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NATIONAL MARINE SANCTUARIES CONSERVATION SERIES

Stetson Bank Long-Term Monitoring: 2020 and 2021 Annual Report

FLOWER GARDEN BANKS
NATIONAL MARINE SANCTUARY

BSEE
Bureau of Safety and Environmental Enforcement

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Cover photo: A school of fish among sponges and sea urchins on the bank crest at Stetson Bank. Image: Schmahl/NOAA

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Abstract

This document contains descriptions of the methods used, analyses of field data collected, summaries of field notes, details of challenges faced, and significant observations made during 2020–2021 annual long-term monitoring of fish and benthic communities at Stetson Bank. Stetson Bank is an uplifted claystone/siltstone feature located 130 km southeast of Galveston, Texas within Flower Garden Banks National Marine Sanctuary in the northwestern Gulf of Mexico. It supports a productive benthic community of sponges and coral. Annual monitoring of the bank crest has been conducted since 1993. Surveys of the mesophotic zone surrounding the bank crest began in 2015.

Field work and data collection were limited in 2020 and 2021 due to vessel, diving, and operational restrictions established in response to the COVID-19 pandemic. In 2020, a single quarterly water sampling cruise was completed, followed by a cruise for water quality instrument exchange. In 2021, two water sampling cruises were completed, and instruments that recorded temperature, salinity, and turbidity data since 2019 were exchanged. A subset of bank crest repetitive photostations (n = 24), representing 40% of all photostations on the Stetson Bank crest, were captured in 2021. In 2021, mean percent cover was 6.56% for coral, 7.09% for sponges, and 42.72% for macroalgae. Bleaching and/or paling was observed in *Millepora alcicornis* colonies in 2021; however, no signs of stony coral tissue loss disease were observed. Seawater temperatures on the bank exceeded 30 ^{o}C for one day in 2020 and for 18 nonconsecutive days in 2021. This report highlights the importance of long-term monitoring efforts by providing a summary of benthic and water quality trends on the bank crest and detailing challenges and resolutions for future field work.

Key Words

benthic community, fish community, Flower Garden Banks National Marine Sanctuary, long-term monitoring, Stetson Bank, water quality

Chapter 1: Introduction

Stetson Bank is an uplifted claystone/siltstone feature located in the northwestern Gulf of Mexico, approximately 130 km southeast of Galveston, Texas and has been protected as part of the National Oceanic and Atmospheric Administration (NOAA) Flower Garden Banks National Marine Sanctuary (FGBNMS) since 1996. Stetson Bank formed atop a salt dome and supports a coral community near the northern limit of reef coral growth in the Gulf of Mexico. The environmental conditions at Stetson Bank are more temperate than those of the Caribbean Sea and tropical Western Atlantic Ocean (Cummings et al., 2018), and seasonal temperatures and variations in light availability prevent coral reef development. In spite of these conditions, Stetson Bank supports a well-developed benthic community dominated by tropical marine sponges and features hydrocorals, hermatypic corals, and other invertebrates.

In 1993, an annual long-term monitoring program was initiated at Stetson Bank by the Gulf Reef Environmental Action Team, a non-profit organization composed of volunteer divers and citizen scientists. On initial monitoring cruises, maps of the bank crest were made, repetitive photostations were installed, semiquantitative reef fish censuses were conducted, random benthic photographs were collected, and thermographs were installed. Following Stetson Bank's addition to FGBNMS in 1996, monitoring efforts were led by the Center for Coastal Studies at Texas A&M University, Corpus Christi until 2001 (Nuttall et al., 2020a). FGBNMS staff and volunteers took responsibility for the monitoring program thereafter (Bernhardt, 2000). Due to funding constraints between 2001 and 2014, annual long-term monitoring at Stetson Bank was limited to repetitive photostations, water temperature, salinity, nutrient analyses, and sporadic fish censuses. However, in 2015, the Bureau of Safety and Environmental Enforcement (BSEE) and FGBNMS entered into an interagency agreement to continue and expand annual long-term monitoring (Nuttall et al., 2020a). Annual benthic, fish, and water quality monitoring efforts were expanded to document spatial and temporal changes resulting from natural and anthropogenic influences, particularly those associated with the petrochemical industry. Early monitoring had focused on the bank crest, which is within non-decompression scuba diving limits (<33.5 m). Following seafloor mapping and remotely operated vehicle explorations, mesophotic communities were discovered on discrete uplifted seafloor features surrounding Stetson Bank in the form of a ring. Because information was limited for this newly discovered habitat, BSEE and FGBNMS expanded the monitoring program to include the mesophotic habitat.

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 sanctuary area from 145 km^2 to 414.4 km^2 (86 Fed. Reg. 4937 [Jan 19, 2021]). With this expansion, the boundary of FGBNMS was modified to fully encompass the mesophotic habitat at Stetson Bank (30–150 m water depth), increasing the protected area around the bank by 1.45 km^2 (2.18 km^2 before expansion to 3.63 km^2 after expansion; Figure 1.1). The ring around Stetson Bank (comprised of outcrops with 0–3 m relief) was originally identified as an important associated feature in 1997 following collection of high-resolution multibeam bathymetry (Gardner et al., 1998). FGBNMS mapped the ring surrounding Stetson Bank in 2001 using a remotely operated vehicle. In doing so, FGBNMS discovered that uplifted siltstone and claystone boulders comprise the features of the ring, providing substrate and habitat for black corals (Anthipatharia), octocorals (Octocorallia), sponges, invertebrates, and deep reef fish.

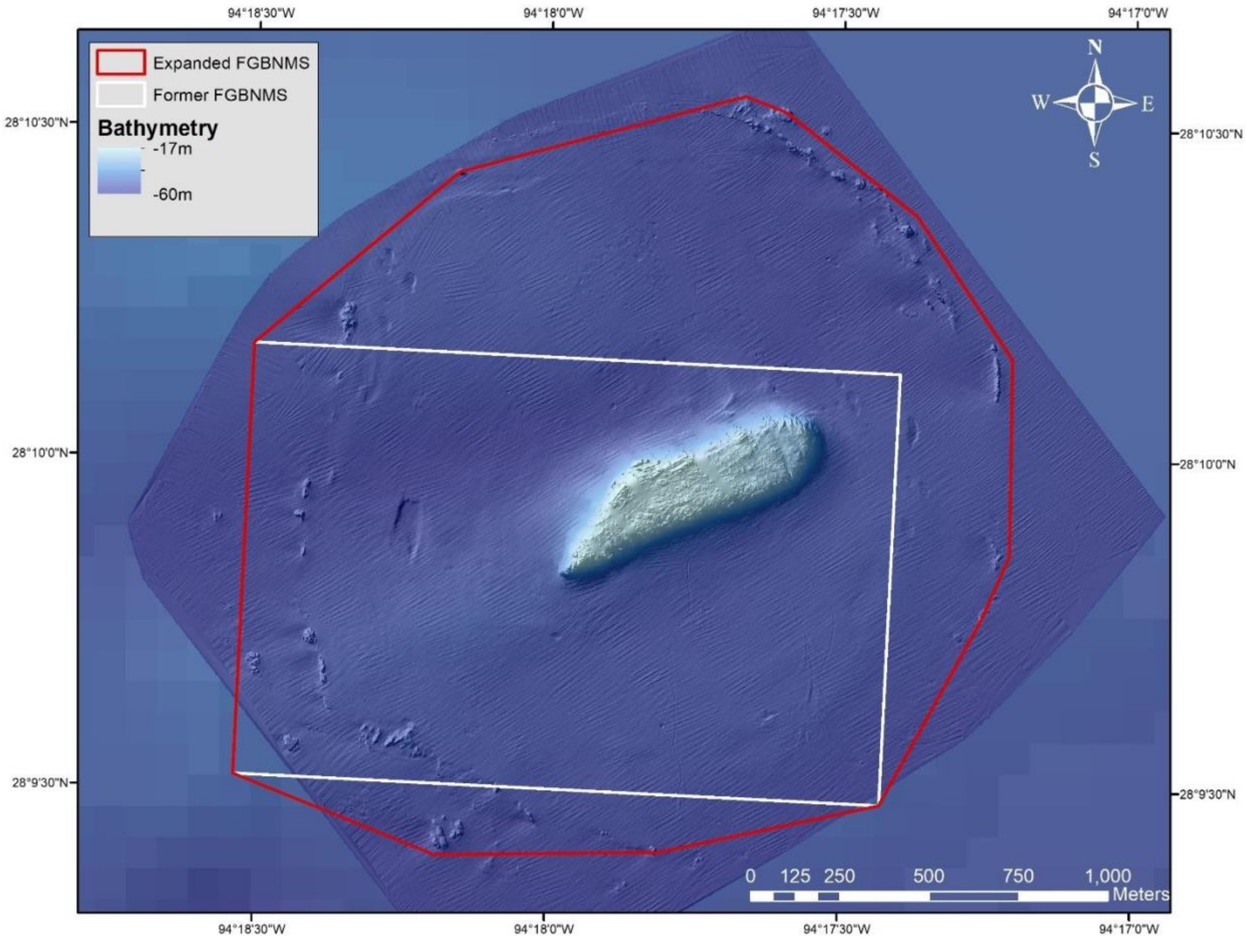


Figure 1.1. Map of FGBNMS boundaries surrounding Stetson Bank. The white line indicates the original boundary from 1996, while the red line represents the expanded boundary from 2021, encompassing the claystone/siltstone feature documented in 1997 (Gardner et al., 1998). Image: NOAA

Marine sponges, primarily *Neofibularia nolitangere*, *Ircinia strobilina*, and *I. felix*, comprise a major portion of the benthic macrobiota on the crest of Stetson Bank (DeBose et al., 2012; Nuttall et al., 2020b). Although sponges remain the most prominent benthic cover, long-term monitoring data have revealed a significant decline in sponge cover since 1999 (Nuttall et al., 2020a). For example, the sponge *Chondrilla nucula* was historically prevalent on the bank crest, but underwent a severe decline in 2005 and is now nearly absent at the bank. Additionally, the hydrozoan *Millepora alcicornis* was historically a prominent benthic biota at Stetson Bank, but underwent rapid decline following a 2005 bleaching event and has not recovered (DeBose et al., 2012). Twelve species of hermatypic corals have maintained low but stable cover at Stetson Bank, including *Pseudodiploria strigosa*, *Stephanocoenia intersepta*, *Madracis brueggemanni*, *Madracis decactis*, and *Agaricia fragilis* (Nuttall et al., 2020b). Macroalgae cover, predominantly *Dictyota* sp. and turf algae, varies among years but has significantly increased over time (Nuttall et al., 2020a, 2020b). Since 1993, a distinct shift has occurred at Stetson Bank from a *Millepora*-sponge-dominated community (Rezak et al., 1985) to an macroalgae-sponge-dominated community (DeBose et al., 2012).

To date, the monitoring program at Stetson Bank comprises 28 years of continuous benthic community monitoring efforts. As increasing anthropogenic stressors to marine environments are projected, long-term monitoring datasets are essential for understanding community stability, ecosystem resilience, and responses to changing conditions. Additionally, as exotic species arrive, become established, and compete for resources, long-term datasets are vital for documenting and tracking impacts to native populations. Continuity and extension of this dataset will provide valuable insight for both research and management purposes.

This report presents methods, data, and notes from the 2020 and 2021 monitoring periods. In 2020, field operations were not conducted after March due to vessel and personnel restrictions instituted by NOAA in response to the COVID-19 pandemic. Field operations in 2021 were limited due to continued COVID-19 restrictions; therefore, only priority long-term monitoring data were collected.

Scuba operations were conducted from the NOAA R/V *Manta* to capture repetitive photostation images and exchange water quality instruments at Stetson Bank. Water samples were collected, and water quality instruments were exchanged and downloaded. In total, data for this report were collected on two cruises in early 2020 and two cruises in late 2021 (Table 1.1).

Table 1.1. 2020 and 2021 cruise information.

Date(s)	Cruise Type and Monitoring Task	Participants
2/23/2020	Water quality: water sampling	Jimmy MacMillan, Kelly O'Connell, Marissa Nuttall
3/12/2020	Water quality: instrument exchange and download	Jimmy MacMillan, Kelly O'Connell, Marissa Nuttall, Fernando Calderon Gutierrez, Emma Clarkson
9/25/2021	Water quality: instrument download; Bank crest monitoring: benthic and fish community monitoring	Emma Hickerson, Kelly O'Connell, Terry Palmer, Fernando Calderon Gutierrez, Justin Blake, Jorge Jaime, Kait Brogan, Marissa Nuttall
11/2/2021–11/3/2021	Water quality: sample collections	Kelly O'Connell, Marissa Nuttall, Ryan Hannum, Adrienne Correa, Kaitlin Brogan, Hang Yin, Justin Blake, Jorge Jaime, Cassidy Brown

Chapter 2: Repetitive Photostations

Introduction

Repetitive photostations were first installed at Stetson Bank in 1993; initially, 36 were installed. These stations were concentrated on the northwestern edge of the bank. Locations were selected along a series of high-relief hard bottom features with a diverse and dense benthic community compared to other habitat types on the bank. The stations were selected by scuba divers and marked using nails or eye bolts and numbered tags. Over time, many of these stations were lost due to tag breakage, loss of hardware, biotic overgrowth, or substrate loss; thus, new stations were established. Today, 59 stations exist at Stetson Bank, 18 of which are original stations installed in 1993.

All photostations occur on hard bottom habitat and are accessible from permanent mooring buoys 1, 2, or 3 (Table 2.1; Figure 2.1). Each station is located by scuba divers using detailed maps (Figure 2.2; Figure 2.3) and photographed annually to monitor for temporal changes in the composition of benthic assemblages.

Table 2.1 Locations of buoys used to access repetitive photostations at Stetson Bank.

Buoy No.	Latitude (DD)	Longitude (DD)	Depth (m)
1	28.16551	-94.29768	22.6
2	28.16635	-94.29723	23.8
3	28.16643	-94.29610	22.3

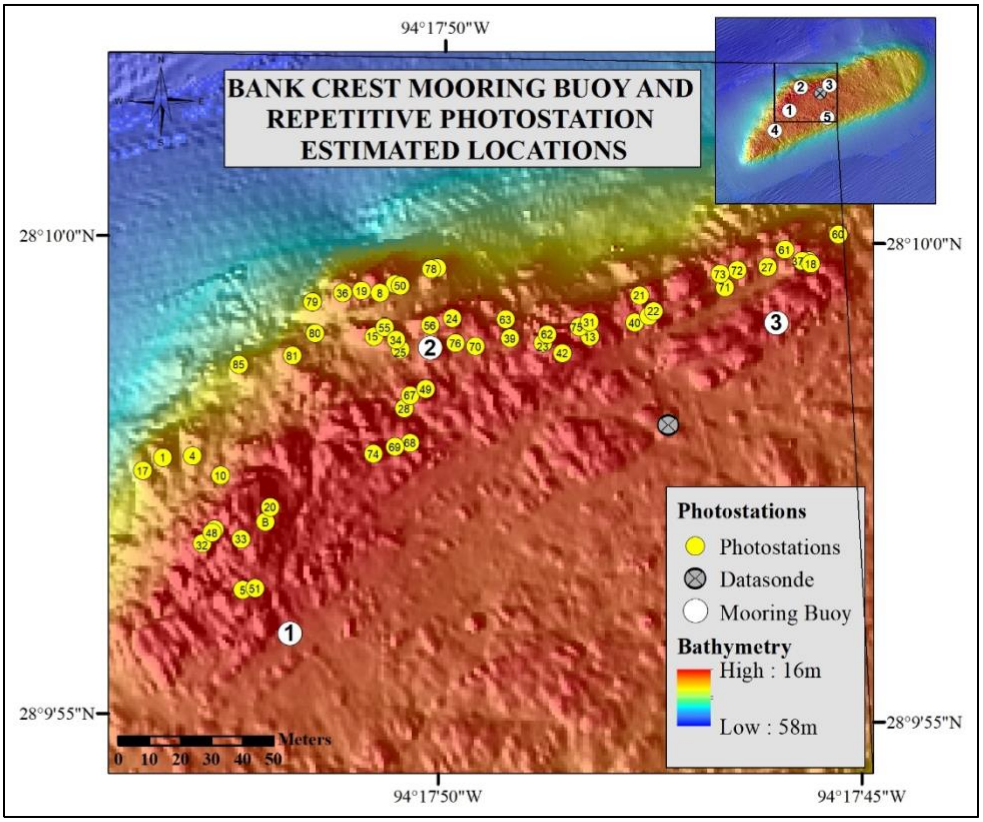


Figure 2.1 Stetson Bank site map. Seafloor bathymetry with mooring buoy locations and approximate repetitive photostation locations. Image: NOAA

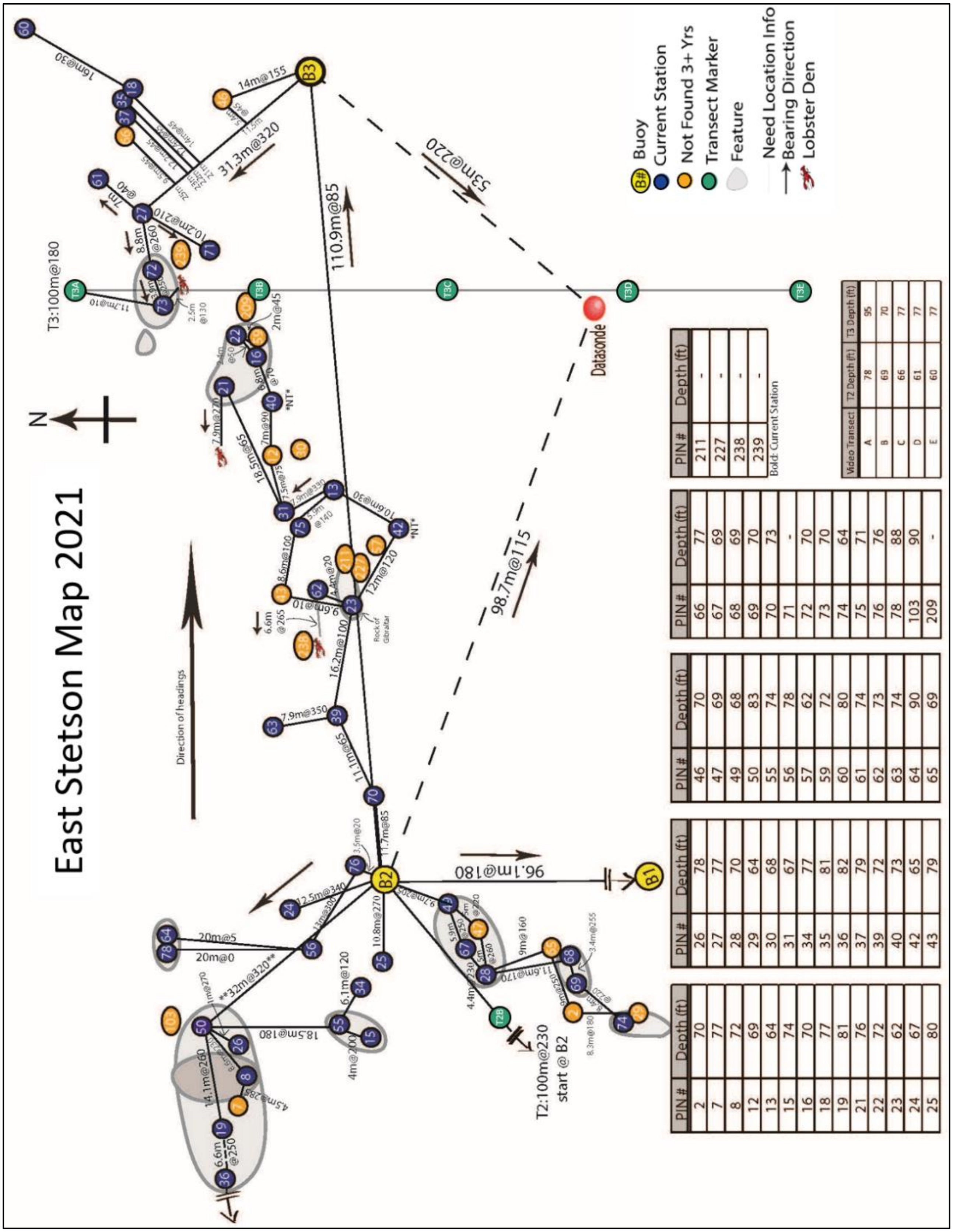
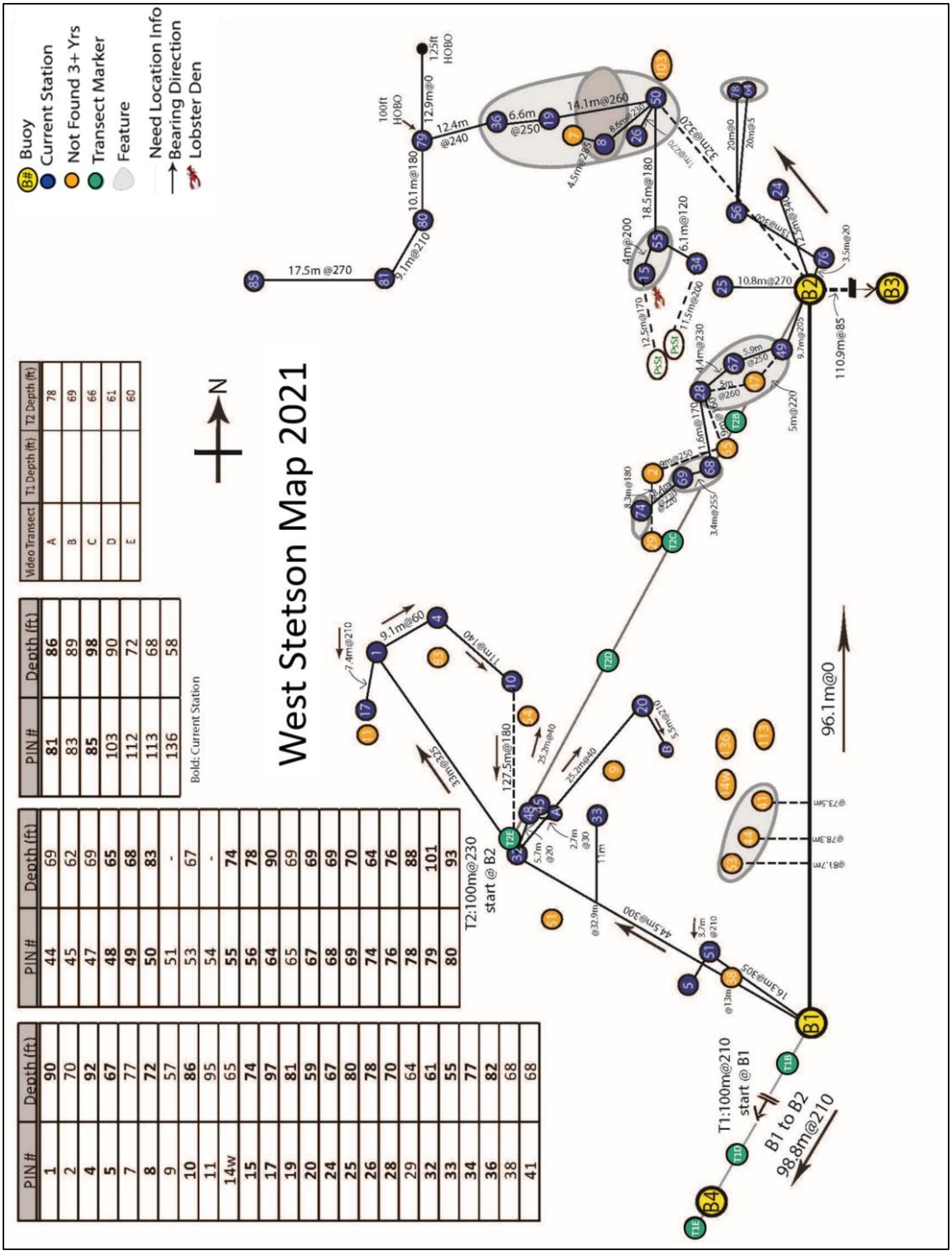


Figure 2.2 East Stetson map used by divers to locate repetitive photostations in the study site. Image: NOAA



PIN #	Depth (ft)
1	90
2	70
4	92
5	67
7	77
8	72
9	57
10	86
11	95
14w	65
15	74
17	97
19	81
20	59
24	67
25	80
26	78
28	70
29	64
32	61
33	55
34	77
36	82
38	68
41	68

PIN #	Depth (ft)
44	69
45	62
47	69
48	65
49	68
50	83
51	-
53	67
54	-
55	74
56	78
64	90
65	69
67	69
68	69
69	70
74	64
76	76
78	88
79	101
80	93

PIN #	Depth (ft)
81	86
83	89
85	98
103	90
112	72
113	68
136	58

Bold: Current Station

Video Transect	T1 Depth (ft)	T2 Depth (ft)
A		78
B		69
C		66
D		61
E		60

Figure 2.3 West Stetson map used by divers to locate repetitive photostations in the study site. Image: NOAA

Methods

Repetitive photostations were located using detailed maps and marked by scuba divers with floating plastic chains attached to small weights. Divers with cameras then photographed each station. In 2021, images were captured using a Sony® A6500 digital camera in a Nauticam® NA-A6500 housing with a Nikkor® Nikonos® 15 mm underwater lens. The camera was mounted onto a T-frame, set at 1.75 m from the substrate to maintain coverage of 1.6 m^2, with two Inon® Z240 strobes set 1.2 m apart (Figure 2.4). A compass and bubble level were mounted to the center of the T-frame so images could be taken in a vertical and northward orientation to standardize the area captured and ensure repeatability.

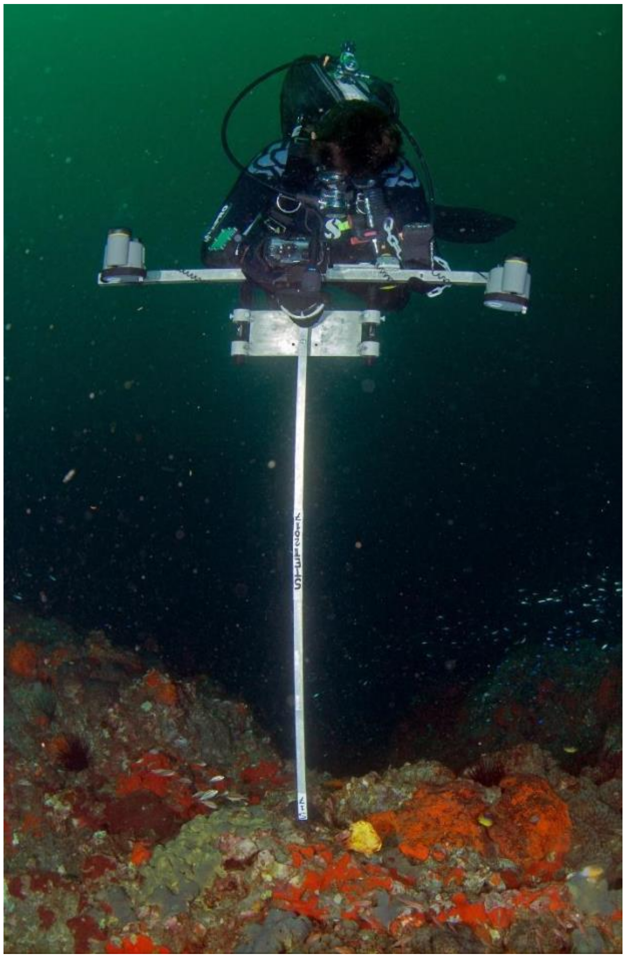


Figure 2.4 Camera and T-frame configuration for repetitive photostation images. Image: Schmahl/NOAA

Benthic cover in repetitive photostation images was analyzed using CPCe version 4.1, a spatial analysis software (Aronson et al., 1994; Kohler & Gill, 2006). A total of 30 random points were overlaid on each photograph and benthic species lying under these points were identified and verified by quality assurance and quality control (QA/QC). Organisms positioned beneath each random point were identified to the lowest possible taxonomic level, and cover was categorized into six groups: 1) coral, 2) sponges (including encrusting sponges), 3) macroalgae (algae longer than approximately 3 mm and thick algal turfs covering underlying substrate), 4) colonizable substrate (including fine turf algae and bare rock), 5) rubble (Aronson & Precht, 2000; Aronson et al., 2005), and 6) other (biotic components such as sea urchins, ascidians, fish, serpulid polychaetes, and unknown species). Additional features (photostation tags, tape measures, scientific equipment) and points with no data (shadows) were excluded from the analysis. Points that could not be differentiated because of camera angle or camera distortion were labeled as "unknown." Point count analysis was conducted for all images and mean percent cover for functional groups was determined by averaging across all photostations in the study site. Results are presented as mean percent cover + standard error (SE). Because photostations were not randomly selected, they are not intended to estimate bank-wide populations or benthic communities. Rather, they document changes in community structure at specific locations and the fate of individual organisms, and may provide evidence of the causes of change.

Coral bleaching, paling, 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 "healthy" and no bleaching or paling was noted in CPCe. Mortality included any point on recently dead but identifiable coral (exposed bare skeleton, with little to no algae growth).

Results

No repetitive photographs were completed in 2020, as NOAA prohibited diving and overnight vessel operations after March 2020 in response to the COVID-19 pandemic. Due to reduced crew capacity (from four to three crew members) and diver capacity (from ten to five divers) on the vessel as a result of COVID-19 precautions, only 24 of the 59 photostations (40%) were located and photographed in 2021, including eight of the 18 remaining original stations (44%).

In 2021, mean percent cover was 6.56% for coral, 7.09% for sponges, and 42.72% for macroalgae within 24 bank crest repetitive photostations (Figure 2.4). The dominant coral species were *M. alcicornis*, *M. decactis*, and *S. intersepta* (Figure 2.5). The dominant sponge species were *I. felix*, *I. strobilina*, and *N. nolitangere*, consistent with previous reports (Nuttall et al., 2020b; Figure 2.6). Bleaching and/or paling was observed in *M. alcicornis* colonies in 2021. No signs of stony coral tissue loss disease were observed.

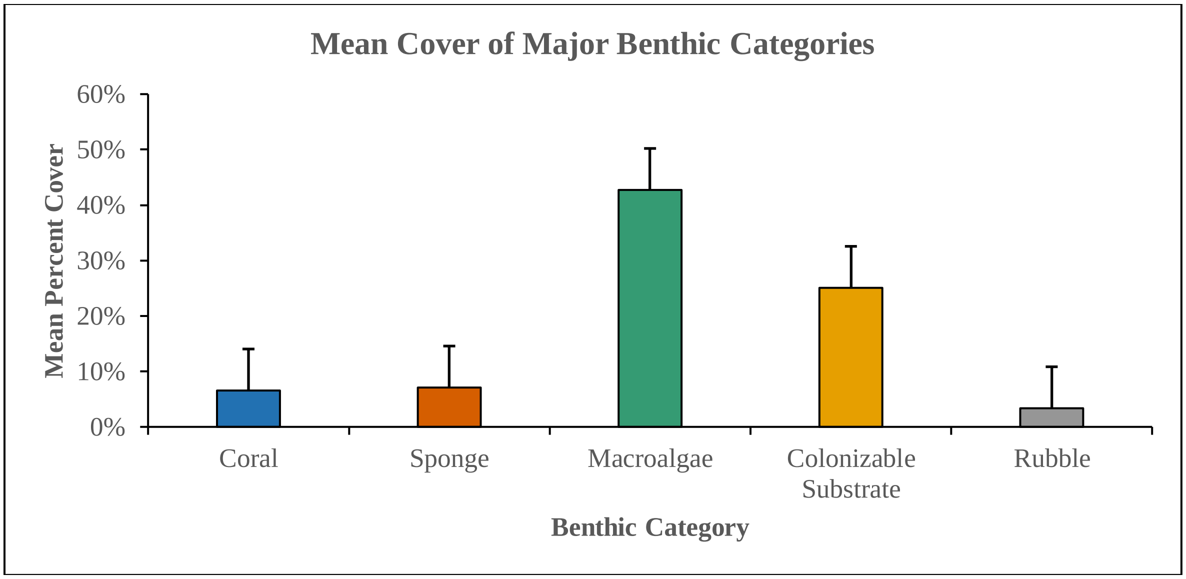


Figure 2.4. Mean percent cover (+ SE) of major benthic categories in 24 repetitive photostations at Stetson Bank in 2021.

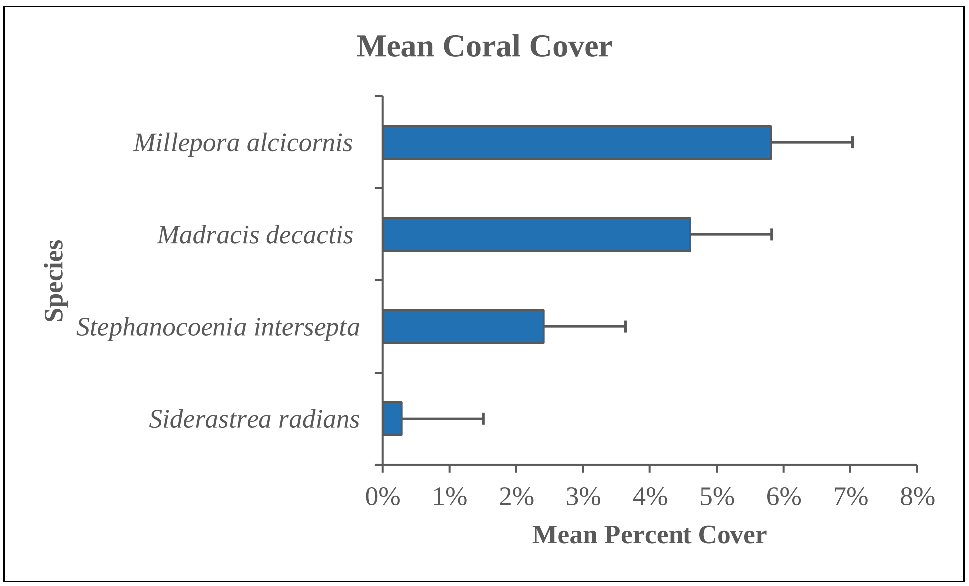


Figure 2.5. Mean percent cover (+ SE) of dominant coral species in 24 repetitive photostations at Stetson Bank in 2021.

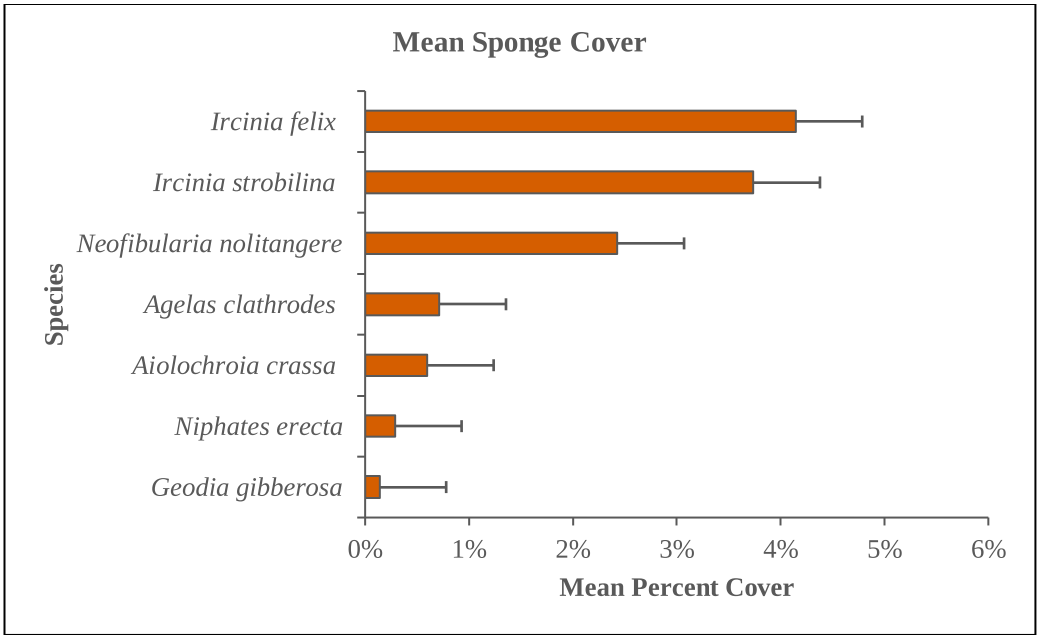


Figure 2.6. Mean percent cover (+ SE) of dominant sponge species in 24 repetitive photostations at Stetson Bank in 2021.

Four stations were missing tags: 25, 55, 56, and 61; however, no new tags were installed given the time constraints and limited number of divers. No new repetitive photostations were installed and no station refurbishment occurred in 2021.

Challenges and Resolutions

There were several challenges in the 2020 and 2021 field seasons brought on by restrictions established in response to the COVID-19 pandemic that limited personnel for vessel and diver 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 limited diving and vessel operations, with authorization 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 reducing the number of personnel on the vessel.

Consistent with ONMS and NOAA small boat program guidance, FGBNMS implemented precautions/requirements to ensure the safety of occupants on overnight cruises. 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’ 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 and minimize sharing of confined spaces (i.e., bunk rooms), limiting divers to six and crew to three, for a total of nine participants on board. This reduced the ability of researchers to complete tasks offshore.

Consequently, no random transect photographs, fish surveys, sea urchin and lobster surveys, or mesophotic monitoring were completed. FGBNMS intends to complete these efforts in 2022.

Despite restricted operations, the collection of some data allowed for continuity in cover estimates at nearly half of the existing repetitive photostations at Stetson Bank. There were no signs of stony coral tissue loss disease, but bleaching and paling were observed on *M. alcicornis* colonies on the bank crest. Approximately 3% of coral cover within Stetson Bank repetitive photostations was pale or bleached in 2021, higher than recorded in previous years. It is unknown whether bleaching occurred in 2020, but temperatures observed (see Chapter 3) exceeded 30 °C for a short period during 2020 and for a longer period in 2021.

Even though repetitive photostations do not provide an accurate representation of mean benthic cover across all bank crest habitats, the sites are critical in enabling researchers to track changes over time. The long-term monitoring cruise prioritized exchanging moored water quality instruments that had been on the bank since 2019. Repetitive photostations were collected opportunistically following instrument change-outs and before deteriorating weather conditions ended the cruise. While the 2021 field season was abnormal due to COVID-19, collecting repetitive photostation data, even if incomplete, was valuable to assess benthic community condition and maintain continuity of this long-term dataset.

Chapter 3: Water Quality

Introduction

Several water quality parameters were continually or periodically recorded at Stetson Bank from December 2019 through September 2021. Salinity, temperature, and turbidity were recorded every hour by data loggers permanently installed on the crest of Stetson Bank at a depth of 24 m. Additionally, temperature was recorded every hour at 30 m and 40 m stations.

Water column profiles and water samples were collected in February 2020 and November 2021. Water samples were collected at three different depths within the water column and analyzed by a U.S. Environmental Protection Agency (EPA)-certified laboratory for chlorophyll *a*, ammonia, nitrate, nitrite, and total Kjeldahl nitrogen (TKN). Additionally, water samples were sent to the Carbon Cycle laboratory at Texas A&M University-Corpus Christi for measurement of ocean carbonate levels. Water profiles and 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.

Methods

Moored Water Quality Instruments

The primary instrument for hourly recording salinity, temperature, and turbidity was a Sea-Bird® Electronics 16plus V2 conductivity, temperature, and depth (CTD) sensor (SBE 16plus) with a WET Labs ECO NTUS turbidity meter, deployed at a depth of 24 m. The logger was installed on a large railroad wheel, situated on a low-relief surface on the bank crest, in the midsection of the bank (Figure 3.1). Instruments were exchanged by divers for downloading and maintenance in March 2020 and September 2021. They were immediately exchanged with an identical instrument to avoid interruptions in data collection. Data were 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 resulting from COVID-19 restrictions.

Onset® Computer Corporation HOBO® Pro v2 U22-001 (HOBO) thermograph loggers recorded temperature hourly. These instruments provided a highly reliable temperature backup for the primary SBE 16plus logging instrument located at 24 m on the bank crest. In addition, single HOBO loggers were attached to eyebolts at 30 m and 40 m to record temperature hourly (Figure 3.1). These instruments operated continuously from June 11, 2019 to September 25, 2021. Due to reduced field capacity, the HOBO loggers at 30 m and 40 m were not retrieved in 2020, but were exchanged once in September 2021. When exchanged, data were downloaded and the loggers were cleaned and relabeled.

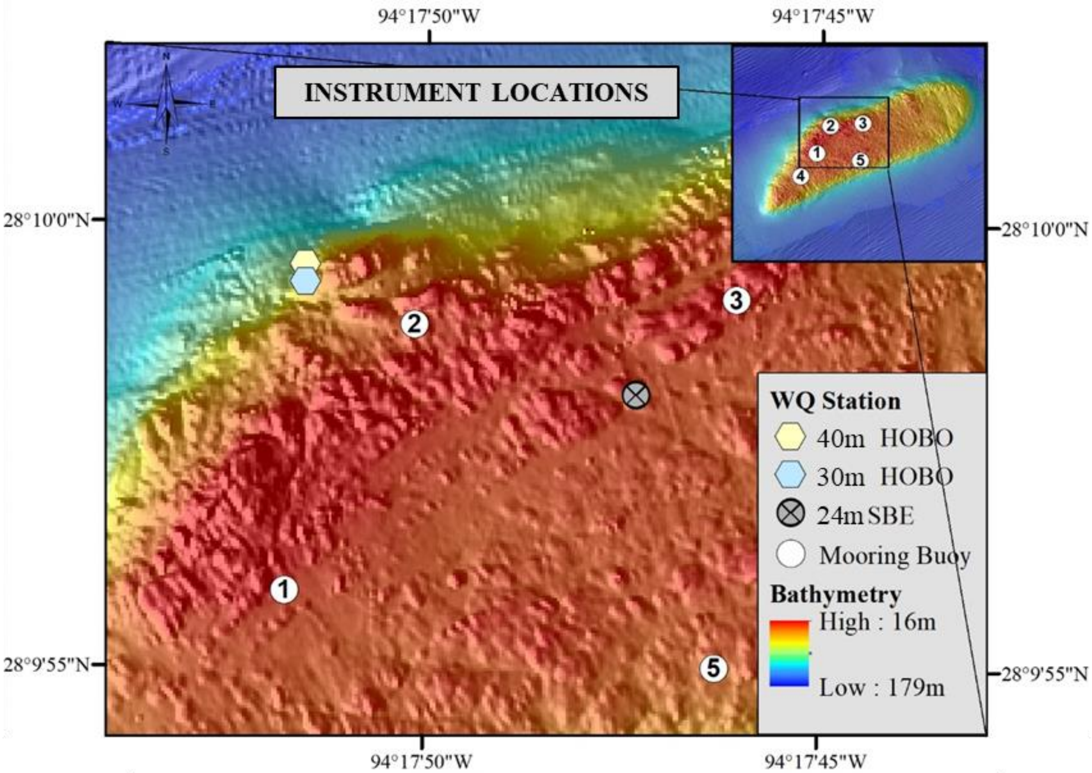


Figure 3.1 Locations of water quality instruments relative to Stetson Bank mooring buoys. Image: NOAA

Satellite Parameters

Daily sea surface temperature data and a suspended sediment proxy (Rrs 667) were downloaded from 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). Satellite-derived one-day mean sea surface temperature data for Stetson Bank were available in 2020 and 2021 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.

Water Column Profiles

Water column profiles from the surface to the bank cap were acquired in February 2020 and November 2021. In February 2020, the carousel package was borrowed from Texas A&M University at Galveston and 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 (SBE 19plus); and a Wet Labs C-Star Transmissometer measuring beam attenuation (Table 3.1). The profiler lacked pH, dissolved oxygen (DO), fluorescence, and turbidity data acquisition capabilities. In November 2021, an SBE 19plus attached to a carousel recorded temperature, salinity, pH, turbidity, fluorescence, and DO every ¼ second to distinguish differences between three main depth gradients: the bank cap (~20 m), mid-water column (~10 m), and near the surface (~1 m; Table 3.2). 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 <1 m/second. The water column profiles were attained February 23, 2020 and November 3, 2021. Tables 3.1 and 3.2 detail the instruments used to collect each parameter.

Table 3.1 Sensors for water quality profiles taken from the Texas A&M University at Galveston carousel in 2020. Sensors were secured to the SBE 19plus V2 CTD.

Sensor	Parameters Measured
SBE 19plus	Depth, salinity, and temperature

Table 3.2 Sensors for water quality profiles taken with the new FGBNMS carousel in 2021. Sensors are secured to the SBE 19plus V2 CTD.

Sensor	Parameters Measured
SBE 19plus	pH
SBE 19plus	Depth, salinity, and temperature
SBE 43	Dissolved oxygen
WET Labs ECO-FL-NTU	Fluorescence and turbidity

Water Samples

In conjunction with water column profiles using the sampling carousels described above, water samples were collected. The carousel was attached to the vessel with a scientific winch cable that allowed activation of the sampling bottles at specific depths from the shipboard wet lab. A total of six nutrient and four carbonate samples were collected using twelve OceanTest® Corporation 2.5-l Niskin bottles attached to the carousel. Three Niskin bottle samples were collected near the bank crest (~20 m depth), mid-water (~10 m depth), and near the surface (~1 m depth) for subsequent transfer to laboratory collection bottles.

Water samples were analyzed for chlorophyll *a* and nutrients including ammonia, nitrate, nitrite, soluble reactive phosphorus (ortho phosphate), and TKN. One sample bottle from each depth was distributed among three containers for nutrient analysis: chlorophyll *a* samples were distributed to 1000-ml glass containers with no preservatives; samples for soluble reactive phosphorus were distributed to 250-ml bottles with no preservatives; and ammonia, nitrate, nitrite, and TKN samples were distributed to 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 and maintained at 0° C; a chain of custody was initiated for processing at an EPA-certified laboratory. The samples were transported for analysis within 24 hours of collection.

Water samples for ocean carbonate measurements, including pH, alkalinity, CO_2 partial pressure (pCO_2), aragonite saturation state, and total dissolved CO_2 (DIC), were collected following methods requested by the Carbon Cycle Laboratory at Texas A&M University-Corpus Christi. Samples were collected in ground neck borosilicate glass bottles. Bottles were filled using a 20-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 and the stopper 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 the Carbon Cycle Laboratory at Texas A&M University-Corpus Christi. Ocean carbonate samples were obtained 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, September 2021, and November 2021. QA/QC procedures included a review of all files to ensure data accuracy and ensuring instruments were serviced 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.

SBE 16plus instruments and backup HOBO loggers located on the bank 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. Results of chlorophyll *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 the Carbon Cycle Laboratory at Texas A&M University-Corpus Christi.

Results

Moored Water Quality Instruments

The year 2020 was Earth's hottest year on record and 2021 was the sixth hottest on record (NASA, 2021). Temperatures recorded on the SBE 16plus at 24 m ranged from 19.12 °C to 30.03 °C in 2020 and 16.07 °C to 30.76 °C in 2021, with nearly identical data recorded by the backup HOBO logger (Figure 3.2). Bank cap temperatures at Stetson Bank exceeded 30 °C for one day in 2020 and 18 nonconsecutive days in 2021. As noted in Chapter 2, coral bleaching was observed in Stetson Bank repetitive photostations in 2021.

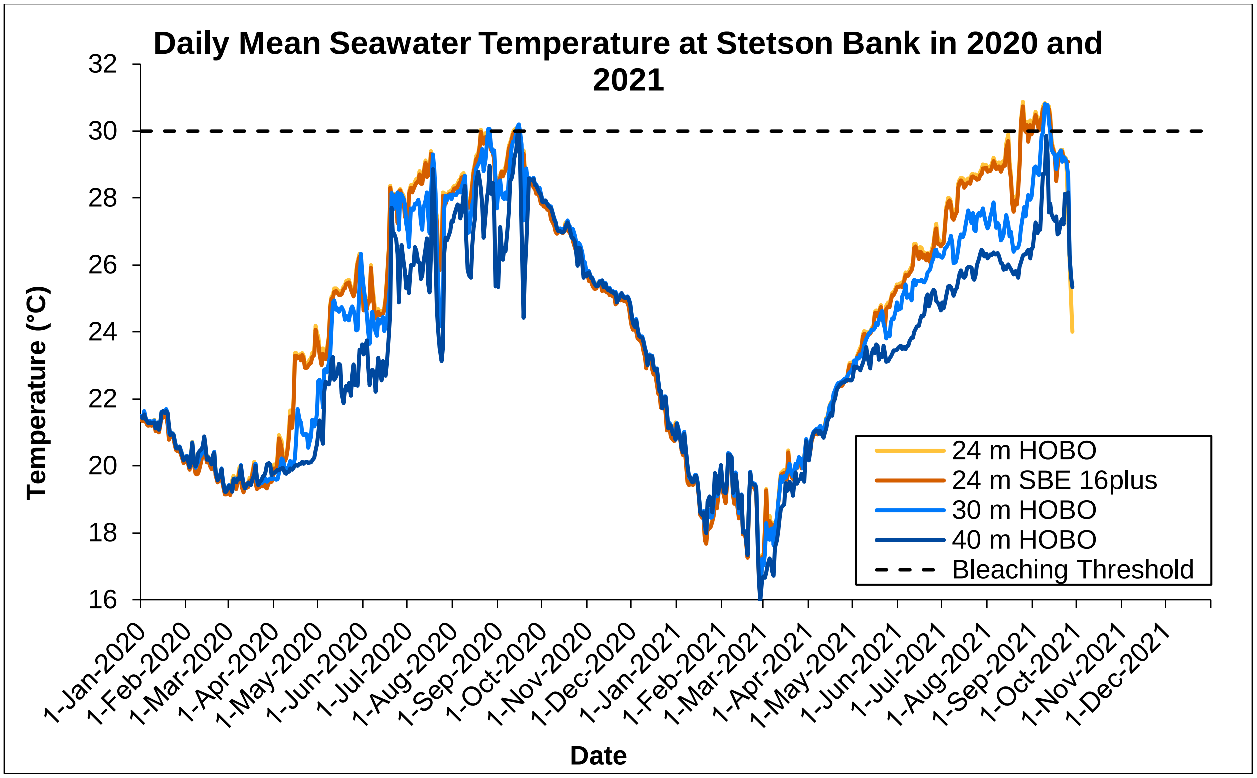


Figure 3.2. Daily mean seawater temperature (°C) at Stetson Bank from various depths in 2020 and 2021. The black hashed line at 30 °C is a threshold beyond which coral bleaching is known to occur.

Water temperatures recorded on the HOBOs at 30 m and 40 m registered similar patterns in 2020 and 2021, showing the development of thermal stratification of the water column during spring and summer, followed by more consistent mixing in fall each year. Temperatures recorded on the HOBO at 30 m ranged from 19.25 °C to 30.19 °C in 2020 and 16.04 °C to 30.81 °C in 2021 (Figure 3.2). The HOBO at 40 m recorded temperatures ranging from 19.22 °C to 30.01 °C in 2020 and 15.96 °C to 29.85 °C in 2021 (Figure 3.2). Data from the 30 m HOBO recorded temperatures exceeding 30 °C for four consecutive days in 2020 and four nonconsecutive days in 2021.

At 24 m, the SBE 16plus recorded salinity ranging from 32.86 to 36.19 psu in 2020 and 33.25 to 36.47 psu in 2021 (Figure 3.3).

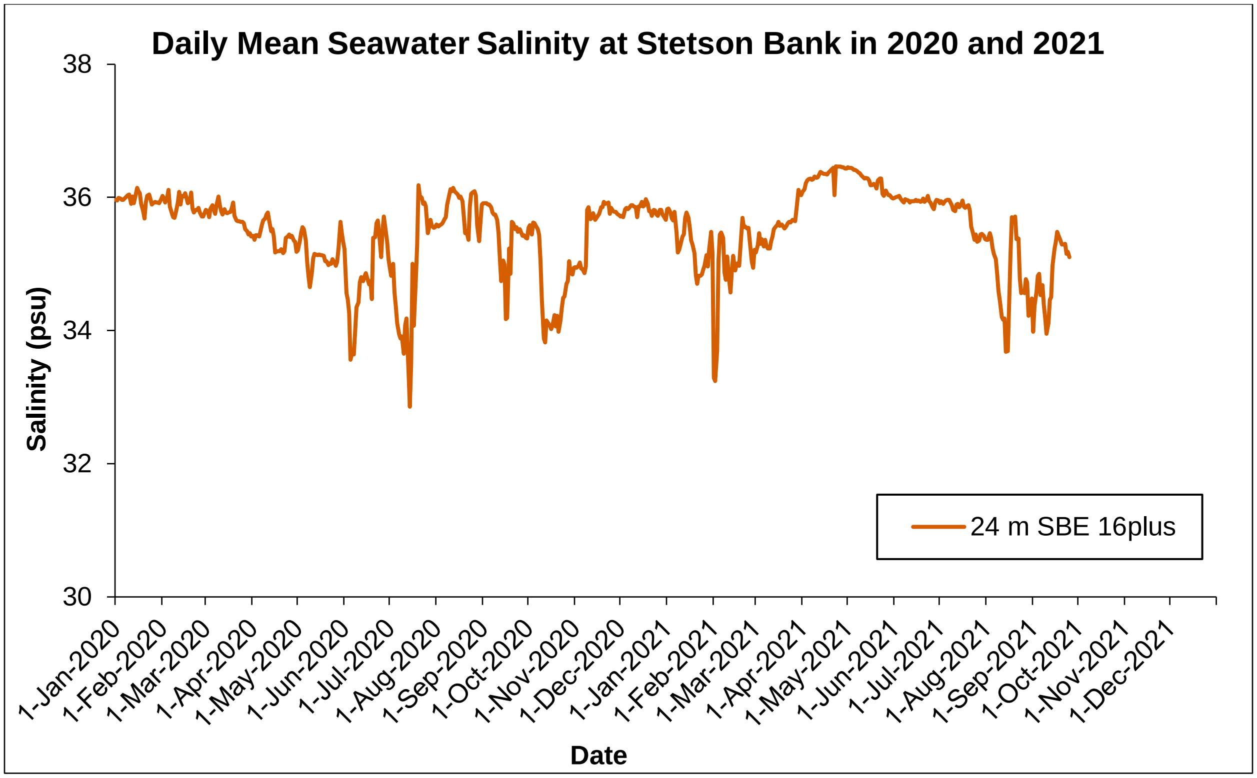


Figure 3.3. Daily mean seawater salinity (psu) at Stetson Bank in 2020 and 2021.

The turbidity sensor on the SBE 16plus experienced periodic malfunctions due to the lack of quarterly maintenance and recorded significant drifts in turbidity values; thus, most data were not reliable for 2020 and 2021. Turbidity readings have been variable for Stetson Bank since data collection began in 2015 (Nuttall et al., 2020b). On average, the maximum turbidity value for Stetson Bank was ~5 ntu. Data are only presented from January 1, 2020 to September 30, 2020 for this study period, as turbidity values drifted far above previously reported values (Nuttall et al., 2020b) and were determined to be unreliable. From January to September 2020, turbidity readings averaged 1.22 ntu at the 24 m SBE 16plus. Peak anomalies occurred on April 26 (13.33 ntu), July 15 (26.99 ntu), and September 20 (12.6 ntu) in 2020 (Figure 3.4).

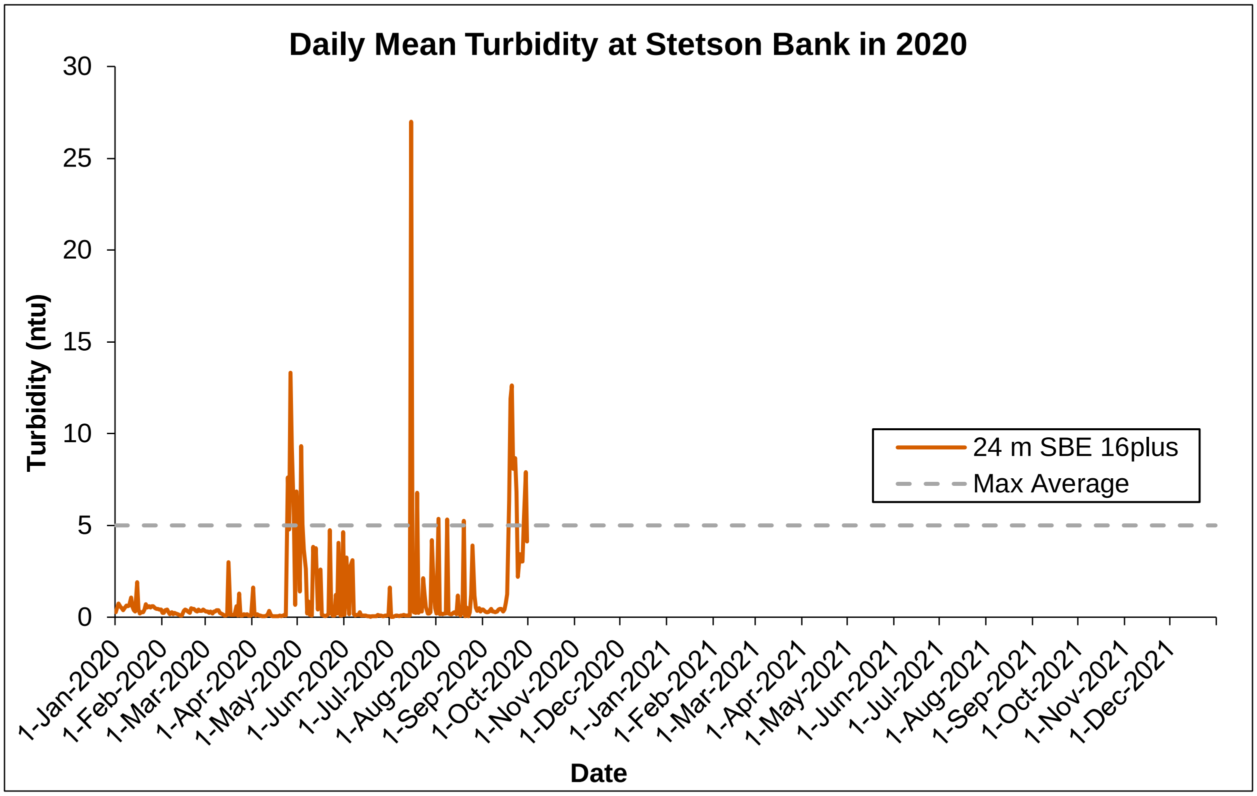


Figure 3.4 Daily mean turbidity (ntu) values in 2020 and 2021 at Stetson Bank. Data were unreliable after September 30, 2020 and were excluded from this report.

Water Column Profiles

The spring and fall water columns were nearly isothemal from just below the surface to the bank cap. No single profile varied more than 1 °C from the surface to the bottom (Figure 3.5). Salinity displayed some stratification in February 2020 at the surface, while the salinity profile from November 2021 showed stratification mid-water column. DO values were variable at the surface and stabilized once reaching four meters water depth. Turbidity and fluorescence values are not presented, as there was an issue with the sensor readings in November 2021 (turbidity exceeded 9 ntu and fluorescence exceed 8 mg/m^3). The CTD used in February 2020 only recorded temperature and salinity (Figure 3.5).

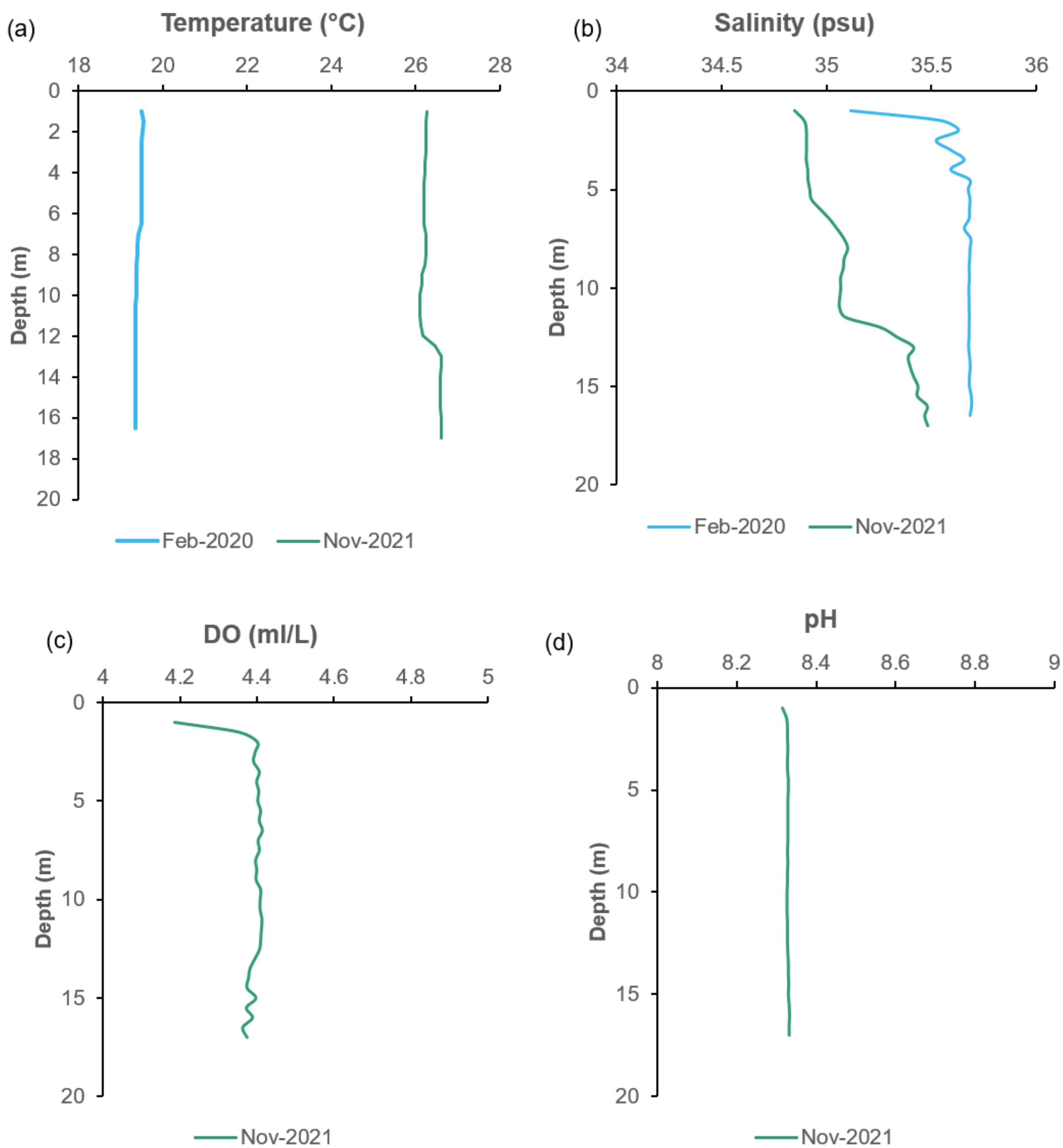


Figure 3.5. Stetson Bank (a) temperature, (b) salinity, (c) dissolved oxygen, and (d) pH data from water column profiles in February 2020 and November 2021. The CTD used in February did not measure DO or pH. Turbidity and fluorescence profiles are not included because of a faulty sensor reading in November 2021.

Water Samples

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 Texas A&M University-Corpus Christi for analysis. At the time of this report, data were still being processed by Texas A&M University-Corpus Christi.

Challenges and Resolutions

In February 2020, a carousel was borrowed from Texas A&M University at Galveston to collect water profiles and water samples due to the loss of the FGBNMS carousel in 2019. The carousel used in February 2020 only measured temperature and salinity, thus other parameters were absent from this profile period. In November 2021, the typical nutrient profiles were collected, but with a new instrument. The turbidity sensor on the SBE 16plus experienced periodic malfunctions due to lack of maintenance during this period, resulting in data that were inaccurate in 2020 and 2021. Turbidity and fluorescence readings from water column profiles were also inaccurate; thus, limited turbidity data were available for 2020 and 2021.

FGBNMS intends to resume quarterly water quality sampling cruises to collect water samples, conduct water column profiles, and exchange and maintain moored water quality instruments on Stetson Bank in 2022.

Chapter 4: Notes and Other Research

General Observations

In 2021, divers noted the continued persistence of the exotic regal demoiselle (*Neopomacentrus cyanomos*), native to the west Indo-Pacific Ocean. Additionally, divers observed a roughtail stingray (*Bathytoshia centroura*) and a Caribbean reef octopus (*Octopus briareus*). Several colonies of *M. alcicornis* were pale or bleached in September 2021, when bottom temperature was recorded at 28.3 °C. Divers also anecdotally noted more algal cover and fewer sponges at repetitive photostations in 2021 than in 2019.

Other Research

While not part of the FGBNMS long-term monitoring program, research that was permitted but could not be completed in 2021 at Stetson Bank included:

- Lionfish removals by a veterans group, funded by the National Marine Sanctuary Foundation. This cruise has been rescheduled for 2022.
- Installation of eight acoustic receivers for an acoustic positioning system as part of a NOAA National Centers for Coastal Ocean Science funded project, in partnership with Texas A&M University Galveston, to study habitat use and connectivity of fish species on northern Gulf of Mexico banks under permit FGBNMS-2021-007. Receivers are scheduled for installation in March 2022.

Chapter 5: Conclusions

The crest of Stetson Bank, which has been monitored continuously for 28 years, has experienced a significant shift in benthic community structure over that time, from a *Millepora* and sponge dominated assemblage to an macroalgae and sponge dominated community (DeBose et al., 2012; Nuttall et al. 2020a). Although COVID-19 restrictions prevented or reduced monitoring activities in 2020 and 2021, divers assessed benthic cover at 24 of the 59 repetitive photostations on the bank, documented bleaching and paling *M. alcicornis* colonies (resulting from high summer temperatures), and did not observe any stony coral tissue loss disease on the bank. Though not quantified, divers anecdotally reported seeing fewer sponges and higher macroalgae cover at the stations while collecting images.

Water sample collections, *in situ* measurements, and profiles in February 2020 and November 2021 suggest nominal conditions, for the most part. This included oligotrophic, isothermal conditions in the spring and summer water columns, as well as summer stratification. High water temperatures for a sustained period in the summer of 2021 likely resulted in bleaching and paling of hydrocorals on the bank. Whether those corals recover or succumb will be assessed in upcoming sampling at the same photostations.

The exotic regal demoiselle persisted in 2021, with schools of hundreds of small fish (5–10 cm), observed over many pinnacles on the bank and within vertical sponges. These schools often included other reef fish, including brown chromis (*Chromis multilineata*) and any impacts to native species have not yet been assessed. Two other unusual observations, a roughtail stingray (*Bathytoshia centroura*) and Caribbean reef octopus (*Octopus briareus*), were made on the bank crest.

The monitoring program at Stetson Bank represents one of the longest running monitoring efforts of a northern latitude coral community that is periodically exposed to environmental conditions considered marginal for the communities it supports. It has already allowed us to document one community phase shift caused by a significant intermediate disturbance event, and should provide a window into community dynamics as it continues to respond. Meanwhile, resource managers will be able to track known drivers of ecosystem variation and change in the northwestern Gulf of Mexico as a result of knowledge gained through monitoring. Continuing this program may also provide valuable information on species that can resist change in the face of declining conditions (Zweifler et al., 2021) and inform coral ecosystem protection and restoration.

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Literature Cited

Aronson, R. B., Edmunds, P. J., Precht, W. F., Swanson, D. W., & Levitan, D. R. (1994). Large-scale, long-term monitoring of Caribbean coral reefs: Simple, quick, inexpensive methods. *Atoll Research Bulletin*, *421*, 1–19. https://doi.org/10.5479/si.00775630.421.1

Aronson, R. B., & Precht, W. F. (2000). Herbivory and algal dynamics on the coral reef at Discovery Bay, Jamaica. *Limnology and Oceanography*, *45*(1), 251–255. https://doi.org/10.4319/lo.2000.45.1.0251

Aronson, R. B., Precht, W. F., Murdoch, T. J. T., & Robbart, M. L. (2005). Long-term persistence of coral assemblages on the Flower Garden Banks, northwestern Gulf of Mexico: Implications for science and management. *Gulf of Mexico Science*, *23*(1), 84–94. https://doi.org/10.18785/goms.2301.06

Bernhardt, S. P. (2000). *Photographic monitoring of benthic biota at Stetson Bank, Gulf of Mexico* [Unpublished master's thesis]. Texas A&M University.

Cummings, K. E., Ruzicka, R. R., Semon-Lunz, K., Brenner, J., Goodin, K. L., & Ames, K. W. (2018). Ecological resilience indicators for coral ecosystems. In K. L. Goodin, D. Faber-Langendoen, J. Brenner, S. T. Allen, R. H. Day, V. M. Congdon, C. Shepard, K. E. Cummings, C. L. Stagg, C. A. Gabler, M. Osland, K. H. Dunton, R. R. Ruzicka, K. Semon-Lunz, D. Reed, & M. Love (Eds.), *Ecological resilience indicators for five northern Gulf of Mexico ecosystems* (pp. 249–319). NatureServe.

DeBose, J. L., Nuttall, M. F., Hickerson, E. L., & Schmahl, G. P. (2012). A high-latitude coral community with an uncertain future: Stetson Bank, northwestern Gulf of Mexico. *Coral Reefs*, *32*, 255–267. https://doi.org/10.1007/s00338-012-0971-3

Gardner, J. V., Mayer, L. A., Hughes, C. J., & Kleiner, A. (1998). High-resolution multibeam bathymetry of East and West Flower Gardens and Stetson Banks, Gulf of Mexico. *Gulf of Mexico Science*, *16*, 131–143. https://doi.org/10.18785/goms.1602.03

Kohler, K. E., & Gill, S. M. (2006). Coral point count with Excel extensions (CPCe): A Visual Basic program for the determination of coral and substrate coverage using random point count methodology. *Computers and Geosciences*, *32*(9), 1259–1269. https://doi.org/10.1016/j.cageo.2005.11.009

Lang, J. C., Marks, K. W., Kramer, P. A., Kramer, P. R, & Ginsburg, R. N. (Eds.). (2012). *Atlantic and Gulf Rapid Reef Assessment Protocols* (Version 5.4). Atlantic and Gulf Rapid Reef Assessment.

NASA. (2021). *Ocean color feature: World map of chlorophyll-a*. https://oceancolor.gsfc.nasa.gov/

Nuttall, M. F., Somerfield, P. J., Sterne, T. K., MacMillan, J. T., Embesi, J. A., Hickerson, E. L., Johnston, M. J., Schmahl, G. P., Sinclair, J. (2020a). *Stetson Bank long-term monitoring: 1993–2015*. National Marine Sanctuaries Conservation Series ONMS-20-06. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Flower Garden Banks National Marine Sanctuary. https://sanctuaries.noaa.gov/science/conservation/stetson-bank-long-term-monitoring-1993-2015.html

Nuttall, M. F., Blakeway, R. D., MacMillan, J., Sterne, T., O'Connell, K., Hu, X., Embesi, J. A., Hickerson, E. L., Johnston, M. A., Schmahl, G. P., & Sinclair, J. (2020b). *Stetson Bank long-term monitoring: 2015–2018 synthesis report*. National Marine Sanctuaries Conservation Series ONMS-21-01. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries. https://sanctuaries.noaa.gov/science/conservation/stetson-bank-long-term-monitoring-synthesis-report.html

Otis, D. (2021). *Flower Garden Banks National Marine Sanctuary data dashboard* [Data set]. http://fgbnms-dashboard.marine.usf.edu:3000

Rezak, R., Bright, T. J., & McGrail, D. W. (1985). *Reefs and banks of the northwestern Gulf of Mexico: Their geological, biological, and physical dynamics*. John Wiley and Sons.

Zweifler, A., O'Leary, M., Morgan, K., & Browne, N. K. (2021). Turbid coral reefs: Past, present, and future—a review. *Diversity*, *13*(6), 251. https://doi.org/10.3390/d13060251

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