



Long-Term Monitoring at East and West Flower Garden Banks: 2020 and 2021 Annual Report



FLOWER GARDEN BANKS
NATIONAL MARINE SANCTUARY

BOEM
BUREAU OF OCEAN ENERGY MANAGEMENT

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Cover photo: A loggerhead sea turtle (*Caretta caretta*) swims over coral colonies at West Flower Garden Bank in November 2021. Photo: Adrienne Correa/Rice University

About the National 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 15 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 nation's 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 almost 583,000 square miles. They serve as natural classrooms and cherished recreational spots, and are home to valuable commercial industries.

Because of considerable differences in settings, resources, and threats, each national 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 National Marine Sanctuaries Conservation Series reflects and supports this integration by providing a forum for publication and discussion of the complex issues currently facing the National Marine 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 (<https://sanctuaries.noaa.gov>).



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Report Availability

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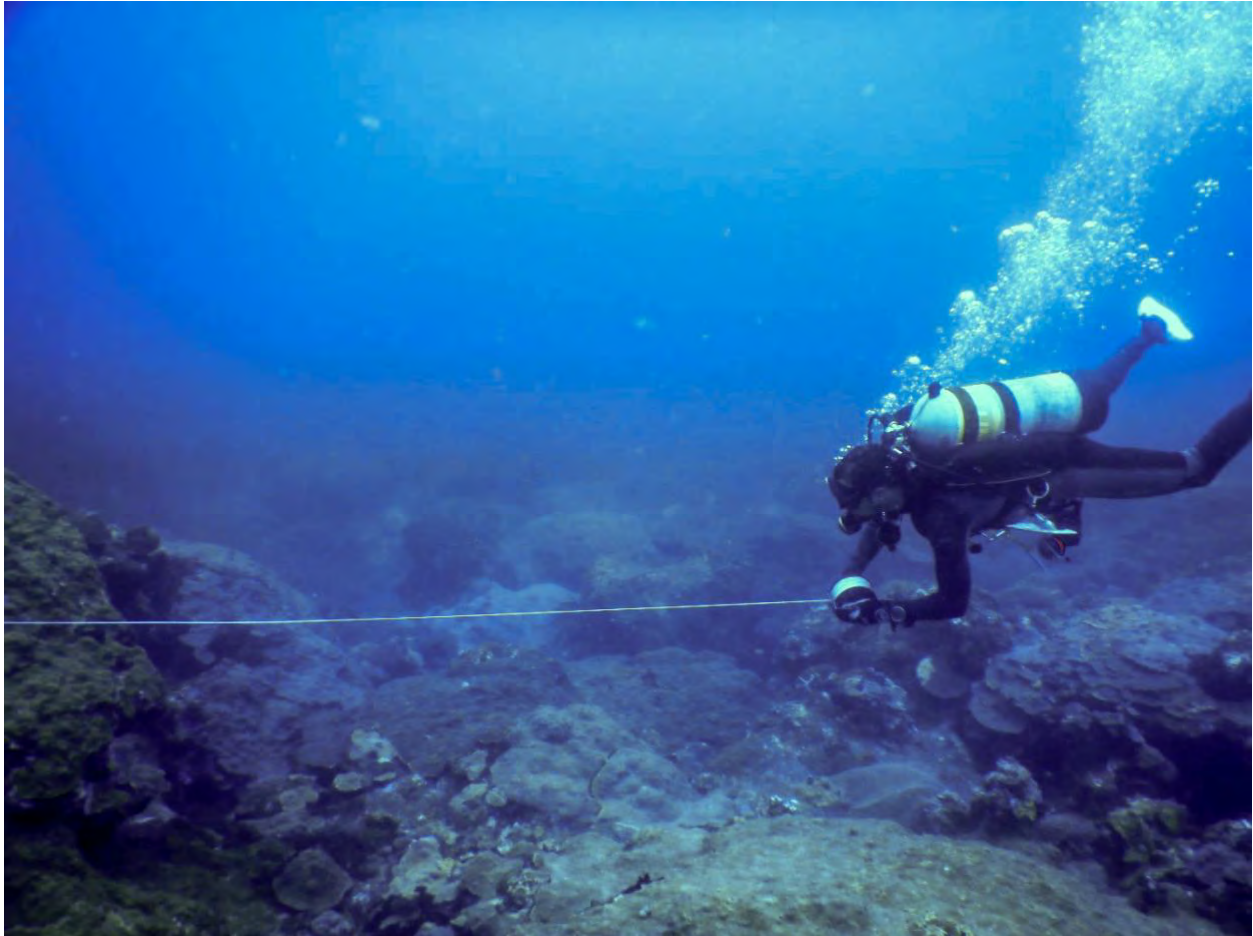
Abstract

This report summarizes benthic community observations and water quality data collected from East Flower Garden Bank (EFGB) and West Flower Garden Bank (WFGB) coral reefs in 2020 and 2021, as part of a program that has generated nearly 32 years of monitoring data. EFGB and WFGB are part of Flower Garden Banks National Marine Sanctuary (FGBNMS), located in the northwestern Gulf of Mexico. The annual long-term monitoring program began in 1989 and is funded by FGBNMS and the Bureau of Ocean Energy Management, with support from the National Marine Sanctuary Foundation. Limited fieldwork and data collection were completed in 2020 and 2021 due to vessel, diving, and other operational restrictions established in response to the COVID-19 pandemic. In 2020, a single quarterly water sampling cruise was completed, followed by a cruise to exchange water quality instruments. In 2021, two water sampling cruises were completed and instruments were exchanged. A subset of repetitive photostations at EFGB ($n = 33$) and WFGB ($n = 34$) were captured within one-hectare study sites, representing 89% and 83% of all photostations at EFGB and WFGB, respectively. In 2021, mean coral cover was 67% within EFGB repetitive photostations and 68% within WFGB repetitive photostations. Bleaching and/or paling was observed in repetitive photostations at both banks. There were no signs of stony coral tissue loss disease within either of the one-hectare study sites. Seawater temperatures on the reef exceeded 30 °C temporarily at both banks in 2020 and 2021, though coral bleaching was only observed in 2021. A significant monotonic increasing trend in seawater temperature was detected at both banks from 1990 to 2021, indicating ocean temperatures have risen at FGBNMS over the past three decades. The results of this report extend one of the longest records of coral reef condition in the Gulf of Mexico and Caribbean region.

Key Words

benthic community, coral ecosystem, coral reef, fish community, long-term monitoring, Flower Garden Banks National Marine Sanctuary, Gulf of Mexico, marine protected area, water quality

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



A scuba diver reels in a guide line while swimming over the coral reef cap at East Flower Garden Bank.
Photo: Kelly O'Connell/CPC, Inc.

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 dome formations located approximately 190 km south of the Texas and Louisiana border, containing several distinct habitats ranging in depth from 16–166 m (Rezak et al., 1985; Schmahl et al., 2008; Figure 1.1).

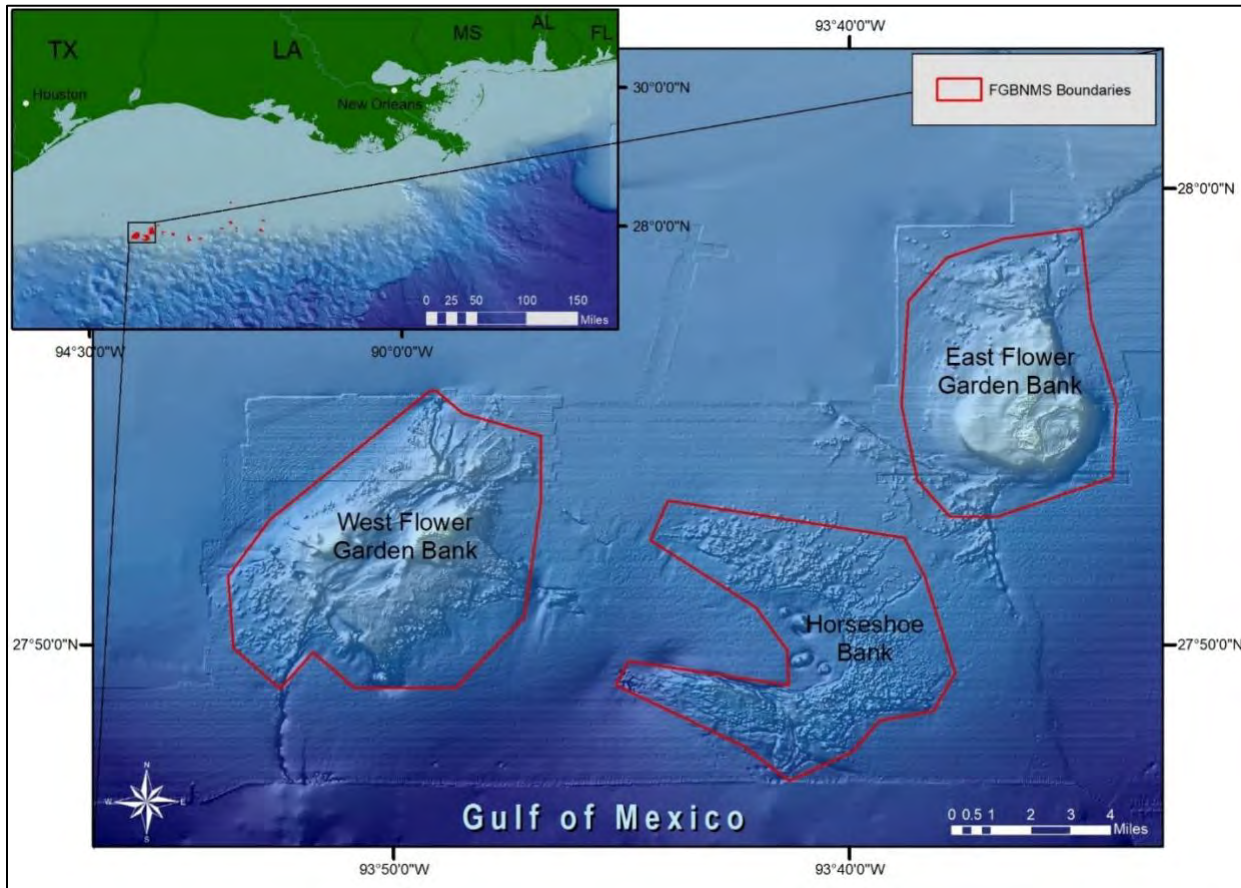


Figure 1.1. Map of EFGB, WFGB, and Horseshoe Bank. The inset shows gulf coast states and other FGBNMS boundaries, marked in red, along the continental shelf of the northwestern Gulf of Mexico. Horseshoe Bank is not part of the study area, but is now part of FGBNMS.

The caps of EFGB and WFGB are approximately 20 km apart and within the photic zone, where conditions are ideal for colonization by species of corals, algae, invertebrates, and fish that are also found in the Caribbean region (Goreau & Wells, 1967; Schmahl et al., 2008; Clark et al., 2014; Johnston et al., 2016). The shallowest portions of each bank are topped by well-developed coral reefs in depths ranging from 16–50 m. Although the coral species found on the reef caps of the banks are the same as those on Caribbean reefs, octocorals are absent in shallow habitats, and scleractinian corals of the genus *Acropora* are rare. These differences are likely due to depth and the latitude of the banks; Flower Garden Banks National Marine Sanctuary (FGBNMS) is

near the northernmost limit of the coral and is distanced from source populations by several hundred kilometers (Bright et al., 1985; Continental Shelf Associates [CSA], 1989). FGBNMS was designated in 1992 (15 C.F.R. § 922.120) by the National Oceanic and Atmospheric Administration (NOAA) under the National Marine Sanctuaries Act. In 2021, FGBNMS was expanded to include an additional 14 reefs and banks along the continental shelf of the northwestern Gulf of Mexico, increasing the total area of the sanctuary from 145 km² to 414.4 km² (86 Fed. Reg. 4937 [Jan 19, 2021]). With this expansion, the boundaries of FGBNMS surrounding EFGB and WFGB were modified, increasing the protected area around EFGB by 6.19 km² (65.86 km² before expansion to 72.05 km² after expansion) and around WFGB by 18.68 km² (77.54 km² before expansion to 96.22 km² after expansion) (Figure 1.1). EFGB and WFGB boundaries were modified to offer protection to mesophotic hard bottom features, which support branching stony coral, black coral, and octocoral communities that were discovered after FGBNMS was first designated.

Long-Term Monitoring Program History

In the 1970s, due to concerns about potential impacts from offshore oil and gas development, the Department of Interior (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 data to determine whether FGBNMS reefs are impacted by nearby oil and gas activities (Figure 1.2).

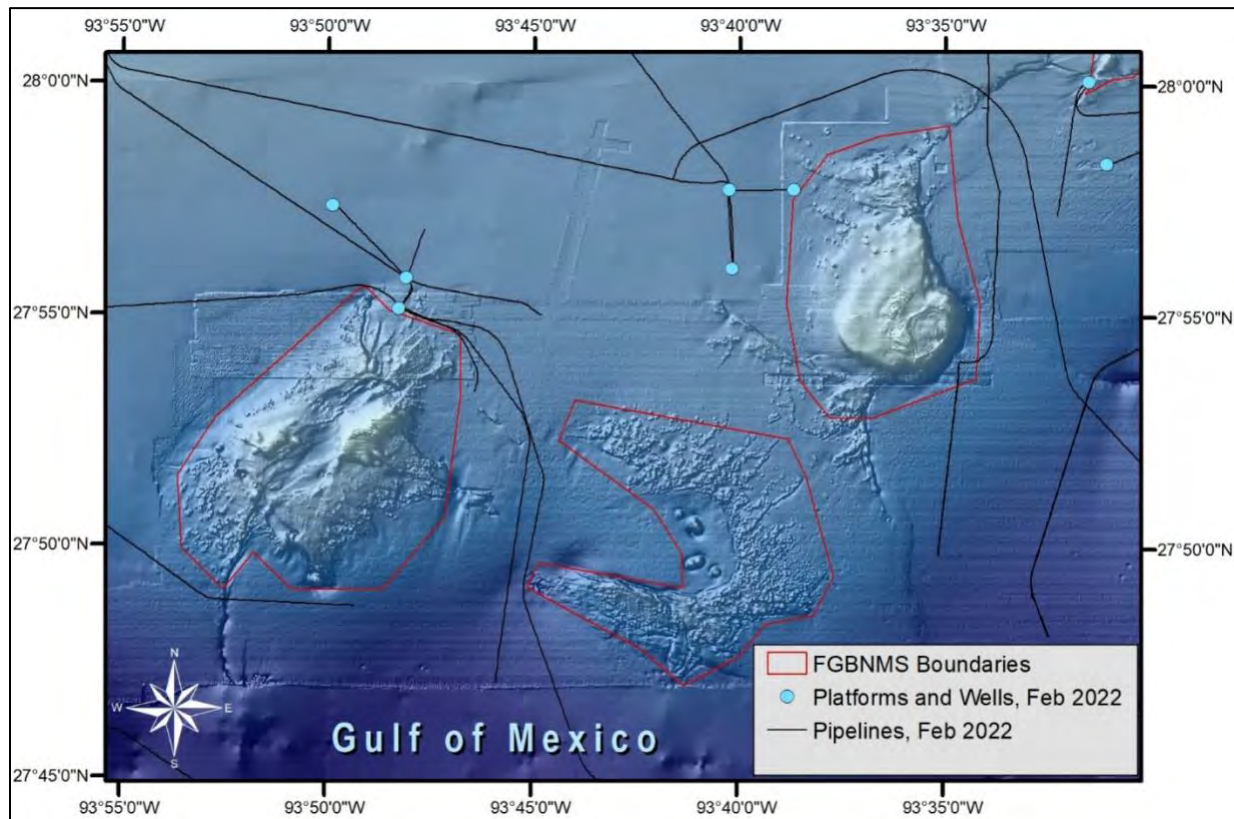


Figure 1.2. Map of oil and gas platforms, wells, and pipelines near EFGB and WFGB as of February 2022. FGBNMS boundaries are outlined in red.

Initially under industry funding, then MMS funding and a contract with Texas A&M University (TAMU), one-hectare long-term monitoring study sites were established on each bank in 1989, marking the start of the Flower Garden Banks long-term monitoring program (CSA, 1989; Gittings et al., 1992; Figure 1.3). Monitoring was conducted by both TAMU and environmental consulting firms through competitive contracts until 2009, at which time BOEM and NOAA established an interagency agreement for FGBNMS to carry out the long-term monitoring program.

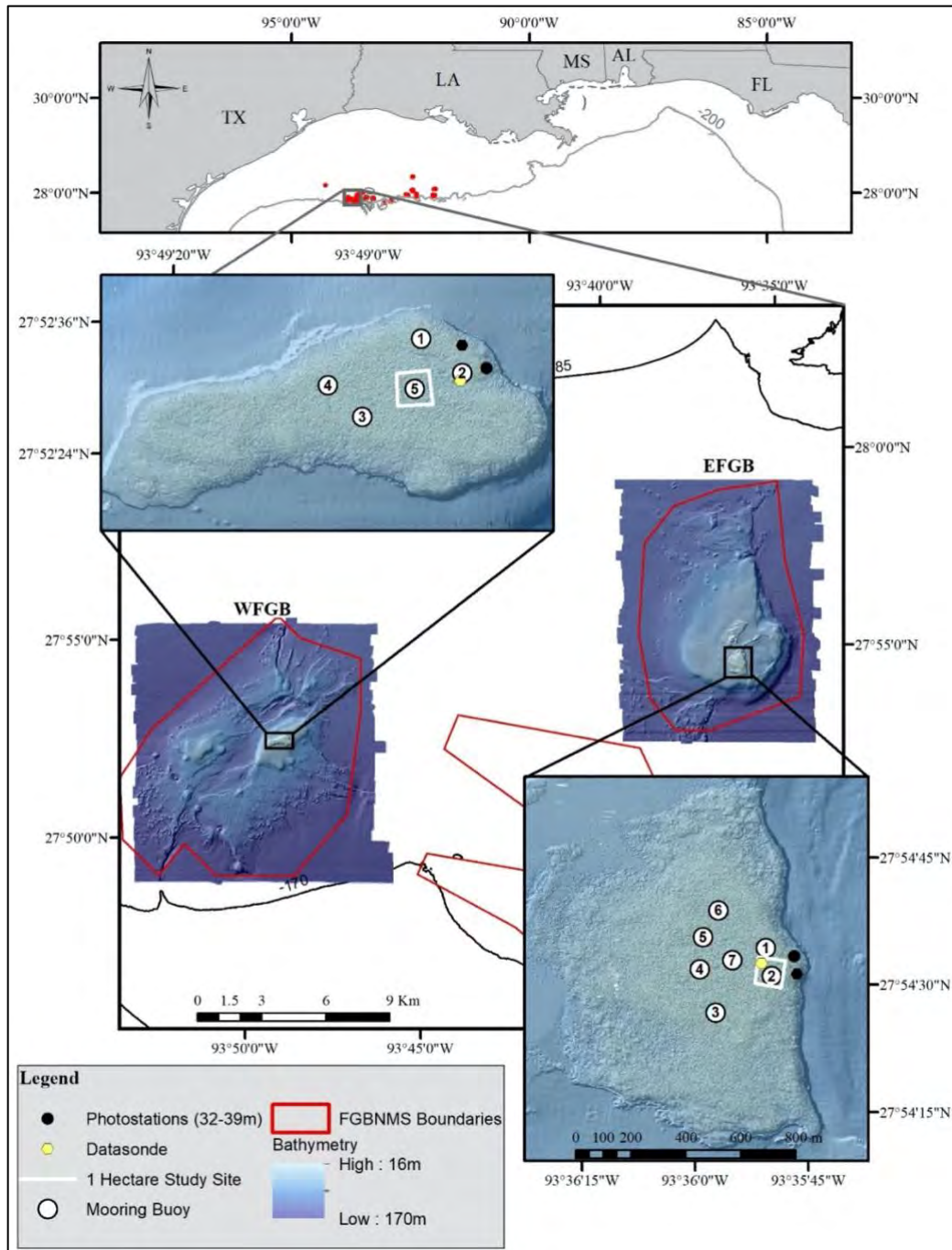


Figure 1.3. Shaded relief maps of EFGB and WFGB, with inset of the Gulf of Mexico coastline, showing the location of one-hectare long-term monitoring program study sites, datasondes, and repetitive photostation locations, which range in depth from 32–39 m.

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 exploration and extraction. Knowing the condition of natural resources within

the national marine sanctuary and providing scientifically credible data are fundamental to NOAA's ability to protect and manage these areas and evaluate management actions.

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

- 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 demographics
- Identify changes in coral reef health resulting from both natural and human-induced stressors to facilitate management responses
 - Indicators: Bleaching, disease, and invasive species
- Facilitate adaptive management of activities impacting reef-related resources
 - Indicators: Baseline data and image archive of damage to resources
- Identify and monitor key species that may be indicative of reef and ecosystem health
 - Indicators: Sea urchin and lobster density
- Provide a consistent and timely source of data on environmental conditions and the status of living marine resources
 - Indicators: Published, peer-reviewed annual reports

Long-Term Monitoring Program Components

The long-term monitoring 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 alter the integrity of EFGB and WFGB coral communities. 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 infrastructure development, make EFGB and WFGB ideal sentinel sites for continued monitoring. The following techniques are used in this monitoring program to evaluate coral reef diversity, growth rates, and community health in designated monitoring areas 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;
- Biennial coral demographic surveys provide information on recruitment, coral density, and coral colony size;
- Stationary reef fish visual census surveys assess community structure of coral reef fishes;
- Long-spined sea urchin (*Diadema antillarum*) and lobster (*Panulirus argus* and *P. guttatus*) surveys establish current population levels and trends;
- Water quality datasondes record salinity, temperature, and turbidity at depth; and
- Quarterly sampling of chlorophyll *a*, ammonia, nitrate, nitrite, total Kjeldahl nitrogen, and phosphorus documents water column productivity.

The long-term monitoring study area consists of several locations on the EFGB and WFGB coral reef caps where benthic, fish, and water quality data are collected. 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 “one-hectare study sites”) at EFGB and WFGB. The corners and centers of the one-hectare study sites are marked by large eyebolts as reference markers. Depth ranges from 17–27 m and 18–25 m within the EFGB one-hectare study site and WFGB one-hectare study site, respectively (Figure 1.4; Figure 1.5). Mooring buoy anchors (#2 at EFGB and #5 at WFGB) were located within the one-hectare study site centers to facilitate field operations (Figure 1.3; Table 1.1). Mooring buoys are installed at these sites only during field research activities, thus restricting access at other times. Additionally, permanent repetitive photostations were installed at each bank beyond the one-hectare study site boundaries to capture benthic cover in depth ranges of 32–39 m. These include 23 repetitive photostations at EFGB, located east of EFGB mooring buoy #2, and 24 repetitive photostations at WFGB, located north of WFGB mooring buoy #2 (Figure 1.4; Figure 1.5). Water quality datasondes are located near EFGB mooring buoy #2 and WFGB mooring buoy #2 (Figure 1.3; Figure 1.4; Figure 1.5). Additional temperature loggers at 30 m and 40 m are paired with repetitive photostations at these depths at EFGB and WFGB (Figure 1.4; Figure 1.5).

Table 1.1. Coordinates and depths for moorings within one-hectare study sites at each bank.

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
WFGB Mooring #2	27° 52.526' N	93° 48.836' W	24.4

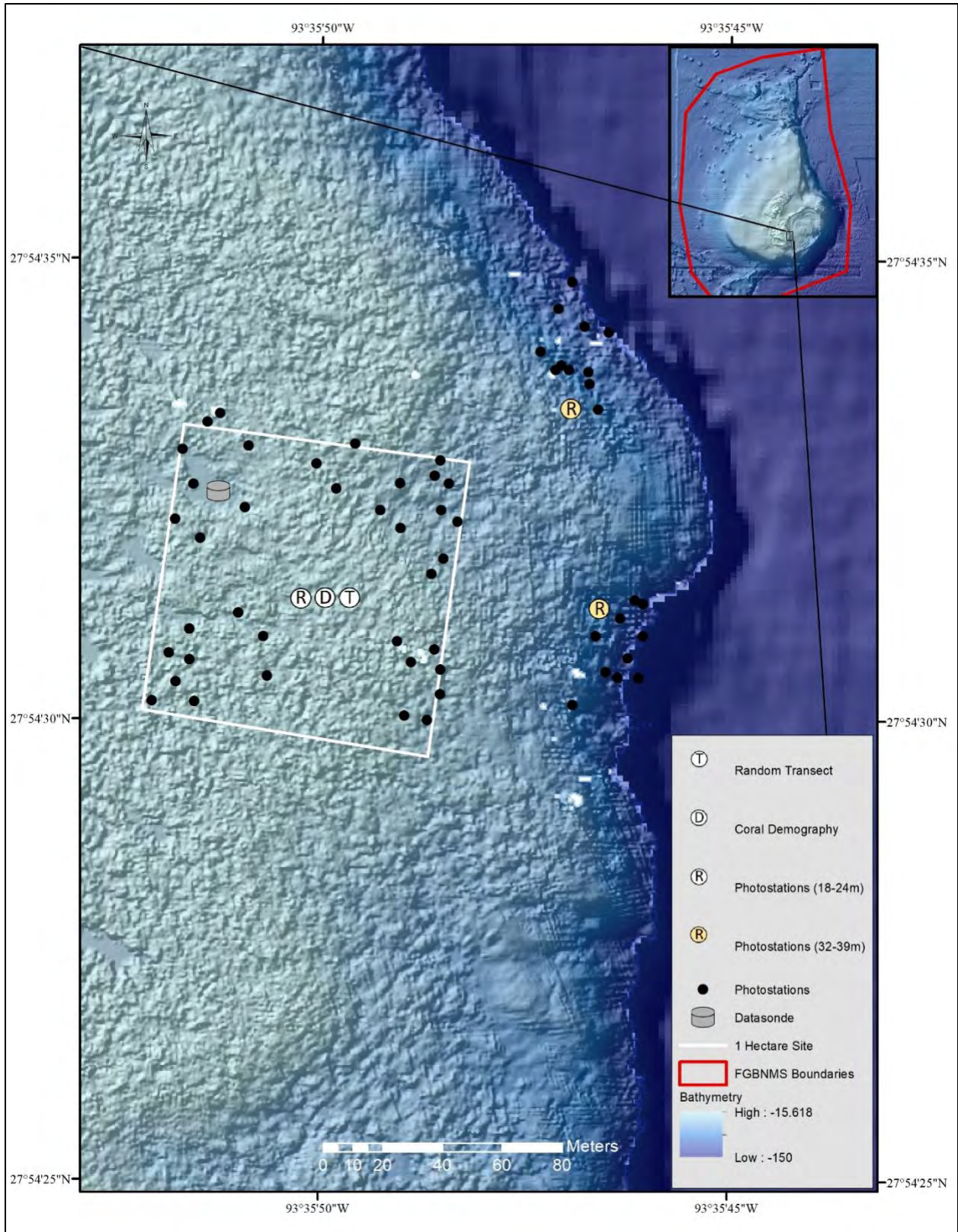


Figure 1.4. Shaded relief map of EFGB showing the location of the one-hectare study site, within which repetitive photostations (18–24 m), random transects, and coral demographic surveys are conducted. Also shown are the water quality datasonde and 32–39 m repetitive photostation locations.

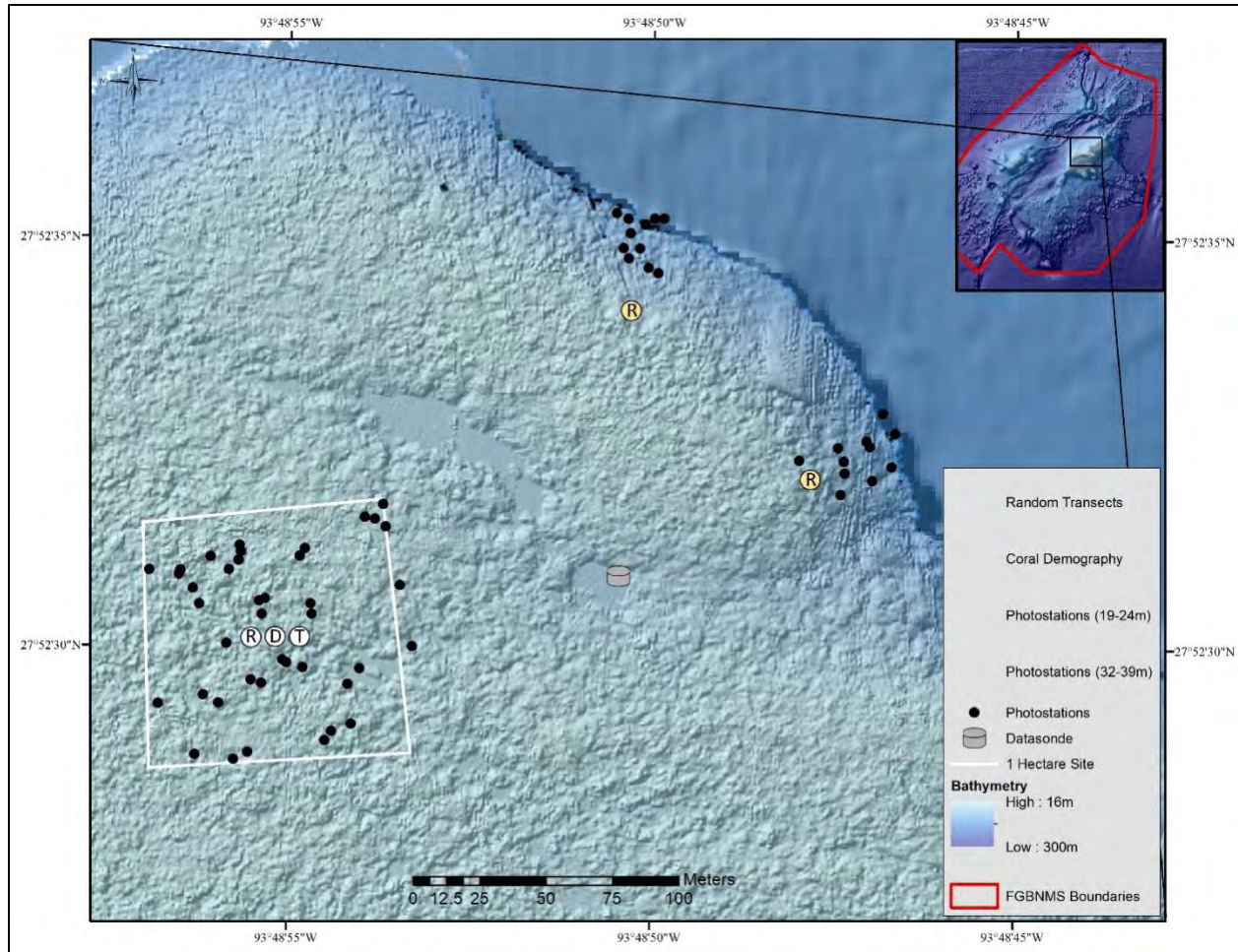


Figure 1.5. Shaded relief map of WFGB showing the location of the one-hectare study site, within which repetitive photostations (18–24 m), random transects, and coral demographic surveys are conducted. Also shown are the water quality datasonde and 32–39 m repetitive photostation locations.

Long-Term Monitoring Field Operations and Data Collection

To date, the long-term monitoring program comprises 32 years of nearly continuous coral reef monitoring data. In 2020, field operations were not conducted after March due to vessel and personnel restrictions established by NOAA in response to the COVID-19 pandemic. Field operations in 2021 were limited due to continued COVID-19 restrictions and precautions (i.e., mission approval by regional managers, reduced crew and divers on the vessel, vaccination and testing requirements, etc.); therefore, only the highest priority long-term monitoring data were collected at both EFGB and WFGB in 2021 (Table 1.2). Scuba operations were conducted aboard the NOAA R/V *Manta*. Water samples were collected, water quality instruments were exchanged, and data were downloaded by FGBNMS staff during two out of four quarters in 2021 (Table 1.2). See each respective chapter for detailed field methodology.

Table 1.2. Monitoring cruises completed at EFGB and WFGB in 2020 and 2021.

Date(s)	Cruise Type and Tasks Completed
2/22/2020– 2/23/2020	Water quality cruise: Water sample collection
3/12/2020	Water quality cruise: Instrument exchange
6/23/2021– 6/26/2021	Water quality cruise: Instrument exchange
8/25/2021– 8/26/2021	Long-term monitoring cruise: EFGB annual monitoring
11/2/2021– 11/4/2021	Long-term monitoring and water quality cruise: WFGB annual monitoring, water quality instrument exchange, and water sample collection

Annual fieldwork at EFGB was conducted August 25–26, 2021 (Table 1.2). Due to reduced crew (from four to three crew members) and dive capacity (from ten to five divers) on the vessel as a result of COVID-19 precautions, only the priority tasks of water quality instrument exchange and repetitive photostation image collection within the one-hectare study sites were completed. Strong surface and bottom currents (0.5 kt) and poor visibility (12 m) shortened the EFGB cruise from four days to two days, as offshore conditions deteriorated with the approach of Hurricane Ida. The storm made landfall near Port Fourchon, Louisiana as a Category 4 hurricane on August 29, 2021.

Annual monitoring at WFGB was conducted November 2–4, 2021 (Table 1.2). Water quality samples were collected and instruments were exchanged, and repetitive photostations within the one-hectare study site were photographed.

Benthic random transect surveys, repetitive photostation photographs within the 32–39 m depth range, fish surveys, water quality instrument exchange at the 30 m and 40 m depth locations, sea urchin surveys, and biennial coral demographic surveys were not performed as a result of weather and COVID-19 precautions. If COVID-19 precautions become less restrictive, these data will be collected in 2022.

Chapter 2: Benthic Community



A scuba diver swims above massive boulder coral colonies at West Flower Garden Bank. Photo: Kelly O'Connell/CPC, Inc.

Benthic Community Introduction

Permanent repetitive photostations were photographed to document changes in the composition of benthic assemblages at select locations within one-hectare study sites at EFGB and WFGB. The photographs were analyzed to measure percent benthic cover, including components such as corals, sponges, crustose coralline algae (CCA), and macroalgae using random-dot analysis. All comparisons within this category are intended solely to assess differences among groups of repetitive photostations, as they were not randomly selected and therefore may not represent the general reef community. While these stations can help identify directions and causes of change, they are not intended to estimate reef-wide populations or communities. Permanent repetitive photostations ranging in depth from 32–39 m and located beyond the one-hectare study site boundaries (23 repetitive photostations at EFGB and 24 repetitive photostations at WFGB) were not photographed in 2021 due to lack of time and reduced capacity of crew and divers due to COVID-19 precautions.

Randomly located 8-m photo transects within EFGB and WFGB one-hectare study sites were not photographed in 2021. These surveys typically are used to compare habitat and document the benthic reef community within EFGB and WFGB one-hectare study sites.

Benthic Community Methods

Repetitive Photostation Field Methods

Repetitive photostations, marked by permanent pins with numbered tags on the reef, were located by scuba divers using underwater maps displaying compass headings and distances to each station. Thirty-three out of 37 photostations were located and photographed within the EFGB one-hectare study site and 34 out of 41 photostations were located and photographed within the WFGB one-hectare study site, representing 89% and 83% of all photostations at EFGB and WFGB, respectively.

After photostations were located, divers photographed each station using a Nikon® D7000® SLR camera with 16-mm lens in a Sea&Sea® housing with a 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 (Figure 2.1). 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 bullseye bubble level and compass (for more detailed methods, see Johnston et al. [2017a]). This set-up produced images covering 5 m².

Due to worsening offshore conditions from Hurricane Ida, not all EFGB located photostations were captured using the Nikon® D7000® SLR camera. Divers used a small GoPro® camera to take pictures of seven stations in heavy current. Photos of stations taken with the GoPro® camera were qualitatively analyzed, as dimensions and scale of these images were not comparable to other images.

It should be noted that during the entirety of the monitoring program, underwater camera setups used to capture benthic cover in the repetitive photostations changed as technology advanced from 35-mm slides and film (1989 to 2007) to digital still images (2008 to 2019)

(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, 2018, 2020, 2021). From 1989 to 2009, photographs for each repetitive photostation encompassed an area of 8 m², but changed to an area of 5 m² in 2009, 9 m² in 2010, and back to 5 m² from 2011 onward due to requirements for consistent image quality, changes in camera equipment, and updated technology. The total number of photostations changed over time as well, as new stations were established or old stations were lost or not located due to missing tags or overgrown stations posts. Approximately 40 photostations have been maintained within each one-hectare study site since 1989. Within the 32–39 m depth range, nine of the 23 EFGB photostations were established in 2003 and 12 of the 24 WFGB photostations were established in 2012. Two additional EFGB stations (30 m and 31 m) were added in 2013. The remaining 12 photostations in this depth range at each bank were added in 2017.



Figure 2.1. A NOAA diver photographs a repetitive photostation using a camera and strobes mounted to an aluminum T-frame. Photo: G.P. Schmahl/NOAA

Repetitive Photostation Data Processing

Mean percent benthic cover from repetitive photostation images was analyzed using Coral Point Count[®] with Excel[®] extensions (CPCe) version 4.1 (Aronson et al., 1994; Kohler & 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 quality assurance/quality control (QA/QC). Organisms beneath each random point were identified to the lowest possible taxonomic level, and cover was categorized into seven groups: 1) coral, 2) sponges (including encrusting sponges), 3) CCA, 4) macroalgae (algae longer than approximately 3 mm and thick algal turfs covering underlying

substrate), 5) colonizable substrate (including fine turf algae, rubble, and bare rock; Aronson & Precht, 2000; Aronson et al., 2005), 6) sand, and 7) an “other” category (biotic components such as sea urchins, ascidians, fish, serpulids, and unknown species). Additional 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. Point count analysis was conducted for all photos and mean percent cover for functional groups was determined by averaging across all photostations per one-hectare study site. Results are presented as mean percent cover \pm standard error (SE). Changes in percent cover at repetitive photostations were compared annually. Because photostations were not randomly located, they are not intended to estimate reef-wide populations or benthic communities. Due to the limited number of stations collected at EFGB, statistical comparisons between EFGB and WFGB were not made for this reporting period.

Coral bleaching, paling, concentrated and isolated fish biting, and mortality were also recorded as “notes” in CPCe, providing additional data for each random point. Any point that landed on a portion of coral that was white in color was characterized as “bleached.” Any point that landed on coral that was pale relative to what is considered “normal” for the species was characterized as “paling” (Lang et al., 2012). If the colony displayed some bleaching or paling, but the point landed on a healthy area of the organism, the point was labeled “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. Recent mortality included any point on exposed bare skeleton with little to no algae growth that could still be identified to the species level, whereas transitional mortality included dead coral with moderate algal growth, and old mortality included dead coral colonized by algae or turf.

All images from 2021, including EFGB stations captured with a GoPro camera, were qualitatively analyzed and compared to 2019 images to capture changes not noted in benthic cover analysis. Any major changes in benthic cover, coral colonies, etc., were noted.

Consistency for repetitive photographic methods was ensured by using multiple, scientific divers trained on the same camera system for correct camera operation. Camera settings and equipment were standardized so that consistent images were taken annually, and equipment checklists were provided in the field to ensure divers had all equipment and were confident with tasks assigned. Photographs were reviewed promptly after images were taken, in the field, to ensure the quality was sufficient for analysis. After all benthic components were identified in CPCe files, QA/QC consisted of an independent review by a separate, trained researcher, different from the CPCe analyzer, to ensure all identified points from the photographs were accurate. Any mistakes were corrected before percent cover analysis was completed.

Benthic Community Results

Repetitive Photostation Mean Percent Cover

Coral and macroalgae were the dominant benthic cover categories in EFGB and WFGB repetitive photostations in 2021 (Figure 2.2; Table 2.1). At EFGB, 2.7% of the coral cover analyzed was observed to be pale or bleached in the repetitive photostations. At WFGB, 5.4% of the coral cover analyzed was observed to be pale or bleached in the repetitive photostations; however, 2021 WFGB photostation images were taken later in the year, when bleaching is expected to be more prevalent at FGBNMS (Johnston et al., 2019). In addition, 0.3% of total coral cover was affected by fish biting, less than 2% was affected by recent mortality, and less than 1% was affected by old mortality in all repetitive photostations combined. Stony coral tissue loss disease (SCTLD) was not observed.

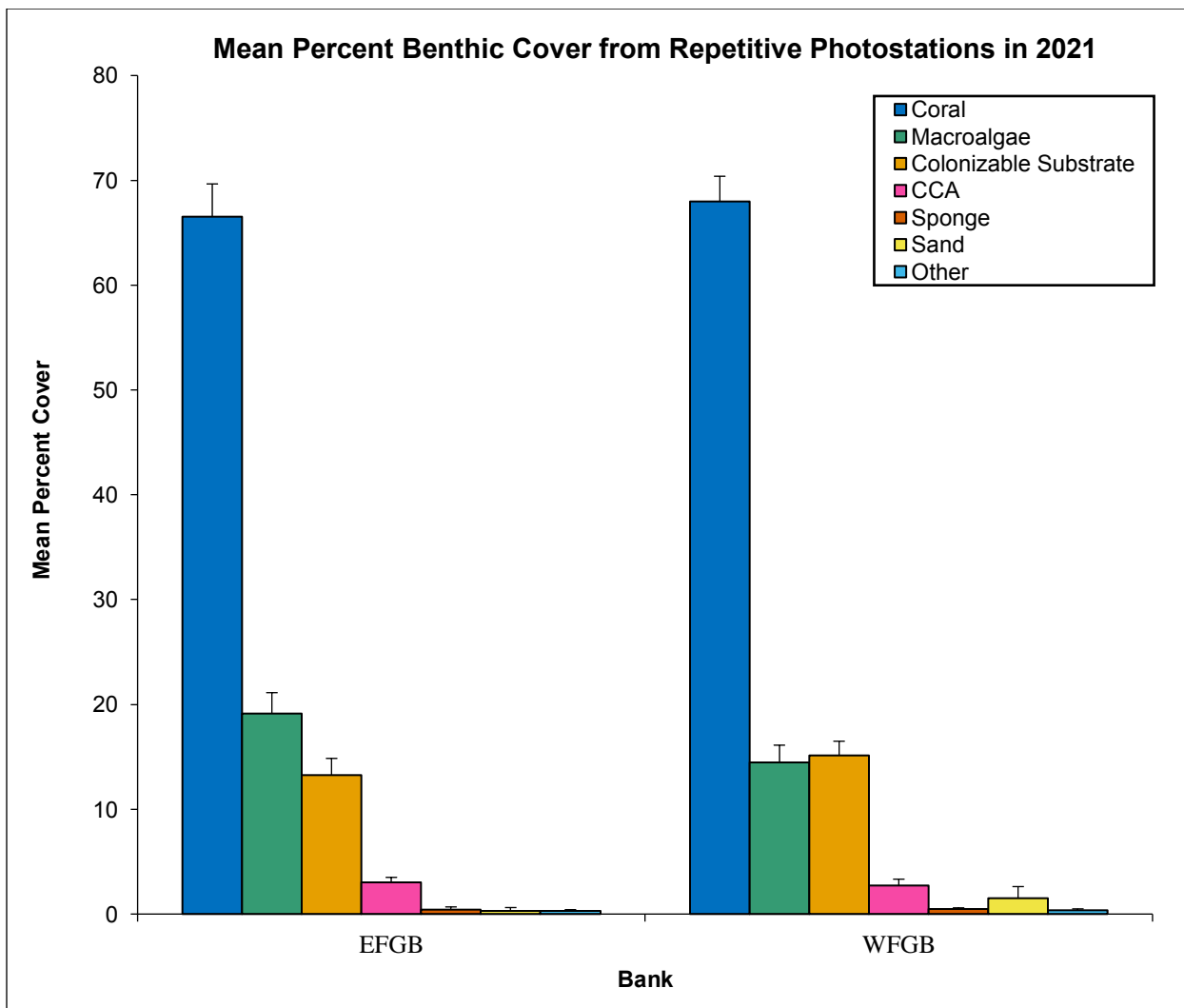
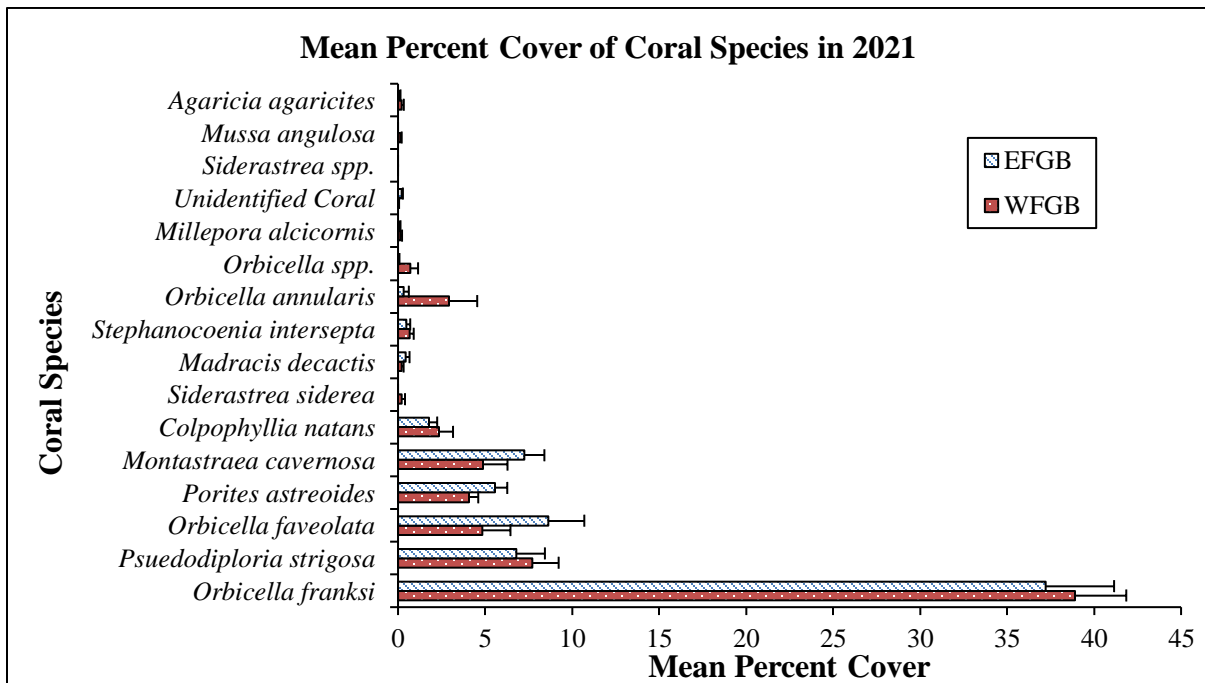


Figure 2.2. Mean percent benthic cover + SE within EFGB and WFGB repetitive photostations in 2021.

Table 2.1. Range of percent cover from EFGB and WFGB repetitive photostations, and all photostations combined, in 2021.

Cover Type	EFGB	WFGB	EFGB and WFGB Combined
Coral	27.08–90.82%	41.41–87.64%	27.08–90.82%
Macroalgae	7.07–44.79%	1.12–39.39%	1.12–44.79%
CCA	0.00–9.68%	0.00–11.83%	0.00–11.83%
Colonizable substrate	0.00–30.11%	3.13–34.41%	0.00–34.41%
Sponge	0.00–5.43%	0.00–3.23%	0.00–5.43%
Sand	0.00–7.61%	0.00–33.67%	0.00–33.67%
Other	0.00–1.06%	0.00–3.23%	0.00–3.23%

Fourteen coral species were observed in EFGB repetitive photostations and 15 were observed in WFGB repetitive photostations. *Orbicella franksi* was the dominant coral species in EFGB repetitive photostations ($37.22 \pm 3.93\%$), followed by *O. faveolata* ($8.63 \pm 2.08\%$) and *Porites astreoides* ($7.64 \pm 1.20\%$) (Figure 2.4). *Orbicella franksi* was the dominant coral in WFGB repetitive photostations ($38.89 \pm 2.96\%$), followed by *Pseudodiploria strigosa* ($7.73 \pm 1.50\%$) and *Montastraea cavernosa* ($4.88 \pm 1.41\%$) (Figure 2.3).

**Figure 2.3.** Mean percent cover + SE of coral species from repetitive photostations at EFGB and WFGB in 2021.

Qualitative Analysis of Repetitive Photostations

The most prominent difference between 2019 and 2022 images was the increased level of paling and bleaching (Table 2.2; Table 2.3). However, 2021 photostation images were taken later in the year when bleaching is expected to be more prevalent at FGBNMS (Johnston et al., 2019). The seven EFGB photostations located and subsequently photographed using a GoPro camera were not comparable to other images due to differences in dimension and scale (Figure 2.4); however, the GoPro images still allowed for qualitative assessment. Numerous colonies were dislodged or absent, and there appeared to be an overall decrease in *Dictyota* sp. and an increase in turf algae.

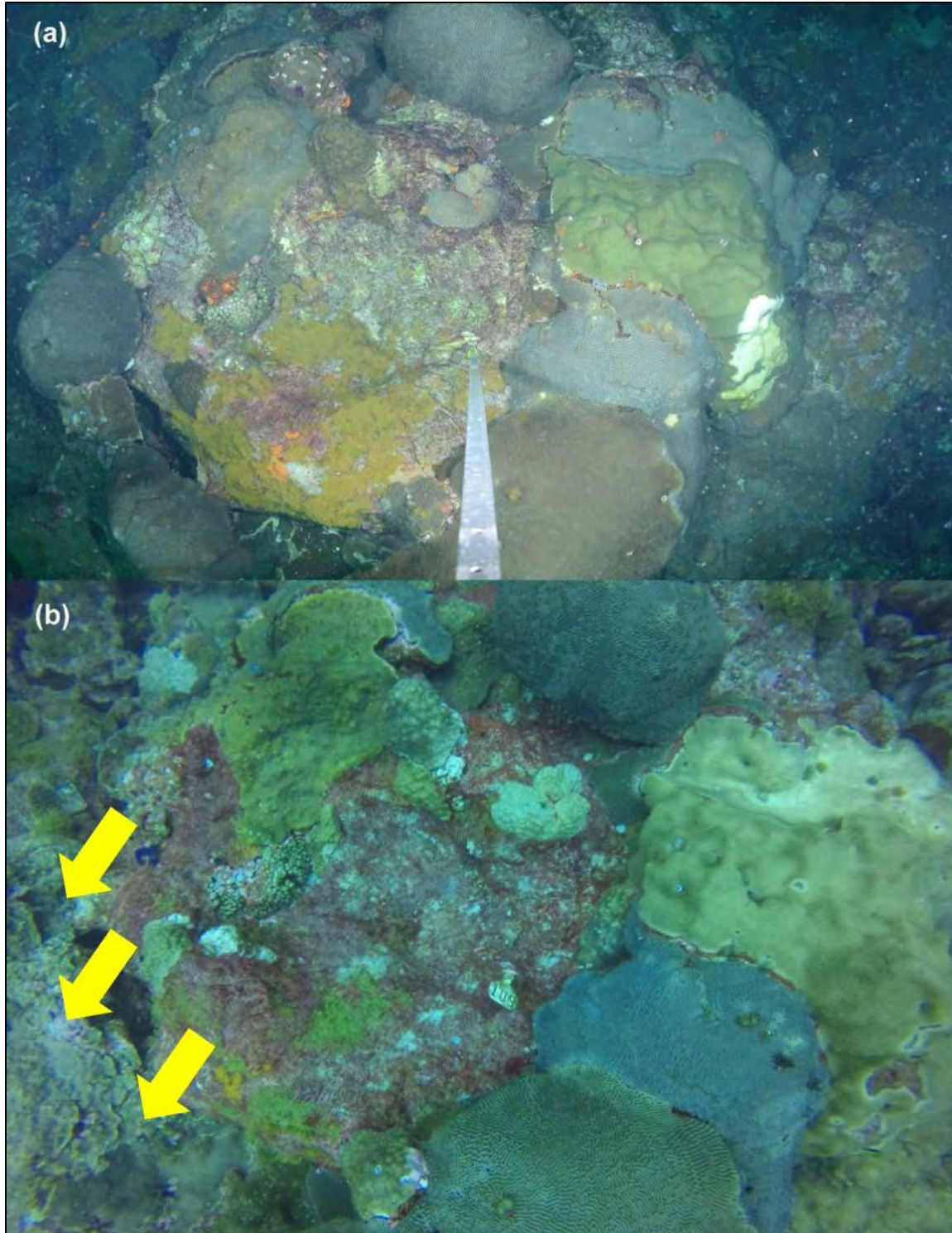


Figure 2.4. EFGB repetitive photostation #109 taken in (a) 2019 with a Nikon® D7000® SLR camera mounted to an aluminum t-frame and (b) 2021 with a GoPro camera, resulting in differences in dimension and scale. Two large *P. strigosa* colonies and one large *P. astreoides* colony were dislodged and missing in 2021 (yellow arrows), which may be evidence of hurricane damage. Photos: NOAA

Table 2.2. Qualitative comparison of EFGB repetitive photostations in 2019 and 2021. Photostations for which 2021 images were taken with a GoPro camera instead of the Nikon® D7000® camera are in bold. Stations 305, 401, 404, and 409 were not photographed in 2021.

Photostation	Site Description in 2019	2019 to 2021 Comparison
EFGB 101	Station dominated by <i>Orbicella franksi</i> colonies, patches of <i>Dictyota</i> sp. present, CCA abundant in between colonies. All colonies healthy. No bleaching observed.	Partial loss of tissue on <i>O. franksi</i> colony, transitional mortality present. Loss of <i>Dictyota</i> sp.; turf algae and CCA colonized opened space.
EFGB 102	Station dominated by large <i>Pseudodiploria strigosa</i> colonies and <i>Orbicella</i> spp. <i>Dictyota</i> sp. present, <i>Agelas clathrodes</i> sponge present.	Tissue recovery in three large <i>P. strigosa</i> colonies in top center. In one case, tissue extension occurred replacing CCA. Loss of tissue in center <i>P. strigosa</i> colony (from middle rather than edges). Loss of half of <i>Dictyota</i> sp. patches. Recovery of tissue between two <i>P. strigosa</i> colonies, closing the space between them. <i>O.</i> species remain unchanged. Sponges still present but diminished in size.
EFGB 103	Station dominated by <i>P. strigosa</i> colonies and <i>Orbicella</i> spp. colonies. <i>A. clathrodes</i> sponge present. <i>Arolochoia crassa</i> sponge present.	Growth of <i>O. franksi</i> colony (patchy colony beginning to reconnect). Extension of <i>P. strigosa</i> colony. Recovery of tissue patches on two <i>P. strigosa</i> colonies. Partial tissue loss of <i>A. clathrodes</i> sponge. Recovery of damselfish bites on an <i>O. franksi</i> colony. Near complete loss of center <i>O. franksi</i> colony. Partial tissue loss on <i>O. franksi</i> colony. Tissue extension of <i>O. franksi</i> colony. Near complete loss of <i>Dictyota</i> sp. Turf algae lacking, more fine turf cover.
EFGB 104	Station dominated by <i>Orbicella</i> spp. <i>Dictyota</i> sp. present in patches. CCA present.	Partial loss of <i>P. strigosa</i> colony (transitional mortality), extension of <i>P. strigosa</i> colony. Unhealthy <i>P. strigosa</i> colony with patchy tissue damage overgrown with turf algae. Loss of all <i>Dictyota</i> sp. patches, increase in turf algae.

Photostation	Site Description in 2019	2019 to 2021 Comparison
EFGB 105	Station dominated by <i>P. strigosa</i> and <i>Porites astreoides</i> colonies. <i>A. crassa</i> sponge present, <i>Millepora alcicornis</i> colonies present, <i>Dictyota</i> present, and CCA present.	Partial tissue loss of two <i>A. clathrodes</i> sponges, partial loss of <i>P. strigosa</i> colony. Loss of rubble with increase in sand. Partial loss of large <i>P. strigosa</i> colony, Complete loss of all <i>M. alcicornis</i> colonies; replaced with CCA. Extension of another sand patch. Complete loss of <i>P. strigosa</i> colony. Addition of large CCA patch. Partial loss of <i>Dictyota</i> sp. patches.
EFGB 106	Station dominated by <i>Orbicella</i> spp. and <i>A. clathrodes</i> sponges present. <i>Dictyonella ruetzleri</i> sponges present. <i>Madracis decactis</i> present and <i>Dictyota</i> sp. present. Some transitional mortality on <i>O. franksi</i> colony.	Loss of some <i>D. ruetzleri</i> , partial loss of two <i>A. clathrodes</i> sponges (overgrown with algae), and CCA maintained. <i>Dictyota</i> sp. maintained with few losses. Near complete loss of large <i>O. franksi</i> colony that had initial transitional mortality.
EFGB 107	Station dominated by <i>O. franksi</i> and <i>P. strigosa</i> colonies. <i>Dictyota</i> sp. present. <i>D. ruetzleri</i> and <i>A. clathrodes</i> sponges present.	Complete loss of two large <i>P. strigosa</i> colonies. Paling of <i>O. franksi</i> and <i>M. cavernosa</i> colonies. Partial loss of <i>D. ruetzleri</i> and <i>A. clathrodes</i> sponges. <i>Dictyota</i> sp. maintained.
EFGB 108	Station dominated by relatively small <i>P. strigosa</i> and <i>P. astreoides</i> colonies. <i>M. cavernosa</i> and <i>Orbicella</i> spp. present. CCA, turf algae, and <i>Dictyota</i> sp. present. <i>A. clathrodes</i> and <i>A. crassa</i> sponges present.	Complete loss of <i>P. strigosa</i> colony. Complete loss of two <i>Agaricia agaricites</i> colonies. Tissue loss on <i>A. clathrodes</i> sponge, overgrown with algae. Paling <i>M. cavernosa</i> colony with some partial tissue loss. Partial tissue loss on <i>P. astreoides</i> colony. Partial tissue loss on <i>A. crassa</i> sponges with discoloration. Slight loss of <i>Dictyota</i> sp. and turf. Increase in CCA.
EFGB 109	Station dominated by <i>P. strigosa</i> and <i>O. franksi</i> . Bleaching and mortality on <i>O. faveolata</i> colony. Large patches of <i>Dictyota</i> sp.	Photo smaller as taken with GoPro. Some mortality from bleaching on <i>O. faveolata</i> colony. Less <i>Dictyota</i> sp. and more turf algae. Tissue recovery on <i>P. strigosa</i> colony. Two large <i>P. strigosa</i> colonies dislodged and missing. Large <i>P. astreoides</i> colony missing. Evidence of hurricane damage. Paling on <i>O. franksi</i> colony.

Photostation	Site Description in 2019	2019 to 2021 Comparison
EFGB 201	Station dominated by large <i>O. faveolata</i> colony and surrounded by <i>O. franksi</i> colonies. Turf algae and CCA present in the middle. <i>O. faveolata</i> experiencing some transitional mortality.	Partial tissue loss in <i>O. faveolata</i> colony, overgrown with fine algae. Extension of loss in areas previously described as transitional mortality, while leftover tissue looks mostly healthy. Evidence of some growth on <i>O. faveolata</i> colony in areas where the tissue was not affected in 2019. Bleaching on <i>M. cavernosa</i> colony.
EFGB 202	Station dominated by <i>O. franksi</i> colonies and large <i>M. cavernosa</i> colony. Small <i>C. natans</i> colony.	Partial loss of <i>C. natans</i> colony (10%), potentially due to fish biting. Slight paling on <i>M. cavernosa</i> colony. Loss of some CCA with increased turf algae.
EFGB 203	Station dominated by <i>O. franksi</i> , <i>Dictyota</i> sp., and <i>Lobophora variegata</i> . Some transitional mortality around <i>O. franksi</i> colonies. Presence of turf algae and CCA. One <i>M. alcornis</i> colony.	Complete loss of <i>O. franksi</i> colony fragment. Loss of some of <i>Dictyota</i> sp. and <i>L. variegata</i> . Bleaching of <i>M. alcornis</i> colony.
EFGB 204	Station dominated by <i>O. franksi</i> and <i>Dictyota</i> sp. Turf algae present. Some transitional mortality on edges of <i>O. franksi</i> colonies with algae overgrown.	Partial tissue loss on <i>O. franksi</i> colony and <i>P. astreoides</i> colony. Slight decline in <i>Dictyota</i> sp. and <i>L. variegata</i> . Increase in turf algae. Paling of some <i>Orbicella</i> spp. colonies.
EFGB 205	Station dominated by <i>O. franksi</i> and <i>Dictyota</i> sp. Small <i>Ircinia felix</i> sponge present.	Partial tissue loss on <i>P. astreoides</i> colony. Paling of <i>O. franksi</i> colony. CCA and <i>Dictyota</i> sp. cover maintained.
EFGB 206	Station dominated by <i>O. faveolata</i> , <i>Dictyota</i> sp., <i>P. strigosa</i> , and <i>L. variegata</i> . Recent mortality on multiple <i>P. strigosa</i> colonies.	Extension of <i>C. natans</i> colony. Growth of <i>Orbicella</i> spp. colony from two fragments into one. Some tissue recovery on <i>P. strigosa</i> colonies. Complete loss of <i>P. strigosa</i> colony fragments. Tissue mortality on <i>P. strigosa</i> colony (covered in CCA). Slight loss of <i>Dictyota</i> sp. and <i>L. variegata</i> .

Photostation	Site Description in 2019	2019 to 2021 Comparison
EFGB 207	Station dominated by large <i>O. faveolata</i> colony. <i>P. strigosa</i> and <i>O. franksi</i> colonies present. <i>Dictyota</i> sp. present.	Tissue recovery on large <i>O. faveolata</i> colony. Decrease in <i>Dictyota</i> sp., increase in turf algae.
EFGB 208	Station dominated by <i>O. franksi</i> . CCA, <i>Dictyota</i> sp., and turf algae. Some transitional mortality on edges of <i>O. franksi</i> colonies, recently colonized by CCA.	Loss of tissue on multiple <i>O. franksi</i> colonies. Loss of <i>Dictyota</i> sp. Loss of tissue on <i>O. faveolata</i> colony.
EFGB 209	Station dominated by <i>O. franksi</i> and <i>O. annularis</i> colonies. Turf algae and CCA present. All colonies appear healthy.	Paling on <i>M. cavernosa</i> colony and <i>O. franksi</i> colony.
EFGB 210	Station dominated by <i>O. franksi</i> colonies. <i>Dictyota</i> sp. present. Turf algae and CCA present.	Tissue loss on <i>O. faveolata</i> colony (recovery of different section of colony). Tissue loss on <i>O. franksi</i> colony. Loss of CCA and macroalgae. Complete loss of <i>M. alricornis</i> colony.
EFGB 211	Station dominated by large <i>P. strigosa</i> colony and various <i>O. franksi</i> colonies. CCA, turf algae, and <i>Dictyota</i> sp. present.	Loss of majority of <i>Dictyota</i> sp. No other distinct changes.
EFGB 212	Station dominated by large <i>O. franksi</i> and <i>P. strigosa</i> colonies. Tissue loss on <i>O. faveolata</i> colony.	<i>C. natans</i> colony dislodged from original place with more than 50% tissue loss. Partial loss of macroalgae.
EFGB 301	Station dominated by large <i>O. franksi</i> and <i>P. strigosa</i> colonies. CCA, turf algae, and <i>Dictyota</i> sp. present.	Recovery of some <i>P. strigosa</i> and <i>O. franksi</i> tissue on originally fragmented colonies. Loss of macroalgae.
EFGB 302	Station dominated by <i>O. franksi</i> colonies. CCA, turf algae, and <i>Dictyota</i> sp. present. Discoloration on large <i>O. faveolata</i> colony.	Tissue loss on fragmented <i>O. franksi</i> colonies and <i>P. astreoides</i> colonies. Tissue loss on large <i>O. faveolata</i> colony where discoloration was.
EFGB 303	Station dominated by <i>O. franksi</i> and <i>P. strigosa</i> colonies. CCA and turf algae present.	Complete loss of <i>P. astreoides</i> colony. More than 50% loss of large <i>O. faveolata</i> colony. No change in turf algae or CCA.

Photostation	Site Description in 2019	2019 to 2021 Comparison
EFGB 304	Station dominated by <i>O. franksi</i> and <i>P. strigosa</i> . Patches of <i>Dictyota</i> sp. and CCA.	Complete loss of two <i>P. astreoides</i> colonies. Partial tissue loss on <i>O. franksi</i> colony. Loss of <i>Dictyota</i> sp.
EFGB 306	Station dominated by large <i>P. strigosa</i> and <i>O. franksi</i> colonies. Turf algae, <i>Dictyota</i> sp., and CCA present. Patchy mortality on <i>M. cavernosa</i> colony. Recent mortality on <i>P. strigosa</i> colony.	Partial tissue loss of <i>O. franksi</i> colony. Some recovery of <i>P. strigosa</i> colony. Loss of macroalgae.
EFGB 307	Station dominated by <i>M. cavernosa</i> and <i>O. franksi</i> . <i>Dictyota</i> sp., turf algae, and CCA present.	Bleaching <i>M. cavernosa</i> colonies. Partial loss of <i>O. franksi</i> colony. Loss of most <i>Dictyota</i> sp. patches.
EFGB 402	Station dominated by <i>P. strigosa</i> and <i>O. franksi</i> . <i>Dictyota</i> sp. patches, <i>A. clathrodes</i> sponges, and scattered <i>P. astreoides</i> colonies present. Hyperplasia on dominant <i>P. strigosa</i> colony.	Photo smaller as taken on GoPro. Partial mortality of <i>P. strigosa</i> colony, with hyperplasia still present. Partial mortality on multiple <i>P. strigosa</i> colonies. <i>Dictyota</i> sp. still present, with more turf algae and a higher concentration of CCA.
EFGB 403	Station dominated by <i>O. franksi</i> colonies. Large patches of <i>Dictyota</i> sp.	Photo smaller as taken on GoPro. Partial loss of <i>P. strigosa</i> colony. Complete loss of <i>C. natans</i> colony, loss of majority of <i>Dictyota</i> sp., increase in turf algae, paling of <i>P. astreoides</i> colonies. Partial mortality of <i>O. franksi</i> colony replaced with turf algae. Increase in CCA.
EFGB 405	Station dominated by <i>P. strigosa</i> and <i>O. franksi</i> . Small patches of <i>Dictyota</i> sp., turf algae, and CCA. No recent coral mortality and all living tissue looks healthy. No bleaching.	Photo smaller as taken on GoPro. Partial loss of large <i>P. strigosa</i> colony, with one piece completely gone and another with damselfish bites and algae overgrowth. Small amounts of growth in <i>P. astreoides</i> colonies, increased turf algae, loss of CCA, complete loss of <i>C. natans</i> colony. Partial loss of additional <i>C. natans</i> colony (damselfish grazing) with new algae growth.
EFGB 406	Large <i>C. natans</i> colony, <i>Dictyota</i> sp. patches, <i>P. astreoides</i> colonies, and <i>M. cavernosa</i> colonies. All coral tissue appears to be healthy.	Photo smaller as taken on GoPro. Partial loss of large <i>C. natans</i> colony. Complete loss of <i>P. astreoides</i> colony. Bleaching and tissue loss on two <i>M. cavernosa</i> colonies. Loss of <i>Dictyota</i> sp. Tissue loss on large <i>P. strigosa</i> colony. Paling on <i>P. astreoides</i> colonies. Increase in turf algae.

Photostation	Site Description in 2019	2019 to 2021 Comparison
EFGB 407	Large patches of <i>Dictyota</i> sp., large <i>O. faveolata</i> colony, <i>A. clathrodes</i> sponges, few <i>P. astreoides</i> colonies, and few <i>P. strigosa</i> colonies.	Photo smaller as taken on GoPro. Loss of most <i>Dictyota</i> sp. Breakage of large <i>O. faveolata</i> colony and recovery of some <i>O. faveolata</i> patches. Partial mortality of <i>A. clathrodes</i> sponge and bleaching of <i>P. astreoides</i> colony. Complete loss of <i>P. astreoides</i> and two <i>P. strigosa</i> colonies. Complete loss of <i>P. astreoides</i> cluster. Growth of another <i>O. faveolata</i> colony into photostation.
EFGB 408	Station dominated by <i>O. franksi</i> and large <i>M. cavernosa</i> colony.	Photo smaller as taken on GoPro. Loss of <i>Dictyota</i> sp., complete loss of single <i>P. astreoides</i> colony layered on top of another, mortality on two <i>P. strigosa</i> colonies, increase in turf algae.

Table 2.3. Qualitative comparison of WFGB 2019 to 2021 repetitive photostations taken with a Nikon® D7000® camera. Stations 703–707 and 810 were not photographed in 2021.

Photostation	Site Description in 2019	2019 to 2021 Comparison
WFGB 501	Station dominated by <i>P. strigosa</i> and <i>O. franksi</i> . Large patches of <i>Dictyota</i> sp. and turf algae. Small <i>P. astreoides</i> colony with mortality.	Less <i>Dictyota</i> sp. and turf algae. <i>P. astreoides</i> colony with mortality gaining tissue and growing.
WFGB 502	Station dominated by <i>P. strigosa</i> and <i>O. franksi</i> . <i>Dictyota</i> sp. patches, scattered <i>P. astreoides</i> colonies with partial mortality on one colony, and <i>A. clathrodes</i> sponge.	Partial mortality of <i>P. strigosa</i> on colony margin. <i>Dictyota</i> sp. reduced, increase in turf algae. Complete mortality of <i>P. astreoides</i> colony.
WFGB 503	Station dominated by healthy <i>O. franksi</i> and <i>P. strigosa</i> colonies and one large <i>M. cavernosa</i> colony. One <i>A. clathrodes</i> sponge and turf algae.	All coral colonies and sponge appear to remain healthy. Decreased turf algae.
WFGB 504	Station dominated by <i>O. franksi</i> , small <i>P. strigosa</i> colonies, and one large <i>O. faveolata</i> colony. Small patches of <i>Dictyota</i> sp., turf algae, and CCA. No recent coral mortality and all living tissue looks healthy. No bleaching.	Bleaching in one <i>M. cavernosa</i> colony. Decreased <i>Dictyota</i> sp. and turf algae.

Photostation	Site Description in 2019	2019 to 2021 Comparison
WFGB 505	Large <i>P. strigosa</i> colony and <i>O. franksi</i> colonies. Two <i>A. clathrodes</i> sponges. All coral tissue appears to be healthy.	Partial mortality (25%) of large <i>P. strigosa</i> colony. Mortality not recent and potentially from damselfish farming. Sponges still present.
WFGB 506	Station dominated by <i>O. franksi</i> colonies and small <i>P. astreoides</i> and <i>M. cavernosa</i> colonies. Patches of CCA, <i>A. clathrodes</i> sponges, and one small colony of <i>M. alvicornis</i> .	One <i>M. cavernosa</i> colony partially bleached and <i>M. alvicornis</i> completely bleached. Patches of CCA covered with turf algae, <i>A. clathrodes</i> sponges still present.
WFGB 507	Station dominated by large <i>O. faveolata</i> colony and patchy <i>M. cavernosa</i> colony with old mortality. Old mortality on <i>Siderastrea siderea</i> colony. <i>A. clathrodes</i> and <i>Xestospongia muta</i> sponges present. Patches of <i>Dictyota</i> sp. One large colony of <i>M. alvicornis</i> .	Loss of <i>Dictyota</i> sp. and increased turf algae, sponges still present. One <i>M. cavernosa</i> colony paling, portion of large <i>O. faveolata</i> colony bleached, and <i>M. alvicornis</i> colony bleached while the remaining portion of the colony is no longer present.
WFGB 508	Station dominated by a large <i>P. strigosa</i> colony and <i>O. faveolata</i> colony. All coral tissue appears to be healthy.	Minor bleaching observed in large <i>P. strigosa</i> colony.
WFGB 509	Station dominated by <i>Orbicella</i> sp., <i>O. faveolata</i> , and <i>O. franksi</i> colonies and <i>L. variegata</i> patches. Small sections of transitional mortality on <i>Orbicella</i> sp.	Mortality patches on <i>Orbicella</i> sp. now overgrown with filamentous algae and <i>L. variegata</i> patches are now dominated by turf algae.
WFGB 510	Station dominated by healthy, large <i>O. franksi</i> colony and small colonies of <i>M. cavernosa</i> and <i>M. alvicornis</i> . CCA and fine turf algae present.	<i>M. cavernosa</i> colonies paling and <i>M. alvicornis</i> colonies bleached. Thick turf algae present in places where fine turf algae was previously.
WFGB 511	Small <i>P. strigosa</i> , <i>O. franksi</i> , and <i>P. astreoides</i> colonies present. Fish biting on one <i>P. astreoides</i> colony. Patches of CCA and <i>L. variegata</i> .	<i>P. astreoides</i> colony recovered from fish biting. <i>M. alvicornis</i> colonies bleached.
WFGB 512	Station dominated by <i>O. faveolata</i> and <i>O. franksi</i> colonies. Small patch of recent mortality on <i>O. faveolata</i> colony. Rectangular debris object with attached line covered in CCA.	Patches of transitional mortality on <i>O. faveolata</i> colony. Paling in small <i>O. franksi</i> colony. Rectangular debris object with attached line covered in CCA but further embedded into reef.
WFGB 513	Station dominated by <i>O. faveolata</i> , <i>O. franksi</i> , and <i>P. astreoides</i> colonies. Small patch of recent mortality on <i>P. astreoides</i> colony.	Small patch of mortality on <i>P. astreoides</i> colony now covered with CCA. Colonies are healthy with no bleaching.
WFGB 601	Station dominated by <i>O. franksi</i> and <i>C. natans</i> colonies. One <i>O. franksi</i> colony with concentrated fish biting.	Fine turf covering fish biting area on <i>O. franksi</i> colony. All coral tissue appears healthy.

Photostation	Site Description in 2019	2019 to 2021 Comparison
WFGB 602	Station dominated by <i>O. franksi</i> , <i>O. faveolata</i> , <i>P. strigosa</i> , and <i>P. astreoides</i> . 25% old mortality on <i>O. faveolata</i> colony and 50% old mortality on <i>P. strigosa</i> colony.	Mortality on <i>O. faveolata</i> colony increased to 50%. Mortality areas covered with fine turf.
WFGB 603	Station dominated by <i>O. franksi</i> , <i>P. strigosa</i> , and <i>C. natans</i> colonies. All living coral tissue appears healthy.	All living coral tissue appears healthy and no bleaching observed.
WFGB 604	Station comprised of <i>O. franksi</i> , <i>P. strigosa</i> , <i>M. cavernosa</i> , and <i>P. astreoides</i> colonies. All living coral tissue appears healthy. Patches of CCA and <i>Dictyota</i> sp.	<i>M. cavernosa</i> and <i>P. astreoides</i> colonies paling. More turf algae present.
WFGB 605	Station dominated by large, healthy <i>O. franksi</i> and <i>M. cavernosa</i> colonies. Patches of CCA and <i>L. variegata</i> .	Paling observed in large <i>M. cavernosa</i> colony and bleaching in one <i>O. franksi</i> colony.
WFGB 606	Station dominated by <i>O. franksi</i> and <i>P. strigosa</i> colonies. All living coral tissue appears healthy. Patches of turf algae.	Concentrated fish biting on small <i>O. annularis</i> colony. Less turf algae than in 2019.
WFGB 607	Station dominated by <i>O. franksi</i> with small <i>O. annularis</i> colony and <i>Stephanocoenia intersepta</i> colony. One colony of <i>Mussa angulosa</i> includes CCA patches.	Bleaching on small portion of <i>O. annularis</i> colony. More coral tissue and less CCA on <i>M. angulosa</i> colony.
WFGB 608	Station dominated by large <i>P. strigosa</i> colony with small patch of mortality near margin. One <i>O. franksi</i> colony with 25% mortality. Large areas of substrate covered with CCA. <i>A. clathrodes</i> sponge.	Large <i>P. strigosa</i> colony with mortality spreading to 50% of colony. Mortality of <i>O. franksi</i> colony now 50%. CCA and <i>A. clathrodes</i> sponge still present.
WFGB 609	Station dominated by <i>O. franksi</i> and <i>M. cavernosa</i> colonies. One <i>C. natans</i> colony with 80% old mortality.	Large <i>M. cavernosa</i> colony 50% bleached and one smaller colony paling. Two <i>O. franksi</i> colonies paling. Turf algae covering mortality area on <i>C. natans</i> colony.
WFGB 701	Station dominated by large <i>P. strigosa</i> colonies and small <i>P. astreoides</i> colonies. All living coral tissue appears healthy.	Three small <i>P. strigosa</i> colonies with small bleaching areas near margins. <i>M. alcornis</i> colony bleached.
WFGB 702	Healthy <i>P. strigosa</i> and <i>O. franksi</i> colonies near sand patch. Patches of CCA and one <i>A. clathrodes</i> sponge.	All living coral tissue appears healthy. Sponge still present.
WFGB 708	Station dominated by large <i>O. franksi</i> and small <i>M. cavernosa</i> colonies. Transitional mortality on two small <i>P. astreoides</i> colonies.	Three <i>M. cavernosa</i> colonies paling.

Photostation	Site Description in 2019	2019 to 2021 Comparison
WFGB 709	Station comprised of small <i>P. astreoides</i> and <i>O. annularis</i> colonies with large patches of CCA and substrate covered with fine turf algae. Transitional mortality on small <i>P. astreoides</i> colonies.	Little change in coral tissue from 2019 to 2021. More turf algae covering substrate.
WFGB 801	Station comprised of <i>P. astreoides</i> and <i>M. cavernosa</i> colonies and one large <i>S. siderea</i> colony. <i>S. siderea</i> colony 25% bleached.	<i>M. cavernosa</i> colonies paling and bleaching. Mortality on <i>S. siderea</i> colony at 2019 bleaching areas.
WFGB 802	Station dominated by <i>O. franksi</i> colonies surrounded by <i>O. faveolata</i> , <i>P. strigosa</i> , <i>C. natans</i> , and <i>P. astreoides</i> colonies. <i>M. alcicornis</i> colony in middle of station with patches of CCA.	One <i>O. franksi</i> colony with 25% mortality and <i>M. alcicornis</i> colony bleached.
WFGB 803	Station comprised of large <i>O. franksi</i> and <i>O. faveolata</i> colonies surrounded by <i>M. cavernosa</i> and <i>P. astreoides</i> colonies. All living coral tissue appears healthy.	All <i>M. cavernosa</i> colonies paling and one 50% bleached. One <i>O. franksi</i> colony paling.
WFGB 804	Station dominated by <i>O. franksi</i> colonies surrounded by <i>O. annularis</i> colonies. Fish biting on <i>O. annularis</i> colonies.	Paling on one small <i>M. cavernosa</i> colony. Recovery from fishing biting on <i>O. annularis</i> colonies.
WFGB 805	Station dominated by <i>O. faveolata</i> colony surrounded by <i>O. annularis</i> colonies. All living coral tissue appears healthy.	Two small <i>M. cavernosa</i> colonies bleached.
WFGB 806	Station comprised of large <i>O. franksi</i> colonies surrounded by <i>M. cavernosa</i> and <i>P. strigosa</i> colonies. All living coral tissue appears healthy.	Three small <i>M. cavernosa</i> colonies are bleached.
WFGB 807	Station dominated by large <i>O. franksi</i> colony. All living coral tissue appears healthy.	All living coral tissue appears healthy. More turf algae in 2021.
WFGB 808	Station comprised of small <i>O. franksi</i> , <i>O. annularis</i> , and <i>P. astreoides</i> colonies. Recent mortality on one small <i>P. astreoides</i> colony. Two <i>A. clathrodes</i> sponges.	Transitional mortality on two small <i>P. astreoides</i> colonies. One <i>M. cavernosa</i> colony bleached. Sponge still present.
WFGB 809	Two <i>P. strigosa</i> colonies and one large <i>O. franksi</i> colony surrounded by sand patch. Transitional mortality (80%) on two <i>P. astreoides</i> colonies and three small <i>P. astreoides</i> colonies growing on colonizable substrate.	Full mortality on the two <i>P. astreoides</i> colonies and full mortality on all three small <i>P. astreoides</i> colonies growing on colonizable substrate. Paling on one small <i>M. cavernosa</i> colony.

Benthic Community Discussion

There were several challenges in the 2020 and 2021 field seasons, brought on by restrictions established during the COVID-19 pandemic that limited personnel for vessel and dive operations, increased the difficulty of offshore planning, and shortened cruises. Additionally, inclement weather shortened or postponed cruises. In response to the COVID-19 pandemic, NOAA instituted mandatory telework for all personnel in March 2020 and prohibited diving and vessel operations, particularly overnight cruises. In 2021, NOAA allowed diving and vessel operations, but required significant precautions, and authorization for operations was provided on a case-by-case basis from Office of National Marine Sanctuaries (ONMS) leadership. In order to receive cruise approval, ONMS vessels were required to meet strict COVID-19 protocols that included assessing local community spread of COVID-19 for Galveston County, testing before departure, and reduced crew and personnel on the vessel. FGBNMS remained consistent with ONMS and NOAA small boat program guidance to ensure the safety of occupants on overnight cruise operations. All cruise participants were required to be fully vaccinated and provide a negative COVID-19 PCR test prior to departure. While on board the R/V *Manta*, individuals were required to maintain a 6-foot distance to the best of their ability and wear face masks while in common areas. The number of individuals was reduced to accommodate safe distancing requirements, limiting divers to six and crew to three, for a total of nine participants on board. This reduced the capacity of researchers to complete the offshore tasks. Consequently, no random transect photographs, fish surveys, sea urchin and lobster surveys, photographs of repetitive photostation between 32–39 m, or coral demographics were completed. FGBNMS intends to complete these efforts in 2022.

Despite restricted offshore operations due to the COVID-19 pandemic, FGBNMS was able to conduct critical monitoring tasks and assess the repetitive photostation benthic communities within one-hectare study sites at EFGB and WFGB. There were no signs of SCTLD within the one-hectare study sites, but the coral species present and high coral cover within the sanctuary suggest this location may be susceptible to and strongly affected by the disease should SCTLD reach FGBNMS coral reefs. Therefore, FGBNMS has established a SCTLD preparedness plan to identify research needs and institute prevention, education, preparedness, early warning, response, and intervention strategies should the disease spread to the northern Gulf of Mexico (Johnston, 2021). Bleaching within the repetitive photostations was higher compared to the past several years. Approximately 3% of coral cover within EFGB photostations and 5% of the coral cover within WFGB photostations was pale or bleached; however, 2021 WFGB photostation images were taken later in the year, when bleaching is expected to be more prevalent at FGBNMS. Despite their remote location and deeper depth compared to other Caribbean reefs, EFGB and WFGB are not impervious to impacts, as seen with the 2016 localized mortality and bleaching events (Johnston et al., 2017b, 2019). Some colonies also appeared to be damaged or dislocated, potentially from severe storms (Figure 2.5). Even though the repetitive photostations are not an accurate representation of mean coral cover across the reef, these sites are critical in enabling researchers to track individual colonies over time, especially during extreme events, such as storms and coral bleaching (Johnston et al., 2019; see Chapter 3, Results, Weather section). While the 2021 field season was abnormal due to COVID-19, collecting repetitive

photostation data, even if incomplete, was valuable to assess the benthic community and monitor the health of the reef.

Chapter 3: Water Quality



A scuba diver inspects water quality instruments at West Flower Garden Bank. Photo: Adrienne Correa/Rice University

Water Quality Introduction

Several water quality parameters were continuously or periodically recorded at EFGB and WFGB from December 2019 through October 2021. At a minimum, salinity, turbidity, and temperature were recorded every hour by data loggers installed in or near the one-hectare study sites at depths of approximately 24 m. Temperature loggers co-located with repetitive photostations at depths of 30 m and 40 m at each bank collected hourly readings; however, they were not retrieved during the reporting period due to lack of time and reduced capacity of crew and divers due to COVID-19 restrictions.

Water samples were collected in February 2020 and November 2021 at three different depths within the water column and analyzed by a U.S. Environmental Protection Agency (EPA)-certified laboratory for select nutrient levels. Water column profiles were also acquired in conjunction with water sample collections. Water samples are usually collected on a quarterly basis, but these cruises were canceled or scaled back due to COVID-19 restrictions. This chapter presents data from moored water quality instruments, water column profiles, and water samples collected in 2020 and 2021.

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 conductivity, temperature, and depth (CTD) sensor (SBE 16plus) equipped with a WET Labs ECO NTUS turbidity meter. Instruments were located at a depth of 23 m at EFGB and 27 m at WFGB. Loggers were secured to mounting anchors and located in sand flats at each bank (see Chapter 1, Figure 1.3, Figure 1.4). These instruments recorded temperature, salinity, and turbidity on an hourly basis. Instruments were exchanged by divers for downloading and maintenance in March 2020, June 2021, and November 2021. They were immediately exchanged with an identical instrument to avoid any interruptions in data collection. Data were then downloaded and reviewed, sensors were cleaned and confirmed to be operable, and battery duration was checked. Maintenance, as well as factory service and calibration of each instrument, was delayed in 2020 and 2021 due to limitations on field work as a result of COVID-19 restrictions.

Onset® Computer Corporation HOBO® Pro v2 U22-001 (HOBO) thermograph loggers were used to record temperature on an hourly basis. These loggers (attached directly to the primary SBE 16plus instrument) provided a highly reliable temperature backup for the primary SBE 16plus logging instruments located at the 23 m and 27 m stations at EFGB and WFGB, respectively. HOBO loggers were also deployed at 30 m and 40 m stations at EFGB and WFGB to record temperature hourly at deeper depths (attached directly to permanent repetitive photostation markers at approximate depths of 30 m and 40 m). Due to reduced field operational capacity, the loggers at 30m and 40 m were not retrieved in 2020 or 2021.

Water Column Profiles

Water column profiles from the surface to the reef cap were acquired in February 2020 and November 2021 with a Sea-Bird® Electronics 19plus V2 CTD that recorded temperature, salinity, pH, turbidity, fluorescence, and dissolved oxygen (DO) every ¼ second. A different carousel was used for the February 2020 water collections and profiles. The carousel package included a Sea-Bird® 55 Frame Eco water sampler equipped with six 4-liter Niskin bottles; a Sea-Bird® Electronics 19plus V2 CTD capable of recording conductivity, depth, salinity, and temperature; and a Wet Labs C-Star Transmissometer measuring beam attenuation. The profiler lacked pH, DO, fluorescence, and turbidity data acquisition capabilities. Data were recorded following an initial three-minute soaking period after deployment, and the resulting profile data were processed to include only downcast data. The CTD was lowered and returned to the surface at a rate of <1 m/second. The water column profiles were obtained on February 23, 2020 and November 3, 2021.

Water Samples

In conjunction with water column profiles using the sampling carousels described above, water samples were collected. The carousel was attached to the R/V *Manta* through a scientific winch cable, thereby allowing the operator to activate the bottles for sample collection at specific depths. Two Niskin bottles collected water samples near the reef cap on the seafloor (~20 m depth), midwater (~10 m depth), and near the surface (~1 m depth) for subsequent transfer to laboratory collection bottles.

Water samples were analyzed for chlorophyll *a* (Chl *a*) and nutrients including ammonia, nitrate, nitrite, soluble reactive phosphorus (ortho phosphate), and total Kjeldahl nitrogen (TKN; Table 3.1). 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 without preservatives. Ammonia, nitrate, nitrite, and TKN 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 0 °C and a chain of custody was initiated for processing at an EPA-certified laboratory. The samples were transported and delivered for analysis to A&B Laboratories in Houston, Texas within 24 hours of collection.

Table 3.1. Standard EPA methods used to analyze water samples collected at FGBNMS.

Parameter	Test Method	Detection Limit
Chl <i>a</i>	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 phosphorus	SM 4500 P-E	0.02–mg/l
TKN	SM 4500NH3D	0.50–mg/l

Water samples for ocean carbonate measurements, including pH, alkalinity, CO₂ partial pressure (*p*CO₂), aragonite saturation state, and total dissolved CO₂, were collected following

methods provided by the Carbon Cycle Laboratory (CCL) at Texas A&M University-Corpus Christi (TAMU-CC). Samples were collected in ground neck borosilicate glass bottles. Bottles were filled using a 30-cm plastic tube connected to the filler valve of a Niskin bottle. Bottles were rinsed three times using the sample water, filled carefully to reduce bubble formation, and overflowed by at least 200 ml. A total of 100 μl of saturated HgCl_2 was added to each bottle, which was then capped. The stopper was sealed with Apiezon[®] grease and secured with a rubber band. The bottles were then inverted vigorously to ensure homogeneous distribution of HgCl_2 and secured at ambient temperature for shipment. Samples and CTD profile data were sent to CCL at TAMU-CC. Ocean carbonate samples were obtained on February 23 2020 and November 3, 2021.

Water Quality Data Processing and Analysis

Temperature, salinity, and turbidity data recorded on SBE 16plus instruments and temperature data recorded on backup HOBO loggers were downloaded and processed in March 2020, June 2021, and November 2021. QA/QC procedures included a review of all files to ensure data accuracy and servicing instruments based on manufacturer recommendations. The 24 hourly readings obtained each day were averaged into a single daily value and recorded in duplicate databases. Each calendar day was assigned a value in the database. Separate databases were maintained for each logger type as specified in the standard operating procedures.

Previous reports used hourly sea surface temperature (SST) and sea surface salinity (SSS) data downloaded from Buoy V and Buoy N of the Texas Automated Buoy System database; however, these buoys were removed in late April 2019 and January 2017, respectively, due to lack of support and funding. Therefore, surface buoy readings were unavailable or absent for the 2020 and 2021 analyses. In lieu of *in situ* surface data, satellite-derived SST and SSS data for 2020 and 2021 were downloaded from the NOAA Environmental Research Division Data Access Program data server for comparison to reef cap data. The SST dataset used was “GHRSSST Level 4 MUR Global Foundation Sea Surface Temperature Analysis (v4.1)” and the SSS dataset used was “Sea Surface Salinity, Near Real Time, Miras SMOS 3-Day Mean (smosSSS3Scan3DayAggLoM), CoastWatch v6.62, 0.25°, 2010-present” (JPL MUR MEaSURES Project, 2015; NOAA Coral Reef Watch, 2021). Satellite-derived one-day mean SST data utilized for WFGB and EFGB in 2020 and 2021 were available as a level-4 global 0.01-degree grid produced at the NASA Jet Propulsion Laboratory Physical Oceanography Distributed Active Archive Center under support by the NASA MEaSURES program. Satellite-derived SSS data were available as a 0.25-degree longitude/latitude level-3 gridded three-day mean dataset from MIRAS satellite observations.

Additional satellite surface parameters including Chl a, algal bloom index (ABI), and a suspended sediment proxy (Rrs 667) were collected by the Moderate Resolution Imaging Spectroradiometer (MODIS-Aqua) sensor (4 km resolution) and obtained from the Ocean Biology Processing Group at NASA's Goddard Space Flight Center via the FGBNMS data dashboard through the University of South Florida (NASA, 2021; Otis, 2021). The ABI was calculated using the method of Hu and Feng (2016). River discharge data were obtained from the United States Geological Survey (USGS) National Water Information System via the

FGBNMS data dashboard (Otis, 2021; USGS, 2021). Discharge values from the Mississippi River and Texas Rivers (Colorado, Brazos, Trinity, Neches, and Sabine) were summed for discharge into the northwest Gulf of Mexico and plotted.

SBE 16plus instruments and backup HOBO loggers located on the reef cap were exchanged in February 2020, June 2021, and November 2021, resulting in a data gap for November and December 2021 until instruments are exchanged again in spring 2022 and these data are recovered. The 30-m and 40-m HOBO loggers were not exchanged, resulting in a data gap for 2020 and 2021. These instruments will be recovered in 2022 and may contain usable data. Results of Chl a and nutrient analyses were obtained from A&B Labs and compiled into an Excel table. Ocean carbonate analyses have not yet been received from CCL at TAMU-CC.

For seawater temperature, salinity, and turbidity, EFGB and WFGB SBE 16plus daily mean data were compared using a paired t-test in R version 2.13.2. Monotonic trends for long-term seawater temperature and salinity data were detected using the Seasonal-Kendall trend test in a Microsoft Windows® DOS executable program developed by USGS for water resource data (Hipel & McLeod, 1994; Helsel & 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.

Water Quality Results

Weather

The year 2020 was Earth's hottest year on record and 2021 was the sixth hottest year on record (NASA, 2021). A very active hurricane season in 2020 resulted in nine tropical weather systems in the northern Gulf of Mexico; five occurred in 2021 (Table 3.2; NOAA National Hurricane Center, 2022).

Table 3.2. Tropical storms and hurricanes in the northern Gulf of Mexico and their distance from FGBNMS. Storms within 200 km of FGBNMS are in bold.

Date	Name	Wind Speed or Category	Northern Gulf of Mexico Location and Approximate Distance from FGBNMS
6/1–9/2020	Cristobal	50 mph	Central GOMEX, 363 km east of EFGB
7/9–11/2020	Fay	50 mph	Eastern GOMEX, 589 km east of EFGB
7/23–26/2020	Hanna	Cat 1	Western GOMEX, 78 km south of WFGB
8/20–29/2020	Laura	Cat 4	Central GOMEX, 69 km east of EFGB
8/21–25/2020	Marco	Cat 1	Central GOMEX, 522 km east of EFGB
9/11–17/2020	Sally	Cat 2	Eastern GOMEX, 589 km east of EFGB
9/17–22/2020	Beta	55 mph	Eastern GOMEX, 47 km south of EFGB
10/4–10/2020	Delta	Cat 4	Central GOMEX, 8 km west of EFGB
10/24–29/2020	Zeta	Cat 3	Central GOMEX, 248 km east of EFGB
6/19–22/2021	Claudette	40 mph	Central GOMEX, 236 km east of EFGB
7/1–9/2021	Elsa	Cat 1	Eastern GOMEX, 700 km east of the EFGB
8/11–18/2021	Fred	55 mph	Eastern GOMEX, 760 km east of the EFGB
9/8–10/2021	Mindy	40 mph	Eastern GOMEX, 563 km east of EFGB
9/12–16/2021	Nicholas	Cat 1	Western GOMEX, 241 km northwest of WFGB

Four major hurricanes were within the 200 km “impact zone” (Lugo-Fernandez & Gravois, 2010) of EFGB and WFGB in 2020 (Figure 3.1). As noted in Chapter 2, several coral colonies within repetitive photostations toppled or were missing, presumably due to storm damage.

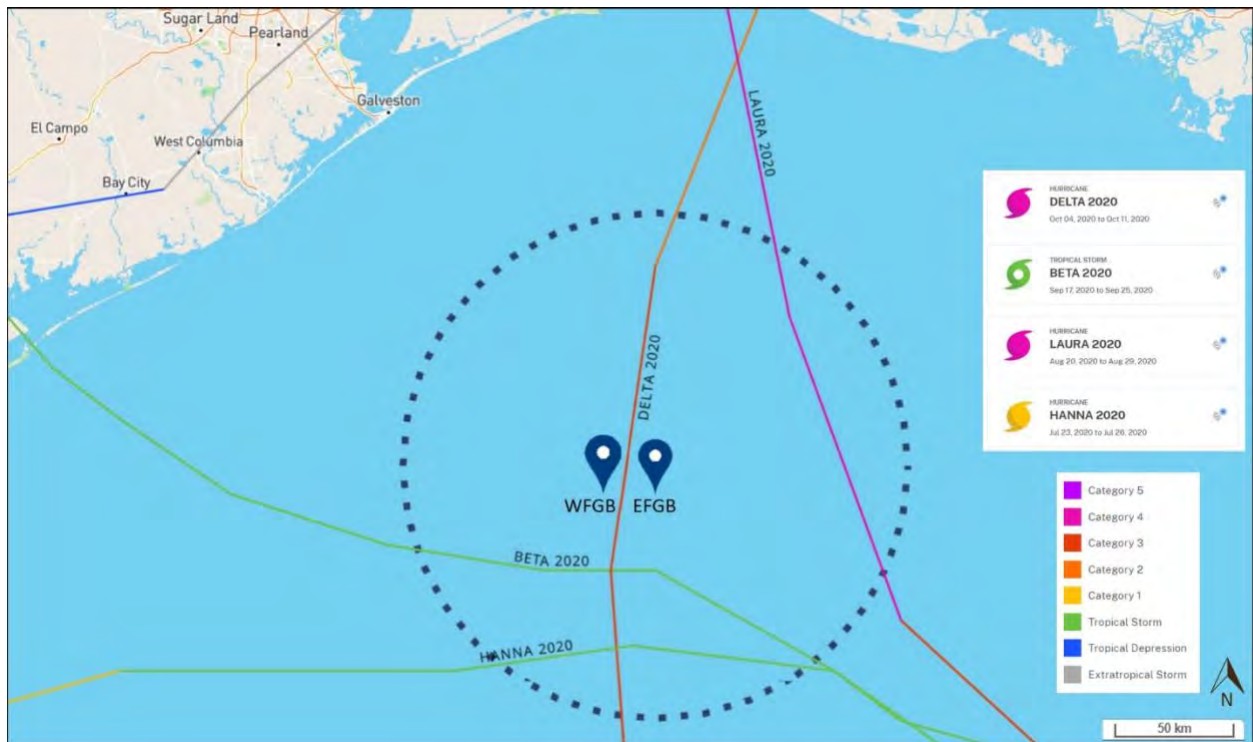


Figure 3.1. Tropical storm and hurricane tracks within 200 km of EFGB and WFGB in 2020. Source: NOAA Office for Coastal Management

Satellite Data

River discharge in 2020 and 2021 was highest in late winter and spring months after rainfall events, corresponding to a similar trend in near-surface Chl a at EFGB and WFGB (Figure 3.2). Chl a concentration at EFGB and WFGB remained within the normal range for oceanic waters (less than 5 mg/m³). Near-surface suspended sediment and the ABI for EFGB and WFGB in 2020 and 2021 were highest in late fall and early winter months (Figure 3.2).

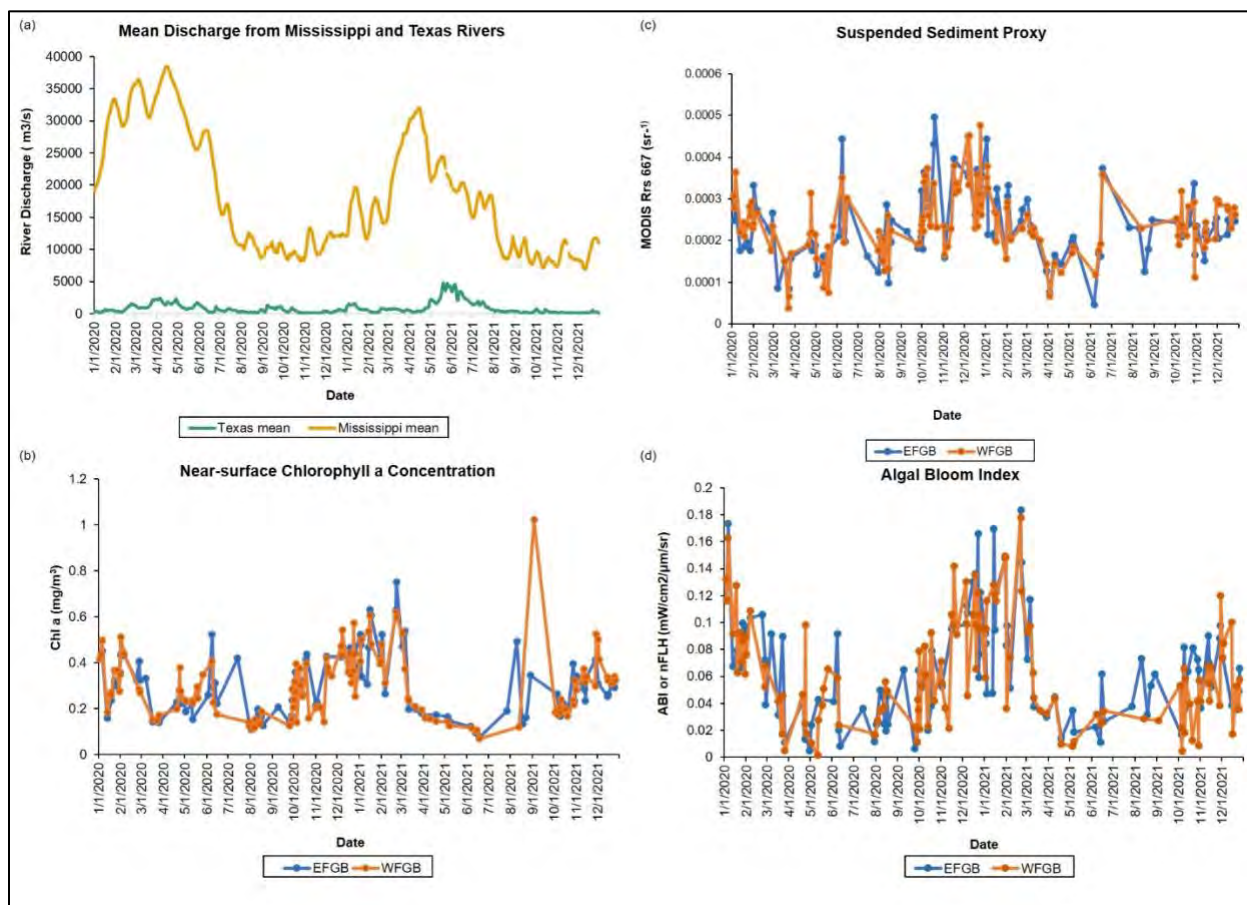


Figure 3.2. (a) Gulf of Mexico river discharge, (b) near-surface Chl a, (c) suspended sediment, and (d) ABI at EFGB and WFGB in 2020 and 2021.

Temperature

Surface temperature at EFGB ranged from 20.80 °C to 30.52 °C in 2020 and 18.96 °C to 31.07 °C in 2021. At 23 m, it ranged from 20.88 °C to 30.07 °C in 2020 and 18.85 °C to 30.94 °C in 2021 (Figure 3.3). The 23-m backup HOBO logger registered temperatures similar to those from the 23-m SBE 16plus (Figure 3.3).

Surface temperature at WFGB ranged from 20.56 °C to 30.72 °C in 2020 and 18.94 °C to 31.13 °C in 2021 (Figure 3.3). At 27 m, it ranged from 21.09 °C to 30.12 °C in 2020 and 19.53 °C to 30.95 °C in 2021 (Figure 3.3). The 27-m backup HOBO logger registered temperatures similar to

those from the 27-m SBE 16plus (Figure 3.3). In 2020, tropical weather systems corresponded with decreased water temperatures at EFGB and WFGB in summer months.

No significant difference occurred between EFGB 23 m and WFGB 27 m SBE 16plus reef cap temperatures in 2020 or 2021.

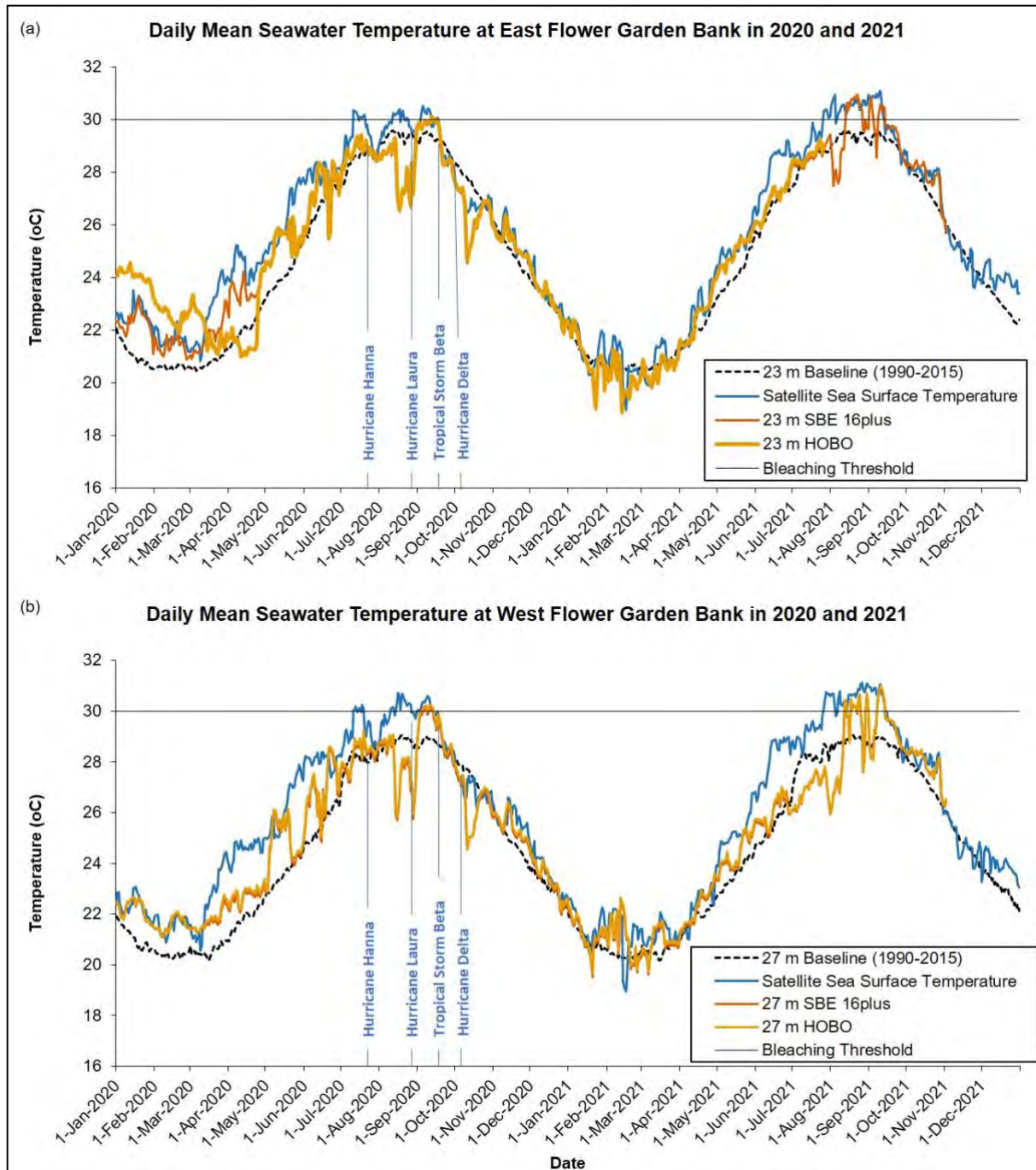


Figure 3.3. Daily mean seawater temperature (°C) at (a) EFGB and (b) WFGB from various depths in 2020 and 2021, as well as the 25-year daily mean water temperature baseline. The solid black line at 30 °C is a level known to trigger coral bleaching. Tropical storms and hurricanes near EFGB and WFGB are indicated in vertical text below data lines.

According to data from the 23-m SBE 16plus, reef cap temperatures at EFGB exceeded 30 °C for one day in 2020 and 24 non-consecutive days in 2021. At WFGB, temperatures at 27-m exceeded 30 °C for six non-consecutive days in 2020 and 16 non-consecutive days in 2021. As noted in Chapter 2, coral bleaching was observed in both EFGB and WFGB repetitive photostations in 2021. Bleaching threshold curves for EFGB and WFGB in Johnston et al. (2019) suggest that a total of 27.5 days or more above 30 °C would result in coral bleaching at EFGB and 21 days or more above 30 °C would result in coral bleaching at WFGB (as observed in 2016). Both exposure times and field observations suggest that 2020 was not a bleaching year and 2021 was a minor bleaching year (Figure 3.4).

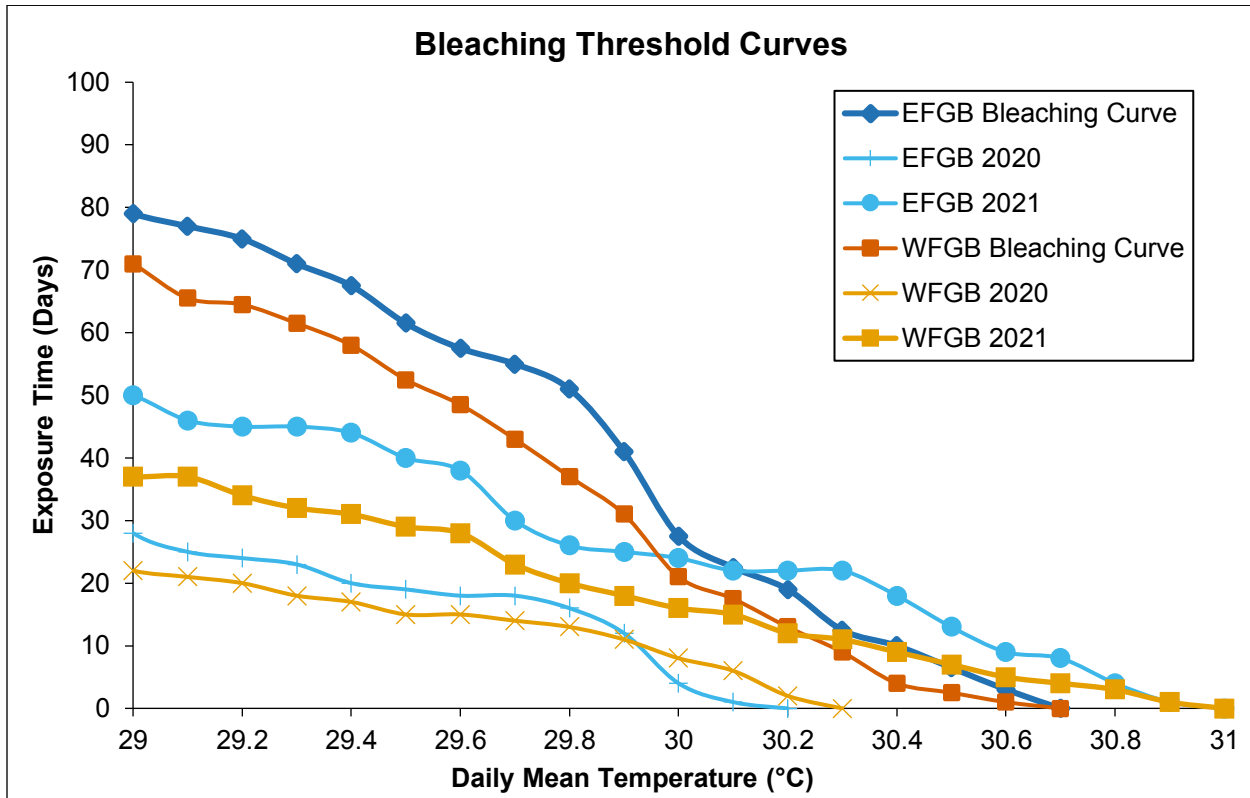


Figure 3.4. Bleaching threshold curves for EFGB and WFGB based on daily mean seawater temperature (°C) at depth (23 m at EFGB and 27 m at WFGB) and exposure time (number of days). Seawater temperatures at depth for EFGB (23 m) and WFGB (27 m) are plotted for 2020 and 2021.

Seawater temperature data obtained from loggers at EFGB (23 m) and WFGB (27 m) have been collected since 1990. Though some data gaps occur due to equipment malfunction and changes in methods and/or instrumentation, long-term trends showed increasing surface and reef cap temperatures at EFGB and WFGB (Figure 3.5). The Seasonal-Kendall trend test on time-series satellite and daily mean seawater temperature data at depth revealed significantly increasing, monotonic trends from 1990 to 2021 for EFGB and WFGB surface waters ($\tau=0.07$, $z=4.28$, $p<0.001$ and $\tau=0.07$, $z=4.66$, $p<0.001$, respectively) and at depth from datasondes (23 m for EFGB and 27 m for WFGB; $\tau=0.29$, $z=6.44$, $p<0.001$ and $\tau=0.28$, $z=6.39$, $p<0.001$, respectively) after adjusting for correlation among seasons (Figure 3.5). Mean temperature on the reef

increased by an average of 0.068°C at EFGB (23 m) and 1.54°C at WFGB (27 m) from 1990 to 2021.

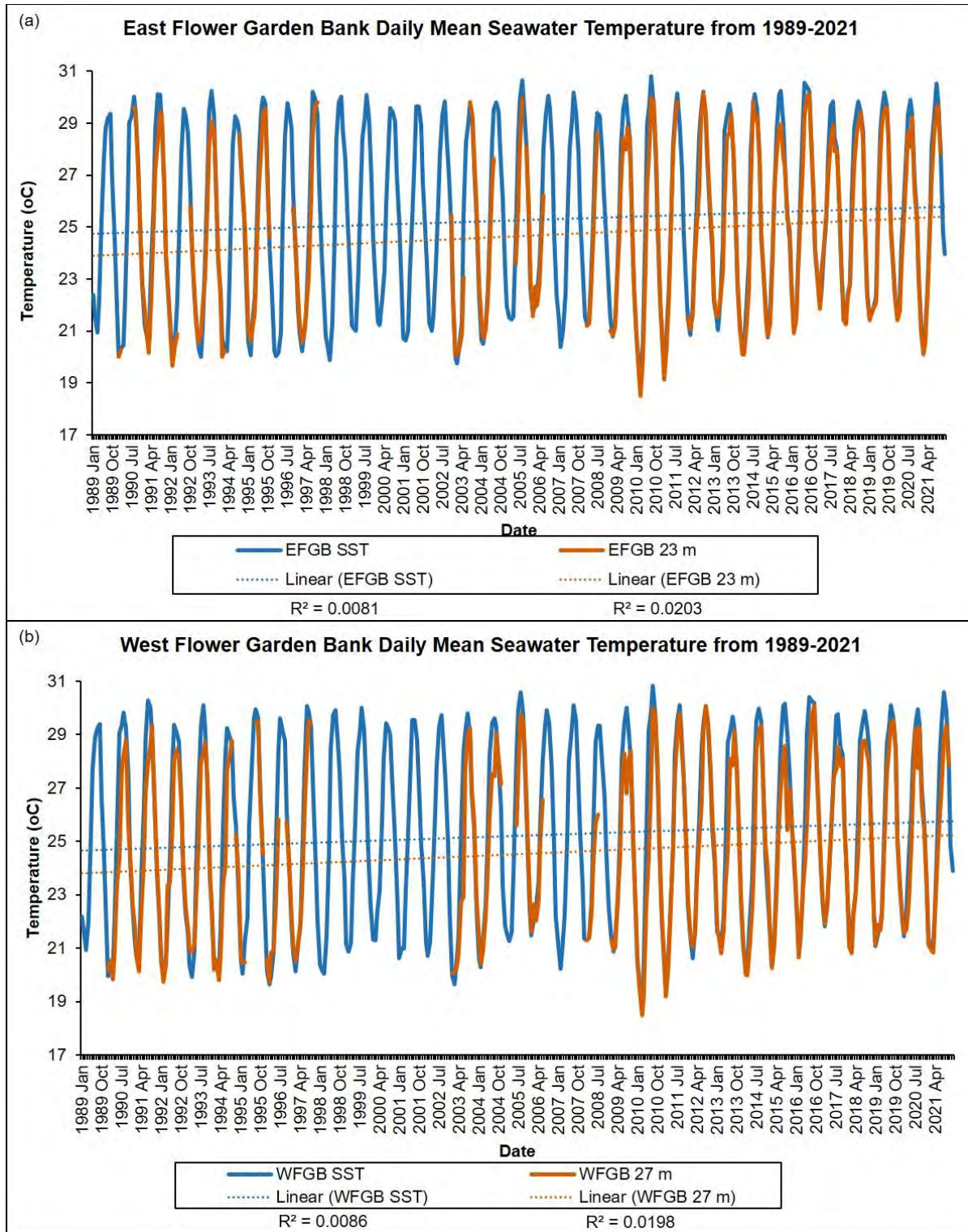


Figure 3.5. Daily mean seawater temperature ($^{\circ}\text{C}$) demonstrates 12-month seasonal variation from various depths at (a) EFGB and (b) WFGB from 1990 to 2021, as well as a significant increase over time (trend lines).

Salinity

Surface salinity at EFGB ranged from 30.13 to 37.39 psu in 2020 and 29.55 to 37.44 psu in 2021. At 23 m, salinity ranged from 32.70 to 36.40 psu in 2020 and 34.11 to 35.89 psu in 2021 (Figure 3.6). At WFGB, surface salinity ranged from 28.96 to 36.79 psu in 2020 and 29.58 to 38.64 psu in 2021 (Figure 3.6). At 27 m, salinity ranged 33.59 to 36.40 psu in 2020 and 34.26 to 36.19 psu in 2021 (Figure 3.6). When comparing EFGB 23 m and WFGB 27 m SBE 16plus reef cap daily mean salinity, no significant difference occurred in 2020. In 2021, there was a significant difference in daily mean reef cap salinity between EFGB and WFGB (t-test, $df=566$, $t=1.96$, $p<0.002$), likely due to lower salinity levels at EFGB from July to October.

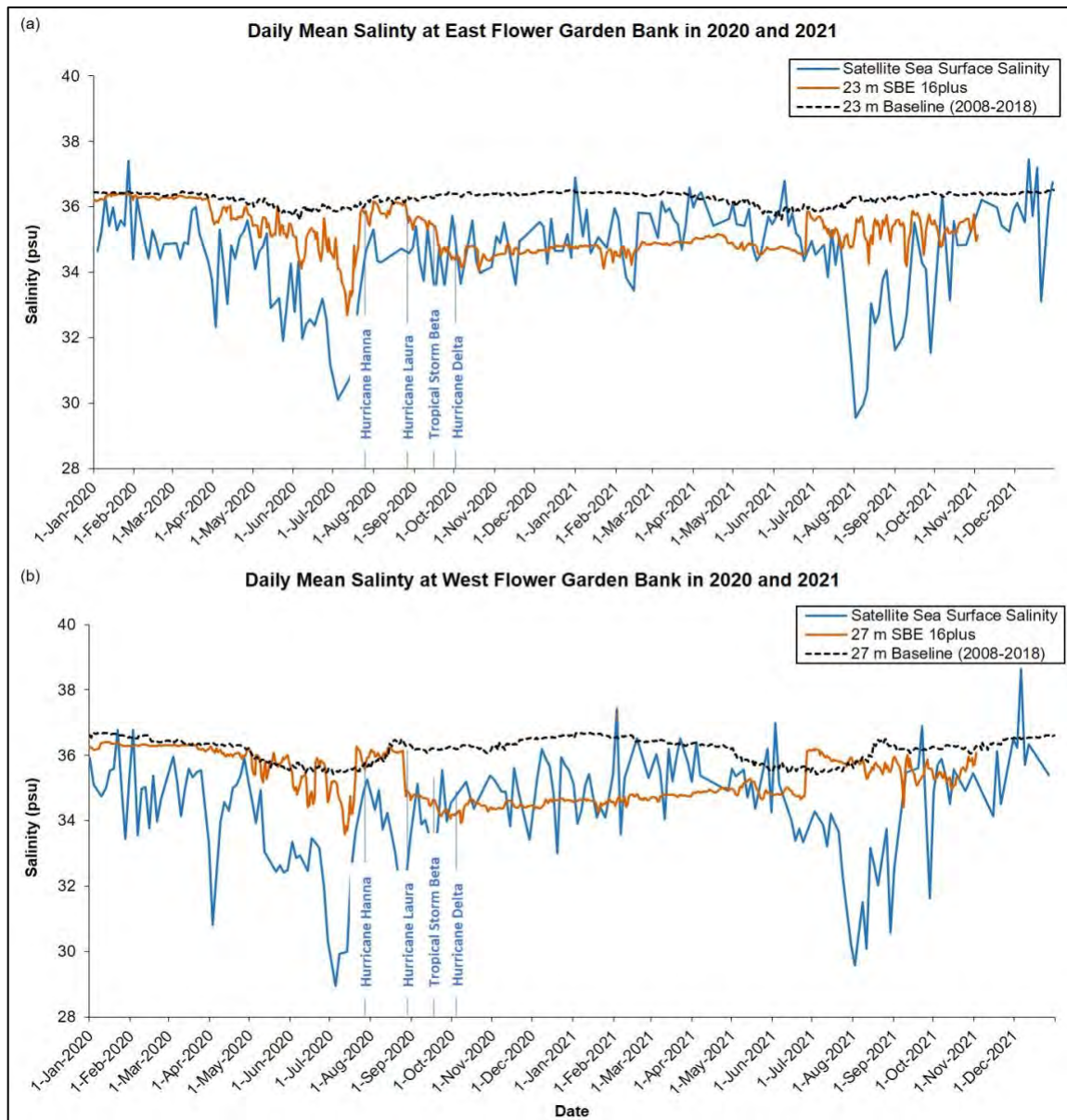


Figure 3.6. Daily mean salinity (psu) at the sea surface, SBE 16plus reef cap station, and the reef cap 10-year daily mean salinity baseline (2008–2018) at (a) EFGB and (b) WFGB in 2020 and 2021. Tropical storms and hurricanes near EFGB and WFGB are indicated in vertical text below data lines.

Salinity data obtained from loggers at EFGB (23 m) and WFGB (27 m) have been collected throughout the monitoring program since 2008 with minimal disruptions in data acquisition. The data show consistent summer minima, often during June and particularly in surface water, long-term decreases in surface salinity at both banks, and decreasing reef cap salinity at EFGB (Figure 3.7). The Seasonal-Kendall trend test on time-series daily mean salinity data at EFGB (23 m) and WFGB (27 m) resulted in a significantly decreasing, monotonic trend from 2008 to 2021 ($\tau=-0.29$, $z=-4.22$, $p=0.01$ and $\tau=-0.24$, $z=-3.70$, $p=0.04$, respectively) after adjusting for correlation among seasons.

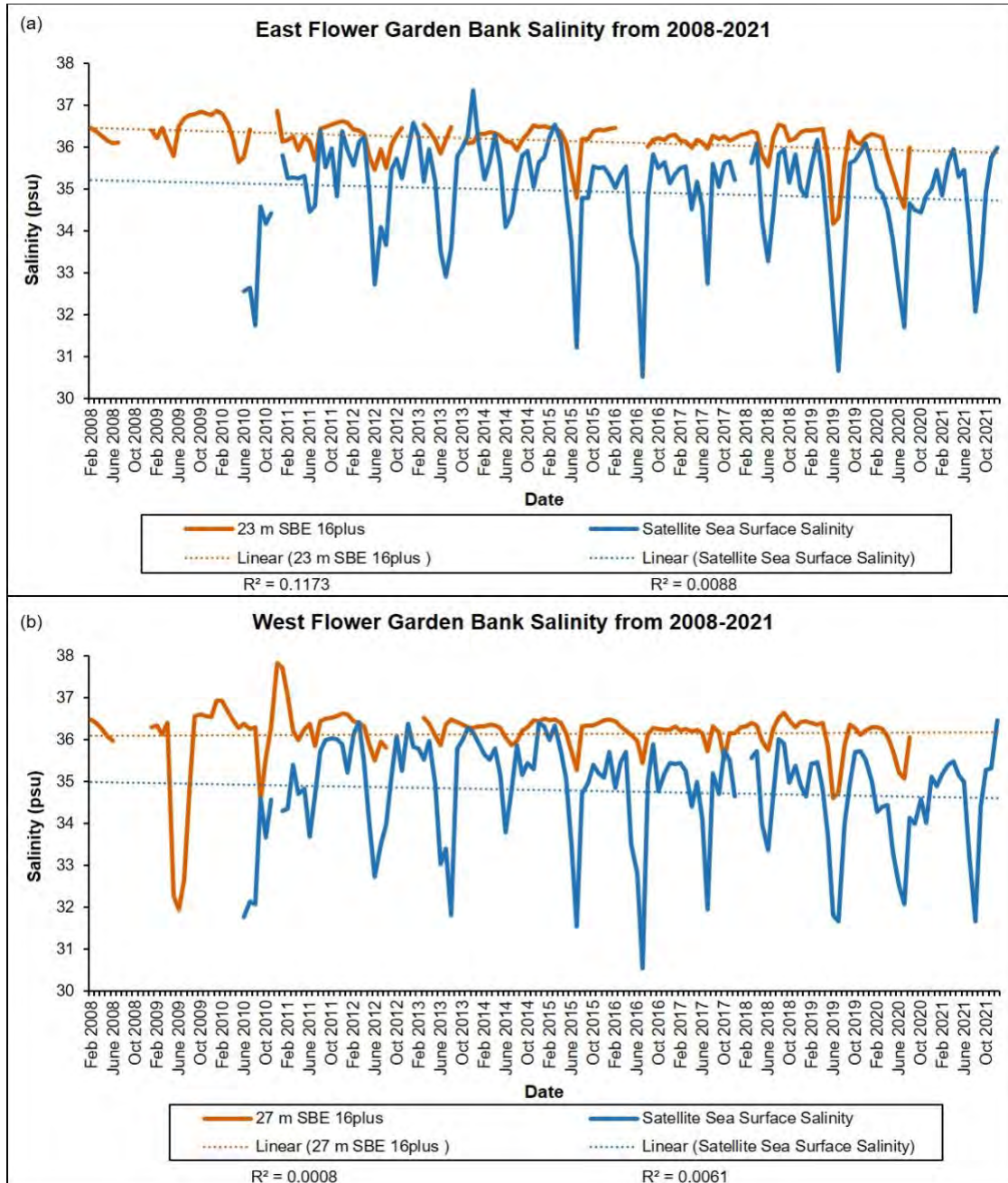


Figure 3.7. Mean salinity demonstrating 12-month seasonal variation at (a) EFGB (23 m) and (b) WFGB (27 m) from 2008 to 2021 with trend lines.

Turbidity

Turbidity ranged from 0–2.02 ntu at EFGB and 0–1.60 ntu at WFGB (Figure 3.8). In 2020, tropical weather systems corresponded with increased turbidity at EFGB and WFGB in summer months. The turbidity sensor at EFGB and WFGB experienced periodic malfunctions, resulting in unreliable data throughout 2020 and 2021; therefore, data from EFGB and WFGB for this time period were removed, resulting in data gaps, and statistical tests were not conducted. Turbidity values were highest in fall and early winter months, similar to satellite suspended sediment values, and spikes in turbidity correlated with tropical weather systems (Figure 3.2).

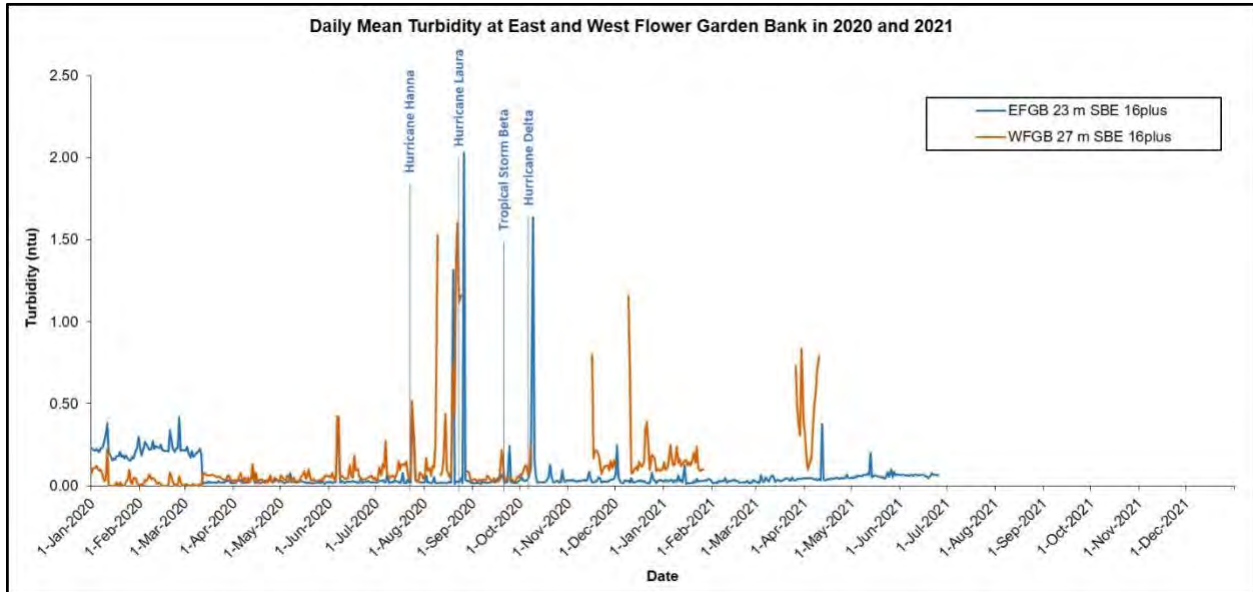


Figure 3.8. Daily mean turbidity (ntu) values in 2020 and 2021 from EFGB (23 m) and WFGB (27 m). Tropical storms and hurricanes near EFGB and WFGB are indicated in vertical text above data lines.

Water Column Profiles

Water column temperatures at both banks were similar and indicated some stratification at the surface but were well mixed just below the surface and at the reef cap. No single profile varied more than 1 °C from the surface to the reef cap (Figure 3.9). Salinity values between the two banks were similar, varying less than 1 psu on average over all profiles. Salinity remained consistent throughout the water column in February and November at WFGB; however, the November 2021 profile at EFGB displayed some stratification. DO and pH values were variable at the surface and were stable below four meters at both banks. Turbidity values were slightly higher at WFGB than EFGB but were uniform below 10 m. Fluorescence values were higher at EFGB than WFGB (Figure 3.9).

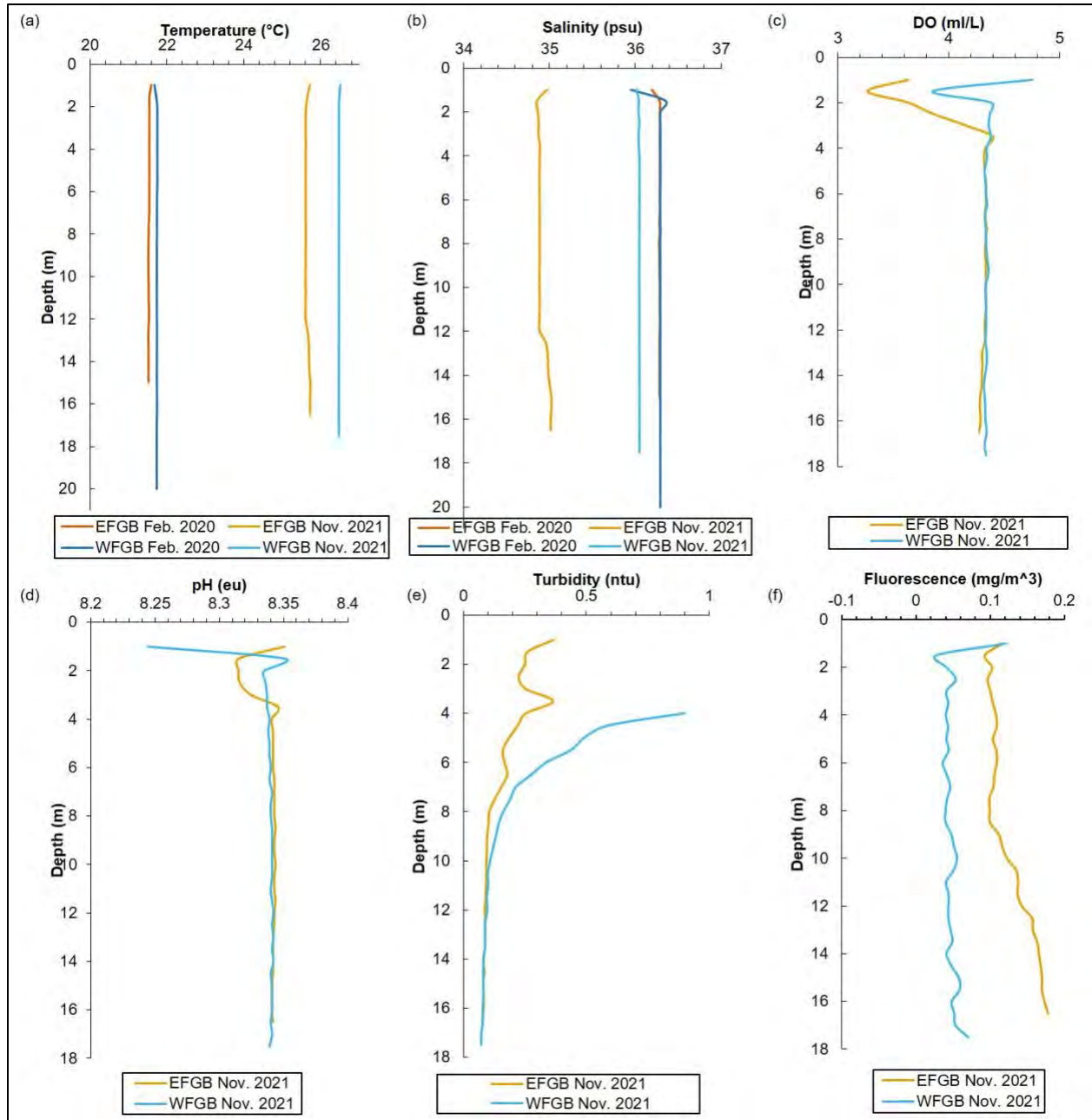


Figure 3.9. EFGB and WFGB (a) temperature, (b) salinity, (c) DO, (d) pH, (e) turbidity, and (f) fluorescence water column profile data in February 2020 and November 2021. The CTD used in February 2020 did not measure pH, fluorescence, turbidity, or DO.

Water Samples

The first Chl a and nutrient samples were taken as part of the long-term monitoring program in 2002. Since then, quarterly nutrient levels have typically been below detection limits, with the exception of occasional ammonia and TKN detections prior to 2012 (Figure 3.10; Figure 3.11). The 2020 and 2021 nutrient levels from each water column depth were below detection limits in all samples, consistent with oligotrophic oceanic conditions. Ocean carbonate measurements conducted in tandem with nutrient sampling were sent to TAMU-CC for analysis. At the time of

this report, data were still being processed by TAMU-CC and will be available in the 2022 report.

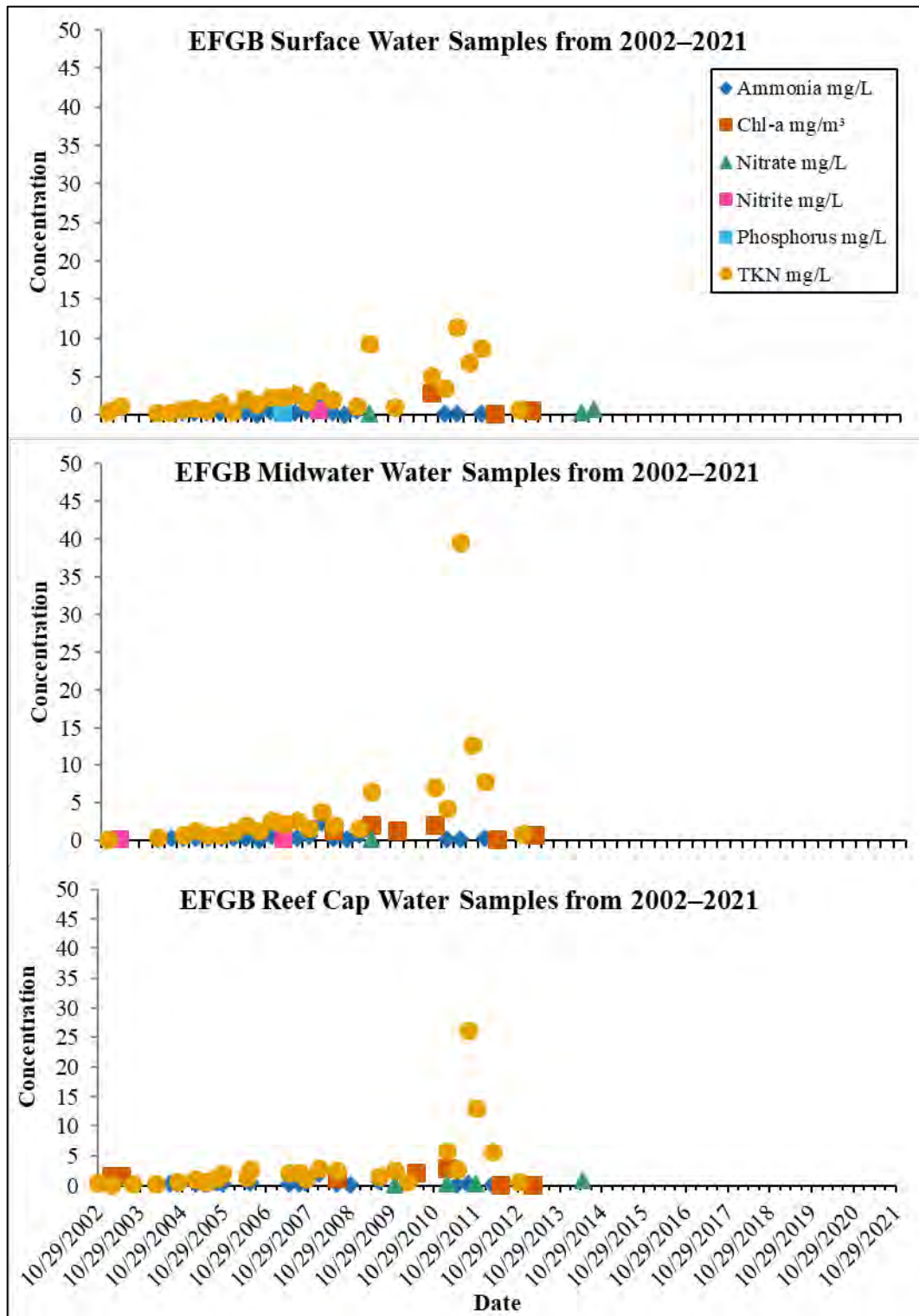


Figure 3.10. Nutrient concentrations from EFGB water samples taken at the surface (~1 m), midwater (~10 m), and reef cap (~20 m) from 2002 through 2021.

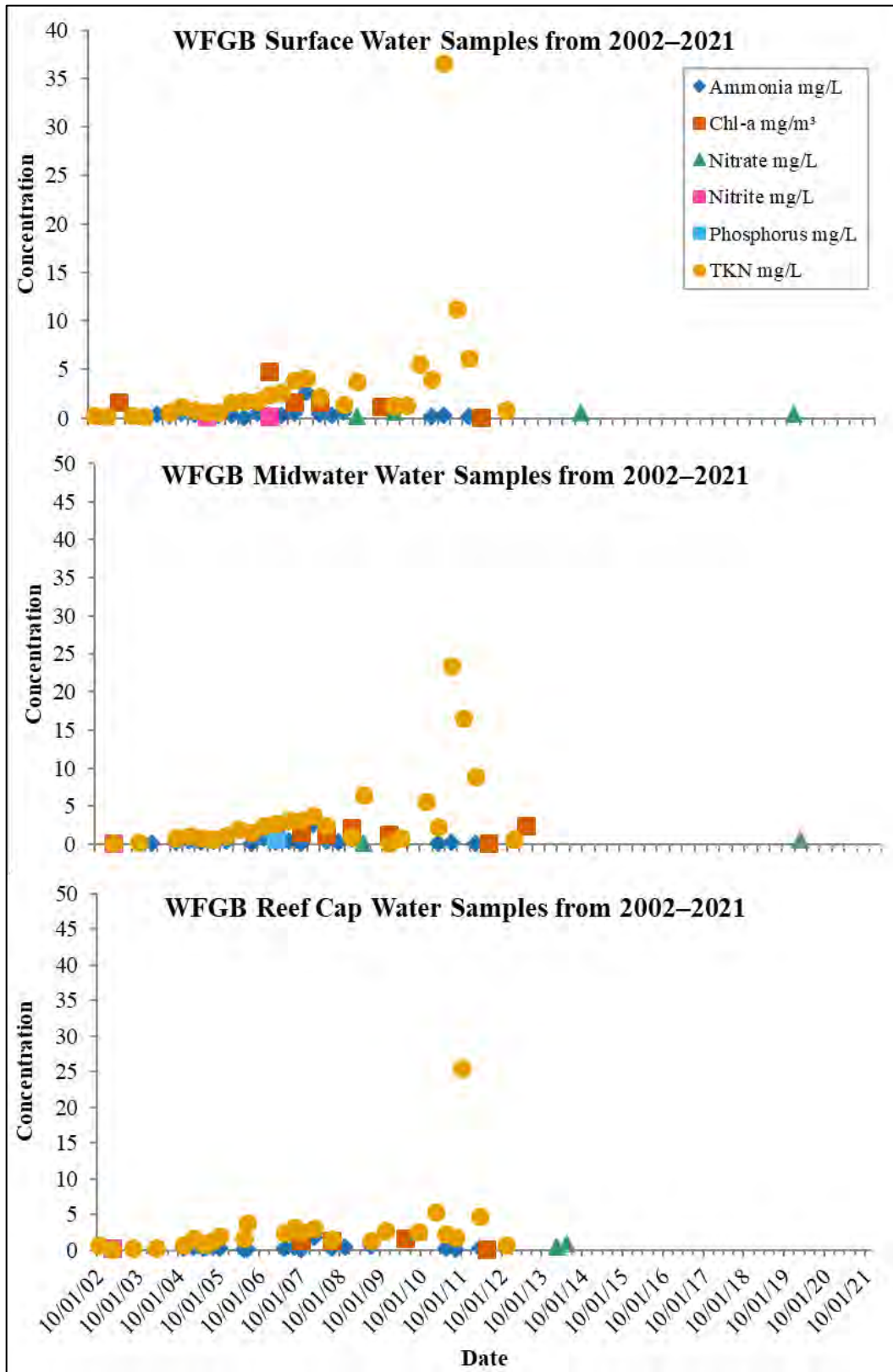


Figure 3.11. Nutrient concentrations from WFGB water samples taken at the surface (~1 m), midwater (~10 m), and reef cap (~20 m) from 2002 through 2021.

Water Quality Discussion

Limited water quality field work occurred in 2020 because diving and vessel operations were prohibited after March 2020 as part of precautions taken in response to the COVID-19 pandemic. There were several challenges in the 2021 field season congruent with those documented in Chapter 2. Data collection is scheduled to resume in 2022 pending updated COVID-19 guidelines.

Seawater temperatures were warmer in 2021 than 2020, which corresponded to four major storms near the banks in 2020 and increased coral bleaching documented in 2021 (see Chapter 2). The tropical weather systems corresponded with increased temperature and turbidity and decreased salinity at EFGB and WFGB in 2020. Significantly increasing monotonic seawater temperature trends from 1990 to 2021 were detected at both banks, suggesting that ocean temperatures at FGBNMS have risen over the past three decades, increasing the likelihood of future bleaching events.

Mean SSS fluctuated considerably at both banks. Reef cap salinity values were below average for the majority of the time period, and significantly decreasing monotonic trends from 2008 to 2021 were detected at depth at both banks. Despite annual variation and a substantial increase in freshwater river influence in 2020, salinity data collected at depth were within the normal range of variation for coral reefs located in the Western Atlantic (31–38 psu; Coles & Jokiel, 1992). The probable source of low-salinity water at the banks is a nearshore river-seawater mix that occasionally extends to the outer continental shelf, emanating principally from the Mississippi and Atchafalaya River watershed, potentially subjecting the banks to nearshore processes (Zimmer et al., 2010). In 2020, Mississippi River discharge was high, as tropical storms and hurricanes brought significant flooding to Louisiana and Texas, as well as locations to the north and east.

Laboratory analyses of nutrients remained below detection limits. TKN concentrations, however, trended upwards from 2002 to 2011. This was likely due to organic nitrogen and ammonia forming in the water column through phytoplankton and bacteria cycling within the food chain. It is therefore subject to seasonal community fluctuations, but could also be affected by both point and non-point sources. When present, the probable sources of nutrients in the water column were nearshore waters (Nowlin et al., 1998), sediments (Entsch et al., 1983), or benthic and planktonic organisms (D'Elia & Wiebe, 1990).

The water column is responsible for the connectivity among all the various coral reef habitats and acts as the medium between aquatic and terrestrial systems. Thus, water quality data are critical components of monitoring programs, as they provide information on the incursion of land-based materials that affect critical coral reef ecosystem functions. Despite the fact that not all quarterly water quality data were collected, including water column profiles, nutrient data, and temperature and salinity data from the 30-m and 40-m EFGB stations, important surface and reef cap data were still collected. The long battery life and robust sensors on moored SBE 16plus and HOBO instruments ensured large data gaps were avoided. The use of satellite data also provided valuable surface parameters for time-series data.

Chapter 4: General Observations



A scuba diver inspects coral colonies at East Flower Garden Bank and the hull of the R/V *Manta* appears as a shadow near the surface. Photo: Fernando Calderón Gutiérrez/TAMU Galveston

General Observations

In March of 2020, notable sightings at EFGB included a scalloped hammerhead shark (*Sphyrna lewini*) and a great hammerhead shark (*Sphyrna mokarran*). In 2020 and 2021, divers noted the continued persistence of the exotic regal demoiselle (*Neopomacentrus cyanomos*) and lionfish (*Pterois volitans*), both native to the Indo-Pacific Ocean, at EFGB and WFGB.

In August 2021, there were indications of temperature-stressed corals at EFGB, including bleached fire coral (*Millepora alcicornis*) and mustard hill coral (*Porites astreoides*), along with many paling *Montastraea cavernosa* colonies. A manta ray (*Mobula birostris*), tiger grouper (*Mycteroperca tigris*), and a small Caribbean reef shark (*Carcharhinus perezii*) were also sighted. In November 2021, divers continued to note bleaching and paling of fire coral and *M. cavernosa* colonies at WFGB, and also observed a loggerhead sea turtle (*Caretta caretta*) with a 1-m carapace.

Other Research

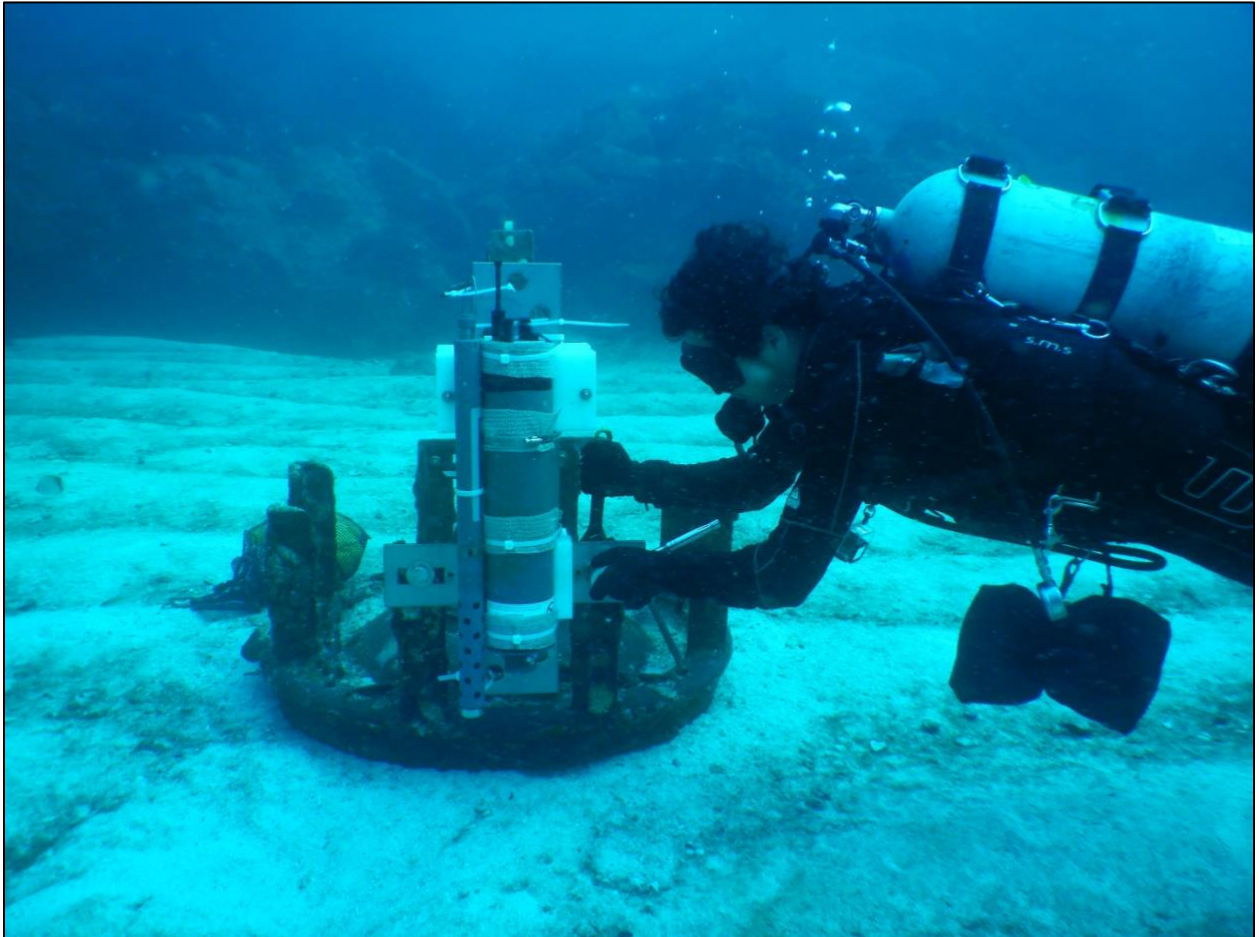
While not part of the FGBNMS long-term monitoring program, permitted research that was conducted in 2021 included:

- Installation of seven acoustic receivers at EFGB for a VPN tracking system as part of a NOAA National Centers for Coastal Ocean Science funded project in partnership with TAMU Galveston to study habitat use and connectivity of fish species on northern Gulf of Mexico reefs under permit FGBNMS-2021-007. Receivers were installed in December 2021. Ultimately, a total of 20 receivers will be installed at EFGB and four receivers will be installed at WFGB in 2022.
- Installation of an ocean acidification instrument at WFGB in partnership with TAMU-CC. The instrument package is equipped with three *in situ* sensors: 1) SATlantic® SeaFET sensor to collect *in situ* pH data, 2) Sunburst® SAMI-CO₂ sensor to collect seawater pCO₂, and 3) YSI 600OMS V2 sonde to collect temperature and salinity data. The instrument was installed in December 2021.

Two permitted projects could not be completed:

- Lionfish Invitational removal cruise on M/V *Fling*, in partnership with Lionfish Invitational, Inc., the Georgia Aquarium, and Fling Charters. This cruise did not occur due to COVID-19 restrictions.
- NOAA National Coral Reef Monitoring Program reef-wide survey and ocean acidification cruises were scheduled 2020 and later rescheduled for 2021, but ultimately did not occur due to COVID-19 restrictions. These cruises have been rescheduled for August 2022.

Chapter 5: Conclusions



A scuba diver installs an ocean acidification water quality instrument, in partnership with TAMU-CC, at WFGB. Photo: Marissa Nuttall/CPC, Inc.

This report summarizes field efforts for annual monitoring conducted at EFGB and WFGB in 2020 and 2021. Limited field operations occurred due to restrictions imposed in response to the COVID-19 pandemic. Only benthic habitat within repetitive photostations was surveyed during this time period. Water quality parameters were also continuously or periodically recorded at EFGB and WFGB during 2020 and 2021.

While repetitive photostations do not capture the entire reef community, this form of benthic monitoring has been conducted annually on the reef since 1989, and is critical in enabling researchers to track individual sites over time (especially during extreme events such as bleaching or tropical storms). They likely also provide an indication of relative levels of change experienced by the broader coral reef assemblage. Only a subset of repetitive photostations were imaged in 2021 due to time constraints and reduced diver personnel on the long-term monitoring cruise. Bleaching and/or paling was observed at both banks. There were no signs of SCTLD within the one-hectare study sites at EFGB or WFGB.

Water temperature, salinity, and turbidity data were collected throughout both years on the reef cap. Seawater temperatures on the reef cap exceeded 30 °C at EFGB and WFGB in 2020 and 2021, corresponding to paling and bleaching observed in coral colonies. Observations at both banks were consistent with significantly increasing monotonic seawater temperature trends from 1990 to 2021, both at the surface and at depth at both banks. It is likely that bleaching events will occur in the future with increasing frequency. Significantly decreasing monotonic trends in salinity on the reef cap from 2008 to 2021 may be indicative of amplified freshwater river discharge from increased tropical weather system frequency and intensity in the Gulf of Mexico.

To date, this monitoring program is one of the longest running coral reef monitoring efforts in the Gulf of Mexico and Caribbean region. The 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) and to preserve the characteristics that sustain the health of this system. Sustained monitoring will continue to document changes in the species composition and general condition of the banks, which will guide research and management decisions in the future.

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Glossary of Acronyms

ABI – Algal Bloom Index
BOEM – Bureau of Ocean Energy Management
CCA – crustose coralline algae
CCL – Carbon Cycle Laboratory
Chl a – chlorophyll a
CPCe – Coral Point Count® with Excel® extensions
CTD – conductivity, temperature, and depth
DO – dissolved oxygen
EFGB – East Flower Garden Bank
EPA – U.S. Environmental Protection Agency
FGBNMS – Flower Garden Banks National Marine Sanctuary
MMS – Minerals Management Service
NOAA – National Oceanic and Atmospheric Administration
 $p\text{CO}_2$ – CO_2 partial pressure
QA/QC – quality assurance/quality control
SCTLD – stony coral tissue loss disease
SE – standard error
SSS – sea surface salinity
SST – sea surface temperature
TAMU – Texas A&M University
TAMU-CC – Texas A&M University Corpus Christi
TKN – total Kjeldahl nitrogen
USGS – United States Geological Survey
WFGB – West Flower Garden Bank

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