individuals per 100 m^2 within study sites.

Chapter 7: Fish Surveys

- Labridae (wrasses and parrotfish) and Pomacentridae (damselfish) were the predominant fish families within the study sites at both banks.
- Brown Chromis (*Chromis multilineata*) and Bluehead (*Thalassoma bifasciatum*) were consistently the most abundant species within the study sites at both banks.
- Mean fish density was greater within the WFGB study site, but mean fish biomass was greater within the EFGB study site.
- For commercially and recreationally important species, grouper density was higher within the EFGB study site while snapper density was higher within the WFGB study site.
- Total lionfish abundance was four individuals within each of the EFGB and WFGB study sites, and sighting frequency was 16.67% in 2016.

Chapter 8: Water Quality

- At a 24 m depth, mean seawater temperatures at EFGB had 36 days above the 30ºC bleaching threshold and WFGB had 21 days above 30ºC.
- Daily mean salinity levels at the 24 m depth were below the historic average in 2016.
- Nutrients sampled in seawater (chlorophyll-*a*, ammonia, nitrate, nitrite, phosphorous, and Total Kjeldahl Nitrogen) were below detectable limits at both banks.
- Carbonate chemistry indicated clear seasonal patterns and the water column around the FGBNMS acted as a net CO_2 sink.

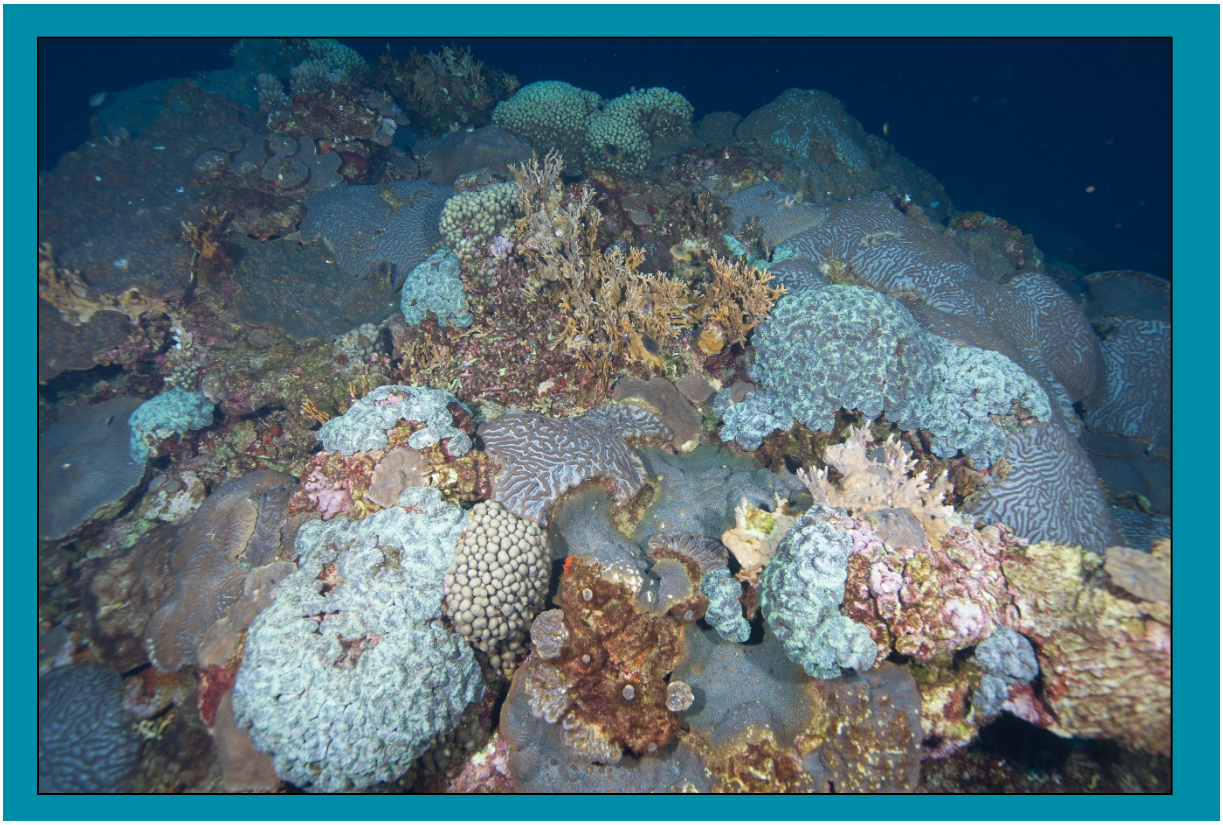
Chapter 9: 2016 Mortality Event

- In late July of 2016, dying coral and sponges were observed at EFGB along with dead bivalves, sea urchins, brittle stars, and crustaceans.
- Based on survey estimates, the extent of mortality was spread across a small 6.5 acre area on the shallow reef cap (<90 feet), approximately 1.4% of the coral reef at EFGB.
- For fish surveys taken within the mortality zone in August of 2016, density was significantly less than in surveys taken outside the mortality zone at EFGB.
- While the exact cause is uncertain, decreased salinity, high seawater temperatures, and low oxygen levels may have been contributing factors to the event.

Chapter 10: 2016 Coral Bleaching Event

- A coral bleaching event beginning in late September and peaking in October 2016 resulted from sustained seawater temperatures in excess of 30ºC.
- Approximately 46% of the coral colonies within EFGB repetitive study site photostations exhibited signs of bleaching stress in 2016.
- Approximately 24% of the coral colonies within WFGB repetitive study site photostations exhibited signs of bleaching stress in 2016.
- Coral species most affected from bleaching stress included *Montastraea cavernosa*, *Orbicella franksi*, *Pseudodiploria strigosa*, and *Millepora alcicornis.*
- After assessing data taken in January 2017 at EFGB, only 4% of the coral colonies within EFGB repetitive study site photostations were still exhibiting signs of bleaching or paling, while the remainder of corals had fully recovered.

Chapter 1. Long-Term Monitoring at East and West Flower Garden Banks



Colorful coral colonies populate West Flower Garden Bank, 2016. (Photo: G.P. Schmahl, NOAA/FGBNMS)

Habitat Description

The coral reef-capped 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). These reefs occupy elevated salt domes located approximately 190 km south of the Texas and Louisiana border, containing several distinct habitats ranging in depth from 16–150 m (Bright and Rezak 1976; Schmahl et al. 2008).

The caps of the banks are approximately 20 km apart and are within the photic zone where conditions are ideal for colonization by species of corals, algae, invertebrates, and fish, similar to coral reefs found in the Caribbean region (Goreau and Wells 1967; Schmahl et al. 2008; Clark et al. 2014; Johnston et al. 2016b). The shallowest portions of each bank are topped by well-developed coral reefs, in depths ranging from 16–40 m. Although the common species found on the EFGB and WFGB reef caps are similar to other species on Caribbean reefs, octocorals are absent and scleractinian corals of the genus *Acropora* are rare on the reefs, likely due to the latitude of the banks being at the northernmost limit of the coral distribution range (Bright et al. 1985; CSA 1989).

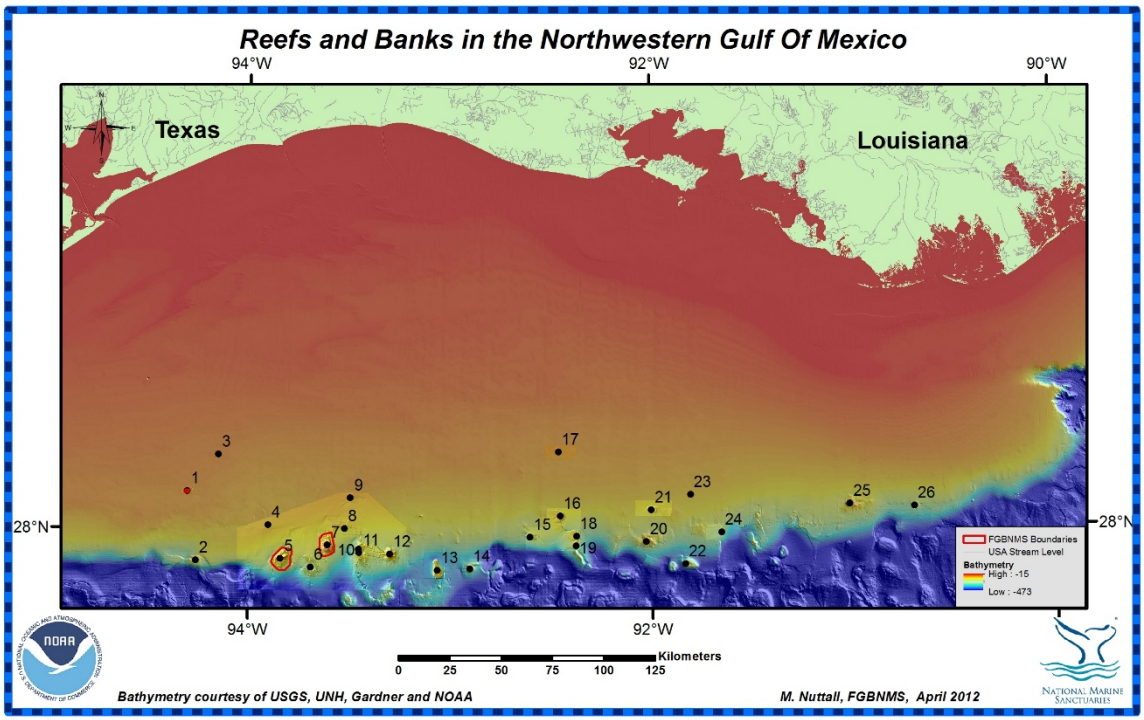


Figure 1.1. Map of EFGB, WFGB, and Stetson Bank (outlined in red) in relation to the Texas-Louisiana continental shelf and other topographic features of the northwestern Gulf of Mexico. Numbered banks include: 1. Stetson Bank, 2. Applebaum Bank, 3. Claypile Bank, 4. Coffee Lump Bank, 5. West Flower Garden 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.

Long-Term Monitoring Program History

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 [MMS], and now the Bureau of Ocean Energy Management [BOEM]) started monitoring EFGB and WFGB to establish baseline data and determine if the reefs were impacted by nearby oil and gas activities (Figure 1.2).

Under MMS funding and a partnership with Texas A&M University (TAMU), long-term monitoring study sites containing repetitive monitoring photostations were established in 1989, marking the official start of the Flower Garden Banks Long-Term Monitoring (LTM) program (CSA 1989; Gittings et al. 1992). The Flower Garden Banks National Marine Sanctuary (FGBNMS) was established in 1992 (Code of Federal Regulations, 15 CFR Part 992, Subpart L, Section 922.120), and monitoring was conducted by both TAMU and environmental consulting groups through competitive contracts throughout the years. Starting in 2009, BOEM and NOAA established an interagency agreement for FGBNMS to carry out the LTM program.

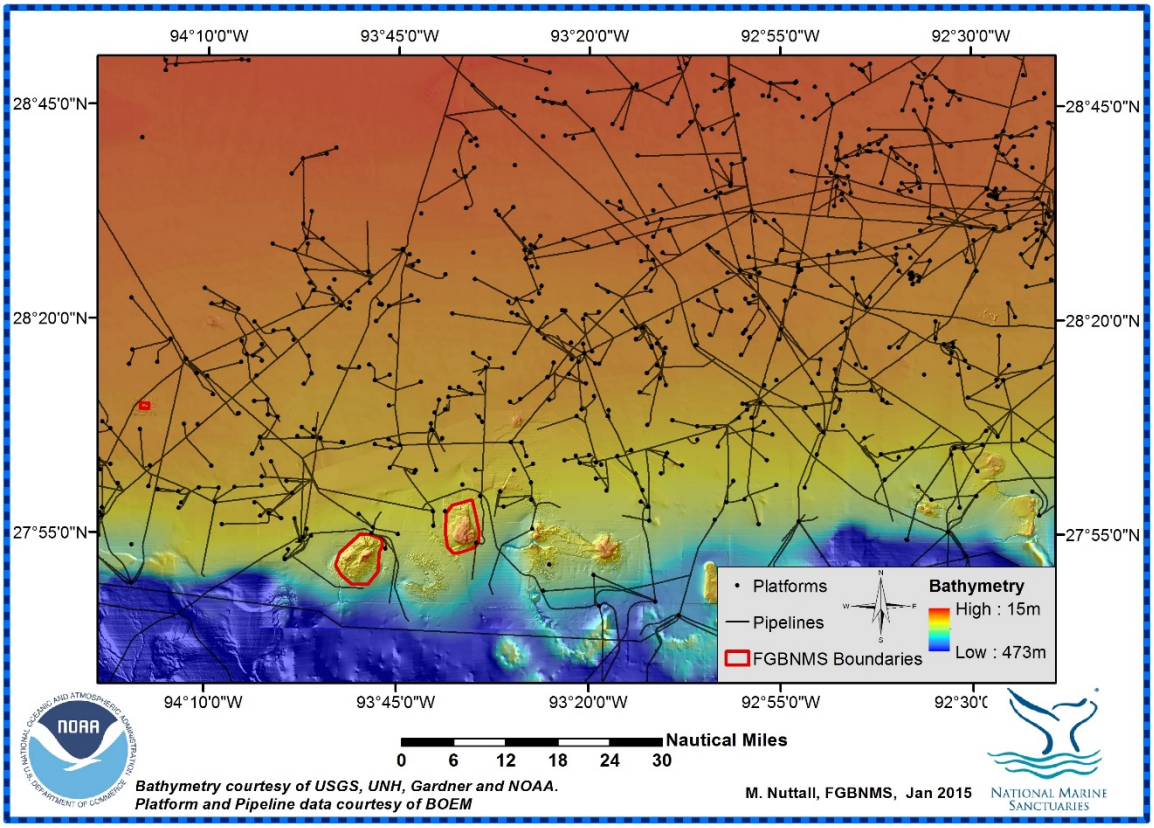


Figure 1.2. Map of oil and gas platforms and pipelines near EFGB, WFGB, and surrounding banks. FGBNMS boundaries outlined in red.

Long-Term Monitoring Program Objectives

Priorities of FGBNMS include managing natural resources as stated in the National Marine Sanctuaries Act, and identifying coral reef threats and potential sources of impacts including: overfishing, pollution, runoff, visitor impacts, disease, bleaching, invasive species, hurricanes, and oil and gas industry. Knowing the condition of natural resources within the national marine sanctuary and providing scientifically credible data is fundamental to NOAA's ability to protect and manage these areas, as well as defend management actions.

Through the interagency agreement, the LTM program is of significant interest to both NOAA and BOEM, who share responsibility to protect and monitor these important marine resources. The long-term monitoring program objectives include:

- Monitor and evaluate environmental changes and variability in abundances of reef-associated organisms across multiple time scales.
    - Measureable goals: Benthic percent cover, fish community dynamics, water quality, and coral demographic analyses.
- Identify changes in coral reef health resulting from both natural and human-induced stressors to facilitate management level responses.
    - Measureable goals: Bleaching, disease, and invasive species.
- Provide a resource to facilitate adaptive management of activities impacting reef – related resources.
    - Measureable goals: Maintain baseline data and image archive of damage to resources if observed.
- Identify and monitor species that may be indicative of reef and ecosystem health.
    - Measurable Goals: Trends in sea urchin and lobster surveys.

The LTM program was designed to assess the health of the coral reefs, to detect change over time, and provide baseline data in the event that natural or human-induced activities endanger the coral community integrity of EFGB and WFGB. The high coral cover and robust fish populations compared to other reefs in the region, combined with historical data collection and the proximity to oil and gas development, make EFGB and WFGB ideal sentinel sites for continued long-term monitoring. The following techniques listed below have been used in this monitoring program to evaluate coral reef diversity, growth rates, and coral reef community health in designated long-term monitoring 10,000 m^2 study sites at each bank:

- Random photographic transects document benthic cover;
- Repetitive photostations detect and evaluate long-term changes at the stations and in individual coral colonies;
- Coral demographic surveys provide information on coral colony size and recruitment;
- Stationary visual fish surveys assess community structure of coral reef fishes;

- Long-spined sea urchin (*Diadema antillarum*) and lobster surveys establish current population levels and trends; and
- Water quality datasondes record salinity, temperature, and turbidity at depth and nutrient sampling documents chlorophyll *a*, ammonia, nitrate, nitrite, total Kjeldahl nitrogen, and phosphorous levels.

Long-Term Monitoring Study Sites and Data Collection

Long-term monitoring data have been collected annually during summer months since 1989 at permanent 10,000 m² study sites (100 m x 100 m or 1 hectare) (hereafter referred to as "study sites") at EFGB and WFGB. The corners and centers of the study sites are currently marked by large eyebolts as reference markers. Permanent mooring buoys (FGBNMS permanent mooring #2 at EFGB and mooring #5 at WFGB) have been established near the study site centers to facilitate field operations (Table 1.1; Figure 1.3 and 1.4).

Within the study sites, depths range from 17–27 m at EFGB and 18–25 m at WFGB. Each year during data collection, divers install reference lines to mark the perimeters of the study sites as well as north-south and east-west centerlines (hereafter referred to as the "crosshairs"). Establishment of the perimeter and crosshairs divide each site into four 25 m x 25 m quadrants. The lines aid divers in orientation-navigation through each study site and allow for efficient completion of monitoring tasks.

Table 1.1. Coordinates and depths for permanent moorings within study sites at each bank.

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

For sampling at deeper depths, permanent monitoring stations are located outside the study sites at each bank ranging in depth from 24–40 m. Eleven repetitive deep photostations at EFGB are located outside the study site (east of buoy#2), ranging in depth from 32–40 m (Figure 1.5). Twelve repetitive deep photostations are located outside the study site at WFGB near buoy #2 (78 m north of the mooring at depths between 24–38 m) (Figure 1.6). EFGB deep repetitive stations were established in 2003 and WFGB deep repetitive stations were established in 2012.

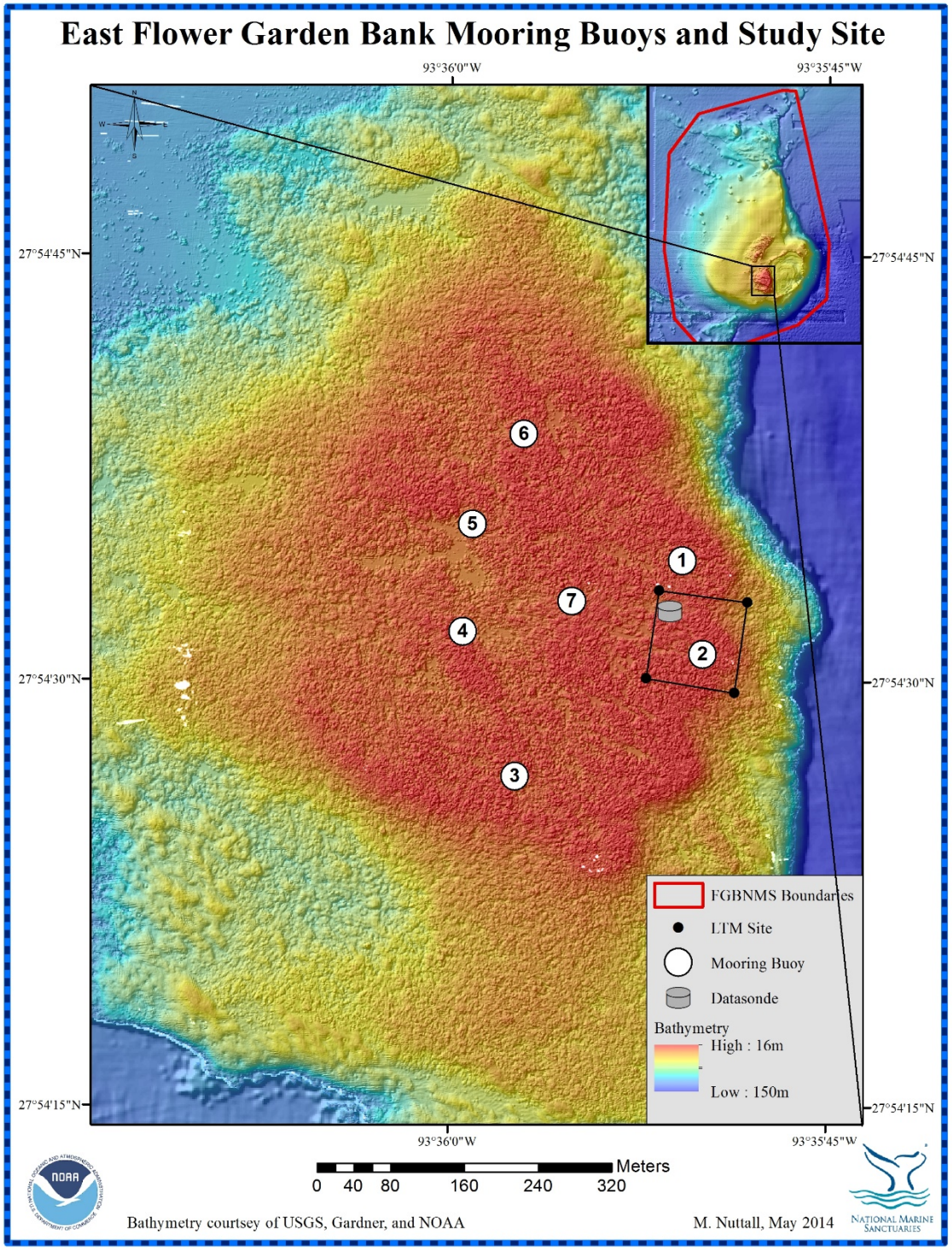


Figure 1.3. Bathymetric map of EFGB with long-term monitoring study site (LTM site), mooring buoy, and water quality datasonde locations.

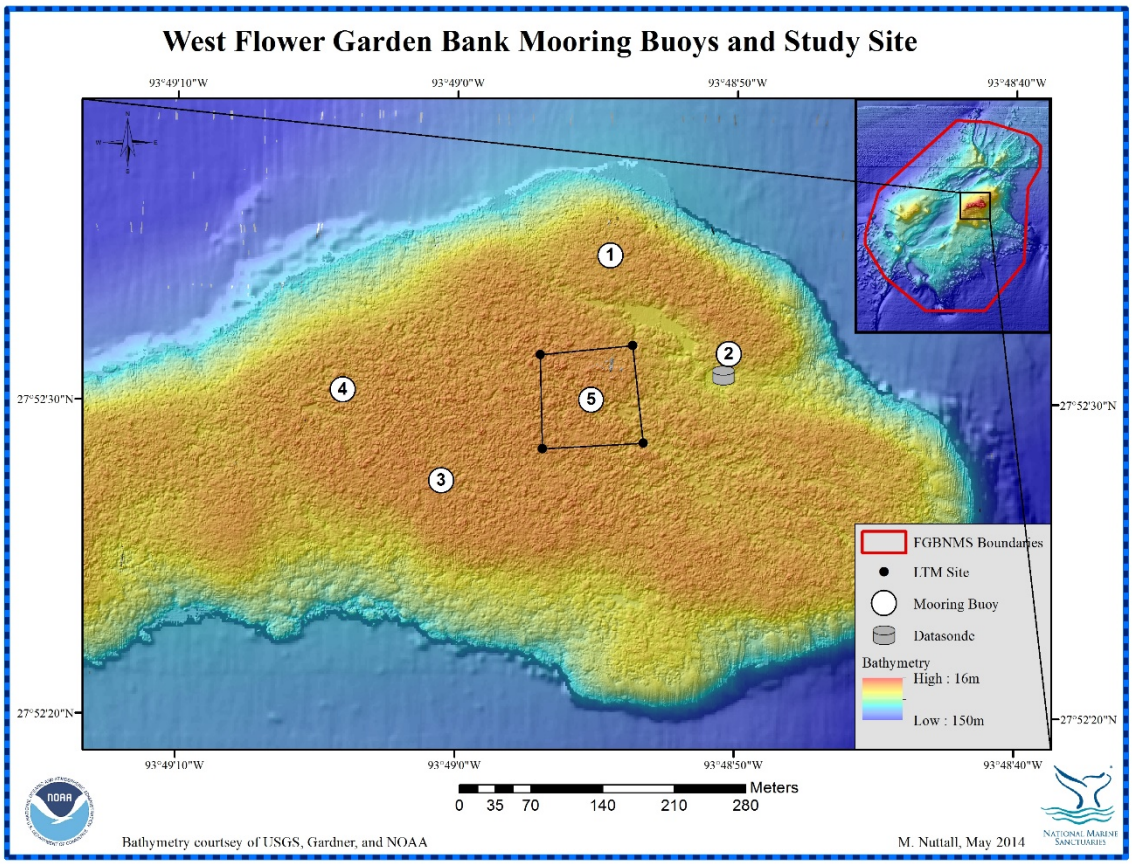


Figure 1.4. Bathymetric map of WFGB with long-term monitoring study site (LTM site), mooring buoy, and water quality datasonde locations.

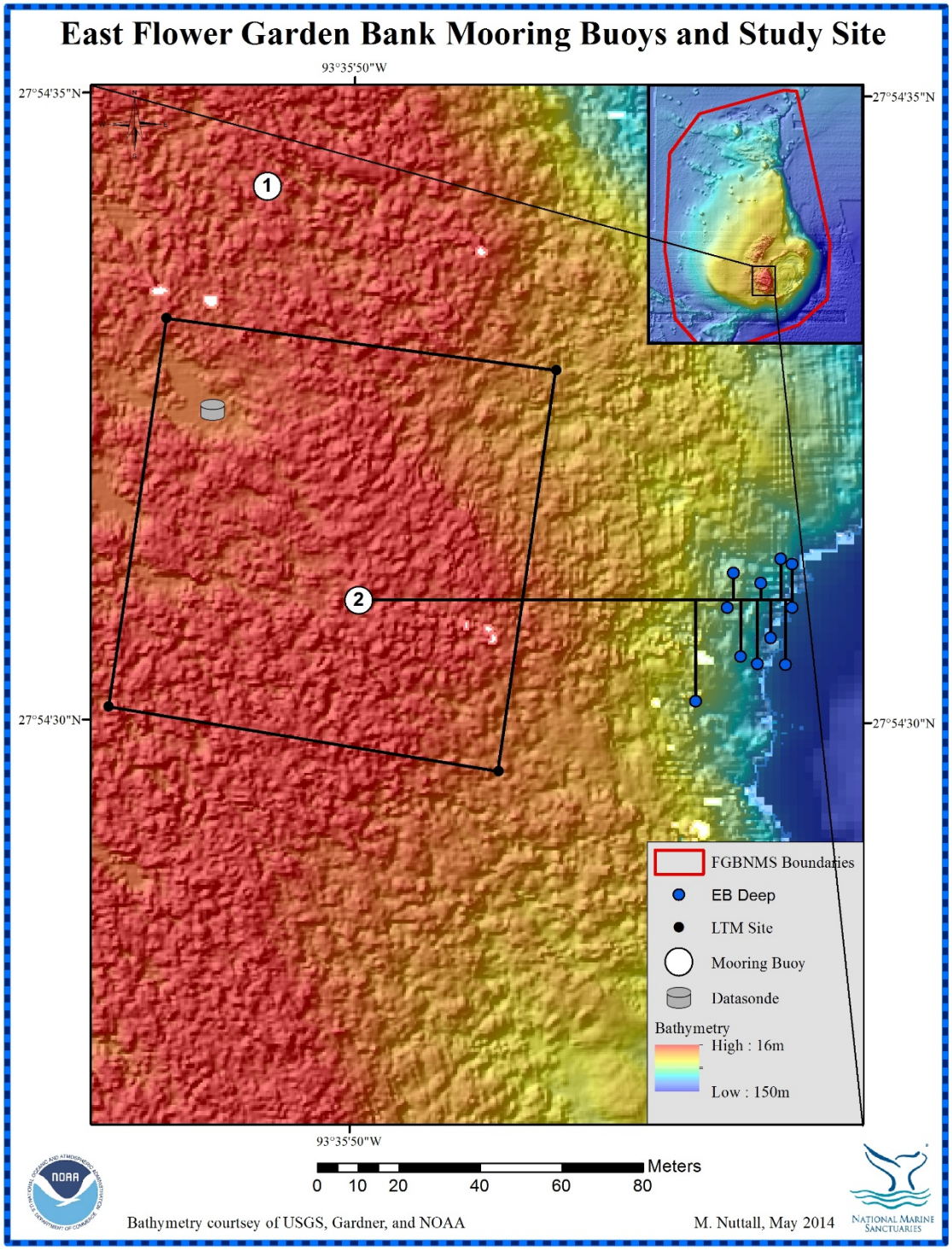


Figure 1.5. Bathymetric map of EFGB with long-term monitoring study site (LTM site), mooring buoy, and repetitive deep photostation locations (EB Deep).

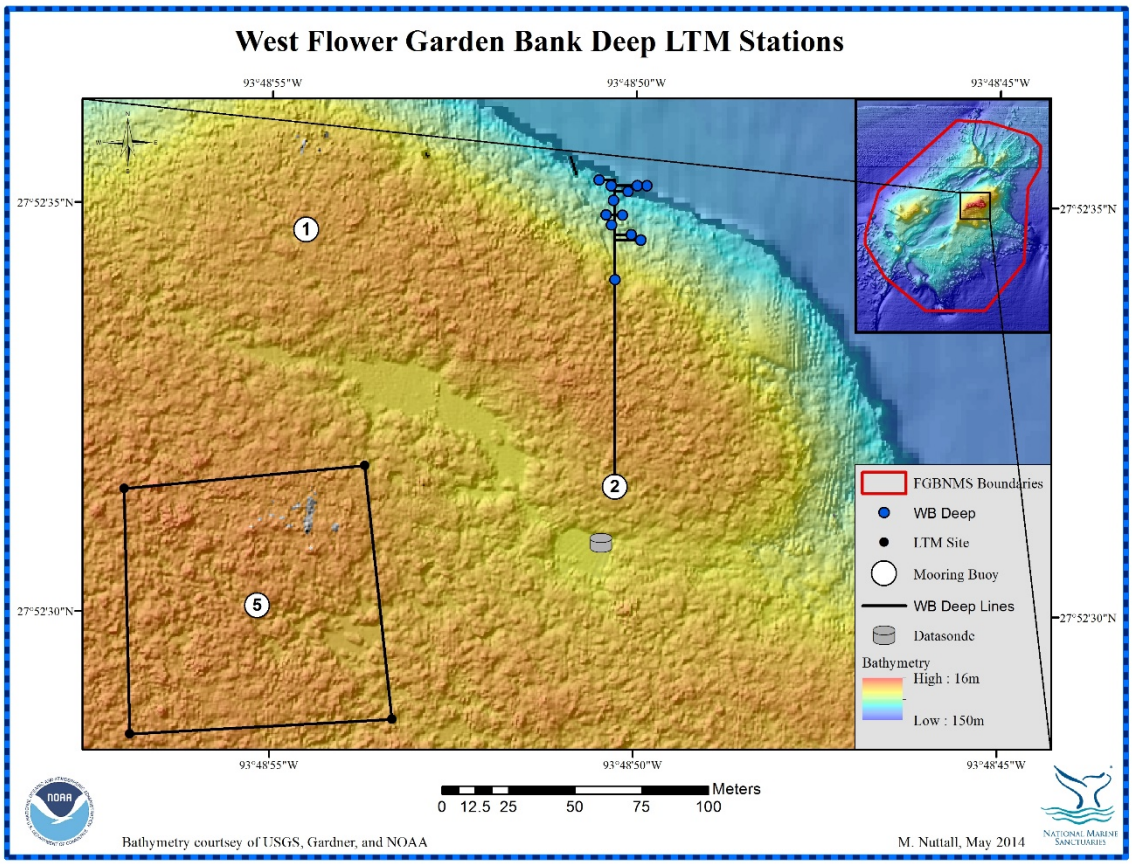


Figure 1.6. Bathymetric map of WFGB with long-term monitoring study site (LTM site), mooring buoy, and repetitive deep photostation locations (WB Deep).

Field Operations

Long-term monitoring data were collected within the study sites at EFGB and WFGB in 2016 and SCUBA operations were conducted off the NOAA *R/V Manta* (Table 1.2). The *R/V Manta* is an 83-foot catamaran and used primarily as a research platform, conducting research and monitoring activities in the waters of the northwestern Gulf of Mexico, mostly within marine sanctuary boundaries. The vessel's A-frame and winch were used for CTD casts on water quality cruises. The extensive dive operations during long-term monitoring cruises were supported by onboard facilities and equipment. Berthing, stowage, galley and safety equipment allowed for multiple day operations supporting four crew and ten scientists. In 2016, additional cruises were conducted in response to a localized mortality event at EFGB, as well as bleaching events at EFGB and WFGB.

Table 1.2. Monitoring and response cruises completed at EFGB and WFGB.

Date	Cruise and Tasks Completed
02/18/2016	Water Quality Cruise: Instrument download and water sample collection
05/19/2016	Water Quality Cruise: Instrument download and water sample collection
07/25/2016 – 07/28/2016	Long-Term Monitoring Cruise: EFGB study site annual monitoring and mortality event initial documentation
07/30/2016 – 08/02/2016	Water Quality Mortality Response: Water sample collection
08/05/2016 – 08/07/2016	EFGB Mortality Event Response: Documentation and sample collection
08/10/2016 – 08/12/2016	Long-Term Monitoring Cruise: WFGB study site annual monitoring and water sample collection
10/05/2016	EFGB Bleaching Response Cruise: Bleaching documentation in study site
10/18/2016 – 10/19/2016	WFGB Bleaching Response Cruise: Bleaching documentation in study site
11/15/2016	Water Quality Cruise: Instrument download and water sample collection
01/31/2017	EFGB Bleaching Response Cruise: Bleaching documentation in study site

Chapter 2. Random Transects

NOAA diver, Ryan Eckert, with camera and strobes mounted on aluminum t-frame taking random transect photographs within the East Flower Garden Bank study site. (Photo: G.P. Schmahl, NOAA/FGBNMS)

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 within study sites. The surveys were used to compare habitat and document the benthic reef community between EFGB and WFGB study sites.

Random Transect Methods

Random Transect Field Methods

Sixteen non-overlapping random transects within each study site were completed in 2016. Divers were given a randomly generated start location and heading for each survey. 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 pre-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 more detailed methods, reference Johnston et al. 2017.

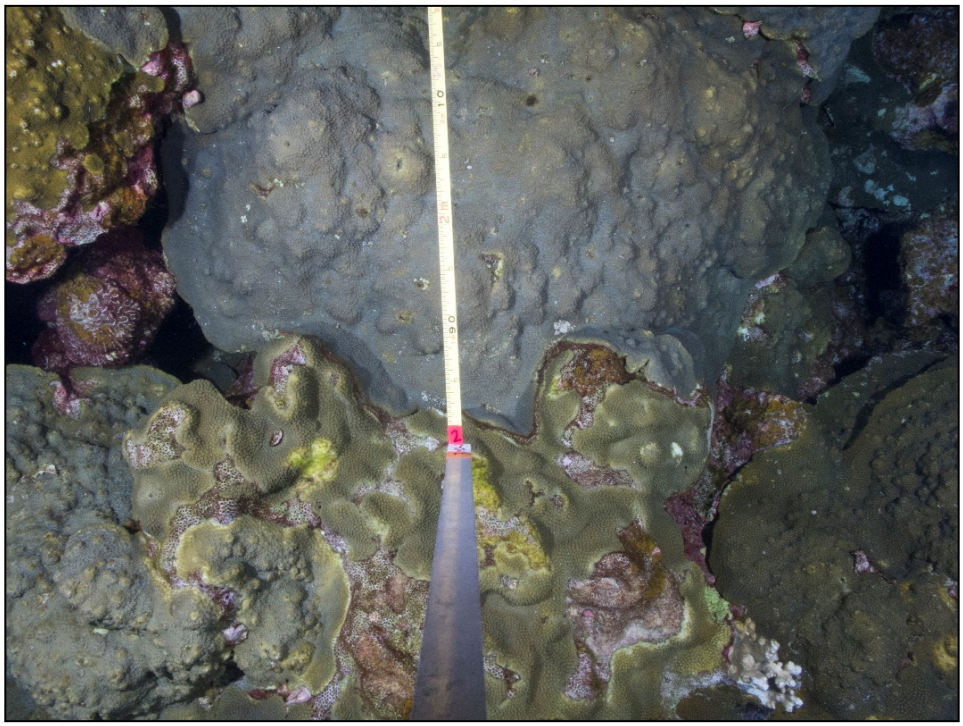


Figure 2.1. Photo taken at marked interval along random transect with camera mounted to aluminum t-frame. (Photo: Ryan Eckert, NOAA/FGBNMS)

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 (30 spatially random points per image) (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) sponges (including encrusting sponges), 3) macroalgae, and 4) "CTB," a composite substrate category that includes the colonizable substrates 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 covering underlying substrate. Additional categories included "other" (other biotic live components including ascidians, fish, serpulids, and unknown species), sand, rubble, abiotic features (photostation tags, tape measures, scientific equipment), and no data (shadows). Sand, rubble, abiotic features, and no data were excluded from the analysis. Points on corals that could not be differentiated because of camera angle or camera distortion were labeled as "unidentified coral." *Orbicella* colonies that could not be identified to the species level were labeled as *Orbicella* sp.

The coverages of coral bleaching, paling, concentrated and isolated fish biting, and mortality were also recorded, providing additional information for each random point. Any point that landed on a portion of coral that was white with no visible zooxanthallae was characterized as "bleached." Any point that landed on coral that was pale relative to what was considered "normal" for the species, was characterized as "paling" coral (AGRRA 2010). If the colony displayed some bleaching or paling, but the point landed on a healthy area of the organism, the point was "healthy" and no bleaching or paling was noted in CPCe. To classify fish biting, any point that landed where fish biting occurred on a coral head more than once was classified as concentrated fish biting, and any point where there was only one occurrence of fish biting was classified as isolated fish biting. Fish biting that resulted in the removal of coral polyps from an affected area is probably the result of grazing by stoplight parrotfish (*Sparisoma viride*) (Bruckner and Bruckner 1998; Bruckner et al. 2000). Recent mortality included any point on recently dead coral (exposed bare skeleton) with little to no algae growth so that the species could still be determined.

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 study site. Results were presented as mean percent cover ± standard error.

Consistency for photographic random transect methods was ensured by multiple, scientific divers all trained on the same camera systems for correct camera operation. Camera settings and equipment were standardized so that consistent transect images were taken annually and equipment checklists were provided in the field to ensure divers had all equipment and were confident with tasks assigned. Random transect photographs were

reviewed promptly after images were taken to ensure the quality was sufficient for analysis. After all benthic components were identified in CPCe files, quality assurance/quality control (QA/QC) consisted of a separate FGBNMS staff member, different from the CPC analyzer, who independently reviewed all identified points from the random transect photographs for accuracy. Any mistakes were corrected before percent cover analysis was completed.

Random Transect Statistical Analysis

Benthic community interactions in EFGB and WFGB random transects were evaluated with non-parametric distance-based analyses with Primer® version 7.0 (Anderson et al. 2008; Clarke et al. 2014). Euclidean distance resemblance matrices were calculated using untransformed percent cover data from random transect primary functional groups. Data were left untransformed so that the significance of non-dominant groups was not overinflated. Permutational multivariate analysis of variance (PERMANOVA) was based on resemblance matrices and used to test for benthic community differences and estimate components of variation between bank study sites (Anderson et al. 2008). If significant differences were found, groups or species contributing to observed differences were examined using similarity percentages (SIMPER) to assess the percent contribution of dissimilarity between groups (Clarke & Warwick 2001).

Significant dissimilarities in coral species composition between bank study sites was tested using analysis of similarity (ANOSIM) (Clarke & Warwick 2001) on square-root transformed coral species percent cover data with Euclidean distance similarity matrices. Diversity indices for coral species, including Margalef's species richness (d), Pielou's evenness (J'), and Shannon diversity (H'), were calculated to make comparisons between sites.

Functional group means by year and bank study sites for historical random transect mean percent cover data (1992 to 2016) were visualized using principal coordinates ordination (PCO), based on similarity matrices, with percent variability explained on each canonical axis. A time series trajectory with correlation vectors (correlation >0.2) were overlaid on PCO plots to represent the direction of the variable gradients for the plot (Anderson et al. 2008; Clarke et al. 2014). Cluster analyses for year groups were performed on Euclidean distance similarity matrices with SIMPROF tests to identify significant (α=0.05) clusters within the data (Clarke et al. 2008). Significant differences between bank study site communities were tested using PERMANOVA. Groups contributing to observed dissimilarities were identified using SIMPER (Clarke & Warwick 2001).

Monotonic trends in mean percent cover data were detected using the Mann-Kendall trend test in R® version 2.13.2 (Hipel and McLeod 1994; Helsel and Hirsch 2002). Tests of significant correlation were completed in R® version 2.13.2 with Pearson's correlation (Helsel and Hirsch 2002). It should be noted that the range of data collected has varied slightly over the years. From 1989 to 1991 only mean percent coral cover data were

collected; other major functional groups were added in 1992. No data were collected in 1993.

Random Transect Results

Random Transect Mean Percent Cover

Mean coral cover (± standard error) within the EFGB study site was 49.92% ± 2.14. Mean sponge cover was 0.54% ± 0.13, macroalgae cover was 37.15% ± 2.35, CTB cover was 11.17% ± 0.93, and other cover was 1.23%± 0.68 (Figure 2.2).

Within the WFGB study site, mean coral cover was 58.54% ± 2.87, followed by macroalgae (25.69% ± 2.44), CTB (14.05% ± 0.98), sponge (0.74% ± 0.14), and other cover (0.98% ± 0.43) (Figure 2.2).

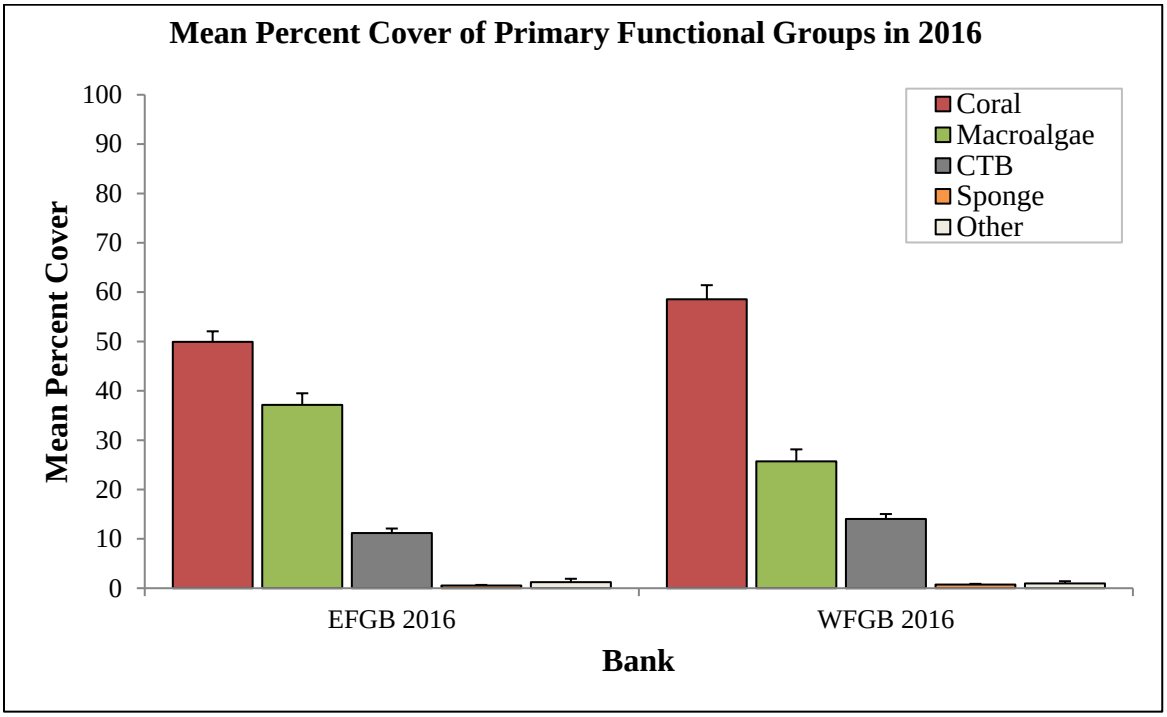


Figure 2.2. Mean percent benthic cover + SE from random transect functional groups within EFGB and WFGB study sites in 2016.

PERMANOVA analysis comparing functional groups revealed significant differences between banks, suggesting that EFGB and WFGB study sites were different in benthic community composition in 2016 (Table 2.1). SIMPER analysis identified that for comparisons between bank study sites, the greatest contributors to the observed dissimilarity were mean macroalgae (43%) and coral (40%) percent cover.

Table 2.1. PERMANOVA results comparing random transect mean percent benthic cover between EFGB and WFGB study sites from 2016. Bold text denotes significant value.

Source	Sum of Squares	df	Pseudo-F	P (perm)
Bank Study Site Cover	1711	1	8.16	**0.005**
Res	6291	30		
Total	8003	31		

Less than 1% of the coral cover analyzed showed incidences of bleaching and paling in the EFGB study site during July 2016 and less than 5% in the WFGB study site in August 2016. It is important to note that surveys occurred in the early summer months when water temperatures were lower than threshold levels known to trigger bleaching (Hagman and Gittings 1992). Chapter 10 reports data and discusses bleaching observed in October of 2016. In addition, less than 1% of fish biting were observed in mean coral cover data.

A total of 17 species of coral were observed within EFGB and WFGB study sites in 2016 (Figure 2.3). *Orbicella franksi* was the most abundant coral species observed at EFGB (20.38% ± 2.66) and WFGB (29.29% ± 2.39). *Pseudodiploria strigosa* was the next most abundant species at EFGB (9.30% ± 1. 61) and WFGB (8.81% ± 1.85) (Figure 2.3). The *Orbicella annularis* species complex including *Orbicella franksi, Orbicella faveolata, Orbicella annularis* (listed as threatened species under the Endangered Species Act) made up 50.99% of the observed coral species within EFGB study sites and 61.67% of the observed coral species within WFGB study sites. ANOSIM revealed no significant differences in coral species composition between bank study sites.

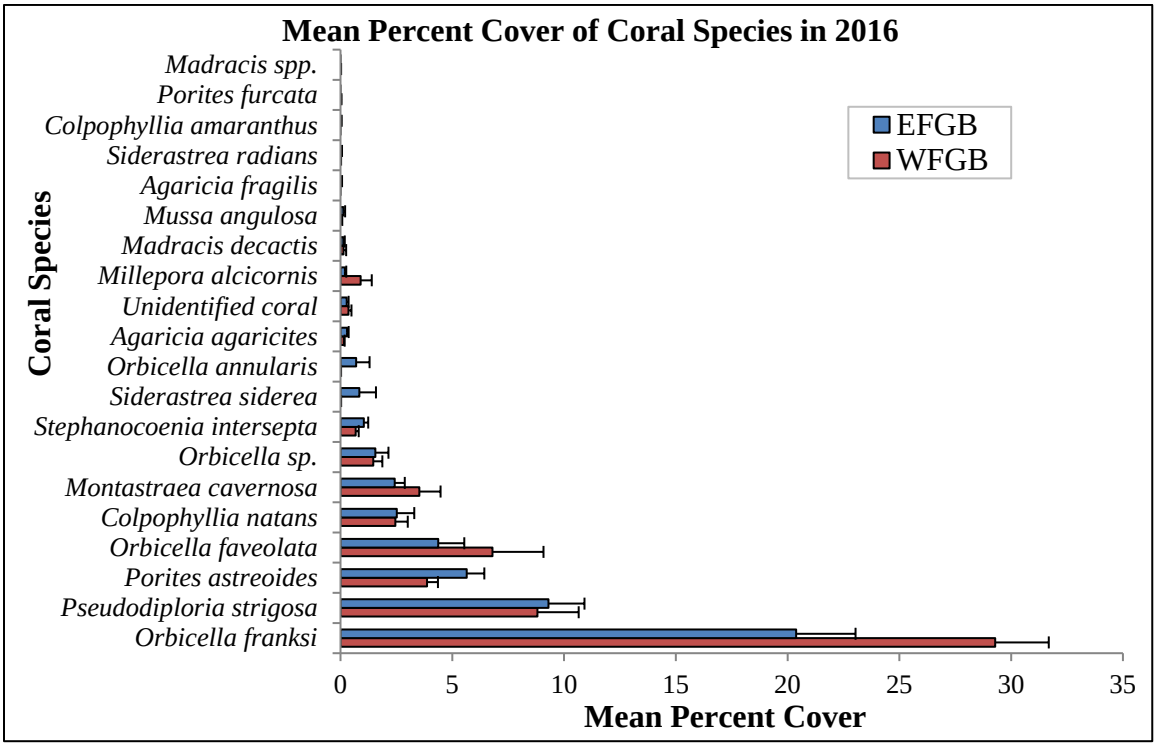


Figure 2.3. Mean percent cover + SE of observed coral species from random transects within EFGB and WFGB study sites in 2016.

Coral species diversity measures were averaged for each study site in 2016 (Table 2.2). Significant dissimilarities were found from ANOSIM results comparing diversity measures between communities (Global R=0.131, p=1.1%), suggesting that the EFGB study site was more diverse than the WFGB study site.

Table 2.2. Mean coral species diversity measures ± SE within EFGB and WFGB study sites in 2016.

Random Transect Coral Diversity Measures	EFGB	WFGB
Margalef's Species Richness (d)	2.41 ± 0.11	2.06 ± 0.08
Pielou's Evenness (J')	0.68 ± 0.02	0.63 ± 0.02
Shannon Diversity (H'(loge))	1.59 ± 0.06	1.39 ± 0.05

Random Transect Long-Term Trends

Mean percent benthic cover from the main random transect functional categories (coral, sponge, macroalgae, and CTB) were analyzed from 1989 to 2016. During the period of study, a variety of underwater camera setups were used as technology advanced from 35-mm slides (1989 to 2001), digital videography using video still frame grabs (2002 to 2009), and digital still images (2010 to 2016) (Gittings et al. 1992; CSA 1996; Dokken et al. 1999, 2003; Precht et al. 2006; Zimmer et al. 2010; Johnston et al. 2013, 2015, 2017). Prior to the use of CPCe, percent cover was calculated with mylar traces and a calibrated planimeter from 1989 to 1995 (Gittings et al. 1992; CSA 1996). From 1996 to 2003, random dot layers were generated manually in photo software programs (Dokken et al. 1999, 2003).

Mean percent coral cover from 1989 to 2016 ranged from 40–64% in EFGB study sites and 37–66% in WFGB study sites, significantly increasing in both study sites over the time period (τ=0.36, p<0.016 and τ=0.68, p<0.001, respectively) (Figure 2.4). Predominant coral species with the greatest mean percent cover were the *Orbicella* species group (31.87%) (primarily *Orbicella franksi*), followed by *Pseudodiploria strigosa* (8.48%) for both banks combined (Figure 2.5). The *Orbicella* species group combines *O. franksi*, *O. faveolata*, and *O. annularis*. These separate species have been distinguished in recent years, but were grouped during historical data collection methods. These species are listed as threatened under the Endangered Species Act.

Prior to 1999, macroalgae cover was consistently below 5% within the study sites; however, in 1999, macroalgae cover increased to approximately 20%, and has averaged 30% in recent years. Macroalgae and CTB cover generally varied inversely and were significantly correlated (τ=-8.18, p<0.001). Macroalgae significantly increased within EFGB (τ=0.67, p<0.001) and WFGB (τ=0.57, p<0.001) study sites while CTB significantly decreased with EFGB (τ=-0.54, p<0.001) and WFGB (τ=-0.53, p<0.001) study sites from 1992 to 2016 (Figure 2.4).

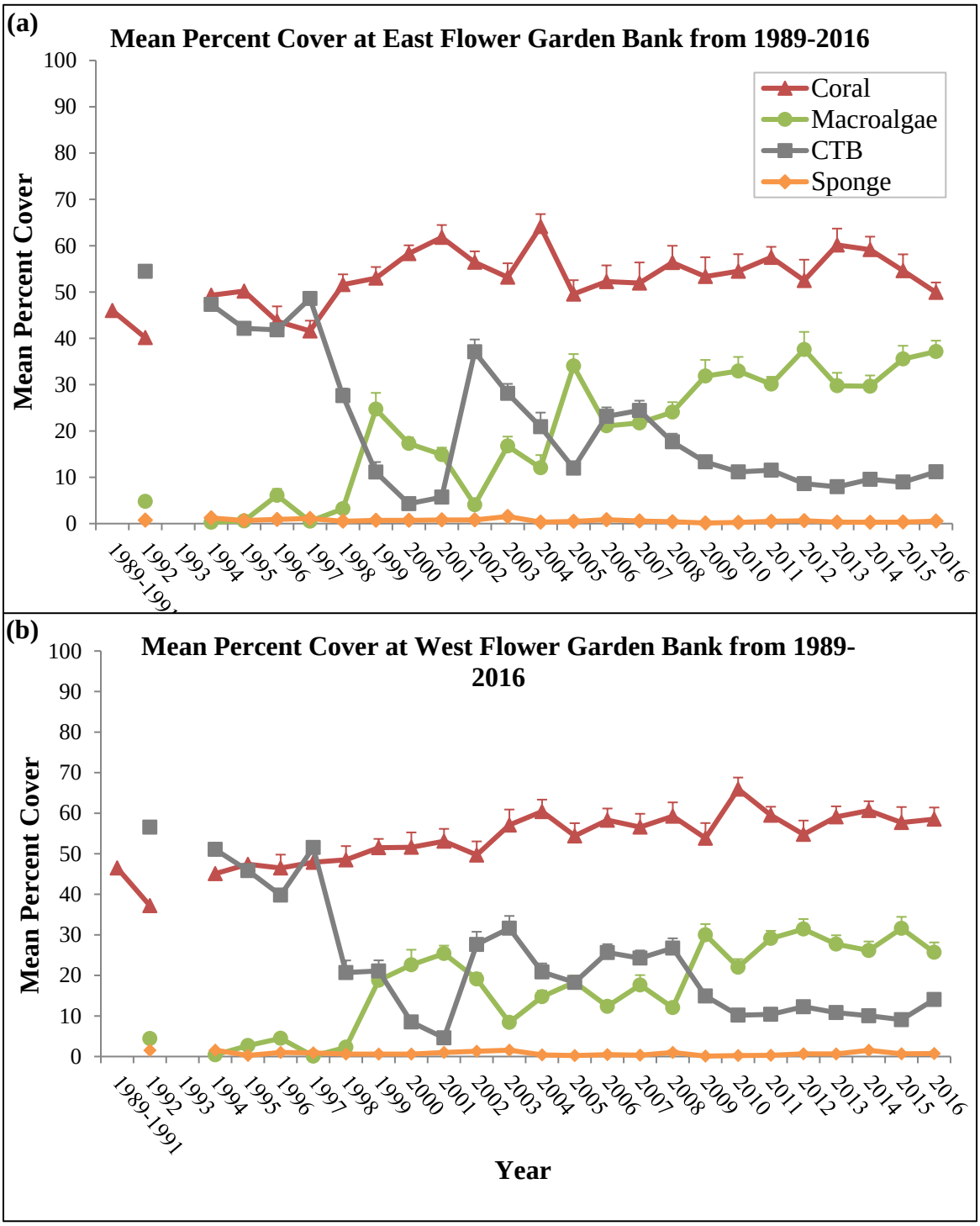


Figure 2.4. Mean percent benthic cover cover +SE from random transect functional groups within (a) EFGB and (b) WFGB study sites from 1989 to 2016.

No mean percent cover data were reported in 1993. Data for 1989 to 1991 from Gittings et al. (1992); 1992 to 1995 from Continental Shelf Associates, Inc. (CSA 1996); 1996 to 2001 from Dokken et al. (2003); 2002 to 2008 from PBS&J (Precht et al. 2006; Zimmer et al. 2010); and FGBNMS for 2009 to 2015 (Johnston et al. 2013, 2015, 2017).

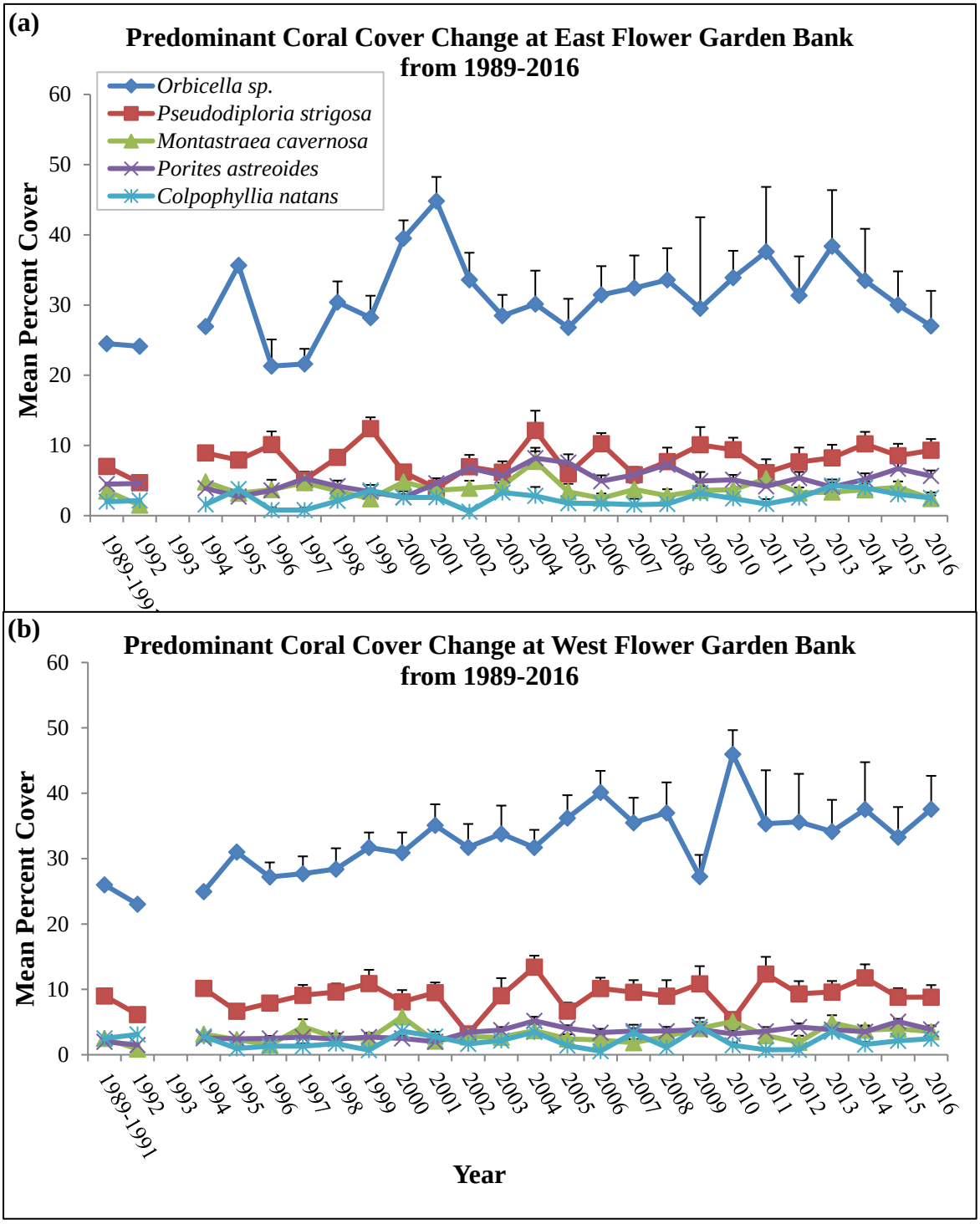


Figure 2.5. Mean percent cover of predominant coral species + S E within (a) EFGB and (b) WFGB study sites from 1989 to 2016. *Orbicella* species combines *O. franksi*, *O. faveolata*, and *O. annularis* for historical data comparison.

No mean percent cover data were reported in 1993. Data for 1989 to 1991 from Gittings et al. (1992); 1992 to 1995 from CSA (CSA 1996); 1996 to 2001 from Dokken et al. (2003); 2002 to 2008 from PBS&J (Precht et al. 2006; Zimmer et al. 2010); and FGBNMS for 2009 to 2015 (Johnston et al. 2013, 2015, 2017).

For yearly mean benthic percent cover data (1992 to 2016), SIMPROF analysis detected four significant year clusters in the EFGB study site (A: 1992 to 1998 and 2002; B: 2003 to 2004 and 2006 to 2007; C: 2001 to 2002; and D: 1999, 2008 to 2016) (Figure 2.6). Between clusters A and B, macroalgae and CTB mean percent cover contributed to over 85% of the dissimilarity (53.27% and 31.76%, respectively), corresponding to the shift in increased macroalgae and decreased CTB cover after 1998 (Figure 2.4). The single contributor to the dissimilarity between clusters B and C was CTB (84.10%), as well as for clusters A and C (79.98%). Between clusters B and D, macroalgae and CTB mean percent cover contributed to over 90% of the dissimilarity (50.18% and 41.28%, respectively), as well as for clusters between A and D (42.42% and 53.07%, respectively).

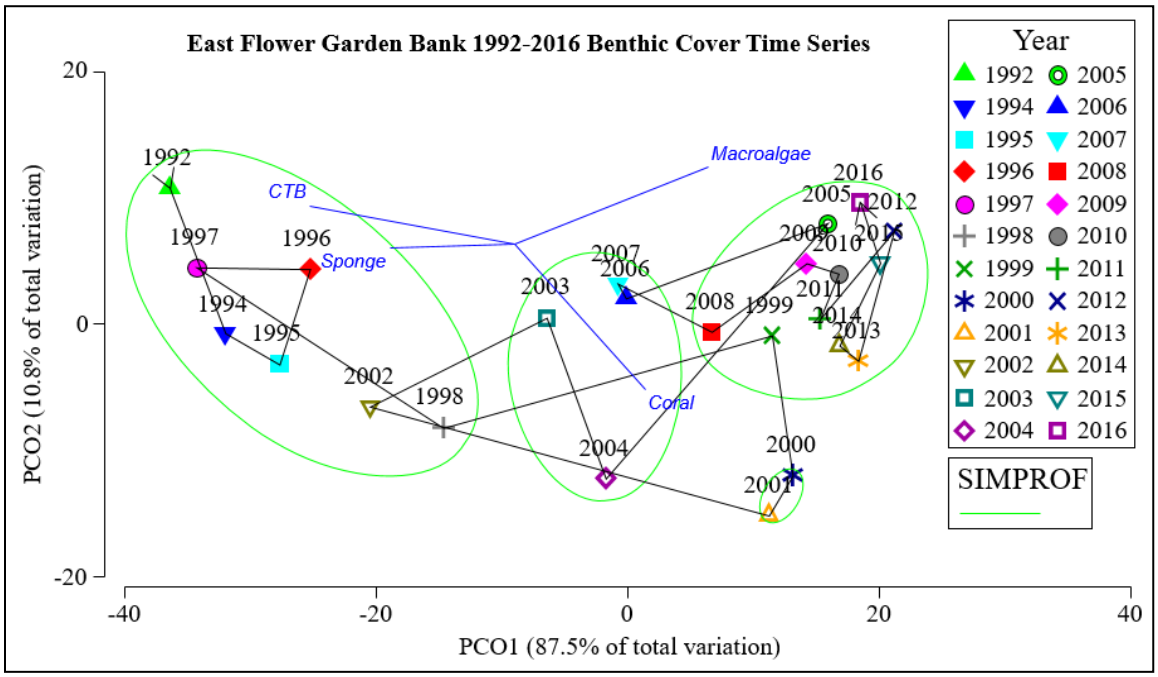


Figure 2.6. PCO for random transect benthic cover analysis from 1992 to 2016 within the EFGB study site. The green ovals are SIMPORF groups representing significant year clusters. The blue vector lines represent the directions of the variable gradients for the plot.

Yearly mean benthic percent cover data from 1992 to 2016 at the WFGB study site displayed a similar pattern to EFGB, resulting in three significant year clusters (A: 1992 to 1997; B: 1998 to 2008; C: 2009 to 2016) (Figure 2.7). Between clusters A and B, macroalgae and CTB mean percent cover contributed to over 85% of the dissimilarity (16.61% and 69.12%, respectively), corresponding decreasing CTB cover from 1997 to 1998 (Figure 2.4). Macroalgae and CTB mean percent cover also contributed to the dissimilarity between clusters B and C (46.92% and 44.73%, respectively), corresponding to the shift in increased macroalgae and decreased CTB cover after 1998 (Figure 2.4). Differences between clusters A and C were also attributed to macroalgae and CTB mean percent cover (26.76% and 65.00%, respectively).

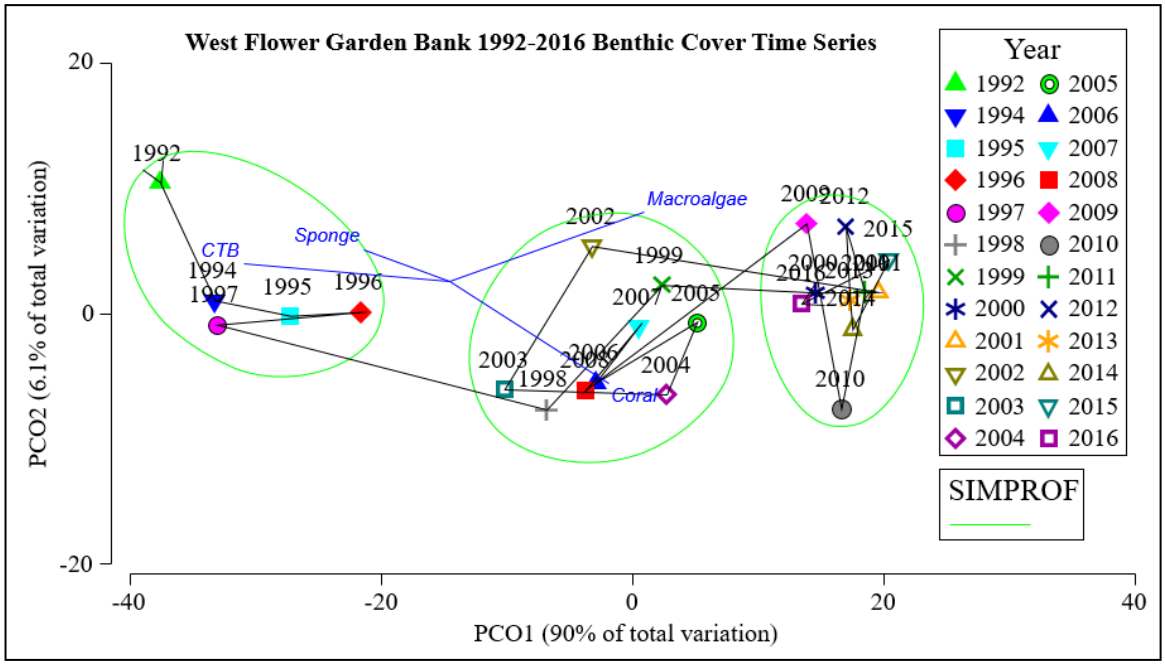


Figure 2.7. PCO for random transect benthic cover analysis from 1992 to 2016 within the WFGB study site. The green ovals are SIMPORF groups representing significant year clusters. The blue vector lines represent the directions of the variable gradients for the plot.

PERMANOVA results revealed no significant differences between bank communities, suggesting that EFGB and WFGB study sites were similar to each other from 1992 to 2016 in overall benthic community composition, experiencing similar shifts though time.

Random Transect Discussion

Despite global coral reef decline in recent decades, mean coral cover within EFGB and WFGB study sites has remained near or above 50% for the combined 27 years of monitoring; however, coral cover within the EFGB study site has been on a decreasing trend since 2014 and was below 50% in 2016 for the first time since 2005. Mean percent coral cover within the WFGB study site was higher than at EFGB, averaging 60% since 2013.

Mean macroalgae percent cover increased significantly between 1998 and 1999, rising from approximately 5% to 20%, and increasing above 30% in recent years. An inverse relationship between macroalgae and CTB has been observed throughout the long-term monitoring program; however, after 2008 macroalgae was greater than CTB cover, continuing to increase or remain stable within both study sites. These trends suggest that from 1992 to 1998, the reef community within the study sites was stable and from 1999 onward, there was a shift as CTB declined and macroalgae cover increased, where colonizable substrate was populated by macroalgae. This shift caused the reef community to change due to significantly higher macroalgae percent cover. In contrast to other shallow water reefs in the Caribbean region and many worldwide, increases in mean

macroalgae cover have not been concomitant with significant coral cover decline at the EFGB and WFGB study sites (Gardner et al. 2003; Mumby and Steneck 2011; DeBose et al. 2012; Jackson et al. 2014; Johnston et al. 2016b). While a portion of the EFGB was affected by a mortality event and bleaching event in 2016, both these events occurred after long-term monitoring data were collected. These events are discussed in Chapters 9 and 10.

The shift in macroalgae cover observed within the EFGB and WFGB long-term monitoring study sites was consistent with other reef shifts in the Gulf of Mexico and Caribbean region. Stetson Bank, for example, a series of claystone and siltstone pinnacles covered by a diverse coral and sponge community located 48 km northwest of WFGB, has shown an analogous but more prominent trend of increasing macroalgae and decreasing sponge and coral cover (DeBose et al. 2012; Nuttall et al. 2017). Also within the Gulf region, increased macroalgae cover and significant coral decline has occurred within monitoring sites at Florida Keys National Marine Sanctuary (Toth et al. 2014). Mean coral cover sanctuary-wide declined from 13% in 1996 to 7% in 2008, and even as low as 3% in 2011 in some areas of the Florida Keys (Ruzicka et al. 2009; ONMS 2011; Toth et al. 2014). This decline in the Florida Keys was most likely due to disease, hurricane damage, and thermal stress (Toth et. al 2014). Overfishing, bleaching, algae competition, coastal development, and coral disease have also caused declines on reefs in the wider Caribbean region (Gardner et al. 2003; Steneck et al. 2011; Jackson et al. 2014).

In contrast, the EFGB and WFGB study sites have not shown a significant decline in coral cover since 1989, and have 6 to 11 times higher coral cover values than other locations in the Caribbean region (Caldow et al. 2009; Clark et al. 2014; Johnston et al. 2017). This may be due to the remote offshore location and deep water surrounding the banks, providing a more stable environment than shallower reefs (Aronson et al. 2005; Johnston et al. 2015). However, despite their remote location and deeper depth compared to shallower Caribbean reefs, EFGB and WFGB are not invulnerable to impacts. Climate change, invasive species, storms, and water quality degradation continue to be threats (ONMS 2008; Nuttall et al. 2014). As the environment in the Gulf of Mexico changes over time (Karnauskas et al. 2015), continued monitoring will be important to document ecosystem variation.

Chapter 3. Repetitive Study Site Photostations

NOAA diver, Ryan Eckert, photographs a repetitive photostation within the East Flower Garden Bank study site with camera and strobes mounted to aluminum t-frame. (Photo: G.P. Schmahl, NOAA/FGBNMS)

Repetitive Study Site Photostation Introduction

Permanent repetitive photostations were photographed to follow specific colonies over time and to document changes in the composition of benthic assemblages in selected sites within EFGB and WFGB study sites. The photographs were analyzed to measure percent benthic cover components using random-dot analysis.

Repetitive Study Site Photostation Methods

Repetitive Study Site Photostation Field Methods

Repetitive study site photostations, marked by permanent pins with numbered tags on the reef, were located by SCUBA divers using detailed underwater maps displaying compass headings and distances to each station within the study sites. After each station was located, divers photographed each one (for more detailed methods, reference Johnston et al. 2017) (Figure 3.1). In 2016, all repetitive study site photostations were located and photographed: 37 at EFGB and 41 at WFGB.

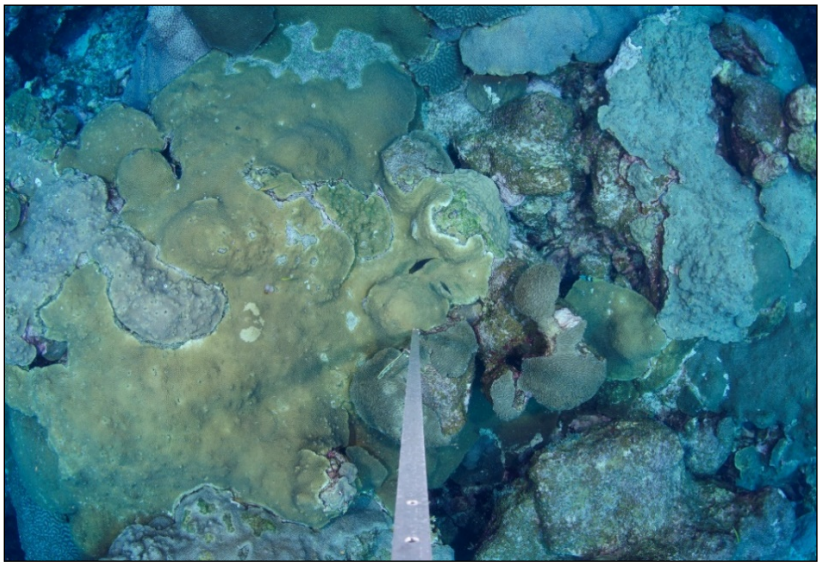


Figure 3.1. WFGB repetitive photostation #504 in 2016. Camera mounted above aluminum t-frame. (Photo: Ryan Eckert, NOAA/FGBNMS)

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 (1.2 m apart). 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 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 and compass (see Chapter 3 title page image). Two Z-Bolt® waterproof green laser pointers with mounting brackets were also attached to the aluminum t-frame post and set 30 cm apart for scale. This set-up produced images covering 5 m².

Repetitive Study Site Photostation Data Processing

Mean percent benthic cover from repetitive study site photostation images was analyzed using CPCe version 4.1 (Aronson et al. 1994; Kohler and Gill 2006). A total of 100 random dots were overlaid on each photograph and benthic species lying under these points were identified and verified by QA/QC, as described in Chapter 2 (See Methods – Random Transect Data Processing). Point count analysis was conducted for all photos and mean percent cover for functional groups was determined by averaging all photostations per bank study site. Results were presented as mean percent cover ± standard error.

Repetitive Study Site Photostation Statistical Analysis

All nonparametric analysis for non-normal data were carried out using Primer® version 7.0 and monotonic trends were detected using the Mann-Kendall trend test in R® version 2.13.2 as described in Chapter 2 (See Methods – Random Transect Statistical Analysis).

Repetitive Study Site Photostation Results

Repetitive Study Site Photostation Mean Percent Cover

EFGB repetitive study site photostation mean coral cover (± standard error) was 62.23% ± 2.77 and macroalgae cover was 28.92% ± 2.37. Mean CTB cover was 7.44% ± 0.76, mean sponge cover was 0.58% ± 0.16, and other cover was 0.84%± 0.30 (Figure 2.2). Within the WFGB study site, mean coral cover was 65.06% ± 2.02 in repetitive study site photostations, followed by mean macroalgae (22.73% ± 1.83), CTB (10.35% ± 0.71), sponge (0.24% ± 0.08), and other cover (1.62% ± 0.84) (Figure 3.2).

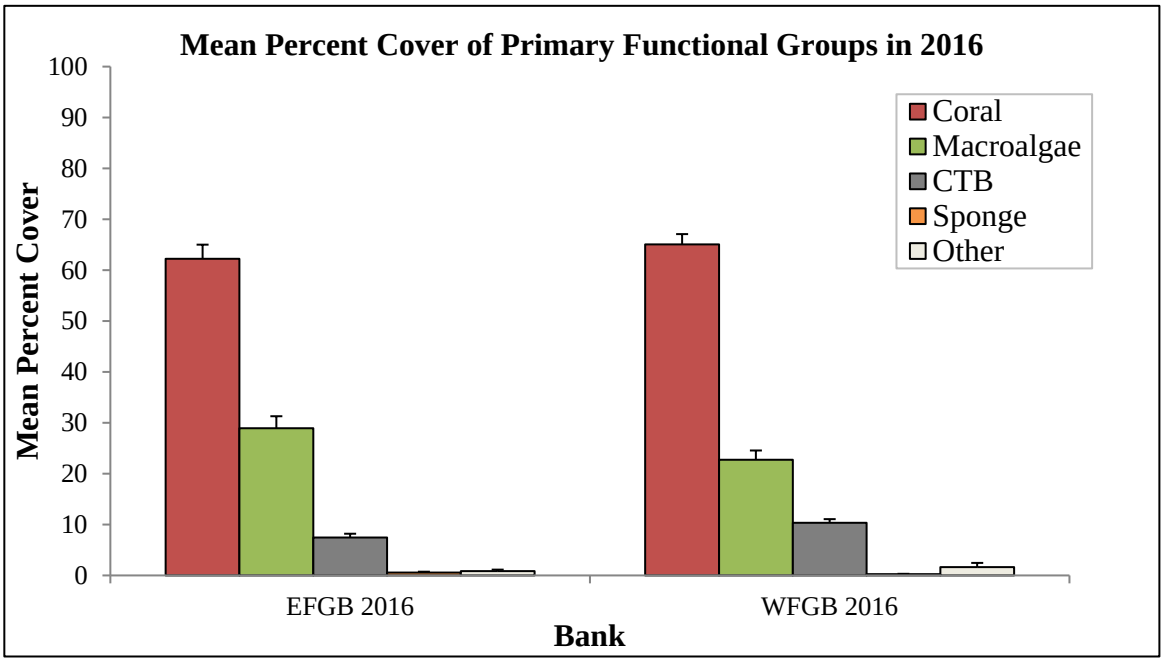


Figure 3.2. Mean percent benthic cover + SE from repetitive study site photostation functional groups within EFGB and WFGB study sites in 2016.

When compared for differences based on functional groups, no significant differences were found, suggesting that EFGB and WFGB repetitive photostations were similar in overall benthic community composition between study sites in 2016.

A total of 13 species of coral were observed between EFGB and WFGB repetitive study site photostations in 2016 (Figure 3.3). *Orbicella franksi* was the most abundant coral species observed in EFGB (29.18% ± 2.90) and WFGB (32.33% ± 2.62) photostations. *Pseudodiploria strigosa* was the next most abundant species in EFGB (11.41% ± 1. 90) and WFGB (9.46% ± 1.47) photostations (Figure 3.3). ANOSIM resulted in no significant differences in coral species composition between banks in the repetitive study site photostations.

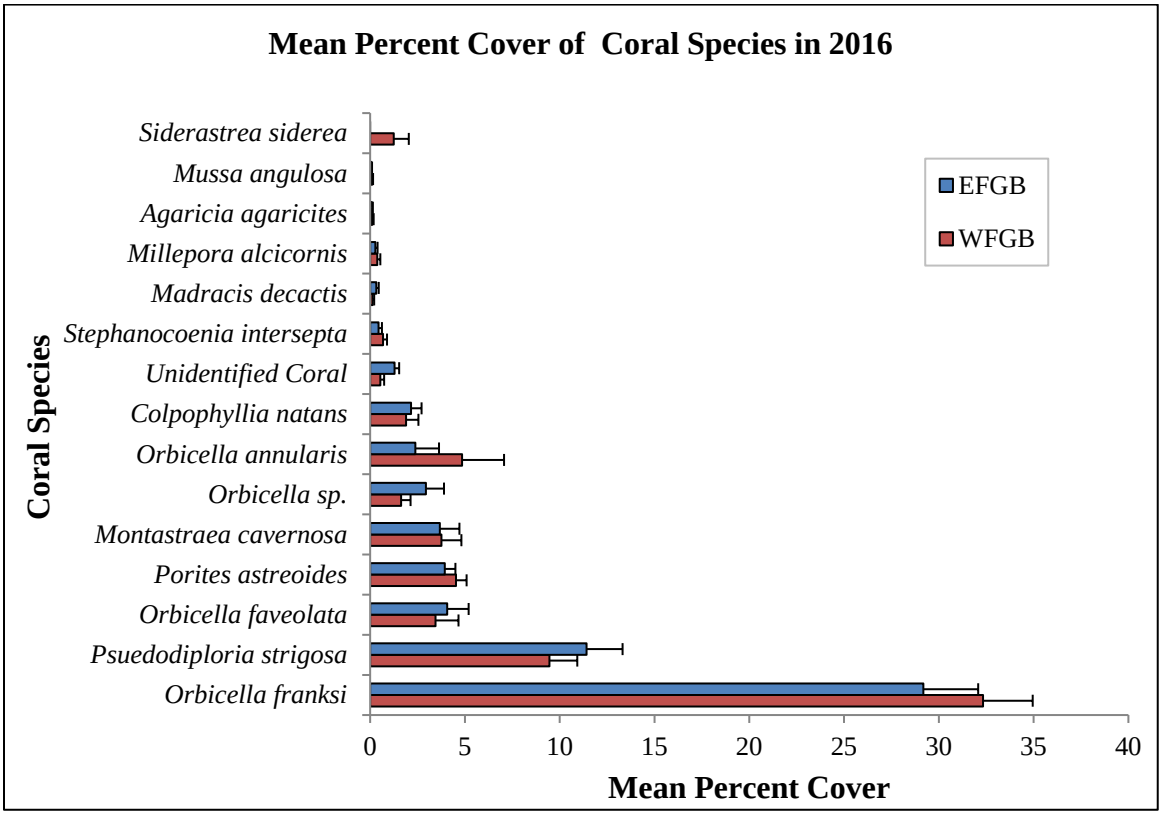


Figure 3.3. Mean percent cover + SE of observed coral species from repetitive study site photostations within EFGB and WFGB study sites in 2016.

Less than 0.5% of the coral cover analyzed was observed to bleach or pale in repetitive study site photostations. It is important to note that surveys occurred in the early summer months when water temperatures were lower than threshold levels known to trigger bleaching (Hagman and Gittings 1992). Chapter 10 reports data and discusses bleaching observed in October of 2016. In addition, concentrated fish biting was below 0.2% in repetitive study site photostations.

Repetitive Study Site Photostation Long-Term Trends

The mean percent benthic cover from the repetitive study site photostations was analyzed to measure changes over time. During the period of study, underwater camera setups used to capture benthic cover in the repetitive stations changed as technology advanced from 35-mm slides and film (1989 to 2007) to digital still images (2008 to 2015) (Gittings et al. 1992; CSA 1996; Dokken et al. 1999, 2003; Precht et al. 2006; Zimmer et al. 2010; Johnston et al. 2013, 2015, 2017). From 1989 to 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.

In repetitive study site photostations from 1989 to 2016, mean percent coral cover ranged from 49–73% at EFGB and 45–74% at WFGB, significantly increasing in photostations at both study sites over time (τ=0.44, p=0.004 and τ=0.34, p=0.027, respectively) (Figure 3.4). Coral species level data in repetitive study site photostations became available in 2000. Predominant coral species with the greatest mean percent cover from 2000 to 2016 were the *Orbicella* species group at EFGB (42.25%) and WFGB (43.64%) (primarily *Orbicella franksi*), followed by *Pseudodiploria strigosa* at EFGB (10.15%) and WFGB (8.95%) photostations (Figure 3.5).

Sponge, macroalgae, and CTB data were not included in the analysis until 2002, and similar to random transect data described in Chapter 2, periods of lower CTB cover generally coincided with increases in the macroalgae component (Figure 3.4). Macroalgae and CTB cover generally varied inversely and were significantly correlated (τ=-5.28, p<0.001). Macroalgae significantly increased at EFGB (τ=0.56, p=0.004) and WFGB (τ=0.58, p=0.003) while CTB decreased at EFGB (τ=-0.28, p=0.166) and significantly decreased at WFGB (τ=-0.64, p=0.001) from 2002–2016 (Figure 3.4).

ANOSIM results comparing benthic cover in repetitive study site photostations revealed no significant dissimilarities, suggesting that photostations at EFGB and WFGB were similar to each other in overall benthic community composition from 2002 to 2016.

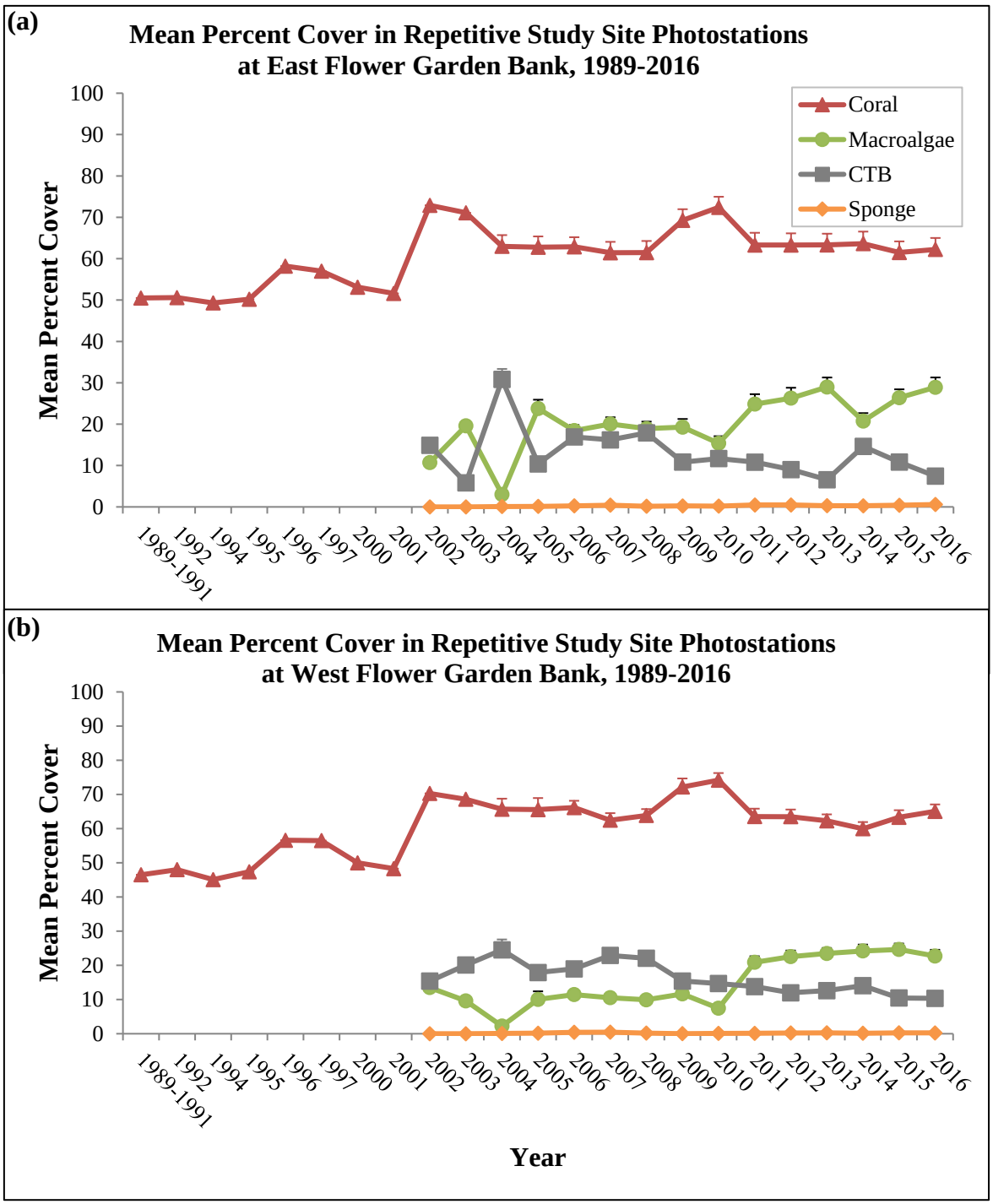


Figure 3.4. Mean percent benthic cover + SE of repetitive study site photostation functional groups within (a) EFGB and (b) WFGB study sites from 1989 to 2016.

Sponge, macrolage, and CTB categories were not reported until 2002. No mean percent cover data were reported in 1993. Data for 1989 to 1991 from Gittings et al. (1992); 1992 to 1995 from Continental Shelf Associates, Inc. (CSA) (1996); 1996 to 2001 from Dokken et al. (2003); 2002 to 2008 from PBS&J (Precht et al. 2006; Zimmer et al. 2010); and FGBNMS for 2009 to 2015 (Johnston et al. 2013, 2015, 2017).

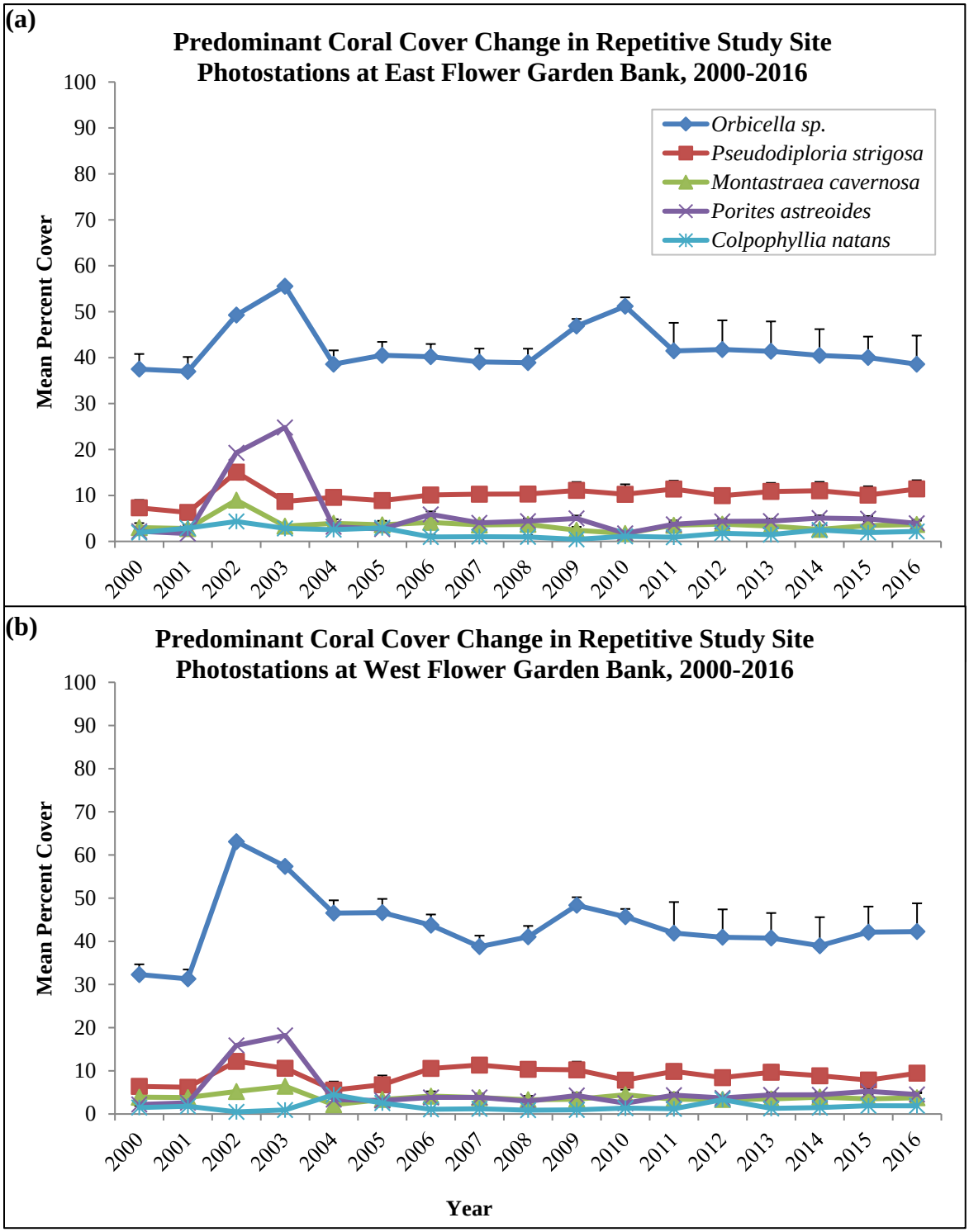


Figure 3.5. Mean percent cover of predominant coral species + S E in repetitive study site photostations at (a) EFGB and (b) WFGB from 2000 to 2016. *Orbicella* species combines *O. franksi*, *O. faveolata*, and *O. annularis* for historical data comparison.

Data for 2000 to 2001 from Dokken et al. (2003); 2002 to 2008 from PBS&J (Precht et al. 2006; Zimmer et al. 2010); and FGBNMS for 2009 to 2015 (Johnston et al. 2013, 2015, 2017).

For yearly mean benthic percent cover data in EFGB repetitive study site photostations (2002 to 2016), SIMPROF analysis detected four significant year clusters (A: 2002 to 2003 and 2009 to 2010; B: 2004; C: 2006 to 2008 and 2014; and D: 2005, 2009 to 2013, and 2015 to 2016) (Figure 3.6). Between clusters A and B, macroalgae and CTB mean percent cover contributed to over 89% of the dissimilarity (27.96% and 61.16%, respectively), corresponding to the shift in increased macroalgae and decreased CTB cover from 2002 to 2003 and after 2010 (Figure 3.4). Macroalgae (56.57%) and CTB (43.16%) again contributed to the dissimilarity between clusters B and C, due to the large increase in macroalgae and decrease in CTB after 2004. Between clusters C and D, macroalgae and CTB mean percent cover contributed to over 98% of the dissimilarity (47.96% and 50.66%, respectively) from continued increasing macroalgae and decreasing CTB through 2016 (Figure 3.4).

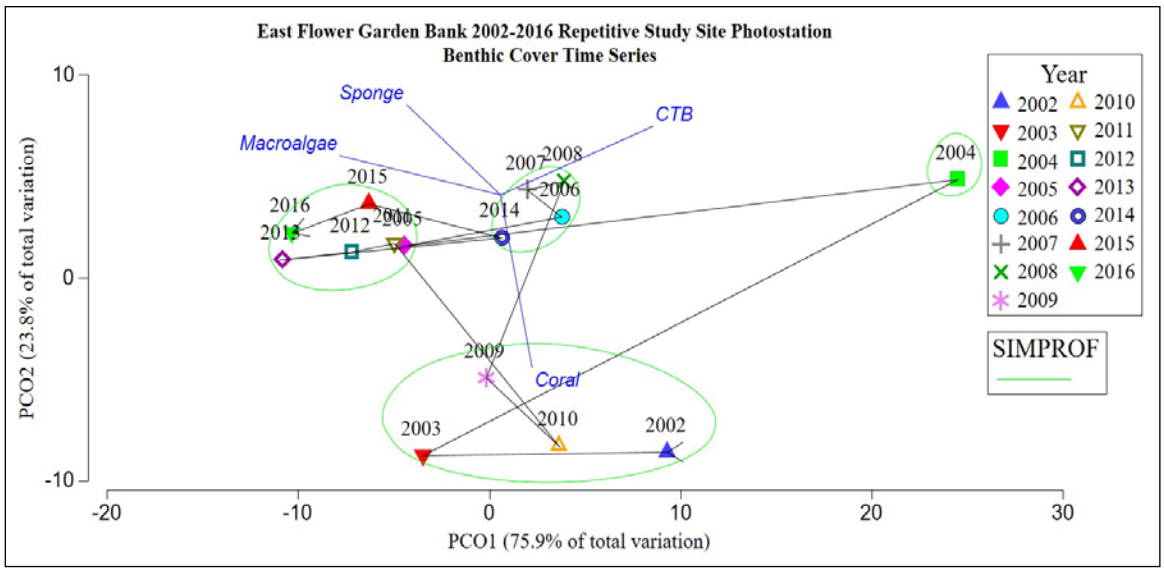


Figure 3.6. PCO for repetitive study site photostations from 2002 to 2016 at EFGB. The green ovals are SIMPORF groups representing significant year clusters. The blue vector lines represent the directions of the variable gradients for the plot.

Yearly mean benthic percent cover data in WFGB repetitive study site photostations resulted in two significant year clusters (A: 2004 to 2010; B: 2011 to 2016) (Figure 3.7). Between clusters A and B, macroalgae and CTB mean percent cover contributed to over 80% of the dissimilarity (52.90% and 27.11%, respectively), corresponding to the shift in increased macroalgae and decreased CTB cover after 2010 (Figure 3.4).

PERMANOVA results revealed no significant differences between bank communities, suggesting that EFGB and WFGB repetitive study site photostations were similar to each other from 2002 to 2016 in overall benthic community composition, experiencing similar shifts though time.

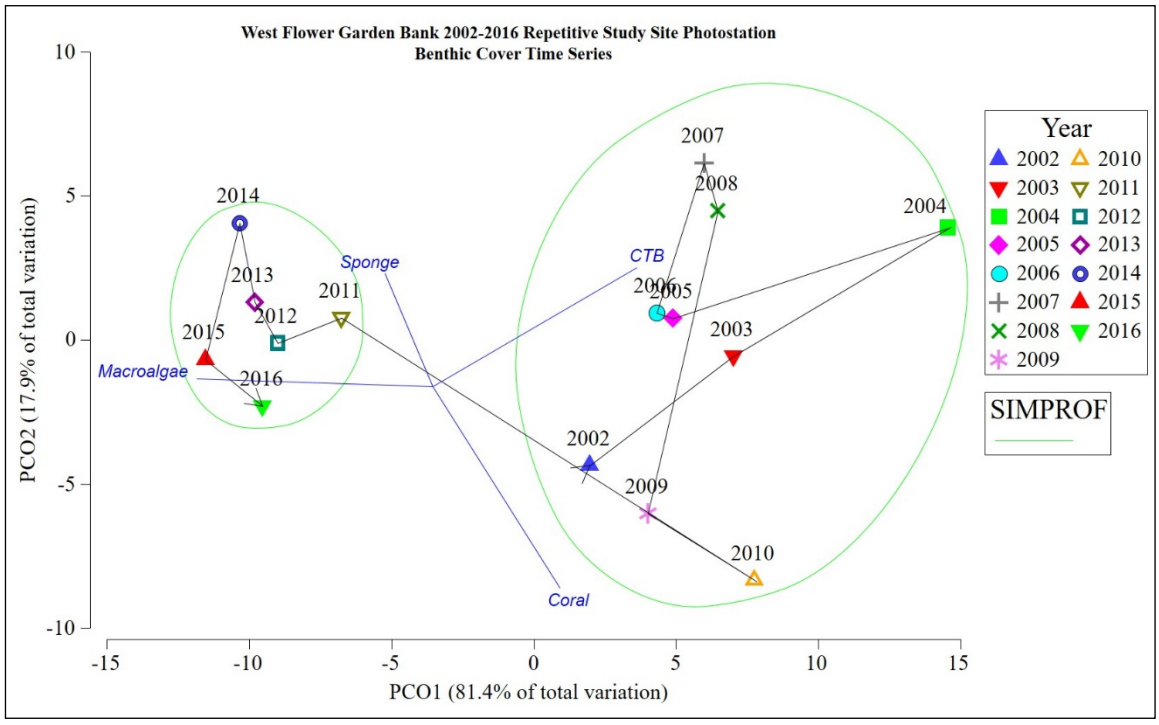


Figure 3.7. PCO for repetitive study site photostations from 2002 to 2016 at WFGB. The green ovals are SIMPORF groups representing significant year clusters. The blue vector lines represent the directions of the variable gradients for the plot.

Repetitive Study Site Photostation Discussion

The majority of the repetitive study site photostations (24 at EFGB and 27 at WFGB) have been in place since the beginning of the monitoring program, and display a time series from 1989 to 2016. As an example of the value of long-term repetitive photographs, EFGB station 102 displays increasing coral cover over time (Figure 3.8). Some colonies appeared paler in certain years due to variations in photographic equipment (e.g., 35 mm slides, 35 mm film, and digital images) and ambient conditions, as all photos were subject to varying degrees of camera settings, lighting, etc., from year to year. Changes over time include bare substrate to colonization and growth of *Pseudodiploria strigosa* and *Porites astreoides* colonies in the center of the station from 1989 to 2016 (Figure 3.6 a and f), algal colonization on an *Orbicella faveolata* head in the upper right corner in 1996 (affecting approximately 50% of the colony) (Figure 3.6 b), bleaching *Millepora alcicornis* that appeared in the center of the station in 2002 (Figure 3.6 c), and algal colonization on a *Pseudodiploria strigosa* head in the lower left corner affecting approximately 50% of the colony in 2016 (Figure 3.6 f).

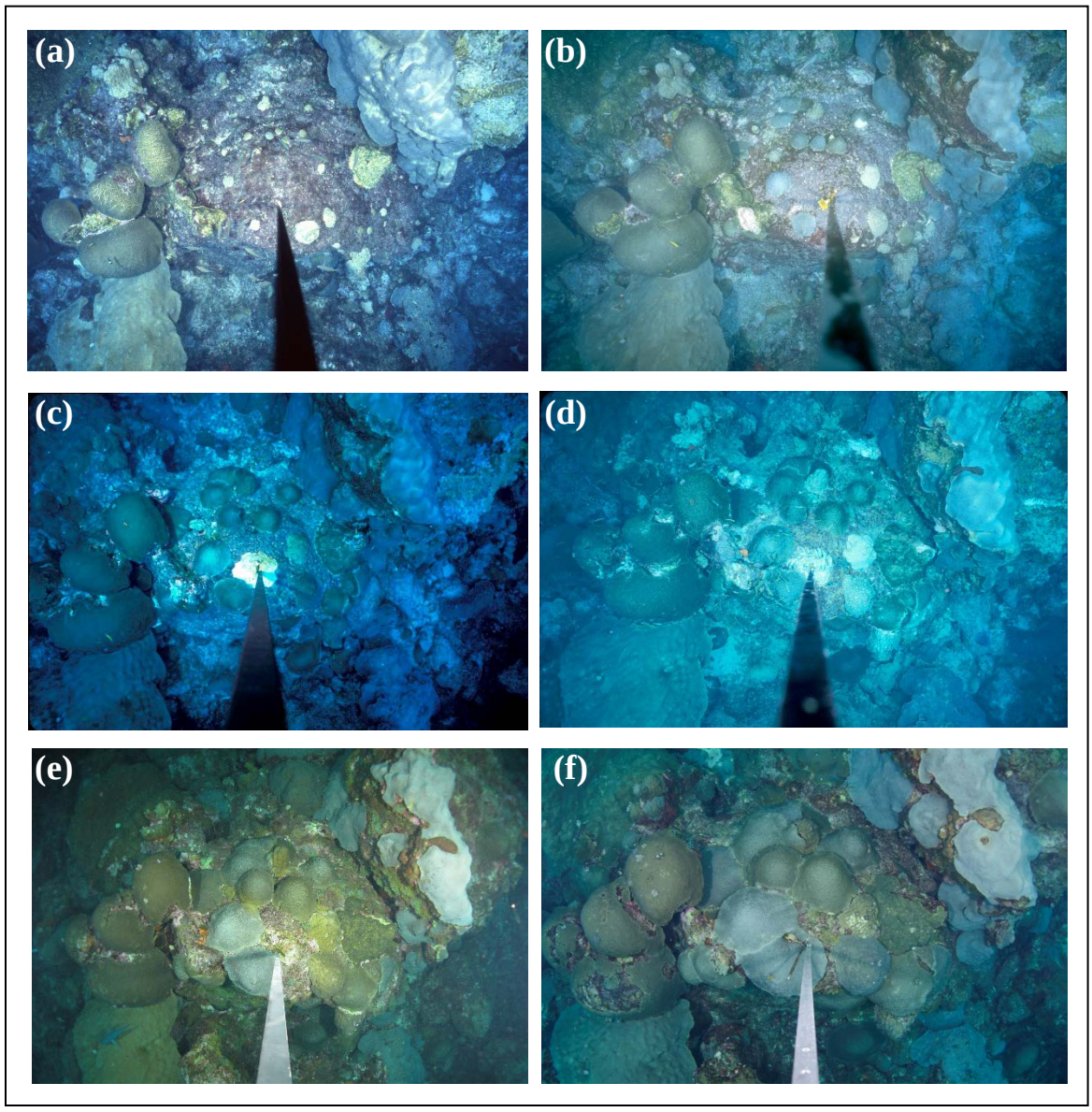


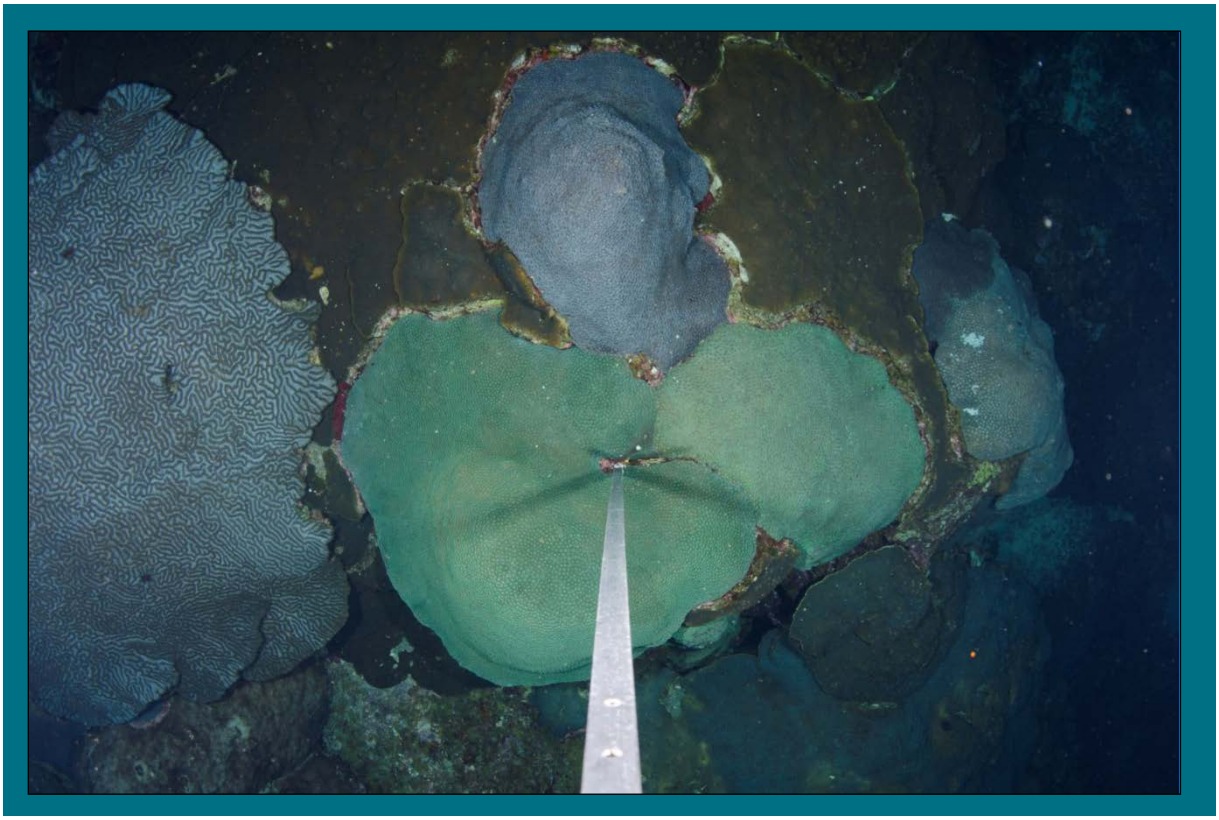
Figure 3.8. EFGB repetitive study site photostation #102 time series from (a) 1989; (b) 1996; (c) 2002; (d) 2006; (e) 2010; (f) 2016. Camera mounted above aluminum t-frame. (Photos: NOAA/FGBNMS)

Mean percent coral cover within the EFGB and WFGB repetitive study site photostations varied greatly from 1989 to 2015. A prominent increase in coral cover from 2001 to 2002 (Figure 3.5), specifically within the *Orbicella* species group, may be an artifact of different groups analyzing the repetitive photostation data, as the methods did not change between these years. The Center for Coastal Studies at Texas A&M Corpus Christi was responsible for the LTM program from 1996 to 2001 (Dokken et al. 2003), and in 2002 it was taken over by PBS&J Ecological Services, a consulting company based out of Miami, Florida (Precht et al. 2006, 2008; Zimmer et al. 2010). Additional photostations were added to both study sites in 1990 and 2003 (Gittings et al. 1992; Precht et al. 2006).

Greater coral cover estimates were obtained from the repetitive study site photostations in comparison to the random transects (64% compared with 54%) at both EFGB and WFGB combined. It should be noted that the repetitive photostations were not intended to provide a comprehensive view of predominant reef community species within EFGB and WFGB study sites, as they were selectively placed on habitat with large coral colonies in order to monitor individual corals and species interactions over time. As described in Chapter 2, the randomly selected benthic transects are the primary mechanism for analysis about the entire study site, while the repetitive photostations provide a long-term dataset allowing for conclusions to be made about specific sites over time.

Overall, in repetitive study site photostations the most evident patterns were: 1) a significant correlation between CTB and macroalgae cover, 2) a significant increase in mean macroalgae cover, and 3) an increase in mean coral cover over time. Despite the higher coral cover in the repetitive study site photostations, these sites 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 macroalgal cover.

Chapter 4. Repetitive Deep Photostations



East Flower Garden Bank repetitive deep photostation #07 in 2016 with camera mounted above aluminum t-frame. (Photo: Ryan Eckert, NOAA/FGBNMS)

Repetitive Deep Photostation Introduction

Permanent repetitive deep photostations were photographed to document changes in the composition of benthic assemblages in deeper repetitive sites, to follow specific colonies over time, and to compare to the benthic composition of the shallower repetitive study site photostations. The deep repetitive photostations were located outside the EFGB and WFGB study sites, ranging in depth from 24–40 m. The photographs were analyzed to measure percent benthic cover components using random-dot analysis.

Repetitive Deep Photostation Methods

Repetitive Deep Photostation Field Methods

Repetitive deep photostations, marked by permanent pins and numbered tags on the reef, were located by SCUBA divers using detailed underwater maps displaying compass headings and distances to each station. Eleven photostations at EFGB were located outside the study site (east of buoy#2) in depths ranging from 32–40 m (Figure 1.5). Twelve photostations at WFGB were located outside the study site, 78 m north buoy #2 in depths ranging from 24–38 m (Figure 1.6). After stations were located, divers photographed each station (for more detailed methods, reference Johnston et al. 2017) (Figure 4.1). All stations were located and photographed in 2016 using a Nikon® D7000® SLR camera, as described in Chapter 3 (See Methods – Repetitive Study Site Photostation Field Methods).

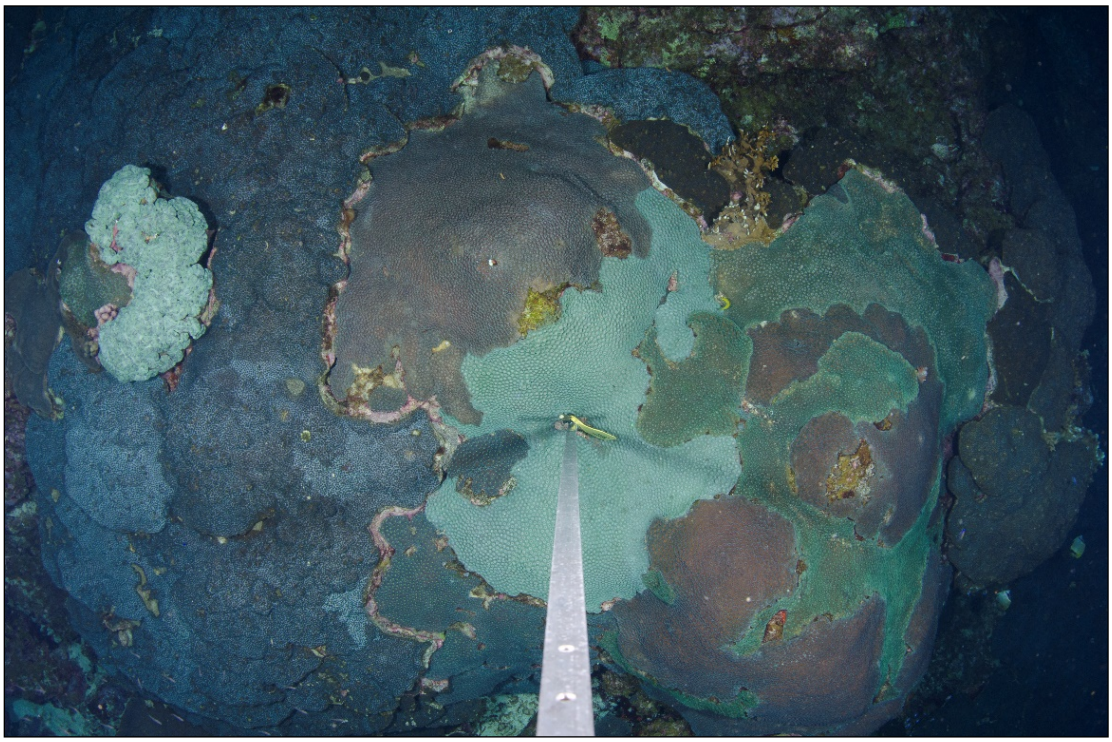


Figure 4.1. EFGB repetitive deep photostation #04 in 2016. Camera mounted above aluminum t-frame. (Photo: Ryan Eckert, NOAA/FGBNMS)

Repetitive Deep Photostation Data Processing

Mean percent benthic cover from repetitive deep photostation images was analyzed using CPCe version 4.1 (Aronson et al. 1994; Kohler and Gill 2006). A total of 100 random dots were overlaid on each photograph and benthic species lying under these points were identified and verified by QA/QC, as described in Chapter 2 (See Methods – Random Transect Data Processing). Point count analysis was conducted for all photos and mean percent cover for functional groups was determined by averaging all photostations per bank study site. Results were presented as mean percent cover ± standard error.

Repetitive Deep Photostation Statistical Analysis

All nonparametric analysis for non-normal data were carried out using Primer® version 7.0 and monotonic trends were detected using the Mann-Kendall trend test in R® version 2.13.2 as described in Chapter 2 (See Methods – Random Transect Statistical Analysis).

Repetitive Deep Photostation Results

Repetitive Deep Photostation Mean Percent Cover

EFGB repetitive deep photostation mean coral cover (± standard error) was 72.61% ± 3.61 and macroalgae cover was 19.79% ± 2.72. Mean CTB cover was 7.19% ± 1.53, mean sponge cover was 0.21% ± 0.14, and other cover was 0.20% ± 0.20 (Figure 4.2). At WFGB, mean coral cover was 75.84% ± 3.90, followed by mean macroalgae (13.07% ± 3.27), CTB (9.82% ± 1.18), sponge (0.64% ± 0.29), and other cover (0.63% ± 0.37) (Figure 4.2). When compared for differences based on functional groups, no significant differences were found, suggesting that EFGB and WFGB repetitive deep photostations were similar to each other in overall benthic community composition.

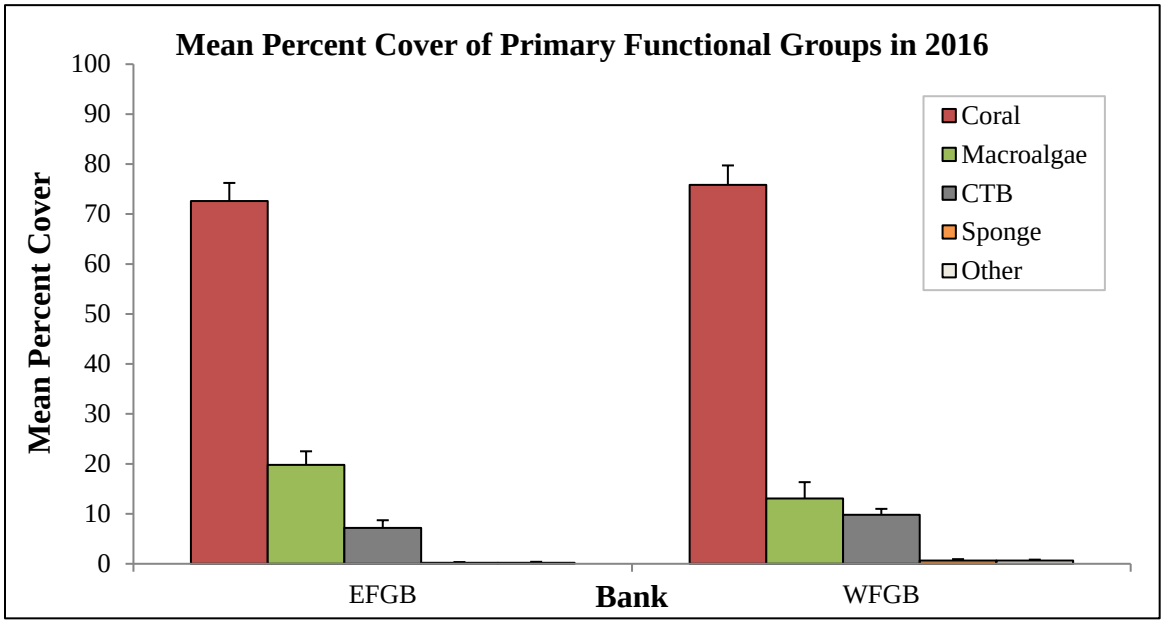


Figure 4.2. Mean percent benthic cover + SE from repetitive deep photostation functional groups at EFGB and WFGB in 2016.

A total of 13 species of coral were observed between EFGB and WFGB repetitive deep photostations in 2016 (Figure 4.3). *Orbicella franksi* was the most abundant coral species observed in EFGB (35.77% ± 4.38) and WFGB (33.75% ± 6.13) deep photostations. *Montastraea cavernosa* was the next most abundant species in EFGB (13.34% ± 3.67) and WFGB (18.71% ± 4.49) deep photostations (Figure 4.3). ANOSIM results revealed no significant differences in repetitive deep photostation coral species composition between banks.

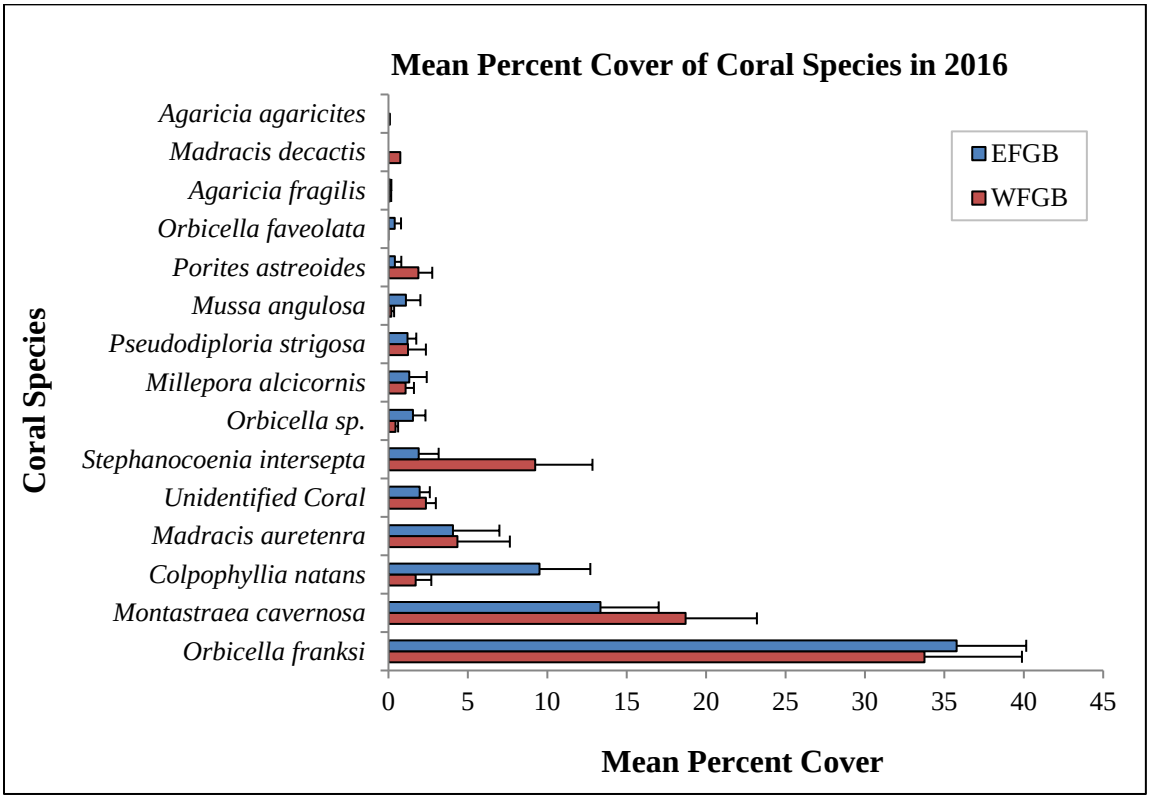


Figure 4.3. Mean percent cover + SE of observed coral species from repetitive deep photostations at EFGB and WFGB in 2016.

Less than 4% of the coral cover analyzed was observed to pale in the EFGB repetitive deep photostations, and no signs of paling or bleaching were observed in the WFGB repetitive deep photostations. It is important to note that surveys occurred in the early summer months when water temperatures were lower than threshold levels known to trigger bleaching (Hagman and Gittings 1992). Chapter 10 reports data and discusses bleaching observed in October of 2016. No signs of fish biting were observed.

Repetitive Deep Photostation and Repetitive Study Site Photostation Comparisons

Mean percent coral cover was higher in the repetitive deep photostations (deep stations) when compared to the shallower repetitive study site photostations (study site stations); averaging 74% at the deep stations and 64% at the study site stations. Mean deep station macroalgae cover for both banks was 16%, while the study site station macroalgae cover was 26%. Mean percent CTB cover at the deep stations and the study site stations was 9%. Mean percent sponge cover was below 1% for both the deep and study site stations, and other cover was below 1% at the deep stations and below 3% at the study site stations (Figure 4.4).

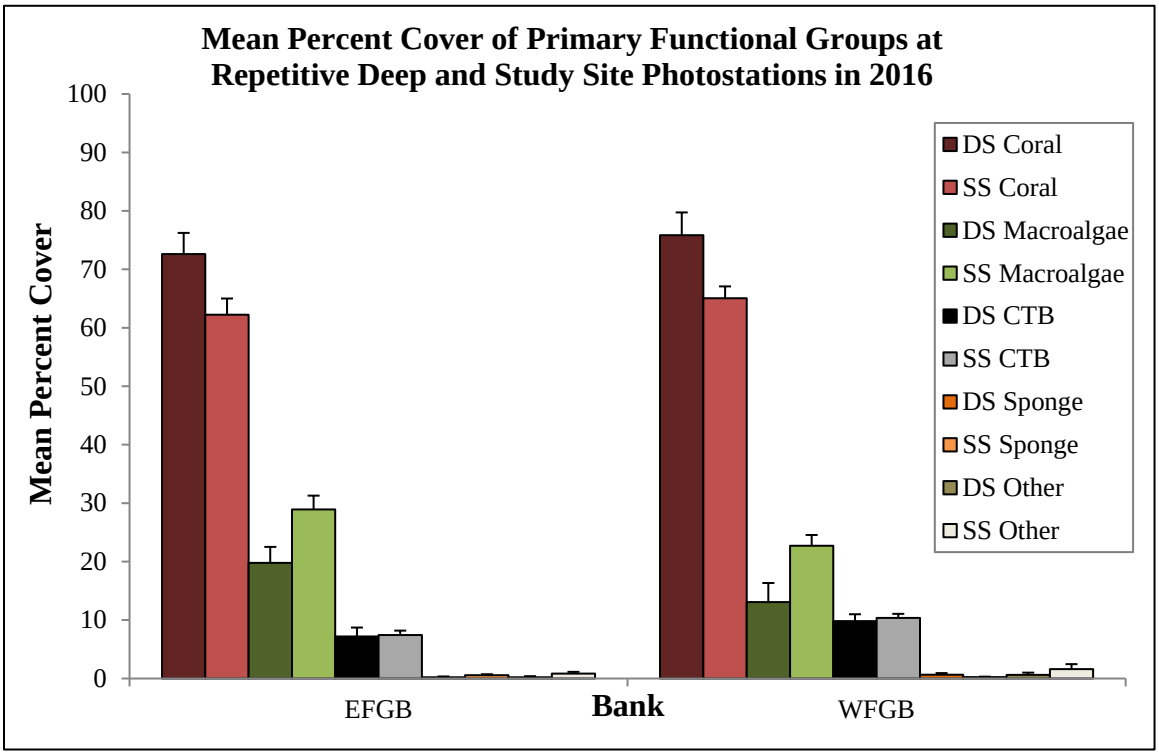


Figure 4.4. Repetitive deep station (DS) and repetitive study site (SS) photostations functional group mean benthic percent cover + SE at EFGB and WFGB in 2016.

When compared for differences between banks and depth based on mean percent cover, PERMANOVA analysis revealed a significant difference between depths, suggesting that EFGB and WFGB repetitive deep photostations were significantly different in overall benthic cover from the shallower repetitive study site photostations (Table 4.1). Mean coral cover was the predominant contributor (43.75%) to the observed dissimilarity between depths, resulting in significantly great coral cover in the deep stations.

Table 4.1. PERMANOVA results comparing repetitive deep photostation and repetitive study site photostation mean percent benthic cover from EFGB and WFGB in 2016. Bold text denotes significant value.

Source	Sum of Squares	df	Pseudo-F	P (perm)
Bank Photostation Cover	1034	1	2.71	0.086
Depth	3537	1	9.25	**0.001**
Bank Photostation Cover x Depth	4.91	1	0.01	0.987
Res	382	96		
Total	41623	99		

Repetitive Deep Photostation Long-Term Trends

The mean percent benthic cover from the repetitive deep photostations was analyzed to measure changes over time. Over the period of study, underwater camera setups used to capture benthic cover changed as technology advanced from 35-mm film (2003 to 2007) to digital still images (2008 to 2015) (Precht et al. 2006; Zimmer et al. 2010; Johnston et al. 2013, 2015, 2017). From 2003 to 2009, photographs for each repetitive deep photostation encompassed an 8 m^2 area, but changed to a 5 m^2 area in 2009 due to updated camera equipment.

In the EFGB repetitive deep photostations from 2003 to 2016, mean percent coral cover ranged from 72–86% (Figure 4.5). Predominant coral species with the greatest mean percent cover were within the *Orbicella* species group (45.13%) (primarily *Orbicella franksi*), followed by *Montastraea cavernosa* (14.49%) (Figure 4.6). Macroalgae and CTB cover were significantly correlated (τ=-4.091, p=0.001), as CTB significantly decreased over time (τ=-0.473, p=0.021), coinciding with macroalgae that significantly increased over time (τ=0.560, p=0.006) (Figure 4.5). Overall, the most noticeable pattern was the inverse relationship between CTB and macroalgae cover, with increased macroalgae cover starting in 2005, and peaking at approximately 21% in 2012 at the EFGB repetitive deep photostations.

In 2012, twelve deep photostations were established at WFGB. The mean percent coral cover ranged from 72–77% from 2012 to 2016 (Figure 4.5). Like the EFGB repetitive deep stations, predominant coral species with the greatest mean percent cover were within the *Orbicella* species group (35.27%) (primarily *Orbicella franksi*), followed by *Montastraea cavernosa* in the WFGB repetitive deep stations (18.26%) (Figure 4.6). Since 2012, macroalgae has ranged from 13–21% and CTB has ranged from 5–10%. Sponge cover was approximately 1% from 2012 to 2016. No significant increases or decreases in percent cover data were detected at the WFGB repetitive deep photostations since they were established in 2012.

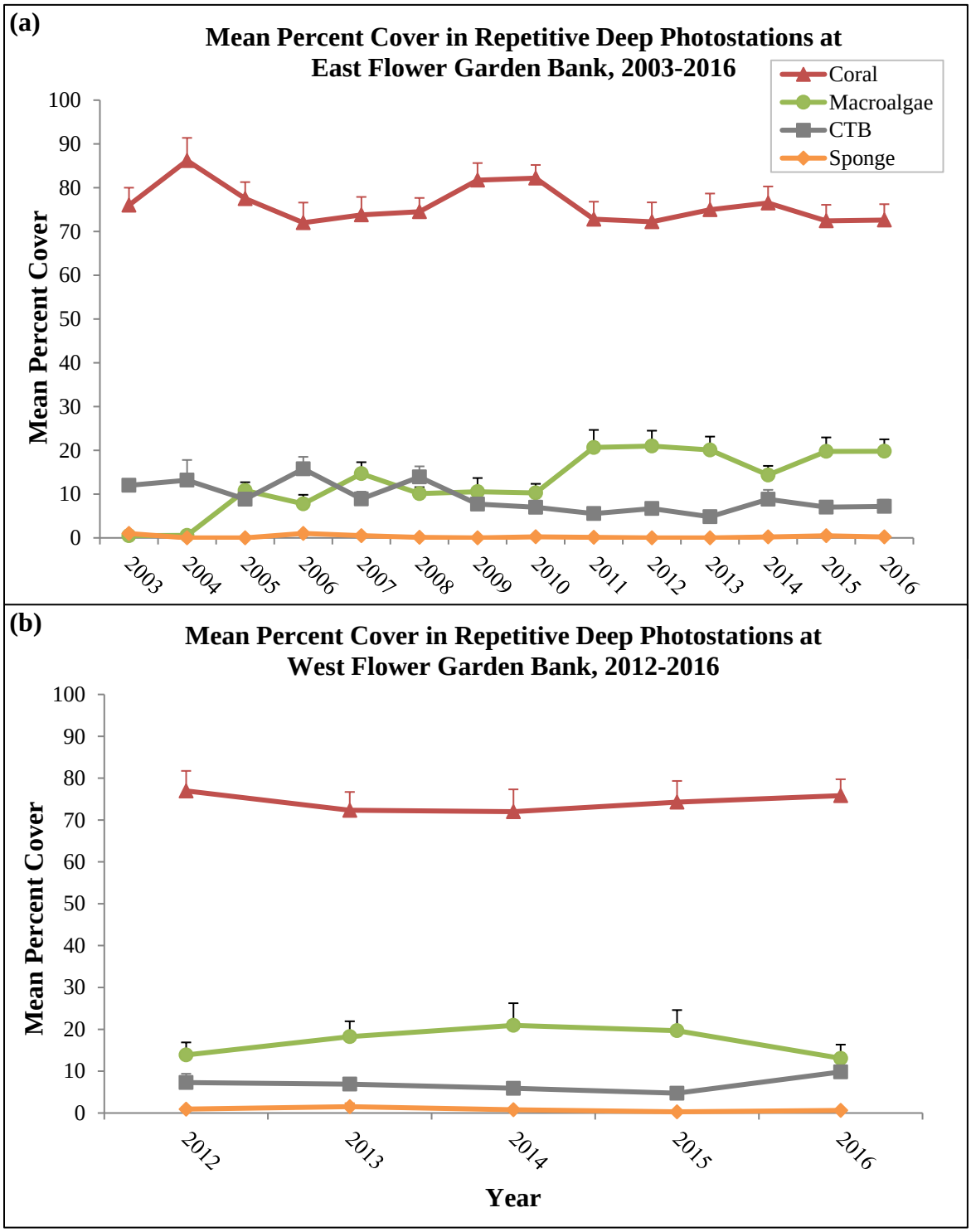


Figure 4.5. Mean percent benthic cover +SE of repetitive deep photostation functional groups at (a) EFGB from 2003 to 2016 and (b) WFGB from 2012 to 2016.

Data for 2003 to 2008 from PBS&J (Precht et al. 2006; Zimmer et al. 2010); and FGBNMS for 2009 to 2015 (Johnston et al. 2013, 2015, 2017).

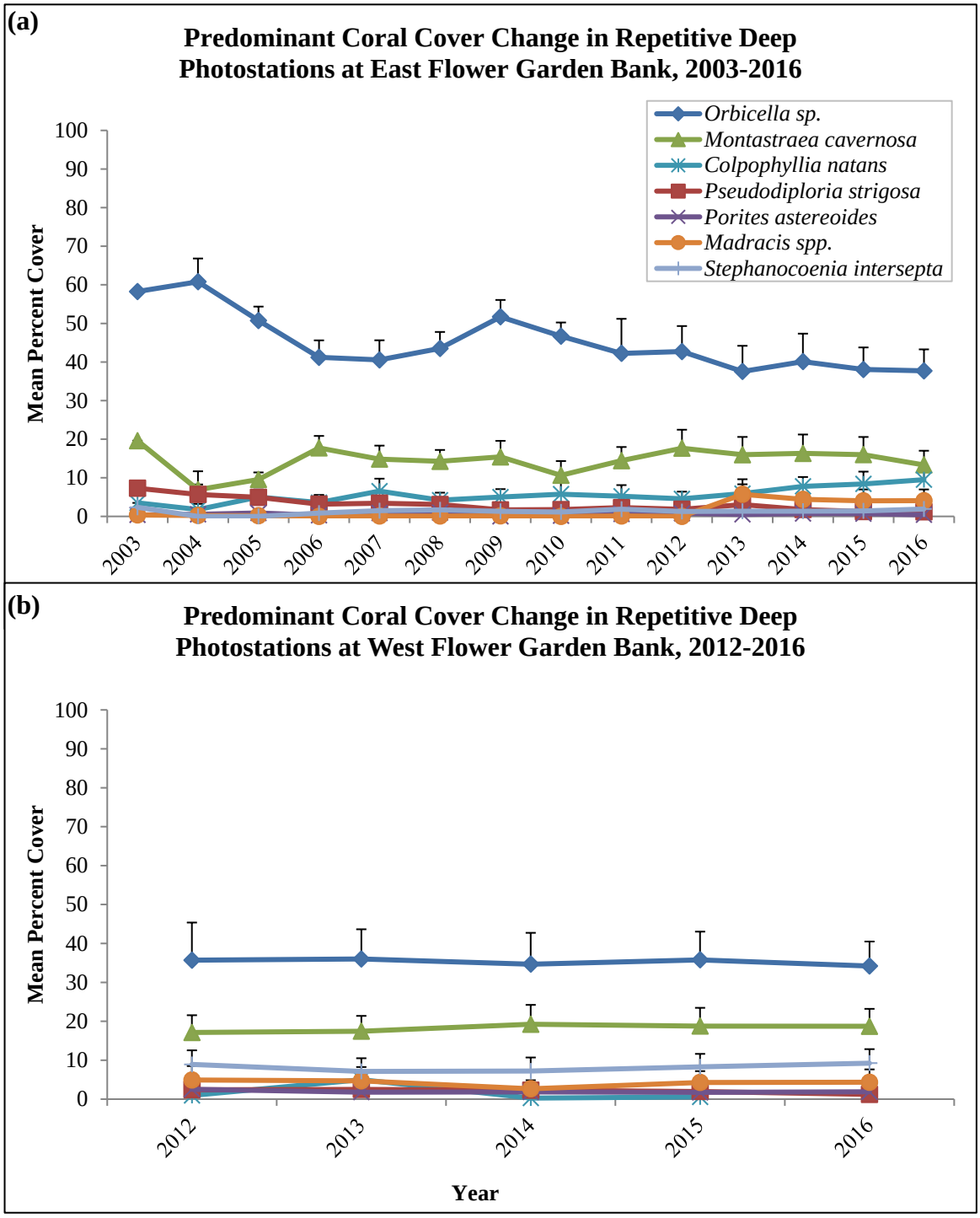


Figure 4.6. Mean percent cover + SE of predominant coral species in repetitive deep photostations at (a) EFGB from 2003 to 2016 and (b) WFGB from 2012 to 2016. *Orbicella* species combines *O. franksi*, *O. faveolata*, and *O. annularis* for historical data comparison.

Data for 2002 to 2008 from PBS&J (Precht et al. 2006; Zimmer et al. 2010); and FGBNMS for 2009 to 2015 (Johnston et al. 2013, 2015, 2017).

For yearly mean benthic percent cover data in EFGB repetitive deep photostations (2003 to 2016), SIMPROF analysis detected four significant year clusters (A: 2003, 2006, and 2008; B: 2004; C: 2005, 2007, 2009 to 2010, and 2014; and D: 2011 to 2013, and 2015 to 2016) (Figure 4.7). Between clusters A and B, mean percent coral cover contributed to 74.23% of the dissimilarity, corresponding to the shift in increased coral cover in 2004 (Figure 4.5). Macroalgae (58.70%) and coral (30.66%) contributed to the dissimilarity between clusters B and C, due to the shifts in macroalgae and coral cover during these years. Between clusters C and D, macroalgae and coral mean percent cover contributed to over 95% of the dissimilarity (60.76% and 34.47%, respectively) from continued increasing macroalgae and decreasing coral cover through 2016 (Figure 4.5). Macroalgae (76.34%) contributed to the dissimilarity between clusters A and D, due to increasing macroalgae percent cover from 2003 to 2016.

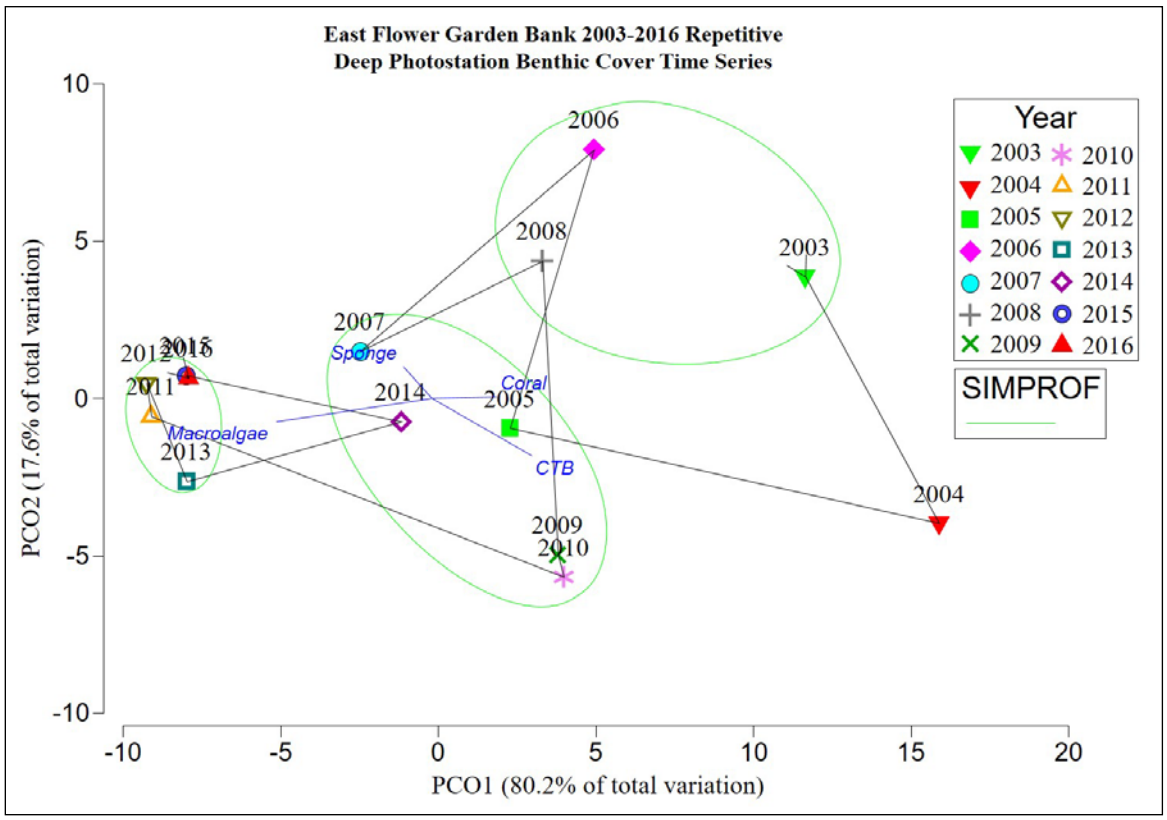


Figure 4.7. PCO for repetitive deep photostations from 2003 to 2016 at EFGB. The green ovals are SIMPORF groups representing significant year clusters. The blue vector lines represent the directions of the variable gradients for the plot.

Yearly mean benthic percent cover data in WFGB repetitive study site photostations resulted in two significant year clusters (A: 2012 and 2016; B: 2013 to 2015) (Figure 4.8). Between clusters A and B, macroalgae (62.25) and coral (21.93) mean percent cover contributed to over 84% of the dissimilarity, corresponding to lower percent cover of macroalgae and higher percent cover of coral in 2012 and 2016 (Figure 4.5).

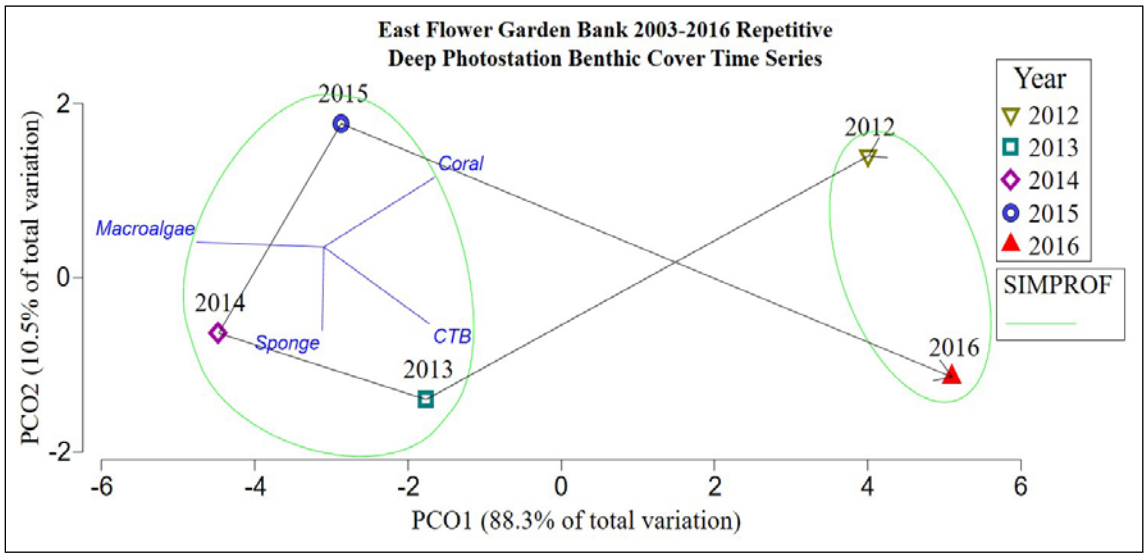


Figure 4.8. PCO for repetitive deep photostations from 2012 to 2016 at WFGB. The green ovals are SIMPORF groups representing significant year clusters. The blue vector lines represent the directions of the variable gradients for the plot.

PERMANOVA results revealed no significant differences among deep photostation communities, suggesting that EFGB and WFGB repetitive deep photostations were similar to each other in overall benthic community composition over time.

Repetitive Deep Photostation Discussion

Nine repetitive deep photostations have been in place since 2003 at EFGB and twelve repetitive deep photostations have been in place since 2012 at WFGB. Percent coral cover within WFGB repetitive deep photostations has remained above 70% since 2012, while percent coral cover has varied from 86% to 72% since 2003 at EFGB photostations (Figure 4.5). In the example from EFGB repetitive deep photostation 07 (Figure 4.9), the overall coral community remained stable and in good health, showing the value of long-term repetitive photographs. Some colonies appeared paler in certain years due to variations in photographic equipment (e.g., 35 mm film and digital images) and ambient conditions, as all photos were subject to varying degrees of camera settings, lighting, etc., from year to year.

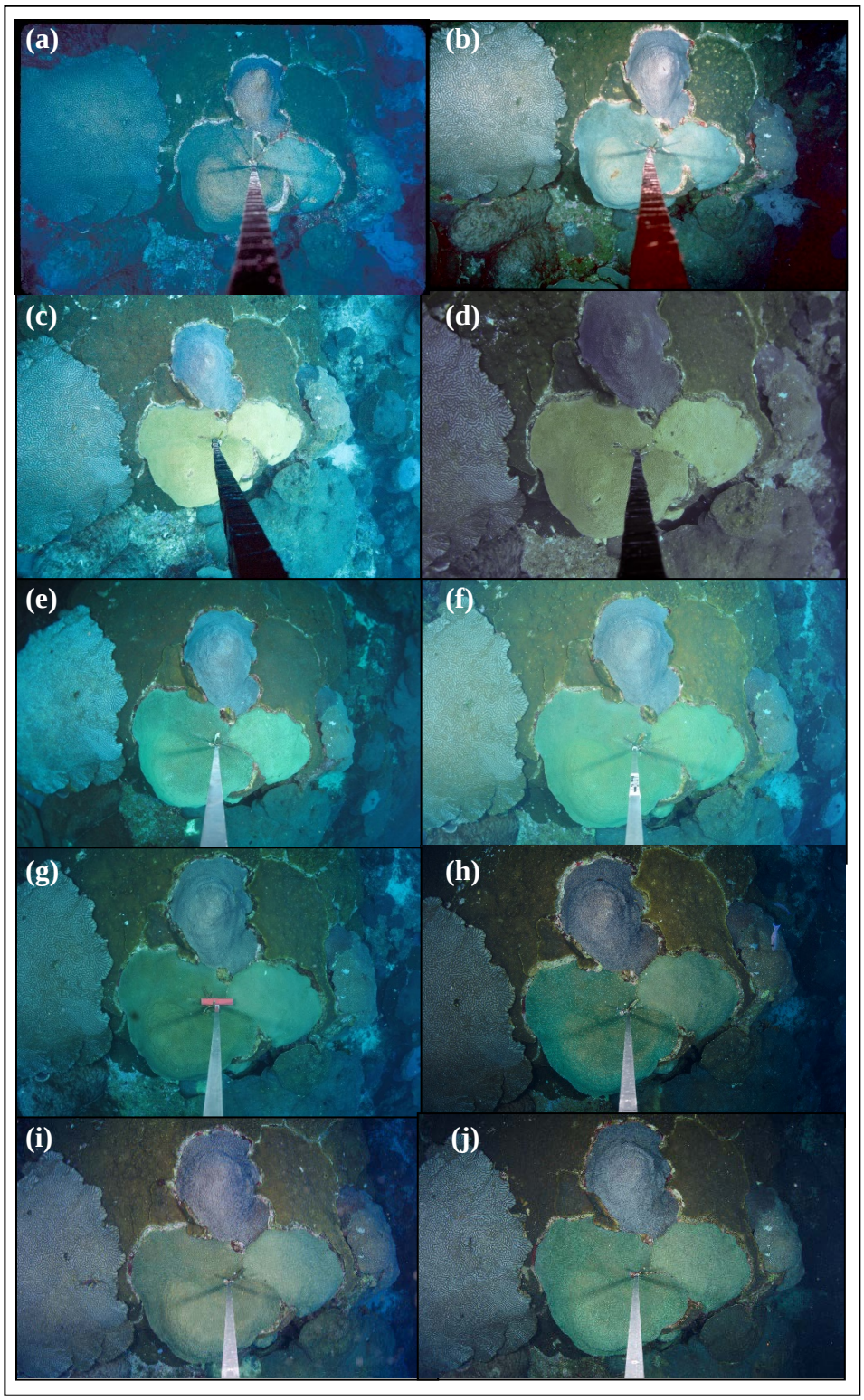


Figure 4.9. EFGB repetitive deep photostation #07 time series from (a) 2005; (b) 2007; (c) 2008; (d) 2009; (e) 2010; (f) 2011; (g) 2012; (h) 2013; (i) 2014; and (j) 2016. No photo available for 2003. (Photos: NOAA/FGBNMS)

The large *Montastraea cavernosa* colonies in the center of the station gain tissue over the years, and the margin of the *Colpophyllia natans* colony on the left side of the station grows closer to the *Montastraea cavernosa* colonies (Figure 4.9 a and j).

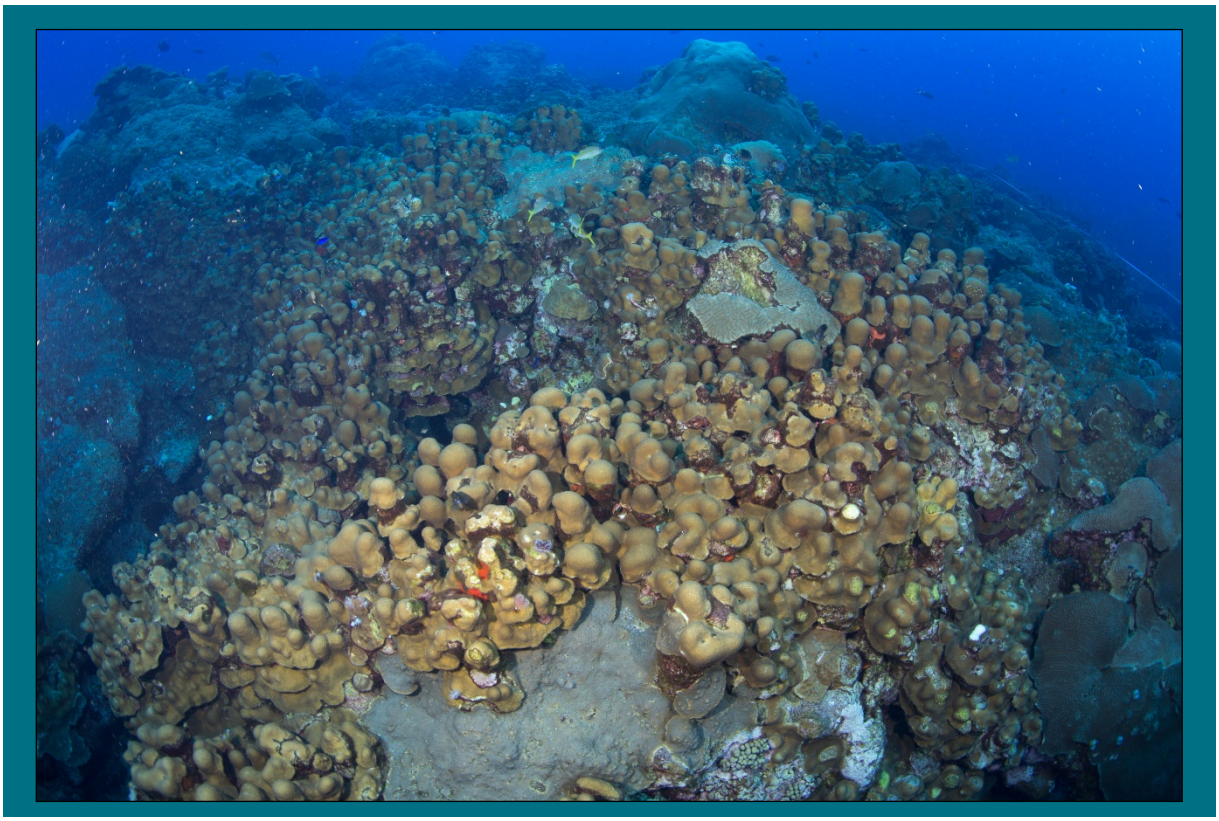
Significantly higher mean coral cover estimates (74%) were obtained from the repetitive deep photostations than from the shallower repetitive quadrats (64%) and the random transects (54%) at both EFGB and WFGB study sites combined. Higher percent mean coral cover in the repetitive deep photostations relative to repetitive quadrats and random transects has also been documented in previous reports (Precht et al. 2006; Zimmer et al. 2010; Johnston et al. 2013, 2015, 2017). The repetitive deep stations were dominated by *Orbicella franksi* (similar to the random transects and repetitive study site photostations); however, *Montastraea cavernosa* was the second-most prominent coral species, unlike the shallower areas in the study sites.

A noticeable difference between EFGB and WFGB repetitive deep photostations and the repetitive study site photostations and random transects, 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.

It should be noted that deep photostations may not provide an accurate assessment of the predominant species within deeper habitats outside the EFGB and WFGB study sites, as these stations were selectively placed on habitat with large coral colonies to monitor individual corals. As described in Chapter 2, the randomly selected benthic transects allowed for conclusions to be made about the entire study site, while the repetitive deep photostations provided a long-term dataset allowing for conclusions to be made about repetitive sites over time in habitat deeper than the study sites.

As with both the repetitive study site photostations and random transects on the shallower portion of the reef, periods of increased algae cover generally coincided with decreases in the CTB category. Similar to random transects, increased macroalgae cover was not concomitant with significant coral cover decline over time in repetitive deep photostations. 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.

Chapter 5. Coral Demographics



A patch of lobed star coral (*Orbicella annularis*) within the West Flower Garden Bank study site, 2016. (Photo: G.P. Schmahl, NOAA/FGBNMS)

Coral Demographic Introduction

To document coral colony size, condition, and observation of coral recruits, coral demographic surveys were conducted along random transects to provide additional species-specific insight for corals than is provided by percent cover alone, as coral size and abundance are key metrics for describing trends in coral reef population dynamics.

Coral Demographic Methods

Coral Demographic Field Methods

Coral demographic surveys were conducted along eight randomly selected transects to document species richness, abundance, density, coral colony size, condition, and coral recruits in 2016. After divers took photographs along a random transect meter tape as described in Chapter 2 (See Methods – Random Transect Field Methods), a second dive team used the same random location and meter tape to conduct a coral demographic survey along the first 10 m of the transect tape. The coral demographic survey team worked as a buddy pair, with one diver collecting large coral colony size data and the second diver collecting coral recruit data.

To document coral colony size and condition, a 10 m x 1 m belt transect survey was conducted. Each coral colony (diameter > 4 cm) was identified and measured (length x width x height (cm)). The entire coral colony (skeleton and live tissue) on a planar dimension was measured, where length was the maximum diameter, width was the perpendicular diameter, and height was measured from the base of the skeletal unit to the top of the colony. The survey began at marker 0 m and ended at 10 m. Divers used meter long PVC measuring poles to aid with coral size estimations (Figure 5.1). Measurements were made to the nearest centimeter. Coral condition measurements such as percent paling or bleaching and mortality (recent, old, or transitional - if any) were also estimated and recorded. Estimation of percent bleaching included the percent of a coral colony that was white with no visible zooxanthellae. Estimate of percent paling included the percent of a colony that was pale in color relative to what was considered “normal” for the species (AGRRA 2010). Estimates of various stages of mortality were made separately. Recent mortality was an estimate of the percentage of a colony with an exposed bare skeleton and little to no algae growth so that the species could still be determined. Transitional mortality was an estimate of the percentage of a colony with an exposed bare skeleton and the colonization of filamentous algae growth. Old mortality was an estimate of the percentage of old dead, tissue-free skeleton on the colony. Datasheets included additional information to be collected by surveyors, such as survey depth and seawater temperature.

The belt transect survey, which was closely based on surveys used for the Atlantic and Gulf Rapid Reef Assessment (AGRRA) program in the Caribbean region, was also used by NOAA’s National Coral Reef Monitoring Program (Kramer et al. 2005; Roberson et al. 2014). These surveys were time intensive due to abundant corals at EFGB and WFGB.

Figure 5.1. A PVC measuring stick aids in estimating the width of coral colony on a coral demographic survey within the EFGB study site. (Photo: G.P. Schmahl, NOAA/FGBNMS)

Coral recruits (maximum diameter ≤ 4 cm) were recorded using a 10 m x 1 m belt transect along the same meter tape by the second diver. Small colonies were measured (length x width x height (cm)) with a small ruler, identified to the lowest possible taxonomic resolution, and photographed if identification was not possible (Figure 5.2).

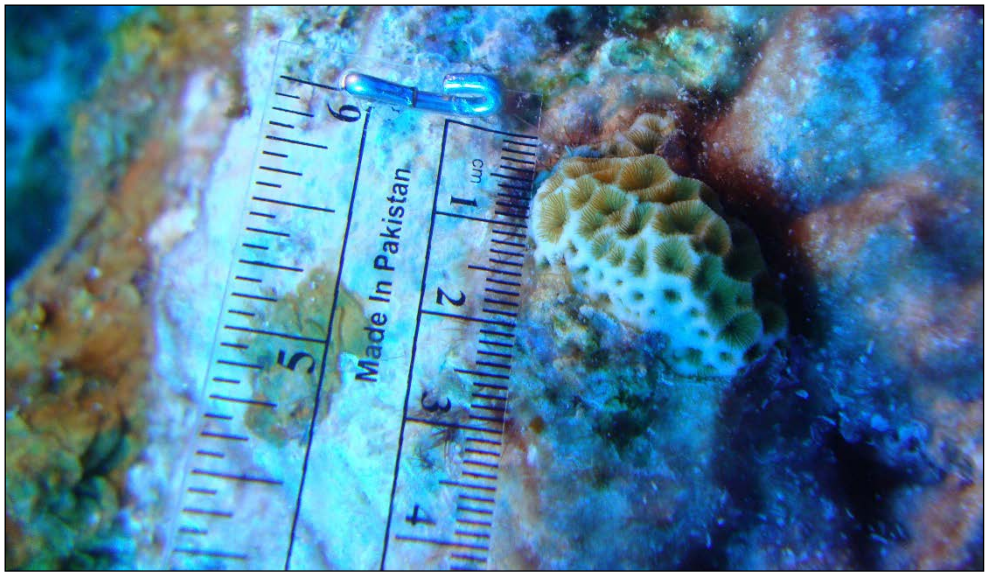


Figure 5.2. A ruler helps estimate the size of a coral recruit colony less than 4 cm on a coral demographic survey within the EFGB study site. (Photo: Amanda Sterne, TAMUG)

Consistency of survey methods was maintained through the use of scientific divers trained to identify coral species found at FGBNMS. Divers were required to be experienced in the survey technique, and equipment checklists were provided in the field to ensure divers had all equipment and were confident with tasks assigned. Surveyors reviewed and entered coral demographic data in a Microsoft® Excel® database on the same date the survey took place. All datasheets were reviewed and compared to data entered in the database during field operations to check for entry errors, and mistakes were corrected before data analysis was completed.

Coral Demographic Data Processing and Statistical Analysis

Coral density was expressed as the number of individual coral colonies per m^2 ± standard error. Estimates of coral colony mean size were obtained by calculating the length, width, and height of colonies measured in the field. Estimates of coral mortality were not subtracted from coral area calculations. Statistical analyses were conducted on square root transformed coral colony size data using non-parametric distance-based analyses with Primer® version 7.0 (Anderson et al. 2008; Clarke et al. 2014). A Bray-Curtis distance similarity matrix was calculated and PERMANOVA was used to test for differences in colony sizes between species and bank study sites. ANOSIM was used to test for differences in coral recruits between study sites.

Coral Demographic Results

For the coral demographic survey data collected in 2016, the average survey depth was 19 m in the EFGB study site and 21 m in the WFGB study site. Species richness included 13 different coral species documented in coral demographic surveys within the EFGB study site and 14 within the WFGB study site (Table 5.1). Overall mean coral density (corals/m^2 ± standard error) was 6.95 ± 0.76 within the EFGB study site and 6.75 ± 0.57 within the WFGB study site. The most abundant species in the surveys was *Porites astreoides*, followed by *Orbicella franksi* and *Pseudodiploria strigosa* (Table 5.1). While *Porites astreoides* was the most abundant species observed, these small corals covered much less area than larger corals. *Orbicella franksi* colonies covered the greatest total area within the EFGB study site surveys and *Orbicella faveolata* colonies covered the greatest total area in the WFGB study site surveys (Table 5.1)

Even though *Orbicella franksi* colonies occupied the most area on surveys, *Orbicella faveolata* colonies were the largest in EFGB study site surveys in 2016, followed by *Pseudodiploria strigosa* and *Montastraea cavernosa* colonies (Table 5.1). At WFGB, *Orbicella faveolata* occupied the most area on surveys and were the largest colonies, followed by *Montastraea cavernosa* and *Orbicella franksi* colonies (Table 5.1).

Table 5.1. Total colony size (cm^3), total number of colonies, and mean colony size (cm^3) from 2016 coral demographic surveys within EFGB and WFGB study sites.

Coral Species	EFGB			WFGB		
	Total Size (cm^3)	Total Colonies	Mean Size (cm^3)	Total Size (cm^3)	Total Colonies	Mean Size (cm^3)
Orbicella faveolata	14,385,950	17	846,232	36,290,058	19	1,910,003
Montastraea cavernosa	27,588,000	44	627,000	8,472,590	26	325,869
Orbicella franksi	58,615,875	134	437,432	12,767,050	115	111,018
Millepora alcicornis	1,276,250	4	319,063	270,640	6	45,107
Pseudodiploria strigosa	9,765,625	54	180,845	2,068,238	54	38,301
Colpophyllia natans	2,144,250	26	82,471	1,451,964	30	48,399
Siderastrea siderea	1,662,500	26	63,942	75	1	75
Madracis decactis	122,000	2	61,000	160,515	6	26,753
Agaricia agaricites	2,281,975	44	51,863	14,364	50	287
Mussa angulosa	93,600	2	46,800	14,010	5	2,802
Orbicella annularis	217,750	6	36,292	0	0	0
Porites astreoides	1,491,250	201	7,419	354,777	176	2,016
Porites furcata	125	1	125	0	0	0
Stephanocoenia intersepta	0	0	0	389,249	24	16,219
Agaricia fragilis	0	0	0	71,368	19	3,756
Scolymia cubensis	0	0	0	23,392	8	2,924
Total	**119,645,150**	**561**	**2,760,484**	**62,348,290**	**539**	**2,533,528**

PERMANOVA results revealed significant differences between species and colony size from study site surveys. The bank colony size by species interaction was also significant, suggesting that coral composition differed between study site surveys and colonies from EFGB coral demographic surveys were significantly larger in size than colonies from WFGB surveys (Table 5.2).

Table 5.2. PERMANOVA results comparing mean colony size (cm^3) by coral species and bank study site from coral demographic surveys in 2016. Bold text denotes significant value.

Source	Sum of Squares	df	Pseudo-F	P (perm)
Colony Size by Bank	8581	1	6.690	**0.001**
Colony Size by Species	643000	15	33.436	**0.001**
Colony Size Bank x Species	76624	10	5.974	**0.001**
Res	1370000	1069		
Total	2200000	1095		

Limited bleaching and paling was observed within colonies on surveys within the EFGB study site, but bleaching and paling became more pronounced in WFGB study site surveys as seawater temperatures increased in August (Table 5.3). Overall prevalence of mortality type (percent of colonies) was most commonly observed as old mortality within colonies on surveys at both study sites, with new mortality observations being rare (Table 5.3)

Table 5.3. Percent paling, bleaching, and mortality type observed in coral colonies from coral demographic surveys within EFGB and WFGB study sites in 2016.

EFGB					
Coral Species	**Paling**	**Bleaching**	**Recent Mortality**	**Transition Mortality**	**Old Mortality**
Agaricia agaricites	0.00	0.00	0.00	0.00	0.00
Colpophyllia natans	0.00	0.00	0.00	0.00	7.69
Madracis decactis	0.00	0.00	0.00	0.00	0.00
Millepora alcicornis	0.00	0.00	0.00	0.00	0.00
Montastraea cavernosa	0.00	0.00	0.00	0.00	11.36
Mussa angulosa	0.00	0.00	0.00	0.00	0.00
Orbicella annularis	0.00	0.00	0.00	0.00	0.00
Orbicella faveolata	0.00	0.00	0.00	0.00	17.65
Orbicella franksi	1.49	0.75	0.75	2.99	18.66
Porites astreoides	0.50	1.00	0.50	1.99	1.49
Porites furcata	0.00	0.00	0.00	0.00	0.00
Pseudodiploria strigosa	1.85	0.00	0.00	0.00	12.96
Siderastrea siderea	0.00	0.00	0.00	3.85	7.69
WFGB					
Coral Species	**Paling**	**Bleaching**	**Recent Mortality**	**Transition Mortality**	**Old Mortality**
Agaricia agaricites	0.00	0.00	0.00	0.00	0.00
Agaricia fragilis	0.00	0.00	0.00	0.00	0.00
Colpophyllia natans	0.00	0.00	6.67	3.33	3.33
Madracis decactis	0.00	0.00	0.00	0.00	0.00
Millepora alcicornis	0.00	0.00	0.00	0.00	0.00
Montastraea cavernosa	7.69	0.00	3.85	0.00	26.92
Mussa angulosa	0.00	0.00	0.00	0.00	20.00
Orbicella faveolata	21.05	0.00	0.00	15.79	42.11
Orbicella franksi	2.61	0.87	0.00	0.87	12.17
Porites astreoides	0.57	0.00	1.14	1.70	1.14
Pseudodiploria strigosa	3.70	1.85	5.56	7.41	14.81
Scolymia cubensis	0.00	0.00	0.00	0.00	12.50
Siderastrea siderea	0.00	0.00	0.00	0.00	0.00
Stephanocoenia intersepta	0.00	0.00	4.17	4.17	8.33

Ten species of coral recruits (≤ 4 cm) were documented in coral demographic surveys. *Porites astreoides* was the most abundant coral recruit species observed in coral demographic surveys within EFGB and WFGB study sites and *Agaricia agaricites* was the second most abundant species (Table 5.4). ANOSIM results revealed no significant dissimilarities, suggesting coral recruits were similar between surveys in EFGB and WFGB study sites in 2016.

Table 5.4. Total colony size (cm^3), total number of colonies, and mean colony size (cm^3) from 2016 coral recruits observed in demographic surveys within EFGB and WFGB study sites.

Coral Recruit Species	EFGB			WFGB		
	Total Size (cm^3)	Total Colonies	Mean Size (cm^3)	Total Size (cm^3)	Total Colonies	Mean Size (cm^3)
Porites astreoides	222	27	8.22	149	15	9.90
Agaricia agaricites	236	25	9.44	159	11	13.36
Pseudodiploria strigosa	43	6	7.17	36	2	18.00
Colpophyllia natans	28	2	14.00	0	0	0.00
Orbicella annularis	57	4	14.25	0	0	0.00
Scolymia cubensis	0	0	0.00	39	4	9.75
Orbicella franksi	0	0	0.00	26.5	2	13.25
Tubastraea coccinea	0	0	0.00	39	2	19.50
Agaricia fragilis	0	0	0.00	0	1	12.00
Madracis decactis	0	0	0.00	12	1	12.00
Total	**586**	**64**	**53.18**	**460**	**38**	**107.76**

Coral Demographic Discussion

Coral size and abundance are important metrics for describing trends in coral reef population dynamics. Although the *Orbicella* species group continue to be the predominant reef building corals within the EFGB and WFGB study sites, *Porites astreoides* was the most abundant species, despite the smaller area covered by these colonies.

Porites astreoides and *Agaricia agaricites* were the most abundant coral recruits in 2016. These corals are generally small-sized and exhibit high rates of recruitment (Green et al. 2008). Though the coral community in the study sites has remained relatively stable throughout the monitoring program from 1989 to 2016, coral communities are rapidly changing worldwide (Jackson et al. 2014; Johnston et al. 2016b). The overall loss of coral cover in the Caribbean region due to disease, hurricane damage, anthropogenic impacts, and thermal stress has resulted in shifts in species composition in certain reef areas (Alvarez-Filip et al. 2013; Jackson et al. 2014).

On many reefs in the Caribbean region, dominant reef-building corals, such as those found at EFGB and WFGB, have declined, allowing weedy opportunistic coral species to increase in abundance (Green et al. 2008; Alvarez-Filip et al. 2013). This decreases reef functionality and complexity, and threatens the stability of coral reef biodiversity (Alvarez-Filip et al. 2013; Graham and Nash 2013). Continued monitoring of the coral community in the study sites will document changes in the community compared to the historical baseline, and enable resource managers to make decisions that enable the survival of keystone reef building species and not just on actions that emphasize maintaining high percentages of coral cover.

Chapter 6. Sea Urchin and Lobster Surveys

A Long-Spined Sea Urchin (*Diadema antillarum*) rests atop the coral reef within the West Flower Garden Bank study site in 2016. (Photo: G.P. Schmahl, NOAA/FGBNMS)

Sea Urchin and Lobster Surveys Introduction

The Long-Spined Sea Urchin (*Diadema antillarum*) was an important herbivore on coral reefs throughout the Caribbean until 1983, when an unknown pathogen decimated populations throughout the region, including the FGBNMS (Gittings and Bright 1987). This invertebrate is a significant marine herbivore and can have substantial effects on macroalgal percent cover on coral reefs. Additionally, lobsters are commercially important species throughout much of the Caribbean and Gulf of Mexico; however, population dynamics of Caribbean Spiny Lobster (*Panulirus argus*) and Spotted Spiny Lobster (*Panulirus guttatus*) in the FGB are not well understood. Therefore, surveys help document the abundance of these species within EFGB and WFGB study sites.

Sea Urchin and Lobster Surveys Methods

Sea Urchin and Lobster Surveys Field Methods

Due to the nocturnal nature of these species, visual surveys were conducted at night, a minimum of 1.5 hours after sunset. Surveys for *Diadema antillarum*, *Panulirus argus*, and *Panulirus guttatus* were conducted along all perimeter lines and crosshairs at EFGB and WFGB study sites. A 2-m wide belt transect was surveyed along each of the six 100 m perimeter lines at each study site, thus totaling 1,200 m^2 per bank. All observed species were recorded. The first diver began on the right side of the line and the second diver on the left. Divers swam slowly along the boundary line, looking for sea urchin and lobsters within a 1 m swath on their side of the line. Divers used flashlights to look into and under reef crevices and, if a sea urchin or lobster was seen, observations were recorded on a datasheet including bank, boundary line, and the number of sea urchin or lobsters observed.

Consistency for the survey method was ensured by multiple, scientific divers trained to identify sea urchin and lobster species located at FGBNMS. Divers were required to be experienced in the survey technique used, and equipment checklists were provided to ensure divers had equipment for assigned tasks. QA/QC procedures ensured surveyors reviewed and entered species count data in a Microsoft® Excel® database on the same date the survey took place. All datasheets were reviewed and compared to data entered in the database during field operations to check for entry errors, and mistakes were corrected before data analysis was completed.

Sea Urchin and Lobster Surveys Analysis

Density was calculated as number of individuals per 100 m^2 for each species ± standard error. Statistical analyses were conducted on square root transformed density data using non-parametric distance-based analyses with Primer® version 7.0 (Anderson et al. 2008; Clarke et al. 2014). PERMANOVA examined differences in density between year and bank study sites with a similarity matrix using the Euclidean distance measure.

Sea Urchin and Lobster Surveys Results

Mean density of *Diadema antillarum* was 0.25 individuals/100 m² ± 0.10 within the EFGB study site and 3.54 individuals/100 m² ± 0.47 within the WFGB study site in 2016. Two *Panulirus argus* were observed on surveys within the EFGB study site in 2016 (mean density 0.03 individuals/100 m² ± 0.02).

Since 2004, *Diadema antillarum* densities have ranged from 0–21.25 individuals/100 m² within EFGB and WFGB study sites. Higher numbers of *Diadema antillarum* were observed during surveys at the WFGB study site throughout the monitoring program (Figure 6.1). Since 2004, lobster densities have ranged from 0–0.25 individuals/100 m² within the EFGB and WFGB study site.

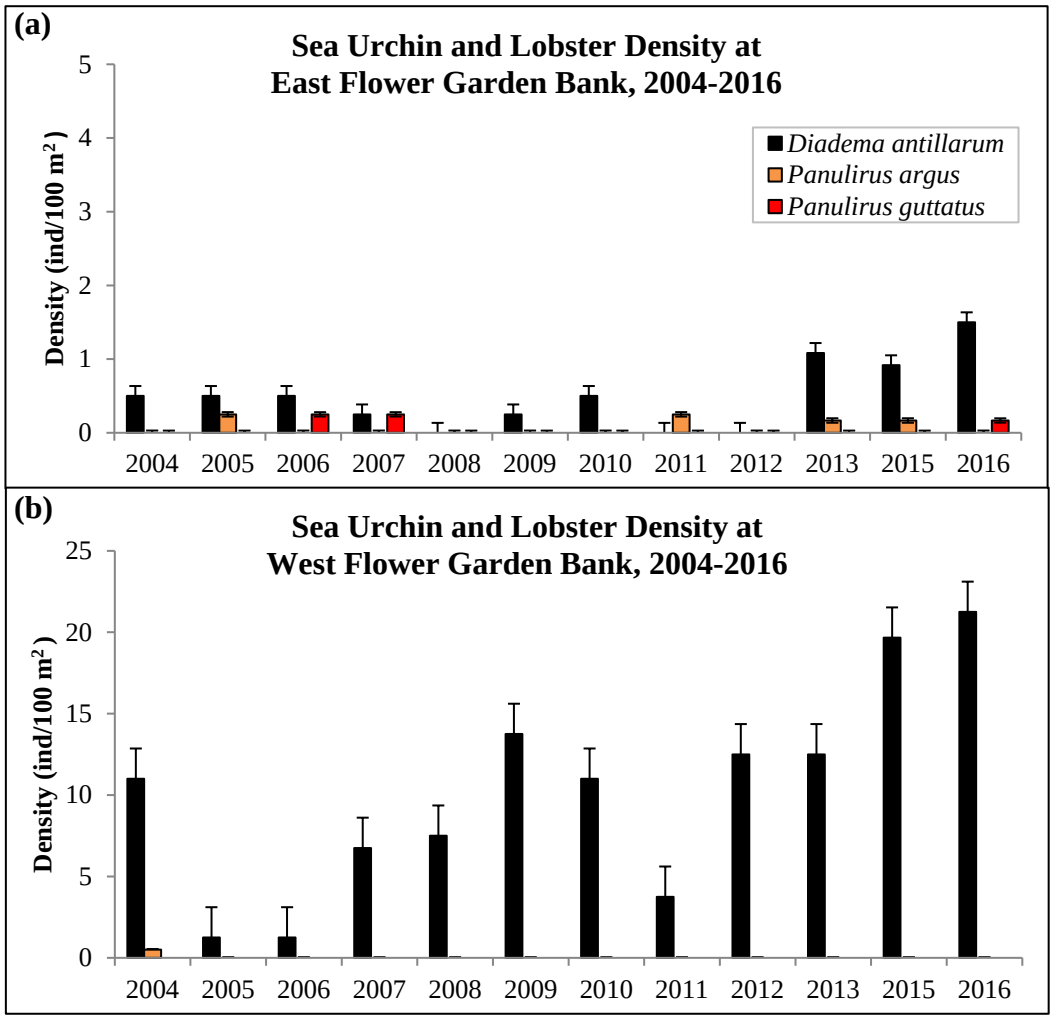


Figure 6.1. Sea urchin and lobster density (individuals/100 m²) + SE within EFGB and WFGB study sites from 2004 to 2016.

No data available for 2014. Data for 2004 to 2008 from PBS&J (Precht et al. 2006; Zimmer et al. 2010) and FGBNMS for 2009 to 2015 (Johnston et al. 2013, 2015, 2017).

When compared for differences between bank study sites and years based on *Diadema antillarum* density, PERMANOVA analysis revealed a significant difference between banks (Table 6.1), suggesting that sea urchin density was significantly greater within the WFGB study site.

Table 6.1. PERMANOVA results comparing sea urchin densities between EFGB and WFGB study sites and years. Bold text denotes significant value.

Source	Sum of Squares	df	Pseudo-F	P (perm)
Bank Study Site	35	1	61.31	**0.001**
Year	10	11	1.60	0.216
Res	6	11		
Total	51	23		

Sea Urchin and Lobster Surveys Discussion

Diadema antillarum are important herbivores on coral reefs, helping to reduce macroalgae through grazing that makes room for coral growth and new recruits (Edmunds and Carpenter 2001; Carpenter and Edmunds 2006). After the mass die off in 1983, *Diadema antillarum* populations have not recovered to pre-1983 levels, which were at least 140 individuals/100 m² at EFGB and 50 individuals/100 m² at WFGB (Gittings 1998). Post-1983 *Diadema antillarum* densities dropped to near zero (Gittings and Bright 1987). Since then, patchy but limited recovery has been documented in the Caribbean region (Edmunds and Carpenter 2001; Karmer 2003; Carpenter and Edmunds 2006). *Diadema antillarum* densities at nearby Stetson Bank have also increased in recent years, averaging 130 individuals/100 m² in 2016 (Nuttall et al. 2017).

Diadema antillarum populations within the EFGB study site remained low during the 2016 monitoring period and were similar to those reported in previous studies (Zimmer et al. 2010; Johnston et al. 2017). Populations within the WFGB study site have been consistently higher than EFGB, and in 2016 were the highest recorded within the WFGB study site since monitoring began. The previous fluctuations in annual density estimates suggest caution in declaring a recovering *Diadema antillarum* population at FGBNMS; continued monitoring will be required to track and compare temporal changes at both bank study sites.

Lobster densities within EFGB and WFGB study sites have been historically low throughout the monitoring program. Lobsters are, however, occasionally observed by divers at other times, occurring on the banks in low abundance.

Chapter 7. Fish Surveys

Two Greater Amberjack (*Seriola dumerili*) swim over the reef at West Flower Garden Bank in 2016. (Photo: G.P. Schmahl, NOAA/FGBNMS)

Fish Surveys Introduction

Divers conducted stationary reef fish visual census surveys in EFGB and WFGB study sites to examine fish population composition and changes over time. The surveys were used to characterize and compare fish assemblages between banks and years.

Fish Surveys Methods

Fish Surveys Field Methods

Fishes were assessed by divers using modified stationary reef fish visual census surveys (Bohnsack and Bannerot 1986). Twenty-four randomly located surveys were each conducted within EFGB and WFGB study sites. Each survey represented one sample. Observations of fishes were restricted to an imaginary cylinder with a 7.5 m radius, extending from the substrate to the surface (for more detailed methods, reference Johnston et al. 2017) (Figure 7.1).

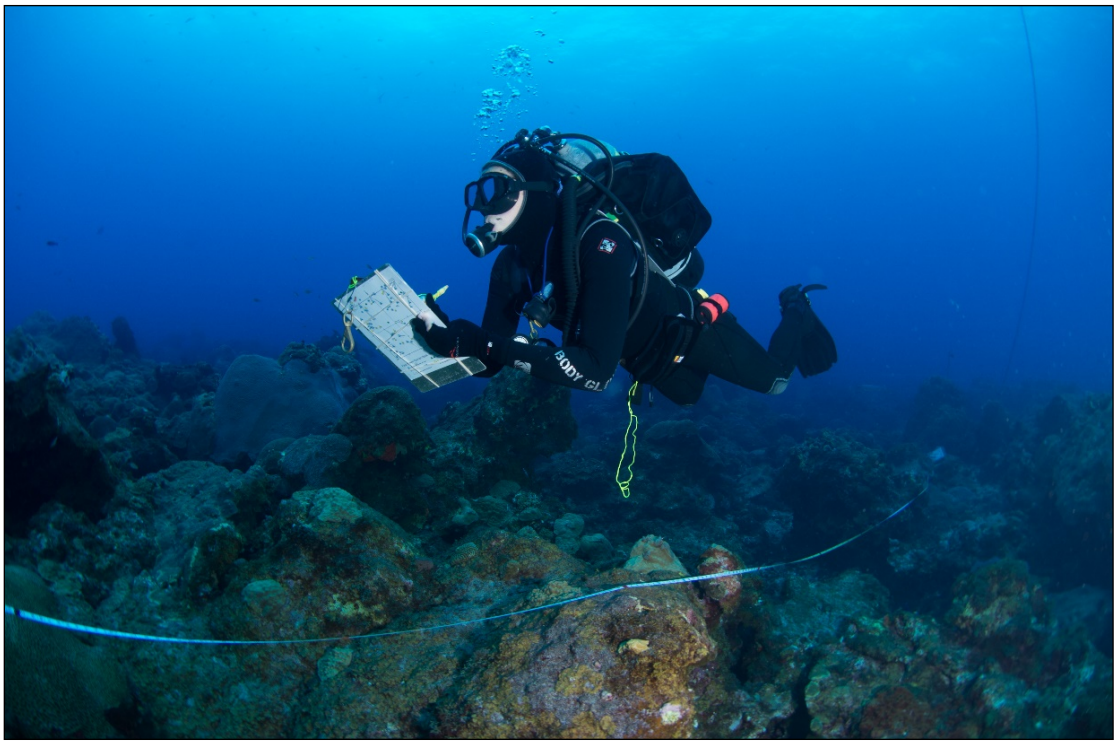


Figure 7.1. NOAA diver, Marissa Nuttall, conducting a fish survey within the EFGB study site. (Photo: G.P. Schmahl, NOAA/FGBNMS)

All fish species observed within the first five minutes of the survey were recorded while the diver slowly rotated in place in the imaginary survey cylinder. 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 fork length (within size bins). Size for each individual was estimated and binned into one of eight groups: <5 cm, ≥5 to <10 cm, ≥10 to <15 cm, ≥15 to <20 cm, ≥20 to <25 cm, ≥25 to <30 cm, ≥30 to <35 cm, and ≥35 cm. If fishes were greater than 35 cm in length, divers estimated the size to the nearest cm. Each survey required 15 to 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.

Consistency in the survey method was maintained with the use of scientific divers trained to identify fish species located at FGBNMS. Divers were required to be experienced in the survey technique used, equipment checklists were provided in the field to ensure divers had equipment for assigned tasks, and all fish survey divers were required to carry a pre-marked PVC measuring stick to provide a set size reference.

Fish Surveys Data Processing

Surveyors reviewed and entered fish survey data in a Microsoft® Excel® database on the same date the survey took place. Fish survey datasheets were retained and reviewed after field work was completed for QA/QC. All datasheets were reviewed and compared to data entered in the database to check for entry errors, and mistakes were corrected prior to data 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 Statistical Analysis

Summary statistics of fish census data included abundance, density, sighting frequency, and species richness. Total abundance was calculated as the number of individuals per sample, and percent relative abundance was the total number of individuals for one species divided by the total of all species and multiplied by 100. Density was expressed as the number of individual fish per 100 m^2 ± standard error, and calculated as the total number of individuals per sample by the area of the survey cylinder (176.7 m^2) and multiplied by 100. Sighting frequency for each species was expressed as the percentage of the total number of times the species was recorded out of the total number of samples. Species richness was expressed as the number of different species represented per sample ± standard error. Mean species richness was calculated for all samples and for each bank.

Fish biomass was expressed as grams per 100 m^2 ± standard error and 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 (2017) 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 m²) was calculated. Observations of manta rays, sting rays, and eels were removed from biomass analyses only, due to their rare nature and large size.

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 optimal, as it would be able to statistically detect a minimum change of 40% in the population within the survey period.

Statistical analyses were conducted on square root transformed density and biomass data using distance-based Bray-Curtis similarity matrices with Primer® version 7.0 (Anderson et al. 2008; Clarke et al. 2014). Community differences were compared for significant differences based on resemblance matrices using PERMANOVA (Anderson et al. 2008). Differences at the family level for key species were compared for significant dissimilarities using ANOSIM. If significant differences were found, species contributing to observed differences were examined using SIMPER to assess the percent contribution of dissimilarity between study sites (Clarke & Warwick 2001). For long-term density and biomass trends for which data was available (2011 to 2016), the distance between centroids was calculated from Bray-Curtis similarity matrices and visualized using metric multi-dimensional scaling (MDS) plots with a time series trajectory overlay split between locations (Anderson et al. 2008).

Dominance plots were generated based on species abundance and biomass with Primer® version 7.0 (Anderson et al. 2008; Clarke et al. 2014). W-values (difference between the biomass and abundance curves) were calculated for each survey (Clarke 1990). W-values range between -1<w>1, where w=1 indicates that the population is dominated by a few large species, w=-1 indicates that the population is dominated by numerous small species, and w=0 indicates that accumulated biomass is evenly distributed between large and small species. Significant dissimilarities in w values between bank study sites was tested using ANOSIM on untransformed data with Euclidean distance similarity matrices (Clarke & Warwick 2001).

Fish Surveys Results

A total of 29 families and 76 species were recorded in 2016 for all samples combined. Mean species richness (± standard error) was 20.67 ± 0.93 per survey within the EFGB study site and 21.63 ± 0.73 per survey within the WFGB study site. Bluehead

(*Thalassoma bifasciatum)* had the highest relative abundance of all species (20%) within the EFGB study site, followed by Brown Chromis (*Chromis multilineata*) (19%), Bonnetmouth (*Emmelichthyops atlanticus*) (14%), Creole Wrasse (*Clepticus parrae*) (13%), and Atlantic Creolefish (*Paranthias furcifer*) (6%) (Figure 7.2).

Within the WFGB study site, Brown Chromis had the highest relative abundance of all species (38%), followed by Bluehead (20%), Creole Wrasse (11%), Atlantic Creolefish (5%), and Bonnetmouth (5%) (Figure 7.2).

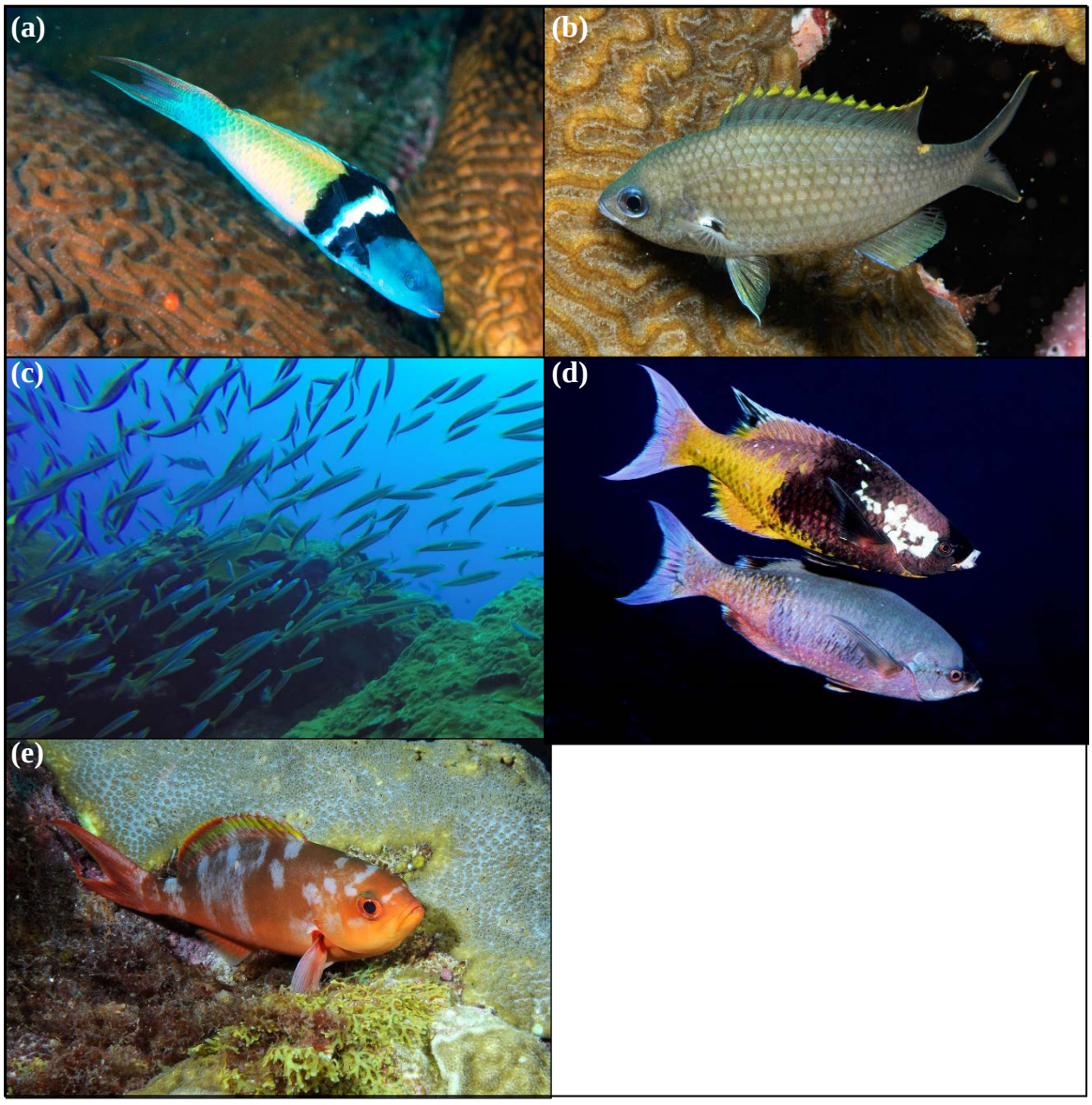


Figure 7.2. Most abundant fish species observed within EFGB and WFGB study sites in 2016: (a) Bluehead, (b) Brown Chromis, (c) Bonnetmouth, (d) Creole Wrasse, and (e) Atlantic Creolefish. (Photos a, b, d, e: G.P. Schmahl, NOAA/FGBNMS; and Photo c: Michelle Johnston, NOAA/FGBNMS)

Sighting Frequency and Occurrence

The most frequently sighted species within study sites at both banks was the Bluehead, observed in approximately 98% of all surveys. Other frequently sighted species included Brown Chromis, Sharpnose Puffer (*Canthigaster rostrata*), Atlantic Creolefish, and Spanish Hogfish (*Bodianus rufus*) (Table 7.1). Most shark and ray species were considered "rare" (occurred in <20% of all surveys) (REEF 2014). Though no shark species were recorded, manta rays (*Manta spp.*) were observed in 12.5% of EFGB surveys. No sharks or mantas were observed in WFGB surveys.

Table 7.1. Top 10 most frequently sighted species within surveys in EFGB and WFGB study sites, including sighting frequency for all surveys combined in 2016.

Family Name: Species Name (Common Name)	EFGB	WFGB	All Surveys
Labridae: *Thalassoma bifasciatum* (Bluehead)	100.00	95.83	97.92
Pomacentridae*: Chromis multilineata* (Brown Chromis)	95.83	91.67	93.75
Tetraodontidae: *Canthigaster rostrata* (Sharpnose Puffer)	87.50	91.67	89.58
Epinephelidae: *Paranthias furcifer* (Atlantic Creolefish)	83.33	87.50	85.42
Labridae: *Bodianus rufus* (Spanish Hogfish)	75.00	91.67	83.33
Pomacentridae: *Stegastes partitus* (Bicolor Damselfish)	83.33	79.17	81.25
Acanthuridae: *Acanthurus coeruleus* (Blue Tang)	75.00	87.50	81.25
Pomacentridae: *Chromis cyanea* (Blue Chromis)	75.00	75.00	75.00
Balistidae: *Melichthys niger* (Black Durgon)	54.17	95.83	75.00
Sphyraenidae: *Sphyraena barracuda* (Great Barracuda)	66.67	79.17	72.92

Density

Mean fish density (individuals/100 m^2) ± standard error was 147.66 ± 45.32 within the EFGB study site and 243.59 ± 87.45 within the WFGB study site. When compared for differences between study sites, PERMANOVA analysis revealed a significant difference (Table 7.2), suggesting that fish density was significantly greater within the WFGB study site. SIMPER analysis identified the main contributors resulting in higher fish density within the WFGB study site were caused by greater local abundance of Brown Chromis (10.33%) and Bluehead (7.56%) (Table 7.3).

Table 7.2. PERMANOVA results comparing mean fish density between EFGB and WFGB study sites from 2016. Bold text denotes significant value.

Source	Sum of Squares	df	Pseudo-F	P (perm)
Bank Study Site	3659	1	2.83	**0.001**
Res	59374	46		
Total	63033	47		

Table 7.3. Mean density (individuals/100 m^2) ± SE of the top 10 densest species from EFGB and WFGB study site surveys, and all surveys combined, in 2016.

Family Name: Species Name (Common Name)	EFGB	WFGB	All Surveys
Pomacentridae*: Chromis multilineata* (Brown Chromis)	27.66 ± 5.48	92.48 ± 25.77	60.07 ± 13.86
Labridae: *Thalassoma bifasciatum* (Bluehead)	29.07 ± 6.72	49.45 ± 17.08	39.26 ± 9.20
Labridae: *Clepticus parrae* (Creole Wrasse)	19.38 ± 7.19	25.96 ± 11.63	22.67 ± 6.78
Haemulidae: *Emmelichthyops atlanticus* (Bonnetmouth)	20.40 ± 10.02	12.14 ± 11.78	16.27 ± 7.67
Epinephelidae: *Paranthias furcifer* (Atlantic Creolefish)	8.77 ± 2.26	12.64 ± 6.95	10.71 ± 3.63
Tetraodontidae: *Canthigaster rostrata* (Sharpnose Puffer)	3.32 ± 0.48	7.19 ± 1.37	5.26 ± 0.77
Pomacentridae: *Stegastes partitus* (Bicolor Damselfish)	3.99 ± 0.65	4.55 ± 0.85	4.27 ± 0.53
Pomacentridae: *Chromis cyanea* (Blue Chromis)	5.12 ± 1.47	3.32 ± 0.73	4.22 ± 0.82
Pomacentridae: *Stegastes variabilis* (Cocoa Damselfish)	2.08 ± 0.75	5.02 ± 1.78	3.55 ± 0.98
Pomacentridae: *Stegastes planifrons* (Threespot Damselfish)	2.15 ± 0.43	4.83 ± 1.29	3.49 ± 0.70

Trophic Guild 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 relative abundance were graphed for each trophic guild (Figure 7.3).

Within both EFGB and WFGB study sites, invertivores were dominated by smaller individuals (<5 cm to <15 cm). Piscivores were dominated by either small (<5 cm) or large individuals (≥35 cm). Planktivores displayed a normal distribution within both study sites, with the majority of individuals of moderate size (≥15 to <30 cm). Herbivore size distribution was variable within the EFGB study site, with a slight trend for larger (≥20 to <35 cm) individuals within the WFGB study site (Figure 7.3).

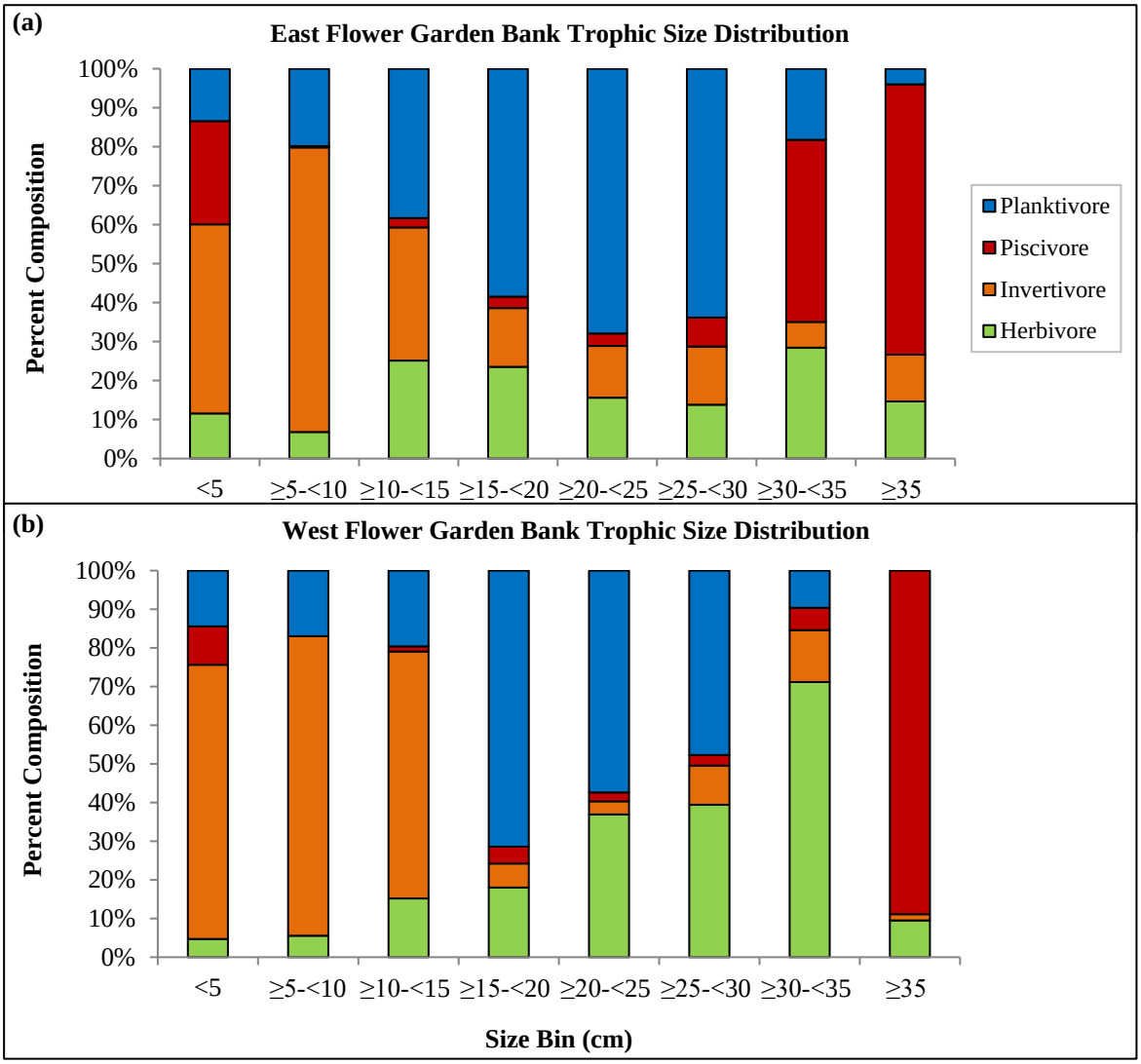


Figure 7.3. Size distribution of individuals by trophic guild within (a) EFGB and (b) WFGB study sites in 2016.

Biomass

Mean biomass (g/100 m^2) ± standard error was 11,221.02 ± 2,459.44 within the EFGB study site and 9,174.32 ± 1,742.09 within the WFGB study site in 2016. When compared for differences between bank study sites, PERMANOVA analysis revealed a significant difference (Table 7.4), suggesting that fish biomass was significantly greater within the EFGB study site. SIMPER analysis identified the main contributors resulting in higher fish biomass within the EFGB study site was caused by greater local abundance of Great Barracuda (*Sphyraena barracuda*) (9.29%) and Horse-eye Jack (*Caranx latus*) (6.46%).

Table 7.4. PERMANOVA results comparing mean fish density between EFGB and WFGB study sites from 2016. Bold text denotes significant value.

Source	Sum of Squares	df	Pseudo-F	P (perm)
Bank Study Site	4976	1	2.43	**0.003**
Res	94346	46		
Total	99323	47		

When classified by trophic guild, piscivores possessed the highest mean biomass for all surveys. The lowest mean biomass for all surveys was represented by invertivores (Table 7.5). PERMANOVA analysis comparing trophic guilds revealed no significant differences, suggesting that trophic communities in EFGB and WFGB study sites were similar in 2016.

Table 7.5. Mean biomass (g/100 m^2) ± SE for each trophic guild from EFGB and WFGB study site surveys, and all surveys combined in 2016.

Trophic Group	EFGB	WFGB	All Surveys
Herbivore	2336.32 ± 476.90	2349.50 ± 479.59	2342.91 ± 478.24
Invertivore	1576.90 ± 321.88	980.08 ± 200.06	1278.49 ± 260.97
Planktivore	2650.81 ± 541.09	1508.67 ± 307.96	2079.74 ± 424.52
Piscivore	4656.99 ± 950.60	4336.08 ± 885.10	4496.53 ± 917.85

Within each trophic guild, mean biomass for each species was calculated (Table 7.6). For the herbivore guild, 21.93% of the biomass was contributed by Bermuda Chub (*Kyphosus saltatrix/incisor*). For the invertivore guild, the greatest contribution was from Ocean Triggerfish (*Canthidermis sufflamen*), at 24.89% of all biomass. For the piscivore guild, Great Barracuda contributed the greatest biomass to all surveys, at 47.97%. For the planktivore guild, the greatest contribution was from Atlantic Creolefish (52.86% of all biomass).

Table 7.6. Biomass (g/100 m^2) ± SE of each species, grouped by trophic guild from EFGB and WFGB study site surveys, and all surveys combined, in 2016.

	Family Name: Species Name - Common Name	EFGB	WFGB	All Surveys
Herbivore	Kyphosidae: Kyphosus saltatrix/incisor (Chub (Bermuda/Yellow)	335.57 ± 68.50	691.82 ± 141.22	513.70 ± 74.15
	Balistidae: Melichthys niger (Black Durgon)	551.29 ± 112.53	261.40 ± 53.36	406.34 ± 58.65
	Labridae: Sparisoma viride (Stoplight Parrotfish)	350.71 ± 71.59	395.89 ± 80.81	373.30 ± 53.88
	Pomacentridae: Stegastes partitus (Bicolor Damselfish)	12.29 ± 2.51	493.40 ± 100.71	252.84 ± 36.50
	Labridae: Scarus vetula (Queen Parrotfish)	319.90 ± 65.30	141.01 ± 28.78	230.45 ± 33.26
	Acanthuridae: Acanthurus coeruleus (Blue Tang)	227.59 ± 46.46	171.92 ± 35.09	199.76 ± 28.83

	Family Name: Species Name - Common Name	EFGB	WFGB	All Surveys
Herbivore	Labridae: Scarus taeniopterus (Princess Parrotfish)	137.94 ± 28.16	93.02 ± 18.99	115.48 ± 16.67
	Labridae: Sparisoma aurofrenatum (Redband Parrotfish)	158.52 ± 32.36	24.62 ± 5.03	91.57 ± 13.22
	Acanthuridae: Acanthurus tractus (Ocean Surgeonfish)	128.65 ± 26.26	5.19 ± 1.06	66.92 ± 9.66
	Acanthuridae: Acanthurus chirurgus (Doctorfish)	53.49 ± 10.92	15.61 ± 3.19	34.55 ± 4.99
	Pomacentridae: Microspathodon chrysurus (Yellowtail Damselfish)	39.71 ± 8.11	24.80 ± 5.06	32.26 ± 4.66
	Labridae: Scarus iseri (Striped Parrotfish)	19.15 ± 3.91	3.60 ± 0.74	11.38 ± 1.64
	Pomacentridae: Stegastes variabilis (Cocoa Damselfish)	1.35 ± 0.27	19.01 ± 3.88	10.18 ± 1.47
	Labridae: Scarus coeruleus (Blue Parrotfish)	0.00	7.54 ± 1.54	3.77 ± 0.54
	Pomacentridae: Stegastes adustus (Dusky Damselfish)	0.07 ± 0.02	0.64 ± 0.13	0.36 ± 0.05
	Blenniidae: Ophioblennius macclurei (Redlip Blenny)	0.09 ± 0.02	0.01 ± 0.00	0.05 ± 0.01
	Labridae: Sparisoma atomarium (Greenblotch parrotfish)	0.00	0.01 ± 0.00	0.01 ± 0.00
	Gobiidae: Gnatholepis thompsoni (Goldspot Goby)	0.01 ± 0.00	0.00	0.00 ± 0.00
Invertivore	Balistidae: Canthidermis sufflamen (Ocean Triggerfish)	571.83 ± 116.72	64.67 ± 13.20	318.25 ± 45.94
	Mullidae: Mulloidichthys martinicus (Yellow Goatfish)	415.45 ± 84.80	27.55 ± 5.62	221.50 ± 31.97
	Labridae: Thalassoma bifasciatum (Bluehead)	44.65 ± 9.11	250.52 ± 51.14	147.58 ± 21.30
	Pomacentridae: Chromis multilineata (Brown Chromis)	91.73 ± 18.72	183.09 ± 37.37	137.41 ± 19.83
	Pomacanthidae: Holacanthus tricolor (Rock Beauty)	66.46 ± 13.57	56.74 ± 11.58	61.60 ± 8.89
	Labridae: Bodianus rufus (Spanish Hogfish)	79.50 ± 16.23	42.28 ± 8.63	60.89 ± 8.79
	Pomacanthidae: Holacanthus ciliaris (Queen Angelfish)	64.41 ± 13.15	49.62 ± 10.13	57.01 ± 8.23
	Pomacentridae: Stegastes planifrons (Threespot Damselfish)	18.88 ± 3.85	60.74 ± 12.40	39.81 ± 5.75
	Lutjanidae: Lutjanus griseus (Gray Snapper)	0.00	54.55 ± 11.14	27.28 ± 3.94
	Balistidae: Balistes capriscus (Gray Triggerfish)	0.00	43.66 ± 8.91	21.83 ± 3.15
	Chaetodontidae: Chaetodon sedentarius (Reef Butterflyfish)	15.10 ± 3.08	28.18 ± 5.75	21.64 ± 3.12
	Tetraodontidae: Canthigaster rostrata (Sharpnose Puffer)	8.52 ± 1.74	33.99 ± 6.94	21.25 ± 3.07
	Labridae: Halichoeres garnoti (Yellowhead Wrasse)	19.98 ± 4.08	18.27 ± 3.73	19.13 ± 2.76

	Family Name: Species Name - Common Name	EFGB	WFGB	All Surveys
Invertivore	Chaetodontidae: Chaetodon ocellatus (Spotfin Butterflyfish)	34.29 ± 7.00	2.81 ± 0.57	18.55 ± 2.68
	Chaetodontidae: Prognathodes aculeatus (Longsnout Butterflyfish)	23.50 ± 4.80	10.85 ± 2.21	17.17 ± 2.48
	Labridae: Halichoeres maculipinna (Clown Wrasse)	26.16 ± 5.34	0.00	13.08 ± 1.89
	Holocentridae: Holocentrus adscensionis (Squirrelfish)	25.05 ± 5.11	0.00	12.53 ± 1.81
	Pomacentridae: Abudefduf saxatilis (Sergeant Major)	11.21 ± 2.29	12.24 ± 2.50	11.72 ± 1.69
	Ostraciidae: Lactophrys triqueter (Smooth Trunkfish)	8.47 ± 1.73	9.90 ± 2.02	9.19 ± 1.33
	Pomacanthidae: Pomacanthus paru (French Angelfish)	0.00	15.11 ± 3.09	7.56 ± 1.09
	Ostraciidae: Acanthostracion polygonius (Honeycomb Cowfish)	14.49 ± 2.96	0.00	7.24 ± 1.05
	Labridae: Bodianus pulchellus (Spotfin Hogfish)	13.08 ± 2.67	0.00	6.54 ± 0.94
	Diodontidae: Diodon hystrix (Porcupinefish)	0.00	9.71 ± 1.98	4.86 ± 0.70
	Epinephelidae: Epinephelus adscensionis (Rock Hind)	3.87 ± 0.79	1.93 ± 0.39	2.90 ± 0.42
	Holocentridae: Holocentrus rufus (Longspine Squirrelfish)	2.24 ± 0.46	3.05 ± 0.62	2.65 ± 0.38
	Monacanthidae: Cantherhines pullus (Orangespotted Filefish)	4.99 ± 1.02	0.00	2.49 ± 0.36
	Monacanthidae: Aluterus scriptus (Scrawled Filefish)	4.73 ± 0.96	0.00	2.36 ± 0.34
	Chaetodontidae: Chaetodon striatus (Banded Butterflyfish)	4.41 ± 0.90	0.00	2.21 ± 0.32
	Monacanthidae: Cantherhines macrocerus (Whitespotted filefish)	2.15 ± 0.44	0.00	1.08 ± 0.16
	Epinephelidae: Epinephelus guttatus (Red Hind)	1.10 ± 0.23	0.00	0.55 ± 0.08
	Blenniidae: Parablennius marmoreus (Seaweed Blenny)	0.23 ± 0.05	0.23 ± 0.05	0.23 ± 0.03
	Labridae: Halichoeres radiatus (Puddingwife)	0.14 ± 0.03	0.29 ± 0.06	0.21 ± 0.03
	Gobiidae: Elacatinus oceanops (Neon Goby)	0.08 ± 0.02	0.09 ± 0.02	0.08 ± 0.01
	Cirrhitidae: Amblycirrhitus pinos (Redspotted Hawkfish)	0.13 ± 0.03	0.00	0.06 ± 0.01
	Pomacentridae: Stegastes leucostictus (Beaugregory)	0.07 ± 0.01	0.00	0.04 ± 0.01
	Muraenidae: Gymnothorax miliaris (Goldentail Moray)	0.02 ± 0.00	0.00	0.01 ± 0.00
	Gobiidae: Coryphopterus glaucofraenum (Bridled Goby)	0.00	0.01 ± 0.00	0.00 ± 0.00
Piscivore	Sphyraenidae: Sphyraena barracuda (Great Barracuda)	2993.20 ± 610.98	1320.70 ± 269.59	2156.95 ± 311.33
	Carangidae: Caranx latus (Horse-eye Jack)	769.49 ± 157.07	1552.86 ± 316.98	1161.18 ± 167.60

	Family Name: Species Name - Common Name	EFGB	WFGB	All Surveys
Piscivore	Lutjanidae: Lutjanus jocu (Dog Snapper)	13.80 ± 2.82	686.01 ± 140.03	349.91 ± 50.51
	Muraenidae: Gymnothorax funebris (Green Moray)	0.00	682.11 ± 139.23	341.05 ± 49.23
	Carangidae: Caranx crysos (Blue runner)	576.65 ± 117.71	28.83 ± 5.89	302.74 ± 43.70
	Epinephelidae: Mycteroperca interstitialis (Yellowmouth Grouper)	129.42 ± 26.42	7.56 ± 1.54	68.49 ± 9.89
	Epinephelidae: Cephalopholis cruentata (Graysby)	49.16 ± 10.03	29.34 ± 5.99	39.25 ± 5.67
	Serranidae: Mycteroperca tigris (Tiger Grouper)	76.90 ± 15.70	0.00	38.45 ± 5.55
	Scorpaenidae: Pterois volitans (Lionfish)	30.30 ± 6.19	26.24 ± 5.36	28.27 ± 4.08
	Carangidae: Caranx ruber (Bar Jack)	8.30 ± 1.69	0.00	4.15 ± 0.60
	Haemulidae: Emmelichthyops atlanticus (Bonnetmouth)	4.08 ± 0.83	2.43 ± 0.50	3.25 ± 0.47
	Aulostomidae: Aulostomus maculatus (Atlantic Trumpetfish)	5.18 ± 1.06	0.00	2.59 ± 0.37
	Carangidae: Elagatis bipinnulata (Rainbow Runner)	0.50 ± 0.10	0.00	0.25 ± 0.04
Planktivore	Epinephelidae: Paranthias furcifer (Atlantic Creolefish)	1512.60 ± 308.76	685.92 ± 140.01	1099.26 ± 158.66
	Labridae: Clepticus parrae (Creole Wrasse)	1128.00 ± 230.25	807.87 ± 164.91	967.93 ± 139.71
	Pomacentridae: Chromis cyanea (Blue Chromis)	6.69 ± 1.37	10.84 ± 2.21	8.77 ± 1.27
	Pomacentridae: Chromis scotti (Purple Reeffish)	3.16 ± 0.65	2.99 ± 0.61	3.08 ± 0.44
	Pomacentridae: Chromis insolata (Sunshinefish)	0.00	0.84 ± 0.17	0.42 ± 0.06
	Opistognathidae: Opistognathus aurifrons (Yellowhead Jawfish)	0.36 ± 0.07	0.00	0.18 ± 0.03
	Echeneidae: Remora remora (Remora)	0.00	0.20 ± 0.04	0.10 ± 0.01

Abundance-Biomass Curves

Mean w values ± standard error for the EFGB study site were 0.12 ± 0.02 and mean w values for the WFGB study site were 0.04 ± 0.01. For all samples within each study site, mean w values remained close to 0, indicating a balanced community where biomass was spread uniformly between large and small species (Figure 7.4). Comparisons of w values between bank study sites using ANOSIM revealed no significant dissimilarities between the dominance plot w values.

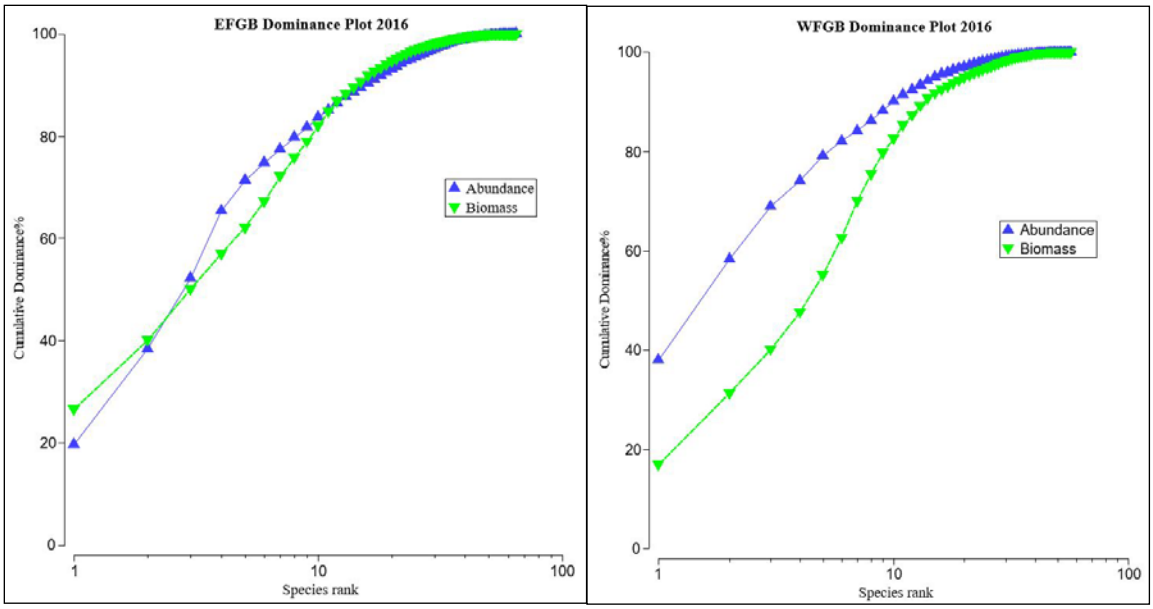


Figure 7.4. Abundance-Biomass curves for EFGB and WFGB study sites in 2016.

Family Level Analysis

Due to particular interest in species from grouper (including *Mycteroperca, Cephalopholis* and *Epinephelus* genera only) and snapper (*Lutjanidae* genus only) families related to fishing, and parrotfish (including *Sparisoma* and *Scarus* genera only) due to their role as important herbivores, additional analyses were conducted on these families to determine size frequency distributions from 2016 surveys.

Grouper species documented at EFGB and WFGB include nine 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*). In 2016, only five species were observed in all surveys: Graysby, Red Hind, Rock Hind, Tiger Grouper, and Yellowmouth Grouper. While it should be noted that coefficient of variation percentages (14.98% for density, 34.96% for biomass) indicated that the density data collected in 2016 had good power to detect population changes, the biomass data provided had poor power to detect population changes. ANOSIM results indicated no significant differences in community composition based on density or biomass between study sites.

Mean biomass (g/100 m^2) ± standard error of small bodied grouper, including Graysby, Red Hind, and Rock Hind was 54.13 ± 14.00 in the EFGB study site and 32.28 ± 8.60 in the WFGB study site. Mean biomass of large bodied grouper, including Tiger Grouper

and Yellowmouth Grouper was greater within the EFGB study site (206.32 ± 100.88) than the WFGB study site (7.56 ± 7.56). Size distributions of observed grouper in 2016 varied by species (Figure 7.5).

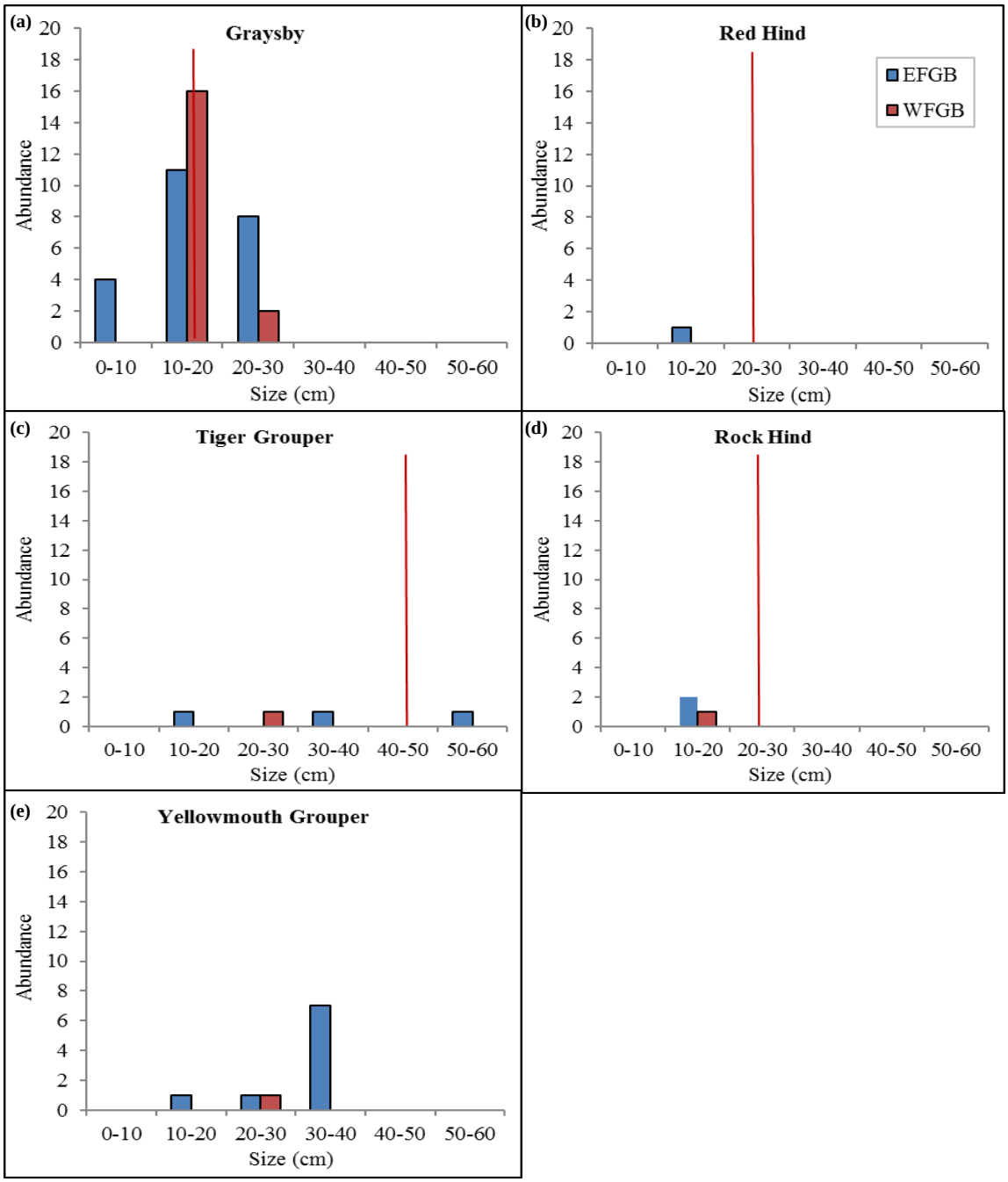


Figure 7.5. Size frequency of grouper species within EFGB and WFGB study site surveys in 2016: (a) Graysby, (b) Red Hind, (c) Tiger Grouper, (d) Rock Hind, and (e) Yellowmouth Grouper.

Vertical solid red lines represent estimated size of female maturity, when available (SAFMC 2005; Heemstra and Randall 1993; Brule et al. 2003; Froese and Pauly 2017).

The snapper family was comprised of two species from the *Lutjanidae* genus: Gray Snapper (*Lutjanus griseus*) and Dog Snapper (*Lutjanus jocu*). Coefficient of variation percentages (32.50% for density, 43.19% for biomass) indicated that the data collected in 2016 had poor power to detect population changes due to the low number of snapper observed. Mean snapper biomass within the WFGB study site was 740.57 ± 311.11. Only one Dog Snapper was observed within the EFGB study site in 2016 (331.29 g/100 m^2). Snapper size distributions were dominated by larger individuals that were reproductively mature (Figure 7.6).

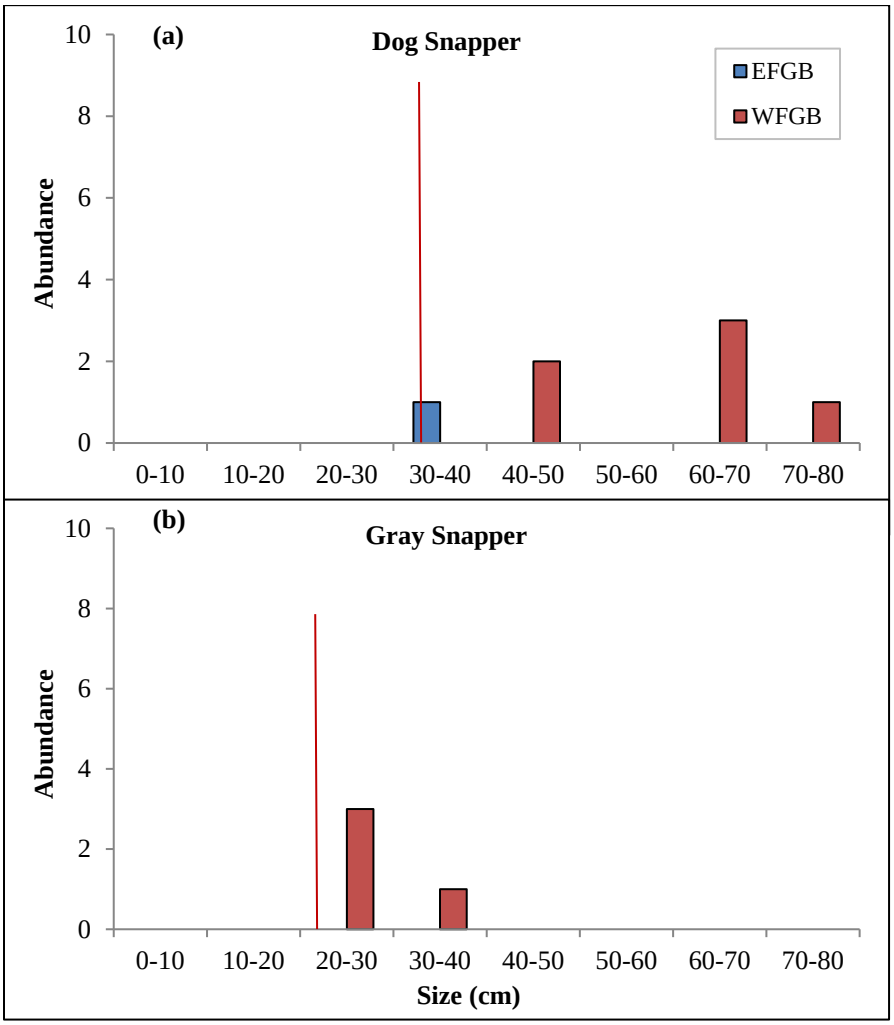


Figure 7.6. Size frequency of snapper species observed within EFGB and WFGB study site surveys in 2016: (a) Dog Snapper and (b) Gray Snapper.

Vertical solid red lines represent estimated size of female maturity (Froese and Pauly 2017).

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. Common parrotfish found at the EFGB and WFGB included six 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 (13.21% for density, 12.20% for biomass) indicated that the data had good power to detect population changes.

Mean biomass of parrotfishes was 986.21 ± 166.14 within the EFGB study site and 665.69 ± 107.89 within the WFGB study site. The parrotfish population at both EFGB and WFGB study sites had wide size distributions, but were dominated by smaller individuals (<25 cm) (Figure 7.7). ANOSIM results indicated significant spatial variation in parrotfish community composition at EFGB and WFGB study sites based on density (*Global R*=0.196, *p*=0.1%) and biomass (*Global R*=0.088, *p*=1.1%). The observed dissimilarity in density between study sites was mainly attributable to Princess Parrotfish (22.31%), as the EFGB study site had greater overall density of Princess Parrotfish. The observed dissimilarity in biomass between study sites was mainly attributable to Stoplight Parrotfish (32.84%), as the WFGB study site had greater overall Stoplight Parrotfish biomass.

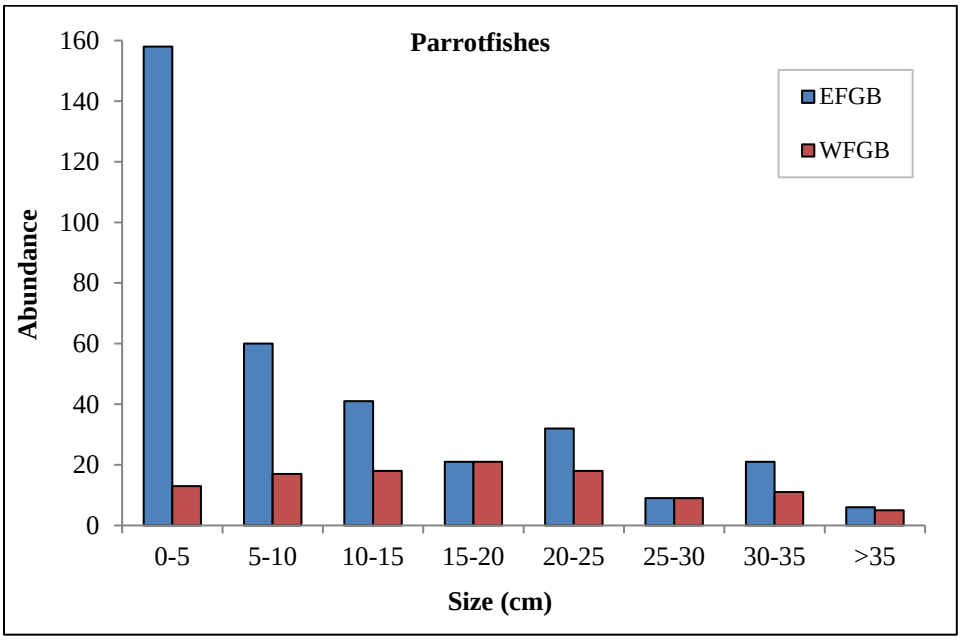


Figure 7.7. Size frequency of parrotfishes within EFGB and WFGB study site surveys in 2016.

Lionfish

This reporting year marks the fourth consecutive documentation of lionfish (*Pterois volitans*), an invasive species native to the Indo-Pacific, in long-term monitoring study site surveys. Total abundance was four individual lionfish within each study site, and sighting frequency was 16.67% in 2016. Since the initial documentation of lionfish in the long-term monitoring dataset, overall abundance increased from 2013 to 2014, but decreased from 2015 to 2016 (Figure 7.8). Lionfish size distributions were dominated by moderate sized individuals (15 to 30 cm) (Figure 7.9).

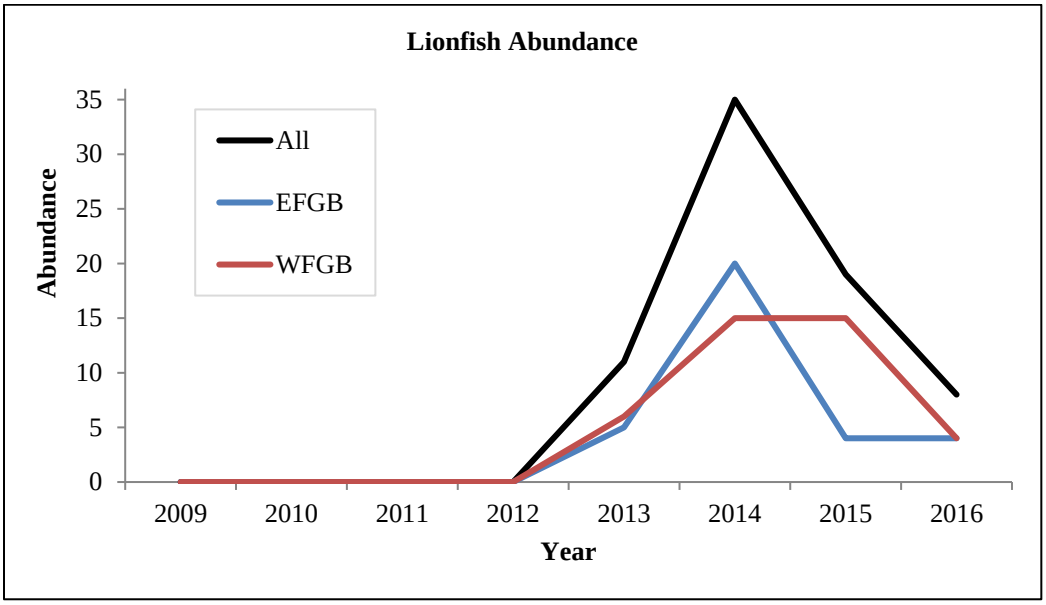


Figure 7.8. Lionfish abundance within EFGB and WFGB study site surveys from 2012 to 2016.

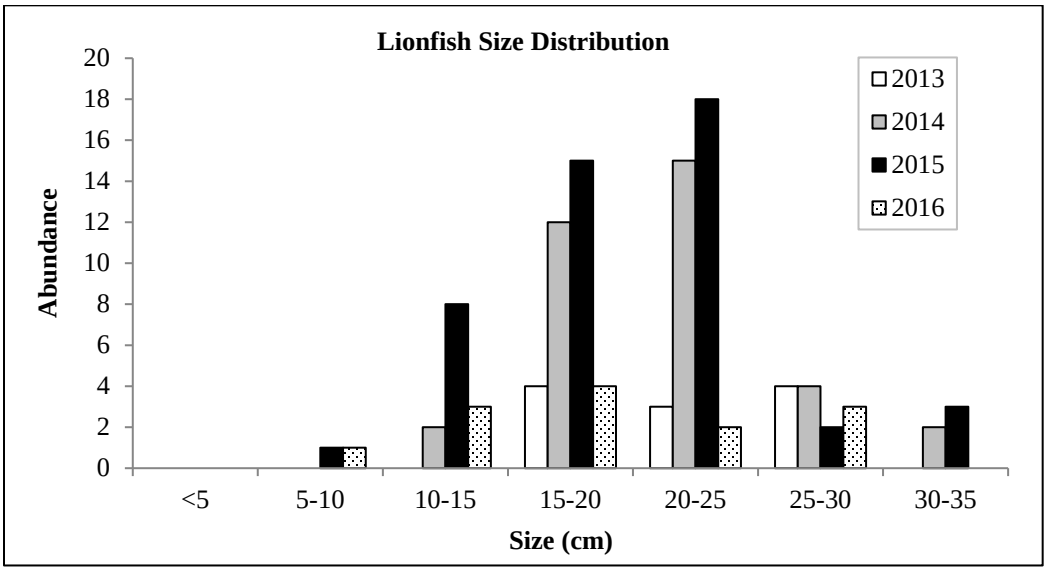


Figure 7.9. Lionfish size distribution within EFGB and WFGB study site surveys from 2013 to 2016.

Coefficient of variation percentages (14.43% for both density and biomass) indicated that the data had good power to detect population changes. Mean density for all surveys was 0.09 ± 0.02 and mean biomass for the EFGB study site was 30.30 ± 6.19 and 26.24 ± 5.36 for the WFGB study site. ANOSIM results indicated no significant differences in lionfish density or biomass between study sites in 2016.

Fish Surveys Long-Term Trends

Since 2002, mean fish density ranged from 52.70 to 302.00 individuals/100 m^2 within EFGB study sites, and 64.80 to 313.40 individuals/100 m^2 within WFGB study sites (Figure 7.10).

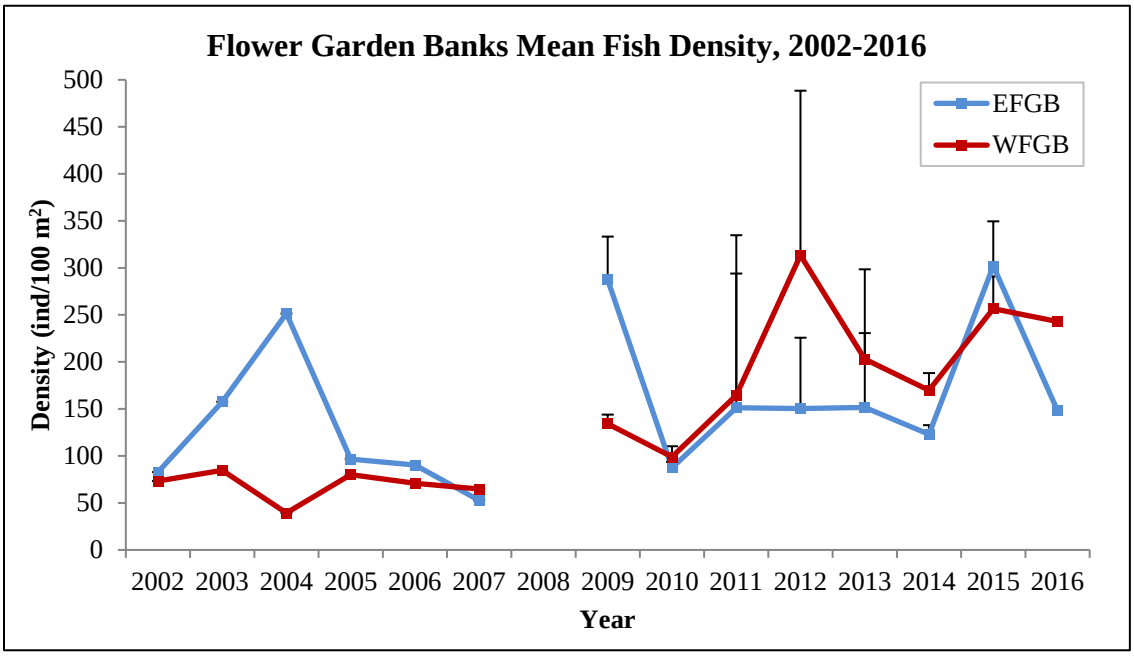


Figure 7.10. Mean fish density (ind/100 m^2) +SE within EFGB and WFGB study sites from 2002 to 2016.

No data were collected in 2008. SE not available before 2009. Data for 2002 to 2008 from PBS&J (Precht et al. 2006; Zimmer et al. 2010); and FGBNMS for 2009 to 2015 (Johnston et al. 2013, 2015, 2017).

Multivariate fish density analysis was compared among years and bank study sites when complete survey data was available (2011 to 2016). PERMANOVA analysis revealed significant differences between bank study sites, years, and the year x bank study site interaction was also significant (Table 7.7), suggesting that fish density within the EFGB and WFGB study sites significantly shifted from 2011 to 2016. Although differences occurred between bank study sites, the MDS plot displayed similar shifts in the fish communities over time (Figure 7.11). The observed dissimilarity in density between study sites from 2011 to 2016 was mainly attributable to Brown Chromis (10.01%), Bonnetmouth (6.48%), and Creole Wrasse (6.35%).

Table 7.7. PERMANOVA results comparing mean fish density within EFGB and WFGB study sites from 2011 to 2016. Bold text denotes significant value.

Source	Sum of Squares	df	Pseudo-F	P (perm)
Year	50748	5	3.73	**0.001**
Bank Study Site	7723	1	6.57	**0.001**
Year*Bank Study Site	13588	5	2.31	**0.001**
Res	339000	288		
Total	411000	299		

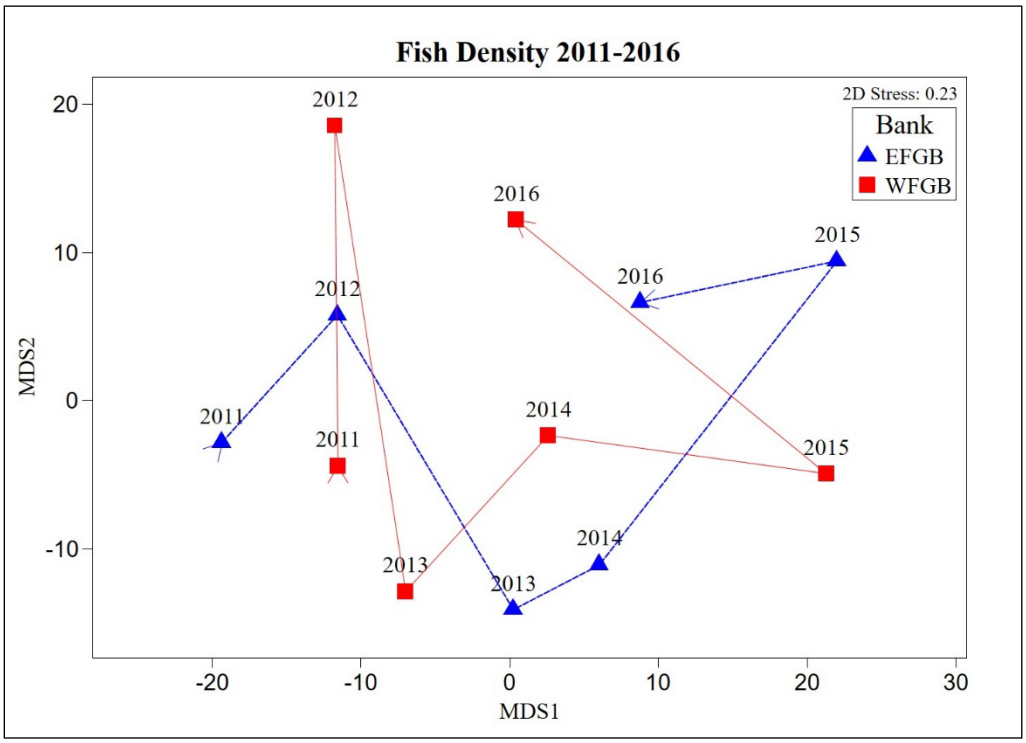


Figure 7.11. Two-dimensional MDS plot based on Bray-Curtis similarities showing shifts in the fish community due to significant changes in density within EFGB and WFGB study sites from 2011 to 2016.

Biomass data was first collected in 2006, and ranged from 51.44 to 242.70 g/100 m^2 within the EFGB study site and 24.58 to 272.26 g/100 m^2 within the WFGB study site from 2006 to 2016 (Figure 7.12).

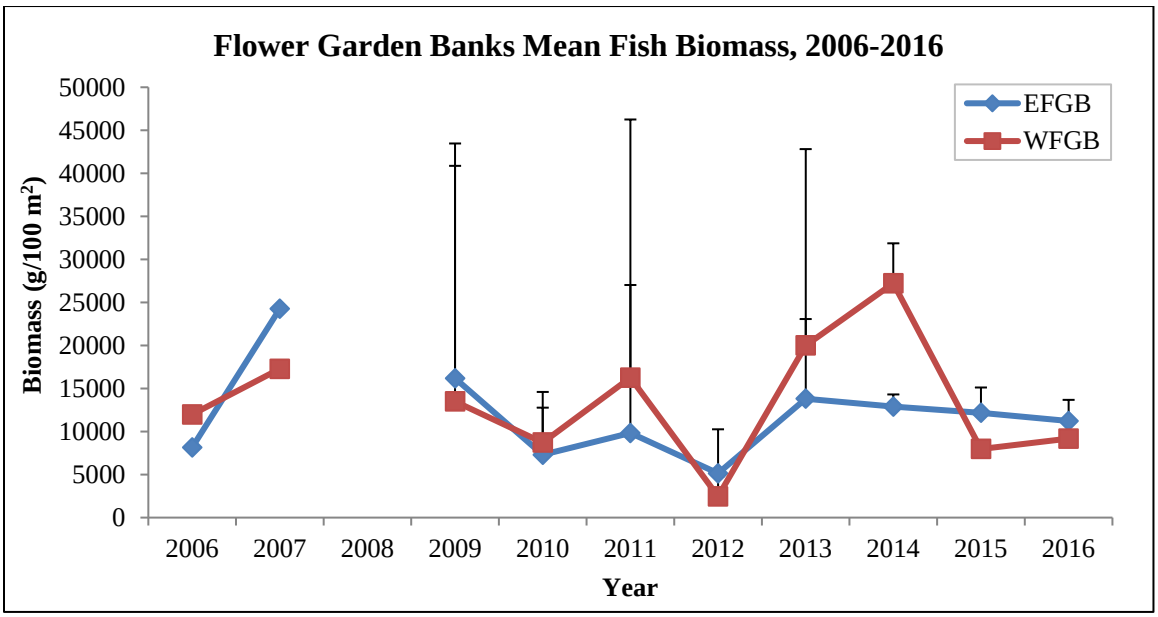


Figure 7.12. Mean fish biomass (g/100 m^2) +SE within EFGB and WFGB study sites from 2006 to 2016.

No data were collected in 2008. SE not available before 2009. Data for 2006 to 2008 from PBS&J (Precht et al. 2006; Zimmer et al. 2010); and FGBNMS for 2009 to 2015 (Johnston et al. 2013, 2015, 2017).

When compared among years and locations from 2011 to 2016, PERMANOVA analysis revealed significant differences between bank study sites, years, and the year x bank study site interaction was also significant (Table 7.8), suggesting that biomass within the EFGB and WFGB study sites significantly shifted from 2011 to 2016 (Figure 7.13). Although differences occurred between banks, the MDS plot displayed similar shifts in the fish communities over time (Figure 7.13). The observed dissimilarity in biomass between study sites from 2011 to 2016 was mainly attributable to Great Barracuda (10.86%), Atlantic Creolefish (9.07%), and Bermuda Chub (8.94%).

Table 7.8. PERMANOVA results comparing mean fish biomass within EFGB and WFGB study sites from 2011 to 2016. Bold text denotes significant value.

Source	Sum of Squares	df	Pseudo-F	P (perm)
Year	329000	5	13.44	**0.001**
Bank Study Site	6050	1	2.98	**0.001**
Year*Bank Study Site	24463	5	2.41	**0.001**
Res	586000	288		
Total	945000	299		

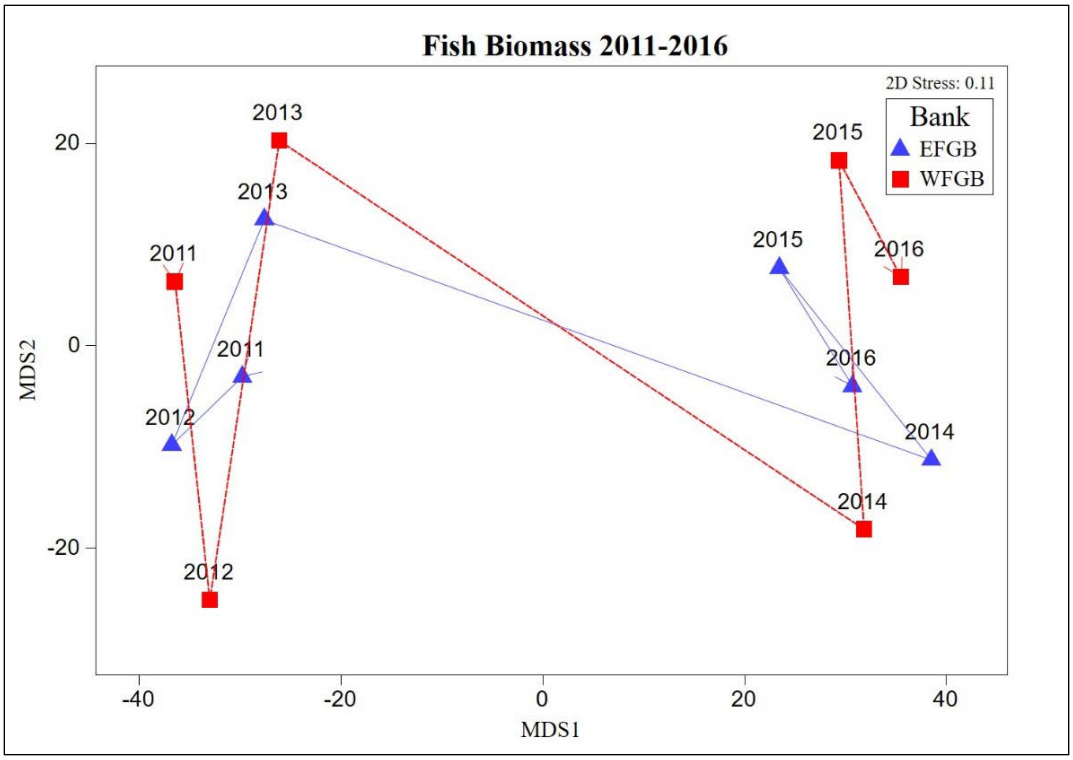


Figure 7.13. Two-dimensional MDS plot based on Bray-Curtis similarities showing shifts in the fish community due to significant changes in biomass within EFGB and WFGB study sites from 2011 to 2016.

To investigate trends in recreationally and commercially important species within EFGB and WFGB study sites, including grouper and snapper, additional analyses were conducted to examine density over time when complete survey data were available (2011 to 2016). The predominant grouper species within both EFGB and WFGB study sites were Graysby, followed by Yellowmouth Grouper. Tiger Grouper, Scamp, and Rock Hind were denser in EFGB study site surveys, and Black Grouper were denser in WFGB study site surveys (Figure 7.14).

Multivariate grouper density was compared among years and bank study sites from 2011 to 2016. PERMANOVA analysis revealed a significant difference between bank study sites (Table 7.9), suggesting that grouper density was higher within the EFGB study site than the WFGB study site. The observed dissimilarity in density between study sites from 2011 to 2016 was mainly attributable to Graysby (41.13%) and Yellowmouth Grouper (23.29%).

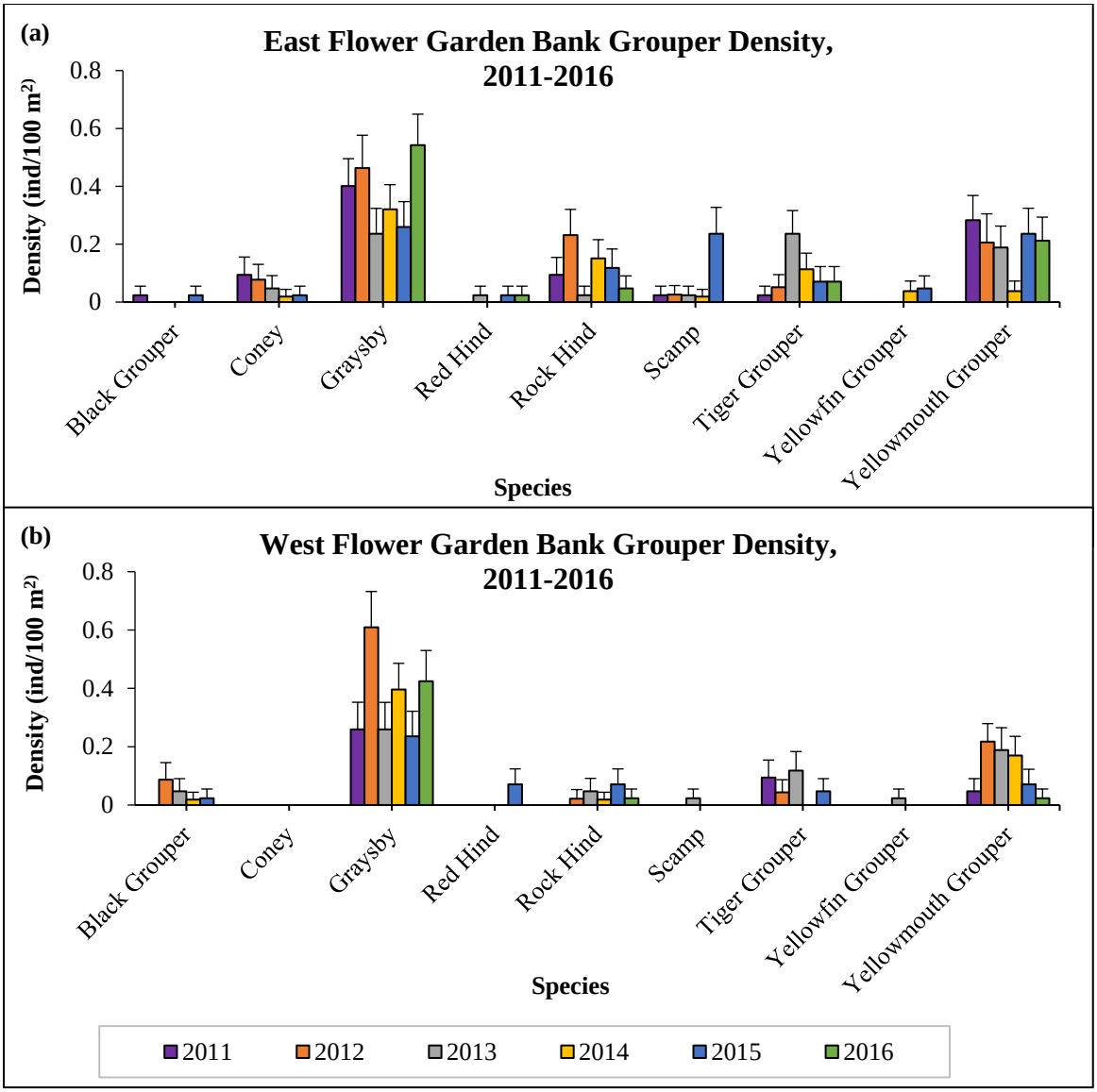


Figure 7.14. Mean density (individuals/100 m^2) +SE of grouper species within (a) EFGB and (b) WFGB study sites from 2011 to 2016.

Data for 2011 to 2015 from FGBNMS (Johnston et al. 2015, 2017).

Table 7.9. PERMANOVA results comparing mean grouper density within EFGB and WFGB study sites from 2011 to 2016. Bold text denotes significant value.

Source	Sum of Squares	df	Pseudo-F	P (perm)
Year	5	5	1.13	0.379
Bank Study Site	2	1	4.26	**0.001**
Year*Bank Study Site	4	5	1.43	0.103
Res	161	288		
Total	172	299		

From 2011 to 2016, Dog Snapper and Gray Snapper were denser in WFGB study site surveys than EFGB study site surveys (Figure 7.15). Multivariate snapper density was compared among years and bank study sites from 2011 to 2016. PERMANOVA analysis revealed a significant difference between bank study sites (Table 7.10), suggesting that snapper density was higher within the WFGB study site than the EFGB study site. The observed dissimilarity in density was mainly attributable to Dog Snapper (63.76%).

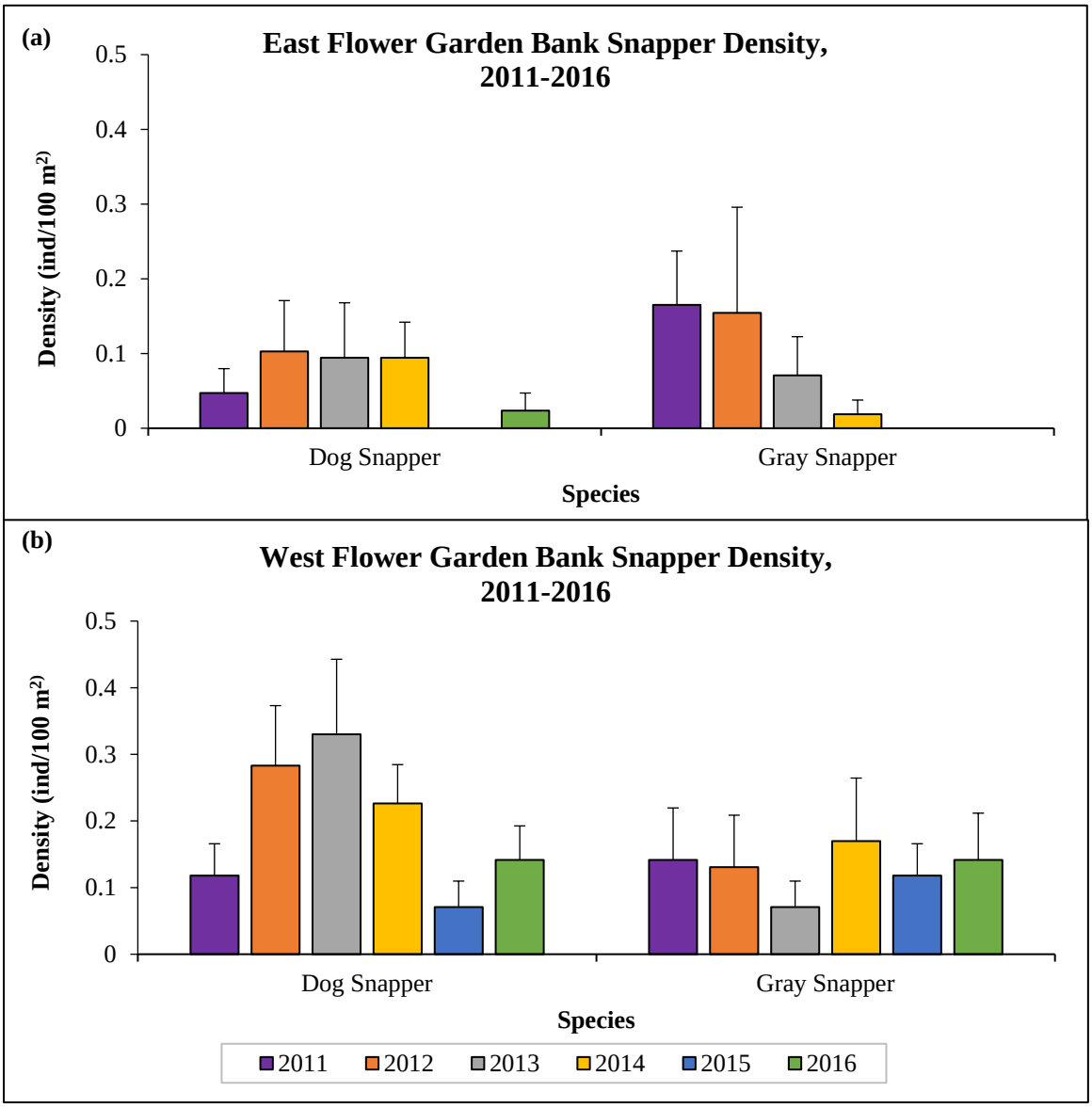


Figure 7.15. Mean density (individuals/100 m^2) +SE of snapper species within (a) EFGB and (b) WFGB study sites from 2011 to 2016.

Data for 2011 to 2015 from FGBNMS (Johnston et al. 2015, 2017).

Table 7.10. PERMANOVA results comparing mean snapper density within EFGB and WFGB study sites from 2011 to 2016. Bold text denotes significant value.

Source	Sum of Squares	df	Pseudo-F	P (perm)
Year	2	5	2.60	0.059
Bank Study Site	2	1	12.38	**0.001**
Year*Bank Study Site	1	5	0.59	0.820
Res	54	288		
Total	59	299		

Fish Surveys Discussion

Fish communities are indicators of ecosystem health (Sale 1991) and therefore an important component to long-term monitoring programs. Monitoring fish community changes over extended periods of time is valuable in detecting changes from normal variations in the community. 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). The fish assemblages of EFGB and WFGB occur near the northern latitudinal limit of coral reefs and are remote from other tropical reefs, and possess significantly different fish assemblages than reef systems in the Caribbean, primarily due to the limited presence of lutjanids (snappers) and haemulids (grunts) (Rooker et al. 1997; Precht et al. 2006; Johnston et al. 2017). Approximately 150 different reef fish species have been documented on the EFGB and WFGB reef cap (Pattengill 1998; Pattengiill-Semmens, C.V. and B.X. Semmens), which is lower than other locations in the U.S. Virgin Islands (~200 species) (Pittman et al. 2008) and the Florida Keys National Marine Sanctuary (~400 species) (ONMS 2011). Recent comparable studies conducted in Puerto Rico, U.S. Virgin Islands, and FGBNMS by NOAA's BioGeography Branch suggest that mean biomass is greater at EFGB and WFGB in comparison to those Caribbean reefs, and mean species richness is also slightly greater (Table 7.11). Though overall fish species diversity may be lower in comparison to other Caribbean reefs, the average number of species observed during individual fish surveys is greater at EFGB and WFGB.

Table 7.11. Comparison of other Caribbean reef biomass (g/100 m^2) ± SE and species richness (richness/100 $m^{2)}$ ± to the FGB.

Region	Mean Biomass (g/100 m^2)	Mean 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
East and West Flower Garden Banks Study Sites	10,197.67 ± 1,498.30	21.65 ± 0.58

(this report)		
East and West Flower Garden Bank Stratified Random Reef Wide Surveys (Clark et al. 2015a)	34,570.87 ± 3,517.95	24.60 ± 0.36

The EFGB and WFGB has lower species richness and overall abundance of herbivorous fishes than other Caribbean reefs (Dennis and Bright 1988). Historically, low macroalgae cover was reported in annual monitoring surveys, while recent data suggest a significant increase in mean macroalgae cover over time. During this study period, the herbivore guild possessed the second greatest mean biomass, contributing to 23% of the total biomass within study sites. Within the herbivore guild, 22% of the total biomass was attributed to Bermuda Chub. The piscivore guild had the greatest mean biomass, contributing approximately 44% of the total biomass within study sites. Within the piscivore guild, Great Barracuda contributed to over 48% of the total biomass; however, this contribution may be over inflated as Great Barracuda are likely attracted to the presence of the *R/V Manta* and often congregate under the vessel within the study sites during sampling.

Piscivore dominated biomass indicated that the ecosystem maintained an inverted biomass pyramid (Table 7.5). 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 refuges, 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 “healthy” and a community dominated by many small species is considered “impacted” (DeMartini et al. 2008; SOKI Wiki 2014). At EFGB and WFGB, results indicated that fish communities within study sites were evenly distributed (w values close to 0), meaning that the population can be considered moderately disturbed, and somewhat lacking in density of large fishes within study sites.

For commercially and recreationally important species, grouper density was higher within the EFGB study site while snapper density was higher within the WFGB study site. For the grouper species observed, Yellowmouth and Tiger Grouper consisted of immature and mature individuals, and all other species observed were immature individuals. In contrast to the grouper population, mature individuals dominated the snapper community. It should be noted that typical recruitment/nursery habitat for snappers (mangroves and sea grasses) are not present at EFGB and WFGB, and the

mechanism for recruitment of this family to the area remains unknown (Mumby et al. 2004; Clark et al. 2014).

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 within the study sites was considered low (Jackson et al. 2014) and similar to other Caribbean reefs (Table 7.12). However, low parrotfish biomass can be frequently associated with high fishing pressure and low coral cover, neither of which are documented at EFGB or WFGB.

Table 7.12. Mean biomass (g/100 m^2) for parrotfish at the FGB and other Caribbean reefs.

Location	Biomass (g/100 m^2)
Mexico	1,710
Belize	1,200
East and West Flower Garden Banks	823
Guatemala	670
Honduras	440

All data, with the exception of the EFGB and WFGB data, is from AGRRA 2012.

Lionfish were recorded in surveys for the fourth consecutive year in 2016, but have been observed by divers consistently on the reefs since 2011. Since their first observation, numbers rapidly increased through 2014, and then declined in 2015 and 2016 (Johnston et al. 2016a). It should be noted that lionfish are commonly seen during crepuscular feeding periods at dawn and dusk, and while fish surveys are spread throughout the day, surveys outside of this period may not accurately capture lionfish densities during peak hours of activity. However, mean lionfish densities at EFGB and WFGB (approximately 4–40 lionfish ha^{-1}) (Johnston et al. 2016a) have yet to reach levels recorded elsewhere in the southeast U.S. and Caribbean region, such as North Carolina (150 lionfish ha^{-1}) (Morris and Whitfield 2009) and the Bahamas (100–390 lionfish ha^{-1}) (Green and Cote 2009; Darling et al. 2011), as well as on artificial reefs in the northern Gulf of Mexico (10–100 lionfish ha^{-1}) (Dahl and Patterson 2014).

It should be noted that the staff of FGBNMS currently work 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 lower estimates for these parameters, as they would presumably be higher if lionfish were not removed from the system.

Chapter 8. Water Quality

Flower Garden Banks National Marine Sanctuary researchers deploy a water quality sampling carousel on the back deck of the NOAA *R/V MANTA*. (Photo: G.P. Schmahl, NOAA/FGBNMS)

Water Quality Introduction

Several water quality parameters were continually or periodically recorded at EFGB and WFGB. At a minimum, salinity and temperature were recorded every hour by data loggers permanently installed in or near the study sites at depths of approximately 24 m, and additional 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 (EPA) certified laboratory for select nutrient levels. Water samples for ocean carbonate measurements were also collected. Along with the quarterly water samples, water column profiles were conducted. This chapter presents data from the instruments at EFGB and WFGB from January 1–December 31, 2016.

Water Quality Methods

Water Quality Field Methods

Temperature and Salinity Loggers

The primary datasonde instrument for recording salinity and temperature was a Sea-Bird® Electronics, Inc. MicroCAT® 37 logger at an approximate 24 m depth. A logger was installed on a large railroad wheel and located in sand flats at each bank (Figure 1.3 and 1.4). The instrument recorded temperature and salinity hourly throughout the year. In August of 2016, new Sea-Bird instruments (Sea-Bird® Electronics 16plus V2 CTD [conductivity, temperature, and depth]) equipped with a WET Labs ECO NTUS turbidity meter replaced the MicroCAT® 37 loggers at EFGB and WFGB. These new instruments recorded temperature, salinity, and turbidity on an hourly basis. Each quarter, instruments were exchanged by divers for downloading and maintenance. They were 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 thermograph loggers were used to record temperature on an hourly basis. These instruments provided a highly reliable temperature backup for the primary Sea-Bird logging instruments located at the 24 m station at EFGB and WFGB. These loggers were also deployed at 30 m and 40 m stations at EFGB and WFGB to record temperature hourly at deeper depths. 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 photostation markers 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.

Sea surface temperature data were downloaded from the Texas Automated Buoy System (TABS) database for Buoy V located within the EFGB marine sanctuary boundaries (27° 53.796 N 93° 35.838 W) and Buoy N located west of the WFGB (27° 53.418 N 94° 02.202 W) to compare to temperatures recorded at depth on the reefs.

Water Column Profiles

Water column profiles were conducted quarterly with a Sea-Bird® Electronics *19plus* V2 CTD that recorded temperature, salinity, pH, turbidity, fluorescence, and dissolved oxygen (DO) every ¼ second to distinguish differences between the surface, mid-water, and reef cap depths. Data were recorded upon ascent following an initial two-minute soaking period after deployment. The CTD was brought to the surface at a rate <1 m/sec.

Water Samples

In conjunction with water column profiles, water samples were collected quarterly using a sampling carousel equipped with a Sea-Bird® Electronics *19plus* V2 CTD and a circular rosette six OceanTest® Corporation 2.5-liter Niskin bottles. The carousel was attached to the *R/V Manta* with a scientific winch cable. The winch cable allowed the operator to activate the bottles to sample at specific depths. Six samples were collected each quarter. Two 2.5 liter water samples were collected near the reef cap on the seafloor (approximately 16 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, soluble reactive phosphorous (ortho phospohate), and Total Kjeldahl Nitrogen (TKN) (Table 8.1). Water samples for chl-*a* analyses were collected in 1000 ml glass containers with no preservatives. Samples for soluble reactive 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 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 2016, water samples were obtained on February 18th, May 19th, August 12th, and November 15th.

Table 8.1. Standard EPA methods used to analyze water samples collected at the FGB.

Parameter	Test Method	Detection Limit
Chlorophyll-*a*	SM 10200H	0.003-mg/l
Ammonia	SM 4500NH3D	0.10–mg/l
Nitrate	SM 4500NO3E	0.04–mg/l
Nitrite	SM 4500NO2B	0.02–mg/l
Soluble reactive phosphorous	SM 4500 P-E	0.02–mg/l
Total Kjeldahl nitrogen (TKN)	SM 4500NH3D	0.50–mg/l

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). Samples were collected in Pyrex 250ml borosilicate bottles with polypropylene caps. Two replicates were collected at each depth. Sample bottles were filled using a 30 cm plastic tube that connected from the spout of the Niskin bottles. Sample 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 sample 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 18th, May 19th, August 12th, and November 15th.

Water Quality Data Processing and Analysis

Temperature, salinity, and turbidity data (when available) obtained from loggers were downloaded and processed each quarter. TABS data were downloaded for each year. QA/QC procedures consisted of a review of all files to ensure data accuracy, and instruments were serviced annually based on manufacturer recommendations. 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.

Due to a battery malfunction, temperature and salinity data from the 24 m SeaBird at EFGB were not available from February 18 to August 6, 2016. Therefore, backup temperature data from the HOBO logger were used for analysis during this time interval.

For seawater temperature data, a historical daily mean from the previous 25 years (1990 to 2015) was used for comparison to 2016 data using one-way analysis of variance (ANOVA) in R® version 2.13.2. For salinity data, a historical daily mean from the previous 8 years (2008 to 2015) was used for comparison. Monotonic trends over the course of the long-term datasets were detected using the Seasonal-Kendall trend test in a Microsoft Windows® DOS executable program developed by the United States Geological Survey (USGS) for water resource data (Hipel and McLeod 1994; Helsel and Hirsch 2002; Helsel et al. 2006). The Seasonal-Kendall trend test performed the Mann-Kendall trend test for each month and evaluated changes among the same months from different years over time, accounting for serial correlation in repeating seasonal patterns.

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.

Water Quality Results

Temperature

Surface seawater temperatures recorded by TABS Buoy V within the EFGB sanctuary boundaries ranged from a maximum of 31.29ºC and minimum of 20.09ºC in 2016, with a total of 85 days above the 30ºC bleaching threshold (Hagman and Gittings 1992) (Figure 8.1). At the EFGB 24 m station, the minimum temperature logged was 20.56ºC, recorded on February 13, 2016. The maximum temperature, recorded on August 10, 2016, was 30.73ºC and a total of 36 days were above 30ºC (Figure 8.1).

At the deeper 30 m and 40 m EFGB stations, slightly cooler temperatures were recorded by the HOBO loggers. At the 30 m station, the minimum temperature logged was 20.13ºC, recorded on February 25, 2016. The maximum temperature, recorded on September 9, 2016, was 30.46ºC (Figure 8.1). At the 40 m station, the minimum temperature logged was 20.07ºC, recorded on February 25, 2016. The maximum temperature, recorded on September 20, 2016, was 29.82ºC (Figure 8.1). There were 15 days above 30ºC at the 30 m station and zero days above 30ºC at the 40 m station at EFGB. At EFGB, the average temperature difference between the 24 m and 30 m stations was -0.63ºC and the greatest temperature difference was -3.61ºC on July 7, 2016. The average temperature difference between the 24 m and 40 m stations was -1.34ºC. The greatest difference in temperature recorded was -6.47ºC on July 24, 2016.

At WFGB, slightly cooler seawater temperatures were recorded in 2016 compared to EFGB. Surface temperatures recorded by TABS Buoy N west of the WFGB ranged from a maximum of 31.07ºC and minimum of 19.03ºC, totaling 69 days above the 30ºC bleaching threshold (Figure 8.1). Data gaps occurred in the TABS Buoy N data in both September and October, and no data was available after October 23, 2016. At the WFGB 24 m station, the minimum temperature logged was 19.78ºC, recorded on February 27, 2016. The maximum temperature, recorded on September 13, 2016, was 30.42ºC and a total of 21 days were above 30ºC (Figure 8.1).

At the WFGB 30 m station, the minimum temperature logged was 19.86ºC, recorded on February 27, 2016. The maximum temperature, recorded on September 14, 2016, was 30.29ºC (Figure 8.1). At the WFGB 40 m station, the minimum temperature logged was 19.74ºC, recorded on February 27, 2016. The maximum temperature, recorded on September 13, 2016, was 30.52ºC (Figure 8.1). There were 10 days above 30ºC at the 30 m station and 24 days above 30ºC at the 40 m station. At WFGB, the average temperature difference between the 24 m and 30 m stations was -0.30ºC and the greatest temperature difference was -3.54ºC on October 7, 2016. The average temperature difference between the 24 m and 40 m stations was -0.57ºC. The greatest difference in temperature recorded was -4.73ºC on July 5, 2016.

When compared to daily mean seawater temperatures at an approximate depth of 24 m from the past 25 years, both EFGB (ANOVA, df=1, f=1235, p<0.001) and WFGB (ANOVA, df=1, f=5216, p<0.001) 2016 seawater temperatures were significantly warmer than the historic 25-year average.

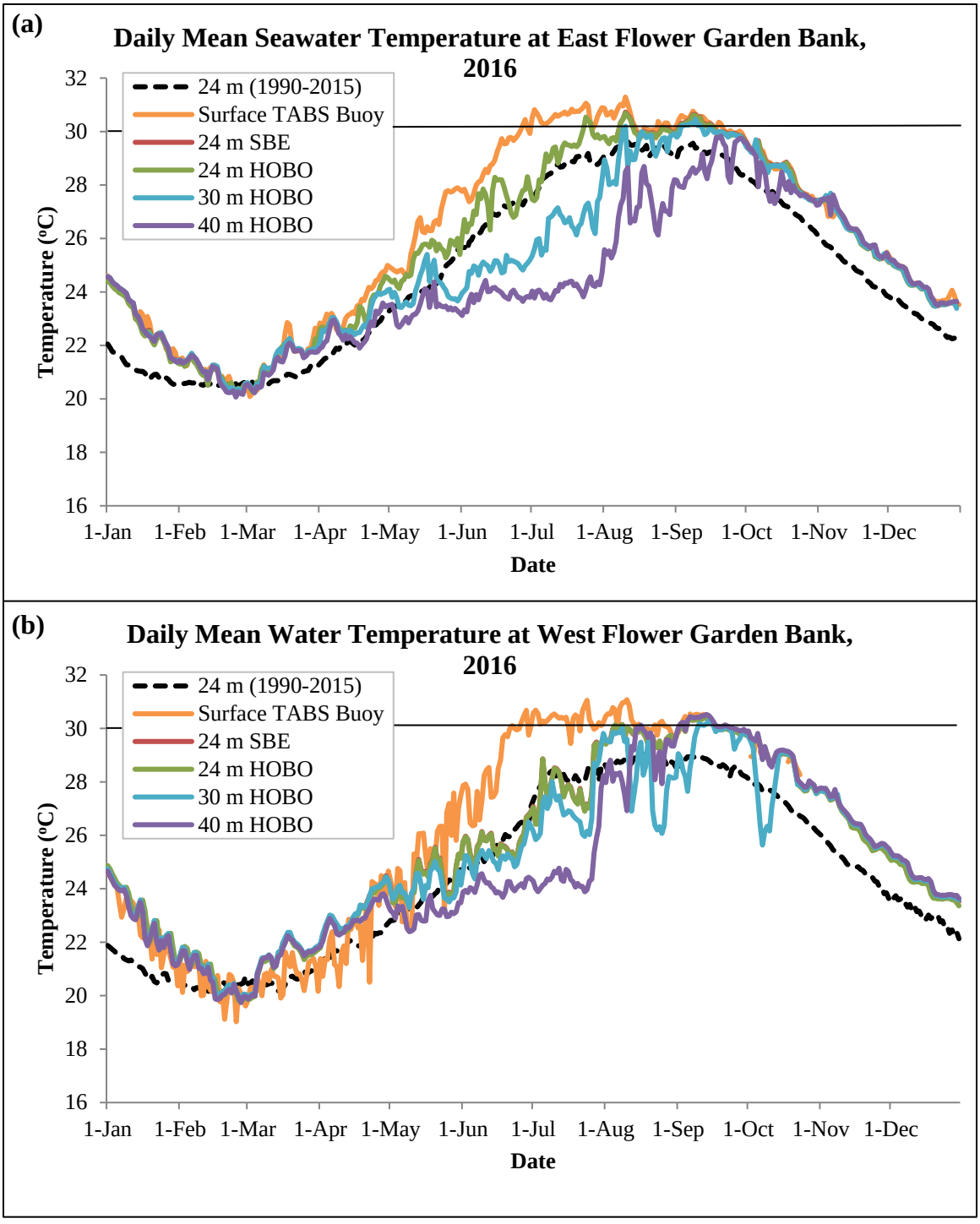


Figure 8.1. Daily mean water temperature (ºC) at (a) EFGB and (b) WFGB from various depths in 2016 and 25-year daily mean temperature. Black represents 30ºC bleaching threshold.

Seawater temperature data obtained from loggers at an approximate depth of 24 m have been collected throughout the monitoring program (1990 to 2016). Though some data gaps occur due to equipment malfunction and changes in program methodology and instrumentation, long-term temperature trends were assessed at EFGB and WFGB. The Seasonal-Kendall trend test on time-series daily mean seawater temperature data at EFGB resulted in a significantly increasing monotonic trend from 1990 to 2016 (τ=0.29, z=5.48, p=0.004) after adjusting for correlation among seasons (Figure 8.2). A significantly increasing monotonic trend was also detected at WFGB from 1990 to 2016 (τ=0.24, z=4.87, p=0.007) after adjusting for correlation among seasons (Figure 8.2).

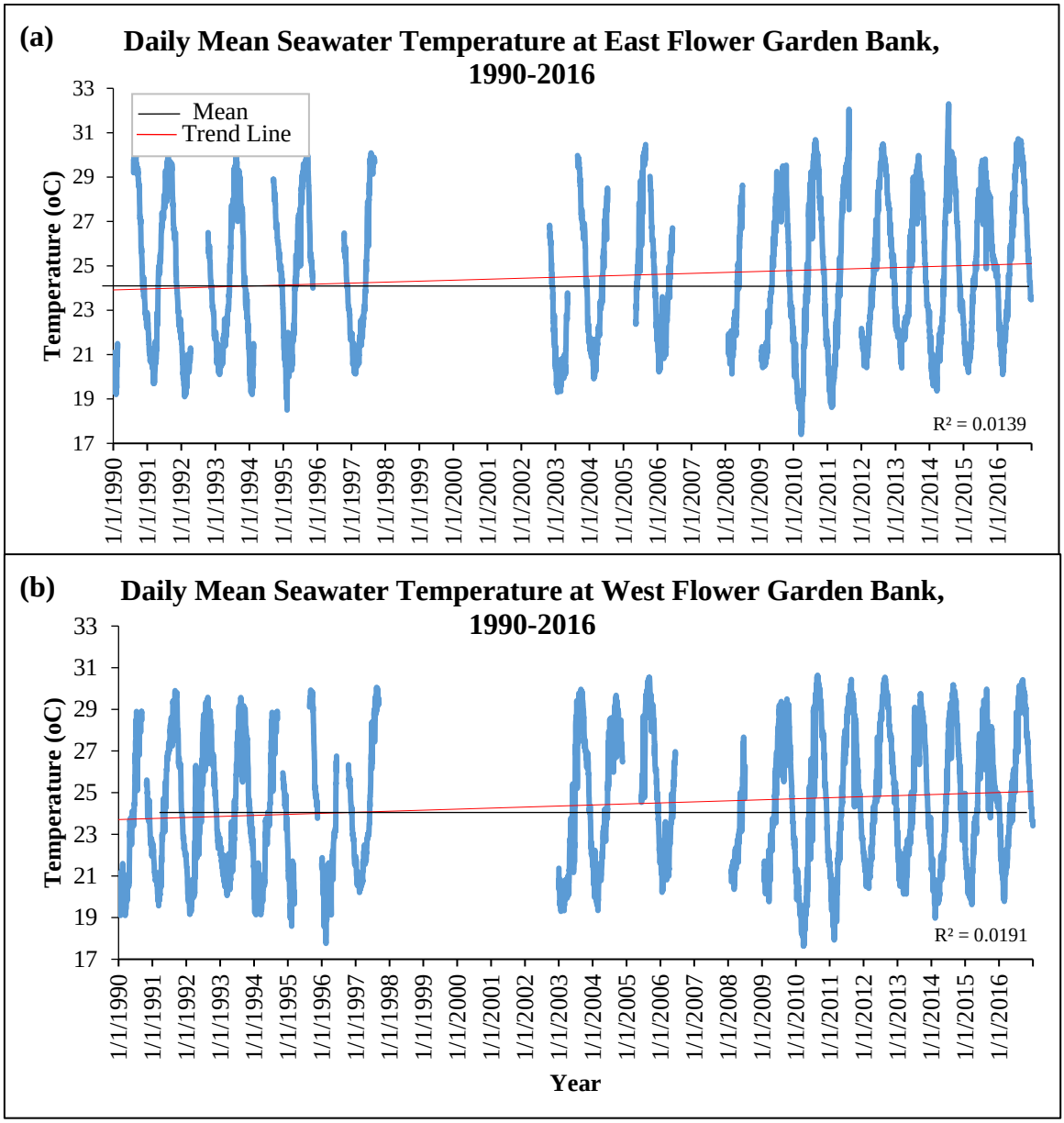


Figure 8.2. Daily mean 12-month seawater temperature (°C) seasonal variation at (a) EFGB and (b) WFGB from 1990 to 2016. Overall mean in black and significant trend line in red.

Salinity

Surface salinity recorded by TABS Buoy V within the EFGB sanctuary boundaries varied greatly in 2016, ranging from a maximum of 36.49 psu on February 12, 2016 and minimum of 13.26 psu on August 5, 2016 (Figure 8.3). At the EFGB 24 m station, the minimum salinity logged was 35.22 psu on February 25, 2016 and the maximum salinity was 36.48 February 3, 2016 (Figure 8.3); however, EFGB minimum salinity levels may have been missed due to unrecoverable data from the SeaBird battery malfunction occurring February 18 to August 6, 2016. When compared to the daily mean salinity observed over the last 8 years at EFGB, the 2016 data was similar to the historic mean when 2016 data were available.

Surface salinity recorded by TABS Buoy N at WFGB ranged from a maximum of 36.42 psu on January 23, 2016 and minimum of 23.23 psu on August 24, 2016 (Figure 8.3). At the WFGB 24 m station, the minimum salinity logged was 34.89 psu on February 5, 2016 and the maximum salinity was 36.54 July 23, 2016 (Figure 8.3). When compared to the daily mean salinity observed over the last 8 years at WFGB, the 2016 data showed greater fluctuation over the summer months from June to August.

Salinity data obtained from loggers at an approximate depth of 24 m were collected throughout the monitoring program (2008 to 2016) with minimal gaps due to equipment malfunction (Figure 8.4). The Seasonal-Kendall trend test on time-series daily mean salinity data at EFGB was not significant from 2008 to 2016, although a slightly decreasing trend in salinity was detected. An increasing trend at WFGB was detected. Results from the Seasonal-Kendall trend test at WFGB were not significant over time.

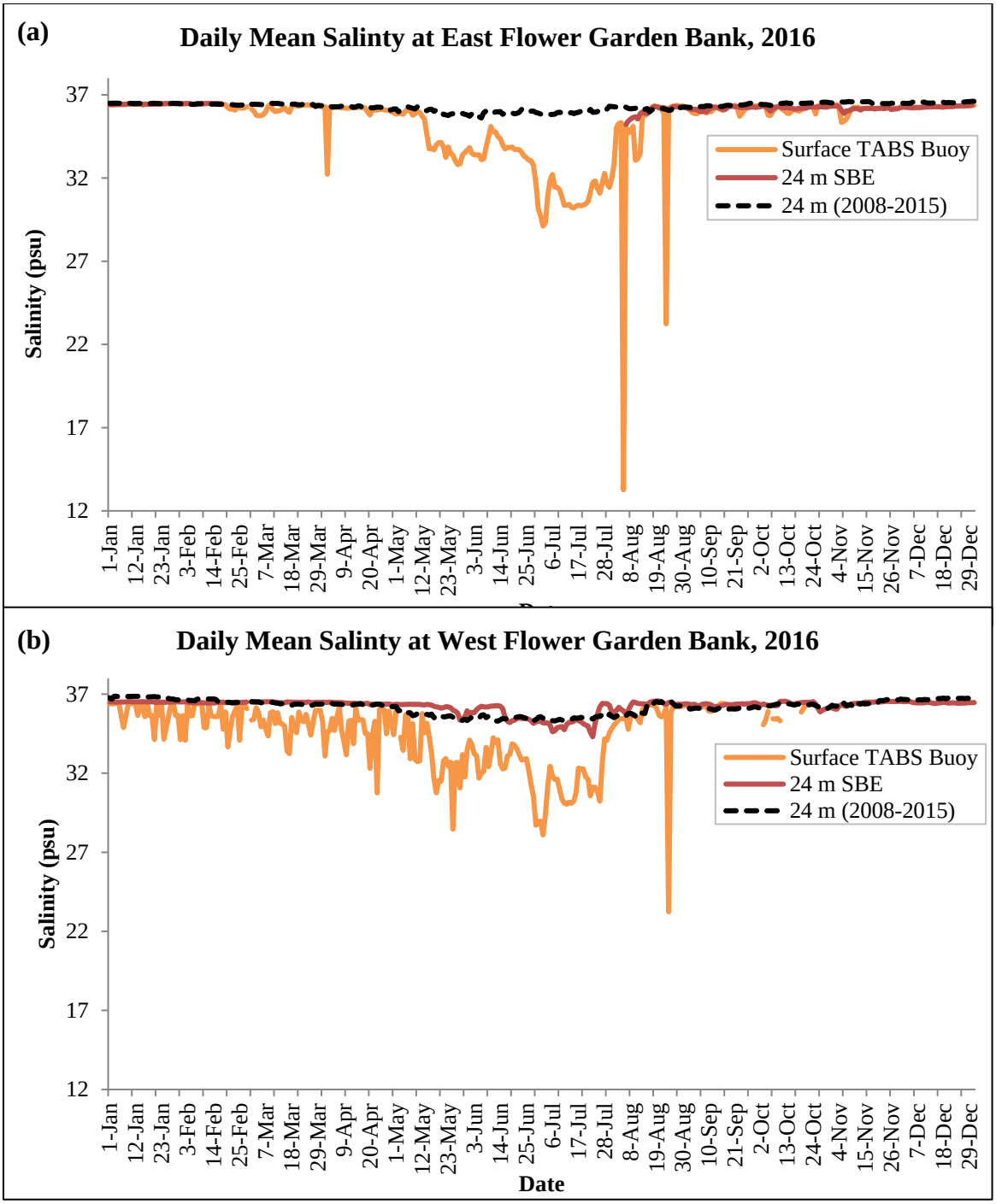


Figure 8.3. Daily mean salinity (psu) at the surface and 24 m station depth at (a) EFGB and (b) WFGB in 2016 compared to the 7-year daily salinity mean.

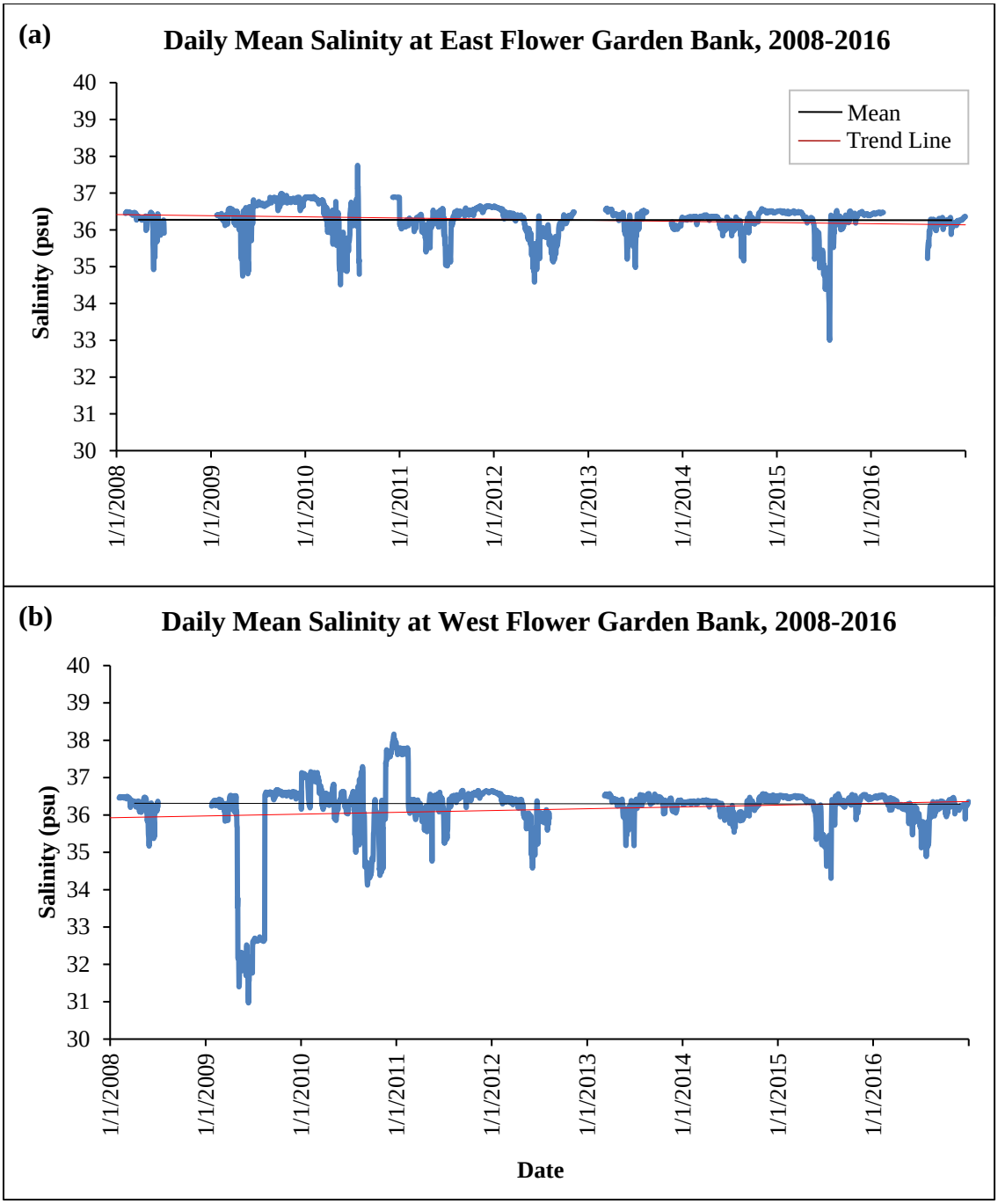


Figure 8.4. Daily mean 12-month salinity seasonal variation at (a) EFGB and (b) WFGB 2008 to 2016. Overall mean in black and trend line in red.

Turbidity

Turbidity was not collected until August of 2016 when the new Sea-Bird® Electronics *16plus* V2 CTD was deployed (24 m depth). At EFGB, the minimum turbidity recorded during this time frame was 0.01 ntu and the maximum turbidity was 0.25 ntu. At WFGB, the minimum turbidity recorded during this time frame was 0.01 ntu and the maximum turbidity was 0.30 ntu.

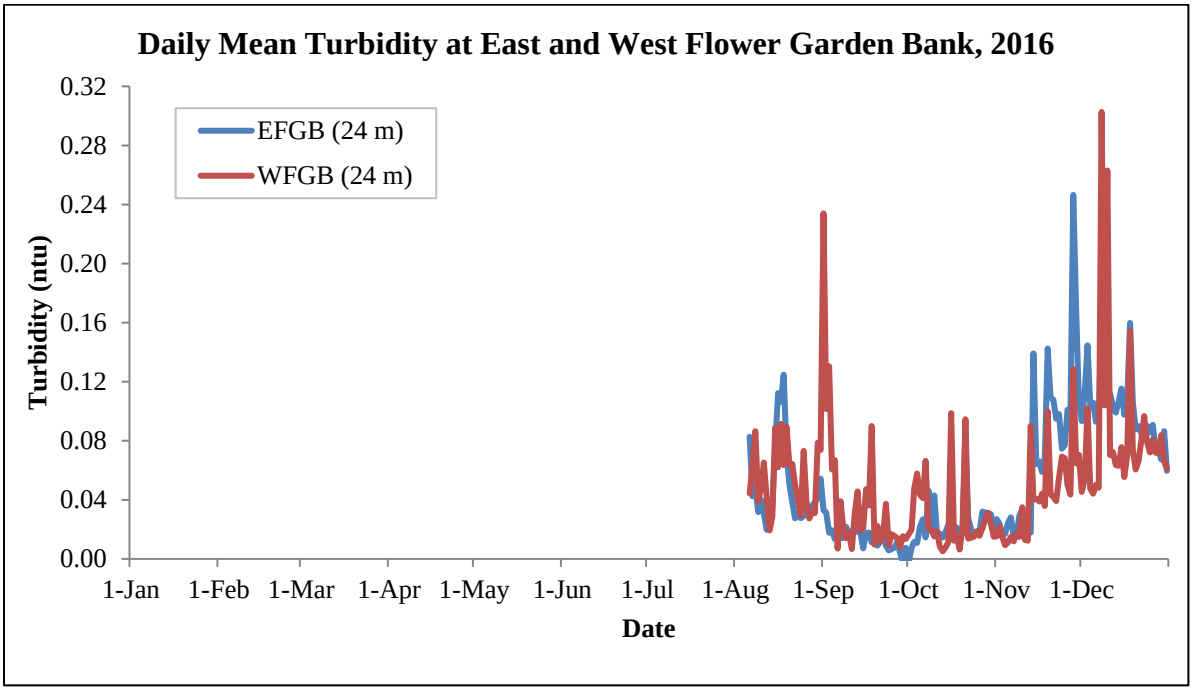


Figure 8.5. Daily mean turbidity (ntu) at EFGB and WFGB at a 24 m depth.

Water Column Profiles

Water column profile data were summarized by three depth gradients including the reef cap (~20 m), mid-water column (~10 m), and the surface (~1 m). Seawater temperatures varied throughout the year, and were warmer at surface depths and cooler on the reef cap (Table 8.1 and 8.2). For data collected in August, all three depths in the water column were greater than 30°C.

Salinity also varied throughout the year, and was observed to be slightly lower on the surface than at depth (Table 8.2 and 8.3). Turbidity and pH remained relatively stable throughout the water column among sampling dates (Table 8.2 and 8.3). Fluorescence was greatest in February throughout the water column at both banks, and DO was lowest in November throughout the water column at both banks (Table 8.2 and 8.3).

Table 8.2. EFGB temperature, salinity, turbidity, pH, fluorescence, and DO data collected from water column profiles in 2016.

Sample Date	Depth (m)	Temp (ºC)	Salinity (psu)	Turbidity (ntu)	pH (eu)	Fluorescence (mg/m^3)	DO (ml/L)
02/18/2016	20.7	20.83	36.40	-0.12	8.16	0.43	4.82
02/18/2016	10.1	20.88	36.41	-0.12	8.18	0.33	4.82
02/18/2016	2.7	20.91	36.41	-0.12	8.19	0.25	4.84
05/19/2016	18.0	26.07	35.35	-0.12	8.17	0.14	4.44
05/19/2016	9.2	26.05	34.09	-0.12	8.18	0.12	4.45
05/19/2016	1.2	26.14	34.01	-0.09	8.18	0.11	4.46
08/12/2016	16.0	30.37	35.30	-0.12	7.98	0.12	1.54
08/12/2016	7.8	30.63	33.89	-0.12	8.05	0.11	1.52
08/12/2016	1.0	30.65	33.43	0.17	8.08	0.13	1.54
11/15/2016	17.4	26.30	36.17	-0.12	8.14	0.13	0.84
11/15/2016	10.1	26.30	36.17	-0.12	8.15	0.13	0.84
11/15/2016	1.6	26.34	36.17	-0.12	8.16	0.08	0.84

Table 8.3. WFGB temperature, salinity, turbidity, pH, fluorescence, and DO data collected from water column profiles in 2016.

Sample Date	Depth (m)	Temp (ºC)	Salinity (psu)	Turbidity (ntu)	pH (eu)	Fluorescence (mg/m3)	DO (ml/L)
02/18/2016	20.5	20.15	36.37	-0.12	8.15	0.45	4.90
02/18/2016	10.2	20.15	36.37	-0.12	8.17	0.40	4.92
02/18/2016	2.1	20.23	36.37	-0.12	8.18	0.23	4.92
05/19/2016	18.5	26.11	36.30	-0.12	8.16	0.10	4.41
05/19/2016	9.0	26.17	34.63	-0.12	8.17	0.11	4.44
05/19/2016	1.3	26.37	34.21	-0.05	8.17	0.07	4.46
08/12/2016	18.8	30.68	36.42	-0.12	7.82	0.09	1.49
08/12/2016	10.1	30.55	35.84	-0.12	7.98	0.06	1.47
08/12/2016	1.6	30.55	35.83	-0.10	8.04	0.07	1.48
11/15/2016	17.3	26.33	36.17	-0.12	8.24	0.14	0.85
11/15/2016	9.2	26.32	36.17	-0.12	8.26	0.12	0.85
11/15/2016	1.7	26.33	36.17	-0.12	8.27	0.05	0.86

Water Samples

Nutrient analyses for ammonia, chl-*a*, nitrate, nitrite, phosphorus, and nitrogen levels for all samples in 2016 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 8.6 and 8.7).

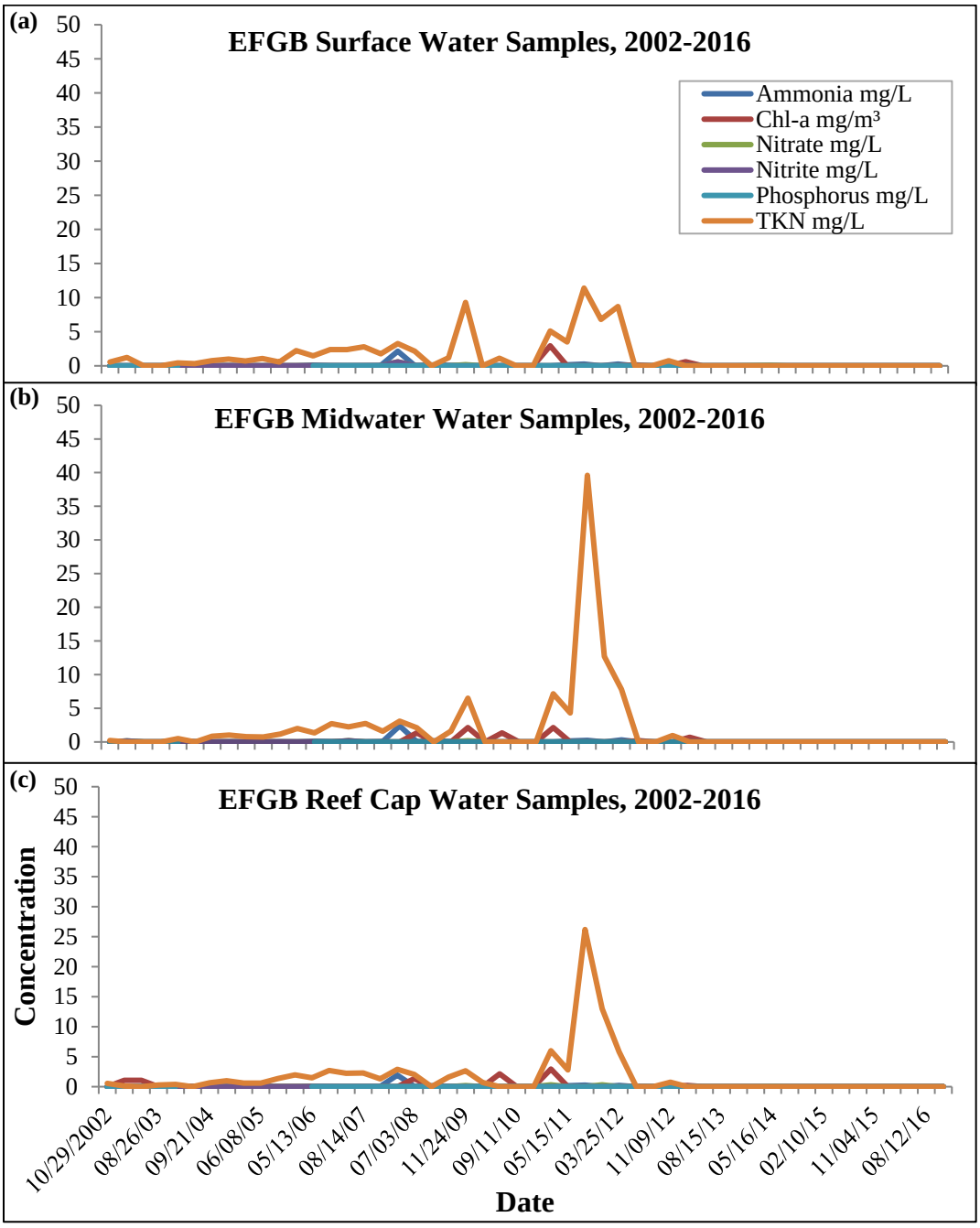


Figure 8.6. Nutrient concentrations from EFGB water samples taken at the (a) surface (1 m), (b) midwater (10 m), (c) and reef cap (16 m) from 2002 to 2016.

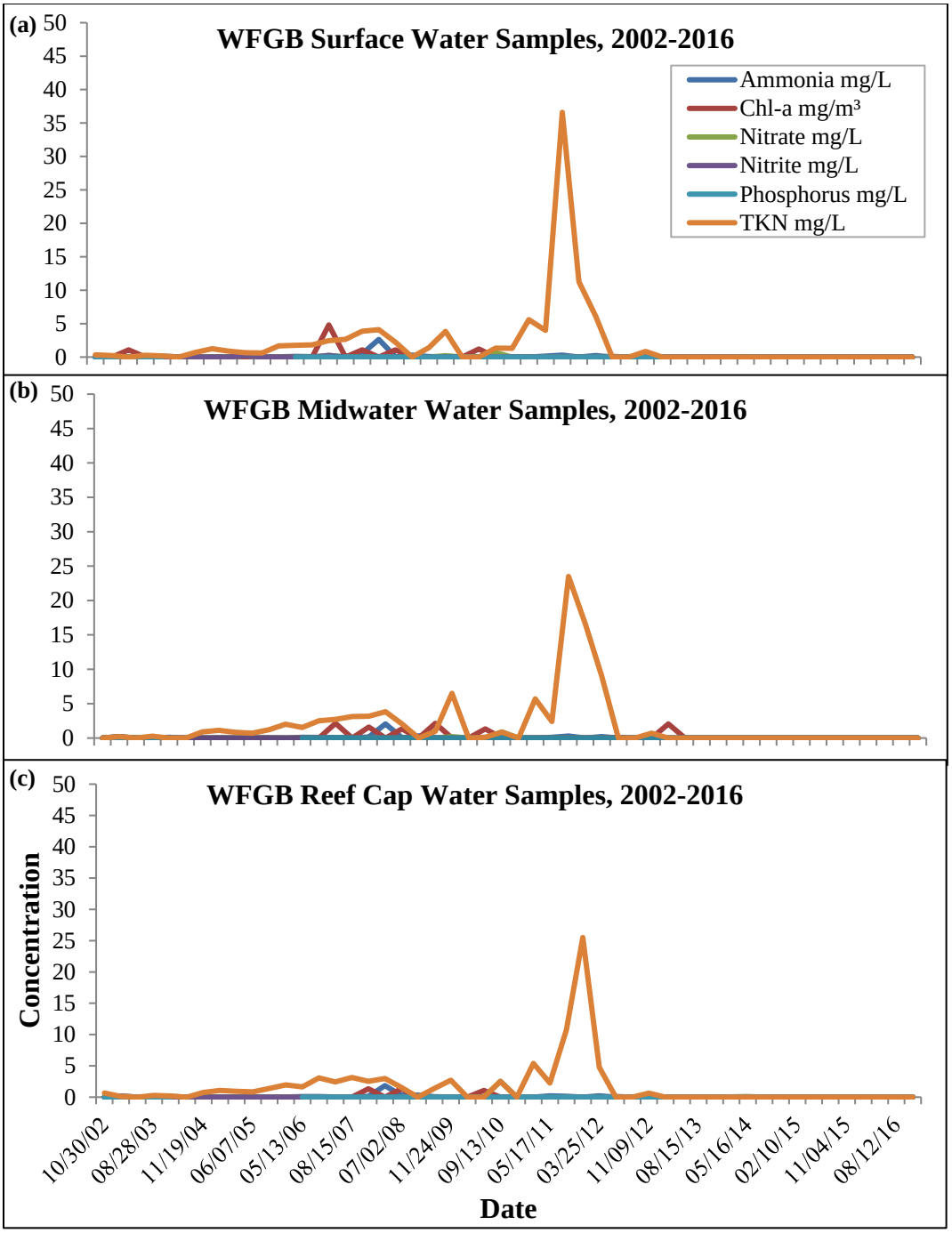


Figure 8.7. Nutrient concentrations from WFGB water samples taken at the (a) surface (1 m), (b) midwater (10 m), (c) and reef cap (16 m) from 2002 to 2016.

Carbonate samples taken throughout the year included pH, alkalinity, CO_2 partial pressure (pCO_2), and total dissolved CO_2 (DIC) (Table 8.4 and 8.5). For EFGB and WFGB, total pH varied in a relatively narrow range throughout the year. The lowest pCO_2 values, where the air-sea pCO_2 gradients were greatest, were observed in February 2016. The lowest $\Omega_{aragonite}$ values and highest DIC were also observed in February 2016.

Table 8.4. EFGB carbonate sample results for 2016.

Sample Date	Depth (m)	Salinity (ppt)	Temp (°C)	pH Total	Alkalinity (µmol/kg)	DIC (µmol/kg)	pH *in situ*	$\Omega_{aragonite}$	pCO_2 (µatm)
02/18/2016	20	36.41	20.83	8.0300	2398.9	2076.0	8.0916	3.38	359.8
02/18/2016	10	36.41	20.88	8.0307	2398.0	2082.5	8.0919	3.40	361.1
02/18/2016	1	36.41	20.91	8.0316	2398.2	2091.6	8.0927	3.43	362.2
05/19/2016	20	35.35	26.07	8.0560	2389.0	2073.9	8.0395	3.62	417.4
05/19/2016	10	34.09	26.05	8.0516	2352.0	2054.7	8.0357	3.50	421.0
05/19/2016	1	34.01	26.14	8.0563	2357.8	2052.1	8.0394	3.53	417.1
08/12/2016	20	35.30	30.37	8.0872	2374.3	2029.9	8.0076	3.89	446.9
08/12/2016	10	33.89	30.63	8.0955	2341.6	2015.4	8.0123	3.86	442.8
08/12/2016	1	33.51	30.65	8.0971	2344.5	2015.5	8.0139	3.86	442.5
11/15/2016	20	36.17	26.30	8.0770	2405.9	2040.3	8.0567	3.76	390.8
11/15/2016	10	36.17	26.30	8.0800	2408.4	2045.8	8.0595	3.79	389.2
11/15/2016	1	36.17	26.31	8.0820	2408.6	2047.8	8.0614	3.81	387.6

Table 8.5. WFGB carbonate sample results for 2016.

Sample Date	Depth (m)	Salinity (ppt)	Temp (°C)	pH Total	Alkalinity (µmol/kg)	DIC (µmol/kg)	pH *in situ*	$\Omega_{aragonite}$	pCO_2 (µatm)
02/18/2016	20	36.37	20.15	8.0346	2395.6	2091.7	8.1066	3.42	348.4
02/18/2016	10	36.37	20.15	8.0347	2397.5	2091.1	8.1071	3.43	348.3
02/18/2016	1	36.37	20.23	8.0362	2396.7	2082.9	8.1076	3.43	346.8
05/19/2016	20	36.30	26.11	8.0646	2405.3	2077.0	8.0475	3.74	407.6
05/19/2016	10	34.64	26.16	8.0545	2369.9	2062.5	8.0370	3.56	420.0
05/19/2016	1	34.22	26.37	8.0545	2357.4	2049.9	8.0342	3.53	421.9
08/12/2016	20	36.42	30.68	8.0964	2408.7	2048.2	8.0121	4.06	443.0
08/12/2016	10	35.84	30.55	8.0890	2391.3	2057.1	8.0069	3.99	452.7
08/12/2016	1	35.81	30.55	8.0901	2389.5	2051.2	8.0082	3.99	450.3
11/15/2016	20	36.17	26.32	8.0880	2411.1	2039.2	8.0668	3.84	380.7
11/15/2016	10	36.17	26.32	8.0900	2410.8	2048.6	8.0693	3.88	380.0
11/15/2016	1	36.17	26.33	8.0908	2409.8	2051.6	8.0698	3.89	380.1

Water Quality Discussion

EFGB and WFGB seawater temperatures in 2016 were warmer than the historical average, which may be resultant from the effects of El Nino and low hurricane activity in the Gulf of Mexico (Klotzbach and Gray 2016). Prolonged temperatures above the 30°C bleaching threshold during summer months led to coral bleaching at both banks in the fall of 2016 (further discussed in Chapter 10).

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 2016, where salinity was less than the historical average. Even though surface salinity from TABS buoys varied widely throughout the summer months, the data collected at depth 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 banks is a nearshore river-seawater mix that reaches the outer continental shelf, emanating principally from the Mississippi and Atchafalaya River watersheds, and occasionally subjecting the banks to nearshore processes and regional river runoff. In 2016, extreme rainfall events occurring in late April and May led to severe flooding and runoff in Texas and Louisiana.

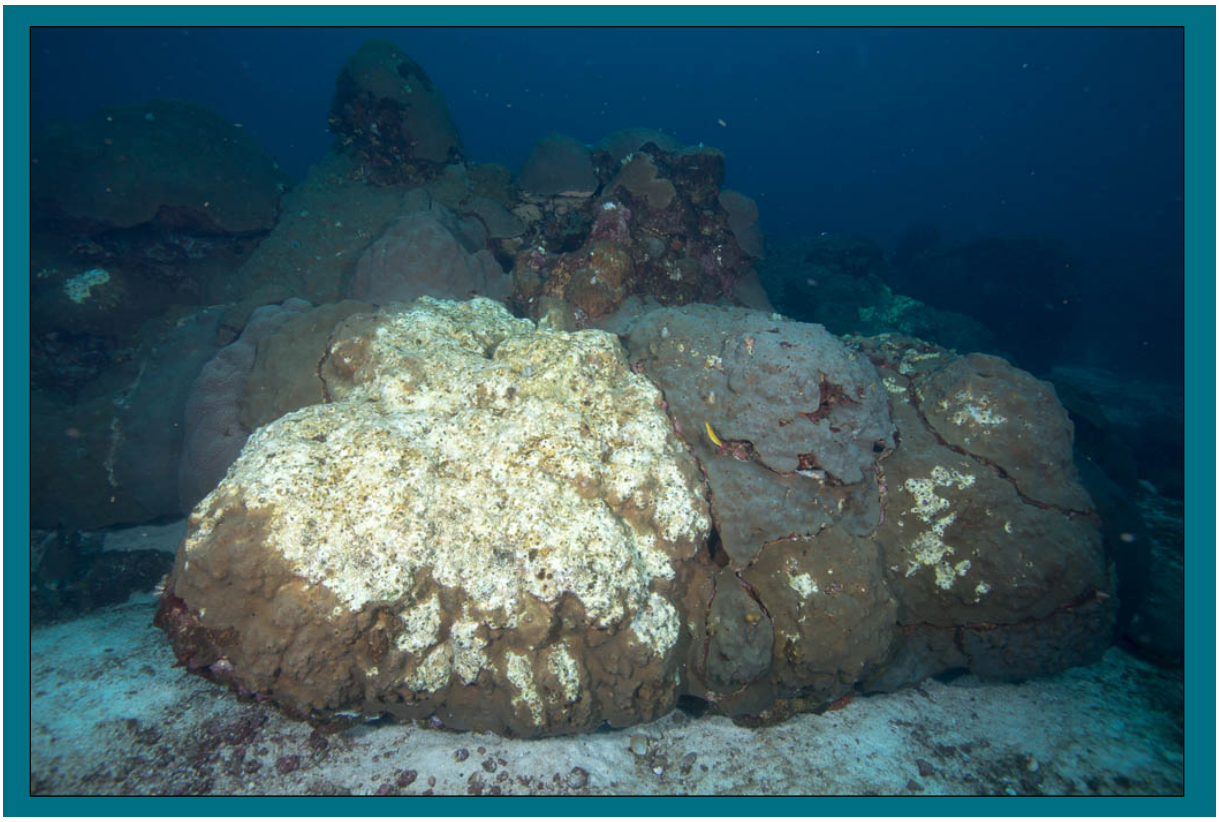
Laboratory analyses indicated that nutrient levels at EFGB and WFGB were below detectable levels, indicating low nutrient waters in 2016; however, it should be noted that these samples are only taken quarterly and episodic events may not be documented. A historical trend that was apparent at EFGB and WFGB was 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 banks were from nearshore waters (Nowlin et al. 1998), sediments (Entsch et al. 1983), or benthic and planktonic organisms (D'Elia and Wiebe 1990).

Carbonate analysis indicated a thermal control on carbonate systems ($pCO2$ and carbonate saturation state) in the region with clear seasonal temperature fluctuations. However, excess rainfall and flooding in 2016 may have influenced EFGB and WFGB by depressing salinity values. In terms of carbonate chemistry, the lowest $\Omega_{aragonite}$ values and highest DIC values were observed in February 2016, and the aragonite saturation states suggested that EFGB and WFGB were bathed in seawater that was well buffered across all survey times.

After controlling for temperature, surface seawater pCO_2 did not significantly deviate from atmospheric values throughout annual cycles, and may have a seasonal pattern with a peak $npCO_2$ occurring in late winter to early spring (February to March) and lowest $npCO_2$ in late summer (August to September). The distribution of ΔpCO_2 on an annual

basis suggested that this area had a small net air-sea CO_2 flux. Sea surface temperature appeared to exert the dominant control on sea surface *p*CO2 levels and could explain 70% of *p*CO2 variation, and sea surface temperature alone could also explain 81% of the variation in $\Omega_{aragonite}$ values. Seasonal and spatial distribution of seawater carbonate chemistry in 2016 demonstrates that seawater in the FGBNMS area, despite its relative proximity to land, behaved like an open ocean setting the majority of the time (such as the Bermuda Atlantic Time-series Study, or BATS) (Bates et al. 2012) in terms of its annual pCO_2 fluctuation and minimal terrestrial influence. However, with continuing CO_2 atmospheric increases, seawater will also take up CO_2 and depress pH and $\Omega_{aragonite}$, leading to long-term acidification in the region.

Chapter 9. 2016 Mortality Event



An *Orbicella franksi* colony impacted by the localized mortality event at EFGB in July 2016. (Photo: G.P. Schmahl, NOAA/FGBNMS)

Mortality Event Introduction

In July 2016, a localized mortality event occurred at EFGB, affecting coral and other invertebrates in an approximate 6.5 acre area on the shallow coral cap. Response cruises were conducted to document the event and collect samples for analysis. While these cruises were not officially part of the long-term monitoring program, FGBNMS and BOEM worked with partners to document the mortality event and collect samples. This chapter highlights collaborations, diver observations, and preliminary data from this event.

Mortality Event Methods

Mortality Event Response Methods

While conducting long-term monitoring at the EFGB study site on July 25, 2016, recreational divers from the M/V FLING, diving near buoy #4 (approximately 275 m away from the study site), reported dying coral, sponges, and invertebrates to FGBNMS and BOEM researchers aboard the *R/V Manta*. The FGBNMS and BOEM divers conducted several benthic transect surveys (as described in Chapter 2), collected coral and sponge samples, and documented observations in the area before returning to shore.

An initial water quality response cruise was conducted by partners from the Department of Oceanography at Texas A&M University (TAMU) on board the *R/V Manta* (July 30 to August 2, 2016). Partners performed CTD water column profiles and collected water samples for nutrient and water chemistry sampling (as described in Chapter 8). Water samples for ocean carbonate measurements were also collected for TAMU-CC partners. Water column profiles were collected with a Sea-Bird® Electronics *25plus* sealogger outfitted with a circular rosette of six OceanTest® Corporation 4-liter Niskin bottles. The CTD recorded temperature, salinity, turbidity, and fluorescence.

A second response cruise (August 4 to 7, 2016), was led by FGBNMS, with partners from Rice University, University of North Carolina-Chapel Hill (UNC), BOEM, and TAMU on board the *R/V Manta*. FGBNMS divers conducted in-water scooter surveys to determine the extent of the mortality area using GPS lat/long locations to mark the edges of the mortality zone.

Starting from the center of the mortality area and moving outward to unaffected areas on the EFGB coral cap, benthic photo transects (as described in Chapter 2) were completed at start locations generated in ArcGIS® using 1 m^2 resolution bathymetric data. Points representing the start location of surveys were generated using the ArcGIS® point tool in a grid pattern across the coral cap (50 m between survey points). Modified stationary visual reef fish surveys (see detailed survey methods in Chapter 7) were conducted in conjunction with benthic transects. One benthic photo transect and one fish survey were completed at each gridded point. Observations of fishes were restricted to an imaginary

cylinder with a 7.5 m radius. To quickly assess impacted corals, after each fish survey percent coral mortality was estimated within the cylindrical area.

Researcher partners collected samples of corals and sponges, both affected and unaffected, for genetic analysis. Samples were collected with a microchisel and hammer to remove tissue and preserved in 15ml conical tubes that were prefilled with EtOH. One diver carefully placed tissue on the tube lid and sealed the tube while upside down to prevent leaking of EtOH (Figure 9.1). Upon arrival to the surface, samples were transferred to 1.5 ml cryotubes with 200 proof EtOH and stored in a -20°C sample freezer. Micro sediment and seawater samples under affected coral colonies and unaffected colonies were also collected in small ziplock bags for culturing. Excess seawater was removed from sediment sample bags. Seawater samples filled in bags were transferred to 50 ml conical tubes. Samples were stored in a cooler on ice.

Figure 9.1. Divers collect tissue samples near the mortality area at EFGB. (Photo: G.P. Schmahl, NOAA/FGBNMS)

Mortality Event Preliminary Results

On July 25 and 26, 2016, divers reported and collected photographic evidence of green, hazy water and signs of stress on the reef, including dying corals and sponges, some of which were coated with white bacterial mats near buoy #4 (Figure 9.2). In many locations, divers observed a clear depth line in which colonies above the line appeared healthy, but below colonies were stressed or dying (Figure 9.3). Along with corals and sponges, dead bivalves, sea urchins, brittle stars, and crustaceans were observed on the seafloor. While collecting initial samples, it was noted by divers that skeletons of deceased organisms (e.g. brittle stars, sea urchins, and sponges) were

unusually fragile and disintegrated at the touch. After the initial observations in late July of 2016, it was believed that the event was no longer active after this timeframe.

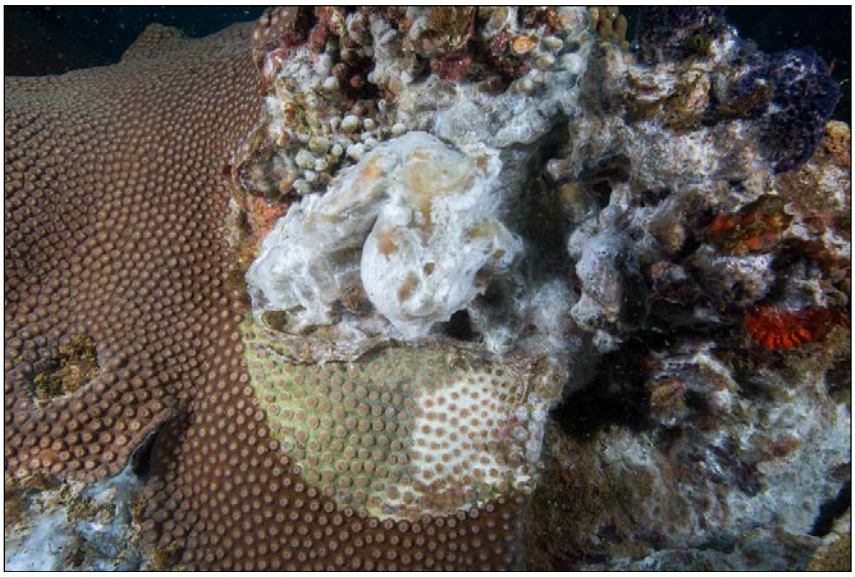


Figure 9.2. White bacterial mats coat dying corals and sponges at EFGB. (Photo: G.P. Schmahl, NOAA/FGBNMS)

Figure 9.3. Clear line of mortality delineates healthy and affected colonies. (Photo: G.P. Schmahl, NOAA/FGBNMS)

During the water quality response cruise lead by partners at TAMU from July 30 to August 2, 2016, a total of 39 CTD stations were completed at EFGB and WFGB. There was a spatial distribution of near-surface salinity displaying differences between

sampling locations at EFGB and WFGB, as a fresh water mass was present over EFGB. A complete summary of the water quality response cruise can be found at:

http://flowergarden.noaa.gov/doc/fgbrr16cruisereport.pdf
Remote sensing data at the time the mortality event agree with the *in situ* data collected during the water quality response cruise, documenting low salinity levels surrounding EFGB (NRL 2017) (Figure 9.4).

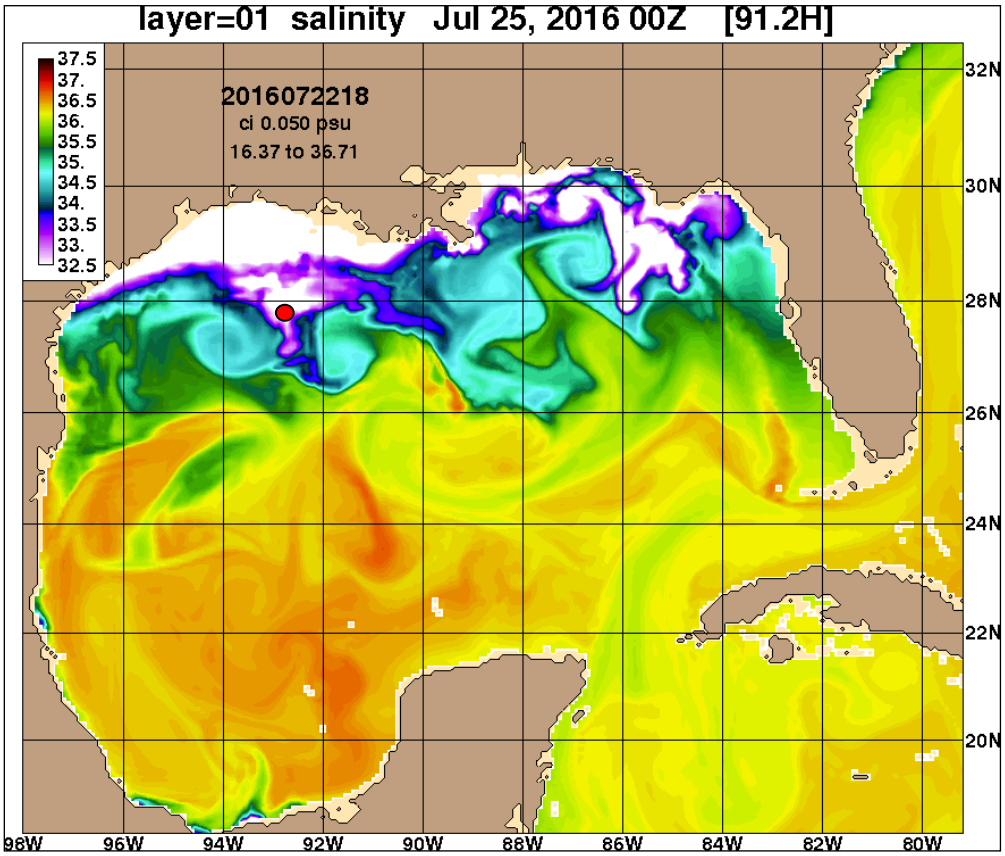


Figure 9.4. EFGB, marked by red dot, and sea surface salinity in the Gulf of Mexico on July 25, 2016. White and purple areas indicate low salinity levels intruding offshore south of the Texas/Louisiana coast. (Figure credit: United States Naval Research Laboratory – Global HYCOM Nowcast/Forecast System)

During the second response cruise lead by the FGBNMS from August 4 to 7, 2016, researcher partners collected over 300 samples of corals and sponges, both affected and unaffected, for genetic analysis.

Initial estimates within Bohnsack survey cylinders (15 m) were used to determine the extent of affected corals on the EFGB coral cap (Figure 9.5). Based on surveys, approximately 6.3% of the corals located on the shallow portions of the reef cap (<90 feet) were affected by the mortality event. The mortality zone was spread across approximately 6.5 acres (1.4% of the coral reef at EFGB). Some surveys exhibited up to

70% of affected corals between buoys #4 and #7. There was no evidence of the die-off within the long-term monitoring study site near buoy #2.

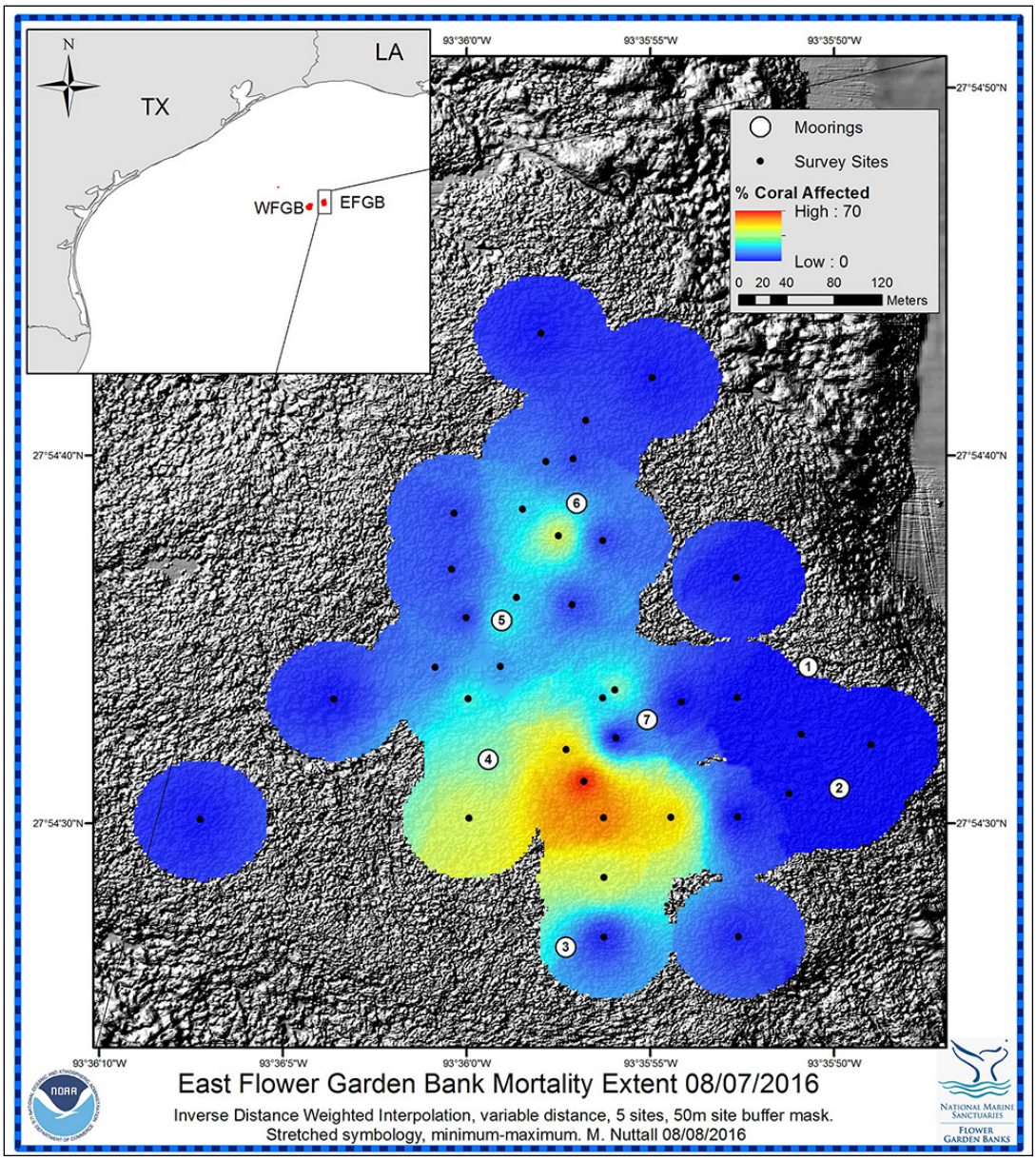


Figure 9.5. Extent of affected corals from diver surveys at EFGB. Numbered circles represent mooring buoys.

For fish surveys taken within the mortality area, density was less than in surveys taken outside the mortality area, or in the study sites at EFGB and WFGB (Table 9.1). Biomass was higher in the mortality surveys due to a large school of Atlantic Creolefish that swam through the water column during one of the surveys; however, if this school was removed

from the dataset, biomass inside the mortality zone (10,340.83 ± 3,371.03) was less than biomass outside of the mortality zone.

PERMANOVA analysis revealed mean fish density inside the mortality zone was significantly less than in surveys taken outside the mortality area, in the EFGB study site, and in the WFGB study site (Table 9.2). SIMPER analysis identified the main contributors leading to differences between fish density inside versus outside the mortality area at EFGB were caused by Atlantic Creolefish (8.22%) and Bluehead (7.50%).

Table 9.1. Mean density (individuals/100 m^2 ± SE) and biomass (g/100 m^2 ± SE) in fish surveys in 2016.

Fish Survey Location	Density	Biomass
EFGB Surveys Inside Mortality Zone	97.26 ± 41.21	14,636.07 ± 6,572.52
EFGB Surveys Outside Mortality Zone	148.31 ± 30.01	13,654.03 ± 5, 987.14
EFGB Study Site	147.66 ± 45.32	11,221.02 ± 2,459.44
WFGB Study Site	243.59 ± 87.45	9,174.32 ± 1,742.09

Figure 9.2. PERMANOVA results comparing mean fish density from surveys inside and surveys outside the mortality area. Bold text denotes significant value.

Source	Sum of Squares	df	Pseudo-F	P (perm)
EFGB Surveys Inside Mortality Zone*Outside Mortality Zone	2584	1	1.82	**0.044**
EFGB Surveys Inside Mortality Zone*EFGB Study Site	4610	1	3.48	**0.001**
EFGB Surveys Inside Mortality Zone*WFGB Study Site	6174	1	5.06	**0.001**
EFGB Surveys Outside Mortality Zone*EFGB Study Site	1989	1	1.41	0.143

Mortality Event Discussion

While there was no clear single cause of the EFGB mortality event, several potential causes were under investigation at the time this report was prepared, and most agree that the event likely resulted from a combination of stressors.

It was clear from the water quality data that surface salinity levels were depressed during July. The Midwest region experienced extreme rainfall and flooding events in 2016, causing freshwater runoff and discharge into the Gulf of Mexico from Texas and Louisiana waterways (TAMU 2017). Large freshwater plumes rich with nutrients are uncommon in offshore locations, as runoff from storm events primarily affect coastal areas as plumes decay; however, this increase in freshwater coupled with elevated seawater temperatures and decreased oxygen may have been contributing factors to the mortality event. Stable isotope analysis of oxygen from surface water samples collected during the water quality response cruise will help determine if the freshwater surrounding EFGB was from Texas/Louisiana runoff sources.

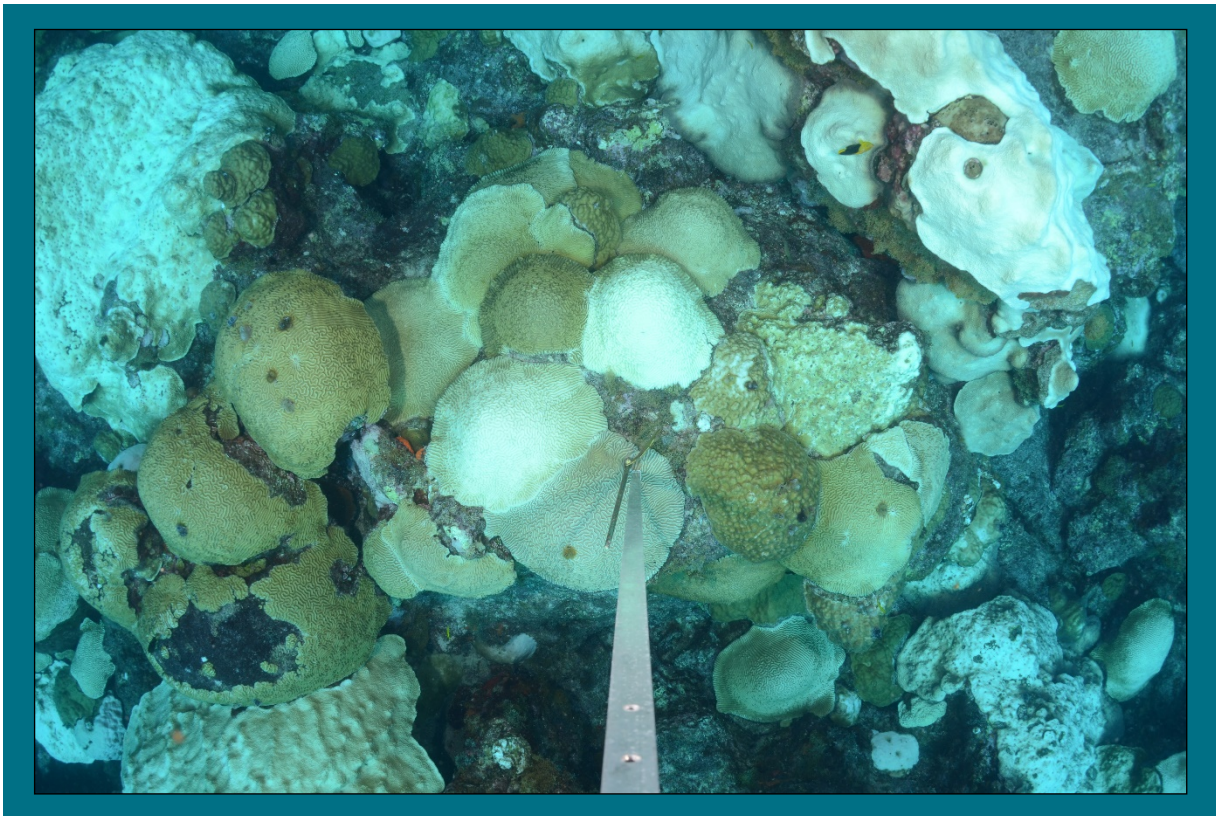
Benthic photo transect results were being processed at the time this report was written. During that time, the FGBNMS was also collaborating with research partners, who were processing samples to study the micro-organism communities and identify genetic markers that indicate specific types of stress.

A preliminary review of vessel traffic data revealed no large vessels near EFGB before the mortality event, thus ruling out the possibility of any acute pollutant discharges that may have triggered the mortality event.

A similar mortality event was documented on coral reefs in Almirante Bay, Bocas del Toro Province, Panama, in 2010, where corals turned white and died in association with the mortality of invertebrates (Altieri et al. 2017). Observations of thick bacterial mats and depth lines of mortality were also observed, comparable to observations at EFGB. Extremely low levels of dissolved oxygen in deeper waters contrasted with higher oxygen levels in shallower waters (where corals were still healthy), resulting in a hypoxic event in the deeper areas of Almirante Bay (Altieri et al. 2017). While there were no instruments collecting dissolved oxygen in the mortality area at EFGB in 2016, observations of affected coral colonies and invertebrates were similar to those documented in Almirante Bay.

It is unclear as to why only a small area of the EFGB coral cap was affected, as there was no evidence of mortality on other areas of EFGB, within the EFGB study site, or at WFGB. It is also unclear why most mortality was confined to depressions and sand flats on the bank. Recently, FGBNMS and partners from Baylor University, have installed a suite of current meters on EFGB and WFGB, which may help elucidate micromovements of water over the banks and discern the dynamics of water movements from the surface to the reef. FGBNMS researchers will continue monitoring the area to determine what factors control recovery, document changes in coral community structure, and monitor for indications of additional mortality or coral disease.

Chapter 10. 2016 Coral Bleaching Event



Bleached and paling corals in repetitive study site photostation #102 at EFGB in October 2016. (Photo: G.P. Schmahl, NOAA/FGBNMS)

Coral Bleaching Event Introduction

A bleaching event began in late September/early October 2016 due to a sustained period of seawater temperatures in excess of 30°C, causing corals to bleach and pale at EFGB and WFGB. Response cruises were conducted at EFGB and WFGB to photograph corals in repetitive study site photostations to document the event. This chapter highlights diver observations and preliminary bleaching data.

Coral Bleaching Event Methods

Coral Bleaching Event Response Methods and Analysis

After observations of bleached and paling corals were made in late September, a response cruise was completed to document affected corals in the EFGB study site on October 10, 2016 and in the WFGB study site from October 18 to 19, 2016. A third cruise to document affected corals was completed at the EFGB study site on Jan 31, 2017. Repetitive study site photostations and deep photostations were located by divers and photographed (as described in Chapter 3). To quickly assess impacts from bleaching stress in the repetitive stations, total coral colonies in each photostation image were counted, along with colonies that were bleached or paling. Bleached and paling coral colonies were divided by the total number of colonies per station and multiplied by 100 to determine percent coral colonies that were bleached or paling (Figure 10.1).

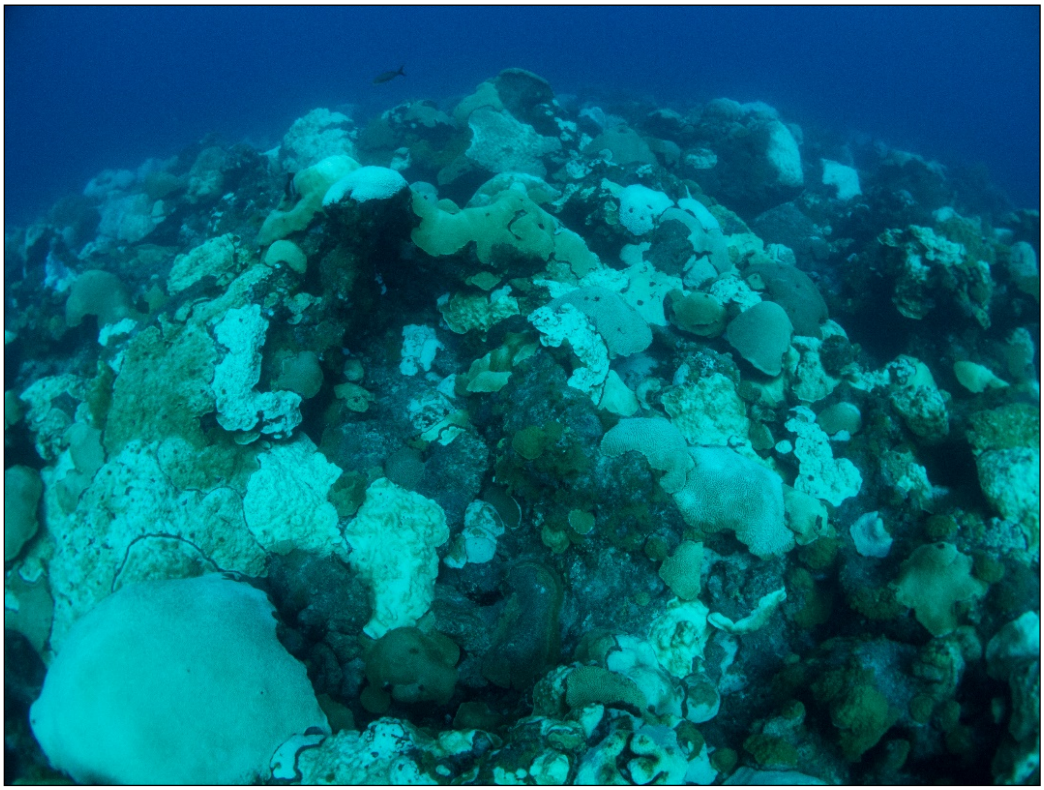


Figure 10.1. Bleached and paling coral colonies at EFGB in October 2016. (Photo: Emma Hickerson, NOAA/FGBNMS)

Coral Bleaching Event Results

During the bleaching response cruises at EFGB and WFGB in October 2016, divers photographed the repetitive study site photostations and repetitive deep photostations – all of which contained bleached and paling coral coloniess that could be tracked over time. Based on colony counts in each repetitive photostation image, approximately 46% of the coral colonies (756 individual colonies) within the EFGB study site exhibited signs of bleaching stress, with 24% of the colonies appearing to be completely bleached (corals had expelled their symbiotic algae, leaving behind transparent coral tissues and a stark white calcium carbonate skeleton) (Figure 10.2). At WFGB, 24% of the coral colonies within the repetitive study site photostations (500 colonies) exhibited signs of bleaching stress, with 10% of the colonies appearing to be completely bleached (Figure 10.2). Within repetitive deep photostations, bleaching stress was less severe, with 16% of the coral colonies at EFGB (46 colonies) and 20% at WFGB (91 colonies) impacted by bleaching and paling (Figure 10.2). Coral species most affected by bleaching stress included *Montastraea cavernosa*, *Orbicella franksi*, *Pseudodiploria strigosa*, and *Millepora alcicornis.*

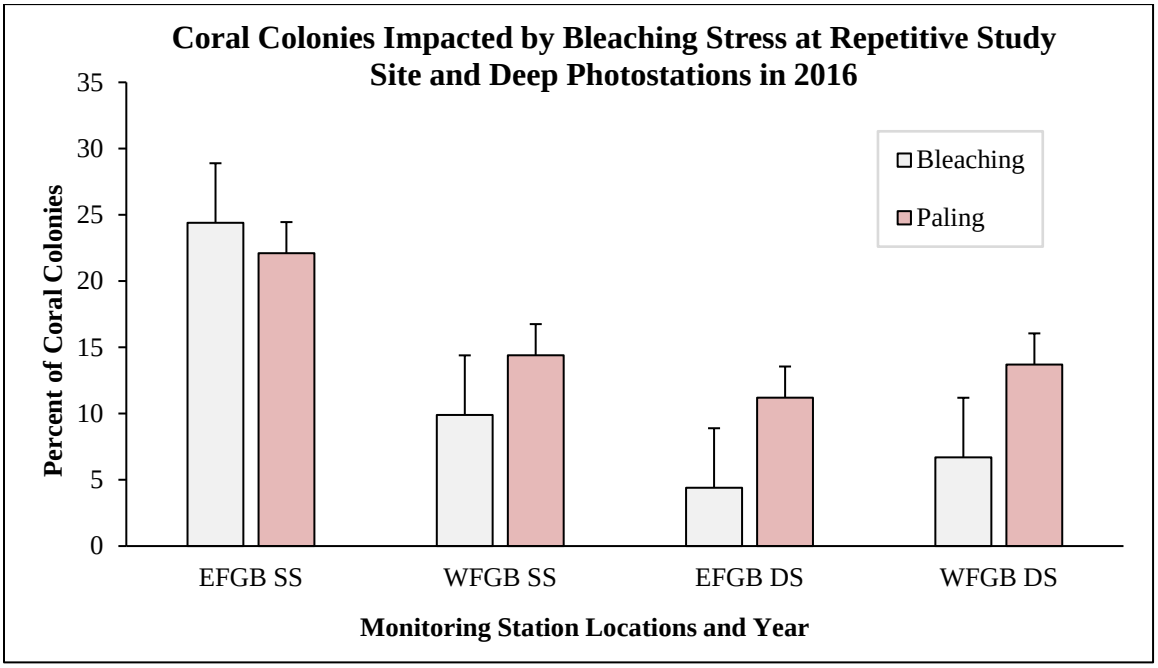


Figure 10.2. Repetitive deep station (DS) and repetitive study site (SS) photostations percent bleaching and paling + SE of coral colonies at EFGB and WFGB in October 2016.

Persistent seawater temperatures above 30°C, causing stressed corals to expel their algae, were recorded at the 24 m depth near the study sites at EFGB and WFGB in 2016. At EFGB, there were 36 days above the bleaching threshold and 21 days above the threshold at WFGB. Differences in the amount of bleaching at EFGB compared to WFGB were likely due to differences in seawater temperatures surrounding the banks. It is possible

that the bleaching threshold at the banks may be less than 30°C, as corals in the EFGB deep photostations bleached; however, seawater temperatures did not exceed 30°C as recorded by the HOBO logger at 40 m (Figure 8.1). Surface seawater temperatures were above 30°C for 85 days at EFGB and 69 days at WFGB in 2016. This *in situ* data correlated with sea surface temperature satellite data as described by NOAA's Coral Reef Watch bleaching alerts (NOAA Coral Reef Watch 2017) (Figure 10.3).

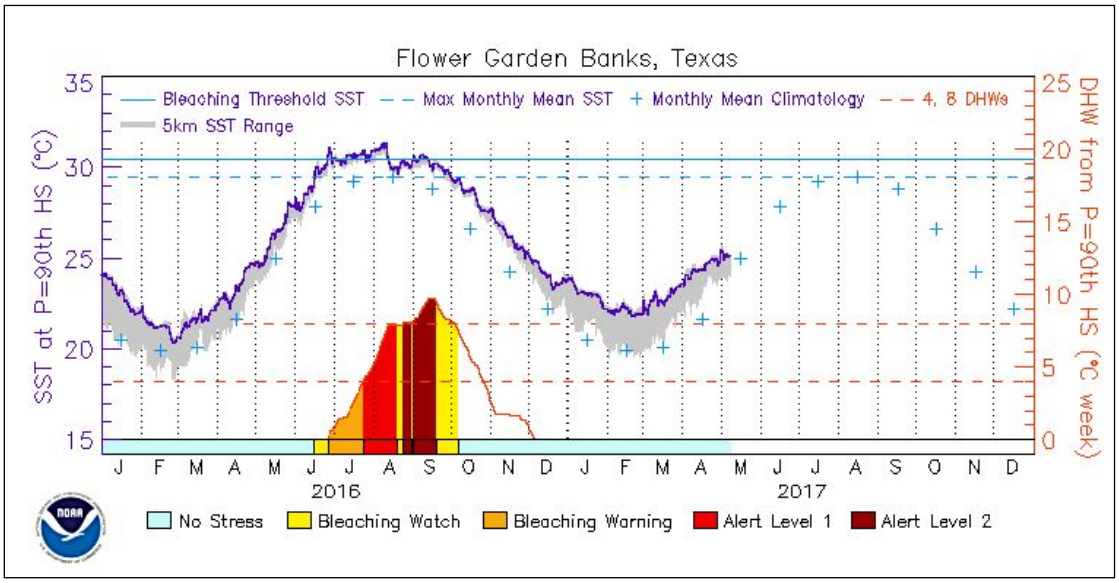


Figure 10.3. NOAA bleaching indicators for FGBNMS in 2016. (Figure Credit: NOAA Coral Reef Watch)

After assessing data taken in January 2017 at EFGB, only 4% of the coral colonies within EFGB repetitive study site photostations were still exhibiting signs of bleaching or paling, as most of the colonies had once again recruited or reestablished their zooxanthellae algae populations and recovered (Figure 10.4). Post-bleaching mortality rates were low, with 4% of colonies exhibiting partial mortality and 1.5% of colonies exhibiting full mortality. At the EFGB repetitive deep stations, less than 5% of colonies were still exhibiting signs of bleaching or paling and only 0.3% of colonies showed signs of partial mortality. No complete colony mortality was observed. WFGB repetitive stations were not photographed in January 2017 due to time and weather constraints, but similar recovery at WFGB was confirmed by diver observations.

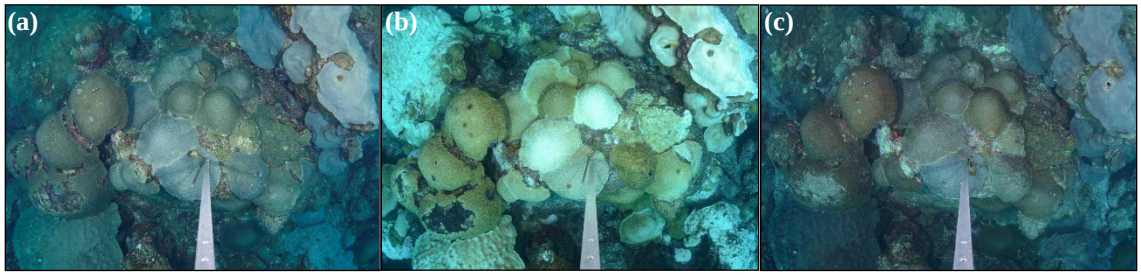


Figure 10.4. EFGB repetitive study site photostation #102 time series showing healthy coral colonies in (a) July 2016; bleached and paling corals in (b) October 2016; and recovered colonies in (c) January 2017. Camera mounted above aluminum t-frame. (Photos: NOAA/FGBNMS)

Coral Bleaching Event Discussion

Isolated bleaching events have been reported at FGBNMS in the past, but due to the location and depth of the FGBNMS, these events have not resulted in significant mortality. It is important to emphasize that long-term monitoring data is typically collected prior to when bleaching may occur (usually in the late fall); therefore, bleaching events are not always fully documented, or documented at all, in the long-term monitoring dataset. The following discussion highlights documented bleaching incidents at EFGB and WFGB; however, the extent of bleaching was most likely not fully documented, and bleaching possibly occurred in other years as well.

From 1992 to 1994, minor occurrences of coral bleaching were documented in individual colonies in repetitive photostations in 1992 (91 colonies) and 1994 (24 colonies); however, 1995 was the first extensive bleaching event documented at the banks (429 colonies bleached) coinciding with seawater temperatures in excess of 30°C for prolonged periods (Hagman and Gittings 1992; Dokken et al. 1999, 2001, 2003). *Montastraea cavernosa* and *Millepora alcicornis* were the species most affected by bleaching, but post-bleaching mortality rates were low at 0.2%–2.8% (1992 to 1995).

In 2005, elevated seawater temperatures above 30°C were recorded for 50 days, and severe bleaching was documented throughout the Caribbean (Eakin et al. 2010). A series of surveys during a post Hurricane Rita assessment at EFGB documented 10% coral bleaching (from percent cover random point count analysis) in repetitive study site photostations (Precht et al. 2008). After Hurricane Rita passed through the Gulf of Mexico, seawater temperatures at the banks declined considerably, which may have helped end the bleaching event.

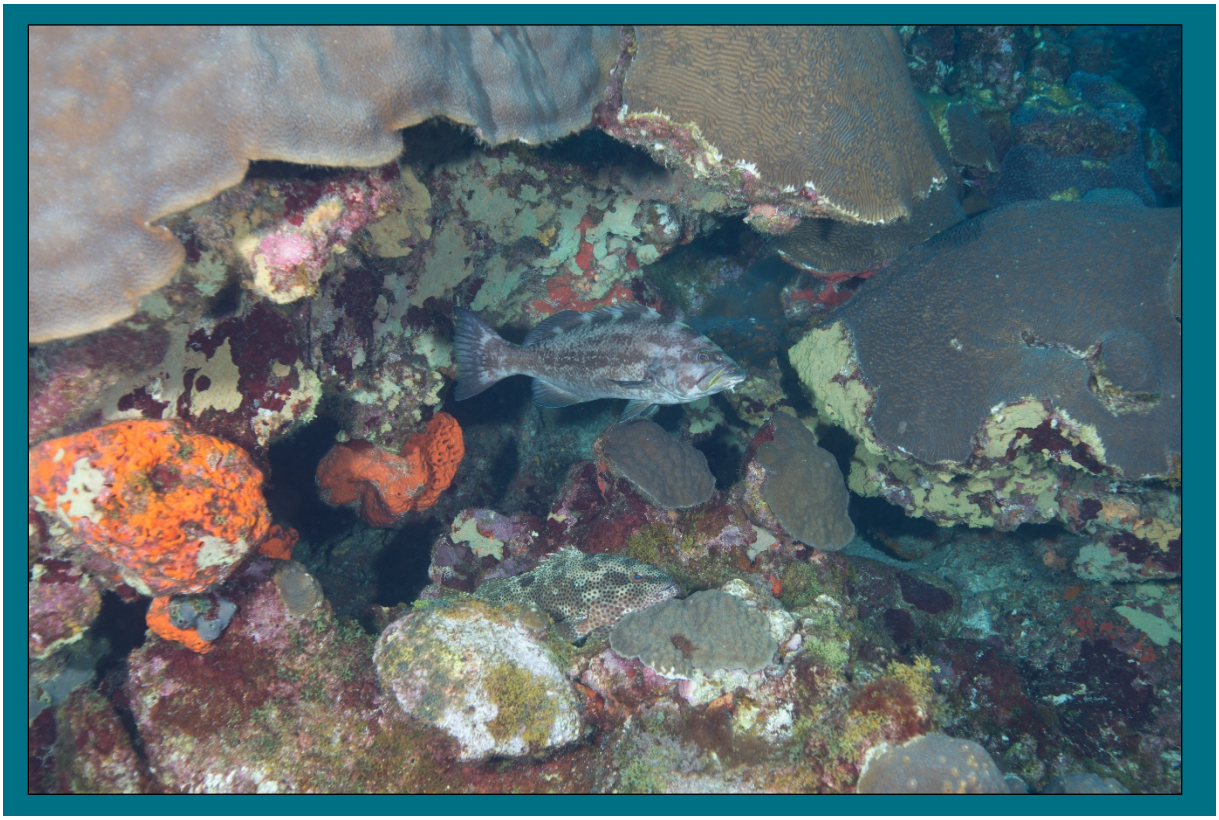
High seawater temperatures were also observed during the late summer months of 2010, exceeding the 30°C coral bleaching threshold (Johnston et al. 2013). Significant bleaching occurred throughout the region in 2010, but only minimal bleaching was observed within the long-term monitoring dataset as signs of bleaching did not manifest until late fall in 2010.

In 2016, corals around the world, most notably the Great Barrier Reef, were exposed to extreme seawater temperatures leading to a severe bleaching event. This was the third global-scale event since mass coral bleaching was first documented in the 1980s (Hughes et al. 2017). From 2014 to 2016, coral reefs were in the midst of the longest bleaching event on record, and climate model projections suggest that frequency of bleaching will continue to increase in the future (Heron et al. 2016; von Hooidonk et al. 2016).

Coral scientists agree that increased levels and frequency of coral bleaching events are correlated to elevated seawater temperatures driven by climate change. As ocean temperatures continue to rise, some corals may be more resistant and resilient than others as environmental conditions change. For research and monitoring at FGBNMS, the value of the long-term monitoring program is extremely important, as repetitive monitoring

stations allow researchers to track individual corals over time, especially during extreme events.

Chapter 11. Conclusions



Grouper hovers under a coral overhang at West Flower Garden Bank, 2016. Photo: G.P. Schmahl, NOAA/FGBNMS)

Despite global coral cover decline on most coral reefs in recent decades, mean coral cover within EFGB and WFGB long-term monitoring study sites has ranged from 40-60% for the combined 27 years of monitoring. Even with macroalgae percent cover increasing significantly after 1998 (with sustained percent cover approximately 30% in recent random transect surveys); unlike many other shallow reefs in the Caribbean region, increases in macroalgae cover have not been concomitant with reduced coral cover at EFGB or WFGB study sites.

Coral cover at repetitive photostations within study sites ranged from 62-65% in 2016, and significantly increased over time. Coral cover in repetitive photostations at deeper depths ranged from 73-76% and remained stable over time. Community shifts were documented in these stations due to increased macroalgae, following a similar pattern as the random transects.

Fish surveys conducted in 2016 indicated an abundant and diverse reef fish community within both EFGB and WFGB study sites, where biomass was uniformly distributed between large and small species. The piscivore guild had the greatest mean biomass, followed by the herbivore guild. Invasive lionfish were documented in fish surveys for the fourth consecutive year, but were first seen on the banks in 2011. Lionfish densities at EFGB and WFGB continue to remain less than other locations in the southeat U.S. and Caribbean region. Lobster densities remained low within both study sites. Sea urchin density within the WFGB study site was significantly higher than at EFGB.

Water column temperatures warmed quickly in 2016, exceeding the 30^{o}C bleaching threshold in July and August, leading to coral bleaching that became visible starting in September of 2016. Salinity declines in July that resulted from unusually large storm and runoff events may have been a contributing factor to the localized mortality event at EFGB. All nutrient samples taken quarterly in 2016 were below detectable limits and carbonate chemistry indicated that the area surrounding EFGB and WFGB acted as a net CO_2 sink.

One of the most apparent changes since monitoring began in 1989 is the significant increase in macroalgae percent cover. The reason for increased macroalgae in both random transects and repetitive photostations is not well defined, as herbivorous fish have not declined as macroalgae increased and most nutrients from quarterly water samples are below detectable limits. Although long-spined sea urchin populations (important grazers on coral reefs) succumbed to a die-off in 1983, populations have slowly been increasing.

The ongoing monitoring program at EFGB and WFGB is critical to ensure data are available to understand and distinguish the drivers of ecosystem variation in the northern Gulf of Mexico (Karnauskas et al. 2015). The FGBNMS is an ideal sentinel site for the detection and tracking of conditions that are changing because of natural events and human threats. These are places where government, academic and citizen scientists join,

align, and focus capabilities for monitoring, research, data analysis, education, and outreach to raise awareness and inform our actions in response to pressing issues of concern.

Until recently, it was apparent that problems affecting coral reefs throughout the southeast U.S. and Caribbean region, including land-based sources of pollution and bleaching, have not had a major impact at the banks (ONMS 2008), partially due to their relative isolation and depth. However, in 2016, evidence of increased macroalgae cover, effects from increasing seawater temperatures, an isolated but severe coral and invertebrate mortality event, and invasive species, are reasons for concern and increased vigilance. All are signs that intensifying regional environmental stressors may be reducing the protection that the isolation of the banks might have previously afforded. Continued monitoring and valuable historic data will help document this system's response to these changes, enable effective management, and inform research on the dynamics of this exceptional and vital ecosystem.

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Glossary of 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
CTD – Conductivity, temperature, and depth
DIC – Total dissolved CO_2
DO – Dissolved oxygen
EFGB – East Flower Garden Bank
EPA – Environmental Protection Agency
FGBNMS – Flower Garden Banks National Marine Sanctuary
GPS – Global positioning system
MMS – Minerals Management Service
NOAA – National Oceanic and Atmospheric Administration
pCO_2 – CO_2 partial pressure
TABS – Texas Automated Buoy System
TAMU – Texas A&M University
TAMU-CC – Texas A&M University Corpus Christi
TAMUG – Texas A&M University Galveston
TKN – Total Kjeldahl Nitrogen
QA/QC – Quality assurance/quality control
WFGB – West Flower Garden Bank

AMERICA'S UNDERWATER TREASURES