Office of National Marine Sanctuaries
National Oceanic and Atmospheric Administration

Marine Conservation Science Series

LONG-TERM MONITORING AT EAST AND WEST FLOWER GARDEN BANKS: 2017 ANNUAL REPORT

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Cover Photo:
A giant barrel sponge (*Xestospongia muta*) within the East Flower Garden Bank long-term monitoring study site in 2017. (Photo: G.P. Schmahl, NOAA/FGBNMS)

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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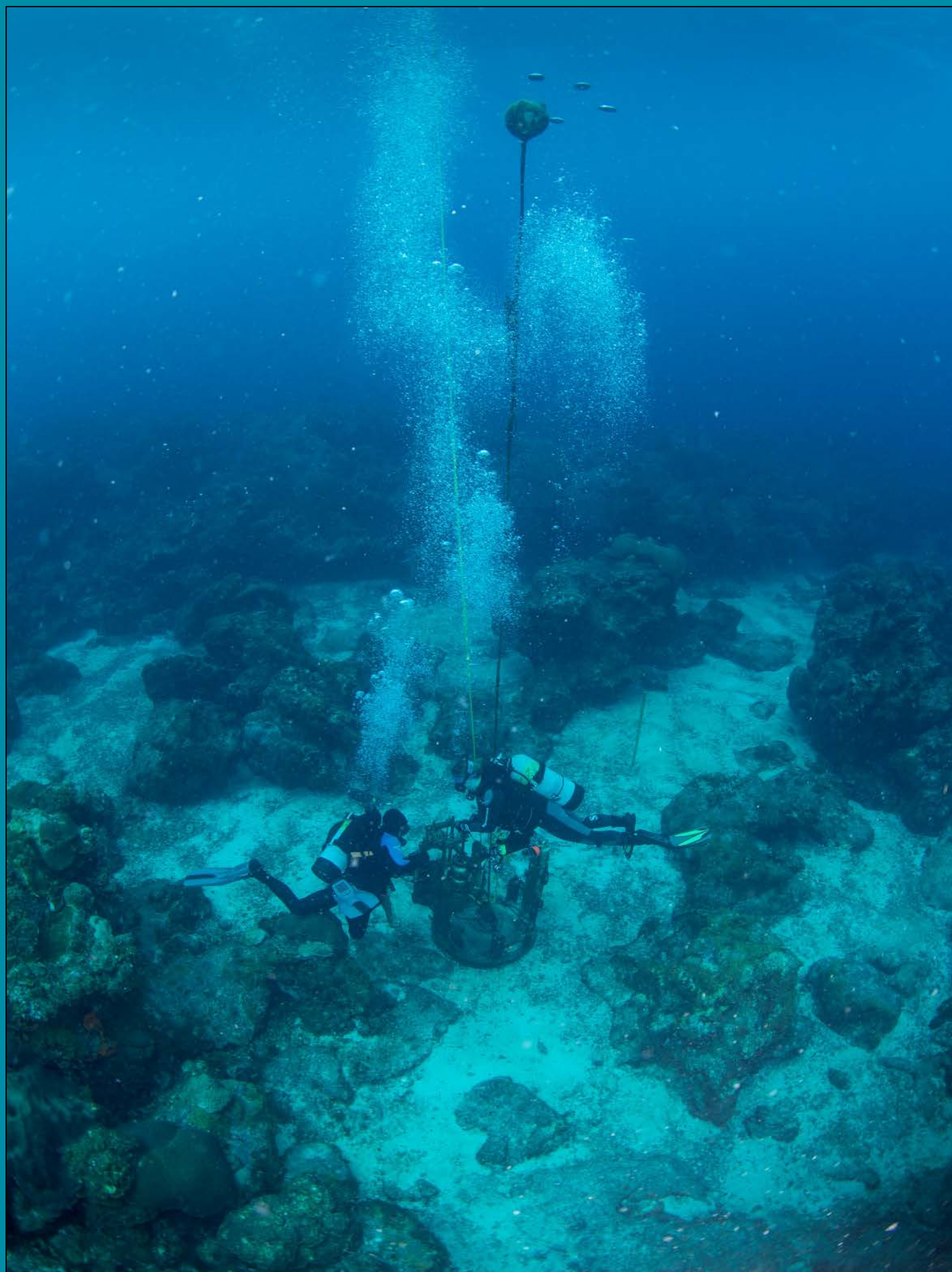
Abstract

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 2017. East Flower Garden Bank and West Flower Garden Bank are part of Flower Garden Banks National Marine Sanctuary and located in the northwestern Gulf of Mexico. The annual long-term monitoring program 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 2017, mean coral cover was 51.46% within the East Flower Garden Bank study site and 56.36% within the West Flower Garden Bank study site. Mean macroalgae cover was 26.75% within the East Flower Garden Bank study site and 22.64% within the West Flower Garden Bank study site. Percent coral cover within repetitive study site photostations and at deep repetitive photostations ranged from 62–72%. 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 2017 indicated an abundant and diverse reef fish community, predominated by the families Labridae and Pomacentridae. Water column temperatures cooled after Hurricane Harvey passed through the Gulf of Mexico in 2017, and coral bleaching at both banks was less than 2%. While a portion of EFGB was affected by a localized mortality event in July of 2016, and both banks were impacted by coral bleaching in the fall of 2016, coral cover within long-term monitoring study sites did not significantly decline in 2017, and no negative impacts to the reef were observed after Hurricane Harvey.

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



Divers inspect water quality instruments at East Flower Garden Bank in 2017. (Photo: G.P. Schmahl, NOAA/FGBNMS)

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. While a portion of EFGB was affected by a localized mortality event in July of 2016, and both banks were impacted by coral bleaching in the fall of 2016, coral cover within long-term monitoring study sites did not significantly decline in 2017, and no negative impacts to the reef were observed after Hurricane Harvey.

This report summarizes fish and benthic community observations and water quality data from 2017, as well as historical data resulting from 28 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 to examine fish population composition within designated study sites at EFGB and WFGB. The annual long-term monitoring program is 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 2017 are described below.

Benthic Community – Percent Cover:

- Percent cover of the benthic community was dominated by coral within EFGB (51.46%) and WFGB (56.36%) study sites.
- *Orbicella franksi* was the principal component of mean coral cover within EFGB (24.71%) and WFGB (29.20%) study sites.
- *Porites astreoides* was the second greatest contributor to mean coral cover within the EFGB study site (6.93%), while *Pseudodiploria strigosa* was the second greatest contributor to mean coral cover within the WFGB study site (9.73%).
- The *Orbicella annularis* species complex including *Orbicella franksi*, *Orbicella faveolata*, and *Orbicella annularis* (all of which are listed as threatened species under the Endangered Species Act) made up 56.57% of the observed coral species within EFGB study sites and 61.91% of the observed coral species within WFGB study sites.
- Macroalgae mean cover within the EFGB study site (26.75%) and the WFGB study site (22.64%) has increased significantly since 1999, and averaged approximately 30% since 2009.
- Mean coral cover in repetitive photostations was 62.55% at EFGB and 61.67% at WFGB, with *Orbicella franksi* as the predominant coral species followed by *Pseudodiploria strigosa.*
- Coral bleaching was minimal in August 2017, and the majority of colonies in repetitive photostations had recovered from the 2016 bleaching event.
- In the 32–40 m depth range, repetitive deep photostation mean coral cover was 68.34% at EFGB and 72.46% at WFGB, and twelve new repetitive deep photostations were installed at EFGB and WFGB in 2017.

- Coral species composition changed slightly with depth, with *Orbicella franksi* (38.49%) and *Montastraea cavernosa* (10.11%) being the most abundant species in photostations in the 32–40 m depth range at both banks combined.
- Mean coral cover was significantly higher in repetitive deep photostations (70.40%) compared to the shallower repetitive study site photostations (62.12%) at both banks combined.

Coral Demographics:

- Due to the approach of Hurricane Harvey in the Gulf of Mexico, not all coral demographic surveys were completed at WFGB in 2017.
- Sixteen coral species were documented in EFGB study site surveys and 15 within WFGB study site surveys.
- Overall mean coral density was 6.41 corals/m^2 within the EFGB study site and 5.83 corals/m^2 within the WFGB study site.
- While *Porites astreoides* was the most abundant species in study site surveys, *Orbicella franksi* colonies covered the greatest total area within the EFGB study site surveys and *Pseudodiploria strigosa* colonies covered the greatest total area in the WFGB study site surveys.
- *Agaricia agaricites* was the most abundant coral recruit species observed within EFGB and WFGB study sites followed by *Porites astreoides*.

Key Species – Sea Urchin and Lobster Surveys:

- Sea urchin and lobster surveys were not completed at WFGB in 2017 due to the approach of Hurricane Harvey in the Gulf of Mexico.
- Long-spined sea urchin (*Diadema antillarum*) mean populations within the EFGB study site have remained low (0.83 per 100 m^2) since monitoring surveys were first conducted in 2004, but densities within the WFGB study site (10.18 per 100 m^2) have been significantly higher than EFGB through 2016.
- Since surveys began in 2004, lobster counts have ranged from zero to two individuals per 100 m^2 within study sites.

Fish Community:

- Labridae (wrasses and parrotfish) and Pomacentridae (damselfish) were the predominant fish families observed within the study sites at both banks.
- Bonnetmouth (*Emmelichthyops atlanticus*) and Mackerel Scad (*Decapterus macarellus*) were the most abundant species within the study sites at both banks in 2017; however, large schools of these fish can be ephemeral.
- Mean fish density was greater within the EFGB study site, but mean fish biomass was greater within the WFGB 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.

- Mean lionfish density (individuals/100 $m^2 \pm SE$) was 0.05 ± 0.03 within the EFGB study site and 0.17 ± 0.07 within the WFGB study site (sighting frequency 8.33% and 20.83%, respectively).

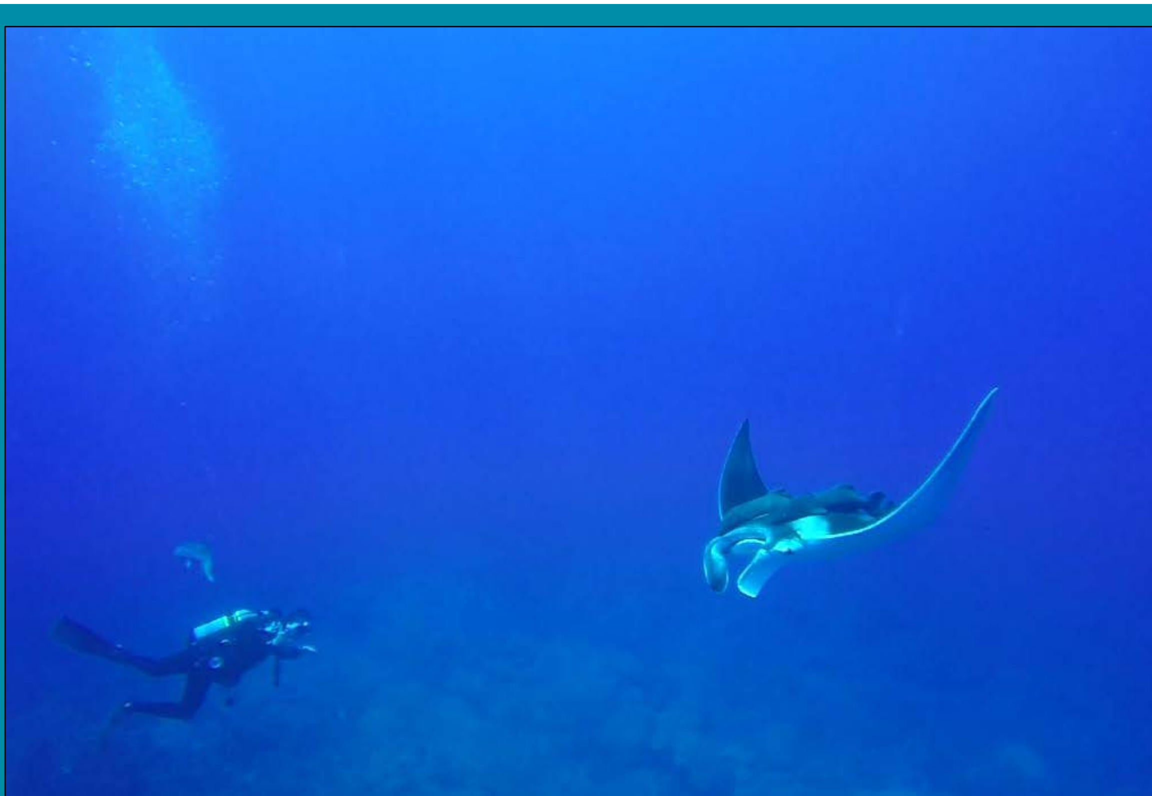
Water Quality:

- At a 24 m depth, mean seawater temperatures at EFGB ranged from 20.92^{o}C to 29.86^{o}C and 21.41^{o}C to 30.10^{o}C at WFGB.
- Daily mean salinity levels at the 24 m depth averaged 36 psu in 2017.
- 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 FGBNMS acted as a net CO_2 sink.
- No negative impacts to the reef were observed after Hurricane Harvey.

Update on the 2016 EFGB Mortality Event:

- In July 2016, a localized mortality event occurred at EFGB, affecting coral and other invertebrates on the shallow coral cap.
- Based on survey estimates a year after the event, percent live coral cover ranged from 12–20% in the center of the affected area, differing dramatically from baseline EFGB benthic coral cover conditions.
- A mini-symposium was held in Galveston, Texas in February 2017 to bring together scientists and collaborators from a wide array of disciplines to discuss potential causes of the event.
- While the exact cause is uncertain, decreased salinity, high seawater temperatures, and low oxygen levels may have been contributing factors to the event.

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



A manta ray (*Manta cf. birostris*) swims through the long-term monitoring study site at East Flower Garden Bank in 2017. (Photo: Brian Zelenke, BOEM)

Habitat Description

The coral reef-capped East Flower Garden Bank (EFGB) and West Flower Garden Bank (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 within the photic zone where conditions are ideal for colonization by species of corals, algae, invertebrates, and fish, similar to coral reef species 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 coral 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).

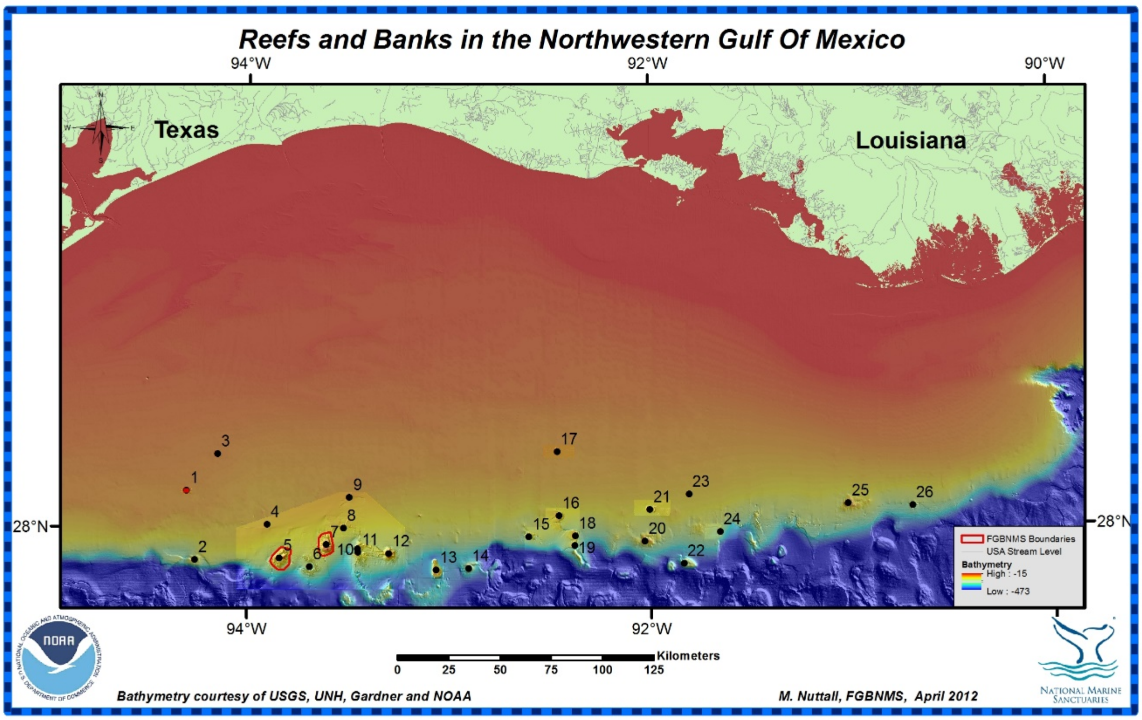


Figure 1.1. Map of EFGB, WFGB, and Stetson Bank (outlined in red) in relation to the Texas-Louisiana continental shelf and other topographic features of the northwestern Gulf of Mexico. Numbered banks include: 1. Stetson Bank, 2. Applebaum Bank, 3. Claypile Bank, 4. Coffee Lump Bank, 5. West Flower Garden 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]) has supported monitoring at EFGB and WFGB to collect baseline data and determine if the reefs are 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). 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.

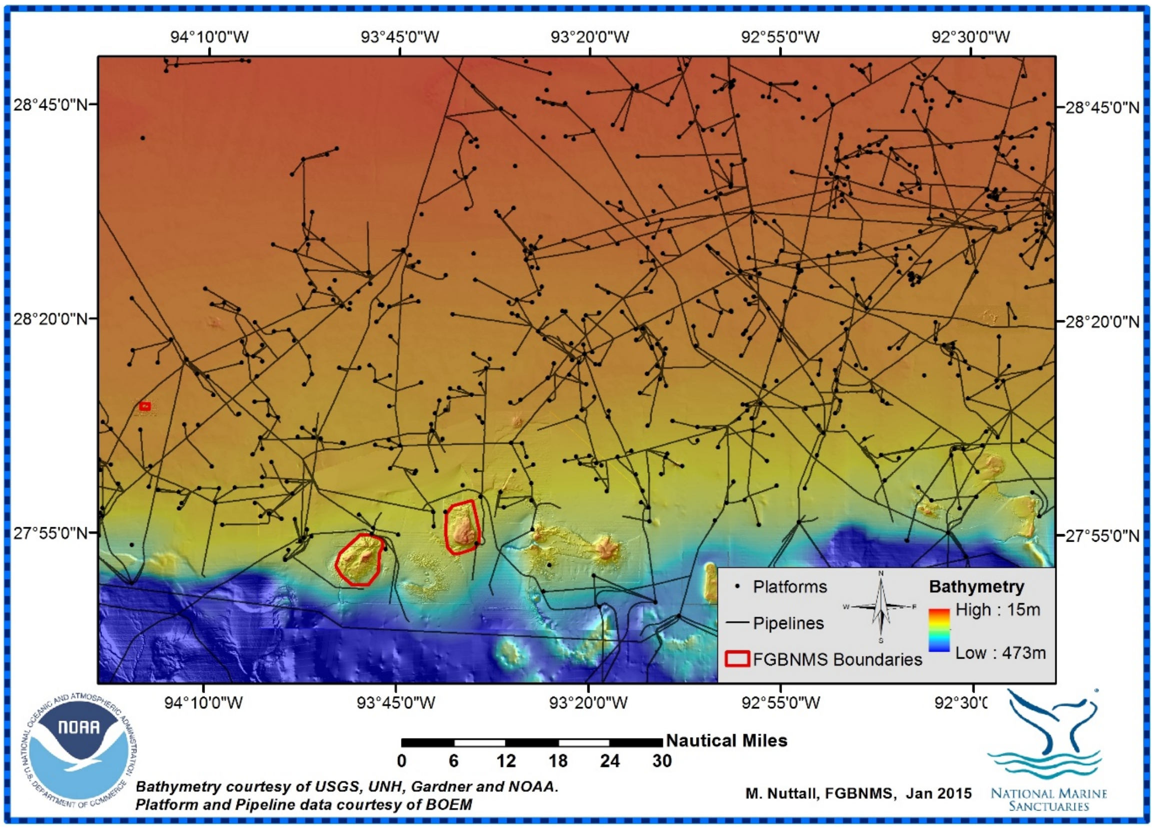


Figure 1.2. Map of oil and gas platforms and pipelines near EFGB, WFGB, and surrounding banks. FGBNMS boundaries outlined in red.

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, and to evaluate 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 five objectives and subsequent indicators of the FGBNMS LTM program include:

- Monitor and evaluate environmental changes and variability in abundances of reef-associated organisms across multiple time scales.
    - Indicators: 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.
    - Indicators: Bleaching, disease, and invasive species.
- Provide a resource to facilitate adaptive management of activities impacting reef – related resources.
    - Indicators: Maintain baseline data and image archive of damage to resources if observed.
- Identify and monitor key species that may be indicative of reef and ecosystem health.
    - Indicators: Trends in sea urchin and lobster surveys.
- Provide a consistent and timely source of data monitoring environmental conditions and the status of living marine sanctuary resources.
    - Indicators: Published peer reviewed annual reports.

Long-Term Monitoring Program Components

The LTM program was designed to assess the health of the coral reefs, 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 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 reef fish visual census surveys assess community structure of coral reef fishes;
- Long-spined sea urchin (*Diadema antillarum*) and lobster (*Panulirus argus*, and *Panulirus guttatus*) 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 in 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 buoy anchors (mooring buoy#2 at EFGB and mooring buoy#5 at WFGB) have been established near the study site centers to facilitate field operations (Table 1.1; Figure 1.3 and 1.4).

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° 52.509 N	-93° 48.900 W	20.7

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"). The perimeter and crosshairs divide each site into four 50 m x 50 m quadrants (Figure 1.5 and 1.6). The lines aid divers in orientation and navigation using maps (Figure 1.5 and 1.6) to find photostations, and allow for efficient completion of monitoring tasks.

For sampling at deeper depths, permanent repetitive photostations are located outside the study sites, ranging in depth from 24–40 m. Twenty-three repetitive deep photostations at EFGB are located outside the study site (east of buoy#2), ranging in depth from 32–40 m. Twenty-four repetitive deep photostations are located outside the WFGB study site (north of buoy#2), ranging in depth from 24–38 m.

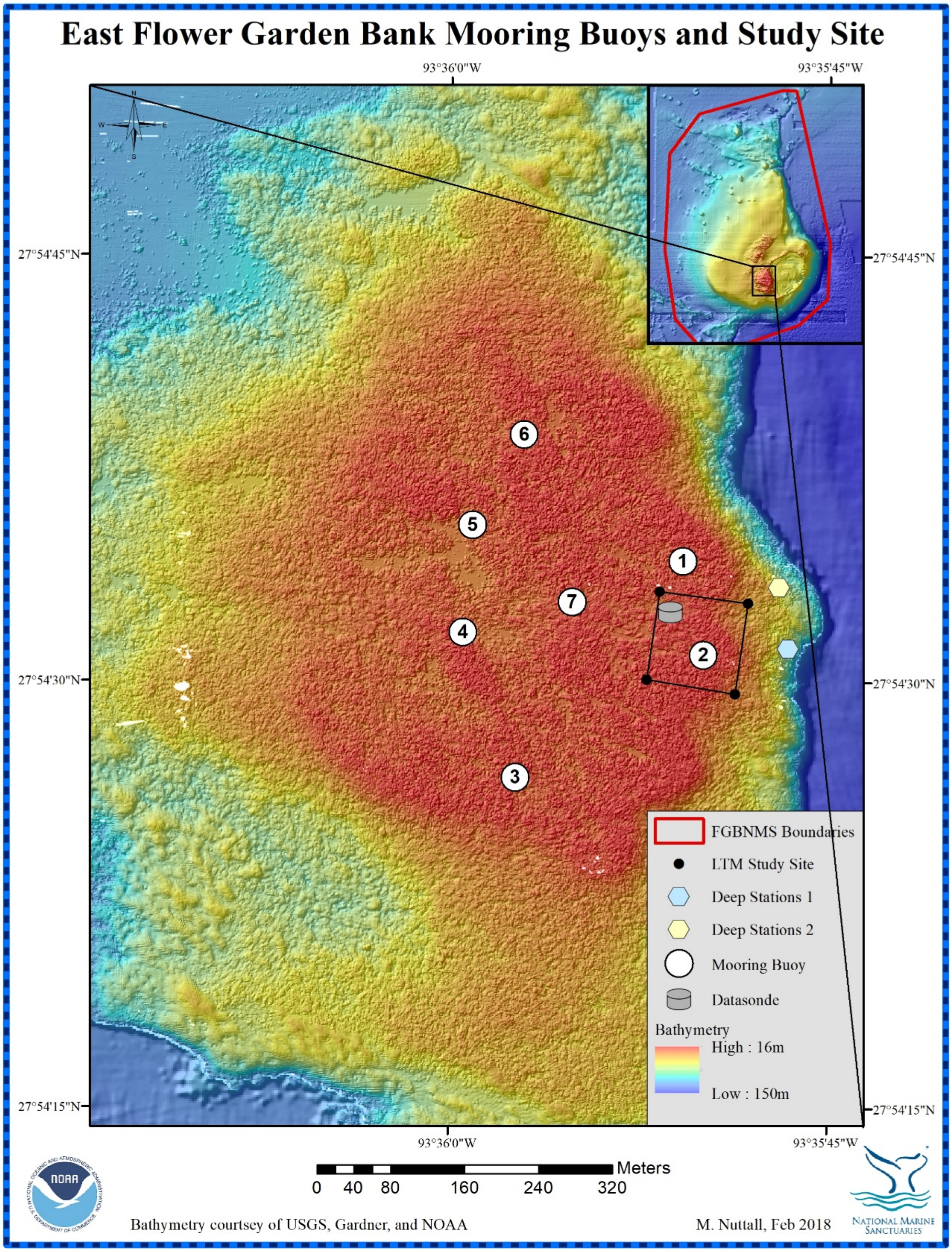


Figure 1.3. Bathymetric map of EFGB with long-term monitoring (LTM) study site, mooring buoy, water quality datasonde, and repetitive deep photostation locations.

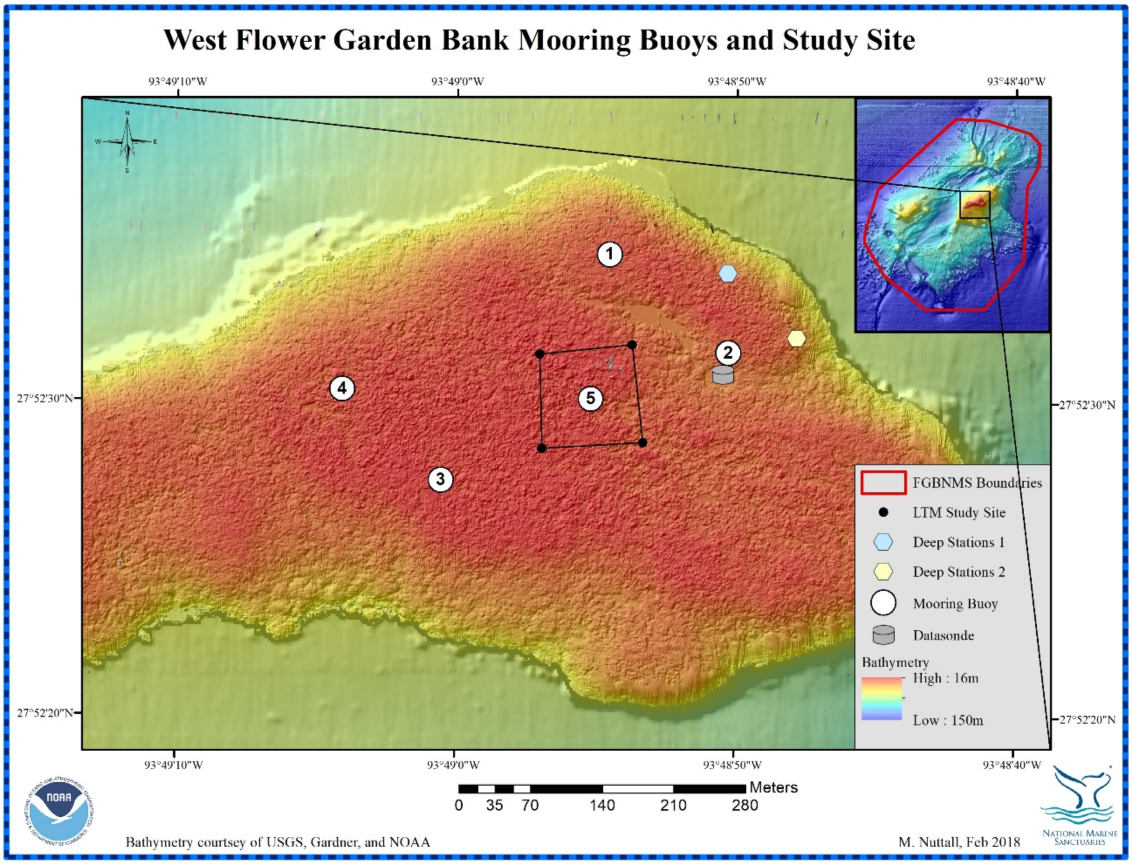


Figure 1.4. Bathymetric map of WFGB with long-term monitoring (LTM) study site, mooring buoy, water quality datasonde, and repetitive deep photostation locations.

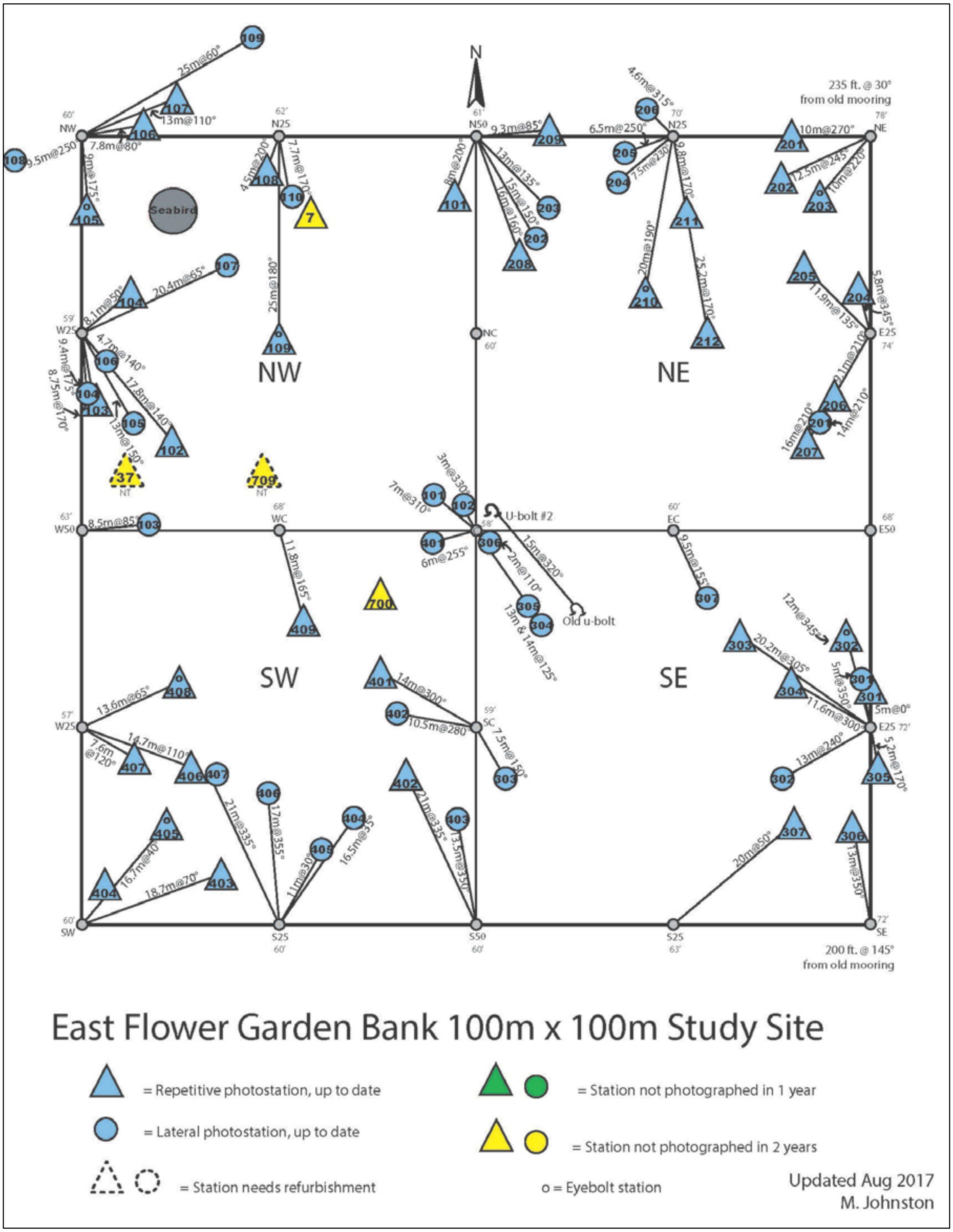


Figure 1.5. Detailed map of the EFGB study site and photostations in 2017. Permanent study site corner markers and eye-bolts installed at 25 m intervals along each perimeter and crosshair line. Reference lines are used to mark the north-south and east-west crosshairs. Establishment of the perimeter and crosshairs divide each site into four 50 m x 50 m quadrants.

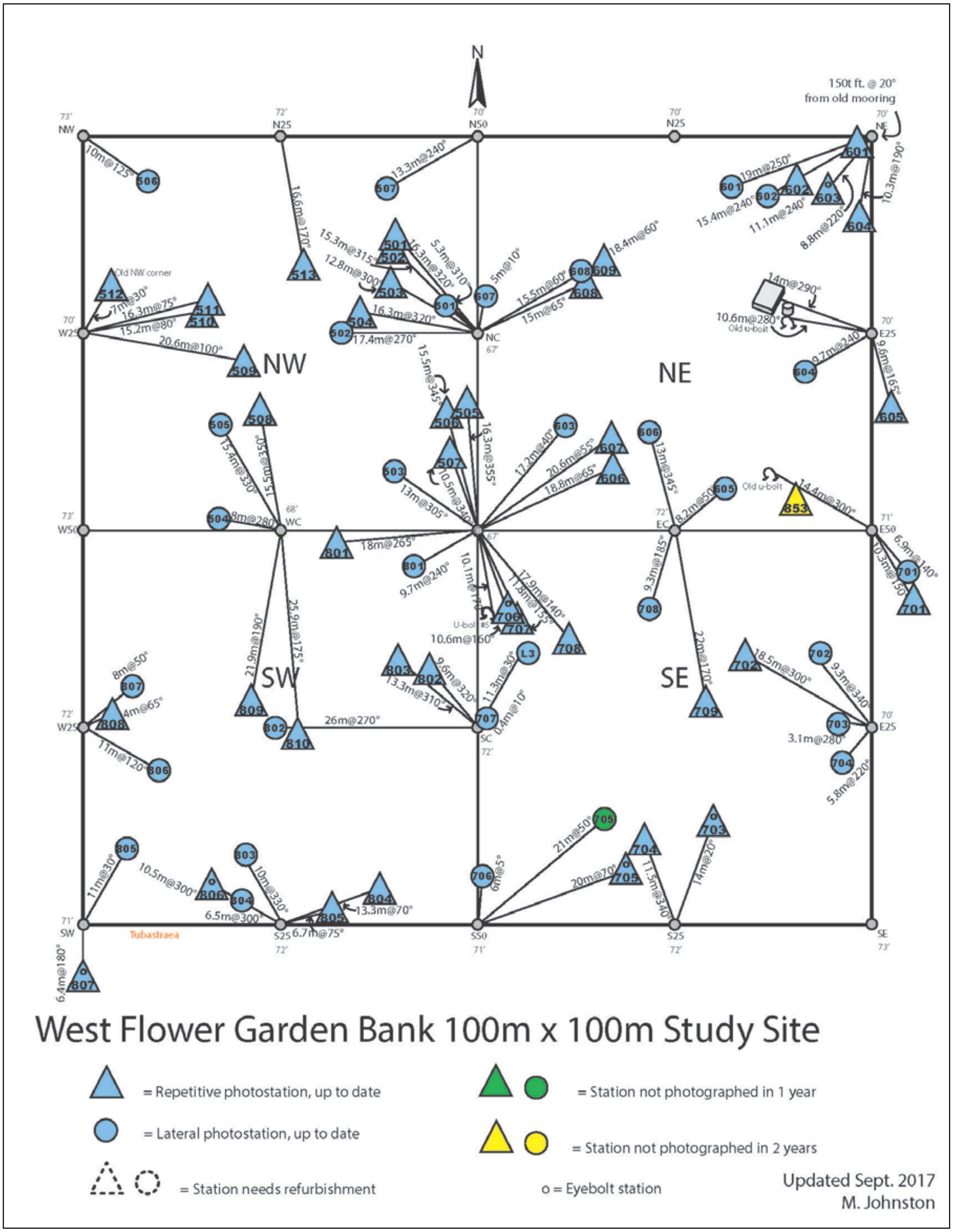


Figure 1.6. Detailed map of the WFGB study site and photostations in 2017. Permanent study site corner markers and eye-bolts installed at 25 m intervals along each perimeter and crosshair line. Reference lines are used to mark the north-south and east-west crosshairs. Establishment of the perimeter and crosshairs divide each site into four 50 m x 50 m quadrants.

Field Operations

Long-term monitoring data were collected within the study sites at EFGB and WFGB in 2017 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.

Table 1.2. Monitoring and response cruises completed at EFGB and WFGB in 2017.

Date	Cruise and Tasks Completed
01/31/2017 – 02/02/2017	Water Quality Cruise: Instrument download and water sample collection; EFGB repetitive stations photographed to monitor bleaching/recovery of coral colonies from bleaching event in 2016.
05/07/2017 – 05/08/2017	Water Quality Cruise: Instrument download and water sample collection; deployed ocean acidification array in EFGB study site
07/25/2017 – 07/27/2017	Repetitive Deep Photostation Installation: Ten additional repetitive deep photostations installed at EFGB and WFGB
08/01/2017 – 08/03/2017	Long-Term Monitoring Cruise: EFGB study site annual monitoring (cut short due to weather)
08/14/2017 – 08/16/2017	Long-Term Monitoring Cruise: EFGB study site annual monitoring
08/21/2017 – 08/23/2017	Long-Term Monitoring Cruise: WFGB study site annual monitoring and water sample collection (cut short due to approach of Hurricane Harvey)
09/16/2017 – 09/17/2017	Post Hurricane Harvey Assessment Cruise: Assessment of reef condition completed on *M/V Fling*
10/30/2017 – 10/31/2017	Water Quality Cruise: Instrument download and water sample collection; ADCP deployed at EFGB

Currents were problematic during fieldwork at the EFGB study site from August 1 to 3, 2017 (Table 1.2). Strong surface currents (>1.5 kt) resulted in difficulties with mooring installation, and night dives were not conducted due to unsafe conditions. Heavy rain, lightening, and winds made dive operations unsafe on August 3, 2017, postponing the remainder of the fieldwork. Tasks not completed within the EFGB study site due to unsuitable weather conditions from August 1 to 3, 2017 were accomplished during August 14 to 16, 2017. The annual coral spawn event occurred the evening of Aug. 14, 2017. While conducting nighttime SCUBA operations, images and video were captured of the coral spawn.

Annual fieldwork within the WFGB study site was conducted August 21 to 23, 2017 (Table 1.2). On August 23, 2017, weather reports about the formation of Hurricane Harvey in the Gulf of Mexico were relayed to scientists on the R/V *Manta*. Based on the forecasted hurricane track, remaining tasks including urchin and lobster surveys and coral demographic surveys were not completed due to the approaching storm. The R/V *Manta* returned to the Texas A&M University Galveston campus dock on August 24, 2017 and began hurricane preparations immediately. Due to the R/V *Manta* being called into service by NOAA's National Ocean Service Response team to survey the Houston ship channel for Hurricane Harvey impacts and debris, an additional cruise was completed on the *M/V Fling* to assess the condition of the reef after Hurricane Harvey.

Quarterly water quality cruises, to exchange instruments on the seafloors and collect water samples, were conducted during favorable weather windows in the winter, spring, summer, and fall seasons.

Chapter 2. Random Transects

NOAA diver with camera and strobes mounted on an aluminum t-frame takes random transect photographs within the EFGB 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 randomly located 8-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 as well as changes over time in each study site.

Random Transect Methods

Random Transect Field Methods

Sixteen non-overlapping random transects within each study site were completed in 2017. 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. 2017a.

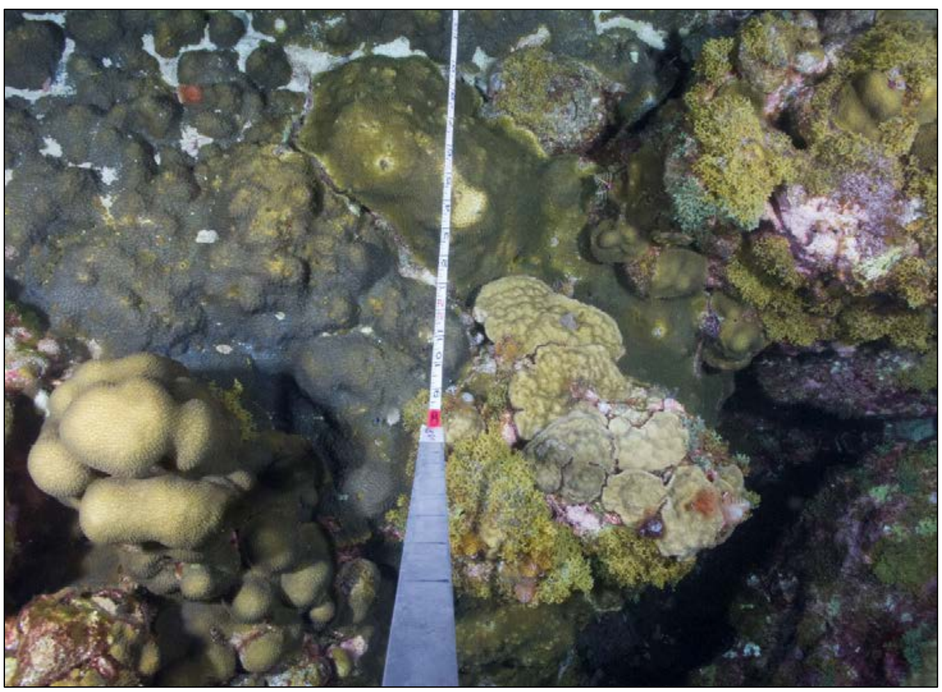


Figure 2.1. Photo taken at marked interval along random transect with camera mounted to aluminum t-frame within the EFGB study site in 2017. (Photo: John Embesi, NOAA/FGBNMS)

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 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, and rubble. Abiotic features (photostation tags, tape measures, scientific equipment) and points with no data (shadows) 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* spp.

The coverages of coral bleaching, paling, concentrated and isolated fish biting, and mortality were also recorded, providing additional metadata 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 2012). 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). 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 et al. 2014).

Significant differences in coral species composition between bank study sites was tested using PERMANOVA 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. Significant dissimilarities in diversity indices was tested using analysis of similarity (ANOSIM) (Clarke et al. 2014) on square-root transformed data with Euclidean distance similarity matrices.

Functional group means by year and bank study sites for historical random transect mean percent cover data (1992 to 2017) 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 et al. 2014).

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 within the EFGB study site was 51.46% ± 2.77. Mean sponge cover was 2.23% ± 0.25, macroalgae cover was 26.75% ± 1.90, CTB cover was 18.34% ± 1.33, and other cover was 1.22%± 0.37 (Figure 2.2). Within the WFGB study site, mean coral cover was 56.36% ± 2.30. Mean sponge cover was 1.02% ± 0.15, macroalgae cover was 22.64% ± 1.59, CTB cover was 18.27% ± 1.12, , and other cover was 1.72% ± 0.43 (Figure 2.2).

PERMANOVA analysis comparing functional groups revealed no significant differences, suggesting that EFGB and WFGB study sites were similar in benthic community composition in 2017.

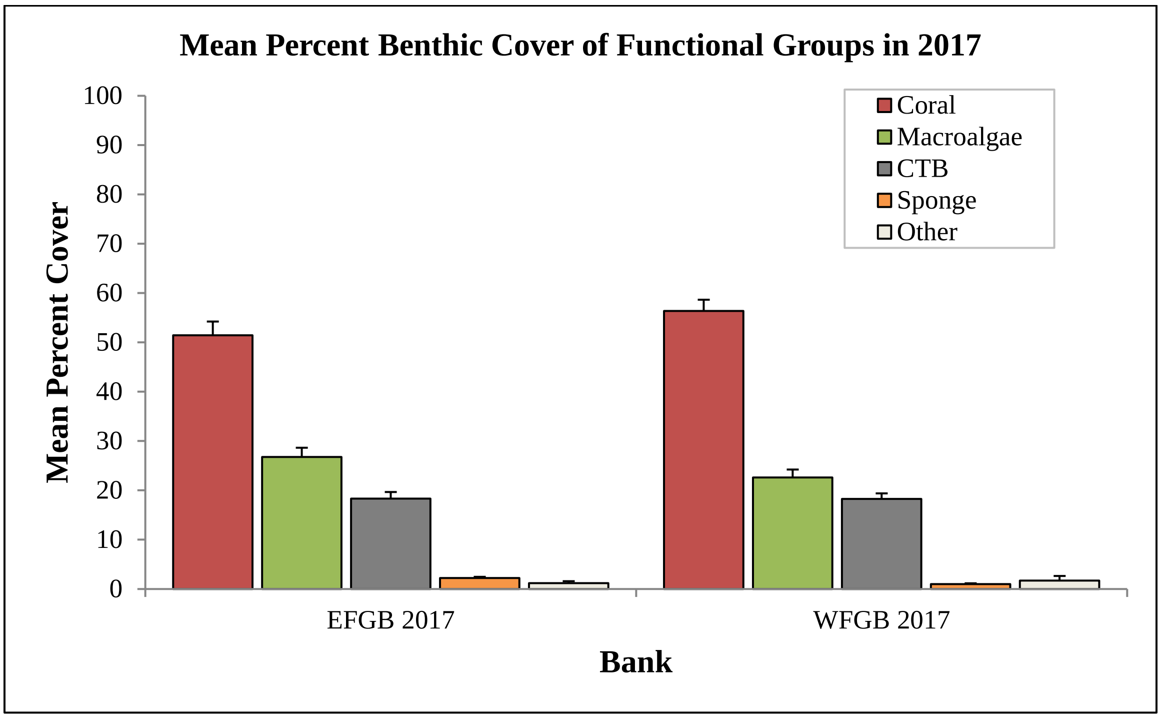


Figure 2.2. Mean percent benthic cover + SE from random transect functional groups within EFGB and WFGB study sites in 2017.

Less than 1% of the coral cover analyzed within the EFGB and WFGB study sites showed incidences of bleaching and paling in August 2017. 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). In addition, less than 0.5% of fish biting and signs of mortality were observed in mean coral cover data.

Sixteen species of coral were observed within the EFGB study site and 13 species of coral were observed in the WFGB study site in 2017 (Figure 2.3). *Orbicella franksi* was the most abundant coral species observed at EFGB (24.71% ± 3.28) and WFGB 29.20% ± 2.77). *Porites astreoides* was the second most abundant species at EFGB (6.93% ± 1. 01), while *Pseudodiploria strigosa* was the second most abundant species at WFGB (9.73% ± 2.13) (Figure 2.3).

The *Orbicella annularis* species complex including *Orbicella franksi*, *Orbicella faveolata*, and *Orbicella annularis* (listed as threatened species under the Endangered Species Act) made up 56.57% of the observed coral cover within the EFGB study site and 61.91% of the observed coral cover within the WFGB study site. PERMANOVA analysis revealed no significant differences in coral species composition between bank study sites.

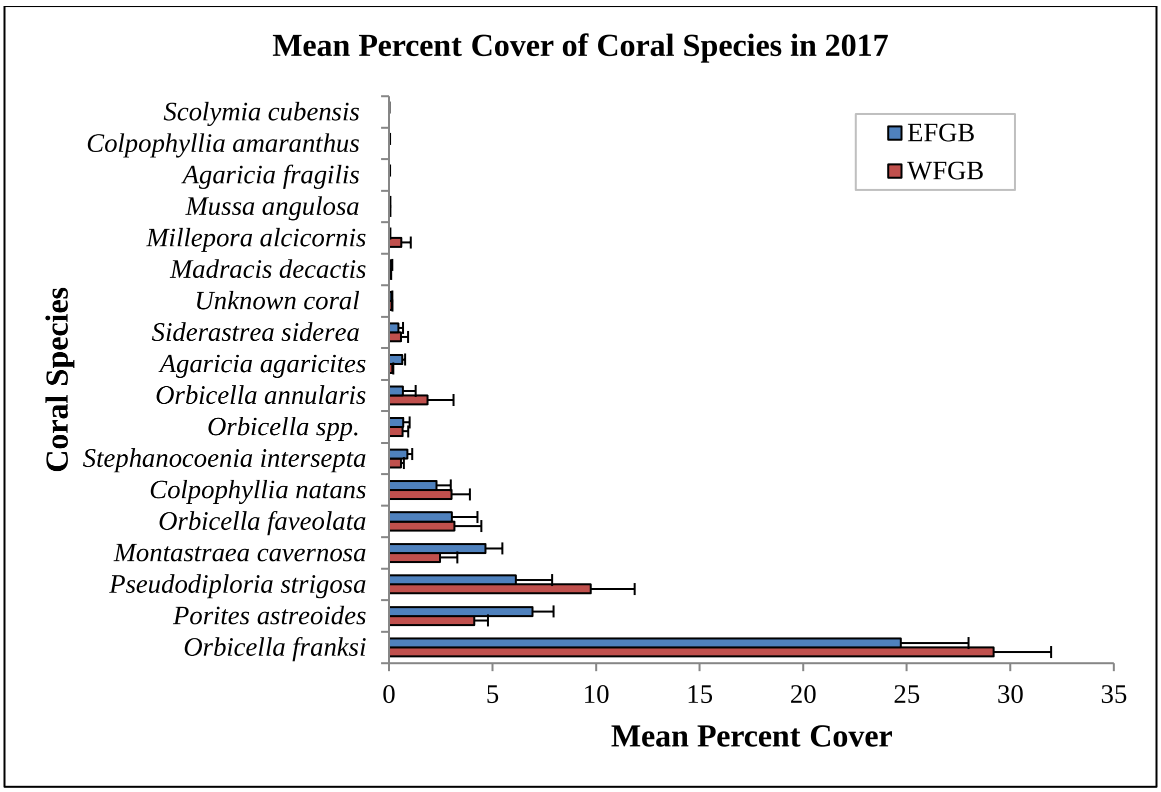


Figure 2.3. Mean percent cover + SE of observed coral species from random transects within EFGB and WFGB study sites in 2017.

Coral species diversity measures were averaged for each study site in 2017 (Table 2.1). Significant dissimilarities were found in ANOSIM results comparing diversity measures between communities (Global R=0.09, p=4.3%), suggesting that the EFGB study site was more diverse than the WFGB study site.

Table 2.1. Mean coral species diversity measures ± SE within EFGB and WFGB study sites in 2017.

Random Transect Coral Diversity Measures	EFGB	WFGB
Margalef's Species Richness (d)	2.03 ± 0.14	1.90 ± 0.06
Pielou's Evenness (J')	0.65 ± 0.03	0.60 ± 0.03
Shannon Diversity (H'(loge))	1.42 ± 0.09	1.28 ± 0.07

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 2017. 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 2017) (Gittings et al. 1992; CSA 1996; Dokken et al. 1999, 2003; Precht et al. 2006; Zimmer et al. 2010; Johnston et al. 2013, 2015, 2017a, 2017b). 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 2017 ranged from 40–64% in the EFGB study site and 37–66% in the WFGB study site, significantly increasing in both study sites over the time period ($\tau=0.29$, $p<0.042$ and $\tau=0.63$, $p<0.001$, 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* (8.46%) for both banks combined (Figure 2.5). The separate species of the *Orbicella annularis* species group complex have been distinguished in recent years, but were grouped during historical data collection methods.

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 in EFGB ($\tau=-7.15$, $p<0.002$) and WFGB ($\tau=-8.45$, $p<0.002$) study sites, allowing macroalgae to colonize available substrate and not out-compete coral. Macroalgae significantly increased within EFGB ($\tau=0.64$, $p<0.008$) and WFGB ($\tau=0.55$, $p<0.001$) study sites while CTB significantly decreased within EFGB ($\tau=-0.49$, $p<0.001$) and WFGB ($\tau=-0.50$, $p<0.001$) study sites from 1992 to 2017 (Figure 2.4).

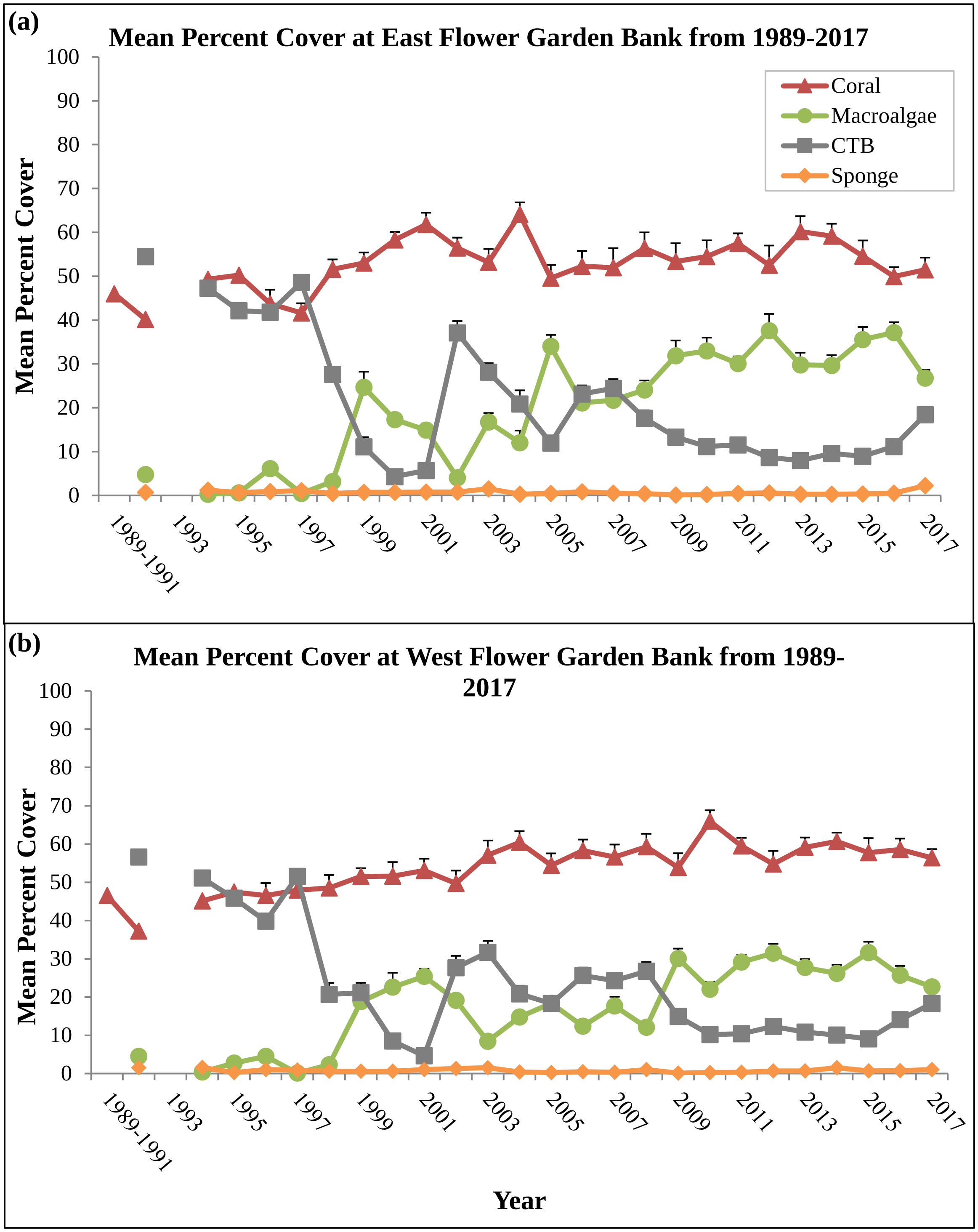


Figure 2.4. Mean percent benthic cover +SE from random transect functional groups within (a) EFGB and (b) WFGB study sites from 1989 to 2017.

No mean percent cover data were reported in 1993. Data for 1989 to 1991 are 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 2016 (Johnston et al. 2013, 2015, 2017a, 2017b).

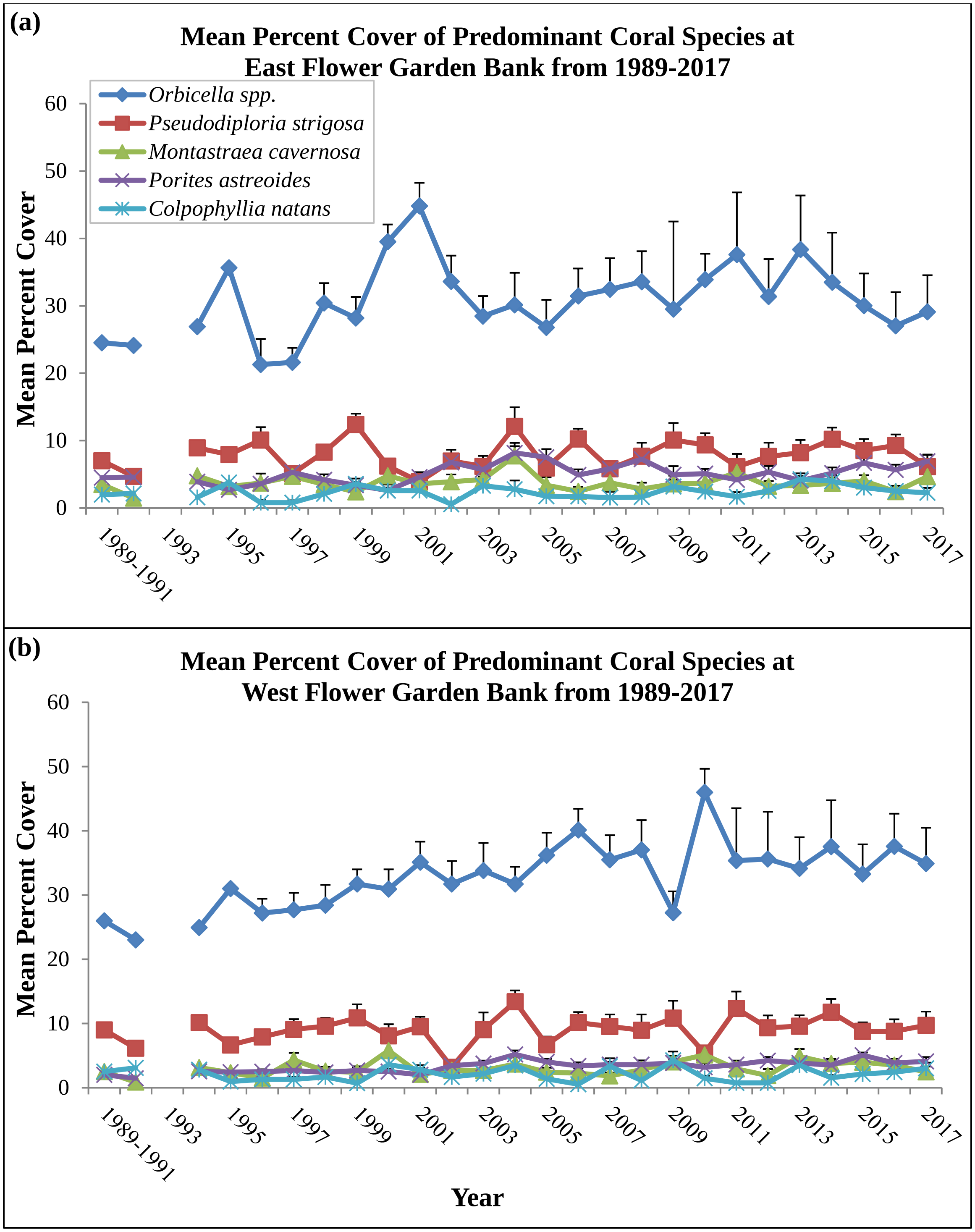


Figure 2.5. Mean percent cover of predominant coral species + S E within (a) EFGB and (b) WFGB study sites from 1989 to 2017. *Orbicella* species combines *Orbicella franksi*, *Orbicella faveolata*, and *Orbicella annularis* for historical data comparison.

No mean percent cover data were reported in 1993. Data for 1989 to 1991 are 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 2016 (Johnston et al. 2013, 2015, 2017a, 2017b).

For available yearly mean benthic percent cover data (1992 to 2017), 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: 2000 to 2001; and D: 1999, 2008 to 2017) (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 increase in macroalgae and decrease in 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 (50.28% and 40.62%, respectively), as well as for clusters between A and D (42.57% and 52.96%, respectively).

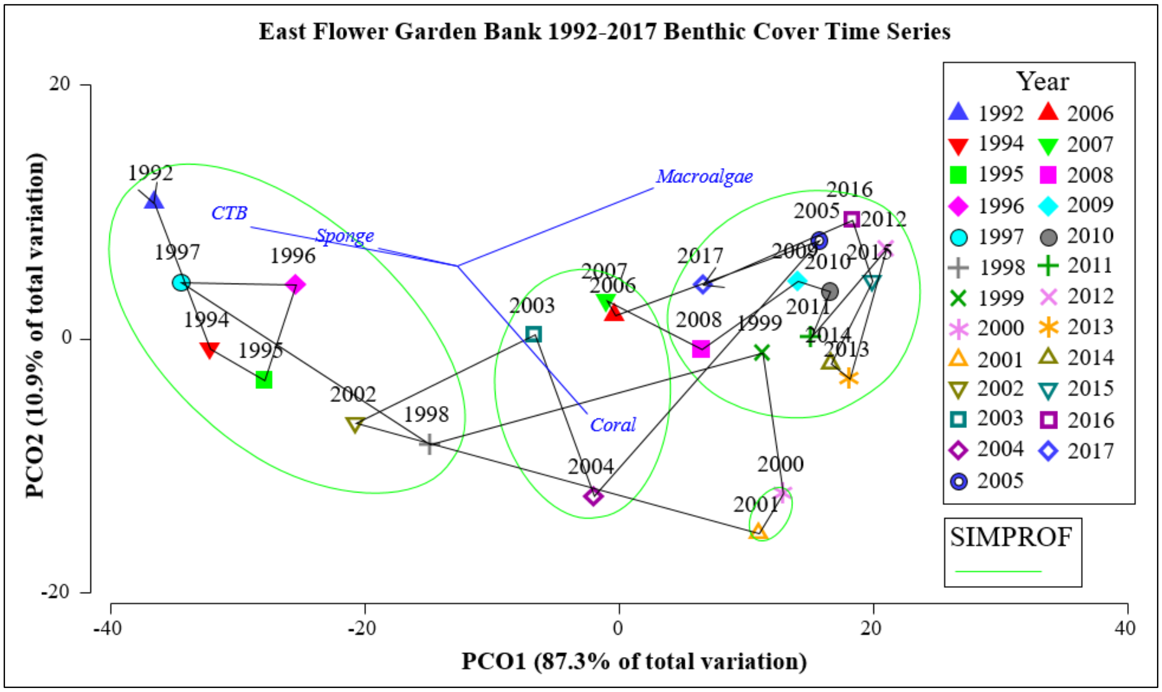


Figure 2.6. PCO for random transect benthic cover analysis from 1992 to 2017 within the EFGB study site. The green ovals are SIMPORF groups representing significant year clusters. The blue vector lines represent the directions of the variable gradients for the plot.

Yearly mean benthic percent cover data from 1992 to 2017 at the WFGB study site displayed a similar pattern to EFGB, resulting in three significant year clusters (A: 1992 to 1997; B: 1998 to 1999 and 2002 to 2008; C: 2000 to 2001 and 2009 to 2017) (Figure 2.7). Between clusters A and B, macroalgae and CTB mean percent cover contributed to over 85% of the dissimilarity (18.14% and 68.28%, respectively), corresponding to 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 (46.37% and 45.10%, respectively), corresponding to the increase in macroalgae and decrease in CTB cover after 1998 (Figure 2.4). Differences between clusters A and C were attributable to macroalgae and CTB mean percent cover (26.76% and 65.00%, respectively).

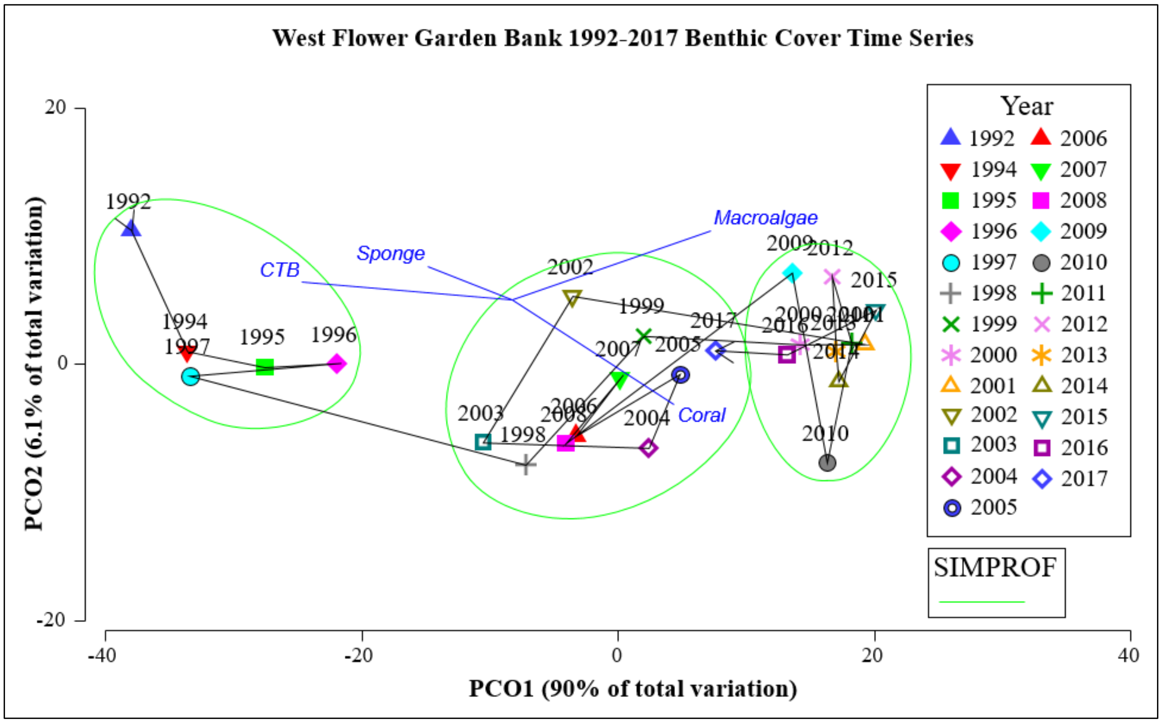


Figure 2.7. PCO for random transect benthic cover analysis from 1992 to 2017 within the WFGB study site. The green ovals are SIMPORF groups representing significant year clusters. The blue vector lines represent the directions of the variable gradients for the plot.

PERMANOVA results revealed no significant differences between study sites, suggesting that EFGB and WFGB study sites were similar to each other from 1992 to 2017 in overall benthic community composition, experiencing similar shifts though time.

Random Transect Discussion

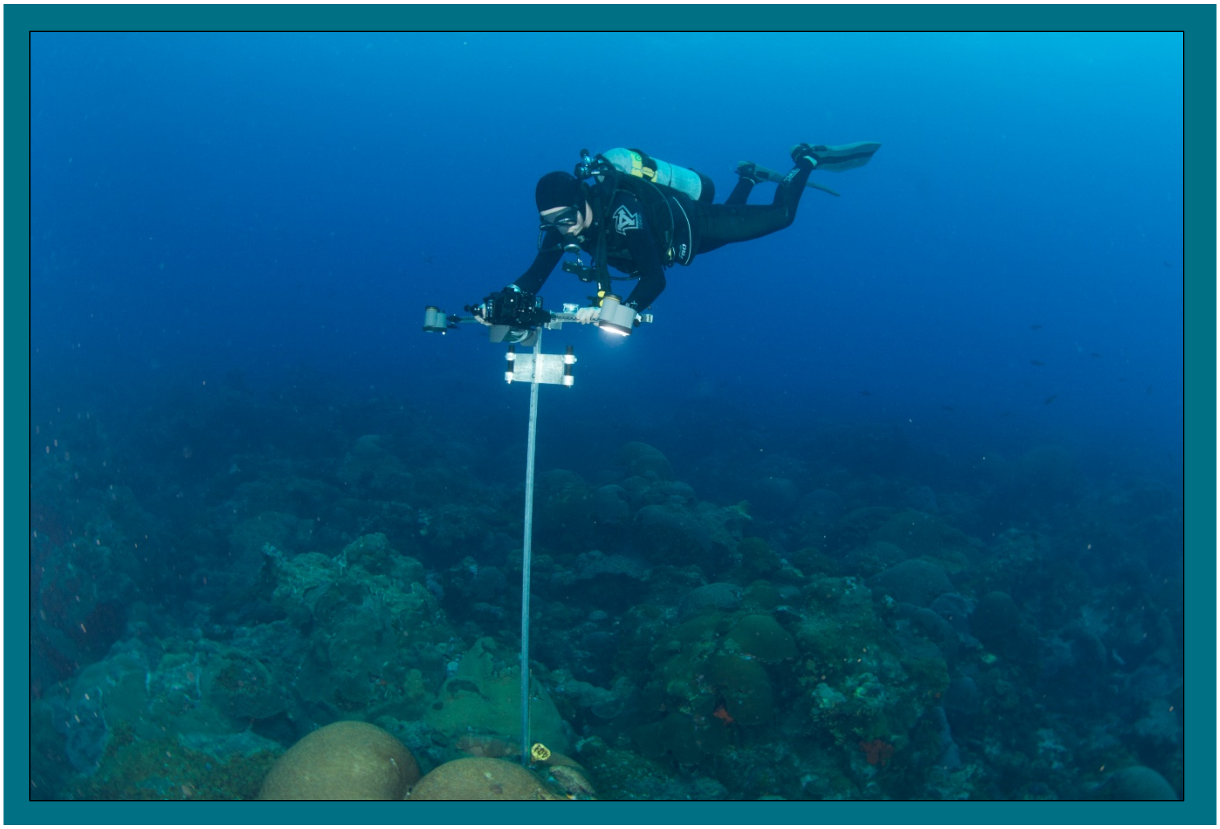
Despite global coral reef declines in recent decades, mean coral cover within EFGB and WFGB study sites has remained near or above 50% for the combined 28 years of monitoring. Mean macroalgae percent cover increased significantly between 1998 and 1999, rising from approximately 5% to 20%, and increasing above 30% in recent years. The inverse relationship between macroalgae and CTB observed throughout the long-term monitoring program reflects the tendency for macroalgae to grow over exposed hard bottom rather than coral or sponges. After 2008, macroalgae percent cover was greater than CTB cover, continuing to increase or remain stable within both study sites. However, in 2017, macroalgae percent cover was the lowest it has been since 2008 in the EFGB study site and 2010 in the WFGB study site, corresponding with increased cover of CTB.

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 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 in 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, 2017a, 2017b). While a portion of EFGB was affected by a localized mortality event in July of 2016, and both banks were impacted by coral bleaching in the fall of 2016, neither of these events resulted in significant coral cover declines within the study sites. Updates on the 2016 localized mortality event are discussed in Chapter 9.

The increase in macroalgae cover observed within the EFGB and WFGB long-term monitoring study sites was consistent with other reefs 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). 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. 2017a, b). 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 impervious to impacts, as seen with the 2016 localized mortality event and bleaching event (Johnston et al. 2017b). Climate change, invasive species, storms, and water quality degradation continue to be threats (ONMS 2008; Nuttall et al. 2014; Johnston 2016a). 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 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 (Figure 1.5 and 1.6). After each station was located, divers photographed each one (for more detailed methods, reference Johnston et al. 2017a) (Figure 3.1). In 2017, all repetitive study site photostations were located and photographed: 37 at EFGB and 41 at WFGB.

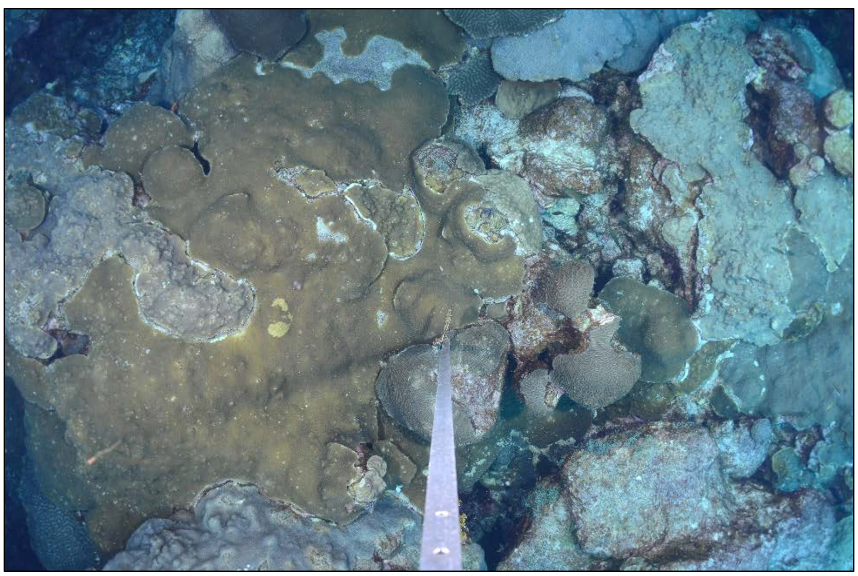


Figure 3.1. WFGB repetitive photostation #504 in 2017. Camera mounted above aluminum t-frame. (Photo: G.P. Schmahl, NOAA/FGBNMS)

Stations were photographed using a Nikon® D7000® SLR camera with 16-mm lens in a 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 m^2.

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 (see Chapter 2 Methods – Random Transect Data Processing for detailed methods). 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 (see Chapter 2 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 was 62.55% ± 2.86 and macroalgae cover was 23.20% ± 1.84. Mean CTB cover was 12.56% ± 1.28, mean sponge cover was 0.59% ± 0.19, and other cover was 1.09% ± 0.34 (Figure 3.2). Within the WFGB study site, mean coral cover was 61.67% ± 1.89 in repetitive study site photostations, followed by mean macroalgae (17.21% ± 1.21), CTB (17.49% ± 1.04), sponge (1.65% ± 0.26), and other cover (1.98% ± 1.07) (Figure 3.2).

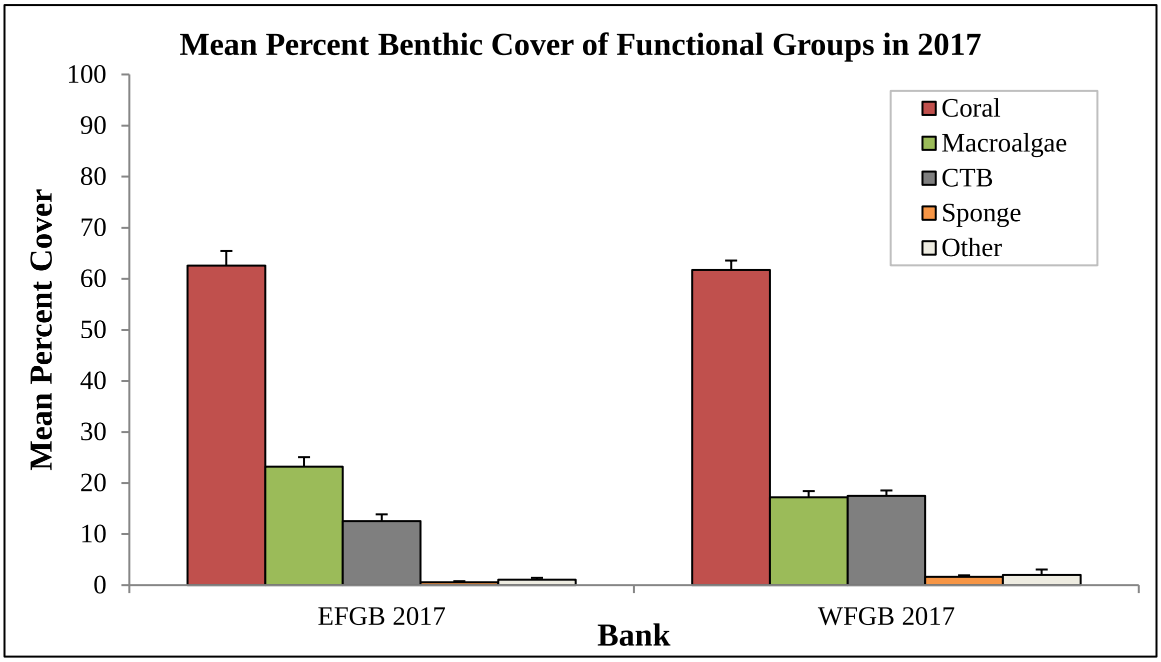


Figure 3.2. Mean percent benthic cover + SE from repetitive study site photostation functional groups within EFGB and WFGB study sites in 2017.

When compared for differences based on functional groups, PERMANOVA analysis revealed no significant differences, suggesting that EFGB and WFGB repetitive photostations were similar in benthic community composition in 2017.

Twelve coral species were observed in EFGB repetitive study site photostations and 15 coral species were observed in WFGB repetitive study site photostations (Figure 3.3). *Orbicella franksi* was the predominant coral species observed in EFGB (32.77% ± 3.03) and WFGB (32.85% ± 2.44) photostations. *Pseudodiploria strigosa* had the second highest cover in EFGB (10.26% ± 1.79) and WFGB (8.12% ± 1.51) photostations (Figure 3.3). PERMANOVA analysis revealed no significant differences in coral species composition between banks in the repetitive study site photostations.

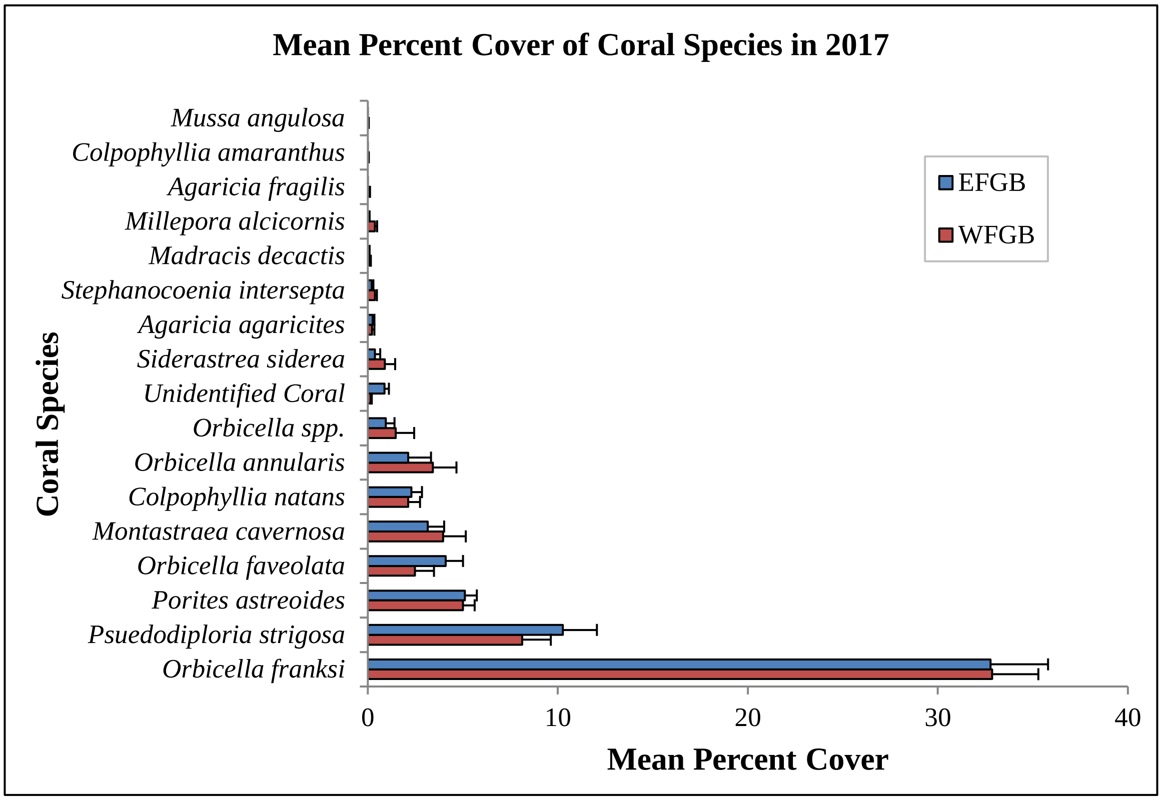


Figure 3.3. Mean percent cover + SE of observed coral species from repetitive study site photostations within EFGB and WFGB study sites in 2017.

Less than 2% of the coral cover analyzed was observed to be bleached or paled 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). In addition, less than 0.5% of fish biting and signs of recent mortality were observed 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. Since the beginning of the monitoring program, 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 2017) (Gittings et al. 1992; CSA 1996; Dokken et al. 1999, 2003; Precht et al. 2006; Zimmer et al. 2010; Johnston et al. 2013, 2015, 2017a, 2017b). From 1989 to 2009, photographs for each repetitive quadrat photostations encompassed an 8 m^2 area, but changed to a 5 m^2 area in 2009, a 9 m^2 area in 2010, and back to a 5 m^2 area from 2011 onward due to changes in camera equipment and updated technology.

In repetitive study site photostations from 1989 to 2017, 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=0.31, p=0.035 and τ=0.29, p=0.050, respectively) (Figure 3.4). percent cover data for individual coral species in repetitive study site photostations became available in 2000. Predominant coral species with the highest mean percent cover in photostations from 2000 to 2017 were the *Orbicella* species group at EFGB (42.13%) and WFGB (43.45%) (primarily *Orbicella franksi*), followed by *Pseudodiploria strigosa* at EFGB (10.16%) and WFGB (8.90%) (Figure 3.5).

Sponge, macroalgae, and CTB data were not available to incorporate into the analysis until 2002. 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 varied inversely and were significantly correlated in the EFGB photostations (τ=-5.06, p<0.001) and the WFGB photostations (τ=-5.52, p<0.001). Macroalgae significantly increased in the EFGB photostations (τ=0.52, p=0.006) and the WFGB photostations (τ=0.53, p=0.005). CTB varied in the EFGB photostations over time but did not result in a significant trend; however, CTB significantly decreased in the WFGB photostations (τ=-0.53, p=0.005) from 2002 to 2017 (Figure 3.4), reflecting increasing overgrowth by macroalgae during this period.

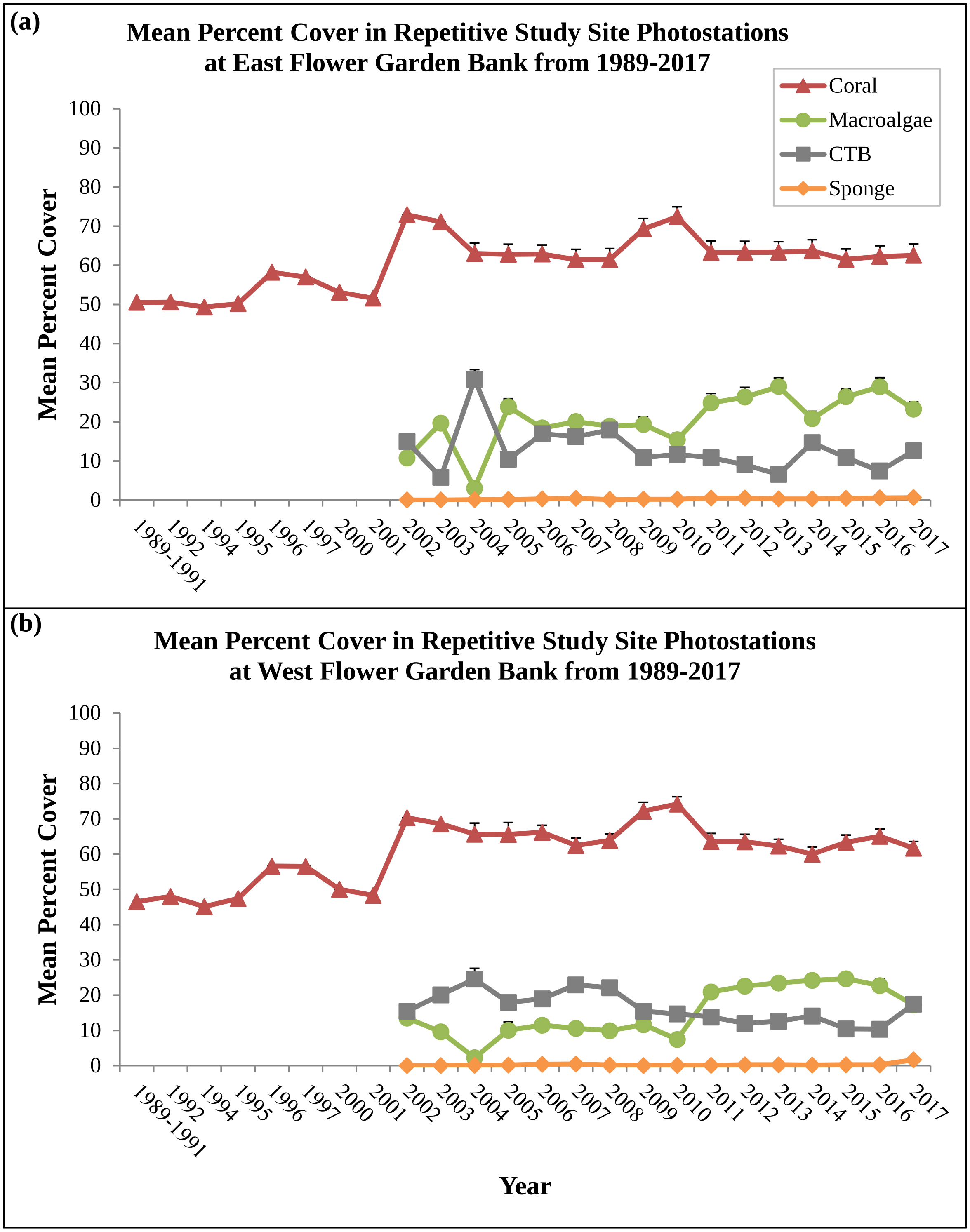


Figure 3.4. Mean percent benthic cover +SE of repetitive study site photostation functional groups within (a) EFGB and (b) WFGB study sites from 1989 to 2017.

Sponge, macroalgae, and CTB categories were not reported until 2002. No mean percent cover data were reported in 1993. Data for 1989 to 1991 are 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 2016 (Johnston et al. 2013, 2015, 2017a, 2017b).

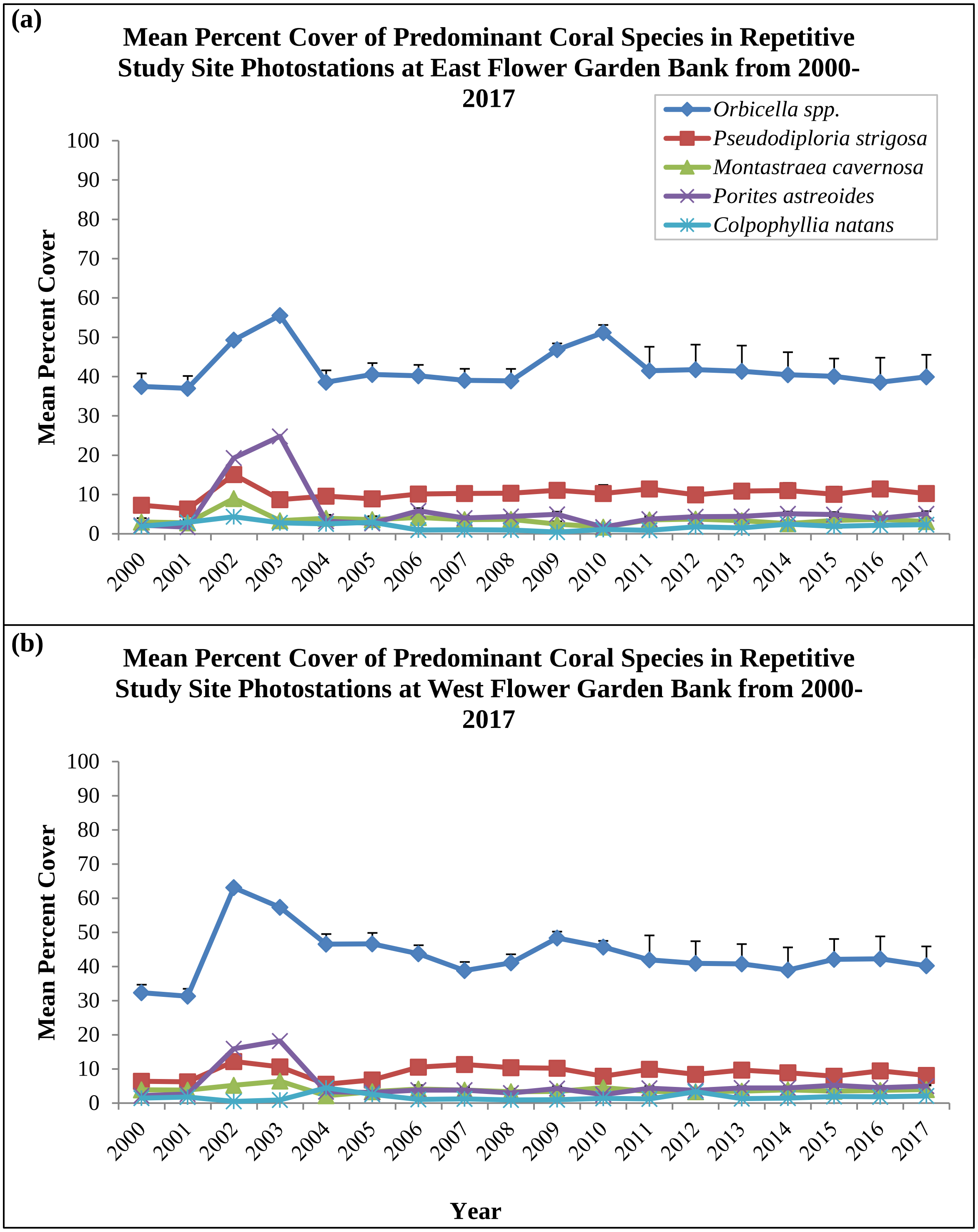


Figure 3.5. Mean percent cover of predominant coral species +SE in repetitive study site photostations at (a) EFGB and (b) WFGB from 2000 to 2017. *Orbicella* species combines *Orbicella franksi*, *Orbicella faveolata*, and *Orbicella annularis* for historical data comparison.

Data for 2000 to 2001 are from Dokken et al. (2003); 2002 to 2008 from PBS&J (Precht et al. 2006; Zimmer et al. 2010); and FGBNMS for 2009 to 2016 (Johnston et al. 2013, 2015, 2017a, 2017b).

For yearly mean benthic percent cover data in EFGB repetitive study site photostations (2002 to 2017), SIMPROF analysis detected four significant year clusters (A: 2002 to 2003 and 2009 to 2010; B: 2006 to 2008 and 2014; C: 2013 and 2016, and D: 2005, 2011 to 2012, and 2015 to 2017) (Figure 3.6). The year 2004 was grouped individually. Between clusters A and B, coral and CTB mean percent cover contributed to over 79% of the dissimilarity (48.81% and 30.42%, respectively), corresponding to the shift in decreased CTB cover from 2002 to 2003 and after 2010 (Figure 3.4). Macroalgae (47.01%) and CTB (46.96%) contributed to the dissimilarity between clusters B and C, due to the large increase in macroalgae and decrease in CTB. Between clusters C and D, macroalgae and CTB mean percent cover contributed to over 89% of the dissimilarity (46.87% and 42.99%, respectively) from continued increasing macroalgae and decreasing CTB through 2016 (Figure 3.4). The year 2004 was not clustered with any other year, and was dissimilar to all the other groups due to high CTB and low macroalgae cover.

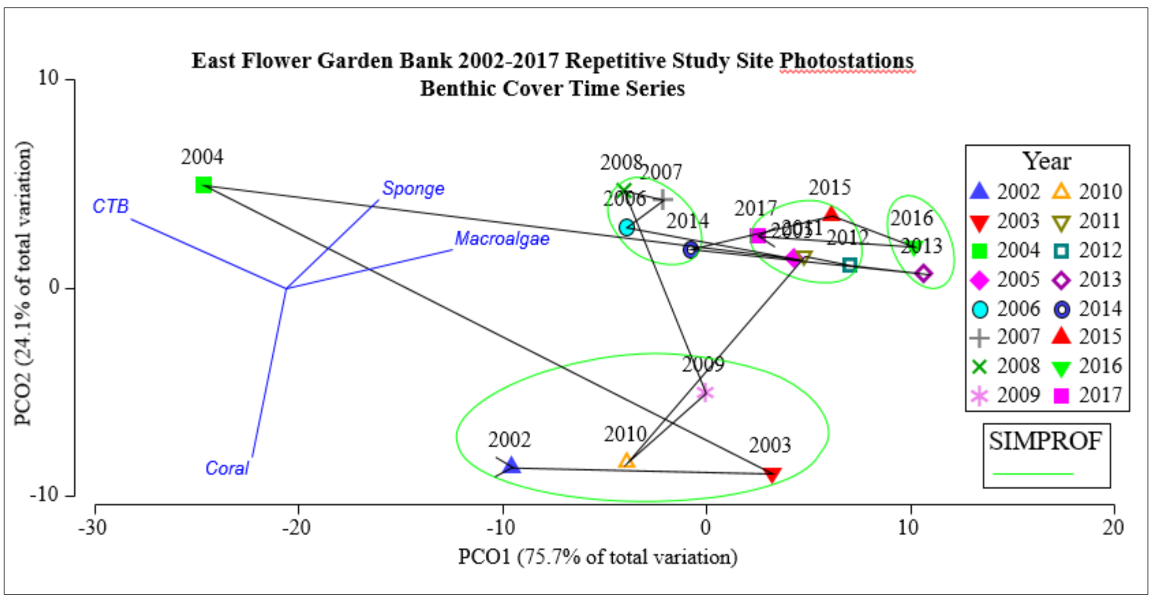


Figure 3.6. PCO for repetitive study site photostations from 2002 to 2017 at EFGB. The green ovals are SIMPORF groups representing significant year clusters. The blue vector lines represent the directions of the variable gradients for the plot.

Yearly mean benthic percent cover data in WFGB repetitive study site photostations resulted in three significant year clusters (A: 2002, and 2009 to 2010; B: 2003 and 2005 to 2008; and C: 2011 to 2016) (Figure 3.7). The years 2004 and 2017 were grouped individually. Between clusters A and B, coral and CTB mean percent cover contributed to over 81% of the dissimilarity (46.65% and 35.27%, respectively), corresponding to the shift in increased coral and decreased CTB cover after 2008 (Figure 3.4). Macroalgae (53.36%) and CTB (34.17%) contributed to the dissimilarity between clusters B and C, due to the large increase in macroalgae and decrease in CTB starting in 2011. Between clusters C and A, macroalgae and coral mean percent cover contributed to over 87% of the dissimilarity (49.65% and 34.17%, respectively) from continued increasing macroalgae and decreasing coral through 2016 (Figure 3.4). The years 2004 and 2017 were not clustered with any other years. The year 2004 was dissimilar to all the other groups due to high CTB and low macroalgae cover. The year 2017 was dissimilar to all the other groups due to increasing CTB and decreasing macroalgae cover (Figure 3.4).

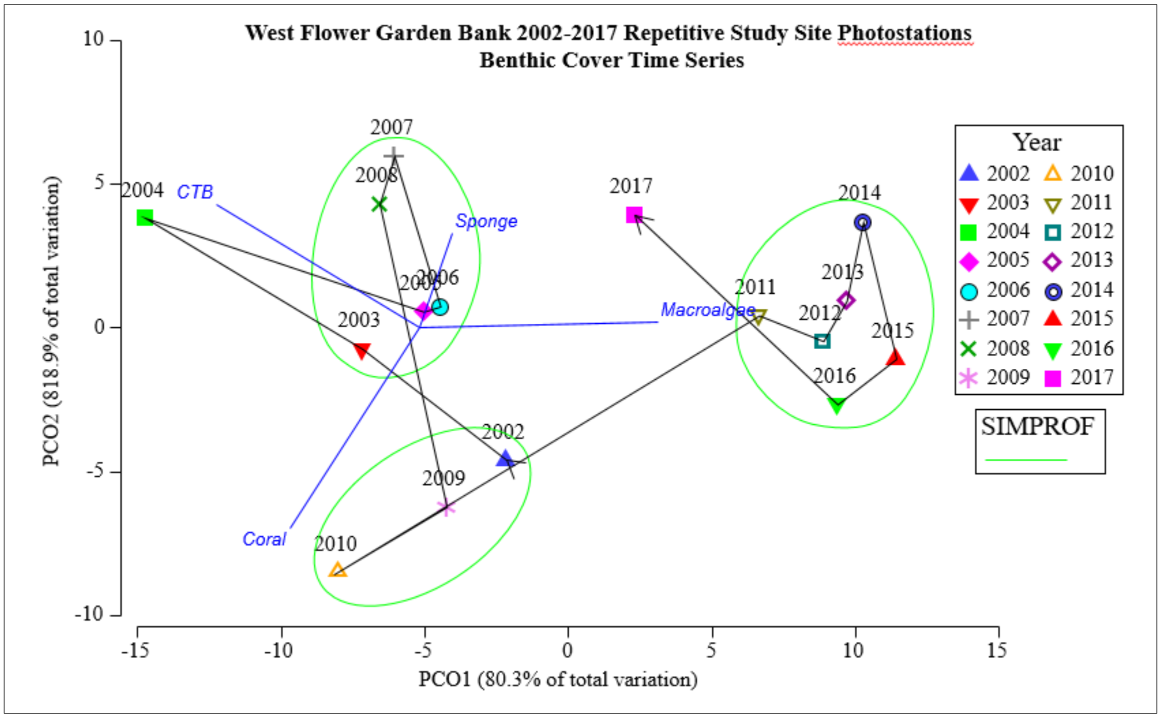


Figure 3.7. PCO for repetitive study site photostations from 2002 to 2017 at WFGB. The green ovals are SIMPORF groups representing significant year clusters. The blue vector lines represent the directions of the variable gradients for the plot.

PERMANOVA analysis comparing benthic cover in repetitive study site photostations revealed significant differences, suggesting that photostations at EFGB and WFGB were different in overall benthic community composition from 2002 to 2017 (Table 3.1). SIMPER analysis identified that for comparisons between repetitive study site photostations, the greatest contributors to the observed dissimilarity were mean macroalgae (45%) and CTB (32.18%) percent cover.

Table 3.1. PERMANOVA results comparing repetitive study site photostation mean percent benthic cover between EFGB and WFGB photostations from 2002 to 2017. Bold text denotes significant value.

Source	Sum of Squares	df	Pseudo-F	P (perm)
Bank Photostation Cover	333	1	3.64	**0.049**
Res	2744	30		
Total	3077	31		

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 2017. As an example of the value of long-term repetitive photographs, EFGB station 102 documents 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 colonization and overgrowth by *Pseudodiploria strigosa* and *Porites astreoides* colonies in the center of the station from 1989 to 2017 (Figure 3.8 a and h); algal colonization after tissue loss on an *Orbicella faveolata* head in the upper right corner in 1996 (affecting approximately 50% of the colony) (Figure 3.8 b); bleaching *Millepora alcicornis* that appeared in the center of the station in 2002 (Figure 3.8 c); algal colonization on a *Pseudodiploria strigosa* head in the lower left corner affecting approximately 50% of the colony after 2013 (Figure 3.8 f); and algal colonization in the center of the station in 2013, with subsequent loss of that algae after 2015 (Figure 3.8 f, g, and h).

Mean percent coral cover within the EFGB and WFGB repetitive study site photostations varied greatly from 1989 to 2017. 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 (62% compared with 54%) at both EFGB and WFGB combined in 2017. 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 specific conclusions about sites over time.

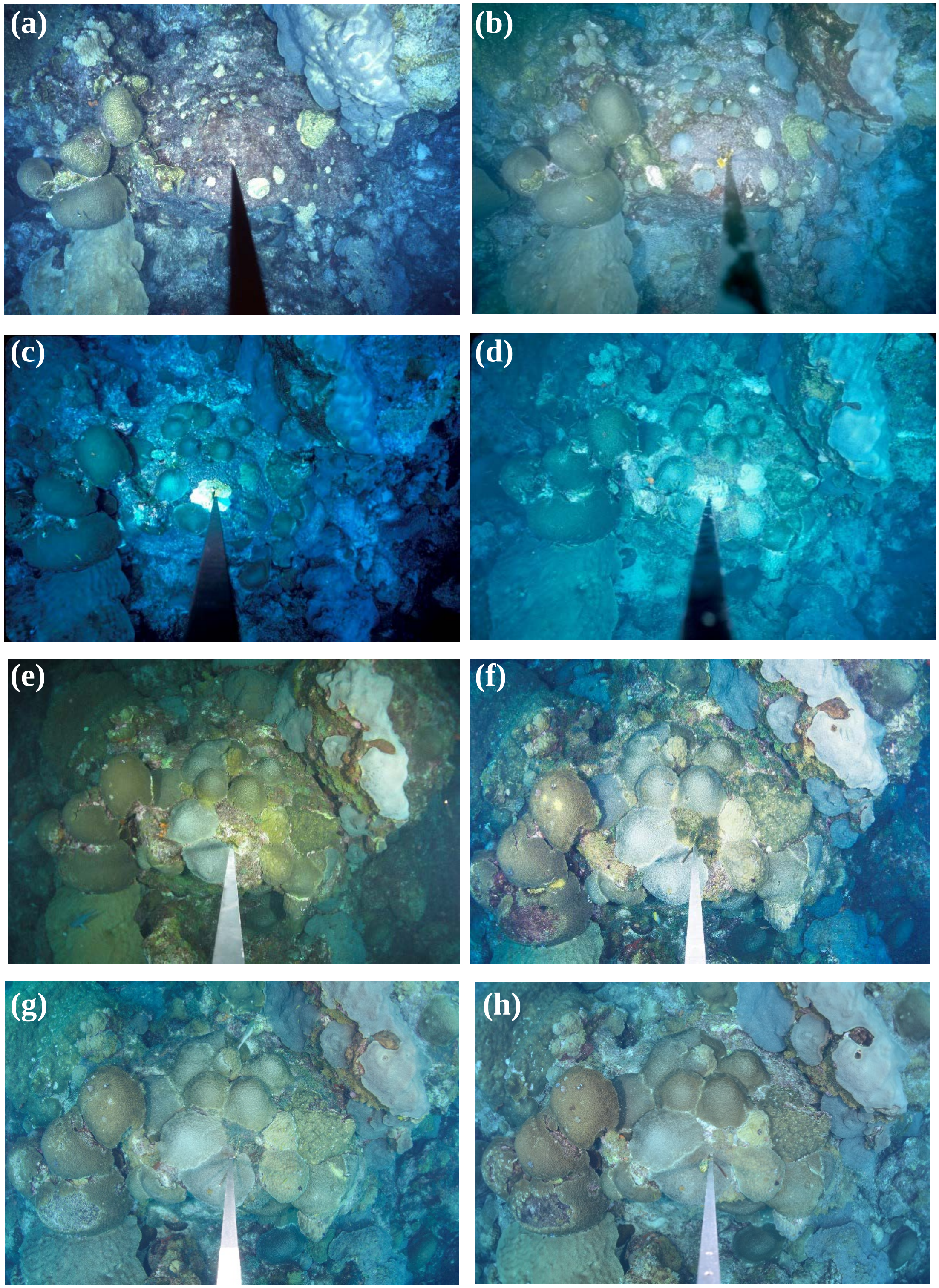
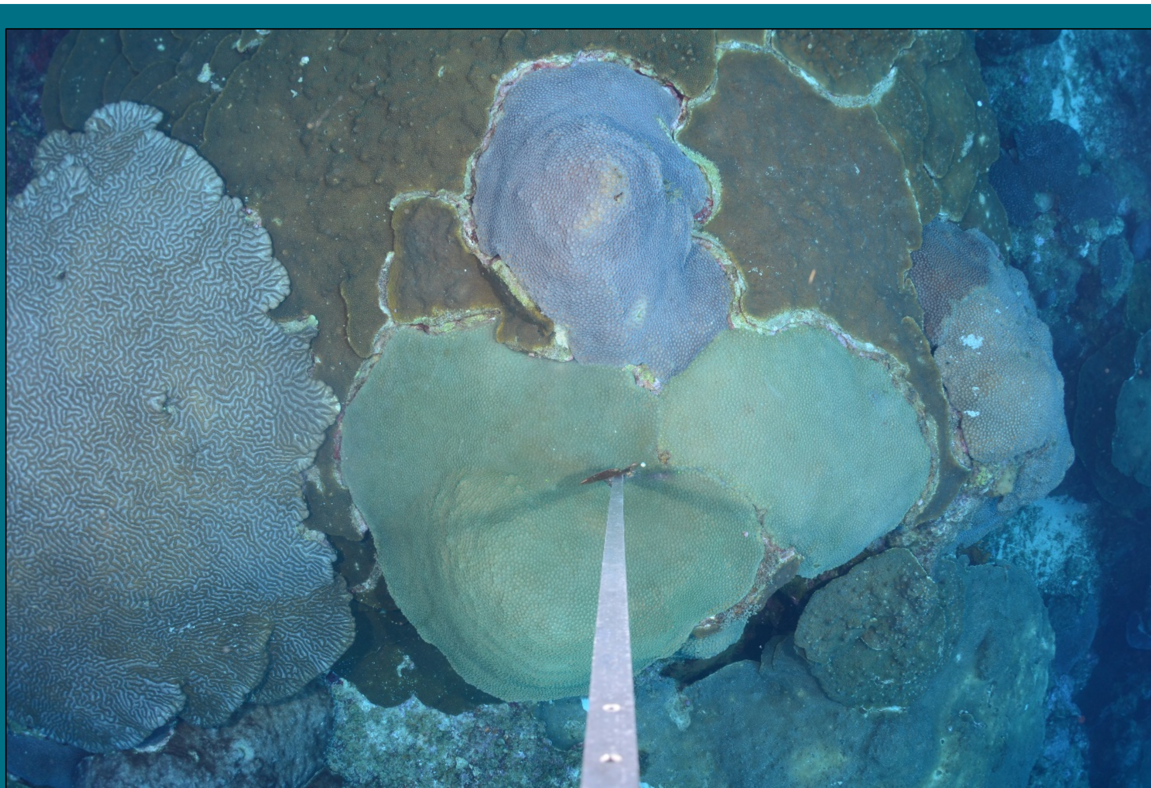


Figure 3.8. EFGB repetitive study site photostation #102 time series from (a) 1989; (b) 1996; (c) 2002; (d) 2006; (e) 2010; (f) 2013; (g) 2015; and (h) 2017. Camera mounted above aluminum t-frame. (Photos: NOAA/FGBNMS)

Less than 2% of the coral cover documented in 2017 was observed to be bleached or paled; however, as mentioned earlier, it is important to note that surveys occurred in the early summer months before signs of bleaching generally occur. This differed from 2016, where corals at EFGB and WFGB began to show signs of bleaching in late August and early September, and then succumbed to significant bleaching in the fall of 2016 due to a sustained period of seawater temperatures in excess of 30℃ (Johnston et al. 2017b). Response cruises were conducted in October 2016 at EFGB and WFGB to photograph corals in repetitive study site photostations to document the event. An additional bleaching response cruise took place in January 2017 at EFGB. Based on CPCe benthic cover analysis, approximately 67% of the coral cover within the EFGB study site repetitive stations exhibited signs of bleaching stress, with 21% of the coral cover appearing to completely bleach (corals had expelled their symbiotic algae). At WFGB, 25% of the coral cover within the repetitive study site photostations exhibited signs of bleaching stress, with 9% of the coral cover appearing to be completely bleached. Coral cover in repetitive photostations remained above 60% in 2017, not differing significantly from percent cover before bleaching in 2016, as most of the colonies had recruited or reestablished their zooxanthellae algae populations and recovered in 2017. As ocean temperatures continue to rise, some corals may be more resistant and resilient than others as environmental conditions change (Heron et al. 2016; von Hooidonk et al. 2016; Hughes et al. 2017). For FGBNMS, the long-term repetitive photostations are critical in enabling researchers to track individual corals over time, especially during extreme events.

Overall, in repetitive study site photostations the most evident patterns were: 1) no significant difference between mean percent coral cover from 2016 to 2017, 2) a significant increase in mean percent coral cover over time, and 3) a significant increase in mean macroalgae percent 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 2017 with camera mounted above aluminum t-frame. (Photo: G.P. Schmahl, 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

The 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. Twenty-three photostations at EFGB were located outside the study site (east of buoy#2) in depths ranging from 32–40 m (Figure 1.3). Twenty-four photostations at WFGB were located outside the study site (near buoy #2) in depths ranging from 24–38 m (Figure 1.4). After stations were located, divers photographed each station (for more detailed methods, reference Johnston et al. 2017a). All stations were located and photographed in 2017 using a Nikon® D7000® SLR camera (see Chapter 3 Methods – Repetitive Study Site Photostation Field Methods).

Nine of the 23 deep repetitive stations at EFGB were established in 2003 and 12 of the 24 deep repetitive stations at WFGB were established in 2012. Two stations were added to EFGB in 2013. From July 25 to 27, 2017, FGBNMS divers along with volunteer divers from Moody Gardens Aquarium and Texas A&M University at Galveston, installed additional repetitive deep photostations at EFGB and WFGB. Twelve new additional stations were installed at each bank at depths ranging from 30–40 m. These new sites increased the number of repetitive sites at these depths, allowing for additional comparisons in the deeper photostations to the benthic community in the shallower monitoring photostations within the study sites.

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 (see Chapter 2 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 was carried out using Primer® version 7.0 and monotonic trends were detected using the Mann-Kendall trend test in R® version 2.13.2 (see Chapter 2 Methods – Random Transect Statistical Analysis).

Repetitive Deep Photostation Results

Repetitive Deep Photostation Mean Percent Cover

EFGB repetitive deep photostation mean coral cover was 68.34% ± 3.20 and macroalgae cover was 19.71% ± 2.17. Mean CTB cover was 10.27% ± 1.43, mean sponge cover 1.50% ± 0.78, and other cover 0.18% ± 0.15 (Figure 4.1). At WFGB, mean coral cover was 72.46% ± 3.20, followed by mean macroalgae (15.26% ± 2.28), CTB (10.92% ± 1.07), sponge (0.94% ± 0.22), and other cover (0.15% ± 0.28) (Figure 4.1). When compared for differences based on functional groups using PERMANOVA, no significant differences were found, suggesting that EFGB and WFGB repetitive deep photostations were similar to each other in overall benthic community composition.

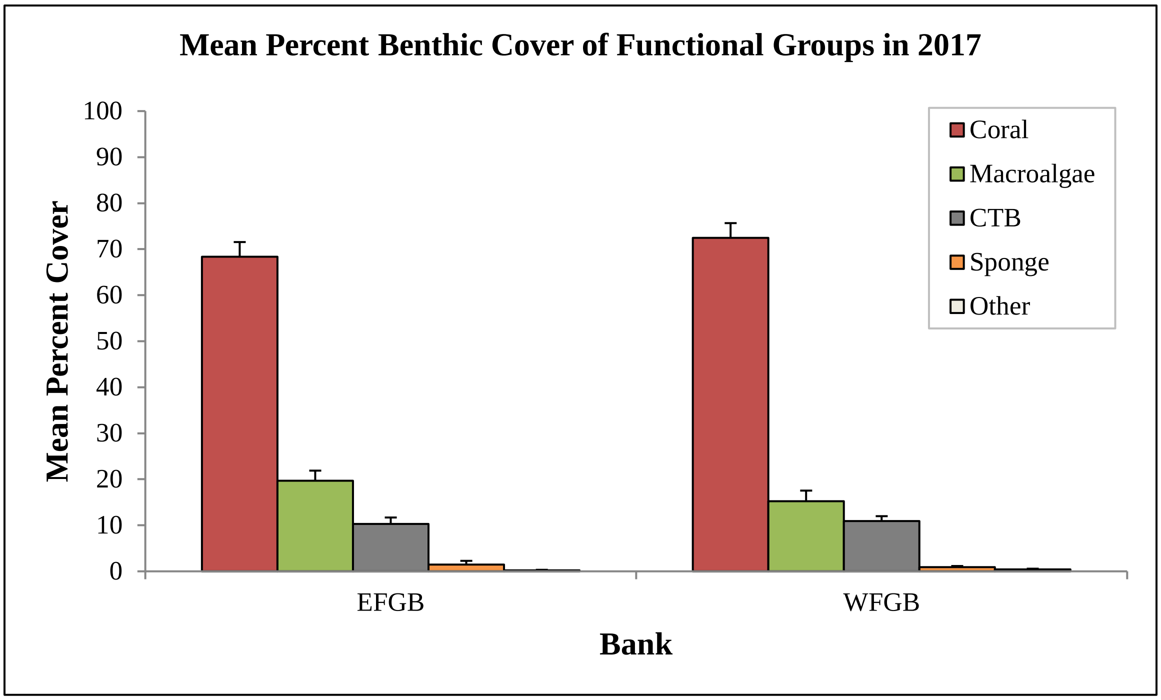


Figure 4.1. Mean percent benthic cover + SE from repetitive deep photostation functional groups at EFGB and WFGB in 2017.

Thirteen species of coral were observed in both EFGB and WFGB repetitive deep photostations (Figure 4.2). *Orbicella franksi* was the most abundant coral species observed in EFGB (37.22% ± 3.23) and WFGB (39.75% ± 5.25) deep photostations. *Montastraea cavernosa* was the next most abundant species in EFGB (8.68% ± 2.48) and

WFGB (11.53% ± 2.90) deep photostations (Figure 4.2). PERMANOVA analysis revealed no significant differences in repetitive deep photostation coral species composition between banks.

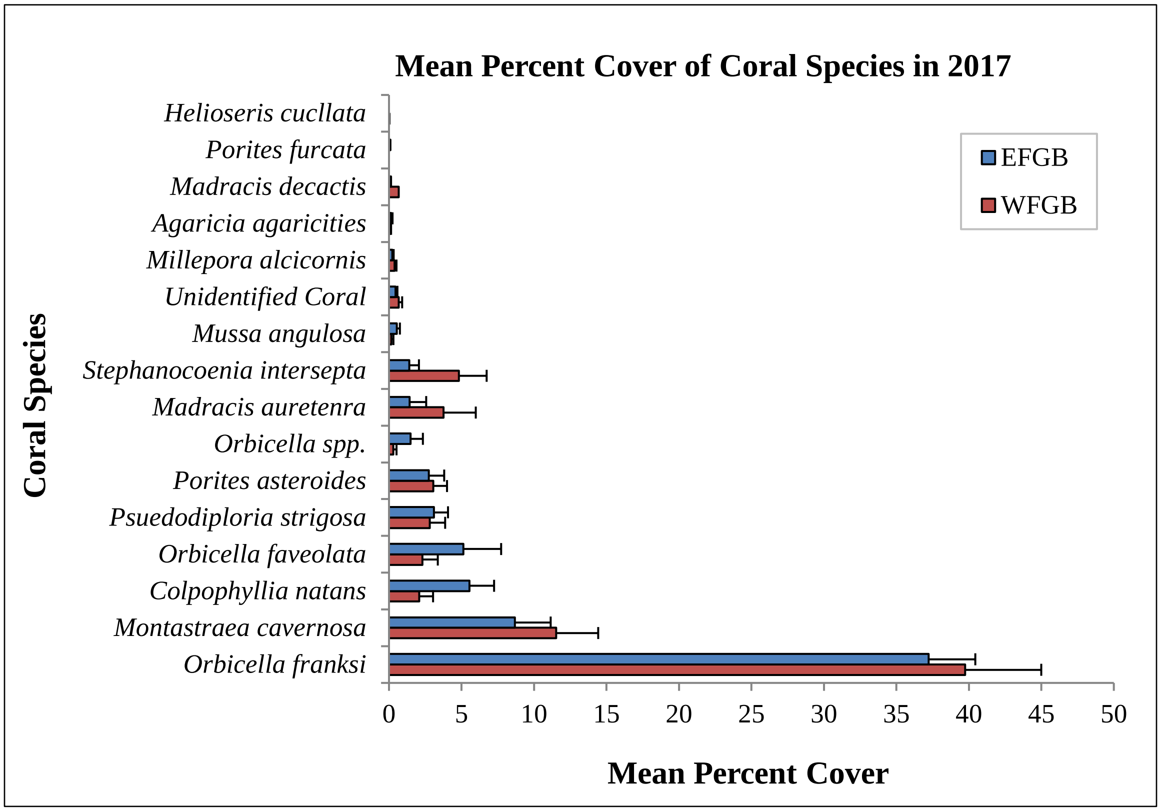


Figure 4.2. Mean percent cover + SE of observed coral species from repetitive deep photostations at EFGB and WFGB in 2017.

Less than 0.4% 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). In addition, no fish biting was observed and signs of mortality was less than 0.3% in the repetitive deep photostations.

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 70.40% at the deep stations and 62.12% at the study site stations for both banks combined. Mean deep station macroalgae cover was 17.49%, while macroalgae cover in the study site stations was 20.21%. Mean percent CTB cover at the deep stations was 10.60% and the study site stations was 15.03%. Mean percent sponge cover was approximately 1% for both the deep and study site stations, and other cover was below 1% at the deep stations and below 2% at the study site stations (Figure 4.3).

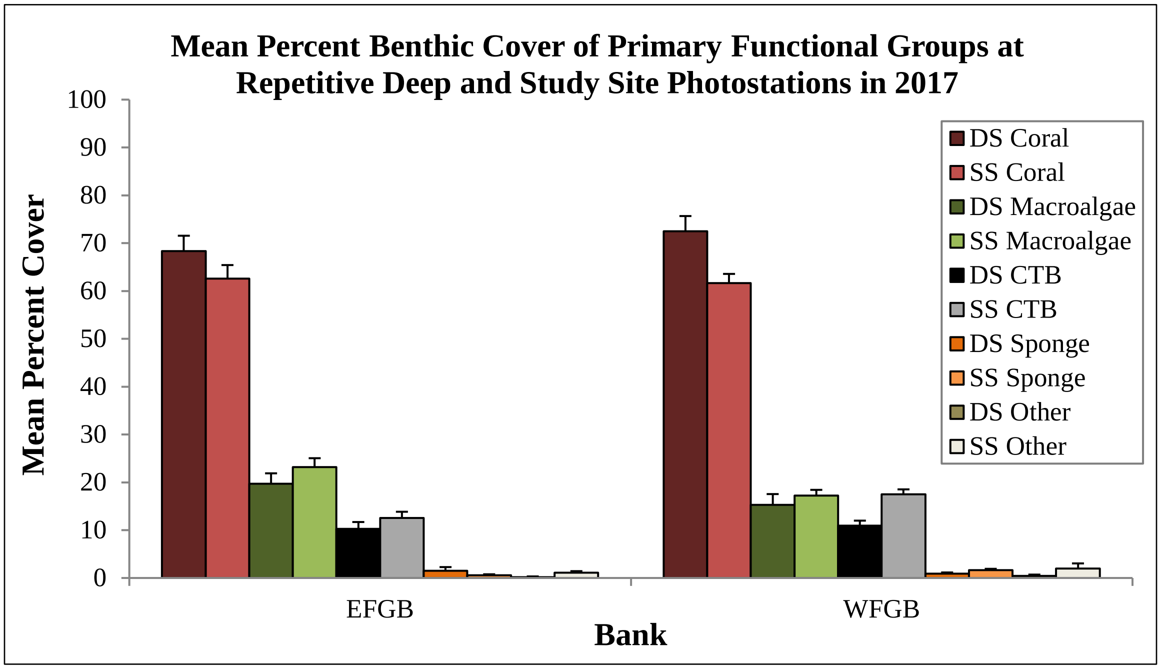


Figure 4.3. Repetitive deep station (DS) and repetitive study site (SS) photostations functional group mean benthic percent cover + SE at EFGB and WFGB in 2017.

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 primary contributor (61.39%) to the observed dissimilarity based on SIMPER analysis, resulting in significantly greater 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 2017. Bold text denotes significant value.

Source	Sum of Squares	df	Pseudo-F	P (perm)
Bank Photostation Cover	1104	1	2.91	0.072
Depth	2804	1	7.39	**0.008**
Bank Photostation Cover x Depth	353	1	0.93	0.357
Res	45914	121		
Total	50414	124		

By further investigating differences in coral cover between depths, species level data was analyzed. Mean *Montastraea cavernosa* percent cover was the primary contributor (18.00%) to the observed dissimilarity between repetitive deep and study site photostation coral species, followed by *Pseudodiploria strigosa* (14.82%).

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 2017) (Precht et al. 2006; Zimmer et al. 2010; Johnston et al. 2013, 2015, 2017a, 2017b). 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, a 9 m^2 area in 2010, and back to a 5 m^2 area from 2011 onward due to changes in camera equipment and updated technology. It should be noted that the twelve additional stations installed in 2017 were incorporated into the long-term trend analysis.

In the EFGB repetitive deep photostations from 2003 to 2017, mean percent coral cover ranged from 72–86% (Figure 4.4). Predominant coral species with the greatest mean percent cover were within the *Orbicella* species group (45.04%) (primarily *Orbicella franksi*), followed by *Montastraea cavernosa* (14.10%) (Figure 4.5). Macroalgae and CTB cover were significantly correlated (τ=-3.652, p=0.003), with macroalgae significantly increasing over time (τ=0.524, p=0.008), coinciding with decreases in CTB cover (Figure 4.4). Overall, the most noticeable pattern was the inverse relationship between CTB and macroalgae cover (similar to benthic cover in both random transects and repetitive study site photostations), with increased macroalgae cover starting in 2005, and peaking at approximately 21% in 2012 at the EFGB repetitive deep photostations.

In 2012, deep photostations were established at WFGB. The mean percent coral cover ranged from 72–77% from 2012 to 2017 (Figure 4.4). Like the EFGB repetitive deep stations, predominant coral species with the greatest mean percent cover were within the *Orbicella* species group (36.45%) (primarily *Orbicella franksi*), followed by *Montastraea cavernosa* in the WFGB repetitive deep stations (17.14%) (Figure 4.5). Since 2012, macroalgae has ranged from 13–21% and CTB has ranged from 5–11%. Sponge cover was approximately 1% from 2012 to 2017. No significant increases or decreases in percent cover data were detected in the WFGB repetitive deep photostations.

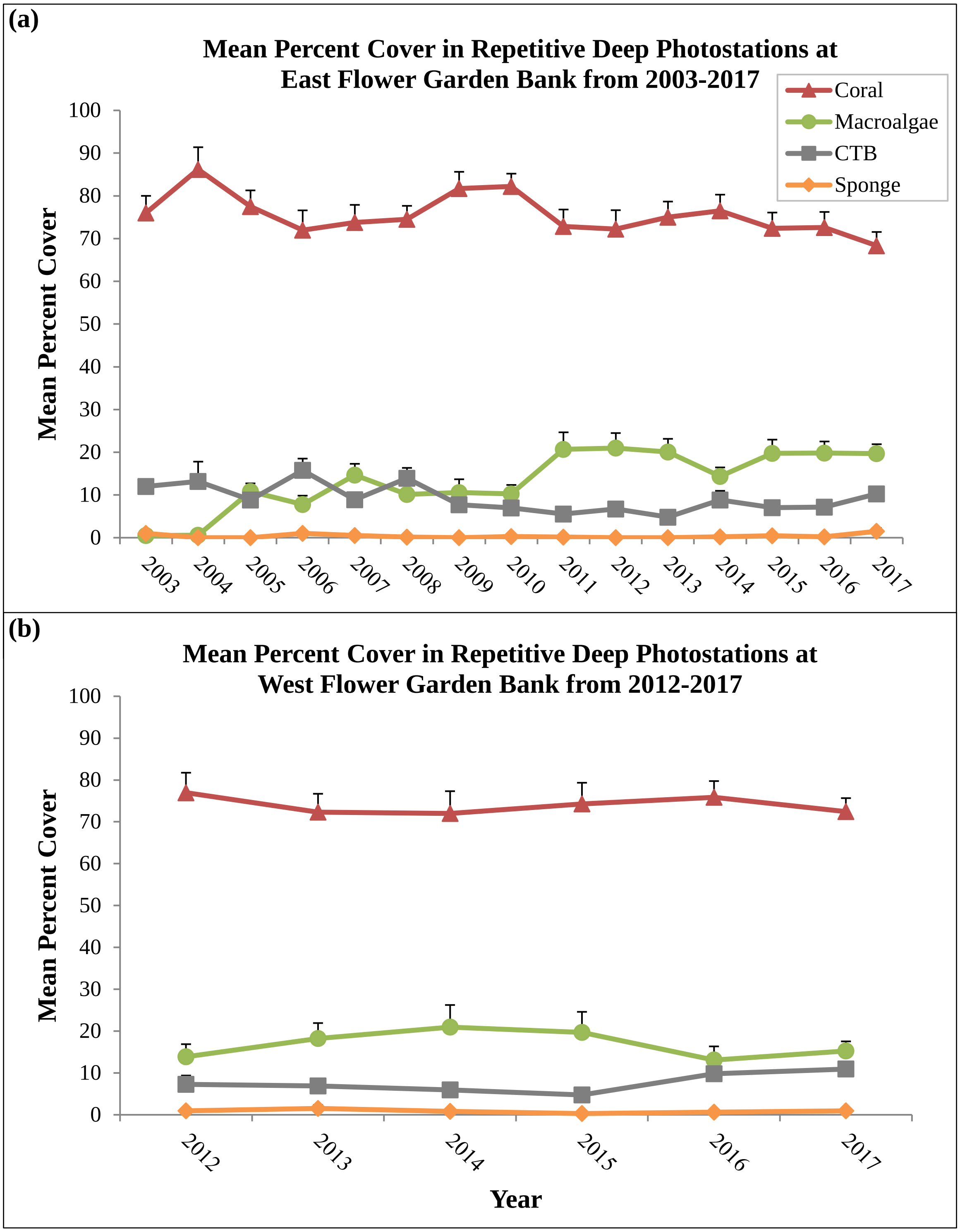


Figure 4.4. Mean percent benthic cover +SE of repetitive deep photostation functional groups at (a) EFGB from 2003 to 2017 and (b) WFGB from 2012 to 2017. Sample size increased from 11 to 23 photostations at EFGB and 12 to 24 photostations at WFGB in 2017.

Data for 2003 to 2008 are from PBS&J (Precht et al. 2006; Zimmer et al. 2010) and FGBNMS for 2009 to 2016 (Johnston et al. 2013, 2015, 2017a, 2017b).

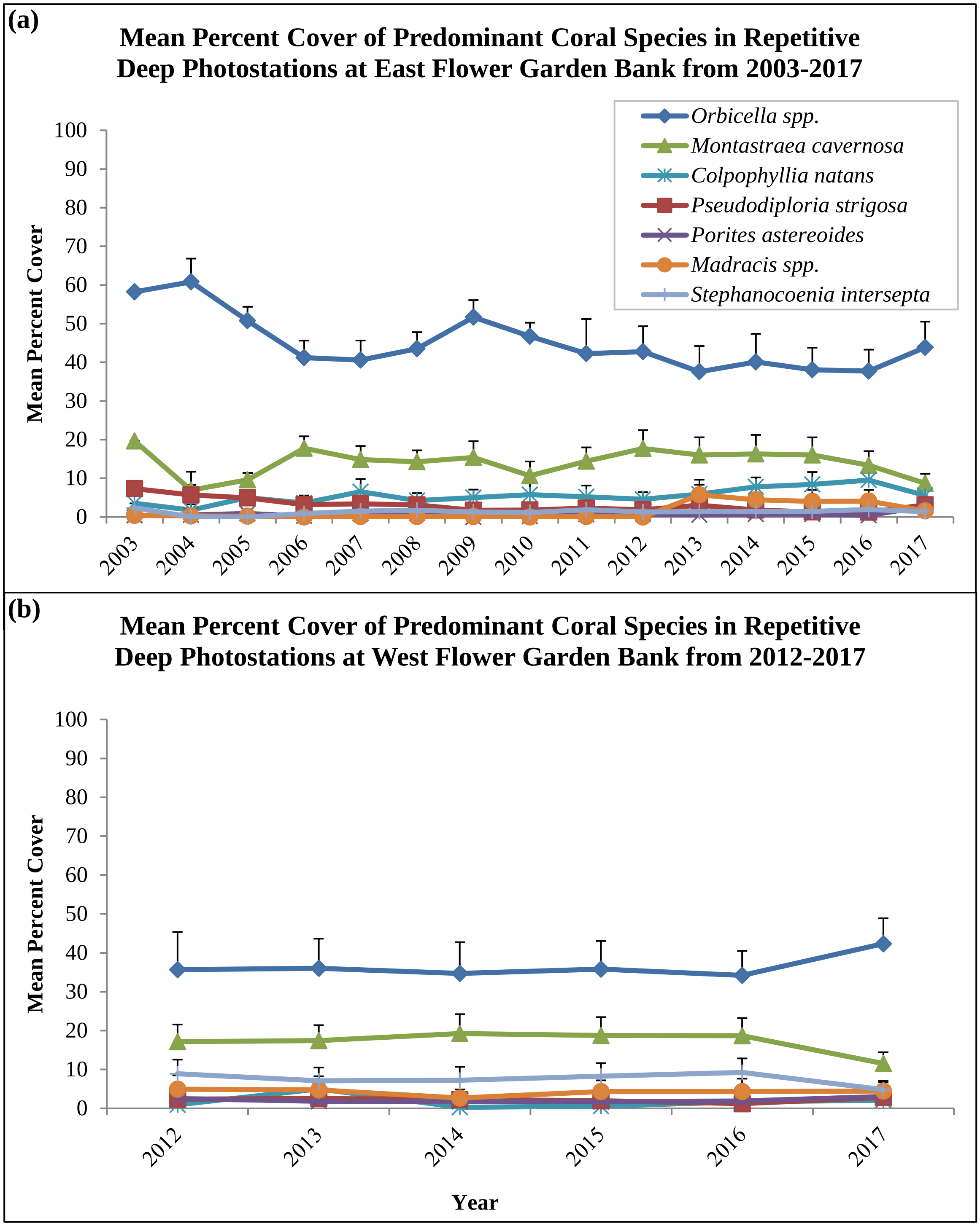


Figure 4.5. Mean percent cover + SE of predominant coral species in repetitive deep photostations at (a) EFGB from 2003 to 2017 and (b) WFGB from 2012 to 2017. Sample size increased from 11 to 23 photostations at EFGB and 12 to 24 photostations at WFGB in 2017. *Orbicella* species combines *Orbicella franksi*, *Orbicella faveolata*, and *Orbicella annularis* for historical data comparison.

Data for 2002 to 2008 are from PBS&J (Precht et al. 2006; Zimmer et al. 2010) and FGBNMS for 2009 to 2016 (Johnston et al. 2013, 2015, 2017a, 2017b).

For yearly mean benthic percent cover data in EFGB repetitive deep photostations (2003 to 2017), SIMPROF analysis detected three significant year clusters (A: 2003, 2006, and 2008; B: 2005, 2007, 2009 to 2010, and 2014; and C: 2011 to 2013, and 2015 to 2016) (Figure 4.6). The years 2004 and 2017 were grouped individually. Macroalgae (36.17%) and CTB (33.32%) contributed to the dissimilarity between clusters A and B, due to the shifts in macroalgae and CTB cover during these years (Figure 4.4). Between clusters B and C, macroalgae and coral mean percent cover contributed to over 85% of the dissimilarity (51.50% and 34.40%, respectively) from continued increasing macroalgae and decreasing coral cover through 2016 (Figure 4.4). Between clusters A and C, macroalgae and CTB mean percent cover contributed to over 89% of the dissimilarity (58.36% and 31.26%, respectively) from increasing macroalgae and decreasing CTB cover (Figure 4.4). The year 2004 was not clustered with any other year, and was dissimilar to all the other groups due to high CTB and low macroalgae cover. The year 2017 was not clustered with any other year, and was dissimilar to all the other groups due to changes in coral cover from the addition of new photostations.

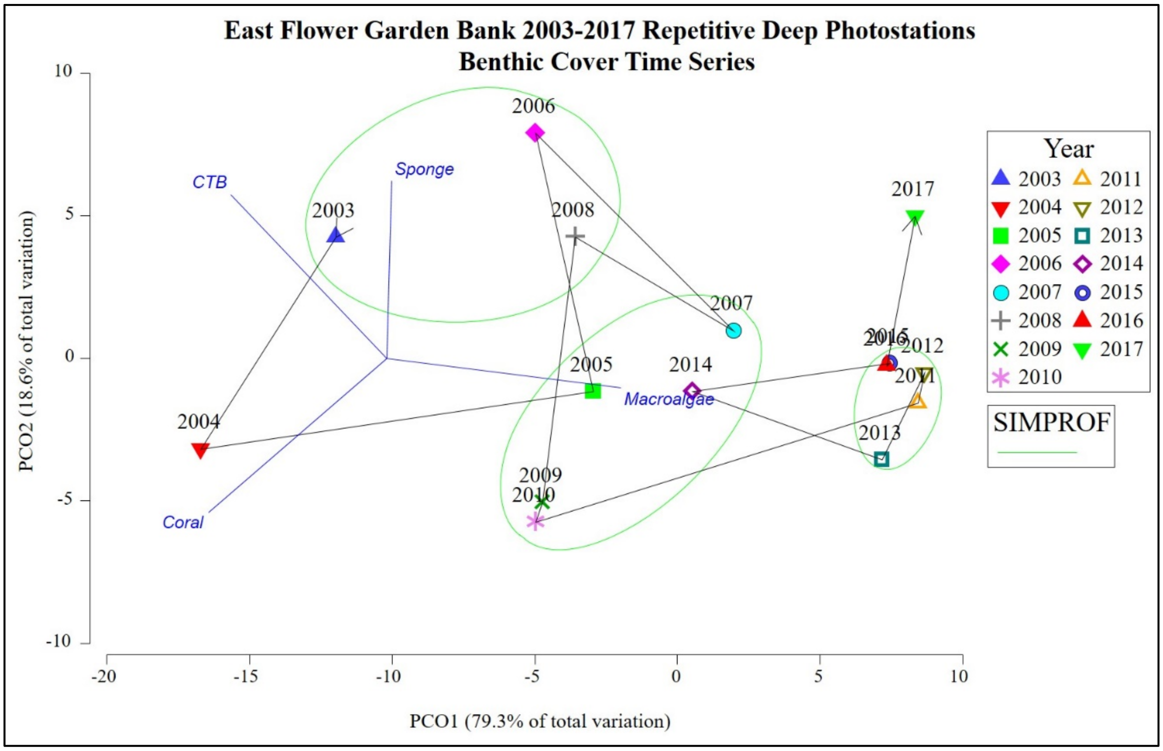


Figure 4.6. PCO for repetitive deep photostations from 2003 to 2017 at EFGB. The green ovals are SIMPORF groups representing significant year clusters. The blue vector lines represent the directions of the variable gradients for the plot.

For yearly mean benthic percent cover data in WFGB repetitive deep photostations (2012 to 2017), no significant year clusters were detected, suggesting the WFGB repetitive deep photostations were similar to each other in overall benthic community composition over time.

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

Repetitive Deep Photostation Discussion

Nine repetitive deep photostations have been in place since 2003 at EFGB (with two stations added in 2013), and twelve repetitive deep photostations have been in place since 2012 at WFGB. Twelve additional stations were added to each bank in 2017. Percent coral cover within EFGB repetitive deep photostations has ranged from 68% to 86% since 2003 (Figure 4.4). Percent coral cover within WFGB repetitive deep photostations has ranged from 77% to 72% since 2012 (EFGB has ranged from 77% to 68% since 2012) (Figure 4.4).

In the example from EFGB repetitive deep photostation #07 (Figure 4.7), 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. The large *Montastraea cavernosa* colonies in the center of the station gained 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 (70%) were obtained from the repetitive deep photostations than from either the shallower repetitive quadrats (62%) and the random transects (54%) at both EFGB and WFGB study sites. This has been documented in previous reports (Precht et al. 2006; Zimmer et al. 2010; Johnston et al. 2013, 2015, 2017a, 2017b). 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, in which *Psuedodiploria strigosa* provided the second highest cover.

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. Macroalgae cover, while less than shallower sites, increased over time in the EFGB repetitive deep photostations, following a similar pattern to the increasing macroalgae cover in the repetitive study site photostations and random transects.

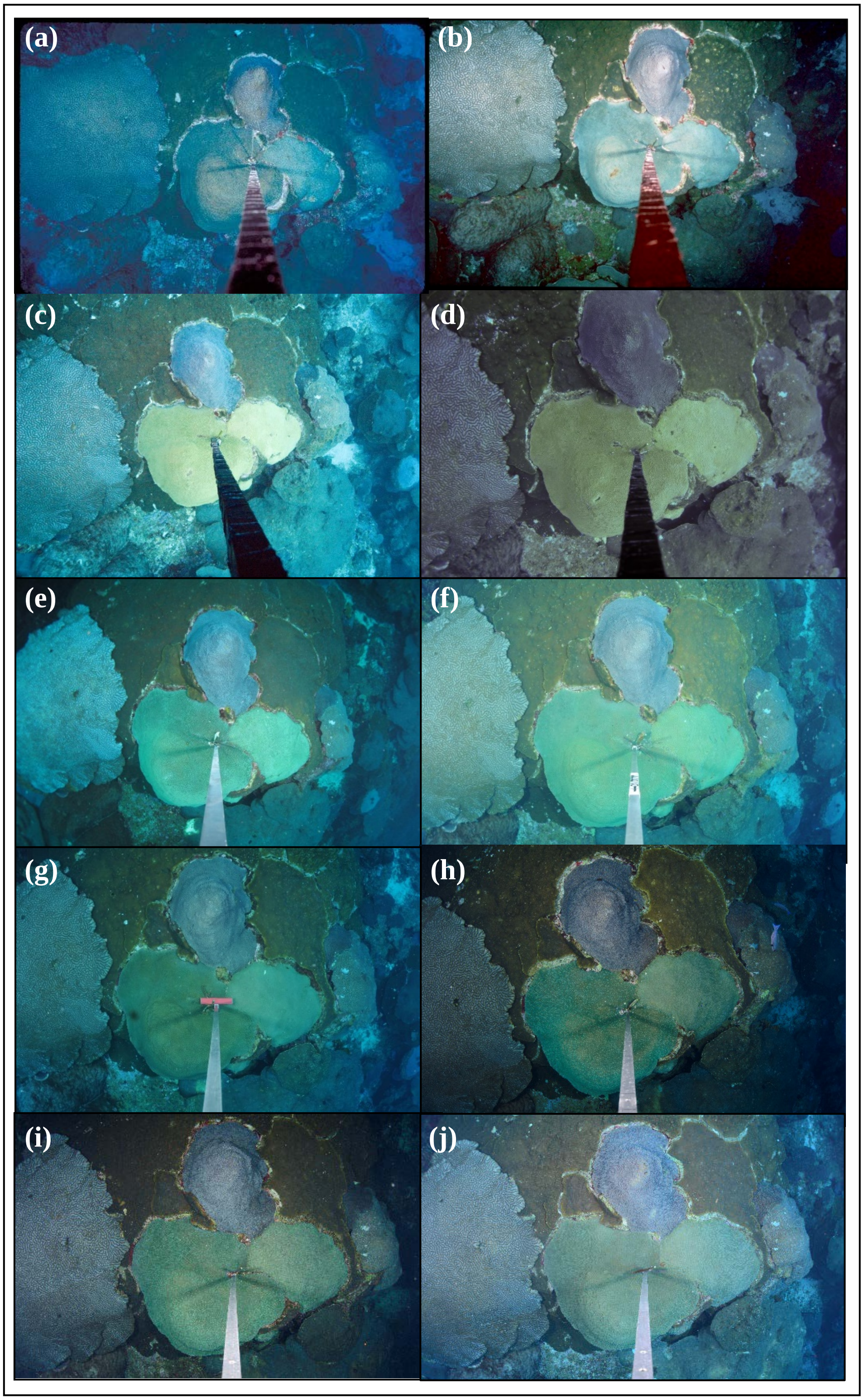


Figure 4.7. Select photos from EFGB repetitive deep photostation #07 show a time series from (a) 2005; (b) 2007; (c) 2008; (d) 2009; (e) 2010; (f) 2011; (g) 2012; (h) 2013; (i) 2016; and (j) 2017. (Photos: NOAA/FGBNMS)

It should be noted that the repetitive 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.

Less than 0.5% of the coral cover documented in 2017 was observed to be bleached or paled in the repetitive deep stations; however, as mentioned earlier, it is important to note that surveys occurred in the early summer months before signs of bleaching generally occur. Based on CPCe benthic cover analysis during the bleaching event in 2016, approximately 29% of the coral cover within the EFGB repetitive deep stations exhibited signs of bleaching stress, with 0.5% of the coral cover appearing to be completely bleached (corals had expelled their symbiotic algae). At WFGB, 15% of the coral cover within the deep repetitive photostations exhibited signs of bleaching stress, with 5% of the coral cover appearing to be completely bleached. Coral cover in the repetitive deep photostations showed minimal signs of mortality in 2017, and percent cover did not differ significantly from percent cover in 2016, as most of the colonies had recruited or reestablished their zooxanthellae populations and recovered in 2017.

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 within the EFGB photostations, and 3) mean coral cover above 70% over time.

Chapter 5. Coral Demographics

A spawning colony of boulder star coral (*Orbicella franksi*) within the East Flower Garden Bank study site in 2017. (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. 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. In 2017, all eight surveys were completed within the EFGB study site; however, only three surveys were completed within the WFGB study site due to fieldwork being cut short because of Hurricane Harvey.

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)) for mean size (cm^3). For example, a coral colony measuring 0.5 m in each dimension would equal 125,000 cm^3. 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 (Roberson et al. 2014). 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 2012). 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 (AGRRA 2012; Roberson et al. 2014). These surveys were time intensive due to abundant corals at EFGB and WFGB.

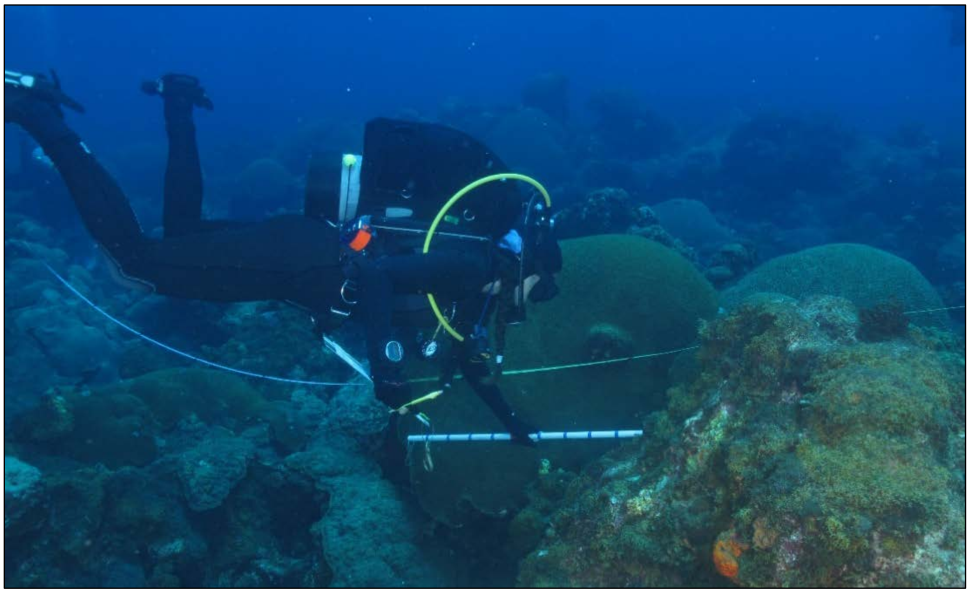


Figure 5.1. A PVC measuring stick aids in estimating the width of a coral colony on a coral demographic survey within the EFGB study site. (Photo: G.P. Schmahl, NOAA/FGBNMS)

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 WFGB study site. (Photo: John Embesi, NOAA/FGBNMS)

Consistency of survey methods was maintained through the use of scientific divers trained to identify coral species found at FGBNMS. Divers were 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 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 not conducted to compare surveys between study sites due to the limited number of surveys collected at WFGB.

Coral Demographic Results

For the coral demographic survey data collected in 2017, the average survey depth was 19.5 m in the EFGB study site and 21 m in the WFGB study site. Species richness included 16 coral species documented in coral demographic surveys within the EFGB study site and 15 within the WFGB study site (Table 5.1). Overall mean coral density (corals/m^2 ± standard error) was 6.41 ± 0.32 within the EFGB study site and 5.83 ± 0.20 within the WFGB study site. The most abundant species in the surveys was *Porites astreoides*, followed by *Orbicella franksi* (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 *Pseudodiploria strigosa* colonies covered the greatest total area in the WFGB study site surveys (Table 5.1)

Orbicella franksi colonies were the largest colonies in EFGB study site surveys in 2017 (83 cm mean maximum diameter), followed by *Orbicella faveolata* (67 cm mean maximum diameter) and *Pseudodiploria strigosa* colonies (58 cm mean maximum diameter) (Table 5.1). Even though *Orbicella franksi* colonies occupied the most area on surveys at WFGB, *Orbicella faveolata* colonies were the largest in WFGB study site surveys in 2017 (131 cm mean maximum diameter), followed by *Pseudodiploria strigosa* (84 cm mean maximum diameter) and *Orbicella franksi* colonies (76 cm mean maximum diameter) (Table 5.1).

Limited bleaching and paling was observed within colonies in 2017 (Table 5.2 and 5.3). Overall, most of the mortality (percent of colonies) observed was old mortality within colonies on surveys at both study sites (Table 5.2 and 5.3)

Table 5.1. Total number of colonies, total colony size (cm^3), and mean colony size (cm^3) from 2017 coral demographic EFGB study site surveys (n=8) and WFGB study site surveys (n=3). Surveys at WFGB were limited due to the approach of Hurricane Harvey.

Coral Species	EFGB Surveys			WFGB Surveys		
	Total Colonies	Mean Max Diameter (cm)	Mean Size (cm^3)	Total Colonies	Mean Max Diameter (cm)	Mean Size (cm^3)
Porites astreoides	185	21	6263	59	20	6,189
Orbicella franksi	71	83	397,140	26	76	406,488
Agaricia agaricites	55	9	253	10	8	200
Pseudodiploria strigosa	43	58	308,153	26	84	609,785
Stephanocoenia intersepta	26	46	109,694	11	23	4,881
Montastraea cavernosa	24	49	278,385	5	63	340,040
Orbicella faveolata	23	67	349,335	4	131	1,683,906
Madracis decactis	19	16	12,609	2	34	2,412
Agaricia fragilis	18	14	853	8	11	213
Orbicella annularis	13	27	21,592	11	6	295
Colpophyllia natans	12	58	121,494	4	41	225,010
Helioseris cucullata	12	33	79,789	2	8	175
Mussa angulosa	5	10	500	2	6	49
Scolymia cubensis	5	6	89	3	8	126
Porites furcata	1	21	2,310	0	0	0
Colpophyllia amaranthus	1	28	1,820	0	0	0
Millepora alcicornis	0	0	0	2	26	2,640
Total	**513**		**1,690,279**	**175**		**3282408**

Table 5.2. Percent paling, bleaching, and mortality type observed in coral colonies from coral demographic surveys within EFGB study sites in 2017.

EFGB Coral Species	%Paling	%Bleaching	%Recent Mortality	%Transition Mortality	%Old Mortality
Porites astreoides	2	1	2	1	1
Orbicella franksi	10	0	1	7	15
Agaricia agaricites	0	4	0	0	0
Pseudodiploria strigosa	0	2	0	0	9
Stephanocoenia intersepta	4	4	0	0	8
Montastraea cavernosa	13	8	4	4	13
Orbicella faveolata	0	0	0	0	22
Madracis decactis	0	0	0	0	11
Agaricia fragilis	0	0	0	0	0
Orbicella annularis	8	8	0	8	8
Colpophyllia natans	8	0	0	17	0
Helioseris cucullata	0	8	0	0	8
Mussa angulosa	0	0	0	0	20
Scolymia cubensis	0	0	0	0	0
Porites furcata	0	0	0	0	0
Colpophyllia amaranthus	0	0	0	0	0

Table 5.3. Percent paling, bleaching, and mortality type observed in coral colonies from coral demographic surveys within WFGB study sites in 2017.

WFGB Coral Species	%Paling	%Bleaching	%Recent Mortality	%Transition Mortality	%Old Mortality
Porites astreoides	5	2	3	7	2
Pseudodiploria strigosa	4	4	0	0	35
Orbicella franksi	8	0	0	0	23
Stephanocoenia intersepta	0	0	0	0	27
Orbicella annularis	0	0	0	0	0
Agaricia agaricites	0	0	0	0	0
Agaricia fragilis	0	0	0	0	0
Montastraea cavernosa	0	0	20	0	40
Orbicella faveolata	0	0	0	0	25
Colpophyllia natans	25	0	0	0	0
Scolymia cubensis	0	0	0	0	0
Millepora alcicornis	0	0	0	0	100
Madracis decactis	0	0	0	0	0
Helioseris cucullata	0	0	0	0	0
Mussa angulosa	0	0	0	0	0

Eleven species of coral recruits (≤ 4 cm) were documented in coral demographic surveys within EFGB study sites and three species of recruits within WFGB study sites. *Agaricia agaricites* was the most abundant coral recruit species observed in coral demographic surveys within EFGB and WFGB study sites and *Porites astreoides* was the second most abundant species in 2017 (Table 5.4).

Table 5.4. Total number of colonies, total colony size (cm^3), and mean colony size (cm^3) from 2017 coral recruits in coral demographic EFGB study site surveys (n=8) and WFGB study site surveys (n=3). Surveys at WFGB were limited due to the approach of Hurricane Harvey.

Coral Recruit Species	EFGB Surveys			WFGB Surveys		
	Total Colonies	Total Size (cm^3)	Mean Size (cm^3)	Total Colonies	Total Size (cm^3)	Mean Size (cm^3)
Agaricia agaricites	39	225	6	6	71	12
Porites astreoides	26	203	8	6	44	7
Agaricia fragilis	17	102	6	0	0	0
Montastraea cavernosa	9	33	4	0	0	0
Madracis decactis	5	41	8	1	14	14
Tubastraea coccinea	5	68	14	0	0	0
Stephanocoenia intersepta	3	40	132	0	0	0
Orbicella faveolata	2	5	2	0	0	0
Mussa angulosa	2	17	9	0	0	0
Colpophyllia natans	1	3	3	0	0	0
Orbicella franksi	1	11	11	0	0	0
Total	**110**	**747**	**201**	**13**	**129**	**33**

Coral Demographic Discussion

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

Agaricia agaricites and *Porites astreoides*, both brooders versus broadcast spawners, were the most abundant coral recruits in 2017. These corals are generally small-sized and exhibit high rates of recruitment (Green et al. 2008). These two brooding species have consistently dominated recruitment at EFGB and WFGB (Baggett and Bright 1985). Though the coral community in the study sites has remained relatively stable throughout the monitoring program from 1989 to 2017, 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 under a colony of symmetrical brain coral (*Pseudodiploria strigoda*). (Photo: Jamie Park, 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 FGBNMS (Gittings and Bright 1987). This invertebrate is a significant marine herbivore and can substantially control 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*) at EFGB and WFGB are not well understood. Therefore, surveys help document the abundance of these species within the 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 study site perimeter lines and crosshairs. 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. 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, recording 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. In 2017, all lines were surveyed within the EFGB study site; however, no surveys were completed in the WFGB study site as fieldwork was cut short due to the approach of Hurricane Harvey in August of 2017.

Consistency for the survey method was ensured by multiple, scientific divers trained to identify sea urchin and lobster species located at FGBNMS. Divers were 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

Density of *Diadema antillarum* was 2.33 individuals/100 m² ± 1.26 within the EFGB study site in 2017. One *Panulirus guttatus* was observed within the EFGB study site (density 0.08 individuals/100 m² ± 0.01) and no *Panulirus argus* were observed. Surveys at WFGB were not completed due to the approach of Hurricane Harvey.

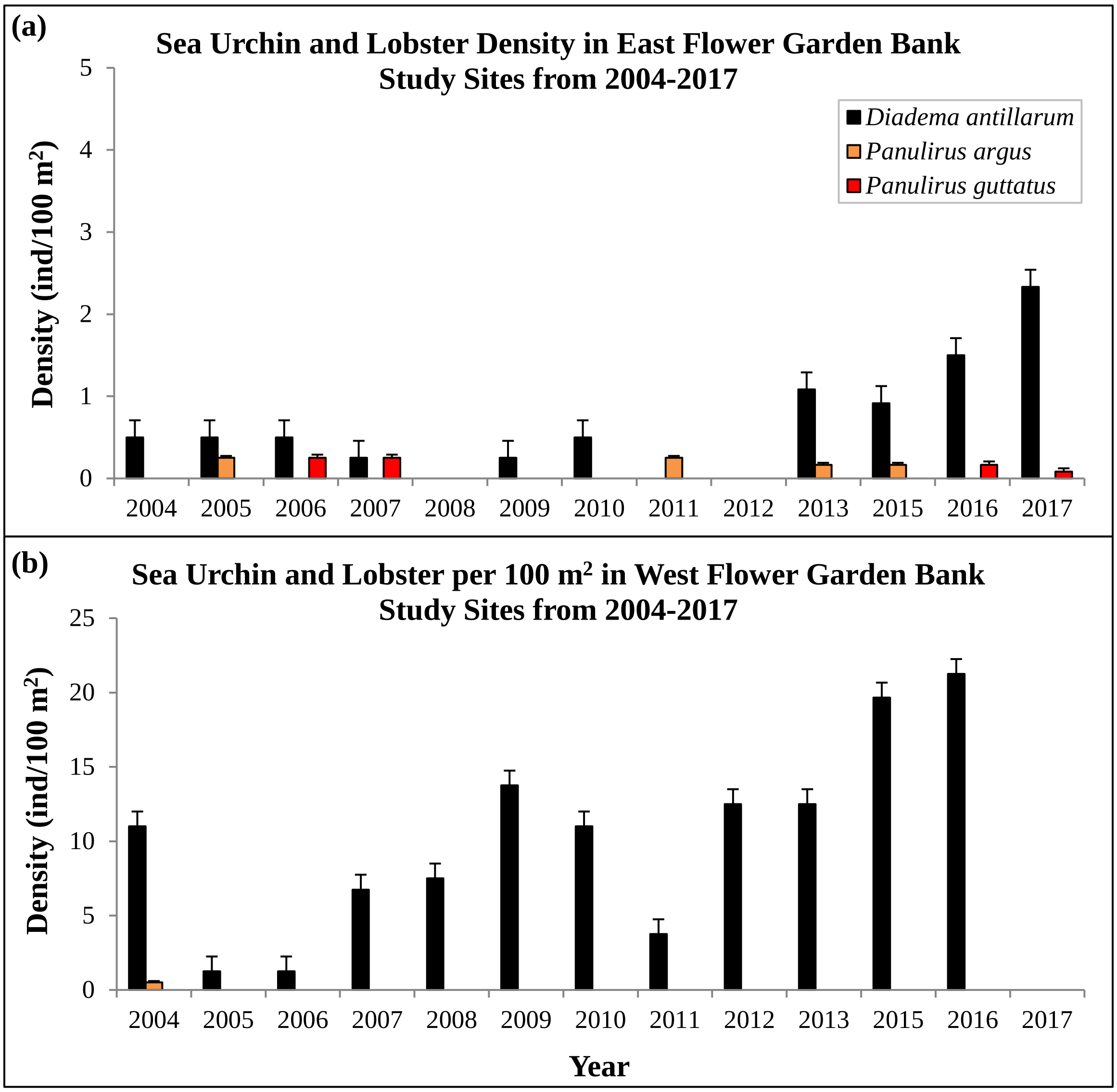


Figure 6.1. Sea urchin and lobster density (individuals/100 m²) + SE within EFGB and WFGB study sites from 2004 to 2017.

No data available for either bank in 2014 and at WFGB for 2017. Data for 2004 to 2008 are from PBS&J (Precht et al. 2006; Zimmer et al. 2010) and FGBNMS for 2009 to 2016 (Johnston et al. 2013, 2015, 2017a, 2017b).

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.

When compared for differences between bank study sites and years based on *Diadema antillarum* density, PERMANOVA analysis revealed a significant difference (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 2004 to 2017. Bold text denotes significant value.

Source	Sum of Squares	df	Pseudo-F	P (perm)
Bank Study Site	29	1	25.84	**0.002**
Year	12	12	0.89	0.571
Res	13	12		
Total	54	25		

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; Kramer 2003; Carpenter and Edmunds 2006). *Diadema antillarum* densities at nearby Stetson Bank have also increased in recent years, averaging 170 individuals/100 m² in 2016 (Nuttall et al. 2018).

Diadema antillarum populations within the EFGB study site remained low during the 2017 monitoring period and were similar to those reported in previous studies (Zimmer et al. 2010; Johnston et al. 2017a, 2017b). Populations within the WFGB study site have been consistently higher than EFGB, and even though surveys were not conducted at WFGB in 2017 due to inclement weather, diver observations supported this status for 2017. 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

NOAA diver swims through a school of Bonnetmouth (*Emmelichthyops atlanticus*) over the reef at East Flower Garden Bank in 2017. (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 based on methods originally described by Bohnsack and Bannerot (1986). Twenty-four randomly located surveys were conducted within study sites at EFGB and WFGB. 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. 2017a) (Figure 7.1).

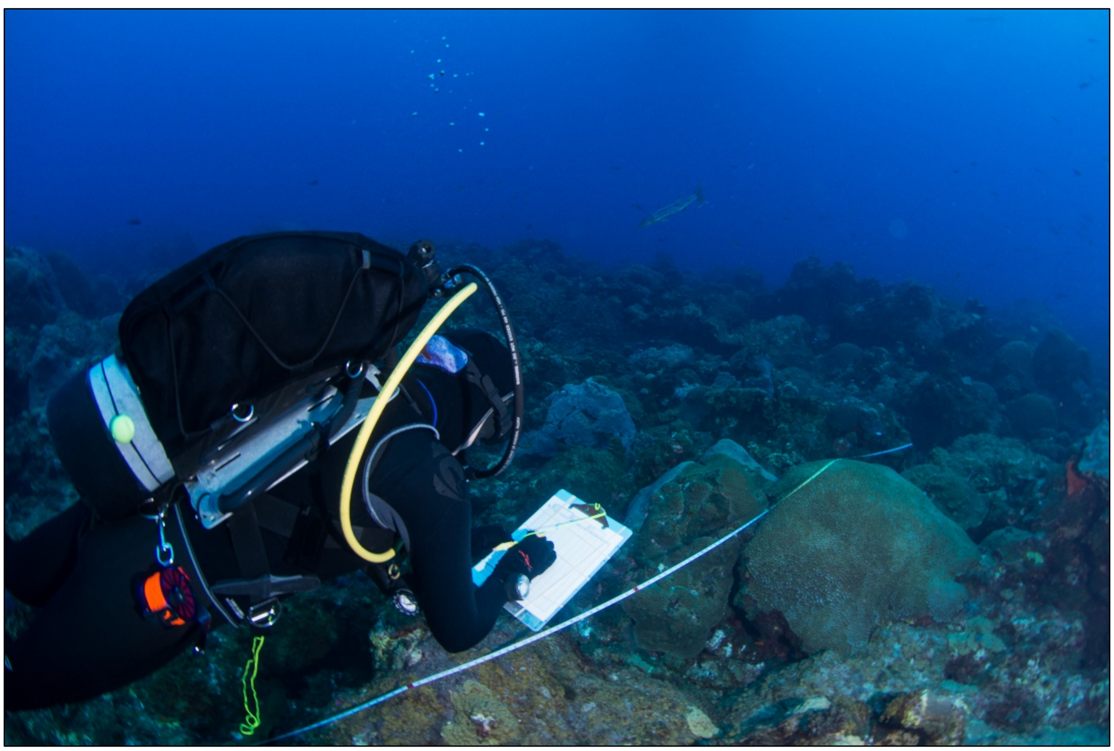


Figure 7.1. NOAA diver conducting a fish survey within the EFGB study site. (Photo: G.P. Schmahl, NOAA/FGBNMS)

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 approximately 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 (1900 CTD).

Consistency in the survey method was maintained with the use of scientific divers trained to identify fish species located at FGBNMS. Divers were 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 carried a pre-marked PVC measuring stick to provide a 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 fieldwork 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 automatically recorded in the database (Bohnsack and Harper 1988; Froese and Pauly 2017). Species were classified into four major trophic guild categories: 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 samples in which the species was recorded out of the total number of samples. Mean species richness was the average number of species represented per sample ± standard error.

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 (Bohnsack and Harper 1988) based on information provided by FishBase (Froese and

Pauly 2017). As sizes less than 35 cm were binned, the median size in each size bin was used to calculate biomass (for example, fish in the ≥5 to <10 cm size bin were assigned the total length of 7.5 cm). Observations of manta rays and stingrays 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 (reducing the influence of large schooling species on analyses) using distance-based Bray-Curtis similarity matrices with Primer® version 7.0 (Anderson et al. 2008; Clarke et al. 2014). Significant differences in the fish community based on species level resemblance matrices were investigated using PERMANOVA (Anderson et al. 2008). 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 et al. 2014). Differences at the family level for key species were compared for significant dissimilarities using ANOSIM. For long-term density and biomass trends for which data was available (2011 to 2017), 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 et al. 2014).

Fish Surveys Results

A total of 24 families and 71 species were recorded in 2017 for all samples combined from EFGB and WFGB study sites. Mean species richness was 20.71 ± 0.81 per survey within the EFGB study site and 17.08 ± 0.76 per survey within the WFGB study site. Bonnetmouth (*Emmelichthyops atlanticus*) had the highest relative abundance of all species (25%) within the EFGB study site, followed by Mackerel Scad (*Decapterus* *macarellus*) (19%), Brown Chromis (*Chromis multilineata*) (14%), and Bluehead (*Thalassoma bifasciatum)* (11%) (Figure 7.2).

Within the WFGB study site, Mackerel Scad had the highest relative abundance of all species (57%), followed by Brown Chromis (11%), Bonnetmouth (10%), and Bluehead (5%) (Figure 7.2).

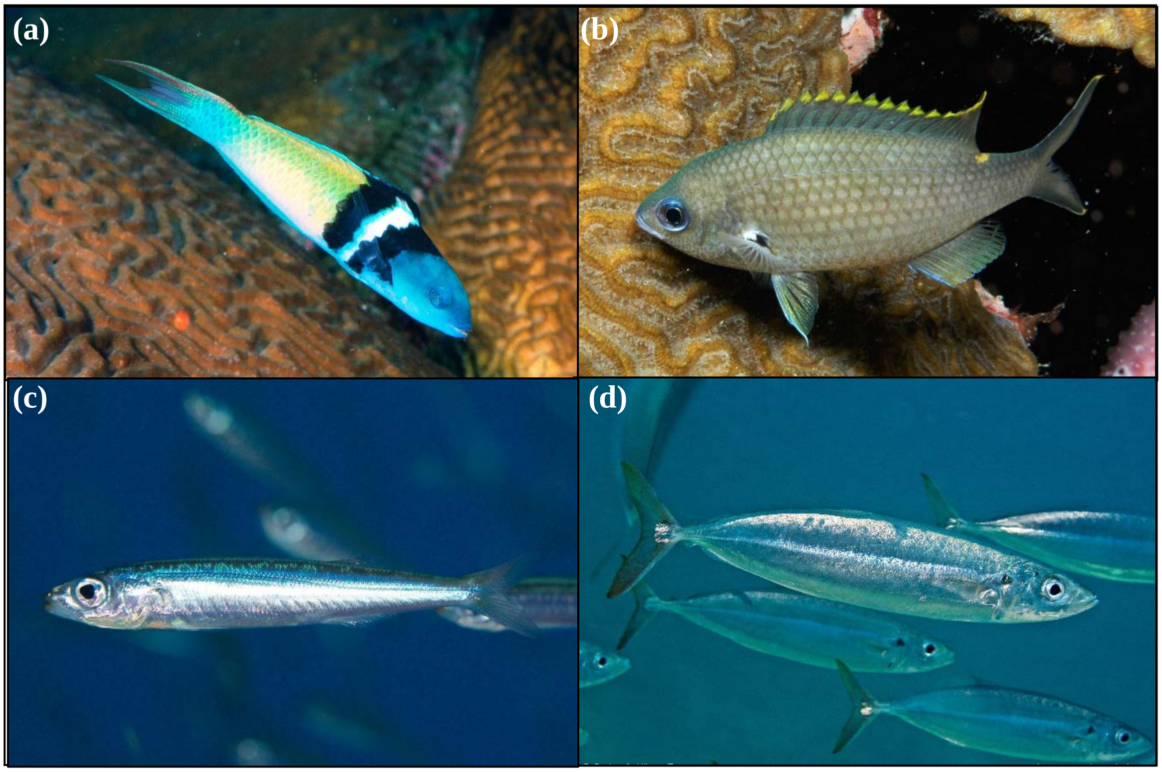


Figure 7.2. Most abundant fish species observed within EFGB and WFGB study sites in 2017: (a) Bluehead, (b) Brown Chromis, (c) Bonnetmouth, (d) Mackerel Scad. (Photos a and b: G.P. Schmahl, NOAA/FGBNMS; Photos c and d: Carlos Estapé)

Sighting Frequency and Occurrence

The most frequently sighted species within study sites at both banks was Bluehead, observed in 100% of surveys. Other frequently sighted species included Brown Chromis, Spanish Hogfish (*Bodianus rufus*), and Bicolor Damselfish (*Stegastes partitus*) (Table 7.1). Most shark and ray species were considered “rare,” typically occurring in <20% of all surveys (REEF 2014). Though no shark species were recorded, manta rays (*Manta spp.*) were observed in two surveys at EFGB. No sharks or mantas were observed in WFGB surveys.

Table 7.1. Top 15 most frequently sighted species within surveys in EFGB and WFGB study sites, including sighting frequency for all surveys combined in 2017.

Family Name: Species Name (Common Name)	EFGB	WFGB	All Surveys
Labridae: *Thalassoma bifasciatum* (Bluehead)	100.00	100.00	100.00
Pomacentridae*: Chromis multilineata* (Brown Chromis)	91.67	91.67	91.67
Labridae: *Bodianus rufus* (Spanish Hogfish)	91.67	79.17	85.42
Pomacentridae: *Stegastes partitus* (Bicolor Damselfish)	95.83	70.83	83.33
Epinephelidae: *Paranthias furcifer* (Atlantic Creolefish)	79.17	83.33	81.25
Acanthuridae: *Acanthurus coeruleus* (Blue Tang)	95.83	62.50	79.17
Labridae: *Sparisoma viride* (Stoplight Parrotfish)	95.83	58.33	77.08
Tetraodontidae: *Canthigaster rostrata* (Sharpnose Puffer)	91.67	58.33	75.00
Labridae: *Scarus vetula* (Queen Parrotfish)	91.67	54.17	72.92
Pomacentridae*: Stegastes variabilis* (Cocoa Damselfish)	91.67	41.67	66.67
Pomacentridae*: Stegastes planifrons* (Threespot Damselfish)	75.00	58.33	66.67
Sphyraenidae: *Sphyraena barracuda* (Great Barracuda)	62.50	70.83	66.67
Balistidae: *Melichthys niger* (Black Durgon)	50.00	66.67	58.33
Labridae: *Scarus taeniopterus* (Princess Parrotfish)	45.83	62.50	54.17
Labridae: *Clepticus parrae* (Creole Wrasse)	33.33	62.50	47.92

Density

Mean fish density (individuals/100 m²) ± standard error was 183.67 ± 32.76 within the EFGB study site and 181.78 ± 36.53 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 EFGB study site. SIMPER analysis identified the main contributors resulting in differences between study sites was due to a greater abundance of Mackerel Scad (14.98%) and Bonnetmouth (9.59%) at WFGB (Table 7.3).

Table 7.2. PERMANOVA results comparing mean fish density between EFGB and WFGB study sites from 2017. Bold text denotes significant value.

Source	Sum of Squares	df	Pseudo-F	P (perm)
Bank Study Site	10964	1	7.12	**0.001**
Res	70845	46		
Total	81809	47		

Table 7.3. Mean density (individuals/100 m^2) ± SE of the top 15 densest species from EFGB and WFGB study site surveys, and all surveys combined, in 2017.

Family Name: Species Name (Common Name)	EFGB	WFGB	All Surveys
Carangidae: *Decapterus macarellus* (Mackerel Scad)	35.49 ± 27.21	104.08 ± 33.59	69.79 ± 21.96
Haemulidae: *Emmelichthyops atlanticus* (Bonnetmouth)	46.69 ± 16.71	18.39 ± 12.93	32.54 ± 10.65
Pomacentridae: *Chromis multilineata* (Brown Chromis)	25.73 ± 3.81	19.76 ± 3.02	22.74 ± 2.45
Labridae: *Thalassoma bifasciatum* (Bluehead)	20.80 ± 3.46	8.77 ± 1.69	14.78 ± 2.10
Labridae: *Clepticus parrae* (Creole Wrasse)	4.79 ± 2.34	6.37 ± 2.42	5.58 ± 1.67
Pomacentridae: *Stegastes partitus* (Bicolor Damselfish)	8.80 ± 2.18	1.04 ± 0.23	4.92 ± 1.22
Epinephelidae: *Paranthias furcifer* (Atlantic Creolefish)	5.05 ± 0.98	1.56 ± 0.26	3.30 ± 0.56
Pomacentridae: *Stegastes variabilis* (Cocoa Damselfish)	5.35 ± 1.61	0.57 ± 0.18	2.96 ± 0.88
Carangidae: *Caranx ruber* (Bar Jack)	0.83 ± 0.25	4.22 ± 2.70	2.52 ± 1.37
Pomacentridae: *Stegastes planifrons* (Threespot Damselfish)	2.26 ± 0.48	1.86 ± 0.50	2.06 ± 0.34
Tetraodontidae: *Canthigaster rostrata* (Sharpnose Puffer)	2.95 ± 0.60	0.78 ± 0.16	1.86 ± 0.34
Labridae: *Scarus vetula* (Queen Parrotfish)	2.81 ± 0.35	0.68 ± 0.20	1.74 ± 0.25
Labridae: *Halichoeres garnoti* (Yellowhead Wrasse)	2.59 ± 0.89	0.85 ± 0.47	1.72 ± 0.52
Acanthuridae: *Acanthurus coeruleus* (Blue Tang)	2.10 ± 0.21	1.01 ± 0.19	1.56 ± 0.16
Sphyraenidae: *Sphyraena barracuda* (Great Barracuda)	0.85 ± 0.20	1.56 ± 0.39	1.20 ± 0.22

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).

Herbivore was the predominant trophic guild within the EFGB study site. Herbivore size distribution was variable within the EFGB study site, with a slight trend for larger individuals (≥20 to <35 cm). Invertivores were predominately smaller individuals (<5 cm to <15 cm). Piscivores were predominately either small (<5 to <10 cm) or large individuals (≥35 cm). The majority of planktivores were of moderate size (≥15 to <20 cm) within the EFGB study site (Figure 7.3).

Planktivore was the predominant trophic guild within the WFGB study site. Planktivore size distribution was variable within the WFGB study site, with a trend for smaller individuals (<5 to <15 cm). Invertivores were predominately smaller to medium size individuals (<5 cm to <25 cm). Piscivores were predominately large individuals (≥30 to

≥35 cm). Herbivore size distribution was variable within the WFGB study site, with a slight trend towards moderate size individuals (≥15 to <55 cm) (Figure 7.3).

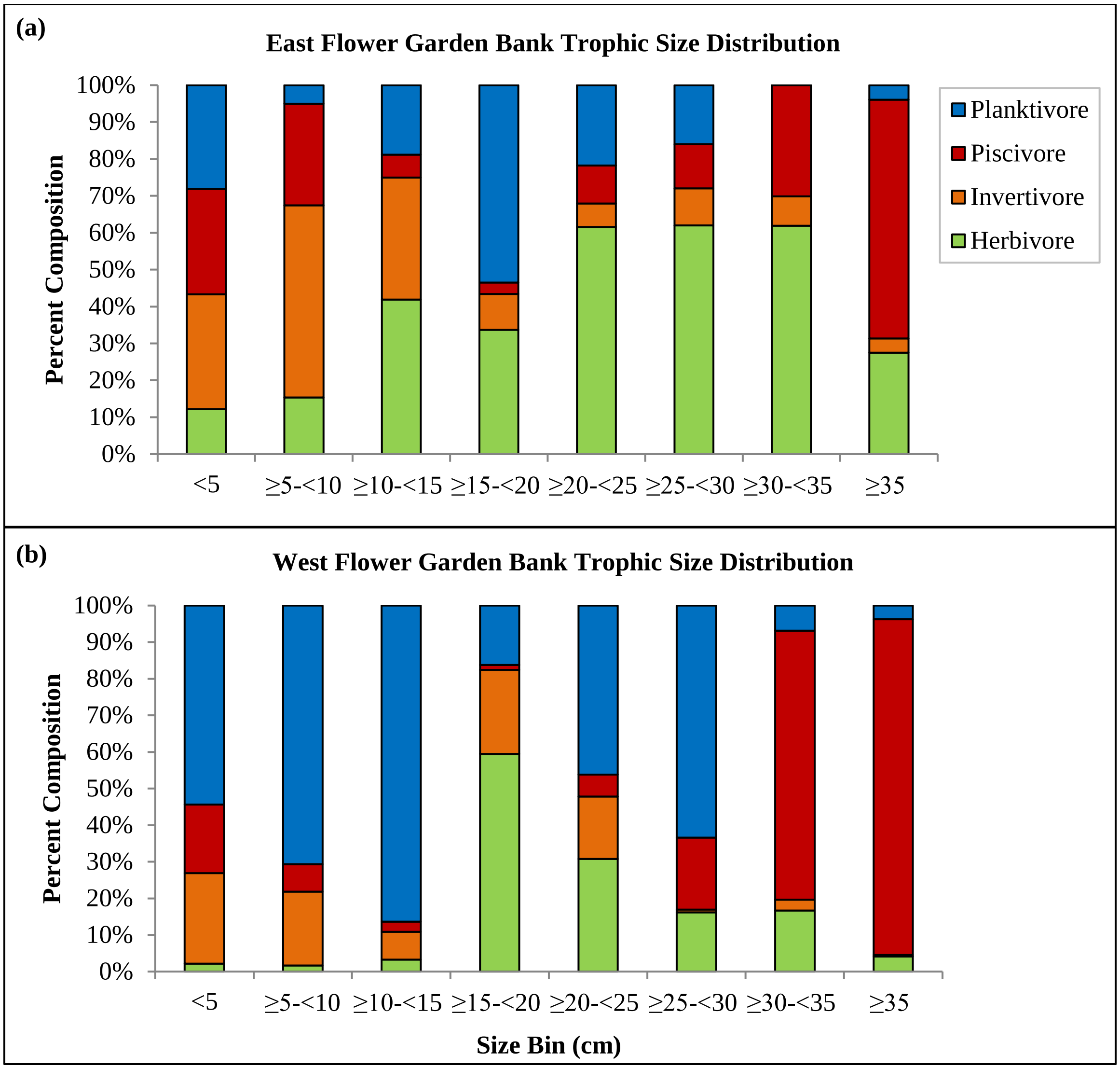


Figure 7.3. Fish survey size distribution by trophic guild within (a) EFGB and (b) WFGB study sites in 2017.

Biomass

Mean biomass (g/100 m^2) ± standard error was 4,547.24 ± 647.93 within the EFGB study site and 9,805.27 ± 1,409.61 within the WFGB study site in 2017. 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 WFGB study site. SIMPER analysis identified the main contributors resulting in higher fish biomass within the WFGB study site was due to greater local abundance of Great Barracuda (*Sphyraena barracuda*) (10.45%).

Table 7.4. PERMANOVA results comparing mean fish biomass between EFGB and WFGB study sites from 2017. Bold text denotes significant value.

Source	Sum of Squares	df	Pseudo-F	P (perm)
Bank Study Site	8511	1	3.80	**0.001**
Res	103000	46		
Total	111510	47		

When classified by trophic guild, piscivores possessed the highest mean biomass for all surveys and the lowest mean biomass for all surveys was represented by invertivores (Table 7.5). PERMANOVA analysis comparing trophic guilds revealed significant differences between study sites (Table 7.6). SIMPER analysis identified the main difference as greater local abundance of piscivores (46.40%) and planktivores (24.68%) in the WFGB study site (Table 7.5).

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 2017.

Trophic Group	EFGB	WFGB	All Surveys
Herbivore	2457.55 ± 501.64	1483.20 ± 302.76	1970.37 ± 402.20
Invertivore	477.85 ± 97.54	382.65 ± 78.11	430.25 ± 87.82
Planktivore	474.20 ± 96.80	1794.48 ± 366.30	1134.34 ± 231.55
Piscivore	1137.65 ± 232.22	6144.93 ± 1254.33	3641.29 ± 743.28

Table 7.6. PERMANOVA results comparing trophic guild biomass between EFGB and WFGB study sites from 2017. Bold text denotes significant value.

Source	Sum of Squares	df	Pseudo-F	P (perm)
Bank Study Site	6206	1	9.65	**0.001**
Res	29593	46		
Total	35799	47		

Overall, piscivores at the study sites represented approximately 51% of biomass, followed by herbivores (28%), planktivores (16%) and invertivores (6%). Piscivores and herbivores differered by bank; however, with piscivores dominating biomass at WFGB (63% vs. 15% for herbivores) and the reverse at EFGB (54% for herbivores and 25% for piscivores).

Within each trophic guild, mean biomass for each species was calculated (Table 7.7). For the herbivore guild, 30% of the biomass was contributed by Stoplight Parrotfish (*Sparisoma viride*). For the invertivore guild, the greatest contribution was from Bluehead (12% of guild biomass). For the piscivore guild, Great Barracuda contributed the greatest biomass to all surveys, at 42%. For the planktivore guild, the greatest contribution was from Atlantic Creolefish (40% of guild biomass).

Table 7.7. 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	Labridae: *Sparisoma viride* (Stoplight Parrotfish)	683.98 ± 274.68	496.45 ± 168.90	590.22 ± 160.09
	Labridae: *Scarus vetula* (Queen Parrotfish)	568.51 ± 117.86	287.12 ± 81.30	427.81 ± 73.74
	Kyphosidae: *Kyphosus saltatrix/incisor* (Chub (Bermuda/Yellow))	608.95 ± 412.13	54.23 ± 23.81	331.59 ± 208.17
	Balistidae: *Melichthys niger* (Black Durgon)	154.53 ± 58.36	236.09 ± 60.50	195.31 ± 42.00
	Acanthuridae: *Acanthurus coeruleus* (Blue Tang)	205.05 ± 32.84	171.54 ± 51.82	188.30 ± 30.45
	Labridae: *Scarus taeniopterus* (Princess Parrotfish)	100.12 ± 35.65	97.12 ± 24.04	98.62 ± 21.27
	Labridae: *Sparisoma aurofrenatum* (Redband Parrotfish)	51.20 ± 22.74	21.17 ± 14.66	36.19 ± 13.56
	Acanthuridae: *Acanthurus chirurgus* (Doctorfish)	60.30 ± 24.88	7.08 ± 6.09	33.69 ± 13.25
	Acanthuridae: *Acanthurus tractus* (Ocean Surgeonfish)	0.00	46.18 ± 19.64	23.09 ± 10.28
	Pomacentridae: *Microspathodon chrysurus* (Yellowtail Damselfish)	4.07 ± 2.24	38.20 ± 14.67	21.13 ± 7.75
	Pomacentridae: *Stegastes adustus* (Dusky Damselfish)	2.36 ± 0.79	13.43 ± 10.27	7.89 ± 5.16
	Pomacentridae: *Stegastes variabilis* (Cocoa Damselfish)	5.96 ± 2.06	7.74 ± 3.65	6.85 ± 2.08
	Pomacentridae: *Stegastes partitus* (Bicolor Damselfish)	8.59 ± 2.45	4.39 ± 1.27	6.49 ± 1.40
	Labridae: *Scarus iseri* (Striped Parrotfish)	2.58 ± 0.96	2.11 ± 2.09	2.35 ± 1.14
	Blenniidae: *Ophioblennius macclurei* (Redlip Blenny)	0.71 ± 0.34	0.37 ± 0.17	0.54 ± 0.19
	Labridae: *Sparisoma atomarium* (Greenblotch Parrotfish)	0.60 ± 0.60	0.00	0.30 ± 0.30
	Gobiidae: *Gnatholepis thompsoni* (Goldspot Goby)	0.01 ± 0.01	0.00 ± 0.00	0.01 ± 0.00
Invertivore	Labridae: *Thalassoma bifasciatum* (Bluehead)	37.31 ± 15.29	66.30 ± 25.77	51.80 ± 14.97
	Labridae: *Bodianus rufus* (Spanish Hogfish)	64.78 ± 21.83	36.11 ± 10.00	50.45 ± 12.06
	Pomacanthidae: *Pomacanthus paru* (French Angelfish)	25.48 ± 25.48	74.24 ± 54.03	49.86 ± 29.76
	Balistidae: *Balistes vetula* (Queen Triggerfish)	58.78 ± 58.78	0.00	29.39 ± 29.39
	Pomacentridae: *Stegastes planifrons* (Threespot Damselfish)	29.76 ± 10.15	26.90 ± 7.96	28.33 ± 6.38
	Pomacentridae: *Chromis multilineata* (Brown Chromis)	9.58 ± 2.57	46.90 ± 11.98	28.24 ± 6.64

	Family Name: Species Name - Common Name	EFGB	WFGB	All Surveys
Invertivore	Chaetodontidae: *Chaetodon sedentarius* (Reef Butterflyfish)	38.36 ± 23.56	15.99 ± 6.97	27.18 ± 12.26
	Lutjanidae: *Lutjanus griseus* (Gray Snapper)	22.01 ± 22.01	23.91 ± 16.54	22.96 ± 13.62
	Mullidae: *Mulloidichthys martinicus* (Yellow Goatfish)	33.81 ± 23.45	11.12 ± 11.12	22.46 ± 12.94
	Pomacanthidae: *Holacanthus ciliaris* (Queen Angelfish)	26.93 ± 16.52	6.63 ± 6.63	16.78 ± 8.93
	Balistidae: *Canthidermis sufflamen* (Ocean Triggerfish)	31.93 ± 31.93	0.00	15.96 ± 15.96
	Pomacanthidae: *Holacanthus tricolor* (Rock Beauty)	14.45 ± 5.99	14.91 ± 8.63	14.68 ± 5.20
	Labridae: *Halichoeres garnoti* (Yellowhead Wrasse)	6.19 ± 1.67	20.90 ± 12.22	13.55 ± 6.20
	Ostraciidae: *Lactophrys triqueter* (Smooth Trunkfish)	16.34 ± 8.73	4.27 ± 2.36	10.30 ± 4.56
	Chaetodontidae: *Chaetodon ocellatus* (Spotfin Butterflyfish)	15.32 ± 8.38	0.00	7.66 ± 4.29
	Epinephelidae: *Epinephelus adscensionis* (Rock Hind)	8.68 ± 5.52	6.04 ± 4.46	7.36 ± 3.52
	Ostraciidae: *Acanthostracion polygonius* (Honeycomb Cowfish)	14.67 ± 14.48	0.00	7.33 ± 7.24
	Tetraodontidae: *Canthigaster rostrata* (Sharpnose Puffer)	8.89 ± 4.05	3.72 ± 0.86	6.31 ± 2.08
	Pomacentridae: *Abudefduf saxatilis* (Sergeant Major)	2.55 ± 1.47	7.12 ± 4.26	4.83 ± 2.25
	Chaetodontidae: *Prognathodes aculeatus* (Longsnout Butterflyfish)	1.24 ± 0.72	5.75 ± 3.37	3.49 ± 1.74
	Epinephelidae: *Epinephelus guttatus* (Red Hind)	0.00	5.86 ± 5.86	2.93 ± 2.93
	Chaetodontidae: *Chaetodon striatus* (Banded Butterflyfish)	3.29 ± 3.06	2.21 ± 2.21	2.75 ± 1.87
	Holocentridae: *Holocentrus adscensionis* (Squirrelfish)	0.00	2.63 ± 2.63	1.31 ± 1.31
	Epinephelidae: *Cephalopholis fulva* (Coney)	2.20 ± 2.20	0.00	1.10 ± 1.10
	Mullidae: *Pseudupeneus maculatus* (Spotted Goatfish)	1.90 ± 1.90	0.00	0.95 ± 0.95
	Monacanthidae: *Aluterus scriptus* (Scrawled Filefish)	1.78 ± 1.78	0.00	0.89 ± 0.89
	Monacanthidae: *Cantherhines macrocerus* (White Spotted Filefish)	1.08 ± 1.08	0.00	0.54 ± 0.54
	Monacanthidae: *Cantherhines pullus* (Orange Spotted Filefish)	0.02 ± 0.02	1.04 ± 1.04	0.53 ± 0.52
	Labridae: *Bodianus pulchellus* (Spotfin Hogfish)	0.16 ± 0.16	0.00	0.08 ± 0.08
	Labridae: *Halichoeres radiatus* (Puddingwife)	0.15 ± 0.14	0.00	0.07 ± 0.07
	Labridae: *Halichoeres maculipinna* (Clown Wrasse)	0.12 ± 0.12	0.01 ± 0.01	0.07 ± 0.06

	Family Name: Species Name - Common Name	EFGB	WFGB	All Surveys
	Cirrhitidae: *Amblycirrhitus pinos* (Redspotted Hawkfish)	0.07 ± 0.06	0.06 ± 0.06	0.06 ± 0.04
	Gobiidae: *Elacatinus oceanops* (Neon Goby)	0.03 ± 0.01	0.01 ± 0.01	0.02 ± 0.01
	Pomacentridae: *Stegastes leucostictus* (Beaugregory)	0.00	0.02 ± 0.02	0.01 ± 0.01
	Tetraodontidae: *Canthigaster jamestyleri* (Goldface Toby)	0.00	0.00	0.00
	Pomacanthidae: *Holacanthus townsendi* (Townsend Angelfish)	0.00	0.00	0.00
Piscivore	Sphyraenidae: *Sphyraena barracuda* (Great Barracuda)	876.04 ± 277.47	2205.43 ± 699.29	1540.74 ± 384.56
	Carangidae: *Caranx ruber* (Bar Jack)	32.32 ± 14.92	1062.52 ± 742.01	547.42 ± 374.72
	Lutjanidae: *Lutjanus jocu* (Dog Snapper)	0.00	813.66 ± 438.16	406.83 ± 224.71
	Carangidae: *Caranx latus* (Horse-eye Jack)	80.51 ± 55.68	697.63 ± 496.67	389.07 ± 251.28
	Carangidae: *Seriola rivoliana* (Almaco Jack)	0.00	584.80 ± 256.00	292.40 ± 133.62
	Carangidae: *Caranx lugubris* (Black Jack)	23.28 ± 23.28	446.42 ± 434.43	234.85 ± 217.40
	Scorpaenidae: *Pterois volitans* (Lionfish)	4.26 ± 3.34	116.33 ± 48.60	60.30 ± 25.44
	Haemulidae: *Emmelichthyops atlanticus* (Bonnetmouth)	43.87 ± 21.55	59.01 ± 40.53	51.44 ± 22.73
	Epinephelidae: *Mycteroperca interstitialis* (Yellowmouth Grouper)	39.81 ± 26.21	35.31 ± 25.50	37.56 ± 18.09
	Epinephelidae: *Cephalopholis cruentata* (Graysby)	27.38 ± 20.49	43.12 ± 17.85	35.25 ± 13.49
	Muraenidae: *Gymnothorax moringa* (Spotted Moray)	0.00	48.81 ± 48.81	24.41 ± 24.41
	Serranidae: *Mycteroperca tigris* (Tiger Grouper)	6.86 ± 6.86	31.89 ± 31.89	19.38 ± 16.24
	Carangidae: *Caranx crysos* (Blue Runner)	3.31 ± 2.42	0.00	1.65 ± 1.22
Planktivore	Epinephelidae: *Paranthias furcifer* (Atlantic Creolefish)	358.05 ± 79.54	539.39 ± 160.45	448.72 ± 89.57
	Labridae: *Clepticus parrae* (Creole Wrasse)	112.23 ± 68.30	742.07 ± 316.78	427.15 ± 166.75
	Carangidae: *Decapterus macarellus* (Mackerel Scad)	3.59 ± 2.76	509.80 ± 211.91	256.70 ± 111.14
	Pomacentridae: *Chromis cyanea* (Blue Chromis)	0.06 ± 0.02	2.85 ± 1.28	1.45 ± 0.66
	Pomacentridae: *Chromis insolata* (Sunshinefish)	0.19 ± 0.09	0.13 ± 0.07	0.16 ± 0.05
	Pomacentridae: *Chromis scotti* (Purple Reeffish)	0.08 ± 0.04	0.24 ± 0.18	0.16 ± 0.09

Abundance-Biomass Curves

Mean w-values for the EFGB study site were 0.07 ± 0.01 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). ANOSIM comparisons of w-values between bank study sites revealed no significant dissimilarities between the dominance plot w-values.

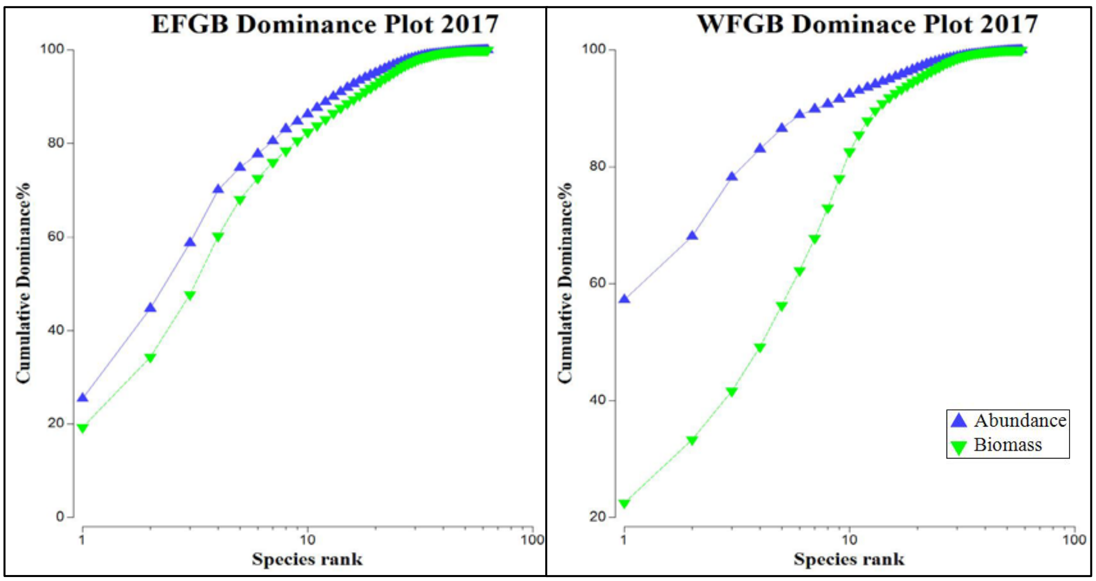


Figure 7.4. Abundance-Biomass curves for EFGB and WFGB study sites in 2017.

Family Level Analysis

Due to particular interest in 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 2017 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 2017, six species were observed in all surveys combined: Coney, Graysby, Red Hind, Rock Hind, Tiger Grouper, and Yellowmouth Grouper. It should be noted that coefficient of variation percentages (24.49% for density, 28.54% for biomass) indicated that the density and biomass data collected in 2017 had poor power to detect population changes due to the relatively low number of grouper observed. ANOSIM results indicated no significant differences in community composition based on density or biomass between study sites.

Mean biomass of small-bodied grouper, including Coney, Graysby, Red Hind, and Rock Hind was 38.26 ± 24.59 in the EFGB study site and 55.02 ± 18.03 in the WFGB study site. Mean biomass of large-bodied grouper, including Tiger Grouper and Yellowmouth was 46.67 ± 26.65 within the EFGB study site and 67.20 ± 39.62 within the WFGB study site. Size distributions of observed grouper in 2017 varied by species (Figure 7.5).

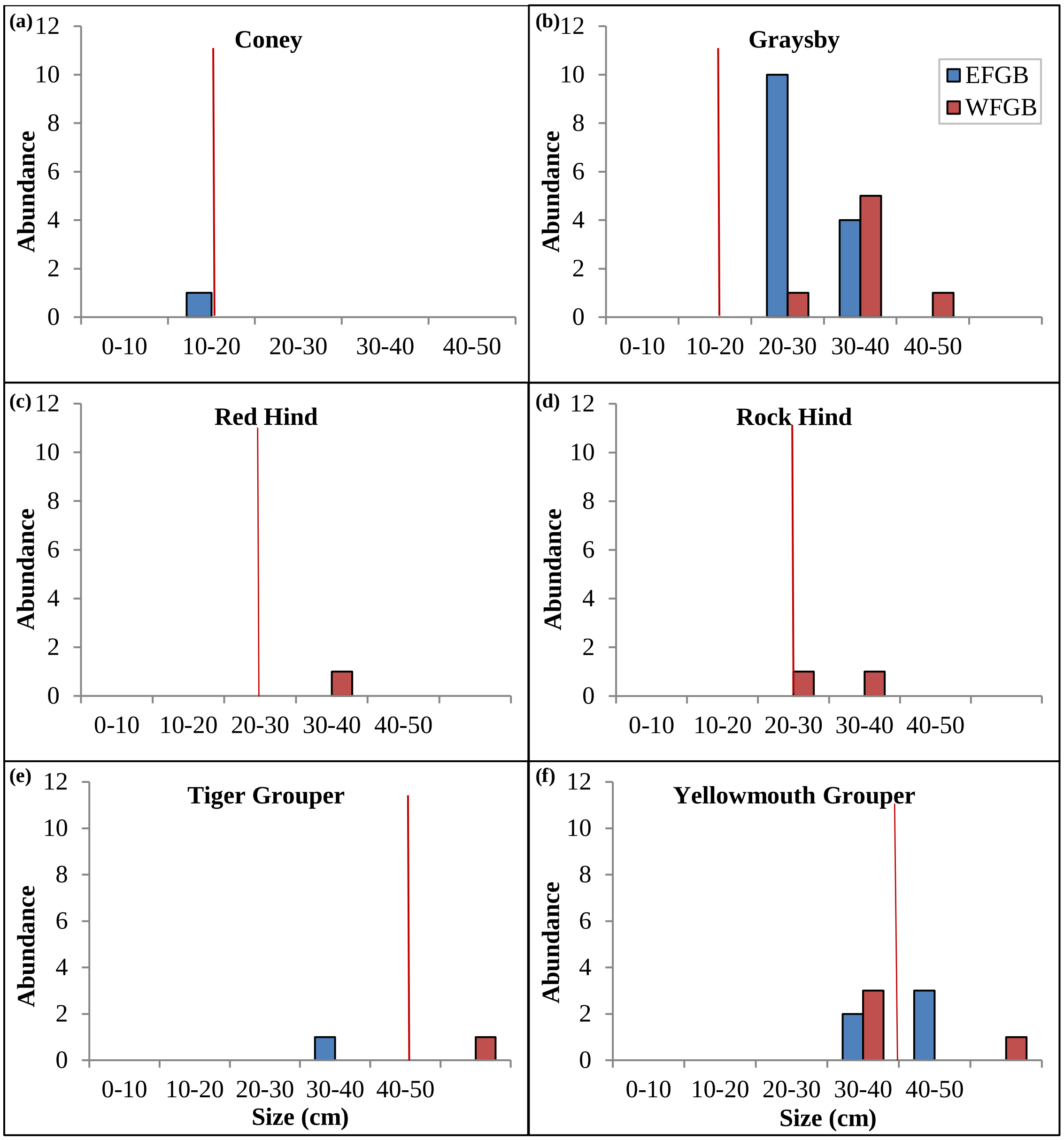


Figure 7.5. Size frequency of grouper species within EFGB and WFGB study site surveys in 2017: (a) Coney, (b) Graysby, (c) Red Hind, (d) Rock Hind, (e) Tiger Grouper, and (e) Yellowmouth Grouper.

Vertical solid red lines represent estimated size of female maturity (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 (37.19% for density, 52.17% for biomass) indicated that the data collected in 2016 had poor power to detect population differences due to the low number of snapper observed. Mean snapper biomass within the EFGB study site was 22.01 ± 22.01 and 837.57 ± 436.54 within the WFGB study site. Snapper size distributions were dominated by larger individuals that were reproductively mature (Figure 7.6). No statistical analysis was completed on snapper biomass or density due to the low number of snapper observed in surveys.

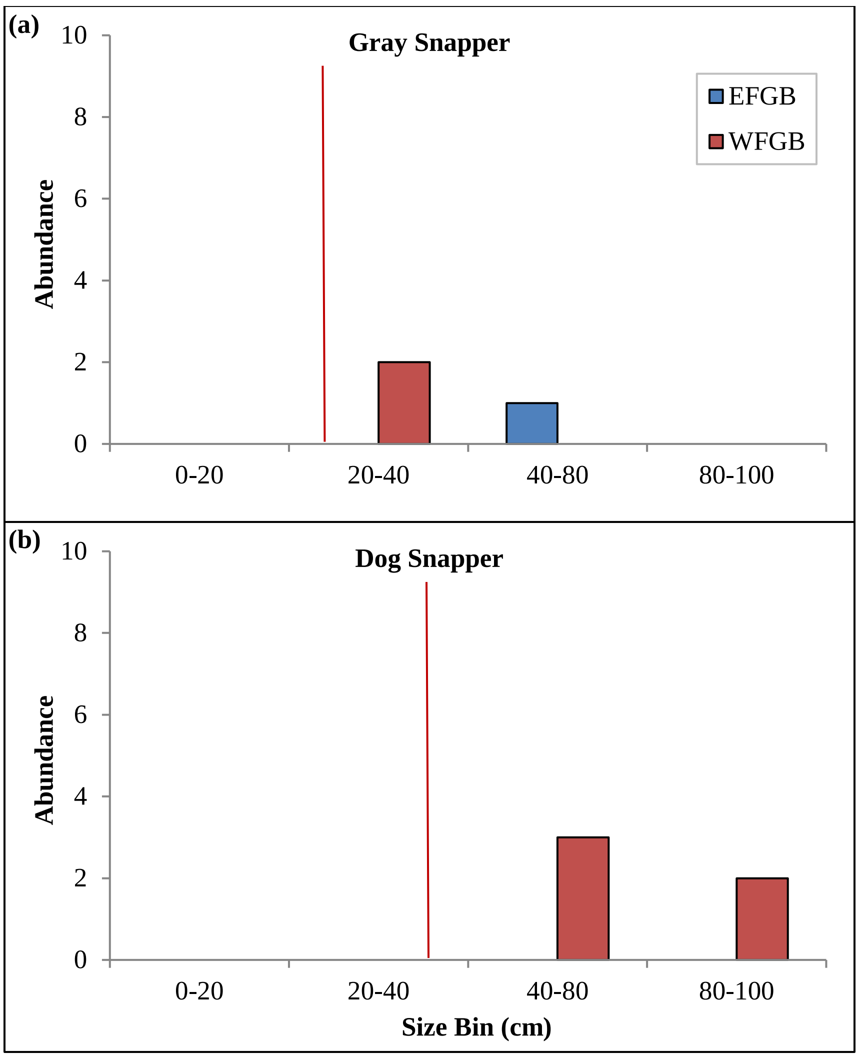


Figure 7.6. Size frequency of snapper species observed within EFGB and WFGB study site surveys in 2017: (a) Gray Snapper and (b) Dog Snapper.

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

Parrotfishes are important herbivores on coral reefs because they are effective grazers on Caribbean reefs (Jackson et al. 2014). 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 (12.17% for density and 16.43% for biomass) indicated that the data had good power to detect population differences.

Mean biomass of parrotfishes was 1407.00 ± 320.71 within the EFGB study site and 903.97 ± 197.63 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 (<20 cm) (Figure 7.7). ANOSIM results indicated significant spatial variation in parrotfish community composition between EFGB and WFGB study sites based on density (*Global R*=0.28, *p*=0.1%). No significant differences in biomass were found. The observed dissimilarity in density between study sites was mainly attributable to Queen Parrotfish (28.40%), as the EFGB study site had greater overall density of Queen Parrotfish.

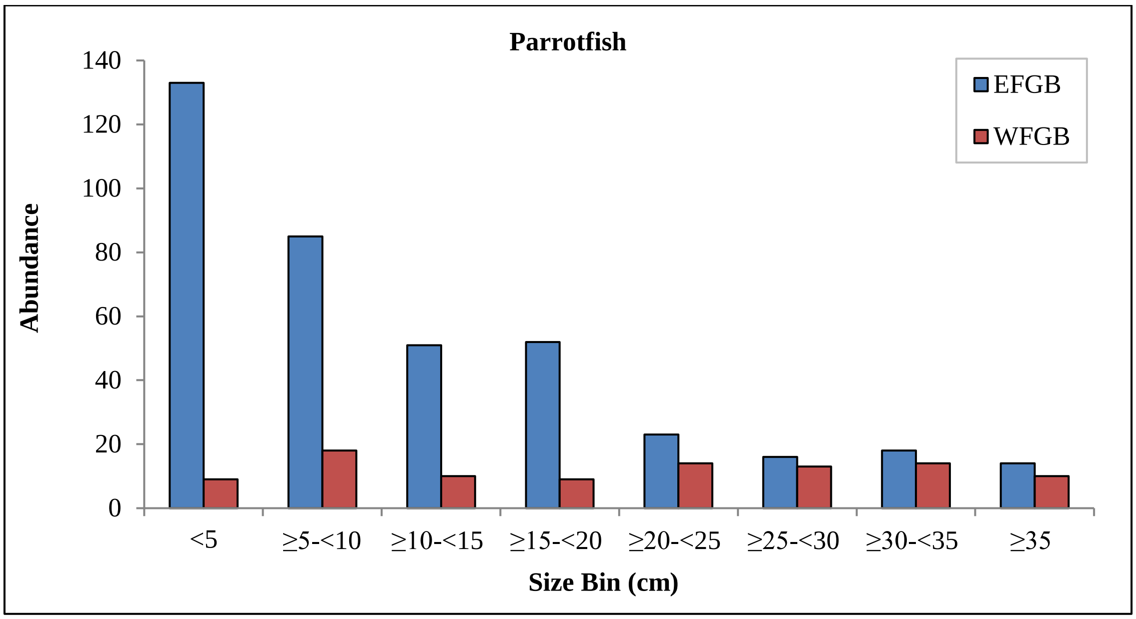


Figure 7.7. Size frequency of parrotfishes within EFGB and WFGB study site surveys in 2017.

Lionfish

This reporting year marks the fifth consecutive documentation of lionfish (*Pterois volitans*), an invasive species native to the Indo-Pacific, in long-term monitoring study site surveys. Total abundance was two individual lionfish within the EFGB study site surveys and seven lionfish in the WFGB study site surveys (sighting frequency 8.33% and 20.83%, respectively). Since the initial documentation of lionfish in the long-term monitoring dataset, overall abundance increased from 2013 to 2014, but decreased in recent years (Figure 7.8). Lionfish size distributions were dominated by moderate and large sized individuals (15 to 35cm) (Figure 7.9).

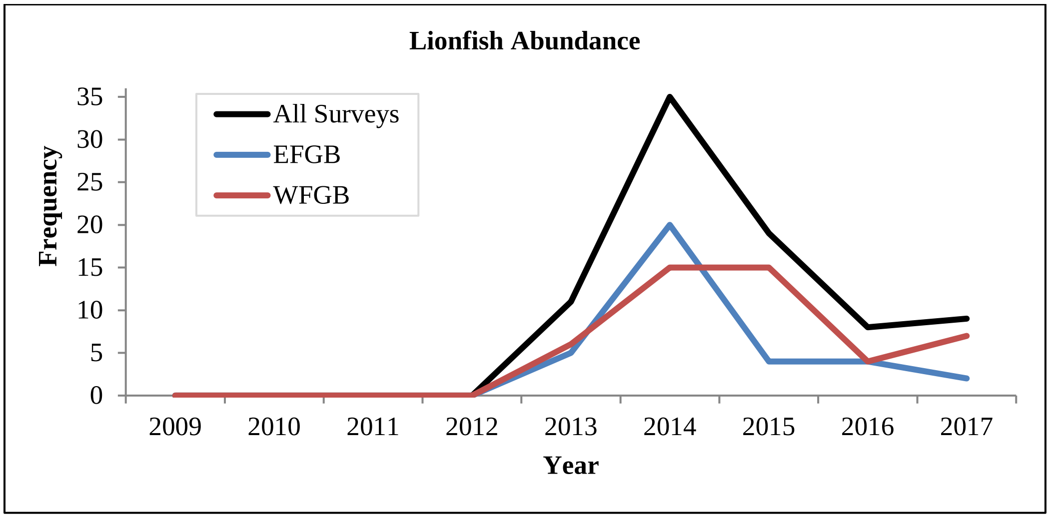


Figure 7.8. Lionfish abundance within EFGB and WFGB study site surveys from 2012 to 2017.

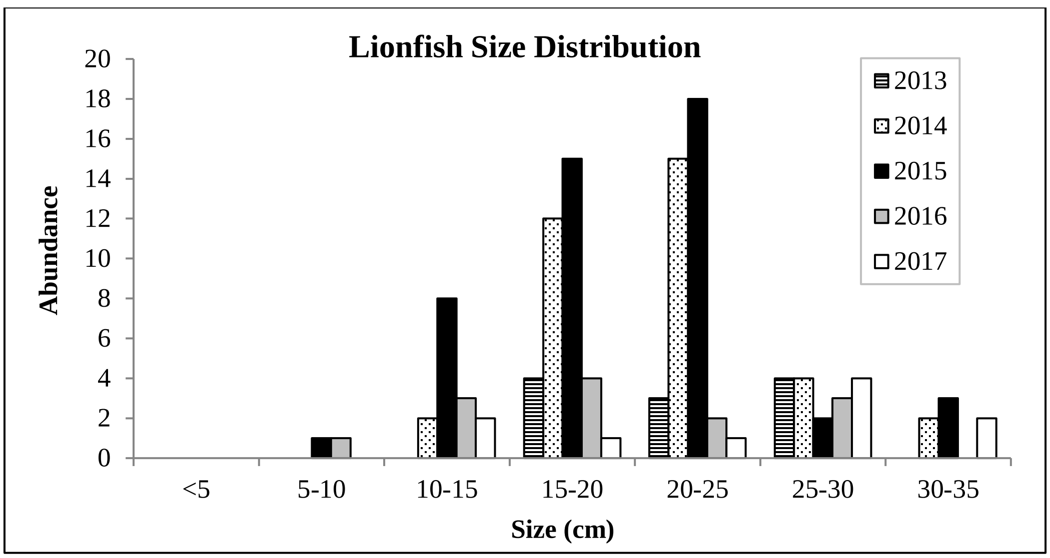


Figure 7.9. Lionfish size distribution within EFGB and WFGB study site surveys from 2013 to 2017.

Coefficient of variation percentages (37.77% for density and 42.20% for biomass) indicated that the data had poor power to detect population differences due to the low number of lionfish observed. Mean density for all surveys was 0.11 ± 0.04 and mean biomass for the EFGB study site was 4.26 ± 3.34 and 116.33 ± 48.60 for the WFGB study site. ANOSIM results indicated no significant differences in lionfish density or biomass between study sites in 2017.

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).

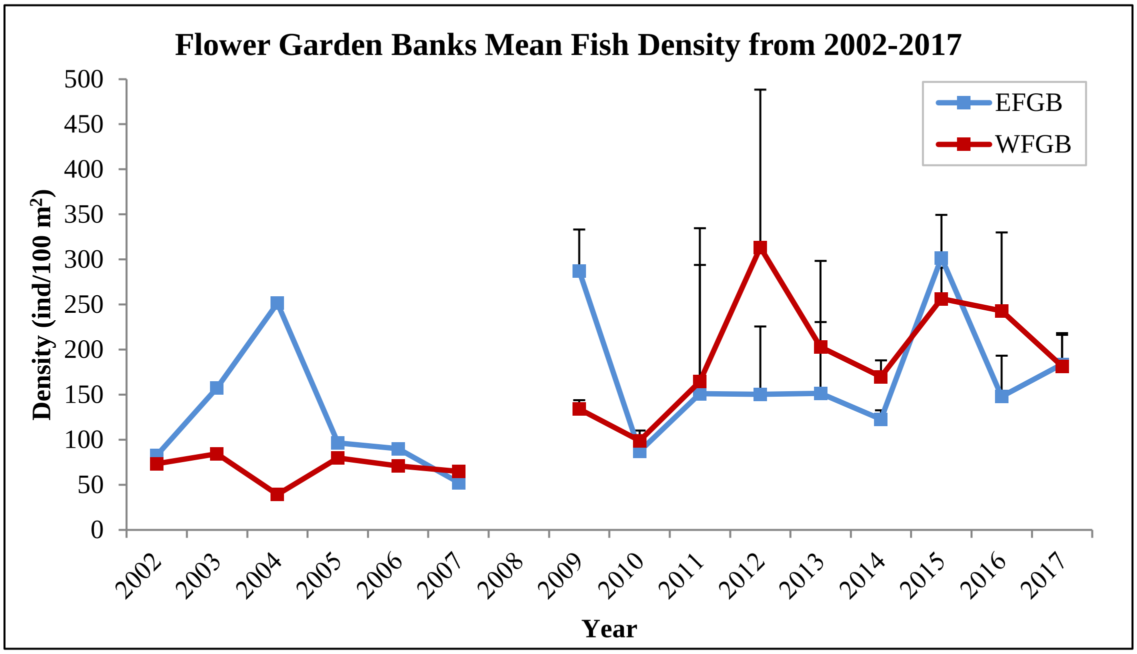


Figure 7.10. Mean fish density (individuals/100 m^2) +SE within EFGB and WFGB study sites from 2002 to 2017.

No data were collected in 2008 and SE was not available before 2009. Data for 2002 to 2008 are from PBS&J (Precht et al. 2006; Zimmer et al. 2010) and FGBNMS for 2009 to 2016 (Johnston et al. 2013, 2015, 2017a, 2017b).

Fish community density was compared among years and bank study sites when complete survey data was available (2011 to 2017). PERMANOVA analysis revealed significant differences between bank study sites, years, and the year x bank study site interaction was also significant (Table 7.8), demonstrating fish density highly variable between year and EFGB and WFGB study sites from 2011 to 2017. 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 2017 was mainly attributable to Brown Chromis (9.40%), Bonnetmouth (6.83%), and Creole Wrasse (6.06%).

Table 7.8. PERMANOVA results comparing mean fish density within EFGB and WFGB study sites from 2011 to 2017. Bold text denotes significant value.

Source	Sum of Squares	df	Pseudo-F	P (perm)
Year	66606	6	2.90	**0.001**
Bank Study Site	9446	1	7.70	**0.001**
Year*Bank Study Site	22981	6	3.12	**0.001**
Res	409620	334		
Total	508530	347		

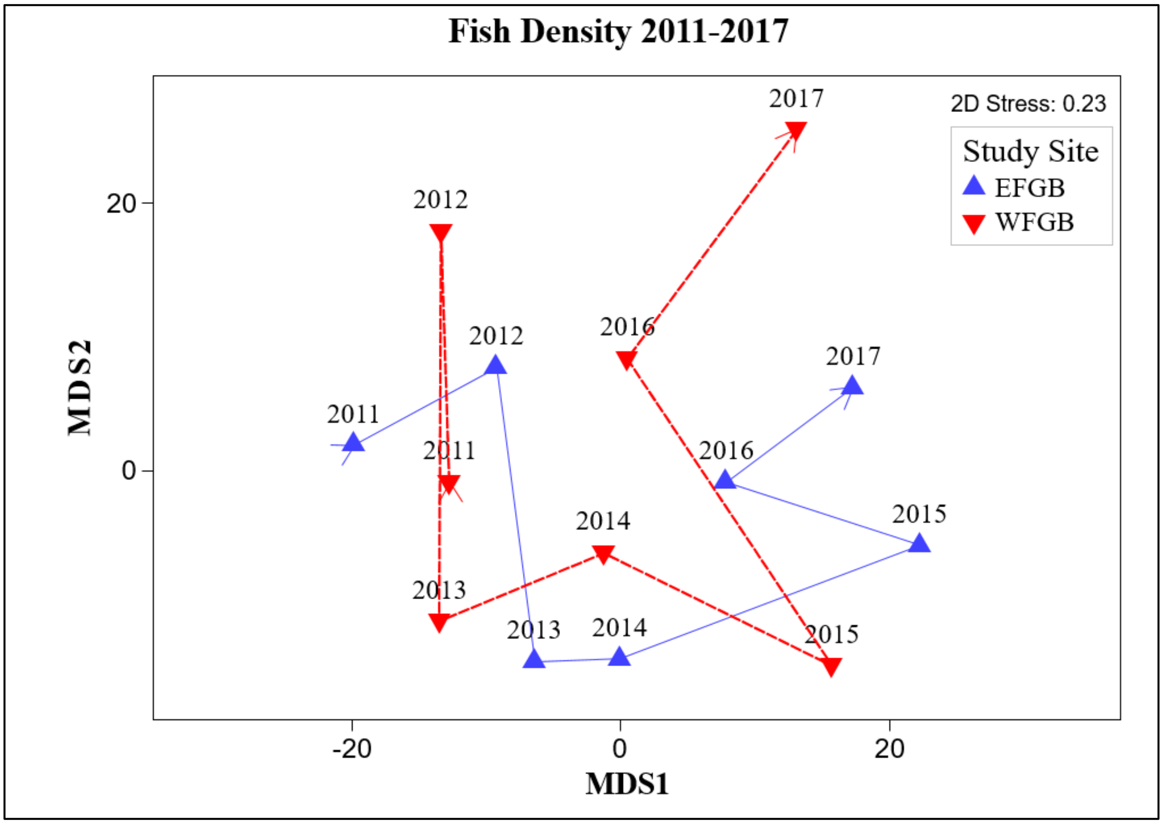


Figure 7.11. Two-dimensional MDS plot based on Bray-Curtis similarities showing shifts in the fish community due to changes in density within EFGB and WFGB study sites from 2011 to 2017.

Biomass data were first collected in 2006, and ranged from 4,547.24 to 24,270.00 g/100 m^2 within the EFGB study site and 2,458.47 to 27,226.00 g/100 m^2 within the WFGB study site from 2006 to 2017 (Figure 7.12).

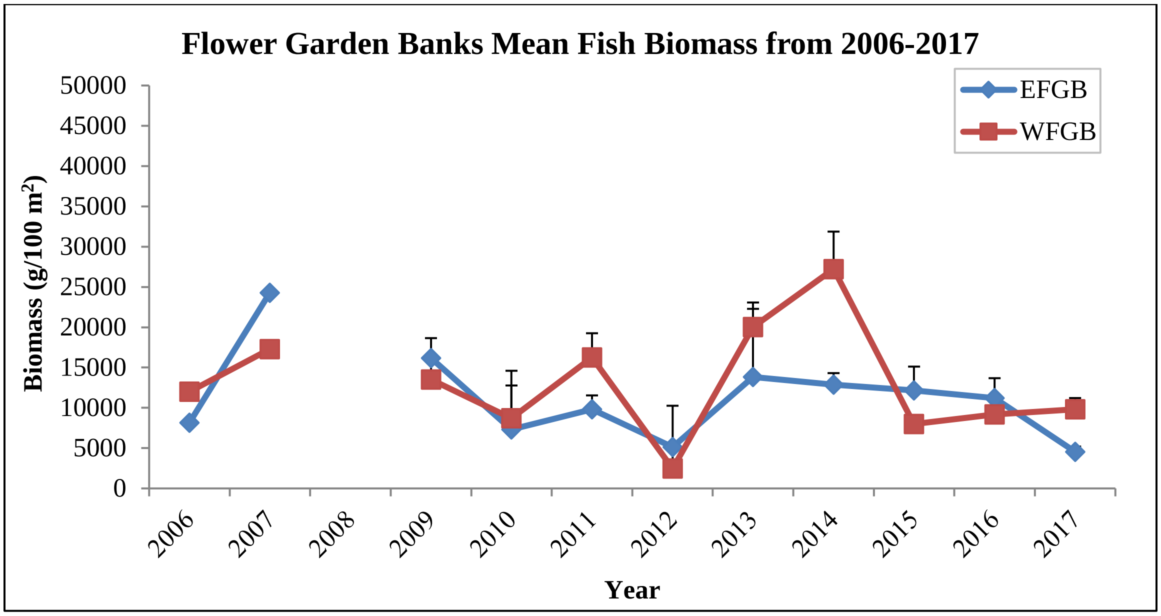


Figure 7.12. Mean fish biomass (g/100 m^2) +SE within EFGB and WFGB study sites from 2006 to 2017.

No data were collected in 2008 and SE was not available before 2009. Data for 2002 to 2008 are from PBS&J (Precht et al. 2006; Zimmer et al. 2010) and FGBNMS for 2009 to 2016 (Johnston et al. 2013, 2015, 2017a, 2017b).

When compared among years and locations from 2011 to 2017, PERMANOVA analysis revealed significant differences between bank study sites, years, and the year x bank study site interaction was also significant (Table 7.9), suggesting that biomass was highly variable in EFGB and WFGB study sites from 2011 to 2017 (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 2017 was mainly attributable to Great Barracuda (10.81%), Atlantic Creolefish (8.48%), and Bermuda Chub (8.01%).

Table 7.9. PERMANOVA results comparing mean fish biomass within EFGB and WFGB study sites from 2011 to 2017. Bold text denotes significant values.

Source	Sum of Squares	df	Pseudo-F	P (perm)
Year	367720	6	11.67	**0.001**
Bank Study Site	7598	1	3.69	**0.001**
Year*Bank Study Site	31514	6	2.55	**0.001**
Res	688510	334		
Total	1095400	347		

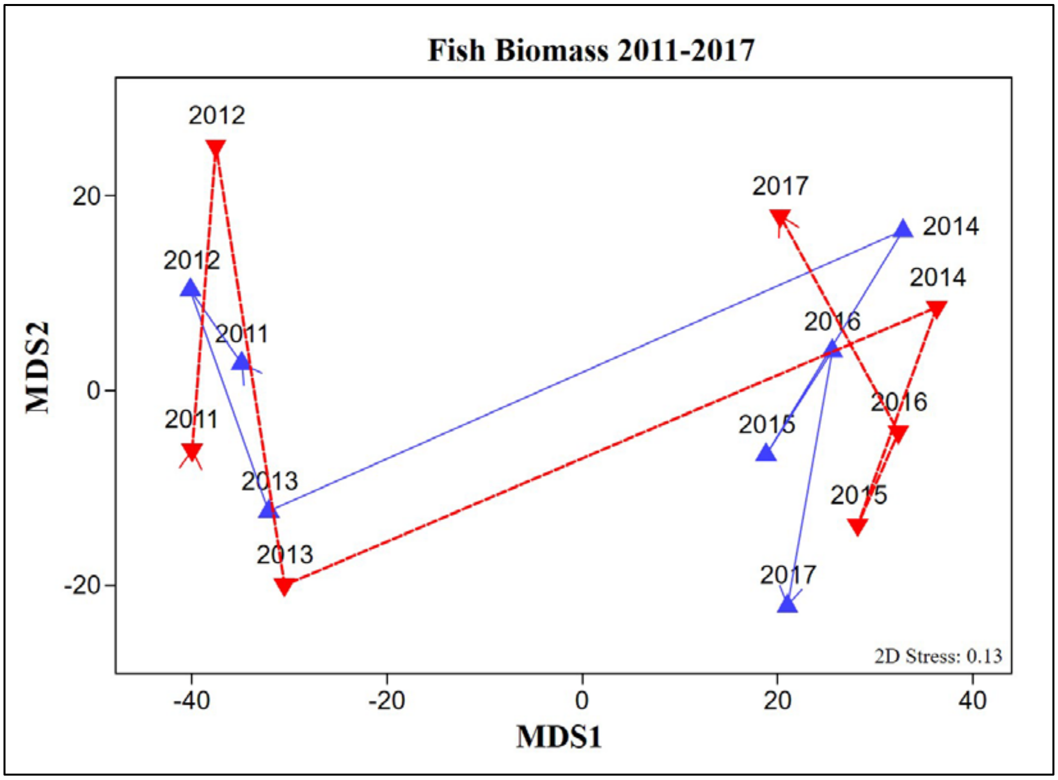


Figure 7.13. Two-dimensional MDS plot based on Bray-Curtis similarities showing shifts in the fish community due to changes in biomass within EFGB and WFGB study sites from 2011 to 2017.

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 2017). 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).

Grouper community density was compared among years and bank study sites from 2011 to 2017. PERMANOVA analysis revealed a significant difference between bank study sites (Table 7.10), 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 2017 was mainly attributable to Graysby (42.13%) and Yellowmouth Grouper (22.51%).

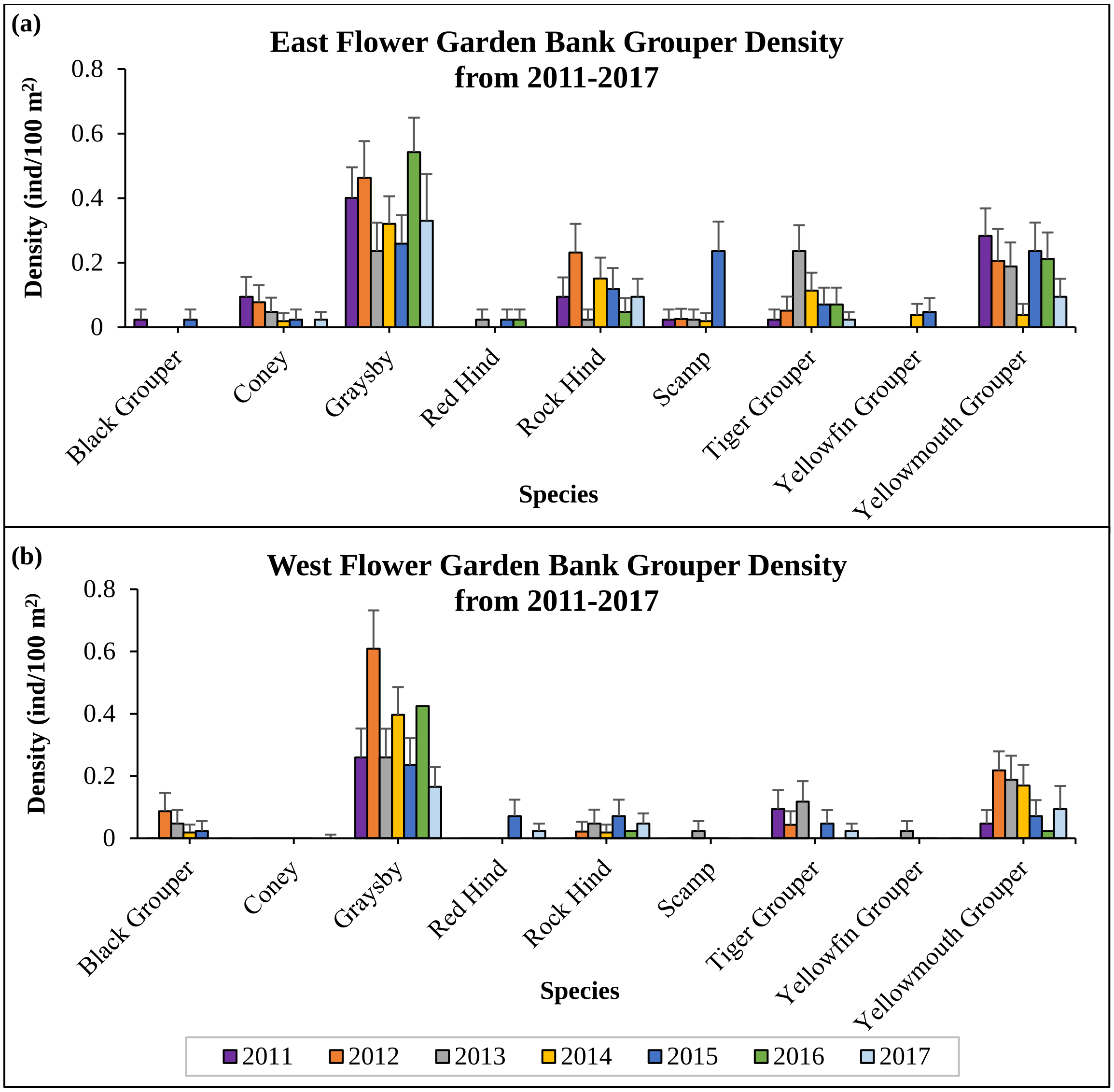


Figure 7.14. Mean density (individuals/100 m^2) +SE of grouper species within (a) EFGB and (b) WFGB study sites from 2011 to 2017.

Data for 2011 to 2016 are from FGBNMS (Johnston et al. 2015, 2017a, 2017b).

Table 7.10. PERMANOVA results comparing mean grouper density within EFGB and WFGB study sites from 2011 to 2017. Bold text denotes significant value.

Source	Sum of Squares	df	Pseudo-F	P (perm)
Year	5	6	1.27	0.277
Bank Study Site	2	1	4.38	**0.003**
Year*Bank Study Site	4	6	1.33	0.127
Res	178	334		
Total	190	347		

From 2011 to 2017, Dog Snapper and Gray Snapper were denser in WFGB study site surveys than EFGB study site surveys (Figure 7.15). Snapper community density was compared among years and bank study sites from 2011 to 2017. PERMANOVA analysis revealed a significant difference between bank study sites and years (Table 7.11), suggesting that snapper density was higher within the WFGB study site than the EFGB study site among years. The observed dissimilarity in density was mainly attributable to Dog Snapper (63.40%).

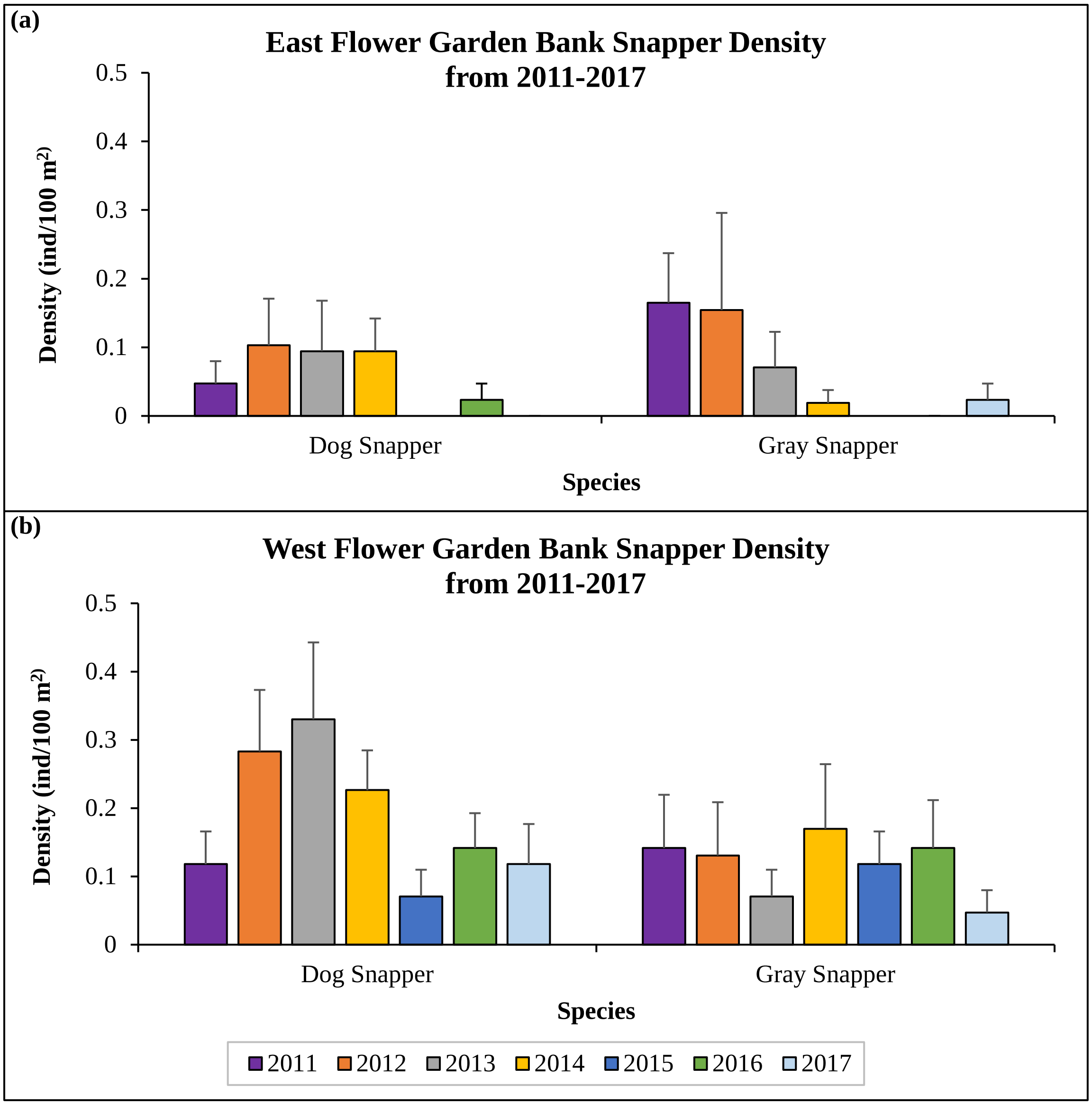


Figure 7.15. Mean density (individuals/100 m^2) +SE of snapper species within (a) EFGB and (b) WFGB study sites from 2011 to 2017.

Data for 2011 to 2016 are from FGBNMS (Johnston et al. 2015, 2017a, 2017b).

Table 7.11. PERMANOVA results comparing mean snapper density within EFGB and WFGB study sites from 2011 to 2017. Bold text denotes significant values.

Source	Sum of Squares	df	Pseudo-F	P (perm)
Year	2	6	2.60	**0.023**
Bank Study Site	3	1	12.38	**0.001**
Year*Bank Study Site	1	6	0.59	0.882
Res	58	334		
Total	63	347		

Fish Surveys Discussion

Fish communities are indicators of ecosystem health (Sale 1991) and therefore an important component to long-term monitoring programs. Monitoring fish communities over time is valuable in detecting changes from normal variations that exist within 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, principally the limited presence of lutjanids (snappers) and haemulids (grunts) (Rooker et al. 1997; Precht et al. 2006; Johnston et al. 2017a). Approximately 150 reef fish species have been documented on the EFGB and WFGB reef caps (Pattengill 1998; Pattengill-Semmens and Semmens 1998). 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 7.12).

Table 7.12. Comparison of other Caribbean reef biomass (g/100 m^2) ± SE and species richness (richness/100 m^2) ± SE to EFGB and WFGB.

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 (this report)	7,176.25 ± 857.88	18.90 ± 0.61
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 overall abundance of herbivorous fishes than other Caribbean reefs (Dennis and Bright 1988). Historically, low macroalgae cover was reported in annual monitoring surveys (Gittings et al. 1992), while recent data suggest a significant increase in mean macroalgae cover over time (Johnston et al. 2017b). During the 2017 study period, the herbivore guild possessed the second greatest mean biomass, contributing to 27% of the total biomass within study sites. Within the herbivore guild, 29% of the total biomass was attributed to Stoplight Parrotfish. The piscivore guild had the greatest mean biomass, contributing approximately 51% of the total biomass within study sites. Within the piscivore guild, Great Barracuda contributed to over 42% 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 human pressures, 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 that have high availability of refuges, rapid turnover rates of prey items, high energy transfer efficiencies, long predator life spans, 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, Graysby, Red Hind, Rock Hind, Yellowmouth and Tiger Grouper consisted of immature and mature individuals, and all Coney 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 and similar to other Caribbean reefs

(Jackson et al. 2014) (Table 7.13). 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 7.13. Mean biomass (g/100 m^2) for parrotfish at EFGB, WFGB, and other Caribbean reefs.

Location	Biomass (g/100 m^2)
Mexico	1,710
Belize	1,200
East and West Flower Garden Banks Study Sites (this report)	1,155
Guatemala	670
Honduras	440

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

Lionfish were recorded in surveys for the fifth consecutive year in 2017, but have been observed by divers consistently on the reefs since 2011. Since their first observation, numbers rapidly increased through 2014, and then declined after 2015 (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 at nearby moorings 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 reef caps.

Chapter 8. Water Quality

Flower Garden Banks National Marine Sanctuary researchers collect water samples from Niskin bottles on the carousel on the back deck of the NOAA R/V *MANTA* in 2017. (Photo: Kelly Drinnen, 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 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 depths 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 instruments and samples collected in 2017.

Water Quality Methods

Water Quality Field Methods

Temperature and Salinity Loggers

The primary instrument used at each bank for recording temperature, salinity, and turbidity was a Sea-Bird® Electronics *16plus* V2 CTD [conductivity, temperature, and depth]) (SBE *16plus*) equipped with a WET Labs ECO NTUS turbidity meter at an approximate 24 m depth. Loggers were secured to large railroad wheels and located in sand flats at each bank (See Chapter 1, Figures 1.3 and 1.4). These 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 (HOBO) thermograph loggers were used to record temperature on an hourly basis. These instruments provided a highly reliable temperature backup for the primary SBE *16plus* logging instruments located at the 24 m stations at EFGB and WFGB. HOBO 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 downloaded, maintained, and replaced on a quarterly basis. The instruments were either attached directly to the primary SBE *16plus* instrument at the 24 m station or to permanent repetitive deep photostation markers at the 30 m and 40 m depths. Prior to re-installation, all previous data were removed from the instrument and battery levels were checked.

Hourly sea surface temperature data were downloaded from the Texas Automated Buoy System (TABS) database for buoys near EFGB and WFGB. Buoy V is located within EFGB marine sanctuary boundaries (27° 53.796 N, 93° 35.838 W) (1.4 km from the

EFGB reef cap) and Buoy N is located 21.8 km west of 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 three main depth gradients, including the reef cap (~20 m), mid-water column (~10 m), and the surface (~1 m). 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. In 2017, profiles were collected on February 1st, May 8th, August 23rd, and October 31st.

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 of twelve OceanTest® Corporation 2.5-liter Niskin bottles. The six-bottle rosette CTD was outfitted with six additional 2.5 liter Niskin bottles to provide a total of twelve sampling bottles for fourth quarter water sampling in 2017. 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 (~20 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 collection for analysis.

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 250 ml 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 200 ml. $HgCl_2$ (100 μl) 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 1st, May 8th, August 23rd, and October 31st in 2017.

Water Quality Data Processing and Analysis

Temperature, salinity, and turbidity data recorded on SBE *16plus* instruments and HOBO loggers were downloaded and processed each quarter. TABS surface 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 unfavorable weather conditions preventing offshore dive operations in the first quarter of 2018, SBE *16plus* instruments and HOBO loggers were not exchanged during this quarter, so temperature and salinity data from EFGB and WFGB were not available for the period from October 29 to December 31, 2017. Additionally, strong currents prevented the exchange of 30 m and 40 m HOBO loggers at WFGB, so temperatures from these depths were not available from August 22 to December 31, 2017. TABS Buoy V data were unavailable from June 7 to August 30, 2017 and December 19 to December 31, 2017. Data from TABS Buoy N, located near WFGB, were unavailable for 2017, as the buoy was discontinued and recovered on January 4, 2017 due to budget limitations.

For seawater temperature, salinity, and turbidity data, EFGB and WFGB SBE *16plus* daily mean 2017 data were compared using a paired t-test in R® version 2.13.2. In addition, a historical daily mean seawater temperature data from the previous 25 years (1990 to 2015) were used for comparison to 2017 EFGB and WFGB data with a paired t-test. 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 minimum of 20.92°C on January 29, 2017 to a maximum of 29.12°C on September 22, 2017 (Figure 8.1). At the EFGB 24 m SBE *16plus* location, the minimum temperature logged was 20.87°C, recorded on January 29, 2017. The maximum temperature, recorded on August 5, 2017, was 29.86°C (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 20.91°C, recorded on January 29, 2017. The maximum temperature, recorded on August 2, 2017, was 29.44°C (Figure 8.1). At the 40 m station, the minimum temperature logged was 20.95°C, recorded on January 29, 2017. The maximum temperature, recorded on August 2, 2017, was 29.15°C (Figure 8.1). At EFGB, the average temperature difference between the 24 m and 30 m stations was -0.37°C and the greatest temperature difference was -3.35°C on July 14, 2017. The average temperature difference between the 24 m and 40 m stations was -0.79°C. The greatest difference in temperature recorded was -4.89°C on September 15, 2017. Throughout this study period, no loggers recorded days of water temperatures exceeding 30°C at EFGB.

Sea surface temperature data were not available for the area around WFGB due to the discontinuation of TABS Buoy N. At the WFGB 24 m SBE *16plus* location, the minimum temperature logged was 21.41°C, recorded on February 5, 2017. The maximum temperature, recorded on August 1, 2017, was 30.10°C, totaling 1 day above the 30°C bleaching threshold (Hagman and Gittings 1992) (Figure 8.1).

At the WFGB 30 m station, the minimum temperature logged was 21.45°C, recorded on February 5, 2017. The maximum temperature, recorded on August 2, 2017, was 29.54°C (Figure 8.1). At the WFGB 40 m station, the minimum temperature logged was 21.40°C, recorded on February 5, 2017. The maximum temperature, recorded on August 21, 2017, was 29.01°C (Figure 8.1). At WFGB, the average temperature difference between the 24 m and 30 m stations was -0.10°C and the greatest temperature difference was -1.59°C on July 5, 2017. The average temperature difference between the 24 m and 40 m stations was -0.61°C. The greatest difference in temperature recorded was -3.71°C on July 5, 2017. There was no significant difference between EFGB and WFGB when 2017 daily mean 24 m SBE *16plus* seawater temperatures were compared.

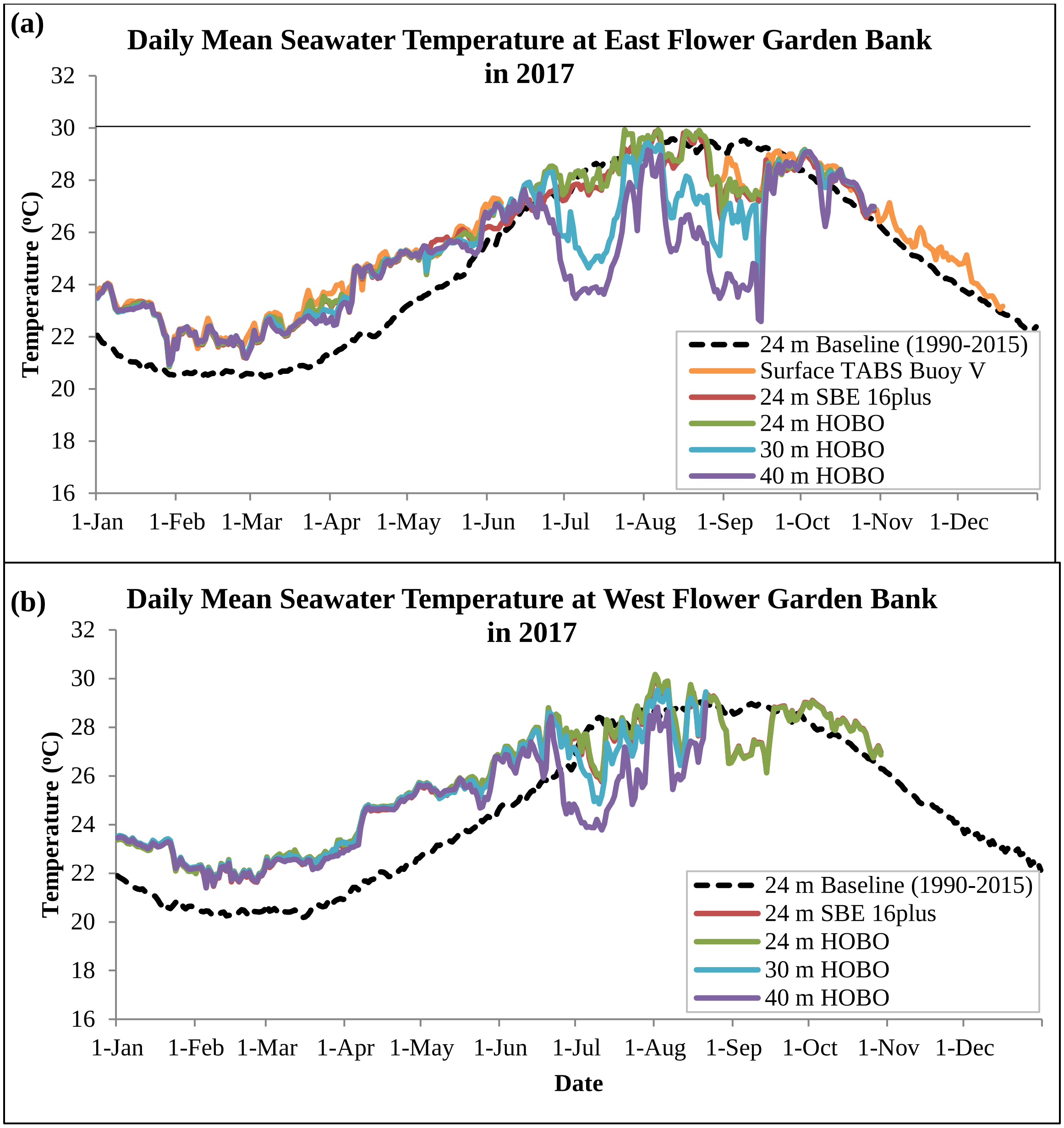


Figure 8.1. Daily mean water temperature (ºC) at (a) EFGB and (b) WFGB from various depths in 2017 and the 25-year daily mean temperature baseline. The solid black line represents the 30ºC bleaching threshold.

Seawater temperature data obtained from loggers at an approximate depth of 24 m have been collected throughout the monitoring program (Figure 8.2). 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. When 2017 data was compared to daily mean seawater temperatures at an approximate depth of 24 m from the past 25 years (1990 to 2015), both EFGB (t-test, df=301, t=10.64, $p<0.002$)

and WFGB (t-test, df=301, t=14.66, p<0.002) 2017 seawater temperatures were significantly warmer than the historic 25-year mean.

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 2017 (τ=0.31, z=5.95, p=0.002) after adjusting for correlation among seasons (Figure 8.2). A significantly increasing monotonic trend was also detected at WFGB from 1990 to 2017 (τ=0.27, z=5.53, p=0.003) after adjusting for correlation among seasons (Figure 8.2).

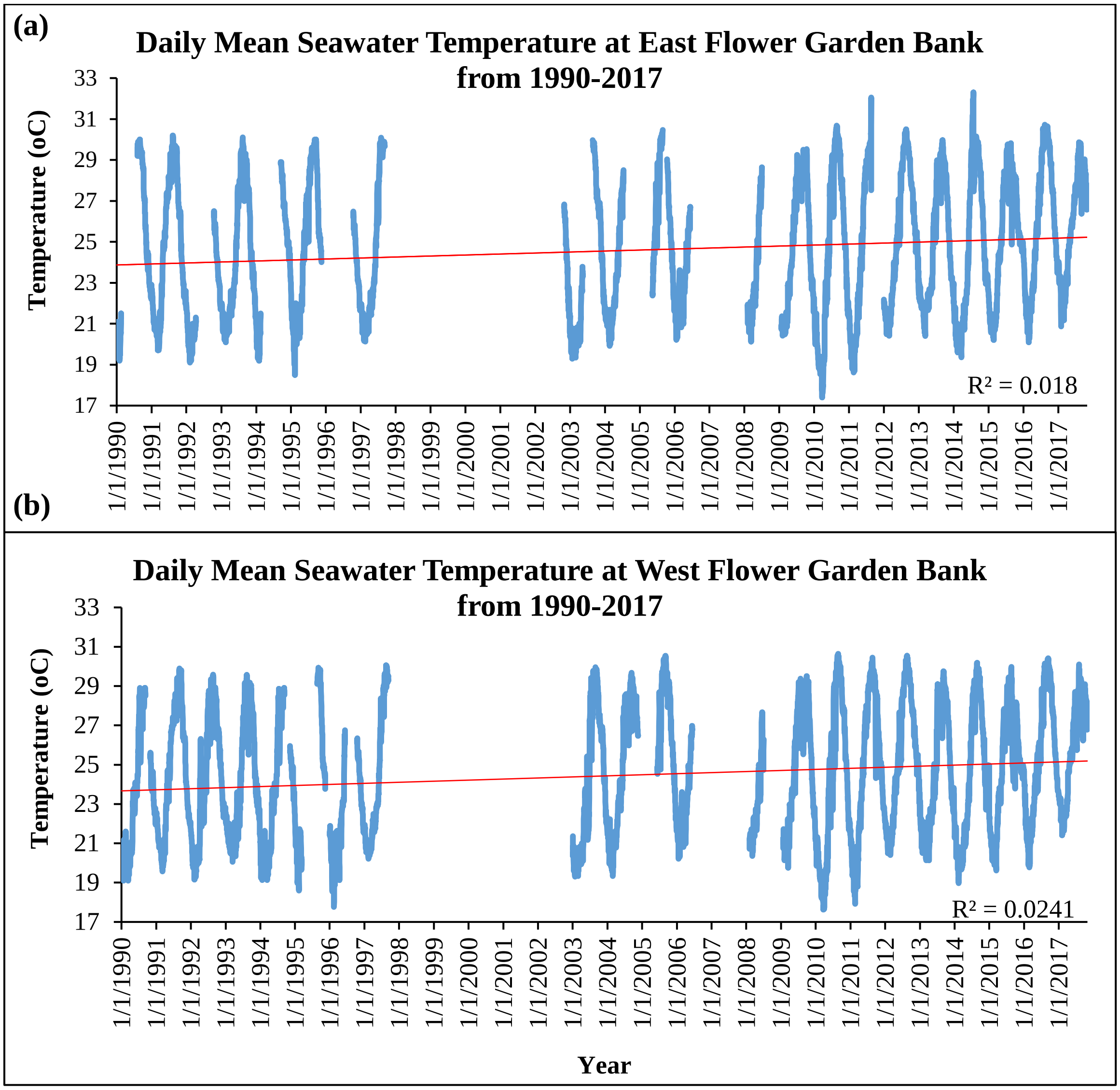


Figure 8.2. Daily mean 12-month seawater temperature (ºC) seasonal variation at (a) EFGB and (b) WFGB from 1990 to 2017. Significant trend line in red.

Salinity

Surface salinity recorded by TABS Buoy V within the EFGB sanctuary boundaries ranged from a maximum of 36.38 psu on February 2, 2017 to a minimum of 33.17 psu on September 29, 2017 (Figure 8.3). At the EFGB 24 m SBE *16plus* location, the minimum salinity logged was 35.74 psu on July 25, 2017 and the maximum salinity was 36.56 psu September 17, 2017 (Figure 8.3).

Surface salinity data were not available for the area around WFGB due to the discontinuation of TABS Buoy N. At the WFGB 24 m SBE *16plus* location, the minimum salinity logged was 35.06 psu on July 1, 2017 and the maximum salinity was 36.50 psu May 30, 2017 (Figure 8.3). When 2017 daily mean 24 m SBE *16plus* salinity data were compared, there was a significant difference between EFGB and WFGB (t-test, df=302, t=2.39, p=0.018) due to lower salinity recorded in the summer of 2017 at WFGB.

Salinity data obtained from loggers at an approximate depth of 24 m have been collected throughout the monitoring program since 2008 with minimal gaps (Figure 8.4). When 2017 data was compared to daily mean salinity at an approximate depth of 24 m from the past eight years, EFGB salinity was significantly lower (t-test, df=302, t=-7.02, p<0.001) than the eight-year mean. WFGB 2017 data was not significantly different from the eight-year mean.

The Seasonal-Kendall trend test on time-series daily mean salinity data at EFGB was not significant from 2008 to 2017, 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.

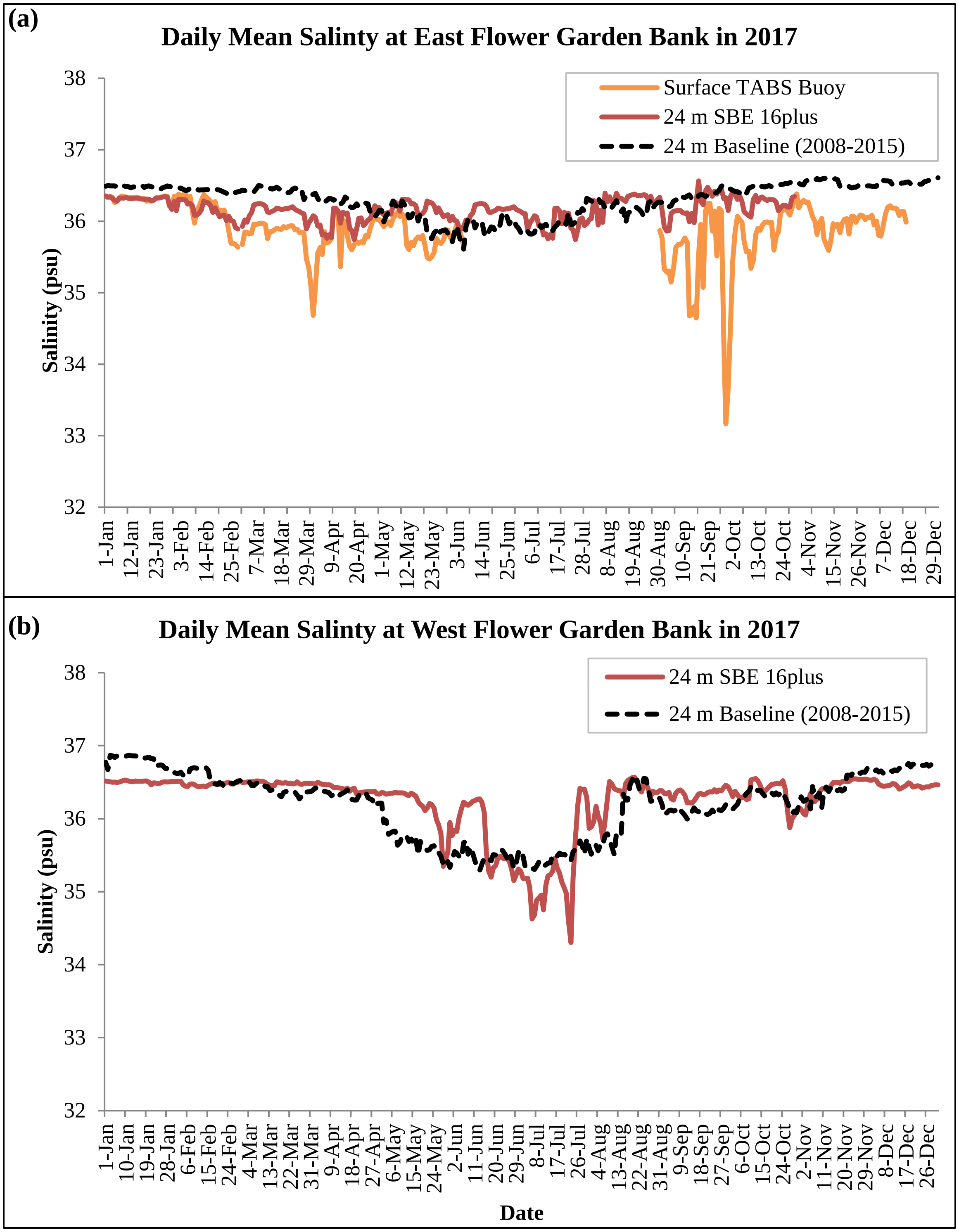


Figure 8.3. Daily mean salinity (psu) at the surface and 24 m station depth at (a) EFGB and (b) WFGB in 2017 compared to an 8-year daily mean salinity baseline.

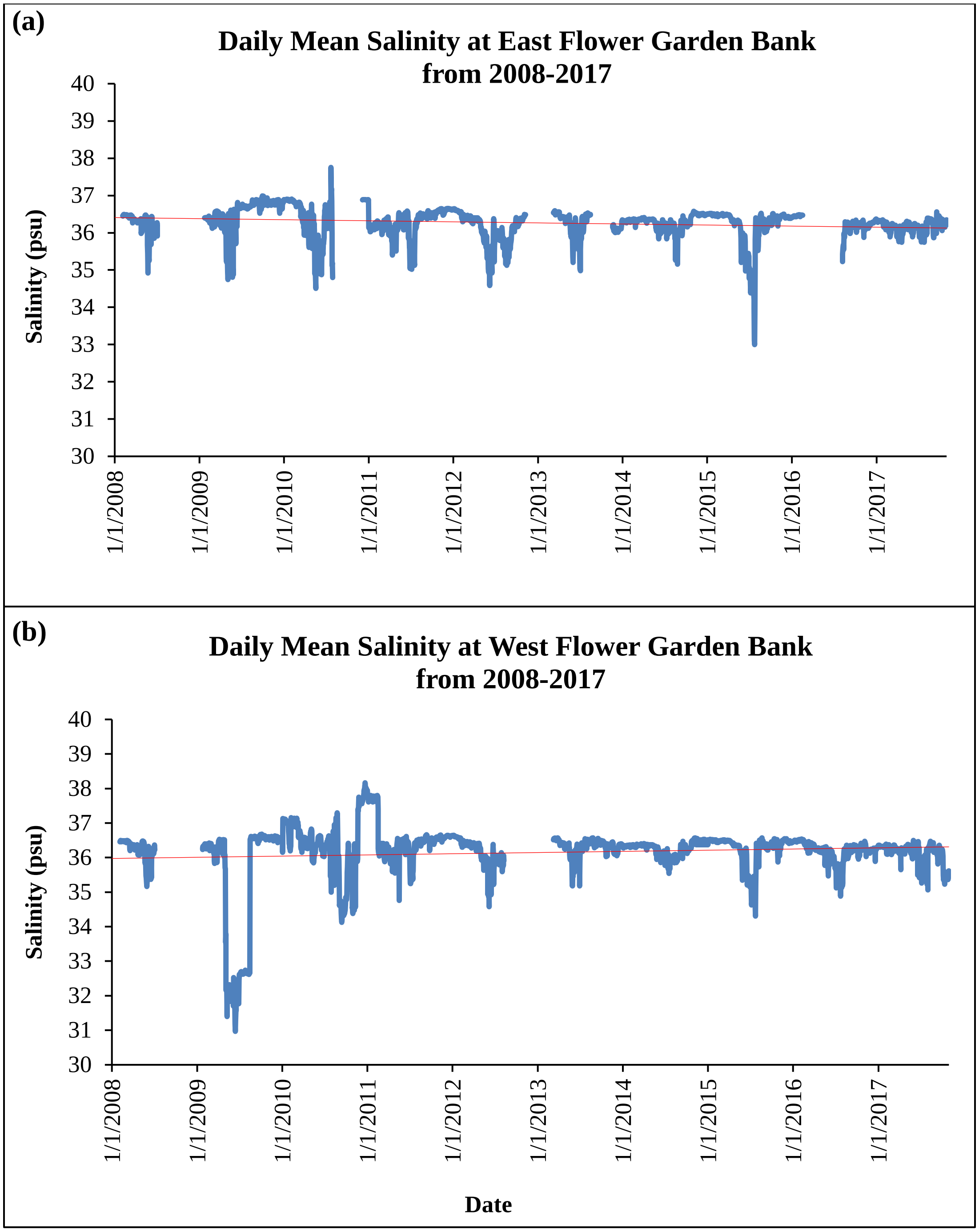


Figure 8.4. Daily mean 12-month salinity seasonal variation at (a) EFGB and (b) WFGB from 2008 to 2017. Trend line in red.

Turbidity

Turbidity was added as a long-term monitoring data parameter in August 2016 (24 m depth). At the EFGB 24 m SBE *16plus* location, the minimum turbidity recorded was 0.01 ntu from January 18-19, 2017 and the maximum turbidity was 0.39 ntu on August 9, 2017 (Figure 8.5). At the WFGB 24 m SBE *16plus* location, the minimum turbidity recorded was -0.01 ntu on April 30, May 5, and July 31 to August 2, 2017 and the maximum turbidity was 0.48 ntu on August 24, 2017 (Figure 8.5). When 2017 daily mean 24 m SBE *16plus* turbidity data were compared, there was a significant difference between EFGB and WFGB (t-test, df=301, t=-4.98, $p<0.001$), as WFGB had a wider turbidity range than EFGB.

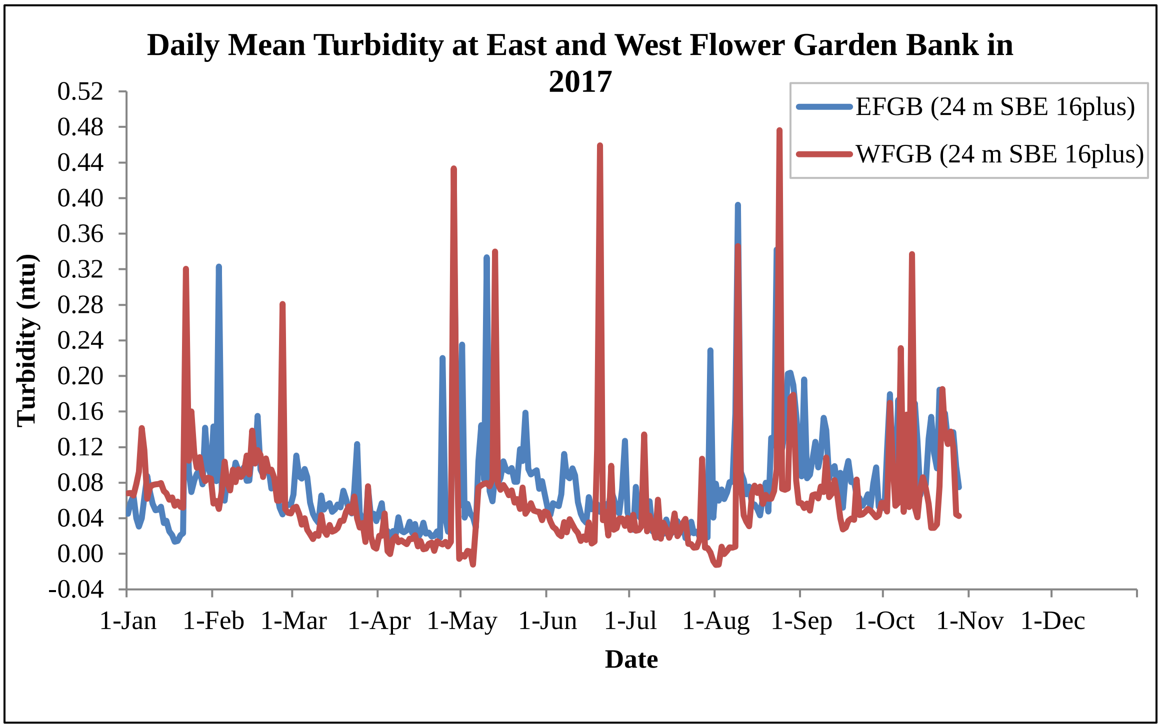


Figure 8.5. Daily mean turbidity (ntu) at EFGB and WFGB at the 24 m depth in 2017.

Water Column Profiles

Water column profile data were summarized by three depth gradients including the reef cap (~18 m), mid-water column (~10 m), and the surface (~1 m). Seawater temperatures varied throughout the year, and were warmer at the surface and cooler on reef cap depths (Table 8.2 and 8.3). For data collected in August at EFGB, temperatures in the water column at all depths were greater than 30°C, which differed from the TABS and SBE *16plus* data. Salinity was approximately 36 psu throughout the water column for all sampling dates (Table 8.2 and 8.3). Fluorescence was greatest in February throughout the water column at both banks, and pH ranged from approximately 7.5-8.4 throughout the water column among sampling dates (Table 8.2 and 8.3). DO and turbidity data were not available in February and May due to an equipment sensor malfunction (Table 8.2 and 8.3).

Table 8.2. EFGB depth, temperature, salinity, turbidity, pH, fluorescence, and DO data collected from water column profiles in 2017.

Sample Date	Depth (m)	Temp (ºC)	Salinity (psu)	Turbidity (ntu)	pH (eu)	Fluorescence (mg/m^3)	DO (ml/L)
02/01/2017	16.19	21.93	36.31	NA	7.52	0.61	NA
02/01/2017	10.03	21.88	36.29	NA	7.60	0.71	NA
02/01/2017	1.06	22.18	36.30	NA	7.72	0.36	NA
05/08/2017	16.70	25.33	36.36	NA	8.36	0.06	NA
05/08/2017	10.19	25.32	36.36	NA	8.37	0.05	NA
05/08/2017	1.07	25.34	36.36	NA	8.37	0.04	NA
08/23/2017	16.70	30.30	36.37	0.61	7.84	0.04	4.38
08/23/2017	10.07	30.36	36.37	0.61	7.91	0.01	4.39
08/23/2017	1.31	30.41	36.37	0.63	7.96	0.10	4.39
10/31/2017	17.86	26.38	36.29	0.60	7.82	0.10	4.32
10/31/2017	10.65	26.39	36.29	0.57	7.93	0.11	4.35
10/31/2017	1.22	26.39	36.28	1.35	7.97	0.04	4.39

Table 8.3. WFGB depth, temperature, salinity, turbidity, pH, fluorescence, and DO data collected from water column profiles in 2017.

Sample Date	Depth (m)	Temp (ºC)	Salinity (psu)	Turbidity (ntu)	pH (eu)	Fluorescence (mg/m3)	DO (ml/L)
02/01/2017	18.77	22.22	36.35	NA	7.48	0.43	NA
02/01/2017	10.26	22.26	36.35	NA	7.63	0.36	NA
02/01/2017	1.36	22.32	36.35	NA	7.72	0.21	NA
05/08/2017	19.20	25.10	36.30	NA	8.03	0.05	NA
05/08/2017	10.51	25.12	36.30	NA	8.08	0.04	NA
05/08/2017	1.30	25.14	36.31	NA	8.12	0.23	NA
08/23/2017	18.34	29.23	36.46	0.61	7.72	0.12	4.49
08/23/2017	10.05	29.68	36.40	0.61	7.87	0.03	4.43
08/23/2017	1.28	29.80	36.41	0.59	7.91	0.00	4.41
10/31/2017	20.09	26.72	36.38	0.58	7.86	0.15	4.32
10/31/2017	10.46	26.77	36.39	0.57	7.96	0.11	4.35
10/31/2017	1.02	26.76	36.38	1.82	8.02	0.06	4.32

Water Samples

Nutrient analyses for ammonia, chl-*a*, nitrate, nitrite, phosphorus, and nitrogen levels for all samples in 2017 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 below detectable limits, with the exception of the occasional spikes in chl-*a*, ammonia, and TKN (Figures 8.6 and 8.7).

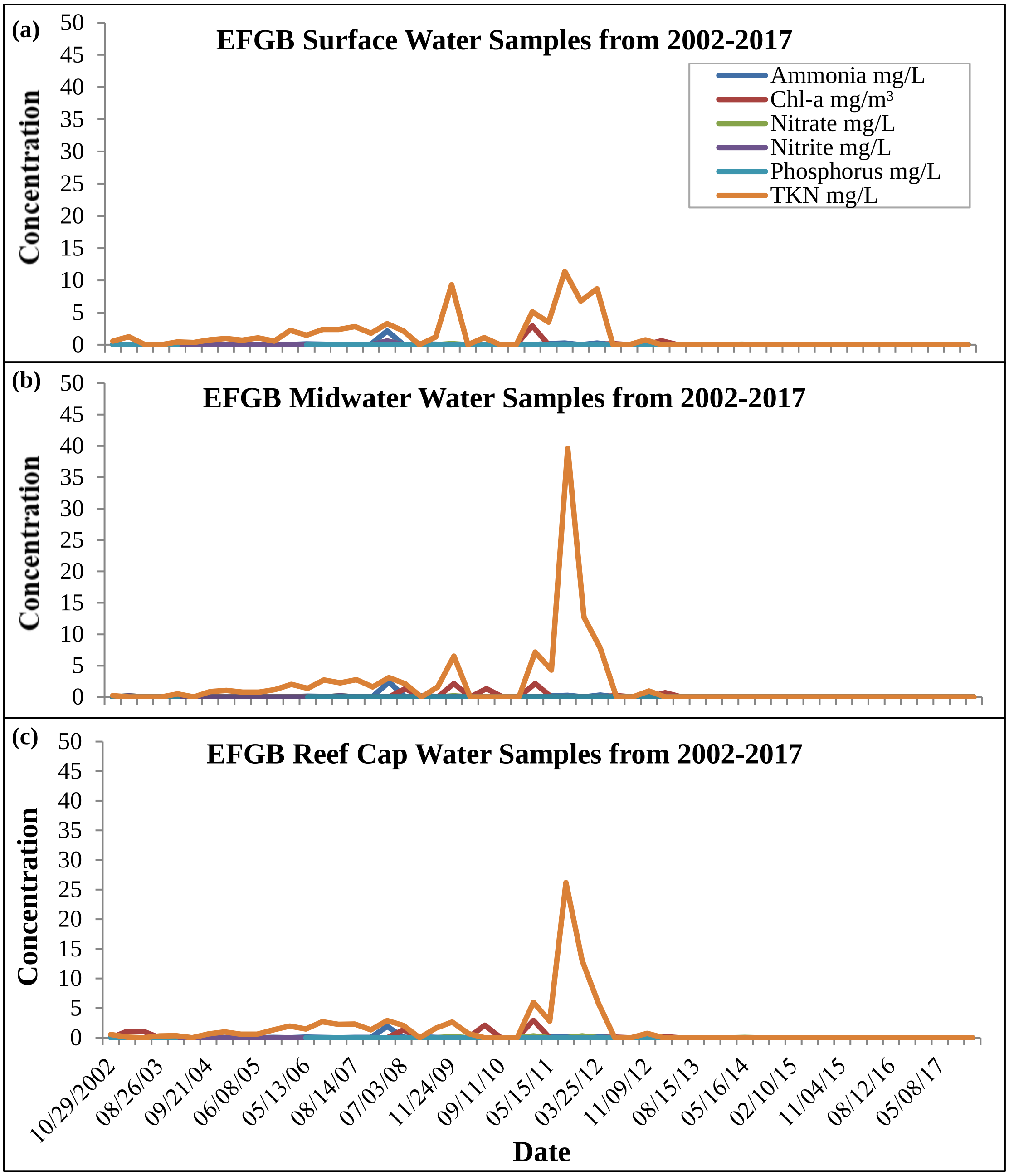


Figure 8.6. Nutrient concentrations from EFGB water samples taken at the (a) surface (1 m), (b) midwater (10 m), (c) and reef cap (16 m) depths from 2002 to 2017.

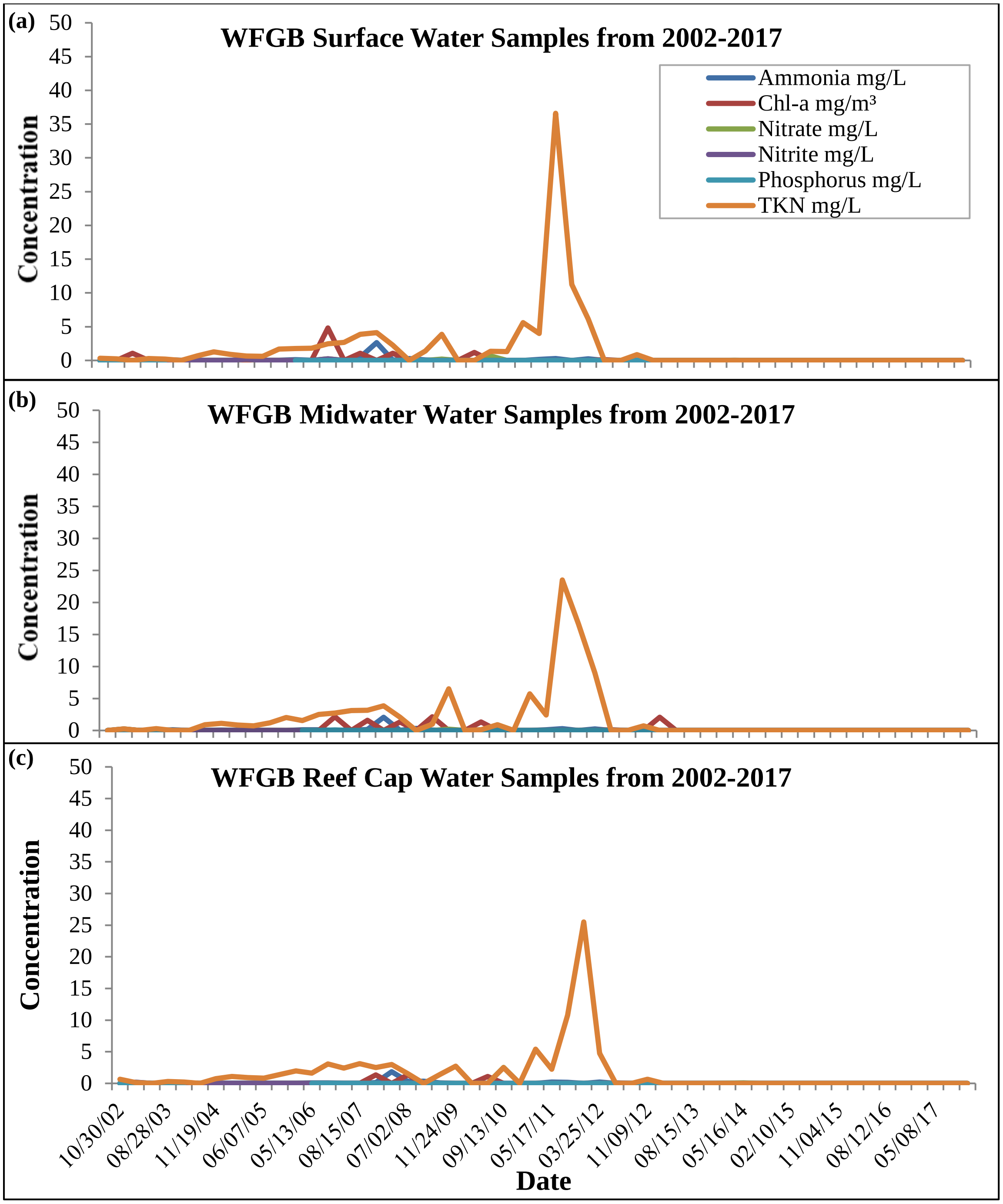


Figure 8.7. Nutrient concentrations from WFGB water samples taken at the (a) surface (1 m), (b) midwater (10 m), (c) and reef cap (16 m) depths from 2002 to 2017.

Carbonate samples taken quarterly at three different depth gradients (approximately 20, 10, and 1 m) 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 2017. The lowest $\Omega_{aragonite}$ values and highest DIC were also observed in February 2017.

Table 8.4. EFGB carbonate sample results for 2017 summarized at three depth gradients.

Sample Date	Depth (m)	Salinity (ppt)	Temp (ºC)	pH Total	Alkalinity (µmol/kg)	DIC (µmol/kg)	pH *in situ*	$\Omega_{aragonite}$	pCO_2 (µatm)
02/01/2017	20	36.29	21.86	8.053	2402.2	2072.9	8.099	3.56	353.7
02/01/2017	10	36.30	21.94	8.056	2401.5	2077.6	8.102	3.59	352.4
02/01/2017	1	36.36	22.19	8.056	2402.2	2078.1	8.098	3.61	355.8
05/08/2017	20	36.36	25.33	8.061	2396.1	2057.9	8.056	3.67	394.6
05/08/2017	10	36.36	25.32	8.067	2398.0	2059.2	8.062	3.72	389.0
05/08/2017	1	36.36	25.34	8.072	2399.9	2061.3	8.067	3.76	385.2
08/23/2017	20	36.37	30.43	8.066	2403.8	2071.6	7.986	3.85	479.6
08/23/2017	10	36.35	30.35	8.076	2402.7	2065.0	7.997	3.92	464.9
08/23/2017	1	36.36	30.30	8.076	2403.3	2060.8	7.998	3.91	462.5
10/31/2017	20	36.29	26.38	8.077	2402.1	2065.1	8.056	3.82	396.9
10/31/2017	10	36.29	26.39	8.080	2406.5	2064.6	8.059	3.85	393.5
10/31/2017	1	36.29	26.38	8.078	2401.1	2062.4	8.058	3.83	395.1

Table 8.5. WFGB carbonate sample results for 2017 summarized at three depth gradients.

Sample Date	Depth (m)	Salinity (ppt)	Temp (ºC)	pH Total	Alkalinity (µmol/kg)	DIC (µmol/kg)	pH *in situ*	$\Omega_{aragonite}$	pCO_2 (µatm)
02/01/2017	20	36.35	22.23	8.053	2400.4	2079.6	8.094	3.58	359.4
02/01/2017	10	36.36	22.28	8.054	2402.3	2080.7	8.094	3.59	359.7
02/01/2017	1	36.36	22.31	8.053	2401.1	2080.9	8.093	3.59	361.1
05/08/2017	20	36.30	25.11	8.061	2397.2	2063.3	8.059	3.67	392.4
05/08/2017	10	36.31	25.14	8.063	2400.6	2066.3	8.061	3.69	391.6
05/08/2017	1	36.30	25.15	8.064	2399.9	2067.8	8.062	3.71	391.1
08/23/2017	20	36.45	29.56	8.087	2405.0	2058.7	8.019	3.97	436.5
08/23/2017	10	36.41	29.67	8.088	2406.2	2061.0	8.019	3.99	437.5
08/23/2017	1	36.41	29.76	8.089	2406.0	2063.0	8.018	4.00	439.3
10/31/2017	20	36.38	26.71	8.084	2407.3	2062.5	8.058	3.88	394.1
10/31/2017	10	36.39	26.76	8.086	2400.2	2059.8	8.059	3.90	392.8
10/31/2017	1	36.39	26.77	8.084	2400.9	2061.1	8.058	3.89	395.1

Water Quality Discussion

EFGB and WFGB seawater temperatures in 2017 were warmer than the historical average from January through May, but then fluctuated throughout the summer months, as both surface (at EFGB) and SBE *16plus* reef cap temperatures at both banks were lower than the historical average from mid-August to mid-September. Only one day at WFGB exceed the 30^{o}C bleaching threshold at depth. The cooler seawater temperatures followed Hurricane Harvey, a Category Four storm in the Gulf of Mexico that formed on August 17, 2017 and dissipated on September 2, 2017 (Klotzbach and Gray 2017).

Hurricane Harvey broke the tropical cyclone-generated rainfall record in the U.S., with over 60 inches of rain falling in Nederland, Texas (Klotzbach and Gray 2017). Despite decreased seawater temperatures following Hurricane Harvey, EFGB and WFGB were unaffected by the storm, as divers on a response cruise to inspect the banks in September 2017 observed no physical damage to the reef. The only observation noted by divers was ripples in sand flats caused by storm surge.

Salinity levels at EFGB and WFGB were similar to historical averages for most of the study period, with the exception of lower salinity at WFGB in July, and fluctuating salinity levels after Hurricane Harvey. Surface salinity readings from TABS buoys also decreased after Hurricane Harvey. Despite variation throughout the year, salinity 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 likely 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. Surface salinity also declined, most likely due to the extreme amount of rainfall associated with the storm.

Water quality parameters indicated slight water column stratification throughout 2017. Laboratory analyses indicated that nutrient levels at EFGB and WFGB were below detectable levels, indicating low nutrient waters in 2017; 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 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. In terms of carbonate chemistry, the lowest $\Omega_{aragonite}$ values and highest DIC values were observed in February 2017, 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 pCO_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. Seasonal and spatial distribution of seawater carbonate chemistry in 2017 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.

Chapter 9. Update on the 2016 EFGB Mortality Event

Diver hovers over corals impacted by the mortality event at EFGB in 2016. (Photo: G.P. Schmahl, NOAA/FGBNMS)

Mortality Event Response Introduction

In July 2016, a localized mortality event occurred at EFGB, affecting coral and other invertebrates in an approximate six-hectare area on the shallow coral cap. A response cruise was conducted to determine the extent of the affected area and impacts to the benthic and fish communities. While not officially part of the long-term monitoring program, FGBNMS and BOEM conducted the response cruise to document the event and collect data.

Mortality Event Response Methods

On July 25, 2016, recreational divers from the *M/V Fling* observed dying coral, sponges, and invertebrates near EFGB mooring buoy #4. A response cruise (August 5 to 7, 2016), was led by FGBNMS on board the R/V *Manta* to collect benthic transect, fish survey, and water quality data. Benthic transects (as described in Chapter 2) and fish surveys (as described in Chapter 7) were collected within and outside the affected area. The area was revisited in October 2017 during the quarterly water quality sampling cruise and three additional benthic transects were completed.

Mortality Event Response Results

Initial observations in late July of 2016 documented the mortality of invertebrates spanning multiple taxa (corals, sponges, sea urchins, crabs, etc.). The affected area was centered on the EFGB coral cap (Figure 9.1). Coral cover within the affected area that was centered on the reef cap (approximately 275 meters away from the EFGB study site) ranged from 22–80%; with lower coral cover surveys falling within the affected area. Fish density in surveys within the affected was lower than in surveys taken outside the area.

In limited surveys conducted in the center of the affected area in October 2017, percent live coral cover ranged from 12–20%, which was only slightly lower than surveys taken in this area in response to the event in 2016. These percentages varied dramatically from baseline EFGB benthic community conditions, where mean coral cover is approximately 50 percent (Johnston et al. 2017b). Other benthic cover categories, such as CTB, also shifted from historic baselines (Figure 9.2).

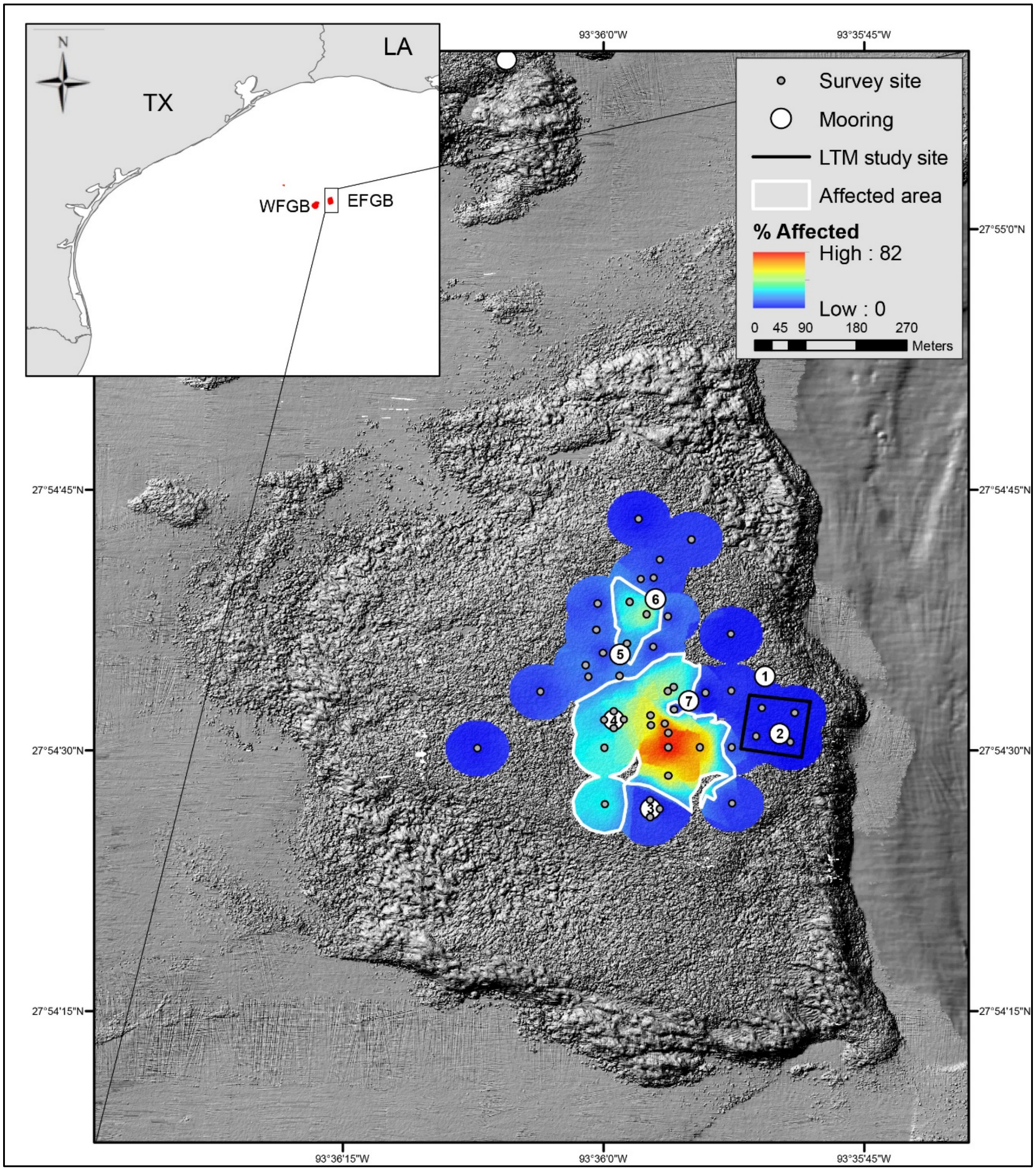


Figure 9.1. Spatial distribution of the mortality area (outlined in white). Numbered circles represent mooring buoys and the long-term monitoring study site is outlined in black. Percent coral affected from high to low ranges in color from red to blue.

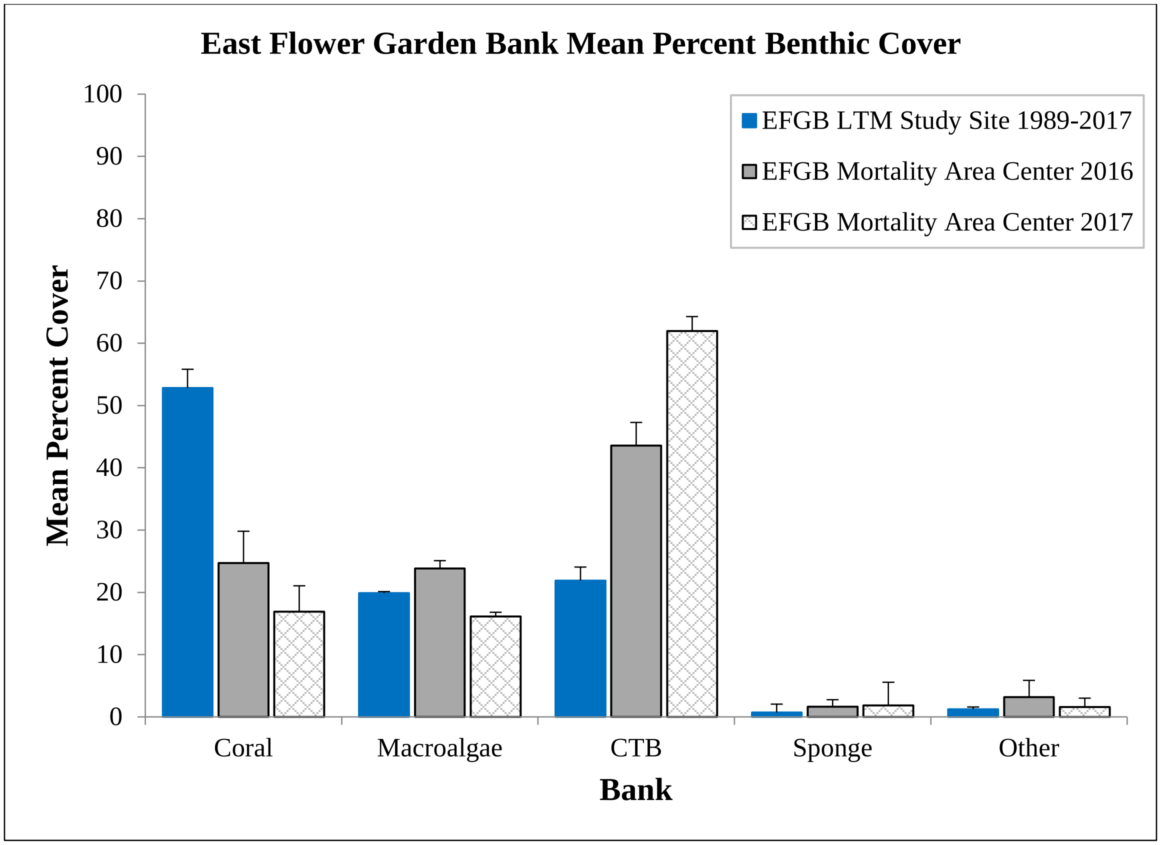


Figure 9.2. Long-term benthic cover from the EFGB study site (1989-2017) compared to benthic cover in the center of the mortality area in 2016 and in 2017.

Mortality Event Discussion

FGBNMS, in partnership with the Gulf of Mexico Coastal Ocean Observing System (GCOOS) and the U.S. Integrated Ocean Observing System (IOOS), hosted a mini-symposium in Galveston, Texas on February 27–28, 2018 to further investigate the localized mortality event that occurred at EFGB in July 2016. The event brought together approximately 40 key scientists and collaborators from a wide array of disciplines - all first responders to the 2016 mortality event at EFGB. During the two-day meeting, principal investigators presented their response activities, results, and hypotheses as to the causes of the event, and time was allotted for round table group discussions.

After key responders presented their data and hypotheses, facilitated group discussion outlined data overlaps and data gaps. Discussions revolved around the evidence that low dissolved oxygen was a likely case, but there was no direct data specifically from the mortality area to measure this at the time of the event. Factors detected and measured in the vicinity of EFGB and the region around the time of the event are listed below:

1. High river outflow

2. Low salinity
3. High chlorophyll
4. High organic matter
5. Low oxygen
6. Sustained high water temperature
7. Low fish density and biomass on reef
8. Benthic cover data showing mortality impacts

While there was no clear single cause of the EFGB mortality event, most believe the event likely resulted from a combination of stressors, with low dissolved oxygen as a key factor. Several different hypotheses describing a low oxygen event as cause or at least associated with the event were put forth by the various responders during the meeting. After taking into consideration all of the evidence and hypotheses by all parties, with continued facilitated discussion, the mini-symposium group drafted the following agreed upon summary statements:

"Low dissolved oxygen was the most likely contributing factor of the 2016 highly localized mortality event at East Flower Garden Bank.

Instrumentation on and around the reef documented low surface salinity and higher than average seawater temperature. High organic matter was detected by remote sensing, and unusually high levels of freshwater outflow from Gulf Coast rivers were also measured. The linkages between the conditions measured on the reef at the time of the event, and dissolved oxygen factor, are undetermined.

The mechanism resulting in the highly localized nature of the mortality event cannot be determined from available data."

Final group discussions revolved around current monitoring activities in place, and future monitoring needs. The meeting reinforced the need for enhanced and sustained observations in and around FGBNMS to support forecasting, mitigation and analysis of future events. At the time this report was prepared, numerous manuscripts were being prepared by principal investigators.

Chapter 10. Conclusions

A scrawled filefish swims over the reef at night at East Flower Garden Bank in 2017. (Photo: G.P. Schmahl, NOAA/FGBNMS)

Despite coral cover declines on most coral reefs of the world in recent decades, mean coral cover within EFGB and WFGB long-term monitoring study sites has ranged from 40–60% for the combined 28 years of monitoring. Even with macroalgae percent cover increasing significantly after the mass mortality of *Diadema antillarium* in the 1980s (with sustained cover of approximately 30% in recent years), 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.

Repetitive photostations within study sites indicated increases in coral cover over time at some stations, and stable cover at others. Twelve new repetitive deep photostations installed in 2017 should provide data with higher resolution in the future. Minimal bleaching and paling was observed in the repetitive stations, and the majority of corals recovered from the bleaching event in 2016.

Fish surveys conducted in 2017 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. Though piscivores had the greatest mean biomass at WFGB, the herbivores had the greatest mean biomass at EFGB. Overall, the high proportion of biomass in the piscivore guild is indicative of an ecosystem with relatively low human impact. Invasive lionfish were documented in fish surveys for the fifth consecutive year, though they were first seen on the banks in 2011. Lionfish densities at EFGB and WFGB continue to remain lower than other locations in the southeast U.S. and Caribbean region.

Water column temperatures cooled after Hurricane Harvey moved through the Gulf of Mexico, and salinity averaged 36 psu throughout 2017 at both banks. All nutrient samples taken quarterly in 2017 were below detectable limits and carbonate chemistry indicated that the area surrounding EFGB and WFGB acted as a net CO_2 sink.

Within the localized area affected by the mortality event in July 2016, coral cover remained low and CTB cover increased. A mini-symposium, bringing together approximately 40 key scientists and collaborators from a wide array of disciplines, was held in Galveston, Texas in February 2017 to present data and discuss hypotheses as to the cause of the event. While there was no clear single cause of the EFGB mortality event, it likely resulted from a combination of stressors, with low dissolved oxygen as a key factor.

Overall, one of the most apparent changes since monitoring began in 1989 has been the increase in macroalgae cover. EFGB and WFGB appear unusual compared to other reefs in the region because macroalgae has experienced a sustained increase, yet coral cover has not declined here, as it has in so many other places throughout the region. The macroalgae increase on these banks began after the sea urchin die off and may persist because of it; however, unlike many regional reefs, herbivorous fish have not declined as macroalgae increased, most nutrients remain below detectable limits, and turbidity remains low. Furthermore, sea urchin populations have slowly been increasing, but remain at a fraction of pre-dieoff densities. It may be that the combination of these factors offset to some extent the competitive advantage that macroalgae might otherwise have over corals.

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). 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.

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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

National Marine Sanctuaries

America's Underwater Treasures