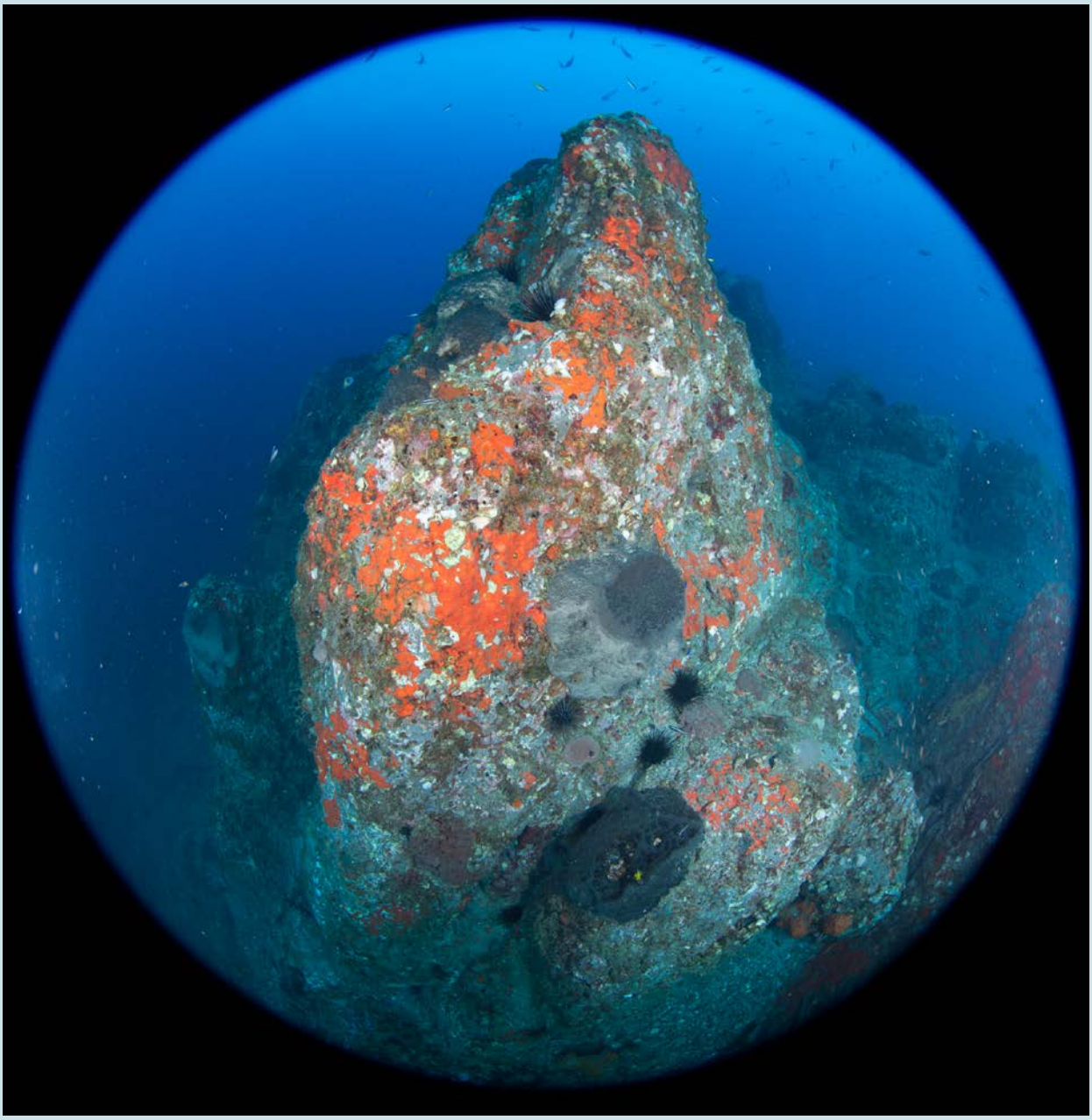
Office of National Marine Sanctuaries
National Oceanic and Atmospheric Administration

Stetson Bank Long-Term Monitoring: 2015 Annual Report



February 2017 | sanctuaries.noaa.gov | MARINE SANCTUARIES CONSERVATION SERIES ONMS-17-06

Suggested Citation:
Nuttall, M.F., T.K. Sterne, R.J. Eckert, X. Hu, J. Sinclair, E.L. Hickerson, J.A. Embesi, M.J. Johnston, G.P. Schmahl. 2017. Long-Term Monitoring at Stetson Bank, Flower Garden Banks National Marine Sanctuary, 2015 Annual Report. Marine Sanctuaries Conservation Series ONMS-17-06. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Flower Garden Banks National Marine Sanctuary, Galveston, TX. 98 pp.

Cover Photo:
A claystone feature that comprises the high relief habitat at Stetson Bank. Various sponges, invertebrates, and fish can be seen. Image credit: G.P. Schmahl /FGBNMS.

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Abstract

This report documents study methods and summarizes key findings and field notes from the 2015 annual long-term monitoring study of fish and benthic communities at Stetson Bank. Stetson Bank is an uplifted claystone/siltstone feature located within the Flower Garden Banks National Marine Sanctuary, in the northwestern Gulf of Mexico, and supports a diverse benthic community of sponges and coral. Benthic monitoring has occurred at the site since 1993 and was expanded in 2015 to include monitoring in the mesophotic zone surrounding the bank crest.

In 2015, bank crest high relief habitat was documented to have higher coral and sponge cover in comparison to low relief habitat, and overall macroalgae cover declined from 2014 levels. Bank crest fish communities were mostly comprised of small individuals and exhibited an inverted biomass pyramid. In the mesophotic zone, two habitats were documented: coralline algae reef and deep reef. Coralline algae reef cover was predominately Rhodophyta and deep reef was Cnidaria. The mesophotic fish community was mostly comprised of fish 15-20 cm in length and biomass was predominately piscivores.

Acknowledgments

FGBNMS would like to acknowledge the many groups and individuals that provided invaluable support to make this monitoring effort successful, including BSEE, UNCW-UVP, TAMUG, and Moody Gardens Aquarium. Researchers and volunteers that assisted with data collection or processing in 2015 include:

Ryan Eckert (FGBNMS)
John Embesi (FGBNMS)
Brandon Escareno (TAMUG)
Ty Hlavaty (Shetler Marine)
Lance Horn (UNCW-UVP)
Chris Horrell (BSEE)
Michelle Johnston (FGBNMS)
Brett Mayberry (Shetler Marine)
Chelsy Moore (TAMUG)
Marissa Nuttall (FGBNMS)
Doug Peter (BSEE)
Victoria Schweitzer (TAMUG)
Mike Shetler (Shetler Marine)
Morgan Sifrit (TAMUG)
James Sinclair (BSEE)
Travis Sterne (FGBNMS)
Tina Thompson (Shetler Marine)
Laura Wandel (Moody Gardens Aquarium)
Jason White (UNCW-UVP)

We would also like to thank the anonymous peer reviewers of the report. This study was funded by the U.S. Department of the Interior, Bureau of Safety and Environmental Enforcement through Interagency Agreement E14PG00052 with the National Oceanic and Atmospheric Administration's National Ocean Service, Office of National Marine Sanctuaries, through Flower Garden Banks National Marine Sanctuary.

Acronyms

BSEE – Bureau of Safety and Environmental Enforcement
CCL – Carbon Cycle Laboratory
CPCe – Coral Point Count® with Excel® extensions
FGBNMS – Flower Garden Banks National Marine Sanctuary
GREAT – Gulf Reef Environmental Action Team
NMSF – National Marine Sanctuary Foundation
NOAA – National Oceanic and Atmospheric Administration
ROV – Remotely Operated Vehicle
TAMU-CC – Texas A&M University – Corpus Christi
TAMUG – Texas A&M University at Galveston
UNCW-UVP – University of North Carolina at Wilmington - Undersea Vehicle Program

Keywords

Long-Term Monitoring, Benthic Community, Fish Community, Water Quality, Mesophotic Coral Ecosystem, Stetson Bank, Flower Garden Banks National Marine Sanctuary.

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Introduction

Stetson Bank, located approximately 70 nautical miles southeast of Galveston, Texas, is an uplifted claystone feature associated with an underlying salt dome. It is a high latitude coral community, existing at the northern limit of coral community ranges, which are considered "marginal" in environmental conditions for coral reefs due to varying temperature and light availability. It supports a well-developed benthic community of tropical marine sponges, coral and other invertebrates. Sponges, primarily *Neofibularia nolitangere*, *Ircinia strobilina*, and *Agelas clathrodes*, comprise a large portion of the benthic biota, but have been in decline in recent years. Twelve species of hermatypic corals have been documented, including *Pseudodiploria strigosa*, *Stephanocoenia intersepta*, *Madracis brueggemanni*, *Madracis decactis*, and *Agaricia fragilis*, with the hydrozoan *Millepora alcicornis* (fire coral) historically comprising the dominant benthic biota at Stetson Bank, but has declined in recent years. Benthic cover of algae, predominately *Dictyota* sp. and turf algae, is highly variable between years.

In 1993, an annual long-term monitoring program was initiated at Stetson Bank by Gulf Reef Environmental Action Team (GREAT), and later conducted by FGBNMS. These historical monitoring programs have focused on the reef habitat within non-decompression SCUBA diving limits (<33.5m) and contributed to the addition of Stetson Bank as part of Flower Garden Banks National Marine Sanctuary in 1996. While the designated boundaries were based on the best available data at that time, subsequent exploration lead to the discovery of mesophotic reefs surrounding Stetson Bank that occur outside of the current Sanctuary boundary (Figure I).

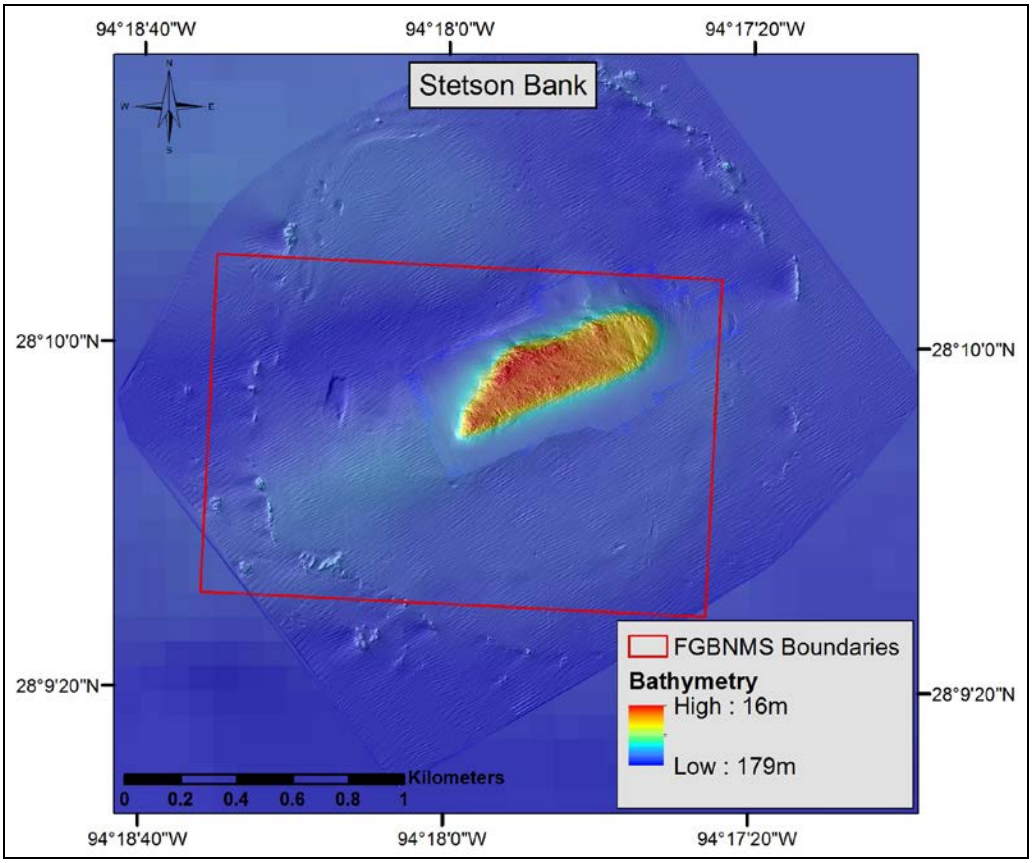


Figure I. Bathymetric map of Stetson Bank. Red lines indicate Sanctuary boundary.

In 2015, Bureau of Safety and Environmental Enforcement (BSEE) and Flower Garden Banks National Marine Sanctuary (FGBNMS) expanded monitoring at Stetson Bank to include both the historically monitored bank crest and the surrounding mesophotic reef habitat. The results from the first year of the study are presented in this report. Data were collected on several cruises throughout the year (Table I).

Table I. Dates and primary tasks of data collection cruises.

Date	Main Task
11/9/2014 – 11/10/2014	Water Quality: Instrument download and sample collection
2/9/2015 – 2/11/2015	Water Quality: Instrument download and sample collection
4/29/2015 – 5/1/2015	Water Quality: Instrument download and sample collection
6/21/2015 – 6/26/2015	Bank Crest Monitoring: Benthic and fish community monitoring
7/12/2015 – 7/16/2015	Mesophotic Monitoring: Benthic and fish community monitoring
10/7/2015 – 10/8/2015	Water Quality: Instrument download and sample collection
11/2/2015 – 11/5/2015	Water Quality: Instrument download and sample collection

To date, the monitoring program at Stetson Bank represents one of the longest continual coral community monitoring efforts. As increasing anthropogenic stressors to marine

environments are projected to continue, long-term monitoring datasets are essential to understanding community stability and ecosystem resilience. Additionally, as invasive species invade and establish, these long term data sets are vital in documenting and tracking their impacts on the natural populations. Continuation and expansion of this extensive dataset will provide valuable insight for both research and management purposes.

1. REPETITIVE PHOTOSTATIONS

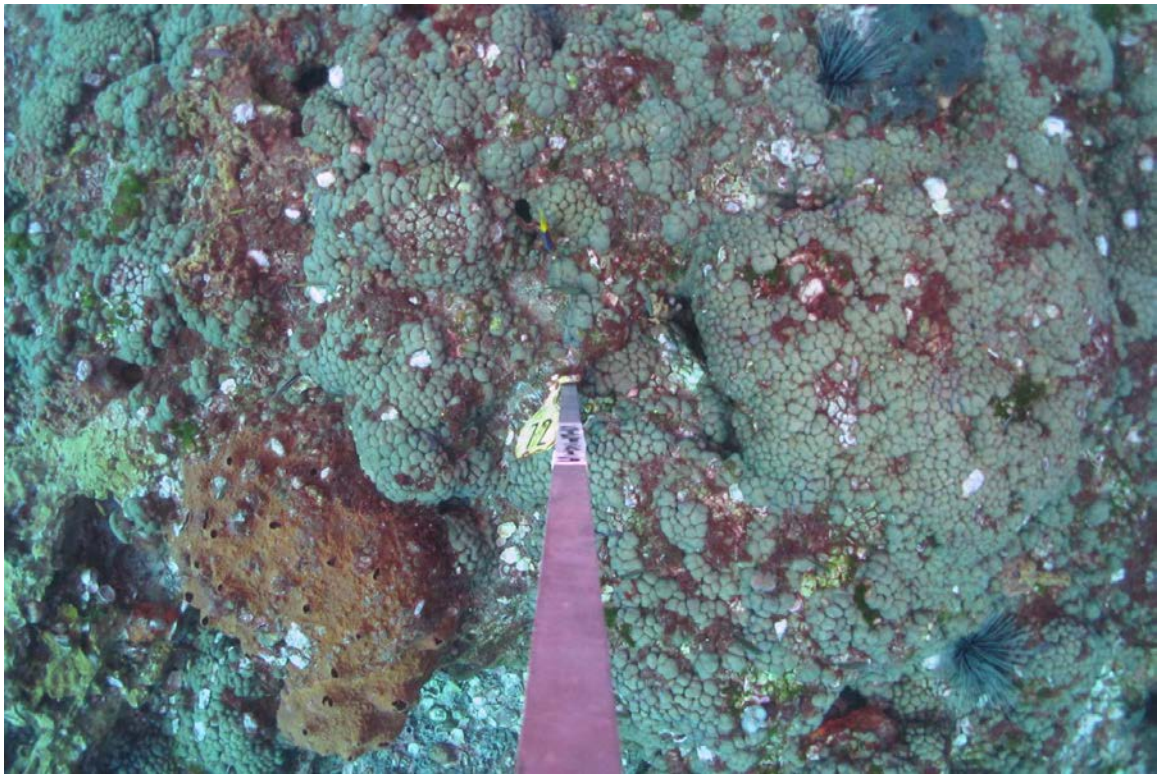


Photo: Ryan Eckert/FGBNMS

Repetitive photostation 72 is dominated by the coral *Madracis decactis*, along with sponges, macroalgae, and sea urchins.

Introduction

Permanent photostations have been in place on Stetson Bank since 1993. Locations were selected along high relief features at biologically interesting locations by SCUBA divers, and marked using nails or eyebolts and numbered tags. Initially, a total of 36 permanent photostations were installed. Over time, many of these stations have been lost, and new stations have been established. As of 2015, a total of 59 stations, with 18 of the original stations, were in use. All of these photostations occur on the diverse and biologically interesting habitat accessible from permanent mooring buoys 1, 2, and 3 (Table 1.1, Figure 1.1). Each station, which is marked by a metal pin or eye-bolt and numbered cattle tag, is located by SCUBA divers using detailed maps (Figures 1.2 to 1.3) and photographed annually to monitor changes in the composition of benthic assemblages.

Table 1.1. Coordinates and depths of buoys at Stetson Bank.

Buoy No.	Latitude (DMD)	Longitude (DMD)	Depth (m)
1	28 09.931	94 17.861	22.6
2	28 09.981	94 17.834	23.8
3	28 09.986	94 17.766	22.3

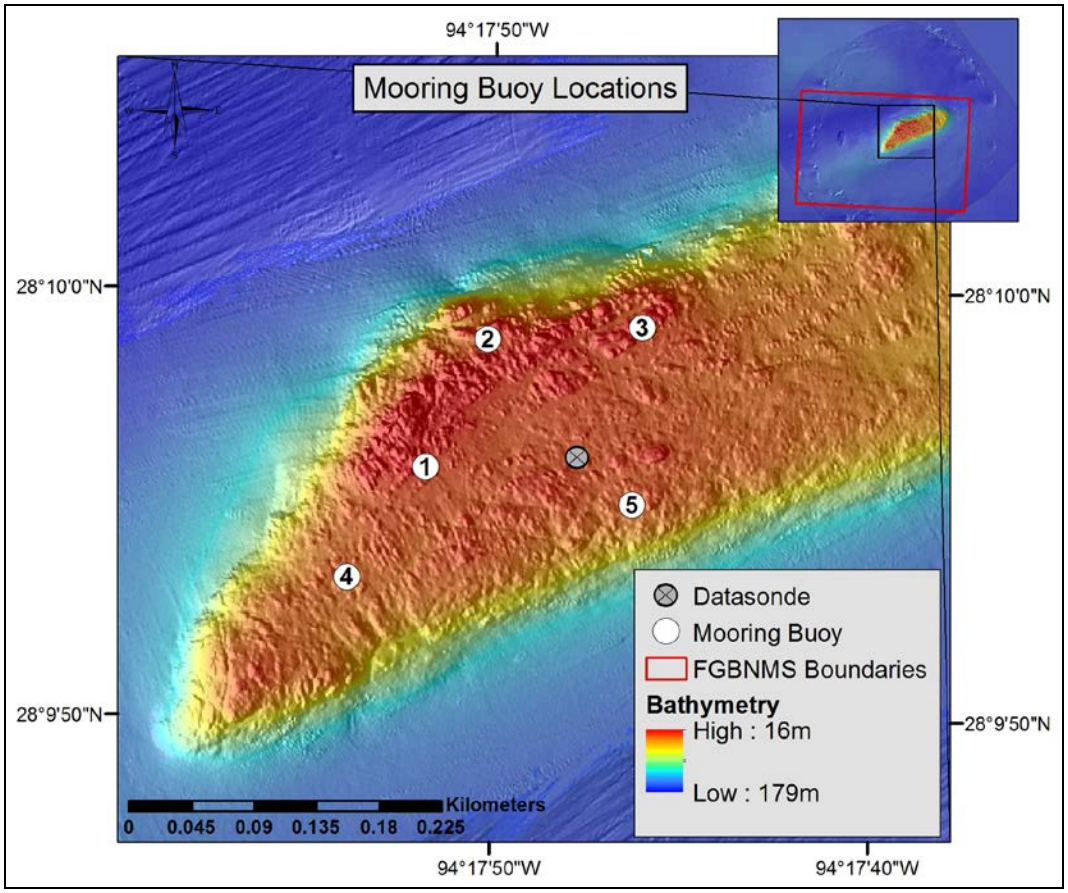


Figure 1.1. Bathymetric map of Stetson Bank showing mooring buoy locations.

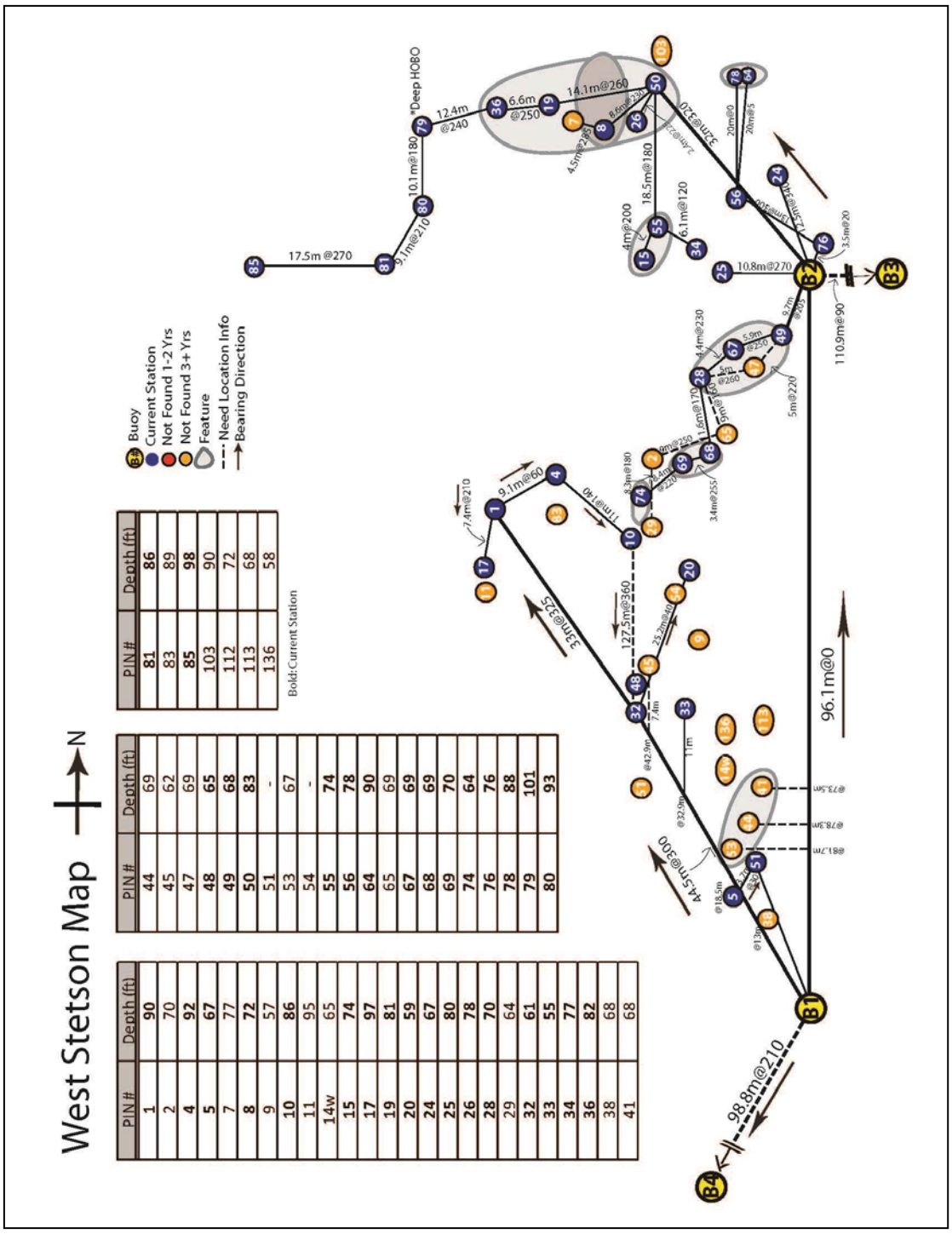
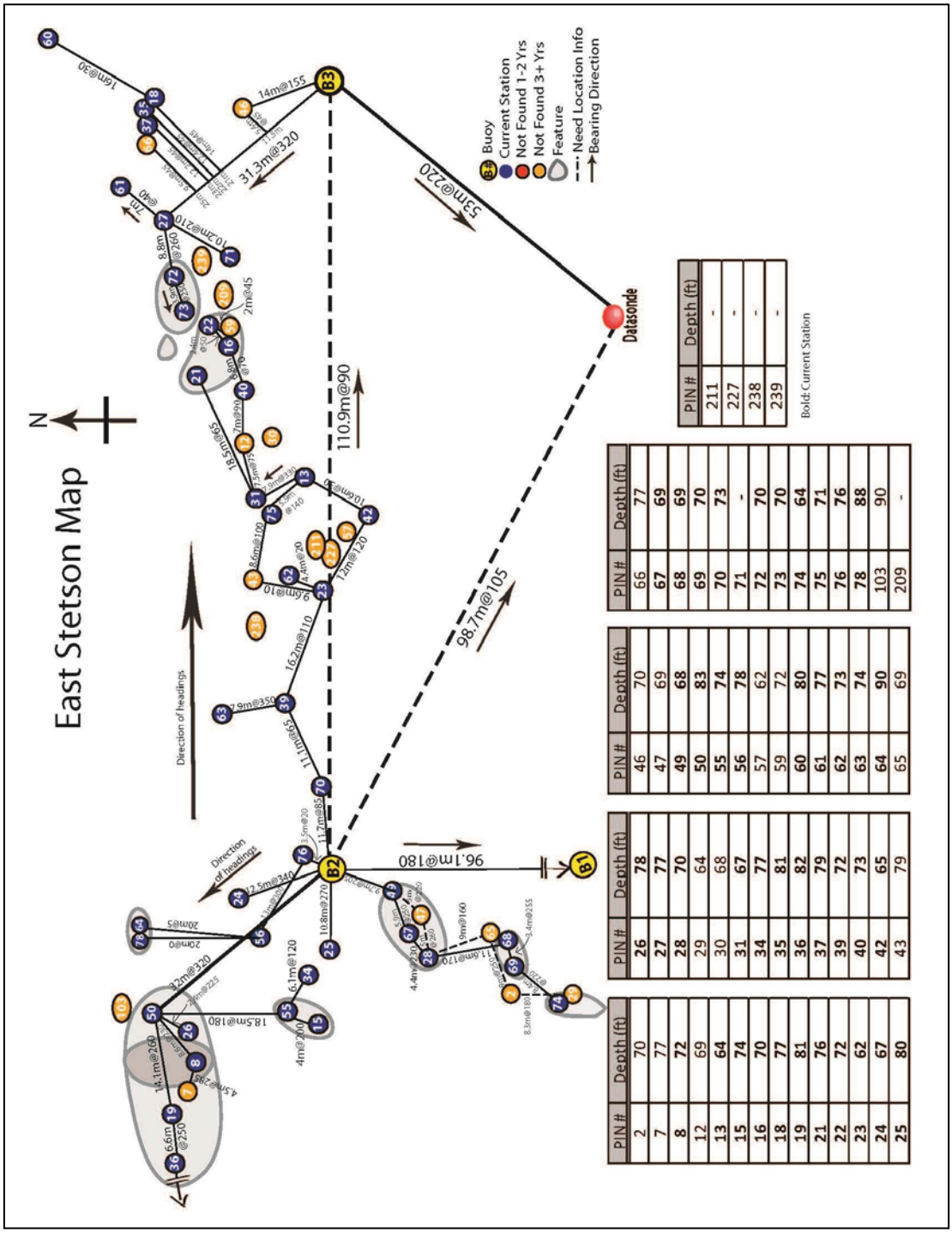


Figure 1.2. West Stetson map, used by divers to locate the repetitive photostations in the study site.



PIN #	Depth (ft)
2	70
7	77
8	72
12	69
13	64
15	74
16	70
18	77
19	81
21	76
22	72
23	62
24	67
25	80

PIN #	Depth (ft)
26	78
27	77
28	70
29	64
30	68
31	67
34	77
35	81
36	82
37	79
39	72
40	73
42	65
43	79

PIN #	Depth (ft)
46	70
47	69
49	68
50	83
55	74
56	78
57	62
59	72
60	80
61	77
62	73
63	74
64	90
65	69

PIN #	Depth (ft)
66	77
67	69
68	69
69	70
70	73
71	-
72	70
73	70
74	64
75	71
76	76
78	88
103	90
209	-

PIN #	Depth (ft)
211	-
227	-
238	-
239	-

Figure 1.3. East Stetson map, used by divers to locate the repetitive photostations in the study site.

Methods

Field Methods

Repetitive photostations were located and marked, using weighted floating chains, by SCUBA divers. Divers then photographed each station. In 2015, images were captured using a Canon Power Shot® G11 digital camera in a G11 Fisheye FIX® housing with a wide-angle dome port. The camera was mounted to a T-frame, set at 1.5 m from the substrate, with two Inon® Z240 strobes set 1.2 m apart (Figure 1.4). A compass and bubble level were mounted to the center of the T-frame and images taken in a vertical and northward orientation to standardize the area captured. Images were corrected as necessary in Adobe Photoshop® CS2 and cropped using a template from previous years, to maintain 1.6 m^2 coverage.

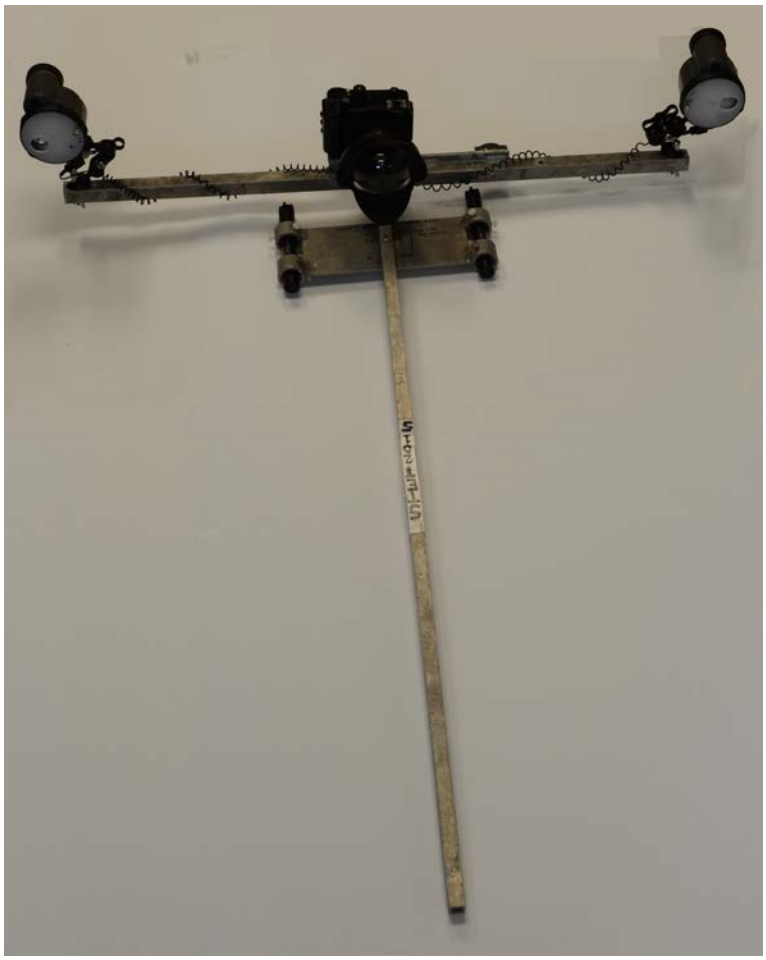


Figure 1.4. T-frame configuration. G11 Fisheye FIX® housing mounted to the frame, set at 1.5 m from the substrate, with two Inon® Z240 strobes, set 1.2 m apart.

Data Processing

Percent cover in each image was analyzed using Coral Point Count® with Excel® extensions (CPCe), provided by the National Coral Reef Institute (Kohler and Gill 2006). Thirty spatially random points were distributed on each image, and benthic species lying under these points were identified. Microsoft® Excel® spreadsheets were created automatically in the program using customized coral code files pertinent to the species in the region.

Organisms positioned beneath each random dot were identified as follows: corals, sponges, and macroalgae were identified to lowest possible taxonomic group (macroalgae included algae longer than approximately 3 mm and included thick algal turfs); and crustose coralline algae, fine turfs, and bare rock were combined into a group denoted as "CTB" (Aronson and Precht 2000). Other live components (ascidians, fish, serpulids, etc.), sand, rubble, and unknown species were recorded in an additional category, "other." The coverage of coral bleaching, paling, fish biting, disease, and other anomalies was recorded as Notes. Summary data were grouped into five functional categories: coral, sponge, macroalgae, CTB, and other.

Qualitative comparisons were made for each photostation from the previous year, when available. Comparisons included notes on the loss, reduction, expansion, or gain of coral and sponge colonies and changes in their general condition.

Results

A total of 59 repetitive photostations were located and photographed, eight of which required refurbishment and two of which were remapped. No new stations were installed in 2015. However, three old stations were found. Depth of the stations ranged from 30.8 – 16.8 m, with an average station depth of 23.0 m.

Overall, coral cover was 5.5% (± 1.5 SE), sponge cover was 14.0% (± 1.3 SE), macroalgae cover was 27.9% (±2.2 SE), and CTB cover was 48.5%. (± 2.8 SE), and other cover was 4.1% (± 0.6 SE) (Figure 1.5). Average species richness at each station was 7.9 (± 0.2 SE).

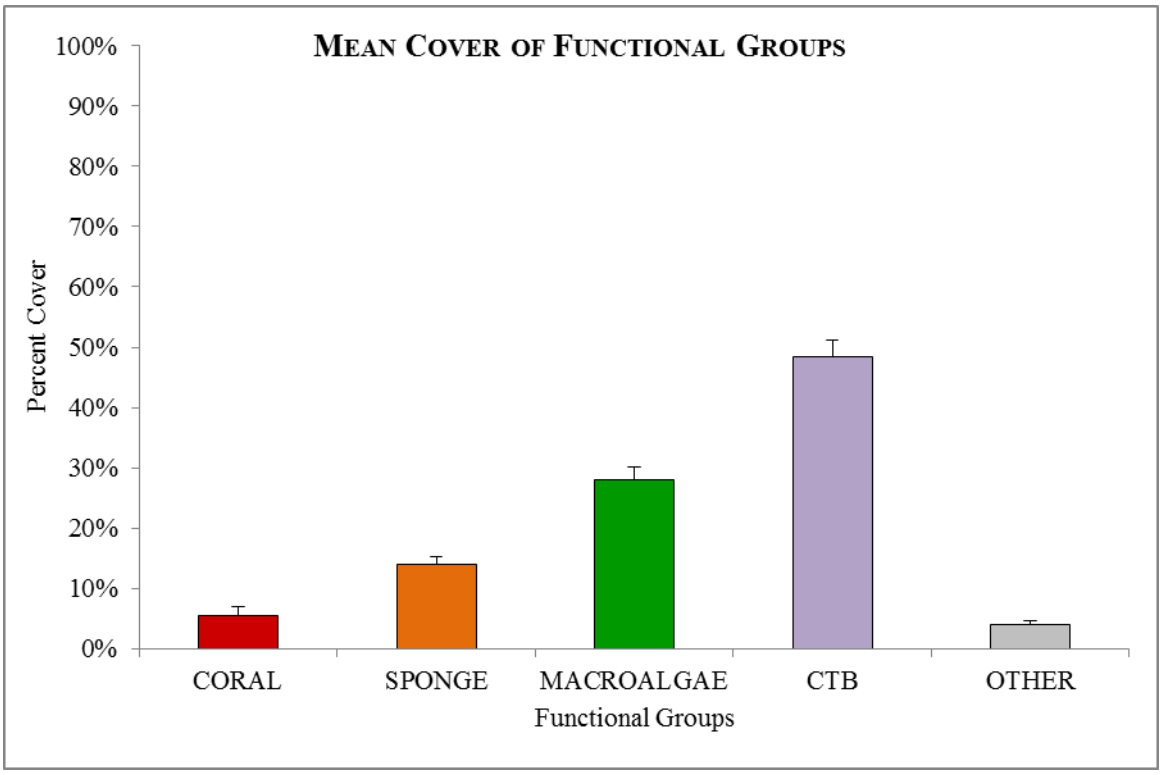


Figure 1.5. Mean functional group percent cover (with standard error bars).

Of the four species of coral observed, *Madracis decactis* was the dominant species (2.5% ± 1.1 SE), in the repetitive photostations (Figure 1.6).

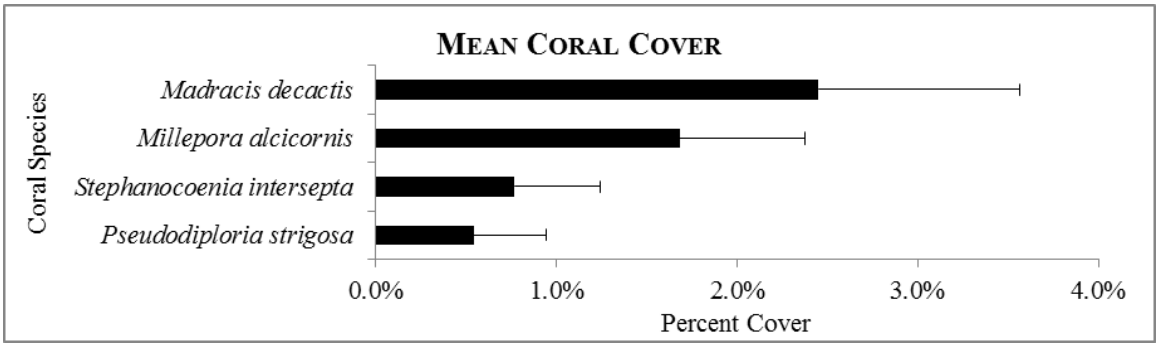


Figure 1.6. Mean coral cover of the observed coral species (with standard error bars).

Twelve species of sponge and encrusting sponge were observed, with *Ircinia strobilina* as the dominant species at 6.6% (± 1.0 SE) cover (Figure 1.7), in the repetitive photostations.

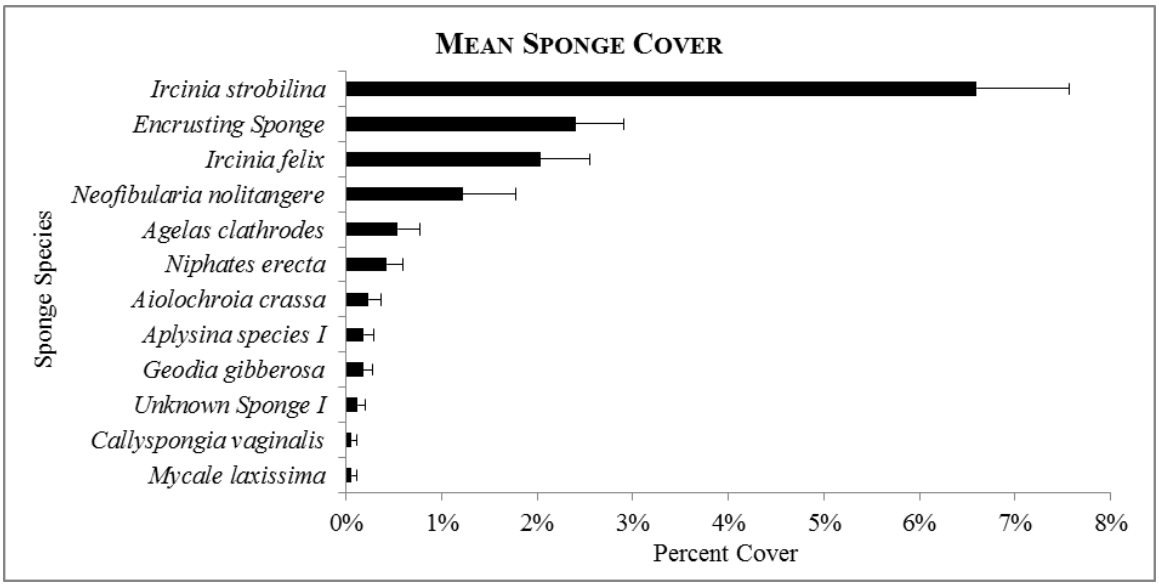


Figure 1.7. Mean sponge cover of the observed sponge species (with standard error bars).

Qualitative comparisons of stations from 2014 noted an overall reduction in macroalgae, particularly *Dictyota* species. Wasting of multiple colonies of *I. strobilina* and *Ircinia felix* was also observed. One colony of *Montastraea cavernosa* that exhibited paling in 2014 was noted to have recovered.

Discussion

Percent cover of each functional group varied between years (Figure 1.8). Macroalgae cover has been in decline from a high in 2012 of 72.5% (± 2.30 SE) to a low of 27.9% (± 2.22 SE) in 2015. As macroalgae cover has declined, CTB cover has increased as more substrate is exposed. However, algal cover can rapidly fluctuate in a short time frame and causality for macroalgae decline and subsequent CTB increase in 2015 was not apparent.

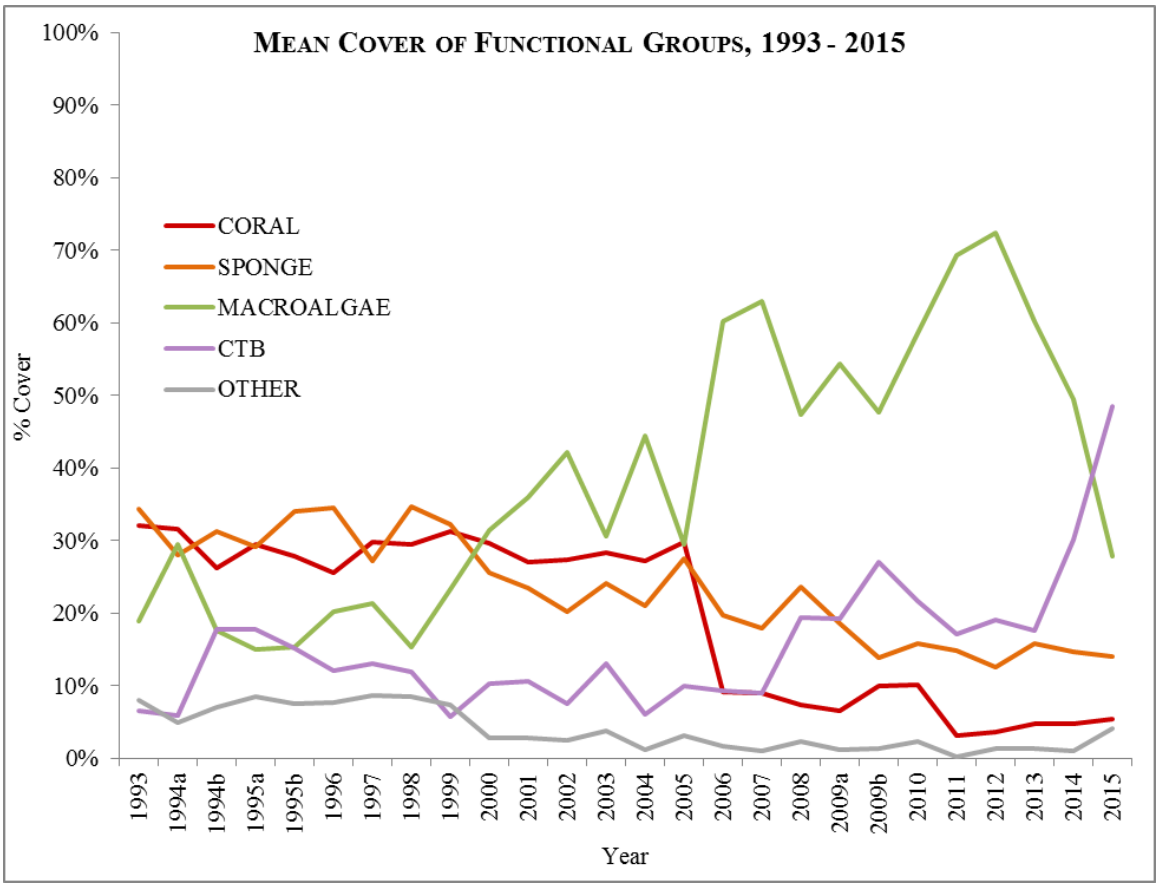


Figure 1.8. Mean percent cover of each functional group from 1993 - 2015.

In 2015, the dominant coral species was *M. decactis* and the dominant sponge species was *I. strobilina*. It should be noted that the repetitive photostations do not provide a comprehensive view of the dominant species on the reef, as stations are selectively placed on diverse habitat (see Chapter 1 Methods for details on site selection).

Qualitative comparisons indicate that a reduction in macroalgae led to an increase in exposed substrate in 2015. The minor decline in sponge cover may be due to death and subsequent wasting of *I. strobilina* and *I. felix*. Coral communities appear stable in recent years, and potentially resilient, with the recovery of one paling colony, from 2014, of a bleaching susceptible species, *M. cavernosa*.

Challenges and Resolutions

- Due to decreased algae cover in recent years, three additional historical stations where found. One of these stations, #45, was lost for seven years following hurricane disturbance in 2008. However, due to the extensive time frame between when these stations were lost and found, two sites were unidentifiable.
    - Sites will continue to be identified as UnkA and UnkB.

2. RANDOM TRANSECTS

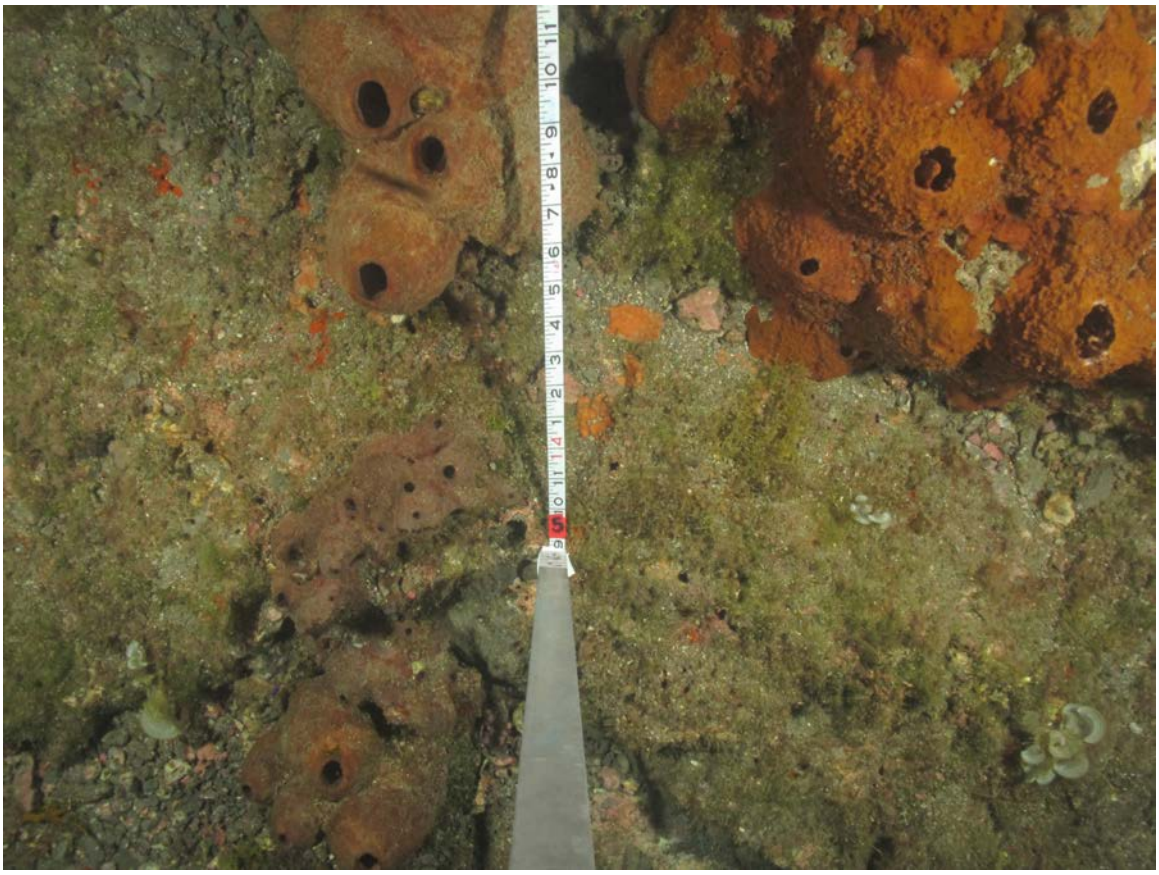


Photo: John Embesi/FGBNMS

Random transect image with sponge and macroalgae.

Introduction

To estimate the areal coverage of benthic components such as corals, sponges, and macroalgae, transect tapes were positioned at stratified random locations within known high relief and low relief habitat on Stetson Bank. These transects were conducted at random locations around the reef and used to compare habitat types and provide information on the sessile benthic community of the entire bank.

Methods

Field Methods

Transect sites were selected in a stratified random design (Figure 2.1) within low relief and high relief habitat on Stetson Bank. Habitat was defined using 1 m^2 resolution bathymetric data. Range was calculated from the bathymetry data using the focal statistics tool in ArcGIS® (5 m x 5 m rectangular window calculating range). This layer was reclassified to define low relief habitat, referenced to as flat habitat henceforth, (<1 m range) and high relief habitat (>1.1 m range). A 33.5 m contour was used to restrict the extent of the range layer, limiting survey to within non-decompression diving limits. Area was calculated for each habitat type in ArcGIS® to distribute transect start points equally by area. Total area available for conducting surveys was 0.12 km^2: 0.08 km^2 flat habitat and 0.04 km^2 high relief habitat. Thirty surveys were distributed among habitat types: 20 in flat habitat and 10 in high relief habitat. Points, representing the start location of transects, were generated using the ArcGIS® random point tool with a minimum of 40 m between sites (Figure 2.1). To reduce the time required to complete these surveys, two, non-overlapping, transects were completed at each random point. The first transect began at the drop site, running along a randomly assigned heading. To arrive at the starting location of the second transect, divers followed a randomly assigned heading and distance (via a randomly assigned number of kick cycles, from 15 – 40 kicks, to ensure transects did not overlap) from the end of the first transect, then laid the transect tape along a randomly assigned heading. Surveyors were instructed to remain within the assigned habitat type. Where this was not possible, habitat type encountered was recorded and noted in the database.

Each transect was designed to capture 8 m^2 of benthic habitat. A still camera, mounted on a 0.65 m T-frame with bubble level and strobes, was used to capture non-overlapping images of the reef. Each image captured approximately 0.8 x 0.6 m (0.48 m^2), requiring 17 images to obtain the desired coverage (8.16 m^2). Spooled, fiberglass, 15 m measuring tapes, with 17 pre-marked intervals (every 0.8 m) were used to provide guides for the camera T-frame, providing a 0.2 m buffer between each image to prevent overlap. A Canon Power Shot® G11 digital camera, in an Ikelite® housing, with a 28 mm equivalent wet mount lens adaptor and two Inon® Z240 strobes set 1.2 m apart on the T-frame, were used.

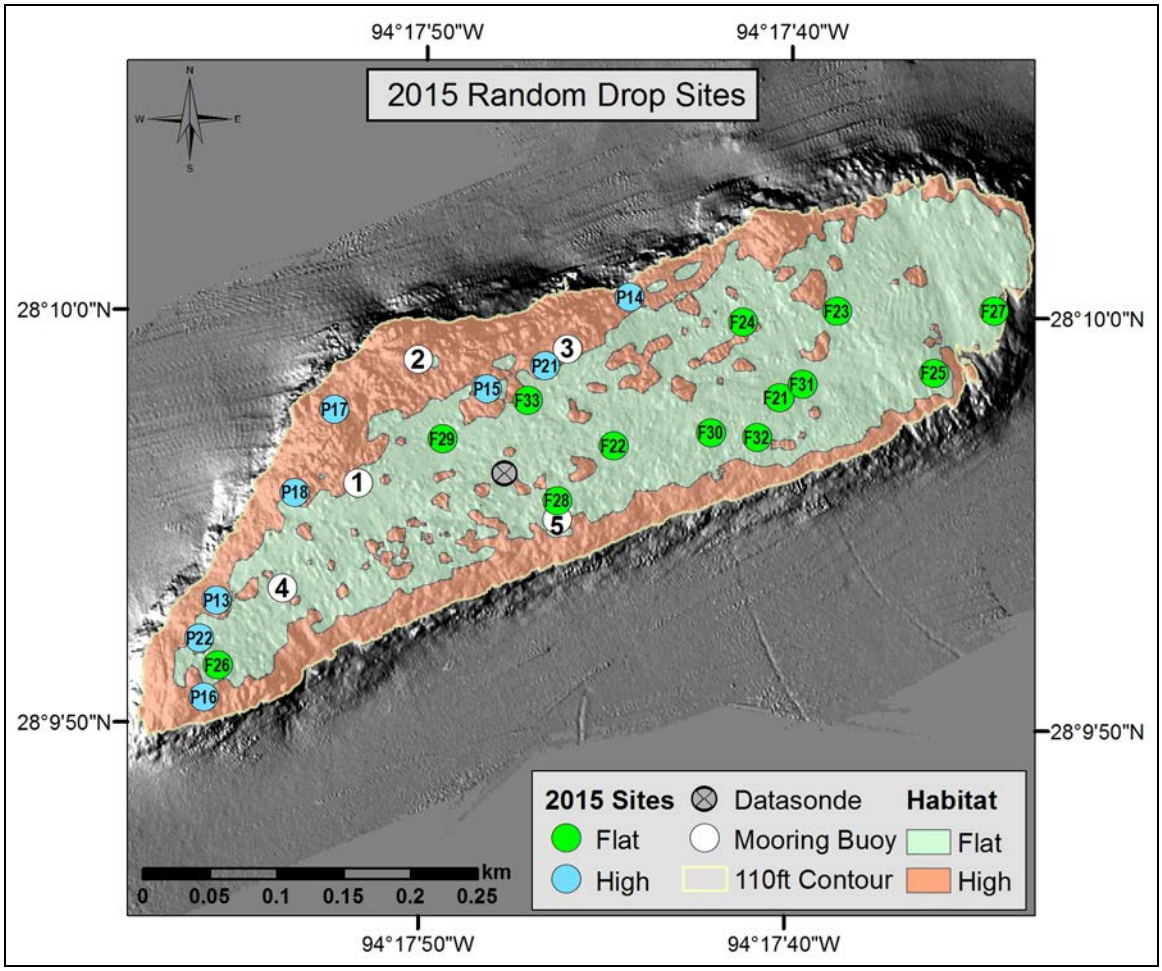


Figure 2.1. Location of random drop sites. Two random transects were conducted at each site.

Data Processing

Percent cover was analyzed using CPCe®. A total of 500 points were randomly overlaid on each transect. Points were equally distributed between the photos that comprised each transect. Identifications and data summaries were made in the same manner described in Chapter 1.

Each transect represented one sample, and resulting percent cover data for each sample were averaged between drop sites and imported into ArcMap®. Surveys were projected over a hillshade map of Stetson Bank with a shapefile delineating flat and high relief habitat. Attribute tables for each survey where populated with percent benthic cover data for each functional group and projected as pie charts using ArcGIS® symbology.

Results

A total of 39 random transects were conducted during this study period. Following the removal of three unusable transects (images were too dark or silted), 36 transects were

processed; 22 in flat habitat and 14 in high relief habitat. The depth of the stations ranged from 22.9 – 32.0 m.

Cover on transects in both the flat and high relief habitat was dominated by both macroalgae (thick turfs and fleshy macroalgal species) and CTB. Coral cover was low in both habitats. However, both mean coral and sponge cover were greater in high relief habitat than in flat habitat.

In flat habitat, coral cover was 0.6% (± 0.1 SE), sponge cover was 10.4% (± 1.3 SE), macroalgae cover was 35.1% (± 2.3 SE), and CTB cover was 38.4%. (± 2.2 SE). Cover that was not defined in those four categories was grouped as 'Other' and had 15.4% (± 1.6 SE) cover. In high relief habitat, coral cover was 2.1% (± 0.9 SE), sponge cover was 12.5% (± 2.2 SE), macroalgae cover was 35.6% (± 2.4 SE), and CTB cover was 38.4%. (± 2.6 SE), and other cover was 11.3% (± 1.4 SE) (Figure 2.2). In flat habitat, average species richness was 13 (± 0.5 SE), and in high relief habitat, average species richness was 14 (± 0.5 SE).

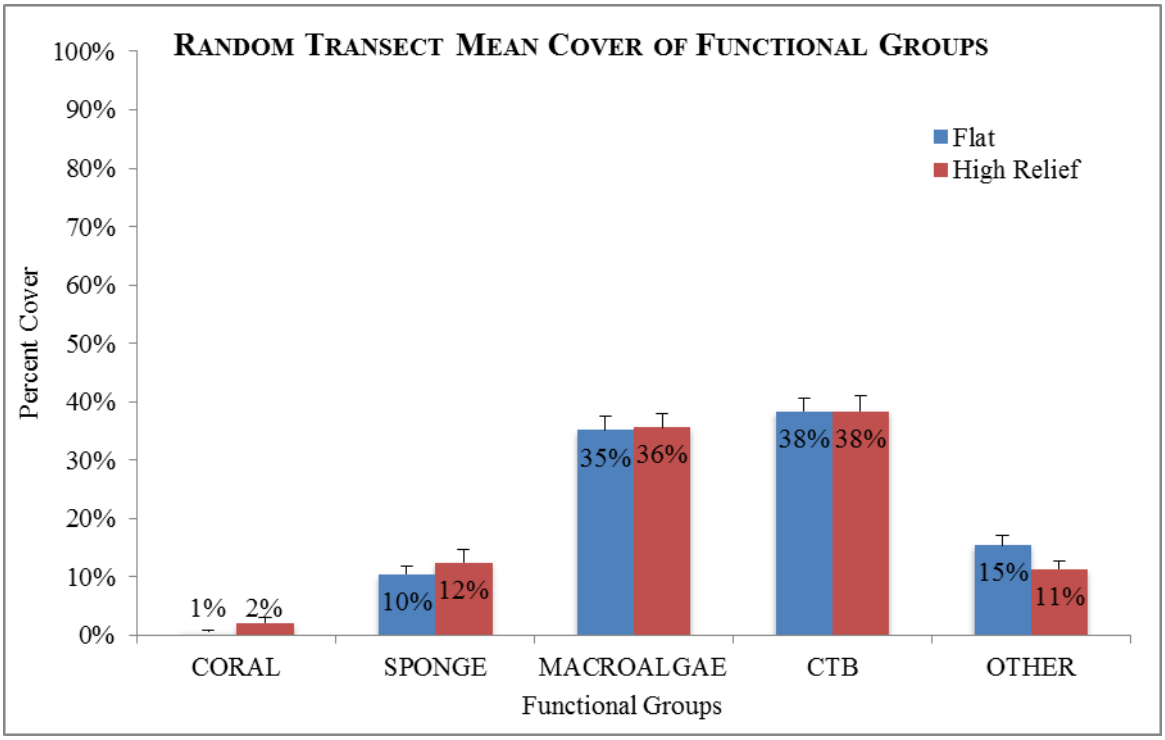


Figure 2.2. Random transect functional group percent cover (with standard error bars).

Six species of coral were observed in the surveys, combined. In flat habitat, *Stephanocoenia intersepta* and *Siderastrea radians* had the greatest cover at 0.19% (± 0.11 SE) and 0.19% (± 0.06 SE), respectively. In high relief habitat, *Millepora alcicornis* had the greatest cover at 1.94% (± 0.87 SE) (Figure 2.3).

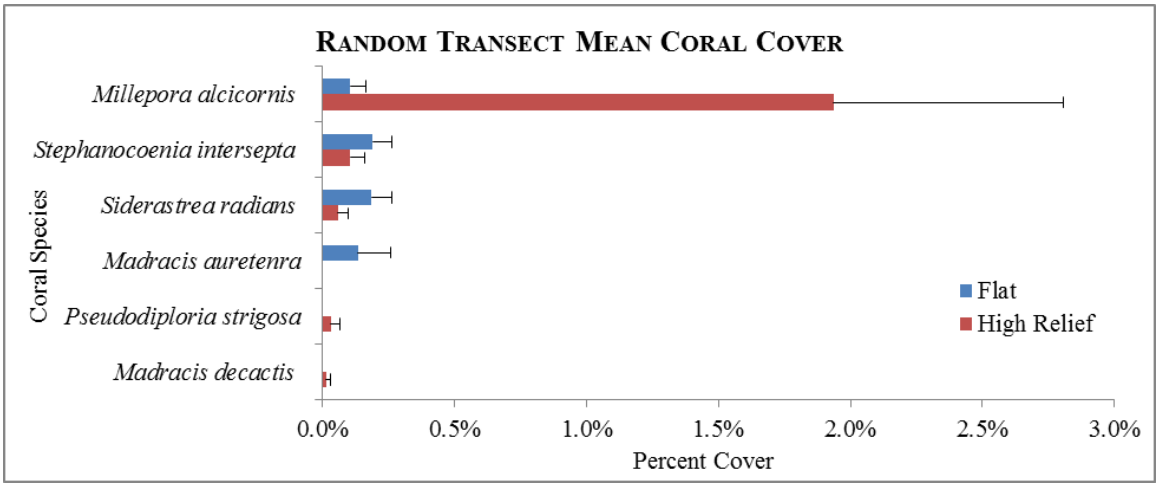


Figure 2.3. Random transect percent cover of each of coral species (with standard error bars).

Eleven species of upright sponge and five species of encrusting sponge were observed in all surveys. In both the flat and high relief habitat, *Neofibularia nolitangere* was the dominant species, comprising 6.4% (± 1.2 SE) of total benthic cover in the flat habitat and 5.7% (± 1.9 SE) in the high relief habitat (Figure 2.4).

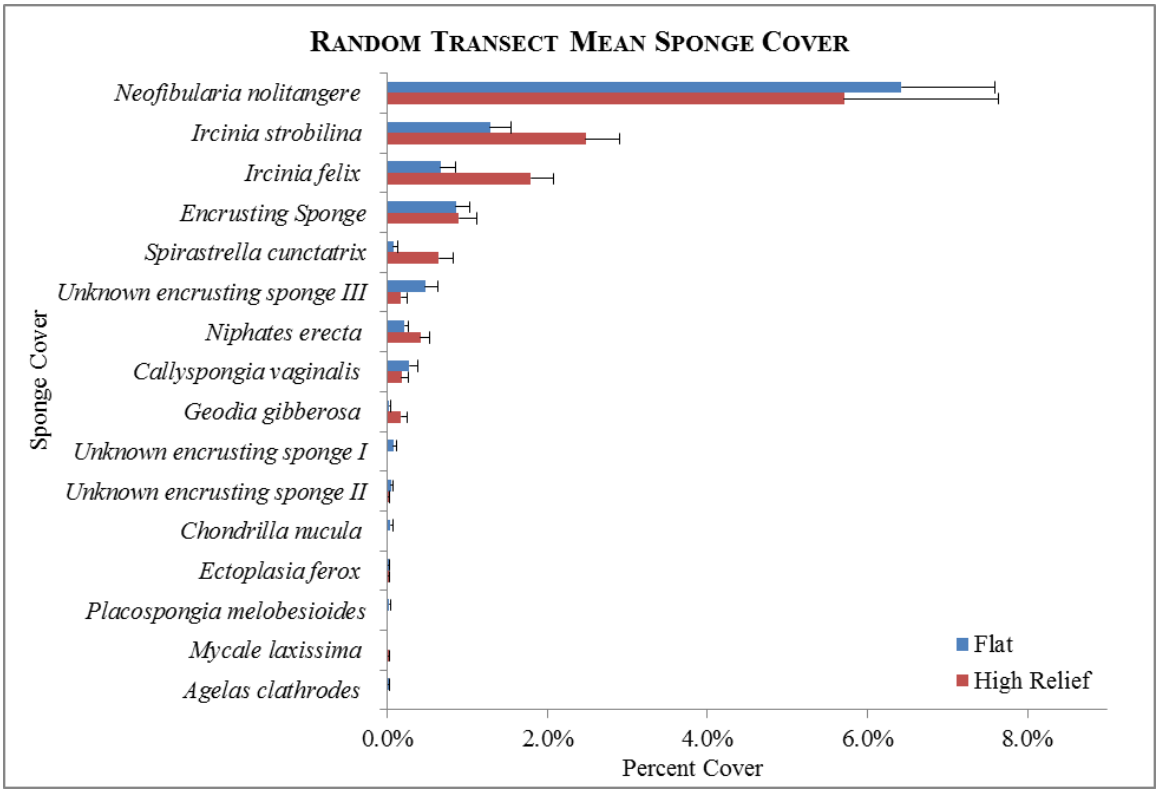


Figure 2.4. Random transect percent cover of each sponge species (with standard error bars).

When percent cover data were projected spatially, no additional trends in benthic cover were observed (Figure 2.5).

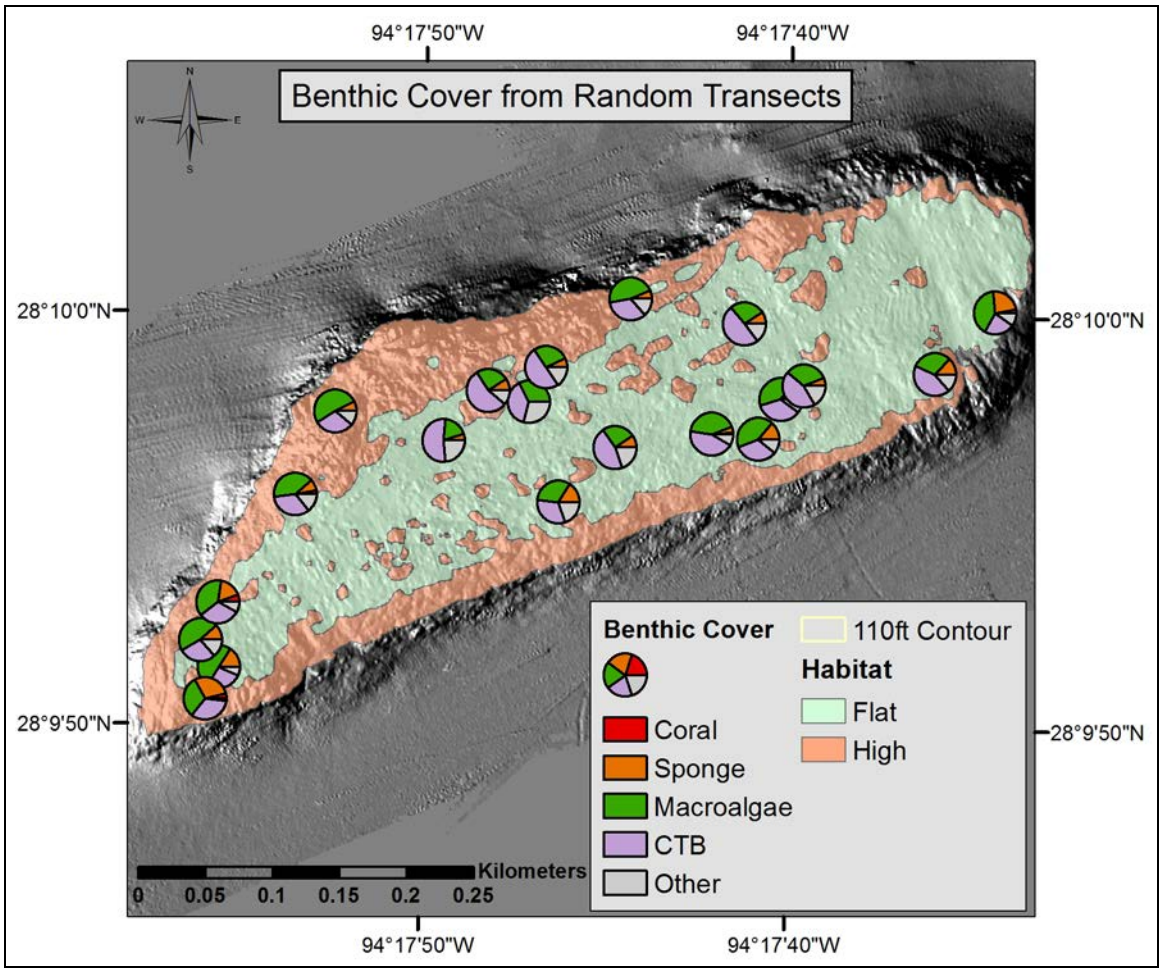


Figure 2.5. Spatial projection of random transect study results. Each pie chart represents the location at which a survey was conducted and the proportion of percent cover represented by each functional group.

Discussion

Randomly selected transect surveys, appropriately distributed between habitat types, allows for inferences to be made about the reef as a whole. While the repetitive photostations discussed in Chapter 1 provide a valuable extensive long-term dataset, they cannot be used to represent the entire benthic community due to the biased original selection criteria of those sites.

Macroalgae cover is a highly dynamic component of the ecosystem, documented to vary in relation to eutrophication, upwelling, nutrient availability, seasonally, and in relation to the grazer community composition in other reef habitats (Bonaldo and Bellwood 2011;

Diaz-Pulido and Garzon-Ferreira 1997; Diaz-Pulido and Garzon-Ferreira 2002; Naim 1993). Due to the high variability of this component of the benthic community, care should be taken when interpreting changes in cover, and monitoring efforts should attempt to evaluate these variables. While not typical in all reef systems, variations in macroalgae cover at Stetson Bank were often inversely proportional to changes in cover of the CTB category, effecting little or no significant change in cover of corals and sponges. This trend has also been observed in the long-term monitoring study by Johnston et al. (*In Press*) at East and West Flower Garden Banks.

While overall coral cover was low in both flat and high relief habitats, in comparison to other Caribbean reefs (Jackson et al. 2014), different species represented the dominant coral in each habitat. The dominant coral species in flat habitat was *S. intersepta* and *S. radians*, whereas high relief habitat, where coral cover is slightly greater, was dominated by the ahermatypic hydrozoan *M. alcicornis* and the scleractinian *S. intersepta*. While sponge cover was marginally lower in flat habitat, in both habitats the dominant sponge species was *N. nolitangere*, contributing to approximately 6% of benthic cover in both habitats. All of these observations were distinctly different from the observations from repetitive photostations, where *M. decactis* and *I. strobilina* were the dominant coral and sponge species, respectively.

Challenges and Resolutions

- During data collection dives, divers had trouble with selecting camera settings to provide sufficient lighting for images. This was corrected as subsequent dives were conducted.
    - Identify standardized camera settings that can be changed as conditions warrant. In addition, provide divers unfamiliar with the camera equipment time to use the camera, in water, before data collection begins.
- Random transect P22-2 conducted on high relief site P22 was identified to be flat habitat by divers.
    - Transect reclassified to flat habitat for data processing.

3. FISH SURVEYS

Photo: Ryan Eckert/FGBNMS

Atlantic Creolefish, *Paranthias furcifer*, in high abundance, schooling at Stetson Bank.

Introduction

To examine fish population composition and changes over time, modified Bohnsack-Bannerot (1986) stationary visual fish censuses were conducted originating from permanent mooring buoys and in conjunction with random transects. Surveys were conducted near permanent mooring buoys used to access the repetitive photostations (Buoy 1, 2, and 3) and at stratified random locations in both flat and high relief habitat on the reef. These surveys were used to characterize fish assemblages.

Methods

Field Methods

Fishes were visually assessed by SCUBA divers using a modified Bohnsack and Bannerot (1986) stationary visual fish census technique. Observations of fishes were restricted to an imaginary cylinder with a radius of 7.5 m, extending to the surface. All fish species observed within the first five minutes of the survey were recorded as the diver slowly rotated in place. Immediately following this five-minute observation period, one rotation was conducted for each species noted in the original five-minute period to record abundance (number of individuals per species) and fork length (within size bins). Size was binned into eight groups; 0 – 5 cm, 5.1 – 10 cm, 10.1 – 15 cm, 15.1 – 20 cm, 20.1 – 25 cm, 25.1 – 30 cm, 30.1 – 35 cm, and >35.1 cm, where each individuals size was recorded. Each survey required 15 minutes to complete. Transitory or schooling species were counted and measured at the time the individuals moved through the cylinder during the initial five-minute period. Surveys began in the early morning (after 0700), and were repeated throughout the day until dusk. Each survey represented one sample.

Fish Surveys Around Buoys

A minimum of twelve buoy surveys were conducted within approximately 50 m of mooring buoys #1, #2, and #3, with four surveys originating from each permanent mooring buoy (Figure 3.1). Mooring buoys were selectively located in flat habitat, near high relief habitat. Starting locations for these surveys was determined by the use of a random heading, from the mooring, of 0° – 360°, and a random number of kick cycles, from 0 – 40 kicks, to arrive at the survey start location. It was estimated that 40 kick cycles moves the diver approximately 50 m, with no current. A third number was generated to provide a random heading, from 0° – 360°, along which the tape was laid to mark the 7.5 m radius of the survey. In 2015, survey metadata included estimated habitat relief breakdowns. Surveys where any of the area was represented by relief >1 m were considered high relief and all other surveys were considered to have occurred in flat habitat.

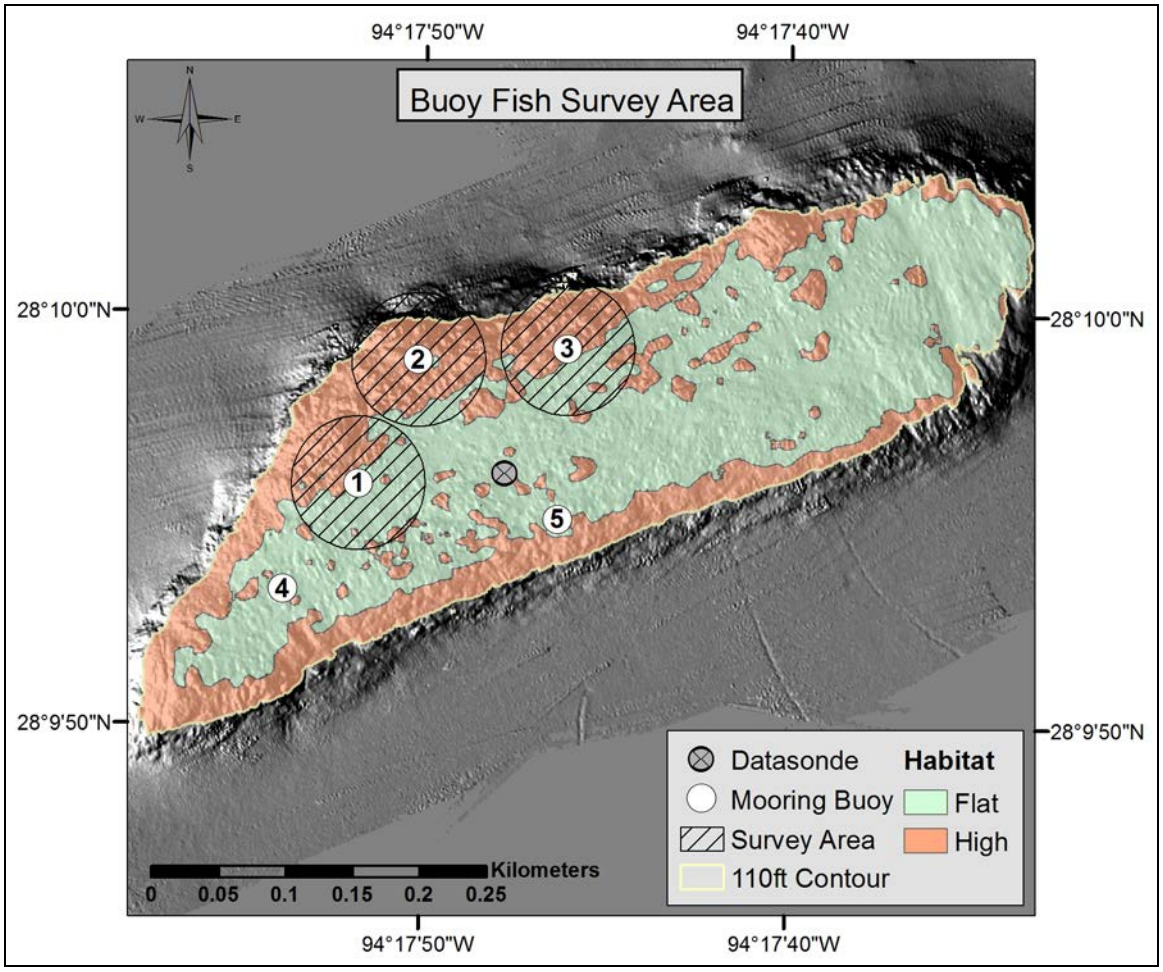


Figure 3.1. Potential survey area of the buoy fish surveys.

Stratified Random Fish Surveys

These surveys were conducted in conjunction with random transects; where the survey start location was selected using a stratified random sampling design (see Chapter 2 Methods). A minimum of fifteen surveys are conducted annually: ten in flat habitat and five in high relief habitat. In 2015, 21 fish surveys were conducted: 13 in flat and eight in high relief habitat.

Data Processing

Fish survey data were entered into a Microsoft® Excel database by the surveyor. Entered data were checked for quality and accuracy prior to processing. For each entry, family, trophic guild, and biomass were recorded. Species were classified by primary trophic guilds; herbivores (H), piscivores (P), invertivores (I), and planktivores (PL), based on information provided from FishBase (Froese and Pauly 2016).

Observations of manta rays, sting rays, and sharks were removed from all biomass analyses due to their rare nature and large size.

Statistical Analyses

Sighting frequency for each species was expressed as the percentage of surveys in which a species was recorded. From this, ranks of the top 10 most frequently sighted species were obtained for each habitat type.

Fish densities are expressed as the number of fish per 100 m², where densities were calculated by dividing the number of individuals per survey by the horizontal area of the survey cylinder (176.7 m²), then multiplying by 100 to provide density per 100 m².

Biomass was computed using the allometric length-weight conversion formula (Bohnsack and Harper 1988) based on information provided by FishBase (Froese and Pauly 2016). Fish biomass was expressed as grams per 100 m².

Relative abundance is the number of individuals of one species divided by the total number of individuals of all species observed and multiplied by 100 to obtain a percentage. Size frequency, using relative abundance, was calculated for each trophic guild and presented as bar graphs.

Based on species abundance and biomass, dominance plots (k-dominance or ABC curves) were generated using PRIMER®. W-values (difference between the abundance curve and biomass curve) were calculated for each survey (Clarke 1990). This value can range between -1 and 1, where w=1 indicates that the population is dominated by a few large species, and w=-1 indicates that the population is dominated by many small species.

Density (individuals/100 m^2) and biomass (g/100 m^2) data from geo-referenced stratified random fish surveys were imported into ArcMap, and projected as pie charts as described in Chapter 2 Methods.

Results

A total of 18 fish surveys were conducted from the permanent mooring buoys, five of which were in flat habitat, and 13 of which were in high relief habitat. In conjunction with random transects, a total of 21 fish surveys were conducted, 13 of which were in flat habitat, and eight of which were in high relief habitat. Total species richness from all surveys was 80, and total family richness from all surveys was 29. Average species richness per survey was 20 (± 0.8 SE), and average family richness per survey was 12 (± 0.3 SE), with the species richness similar between high relief and flat habitats (19.0 ± 0.9 SE and 21.8 ± 1.2 SE, respectively).

Sighting Frequency and Occurrence

Overall, Sharpnose Puffer (*Canthigaster rostrata*) had the highest sighting frequency of all species. Slight variations were observed in the sighting frequency of the top 10 most

frequently sighted species between habitat types (Table 3.1; Figure 3.2). However, the most frequently observed species for each habitat, and overall, was represented by the same species.

Table 3.1. Sighting frequency of the 10 most observed species. Bold text indicates species that were among the 10 most frequently seen species in all habitat types.

(Family Name: Species Name (Common Name - Trophic Guild) Species ID	Sighting Frequency (%)		
	All	Flat	High Relief
Tetraodontidae: *Canthigaster rostrata* (Sharpnose Puffer-I)	100.0	100.0	100.0
Pomacentridae: *Stegastes variabilis* (Cocoa Damselfish-H)	97.4	100.0	95.2
Blenniidae: *Parablennius marmoreus* (Seaweed Blenny-I)	94.9	94.4	95.2
Labridae: *Thalassoma bifasciatum* (Bluehead-I)	94.9	88.9	100.0
Acanthuridae: *Acanthurus chirurgus* (Doctorfish-H)	92.3	83.3	100.0
Pomacentridae: *Stegastes partitus* (Bicolor Damselfish-H)	92.3	100.0	85.7
Tetraodontidae: *Sphoeroides spengleri* (Bandtail Puffer-I)	76.9	83.3	71.4
Pomacanthidae: *Pomacanthus paru* (French Angelfish-I)	74.4	77.8	71.4
Chaenopsidae: *Emblemaria pandionis* (Sailfin Blenny-PL)	69.2	55.6	81.0
Blenniidae: *Ophioblennius macclurei* (Redlip Blenny-H)	66.7	77.8	57.1
Chaetodontidae: *Chaetodon sedentarius* (Reef Butterflyfish-I)	61.5	83.3	42.9

Photo: G.P. Schmahl/FGBNMS

Figure 3.2. Sharpnose Puffer (*C. rostrata*). This species was the most frequently sighted fish over all habitat types.

In this report, species were considered “rare” if they were recorded in less than 20% of all surveys, while “prevalent” species were recorded in ≥20% of surveys (Zimmer et al. 2010). Overall, a total of 47 species were characterized as “rare,” while 33 species were characterized as “prevalent.” Most shark and ray species are considered ‘rare’ (occur in

<20% of all surveys) throughout the Caribbean (REEF 2014), and, although divers observed them while completing other tasks, none were recorded in surveys at Stetson Bank during this study period.

Density

Average fish density was greatest in flat habitats, with 274 individuals per 100m^2 (± 33.5 SE). High relief habitat density was 168 individuals per 100m^2 (± 25.0 SE).

When averaged by habitat type, some similarities were observed between the densest species populations in each habitat type (Table 3.2). In all habitat types, Bluehead (*Thalassoma bifasciatum*) had the greatest average density.

Table 3.2. Average density (individuals/100m^2) of the 10 densest species. Grouped by habitat type, ± standard error, where bold text indicates species that were among the 10 densest species in all habitat types and dashes indicate that the species was not observed in that habitat type.

(Family Name: Species Name (Common Name - Trophic Guild) Species ID	Density (Individuals/100m^2)		
	All	Flat	High Relief
Labridae: *Thalassoma bifasciatum* (Bluehead-I)	63.1 ± 10.0	71.0 ± 15.5	56.3 ± 13.2
Blenniidae: *Parablennius marmoreus* (Seaweed Blenny-I)	35.7 ± 5.9	45.3 ± 10.0	27.5 ± 6.4
Pomacentridae: *Chromis multilineata* (Brown Chromis-I)	31.5 ± 8.3	50.6 ± 14.9	15.1 ± 7.2
Pomacentridae: *Stegastes variabilis* (Cocoa Damselfish-H)	20.0 ± 2.3	19.0 ± 3.8	20.8 ± 2.8
Tetraodontidae: *Canthigaster rostrata* (Sharpnose Puffer-I)	7.2 ± 0.5	7.2 ± 0.7	7.1 ± 0.6
Pomacentridae: *Stegastes partitus* (Bicolor Damselfish-H)	6.6 ± 1.1	10.3 ± 1.9	3.4 ± 0.6
Acanthuridae: *Acanthurus chirurgus* (Doctorfish-H)	6.0 ± 1.1	5.8 ± 1.7	6.2 ± 1.5
Labridae: *Clepticus parrae* (Creole Wrasse-PL)	5.5 ± 3.7	11.2 ± 7.8	0.6 ± 0.5
Epinephelidae: *Paranthias furcifer* (Atlantic Creolefish-PL)	3.7 ± 2.1	8.1 ± 4.5	0.0 ± 0.0
Blenniidae: *Ophioblennius macclurei* (Redlip Blenny-H)	3.4 ± 0.9	5.8 ± 1.7	1.4 ± 0.4
Chaenopsidae: *Emblemaria pandionis* (Sailfin Blenny-PL)	3.3 ± 0.6	2.5 ± 0.9	4.0 ± 0.9
Pomacentridae: *Chromis enchrysura* (Yellowtail Reeffish-I)	2.4 ± 0.7	0.7 ± 0.5	4.0 ± 1.1
Pomacentridae: *Chromis insolata* (Sunshinefish-PL)	2.0 ± 0.5	1.2 ± 0.4	2.6 ± 0.8

Biomass

Average biomass across all surveys was 8633.0 g/100m^2 (± 2401.9 SE). Flat habitat possessed the greatest average biomass, with 12251.5 g/100m^2 (± 4203.8 SE). High relief habitat had 5533.0 g/100m^2 (± 2538.7 SE).

When averaged by habitat type, some similarities were observed between the species contributing the greatest biomass in each habitat type. Table 3.3 shows the 10 species contributing the most to observed biomass in each habitat, and overall. In flat habitat, Creolefish (*Paranthias furcifer*) had the greatest average biomass, with 4088.6 g/100m^2 (± 2367.0 SE). In high relief habitat, Crevalle Jack (*Caranx hippos*) had the greatest average biomass, with 4035.3 g/100m^2 (± 1537.2 SE).

Table 3.3. Average biomass of the top 10 species. Grouped by by habitat type, ± standard error, where bold text indicates species that were among the 10 densest species in all habitat types and dashes indicate that the species was not observed in that habitat type.

(Family Name: Species Name (Common Name - Trophic Guild)	Biomass (g/100m^2)		
Species ID	All	Flat	High Relief
Sphyraenidae: *Sphyraena barracuda* (Great Barracuda-P)	1366.4 ± 671.6	2925.7 ± 1252.9	1907.2 ± 635.2
Epinephelidae: *Paranthias furcifer* (Atlantic Creolefish-PL)	1362.9 ± 1101.8	4088.6 ± 2367.0	0.0 ± 0.0
Lutjanidae: *Lutjanus griseus* (Gray Snapper-I)	1291.1 ± 482.0	2729.2 ± 906.7	1822.9 ± 429.1
Carangidae: *Caranx hippos* (Crevalle Jack-P)	1031.0 ± 834.9	609.7 ± 307.6	4035.3 ± 1537.2
Pomacanthidae: *Pomacanthus paru* (French Angelfish-I)	777.2 ± 139.0	852.2 ± 215.7	825.5 ± 182.1
Acanthuridae: *Acanthurus chirurgus* (Doctorfish-H)	776.1 ± 225.6	1242.1 ± 451.8	907.7 ± 168.1
Kyphosidae: *Kyphosus saltatrix/incisor* (Chub (Bermuda/Yellow)-H)	236.5 ± 133.8	581.0 ± 277.9	41.5 ± 65.0
Mullidae: *Mulloidichthys martinicus* (Yellow goatfish-I)	231.1 ± 231.1	693.4 ± 500.8	0.0 ± 0.0
Pomacanthidae: *Holacanthus bermudensis* (Blue Angelfish-I)	204.1 ± 65.2	266.7 ± 124.1	174.1 ± 61.4
Carangidae: *Alectis ciliaris* (African Pompano-I)	198.4 ± 198.4	595.3 ± 429.9	0.0 ± 0.0
Labridae: *Thalassoma bifasciatum* (Bluehead-I)	58.5 ± 17.5	53.5 ± 15.1	128.4 ± 30.2
Ostraciidae: *Lactophrys triqueter* (smooth trunkfish-I)	62.9 ± 22.2	120.6 ± 40.9	99.0 ± 21.6
Pomacanthidae: *Holacanthus ciliaris* (Queen Angelfish-I)	97.6 ± 34.0	199.7 ± 62.7	93.4 ± 32.3
Epinephelidae: *Epinephelus adscensionis* (Rock Hind-I)	101.9 ± 23.6	113.6 ± 36.3	85.9 ± 31.7

Trophic Guilds

Species richness within trophic guild was calculated overall and between habitats (Table 3.4). Overall, invertivores possessed the greatest species richness, with 42 species and 20 families comprising the guild, and planktivores possessed the lowest species richness,

with nine species and seven families comprising the guild overall. This trend was also observed when surveys were analyzed by habitat type.

Table 3.4. Species and family richness by trophic group. Grouped by habitat type and overall, where the number in parenthesis represents family richness.

Trophic Guild	All	Flat	High Relief
Herbivore	17 (6)	13 (6)	16 (6)
Planktivore	9 (7)	9 (7)	7 (5)
Invertivore	42 (20)	37 (19)	33 (17)
Piscivore	12 (7)	9 (5)	8 (6)

Density and biomass were calculated for each trophic guild and averaged across survey and habitat type, then converted to percent contribution (Table 3.5). Invertivores contributed most to overall density, at 72.2% and piscivores contributed the least, at 0.6%. This trend was observed in all habitat types. Additionally, for all surveys combined, invertivores contributed the greatest biomass while herbivores contributed the least (39.9% and 13.4%, respectively). A similar pattern was observed in flat habitat. In high relief habitat, biomass was dominated by piscivores and the lowest contributor to biomass was planktivores.

Table 3.5. Percent composition of trophic guild to density and biomass.

Trophic Guild	Density (% Contribution)			Biomass (% Contribution)		
	All	Flat	High Relief	All	Flat	High Relief
Herbivore	19.0	21.5	18.1	13.4	12.9	14.4
Planktivore	8.2	8.7	8.0	15.9	24.2	0.3
Invertivore	72.2	69.2	73.2	39.9	40.2	39.1
Piscivore	0.6	0.6	0.6	30.8	22.7	46.2

The three species contributing the most to observed density (Table 3.6) and biomass (Table 3.7) within each habitat type and from each trophic guild were calculated.

Table 3.6. Percent contribution of density of the top three species by trophic guild. Grouped by habitat type, where bold text indicates species that were among the three densest species in all habitat types

Trophic Guild	(Family Name: Species Name (Common Name - Trophic Guild) Species ID	Density (Individuals/100m^2)		
		All	Flat	High Relief
H	**Pomacentridae: *Stegastes variabilis* (Cocoa Damselfish-H)**	48.5	39.6	58.8
	Acanthuridae: *Acanthurus chirurgus* (Doctorfish-H)	14.6	12.1	17.4
	Pomacentridae: *Stegastes partitus* (Bicolor Damselfish-H)	16.1	21.5	9.7
I	**Labridae: *Thalassoma bifasciatum* (Bluehead-I)**	40.3	35.9	46.4
	Blenniidae: *Parablennius marmoreus* (Seaweed Blenny-I)	22.8	22.9	22.6
	Pomacentridae: *Chromis multilineata* (Brown Chromis-I)	20.1	25.6	12.4
P	**Sphyraenidae: *Sphyraena barracuda* (Great Barracuda-P)**	28.0	37.3	11.8
	Carangidae: *Caranx ruber* (Bar Jack-P)	24.7	16.9	38.2
	Carangidae: *Caranx bartholomaei* (Yellow Jack-P)	7.5	11.9	0.0
	Epinephelidae: *Mycteroperca phenax* (Scamp-P)	8.6	6.8	11.8
	Carangidae: *Caranx hippos* (Crevalle Jack-P)	7.5	3.4	14.7
PL	Labridae: *Clepticus parrae* (Creole Wrasse-PL)	30.8	42.7	5.8
	Epinephelidae: *Paranthias furcifer* (Atlantic Creolefish-PL)	20.9	30.9	0.0
	Chaenopsidae: *Emblemaria pandionis* (Sailfin Blenny-PL)	18.6	9.6	37.6
	Pomacentridae: *Chromis insolata* (Sunshinefish-PL)	11.1	4.6	24.7
	Pomacentridae: *Chromis scotti* (Purple Reeffish-PL)	10.8	9.4	13.9

Table 3.7. Percent contribution of biomass of the top three species from each trophic guild. Grouped by habitat type, where bold text indicates species that were among the three densest species in all habitat types

Trophic Guild	(Family Name: Species Name (Common Name - Trophic Guild) Species ID	% Contribution to Trophic Biomass		
		All	Flat	High Relief
H	**Acanthuridae: *Acanthurus chirurgus* (Doctorfish-H)**	67.0	59.8	83.0
	Acanthuridae: *Acanthurus tractus* (Ocean Surgeonfish-H)	4.7	3.6	7.6
	Kyphosidae: *Kyphosus saltatrix/incisor* (Chub (Bermuda/Yellow)-H)	20.4	28.0	3.8
	Labridae: *Sparisoma atomarium* (Greenblotch Parrotfish-H)	4.9	7.0	2.4
I	**Lutjanidae: *Lutjanus griseus* (Gray Snapper-I)**	37.4	43.5	52.9
	Pomacanthidae: *Pomacanthus paru* (French Angelfish-I)	22.5	13.6	23.9
	Pomacanthidae: *Holacanthus bermudensis* (Blue Angelfish-I)	5.9	4.2	5.0
	Mullidae: *Mulloidichthys martinicus* (Yellow goatfish-I)	6.7	11.0	0.0
P	**Sphyraenidae: *Sphyraena barracuda* (Great Barracuda-P)**	51.2	76.5	31.5
	Carangidae: *Caranx hippos* (Crevalle Jack-P)	38.7	16.0	66.6
	Carangidae: *Seriola dumerili* (Greater Amberjack-P)	4.7	0.0	0.0
	Carangidae: *Caranx bartholomaei* (Yellow Jack-P)	2.5	5.3	0.0
	Carangidae: *Caranx ruber* (Bar Jack-P)	1.5	0.1	1.2
PL	Epinephelidae: *Paranthias furcifer* (Atlantic Creolefish-PL)	98.9	99.7	<0.1
	Ptereleotridae: *Ptereleotris helenae* (Hovering Dartfish-PL)	0.4	0.0	40.4
	Chaenopsidae: *Emblemaria pandionis* (Sailfin Blenny-PL)	0.3	<0.1	7.1
	Labridae: *Clepticus parrae* (Creole Wrasse-PL)	0.3	0.3	7.7
	Pomacentridae: *Chromis scotti* (purple reeffish-PL)	0.1	<0.1	8.1
	Pomacentridae: *Chromis cyanea* (Blue Chromis-PL)	<0.1	<0.1	16.4
	Pomacentridae: *Chromis insolata* (Sunshinefish-PL)	<0.1	<0.1	12.5

Size-Frequency

Size frequency, using relative abundance, was calculated for each survey and averaged between habitat types and overall. In all surveys, most individuals were <5 cm, comprising 79.1% of individuals recorded. A similar pattern was found in all habitat types.

Size frequency distributions, using the relative abundance of individuals for each trophic guild, were graphed for each habitat type and overall (Figure 3.3). Within all habitat types, herbivores, invertivores, and planktivores were dominated by smaller individuals, while piscivores were dominated by larger individuals.

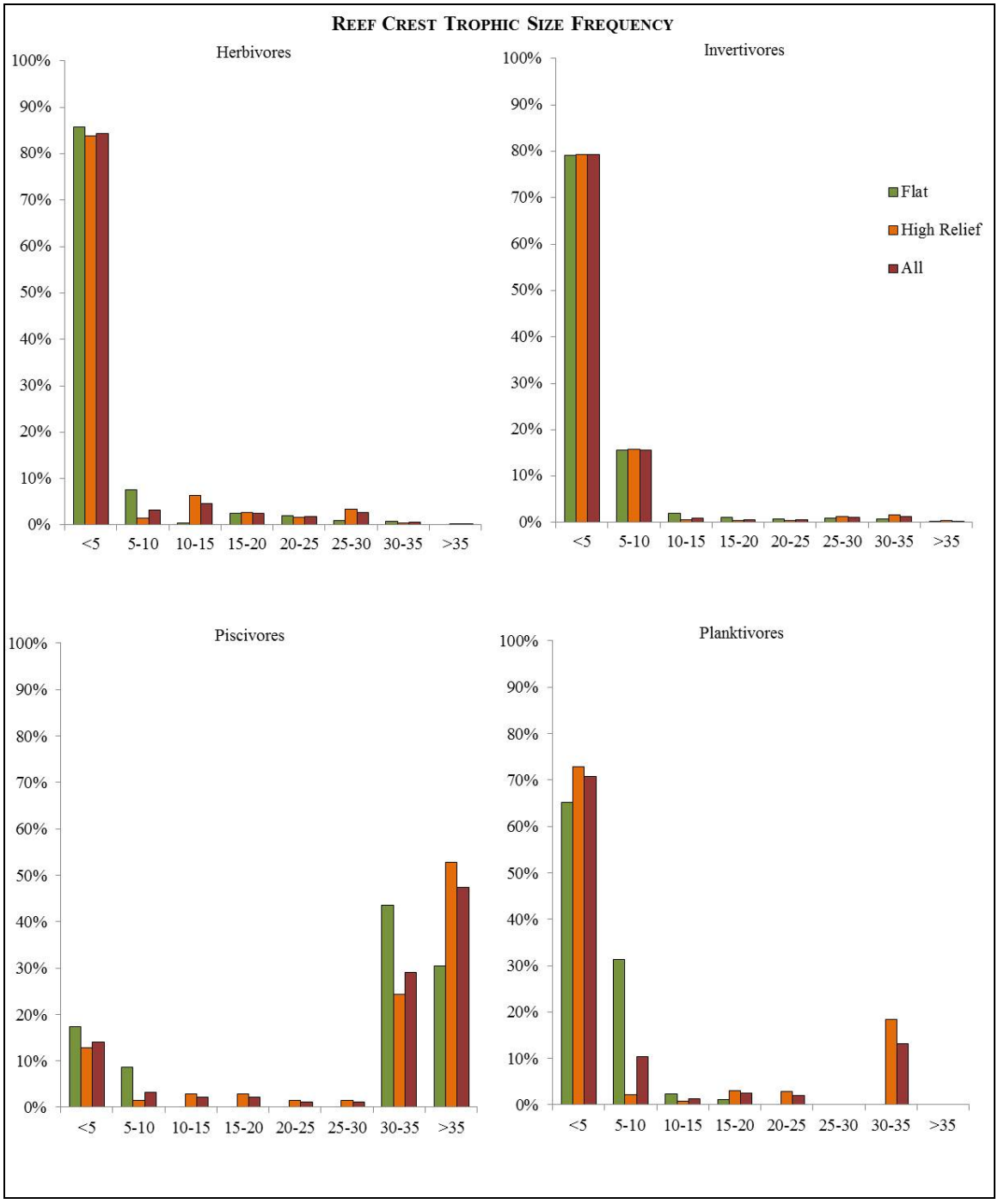


Figure 3.3. Size distribution by trophic guild. Green columns represent flat habitat, orange columns are high relief habitat, and red columns are all surveys.

Dominance Plots

When averaged between all samples, the average dominance plot *w* value was slightly positive, 0.10 (± 0.02 SE) overall. All average values were close to zero within each

habitat type (Table 3.8), indicating that accumulated biomass was evenly distributed between large and small species.

Table 3.8. Averaged dominance plot w values. Values ± standard error, for each habitat type and overall.

Flat	High Relief	All Surveys
0.12 ± 0.03	0.09 ± 0.02	0.10 ± 0.02

Spatial Analysis

When stratified random surveys were projected spatially, additional trends in species distributions were observed (Figure 3.4). During the study period, density of piscivores was low and surveys were dominated in density by invertivores and herbivores.

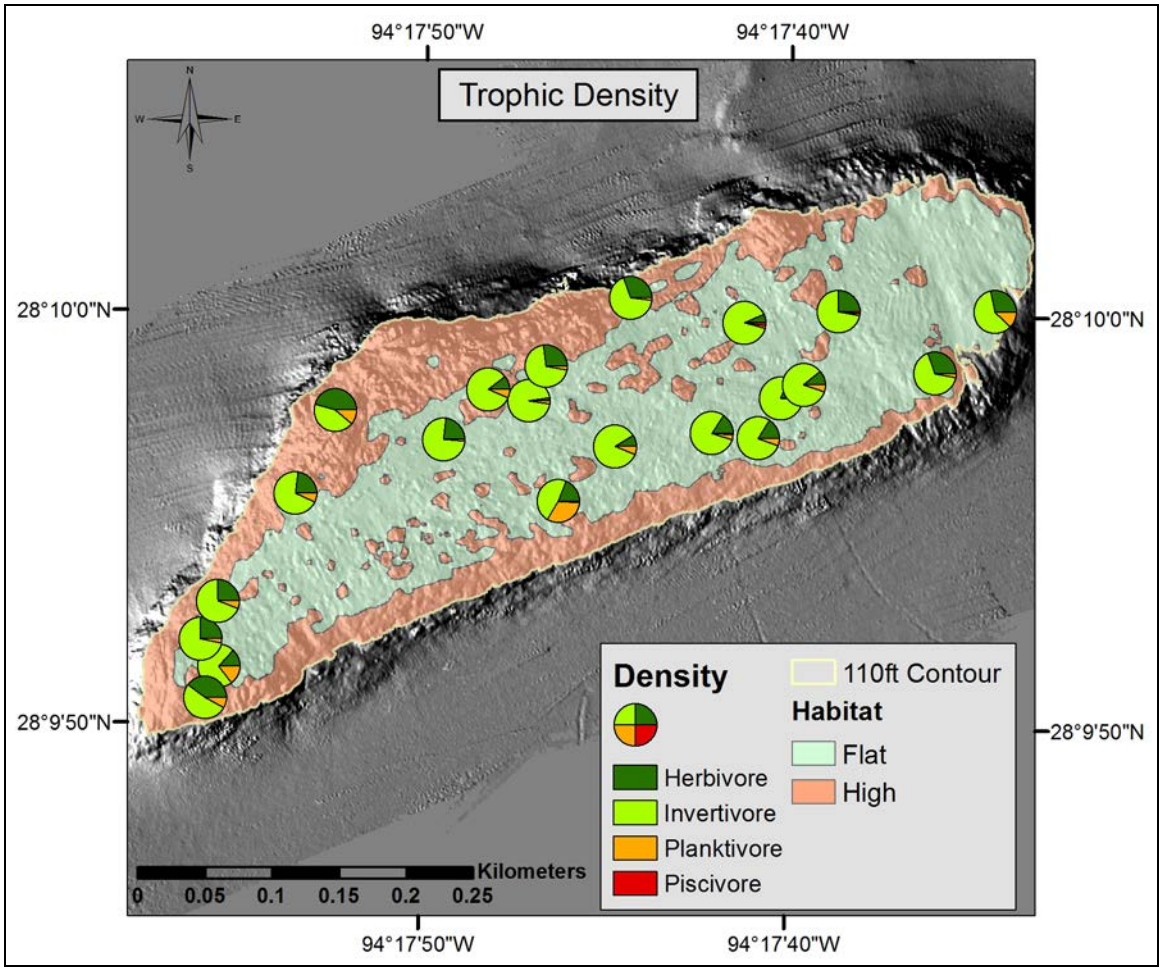


Figure 3.4. Spatial projection of trophic group density. Each pie chart represents the location at which a survey was conducted and the proportion of density represented by each trophic guild.

The biomass of each trophic guild at each survey site was also projected (Figure 3.5). During the study period, overall biomass of piscivores was greater in surveys located on the edges of the bank, where the recorded biomass of Crevalle Jack, Great Barracuda, and Greater Amberjack was variable but large at certain locations. Invertivore biomass was higher in the middle of the bank, where the recorded biomass of angelfish, particularly French Angelfish, was large.

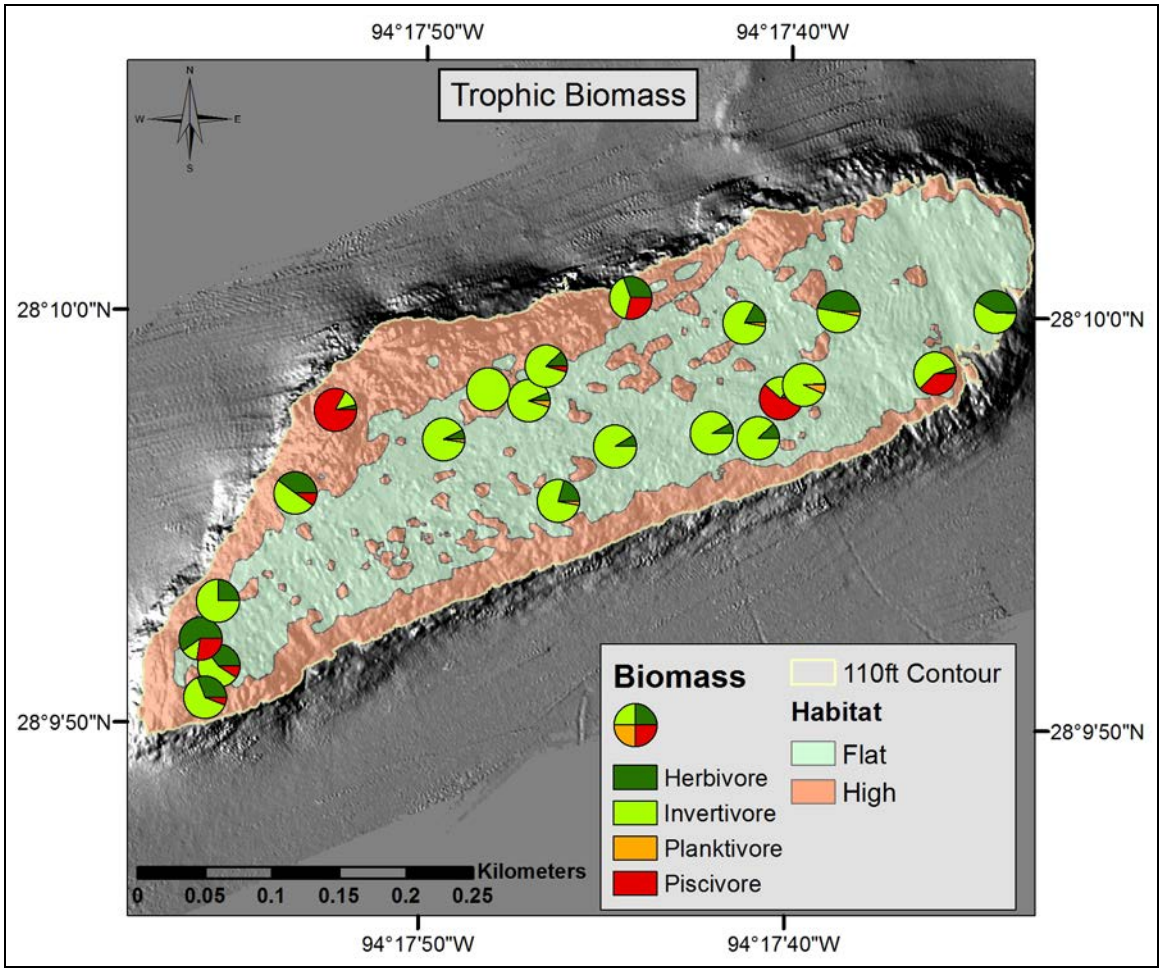


Figure 3.5. Spatial projection of trophic group biomass. Each pie chart represents the location at which a survey was conducted and the proportion of biomass represented by each trophic guild.

Discussion

Fish communities are considered indicators of ecosystem health (Sale 1991) and are therefore an important component to long-term monitoring programs. Monitoring fish community changes over extended periods of time is valuable in detecting changes from normal variations in the community.

Small invertivorous fish dominated density at Stetson Bank. Additionally, the invertivore guild was represented by the most individual species and families, and possessed the greatest overall density and biomass of any trophic guild.

Piscivore biomass was greater than herbivore biomass in high relief habitat. Piscivore dominated biomass indicates that the ecosystem maintains an inverted biomass pyramid, where piscivore dominance is associated with minimal detrimental environmental impacts, particularly from fishing (DeMartini et al. 2008; Friedlander and DeMartini 2002; Knowlton and Jackson 2008; Sandin et al. 2008; Singh et al. 2012). Typically, inverted biomass pyramids are associated with healthy reef systems with high coral cover. However, coral cover at Stetson Bank is low, compared to other Caribbean reefs (Jackson et al. 2014), comprising less than 3% of the benthic cover. Despite the overall lack of coral cover, high relief habitats possess complex habitat, both geological and biological, that provide potential refuges for prey fishes to find shelter from predators, which is nearly absent in flat habitat. The observed inverted biomass pyramid in the high relief habitat is likely due to the availability of refuges, rapid turnover rates of prey items, slow growth rates of predators, and potential food subsidies from the surrounding pelagic environment (DeMartini et al. 2008; Odum and Odum 1971; Wang et al. 2009). The lack of an inverted biomass pyramid in the flat habitat may be attributed to the lack of refuge available for prey items, highlighting the importance of refuge (Hixon and Beets 1993).

The density of reef fish at Stetson Bank was dominated by small individuals (<5cm), which account for 79.1% of all recorded individuals. However, when density and biomass were analyzed, the fish community at Stetson Bank appears to be well balanced between density and biomass, where it is neither dominated by many small individuals nor few large individuals.

Although lionfish have been reported at Stetson Bank by recreational SCUBA divers since 2011, no lionfish observations were recorded in surveys during this study period. The invasion of this exotic species is of particular concern and continued attention to changes in their population is recommended.

Overall, the fish community suggests a variable fish population, comprised of both commercially and recreationally valuable fish species. Additional variation of the fish community at Stetson Bank might be occurring at both the diurnal and seasonal scale. However, continued monitoring of this community is necessary to understand natural variation of the fish community and detect significant changes from the normal variation of the fish assemblage, in addition to documenting potential impacts of invasive species.

Challenges and Resolutions

No problems were encountered in the 2015 field season.

4. SEA URCHIN AND LOBSTER SURVEYS

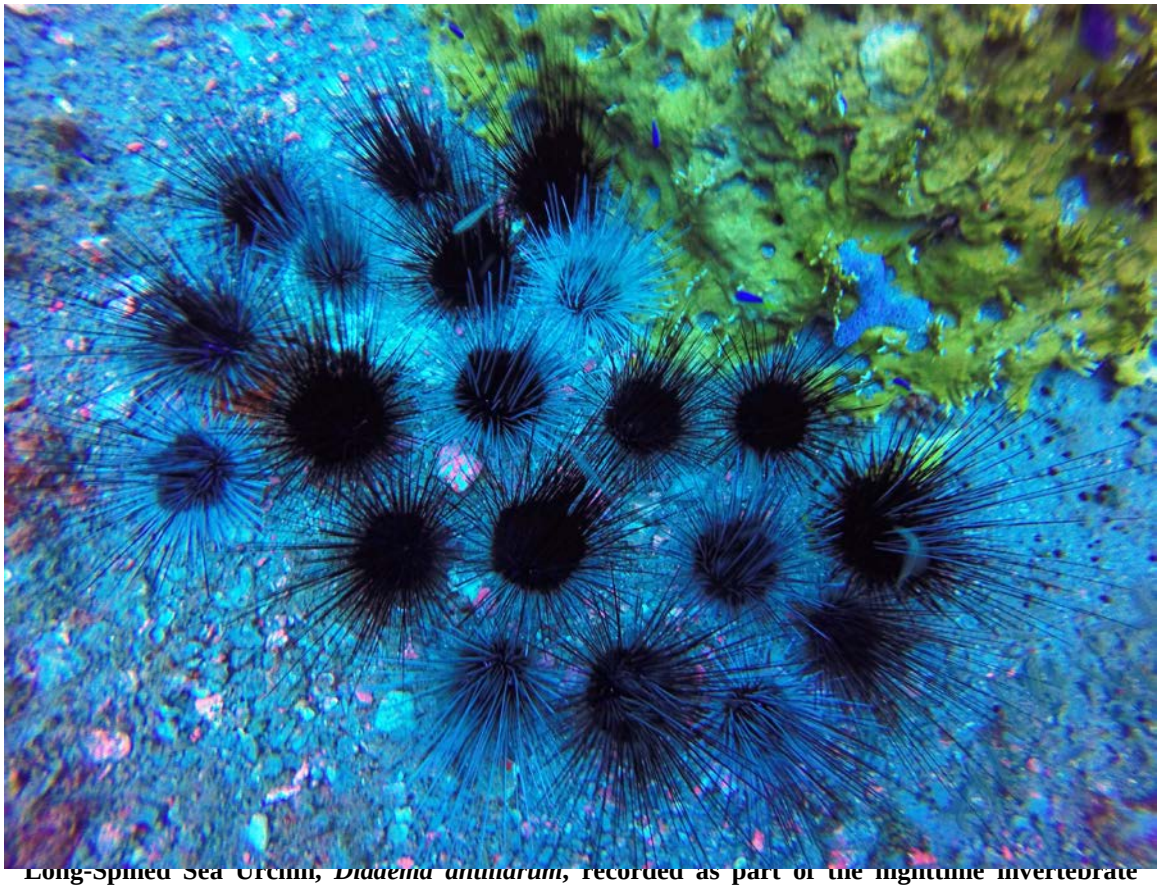


Photo: Wendy Cover/FNMSAS

Long-Spined Sea Urchin, *Diadema antillarum*, recorded as part of the nighttime invertebrate survey.

Introduction

The Long-Spined Sea Urchin, *Diadema antillarum*, was an important herbivore on coral reefs throughout the Caribbean until the mid-1980s. At that time, an unknown pathogen decimated populations throughout the region, including FGBNMS. Since then, irregular limited recovery has been documented in the region (Edmunds and Carpenter 2001). Additionally, commercially important lobster and slipper lobster population dynamics throughout this region are not well understood. The surveys presented here document the abundance of the Long-Spined Sea Urchin and various lobster species at Stetson Bank.

Methods

Field Methods

Due to the nocturnal nature of these species, visual surveys were conducted at night, a minimum of 1.5 hours after sunset. Two belt transects, 2 m wide and 100 m long, were conducted by diver teams on lines between permanent mooring buoys (between buoy #1 – #2 and #2 – #3). One additional belt transect, 2 m wide and 50 m long (between buoy #3 – repetitive photostation 27) was also conducted. In total, 500 m^2 was surveyed. The abundance of Long-Spined Sea Urchin, Caribbean Spiny Lobster (*Panulirus argus*), Spotted Spiny Lobster (*Panulirus guttatus*), and slipper lobster species (Scyllaridae) were noted.

In addition, urchin counts were conducted on both repetitive photostation images and random transect images. The abundance of Long-Spined Sea Urchin at each photostation or transect was recorded. These images were captured throughout the daytime hours.

Data Processing

Density of each species of interest was calculated as number of individuals per m^2, for each survey type. When multiple surveys were conducted along the same transect line, the surveys were averaged for that transect before processing for density.

Results

On night surveys, the average density of Long-Spined Sea Urchins was 0.83 individuals per m^2 (± 0.002 SE) and slipper lobster species was 0.002 individuals per m^2 (± <0.001 SE). No Caribbean Spiny Lobster or Spotted Spiny Lobster were observed in 2015 surveys.

Repetitive photostations, which were selectively placed in high relief habitat with interesting features, had an average density of 2.08 individuals per m^2 (± 0.295 SE). Along random transects, the density of Long-Spined Sea Urchins was higher in high relief habitat where the average density was 1.75 per m^2 (± 0.412 SE), than flat habitat, where the average density was 1.10 individuals per m^2 (± 0.240 SE).

Discussion

Long-Spined Sea Urchin populations at Stetson Bank were different between the survey methods and habitat types. Average density was higher in daytime repetitive photostations and random transects, where abundance was obtained from image analysis. While night surveys attempted to capture abundance while the species were more active, the number of surveys was limited, limiting power of the data analyses. The lower densities observed during night surveys compared to day surveys may be due to the increased urchin activity increasing their spatial distribution and habitat type encountered along the survey lines (while both high relief and flat habitat is surveyed at night, the coverage of each has not been calculated).

Studies have demonstrated that increasing Long-Spined Sea Urchin populations have led to reduced macroalgae cover, increasing coral recruitment (Carpenter and Edmunds 2006). Further, modeling studies suggest that reef systems with urchin densities >1 per m^2, in addition to a robust grazing fish community, are more resilient than reef systems with lower urchin densities (Mumby et al, 2006; Mumby et al. 2007). Following the 1983-1984 die-off, limited recovery of Long-Spined Sea Urchin populations has been seen throughout the Caribbean, with a regional average density of 0.023 per m^2 (Karmer 2003). Studies have documented local densities ranging from 0 – 8.9 per m^2 throughout the Caribbean (Carpenter and Edmunds 2006) and a high of 12 per m^2 at Discovery Bay in Jamaica (Edmunds and Carpenter 2001), while East and West Flower Garden Banks in the Gulf of Mexico have documented average densities from 0 – 0.13 per m^2 (Johnston et al. 2015). Long-Spined Sea Urchin density at Stetson Bank was higher than the regional average for the Caribbean but lower than some observed regional maxima.

Lobster densities have historically been low at Stetson Bank, and continue to show this trend. In 2015, dens inhabited by Caribbean Spiny Lobster around the study area were documented and added to the study area map for potential surveys in the future.

Challenges and Resolutions

No problems were encountered in the 2015 field season.

5. WATER QUALITY

Photo: FGBNMS

Water samples are collected for nutrient analyses from the sampling carousel aboard the R/V MANTA.

Introduction

Several water quality parameters were continually or periodically recorded at Stetson Bank. At minimum, salinity and temperature were recorded every hour by data loggers permanently installed on the crest of Stetson Bank at a depth of 24 m and a temperature logger collected temperature data every hour at 30 m.

Water column profiles recording, at minimum, temperature and salinity were conducted quarterly throughout the year. With these profiles, water samples were collected each quarter and analyzed by a laboratory for select nutrient levels and ocean carbonate measurements.

Methods

Field Methods

Temperature and Salinity Loggers

At 24 m depth, the primary instrument for recording salinity and temperature was a Sea-Bird® Electronics, Inc. MicroCAT® 37 logger. The logger was installed on a large railroad wheel, on a flat surface of the bank crest, in the midsection of the bank. The instrument recorded temperature and salinity hourly throughout the year. Each quarter year, the instrument was exchanged by SCUBA divers for downloading and maintenance. It was immediately exchanged with an identical instrument to avoid any gaps in the data collection. Prior to re-installation, all previous data were removed from the instrument and battery life checked. Maintenance and factory service of each instrument were performed annually.

In October 2015, a Sea-Bird® Electronics, *16plus* V2 CTD was deployed in conjunction with the MicroCAT® 37 logger. After the data were verified as comparable, the MicroCAT® 37 logger was removed in November 2015. The *16plus* V2 CTD is equipped with a WET Labs ECO NTUS turbidity meter, and will record turbidity, hourly.

Onset® Computer Corporation HOBO® Pro v2 U22-001 thermographs were used to record temperature levels on an hourly basis. These instruments provide a highly reliable temperature backup for the primary logging instrument at the 24 m station. In addition, one of these loggers was deployed at a 30 m station to record temperature hourly. In June 2015, an additional logger was installed at 40 m to record temperature hourly. The loggers were also downloaded, maintained and replaced on a quarterly basis. The instruments were either attached directly to the primary instrument at the 24 m station or to eyebolts at the 30 m and 40 m stations. Prior to re-installation, all previous data were removed from the instrument and battery levels were checked.

This chapter presents data from the instruments at Stetson Bank from October 8, 2014 – October 7, 2015.

Water Column Profiles

Water column profiles were collected quarterly in conjunction with water samples. A Sea-Bird® Electronics *19plus* V2 CTD recorded temperature and salinity every ¼ second. Data were recorded following an initial soaking period, on the up cast phase of each deployment, while the CTD was brought to the surface at a rate <1 m/sec.

In September, 2015, the *19plus* V2 CTD was expanded with instruments to record pH, turbidity, fluorescence, and dissolved oxygen (DO). A complete list of these instruments can be found in Table 5.1.

Table 5.1. New sensors added to SBE 19*plus* V2 CTD.

Sensor	Parameter Measured
SBE-18	pH
SBE-43	Dissolved oxygen
WET Labs ECO-FLNTUrtd	Fluorescence and turbidity

Profiles containing only temperature and salinity were collected on February 11th and May 1st, 2015. Profiles containing temperature, salinity, pH, dissolved oxygen, turbidity, and fluorescence, were collected on September 1st, October 8th, and November 4th, 2015.

Water Samples

Water samples were collected each quarter year using a sampling carousel equipped with a Sea-Bird® Electronics *19plus* V2 CTD and six OceanTest® Corporation 2.5 liter Niskin bottles. The carousel was attached to the vessel with a scientific winch cable. The winch cable allows the operator to activate the bottles to sample at specific depths. A total of six samples were collected each quarter. Two 2.5 liter water samples were collected near the seafloor (approximately 20 m depth), mid-water (10 m depth) and near the surface (1 m depth).

Water samples for chlorophyll-*a* analyses were collected in 1000 ml glass containers with no preservatives. Samples for reactive soluble phosphorous were placed in 250 ml bottles with no preservatives. Ammonia, nitrate, nitrite, and total nitrogen samples were collected in 1000 ml bottles with a sulfuric acid preservative. An additional blind duplicate water sample was taken at one of the sampling depths for each sampling period. Within minutes of sampling, labeled sample containers were stored on ice at 4 °C and a chain of custody was initiated for processing at an EPA certified laboratory. The samples were transported and delivered to A&B Laboratories in Houston, TX, within twenty-four hours of being collected. Each sample was analyzed for chlorophyll-*a* and nutrients (ammonia, nitrate, nitrite, phosphorous and total nitrogen). In 2015, water samples were obtained on February 11th, May 1st, September 1st, and November 4th.

Water samples for ocean carbonate measurements were collected following methods requested by the Carbon Cycle Laboratory (CCL) at Texas A&M University – Corpus Christi (TAMU-CC). Samples were collected in Pyrex 250ml borosilicate bottles with polypropylene caps. Two replicates were collected at each depth. Bottles were filled using a 30cm plastic tube that connected from the spout of the Niskin. Bottles were rinsed three times using the sample water, filled carefully to reduce bubble formation, and overflowed by at least 200ml. 100µl of $HgCl_2$ was added to each bottle before inverting vigorously. Samples were then stored at 4°C. Samples and CTD profile data were sent to CCL at TAMU-CC, in Corpus Christi, TX. Samples were obtained on February 11th, May 1st, October 8th, and November 4th.

Data Processing

Temperature and salinity data obtained from loggers were downloaded and processed each quarter. The twenty-four hourly readings obtained each day were averaged into one daily value and recorded in a database. Each calendar day was assigned a value in the database. Separate databases were maintained for each type of logger. For temperature data, a historical average of data from the previous 10 years (2005-2014) was used for comparison. For salinity data, a historical average of data from the previous 5 years (2010-2014) was used for comparison.

Chlorophyll-*a* and nutrient analyses results were obtained quarterly from A&B Laboratories and compiled into an excel table. Ocean carbonate analyses results were compiled and received as an annual report from the CCL at TAMU-CC.

Results

Temperature and Salinity Loggers

Slightly cooler temperatures were observed at the deeper stations year round. Sea-Bird instruments, at the 24 m station, showed the minimum temperature logged during this time frame was 18.8 ºC, recorded on both February 26 and March 23, 2015. The maximum temperature, recorded on September 9, 2015, was 29.8 ºC. At the 30 m station, the minimum temperature logged during this time frame was 18.4 ºC, recorded on April 4, 2015. The maximum temperature, recorded on both September 1st and September 8th, 2015, was 29.4 ºC. The 40 m station was only installed in June, 2015, and is therefore lacking winter temperature data. The maximum temperature, recorded on September 2nd, 2015, was 28.7 ºC.

Based on data from HOBO thermographs, a temperature difference >2.0 ºC was observed between the 24 m and the 30 m station for eight days in May, two in June, one in July, two in August, and one in September, where the deeper station possessed the coldest

temperature. The maximum difference recorded was 2.7 ºC. A temperature difference >2.0 ºC was observed between the 30 m and the 40 m station on two days in June, six in July, 21 in August, 18 in September, and five in October. The maximum difference recorded was 4.8 ºC on September 20th.

Water temperatures at the 24 m station are compared with averages for that station from the past 10 years in Figure 5.1. Temperatures for the current cycle were similar to the 10-year average temperature data from October 2014 through March 2015, however temperatures were then colder than average before rising in mid-April 2015 to warmer than average temperatures through mid-July 2015. The 10-year average record is only available for the 24 m station.

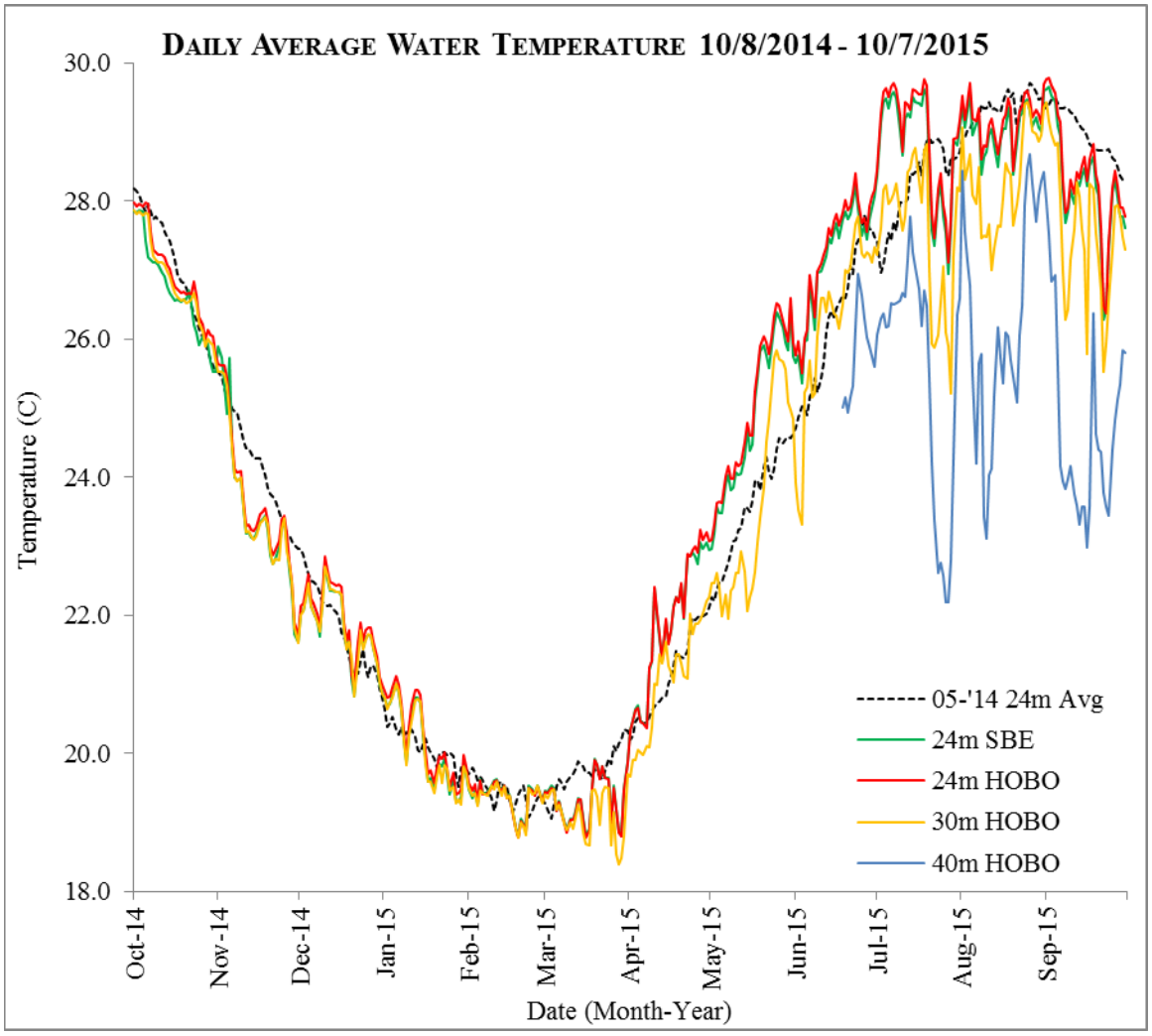


Figure 5.1. Temperature (ºC) at Stetson Bank from 10/8/2014 – 10/7/2015. Black dashed line represents 10-year average temperature.

The minimum salinity level recorded during this time frame was 33.3 psu on July 14, 2015. The maximum salinity level was 36.6 psu on January 17, 2015. Figure 5.2 shows the salinity recorded at the 24 m station and the average salinity observed over the last 5 years at this station. Salinity was similar to average over most of the year, but showed greater fluctuation over the summer months. Lower than average salinity (by a maximum of 2.2 psu) was observed between July 2015 and August 2015.

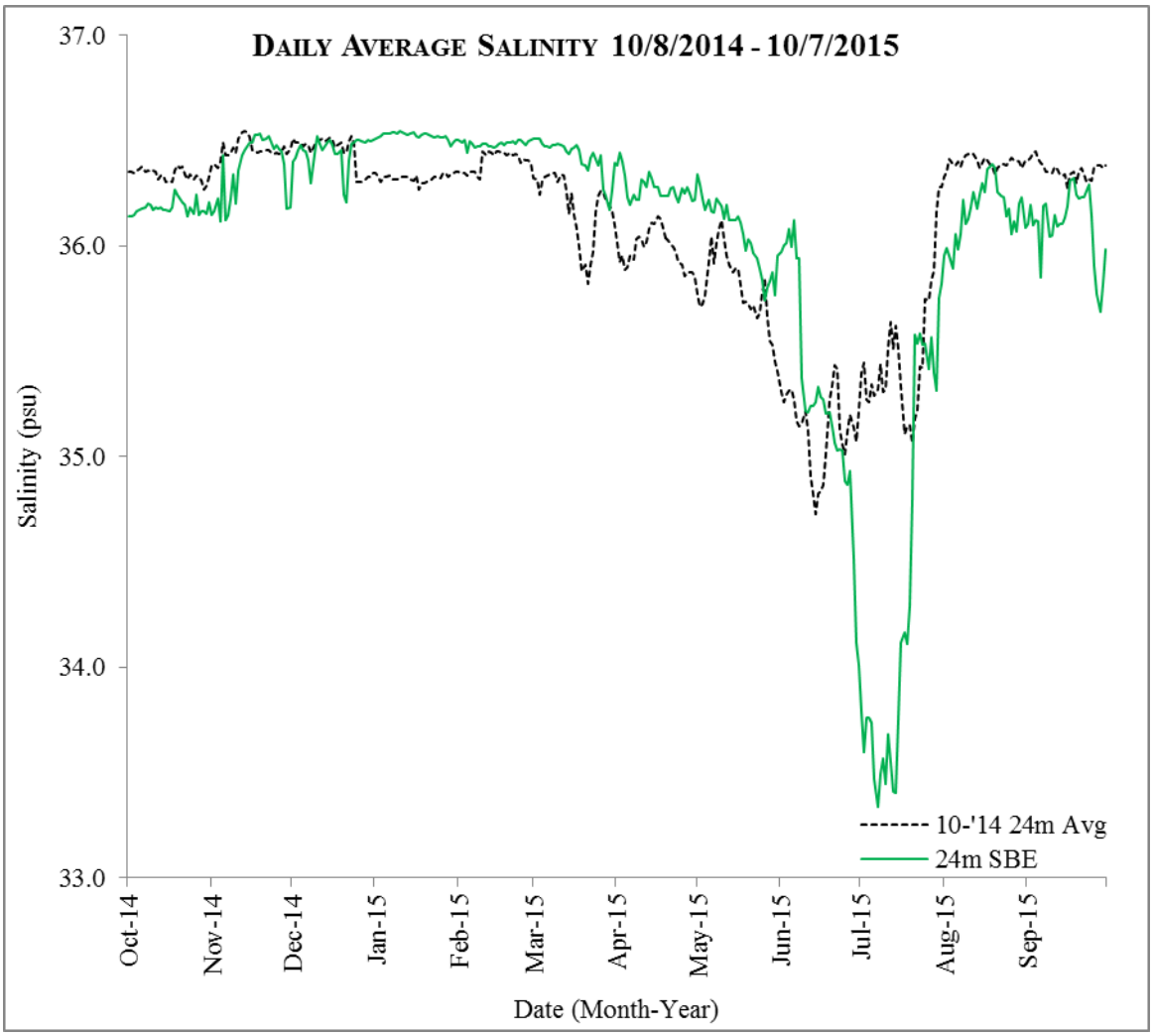


Figure 5.2. Salinity (psu) on the bank crest from 2015. Black dashed line represents a 5-year average salinity.

Water Column Profiles

In 2015, a total of five temperature profiles were collected: February 11th, May 1st, September 1st, October 8th, and November 4th. Henceforth, the dates will be referred to by month and year.

Water temperatures varied throughout the year, and showed only slight variation between the surface and 20 m (Figure 5.3). In May, 2015, the upper 2 m of the water column were warmer than the deeper water. In September, 2015, a small thermocline was observed at 8 m, where the surface waters were slightly cooler than the deeper water.

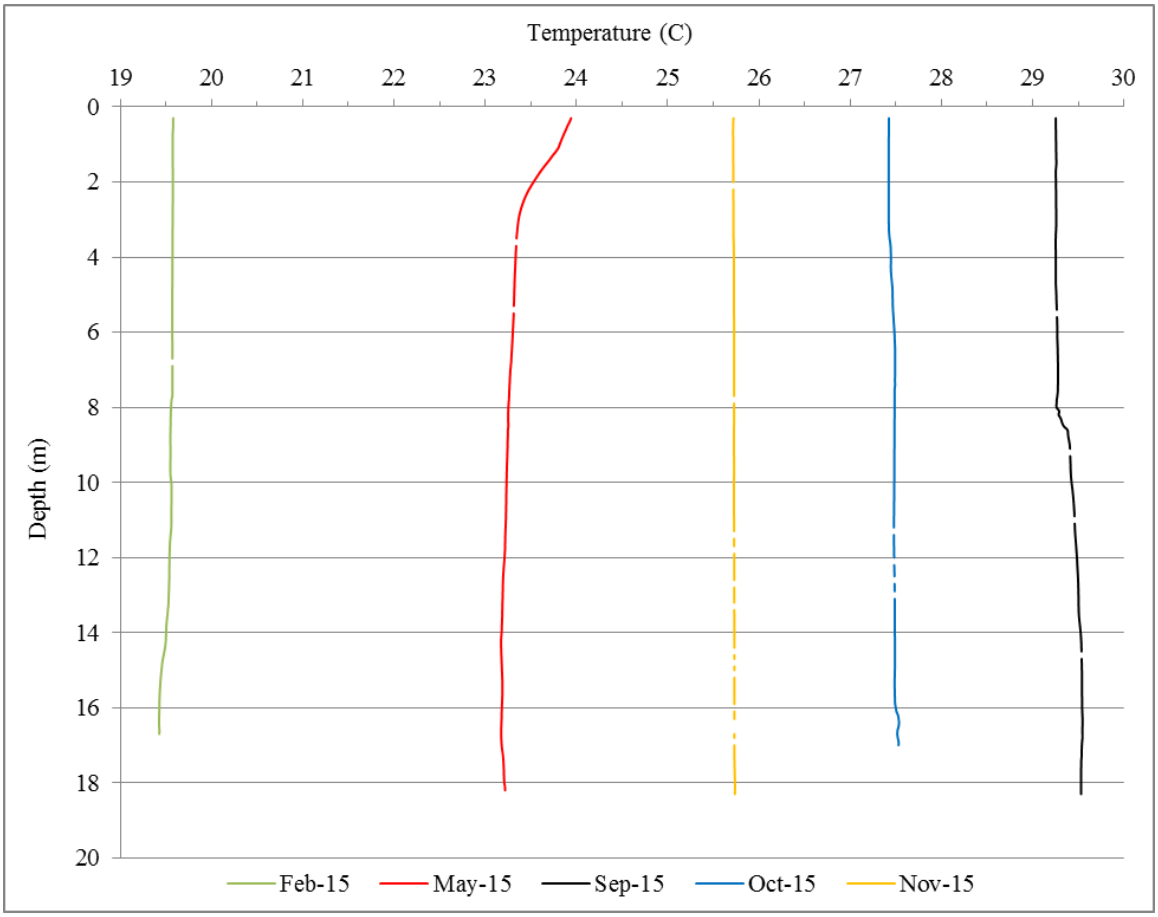


Figure 5.3. Temperature profiles for 2015.

Salinity varied throughout the year, with the lowest salinity recorded in September, 2015 (Figure 5.4). In both September and October, 2015, lower salinity was observed in the surface waters, and an increase in salinity was observed with depth.

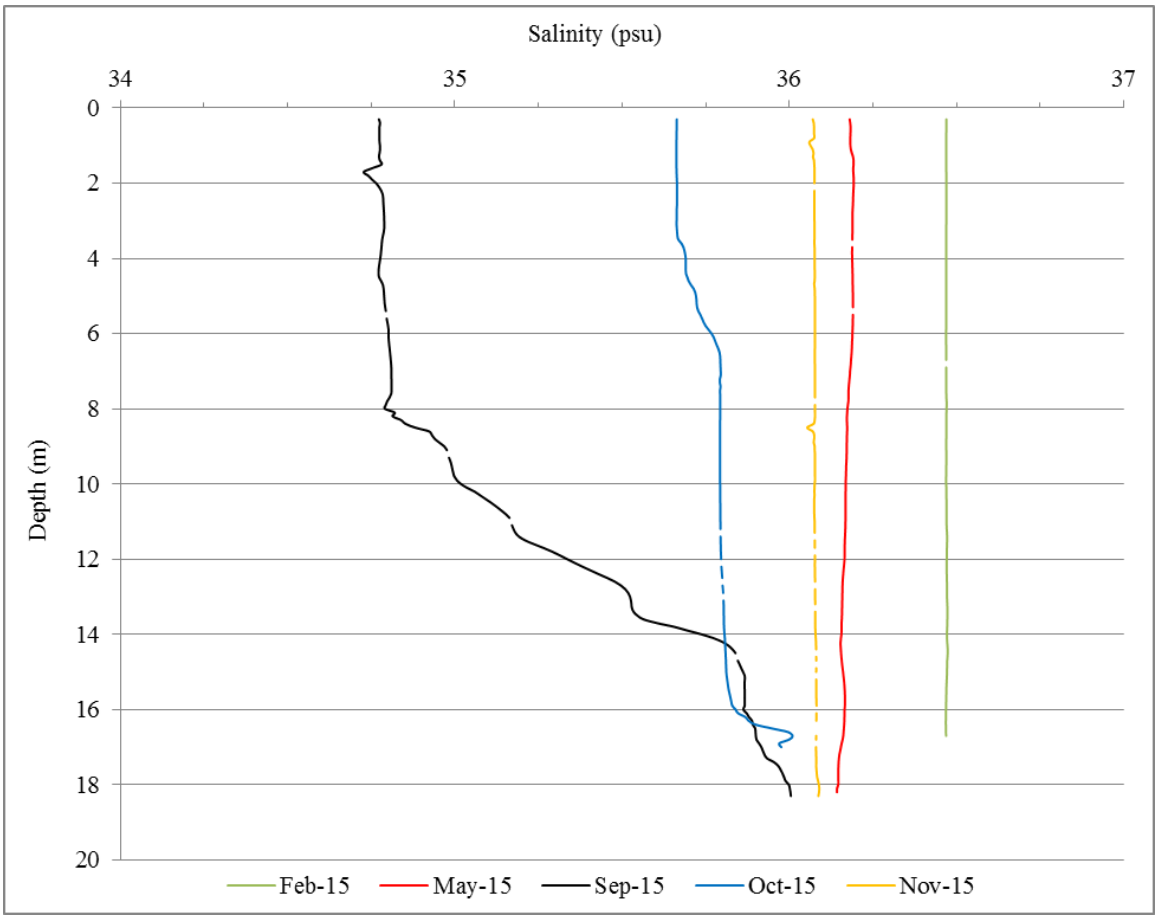


Figure 5.4. Salinity profiles collected in 2015.

From September 2015 onward, pH, turbidity, fluorescence, and DO were recorded in each profile. November, 2015, had slightly lower pH than September and October, 2015, but pH was stable throughout the water column (Figure 5.5). Turbidity was similar throughout the year at depths >8 m (Figure 5.6). In both September and November, 2015, variability in turbidity was seen only in the surface waters. Fluorescence fluctuated with increasing depth throughout the sampling period (Figure 5.7). The lowest fluorescence was recorded in October, 2015, and the highest in November, 2015. Dissolved oxygen profiles were also variable with depth, with the lowest recorded DO observed in September, 2015 (Figure 5.8).

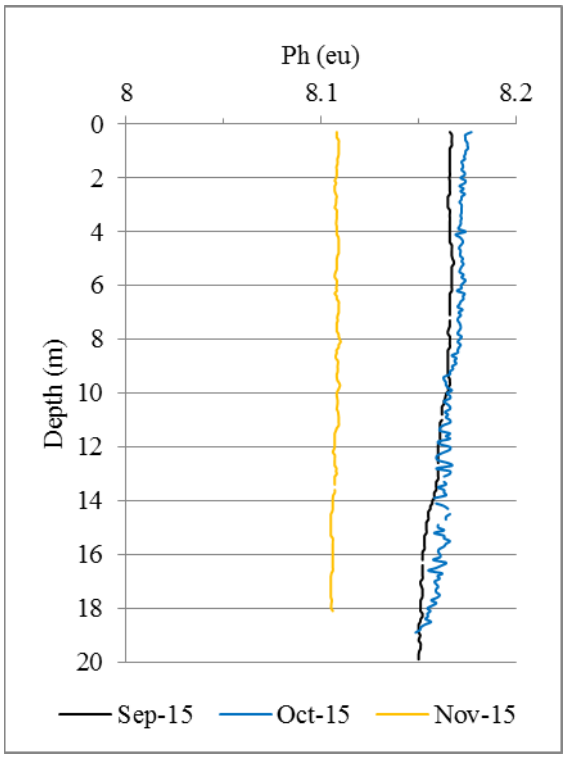


Figure 5.5. Ph profiles collected in 2015.

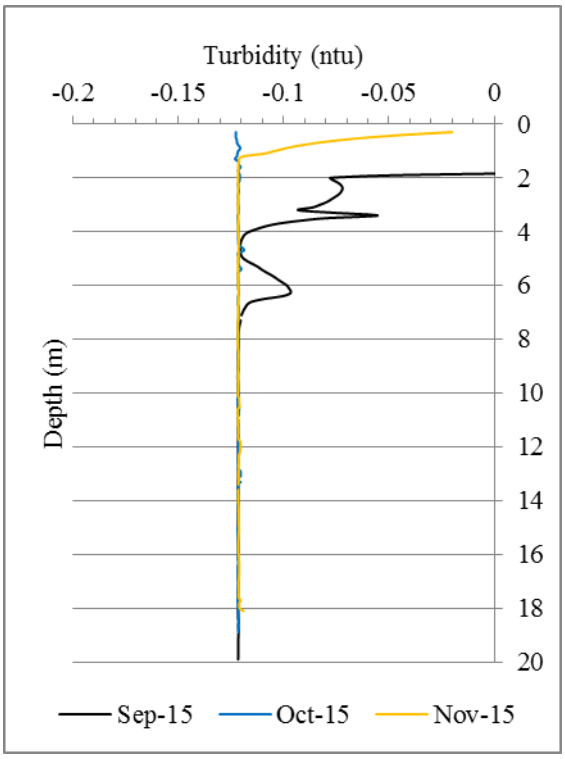


Figure 5.6. Turbidity profiles collected in 2015.

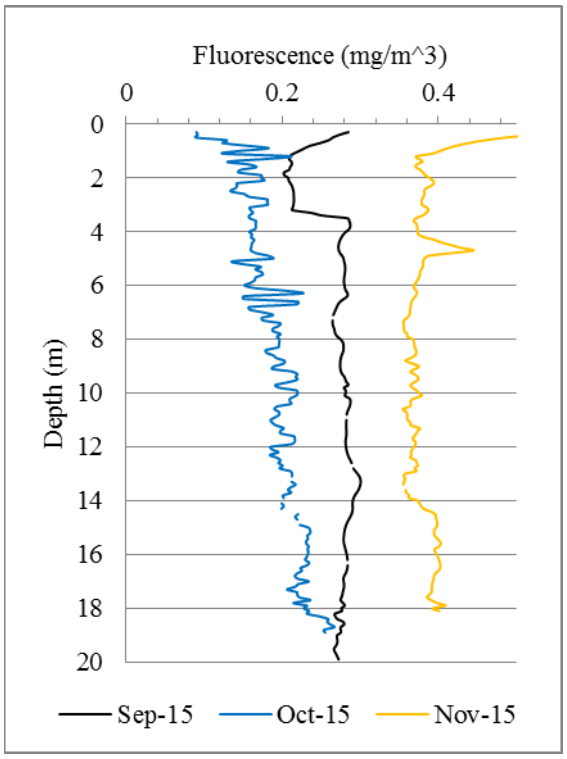


Figure 5.7. Fluorescence profiles collected in 2015.

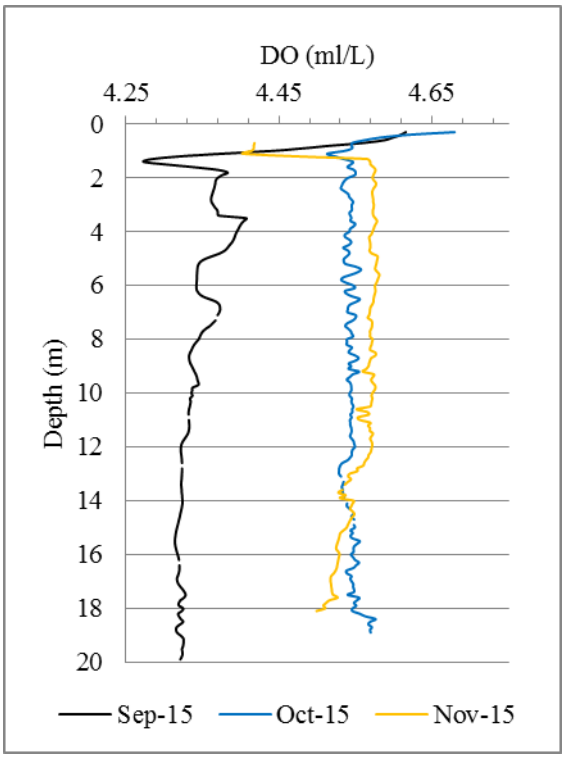


Figure 5.8. DO profiles collected in 2015.

Water Samples

Nutrient analyses indicate that ammonia, chlorophyll-*a*, nitrate, nitrite, phosphorus, and nitrogen levels for all samples in 2015 were below detectable levels.

Carbonate samples taken throughout the year included pH, pCO_2, alkalinity, and total dissolved CO_2 (DIC) (Table 5.2). Total pH showed small variations throughout the year. The lowest pCO_2 value, where the air-sea pCO_2 gradient was greatest, was observed in February, 2015. The lowest $\Omega_{aragonite}$ values and highest DIC were also observed in February, 2015, but aragonite saturation states suggested the seawater was well buffered across all survey times.

Table 5.2. Carbonate sample results for 2015.

Sample Date	Depth (m)	Salinity (ppt)	Temp (°C)	pH Total	Alkalinity (µmol/kg)	DIC (µmol/kg)	pH *in situ*	$\Omega_{aragonite}$	pCO_2 (µatm)
2/11/2015	20	36.64	19.56	8.0379	2400.3	2082.1	8.1192	3.44	335.3
2/11/2015	10	36.65	19.57	8.0575	2402.5	2079.9	8.1390	3.59	319.2
2/11/2015	1	36.65	19.59	8.0335	2401.4	2083.5	8.1147	3.42	339.7
5/1/2015	20	36.16	23.17	8.0439	2396.1	2077.7	8.0569	3.54	396.7
5/1/2015	10	36.17	23.29	8.0435	2396.9	2078.7	8.0568	3.54	397.4
5/1/2015	1	35.95	23.85	8.0426	2398.7	2077.8	8.0562	3.53	398.6
10/8/2015	20	35.93	27.54	8.0700	2392.2	2050.9	8.0318	3.75	420.9
10/8/2015	10	35.79	27.49	8.0682	2393.4	2053.5	8.0310	3.74	422.9
10/8/2015	1	35.66	27.42	8.0846	2388.8	2051.8	8.0487	3.86	404.5
11/4/2015	20	36.08	25.73	8.0607	2379.3	2052.1	8.0493	3.65	399.8
11/4/2015	10	36.07	25.72	8.0650	2381.6	2053.5	8.0539	3.69	395.7
11/4/2015	1	36.07	25.73	8.0666	2381.4	2050.3	8.0558	3.70	393.5

Discussion

Stetson Bank water temperature readings during this period were initially similar to averaged historical data. However, springtime temperatures reached lower than average temperatures, and were quickly followed by warming, where temperatures became warmer than average in early summer. While temperatures reached maximum highs of 29.8 °C, temperatures on the bank crest did not exceed 30 °C at any point in the year. Temperatures were similar to historical averages in the summer, before cooling to below historical averages in the fall.

Salinity levels at Stetson Bank were similar to historical averages for most of the study period, with the exception of an extended event in July, 2015, where salinity was reduced by >2 psu. Typically, the summer months at Stetson Bank see lower salinity levels, which correlate with months of increased flow rates of the Mississippi and Atchafalaya Rivers, where April is the peak month, and flow rates decline gradually through July (Meade 1995).

Laboratory analyses indicated that nutrient levels at Stetson Bank continued to be below detectable levels, indicating low nutrient waters. Carbonate analysis indicate a thermal control on carbonate systems (carbonate saturation state and CO_2 partial pressure, or pCO_2) in this region. After normalization using the annual mean temperature, annual mean of surface seawater npCO_2 does not appear to significantly deviate from the atmospheric value, but appears to have a seasonal pattern with a peak npCO_2 occurring in late winter to early spring (February-March) and lowest npCO_2 in late summer (August-September). With minimal terrestrial influence (as reflected by high salinity all year round), it may correspond to a shift in the balance between respiration and production, but continued field sampling (in conjunction with phytoplankton survey) is needed to test this explanation. The distribution of ΔpCO_2 on an annual basis suggested that this area had a small net air-sea CO_2 flux. Seasonal and spatial distribution of seawater carbonate chemistry in 2015 demonstrates that seawater in the FGBNMS area (including East Bank, West Bank, and Stetson Bank), despite its proximity to the land, behaved like an open ocean setting (such as the Bermuda Atlantic Time-series Study, or BATS) (Bates et al. 2012) in terms of its annual pCO_2 fluctuation and minimal terrestrial influence. Carbonate chemistry data can be used as a reference for future studies in this region in terms of investigating ocean acidification (due to atmospheric CO2 intrusion) and man-made or naturally occurring petroleum leakage in the northern Gulf of Mexico.

Challenges and Resolutions

- Decreased analytical precision on the 2015 ocean carbonate samples, presumably due to issues during transportation and sampling bottles used.
    - CCL recommends that ground glass bottles be used in the future for water sample collection to conform to the standard operating procedure for ocean acidification study. CCL will provide training and sampling gear to FGBNMS.

6. MESOPHOTIC REPETITIVE QUADRANTS

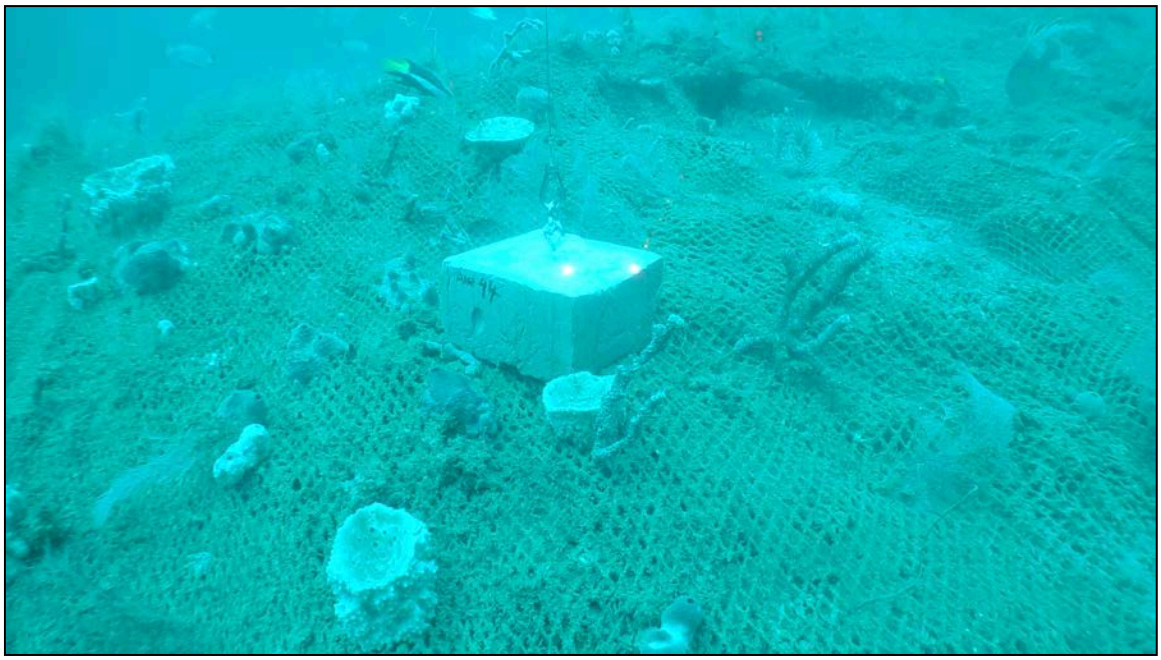


Photo: FGBNMS/UNCW-UVP

An example of one of the mesophotic repetitive photostations, M03, which was deliberately placed on a fishing net in order to monitor changes in the biological community that has established on the netting.

Introduction

Seven permanent photostations were marked on the mesophotic reefs surrounding Stetson Bank in 2015. Locations of biological interest were selected along the hard bottom reef features and markers were deployed by ROV. The latitude and longitude of locations were recorded using the navigation system on the ROV (Figure 6.1). Each station will be located and photographed annually, using an ROV.

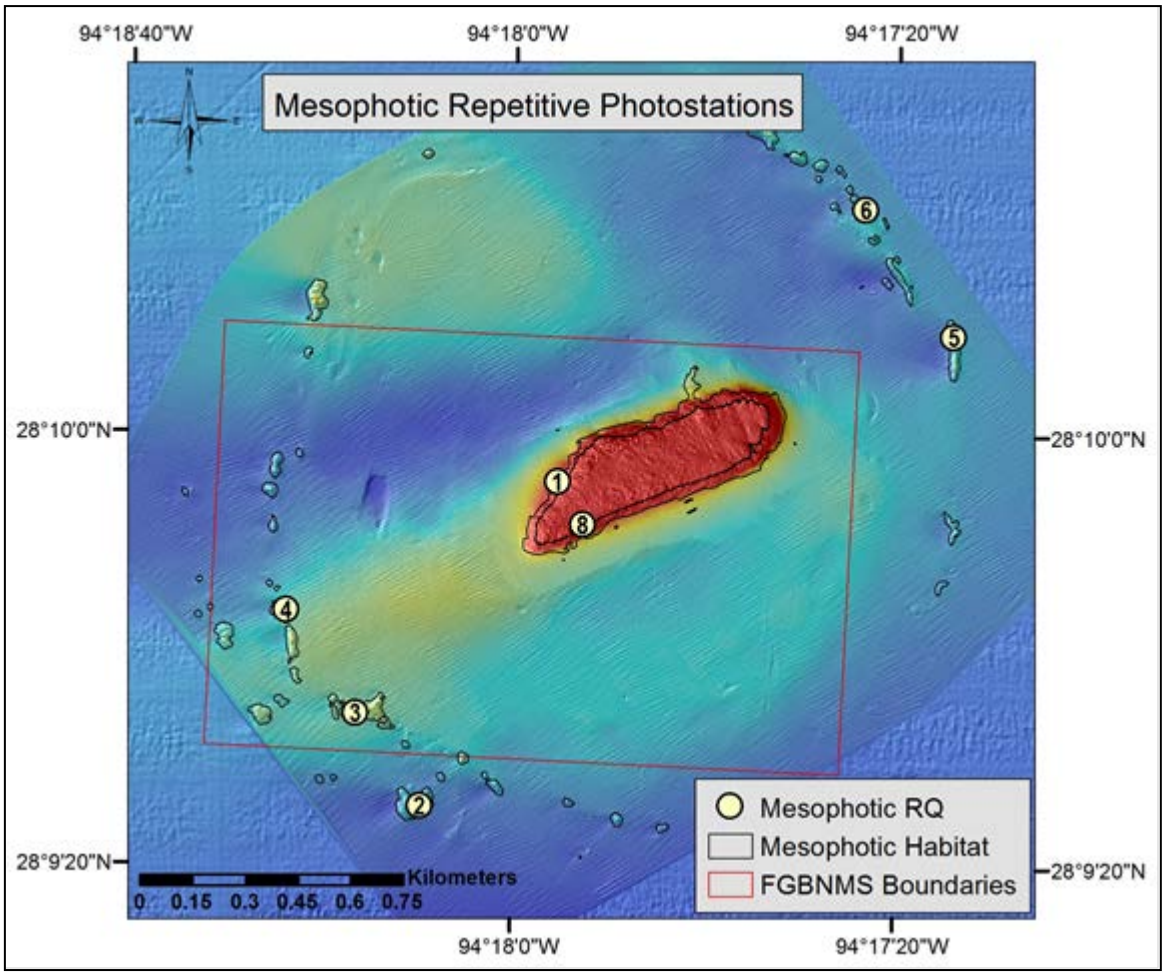


Figure 6.1. Locations of mesophotic repetitive photostations at Stetson Bank.

Methods

Field Methods

Historical Remotely Operated Vehicle (ROV) surveys and notable sites (high coral or sponge densities or marine debris) observed during random transects were used to compile a list of potential repetitive photostation locations. The ROV was deployed on the location, to find the feature of interest and allow the topside science team to visually

assess the feasibility of deploying a marker at the site. Factors considered included visibility (sufficient visibility to operate the ROV safely and capture an image of the feature of interest) and habitat (sufficient flat habitat on which to deploy the marker).

Once an appropriate location was found, a second dive was made on the site to deploy the marker. Markers consisted of a concrete block (25.4 cm x 25.4 cm x 15.2 cm) weighing 25 kg in air (9 kg in saltwater). An eyebolt was embedded into the concrete block, to which 1.8 m of wire rope was attached via a shackle and thimble. A small 20 cm hard trawl float (3.15 kg buoyancy) was attached to the wire rope using crimping sleeves (Figure 6.2).

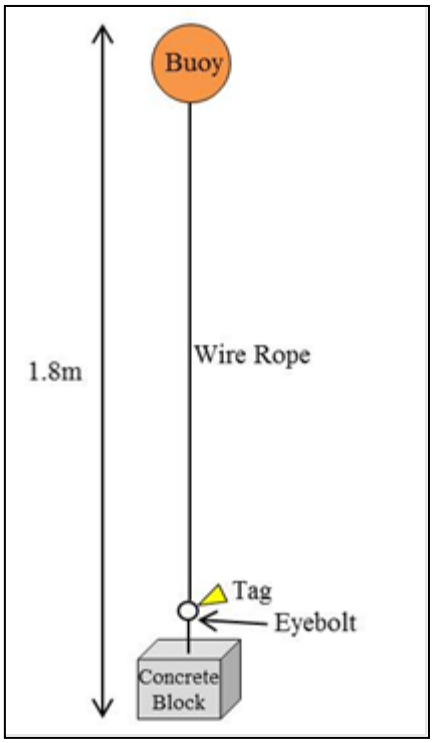


Figure 6.2. Mesophotic repetitive quadrant marker.

The wire rope was coiled and lightly secured with painters tape to contain the wire during deployment. Each marker was made 1 kg negative in the water through the use of a cut away float system. The cut away float was comprised of additional hard trawl floats secured to the marker using 136 kg test fishing line.

The ROV was used to deploy the marker, placing the concrete block on the sampling sled and held in place with the manipulator arm clasped around the eyebolt. Once on site, the marker was positioned using the manipulator and extra floats removed using a cutting tool mounted to the back of the manipulator arm and the wire rope deployed to its full length. The cut away float, and associated fishing line, was collected on the surface by the vessel.

The ROV was then used to survey the station. A heading was recorded for each station, from which the ROV collected high definition video imagery of the site, with the marker in view. Site ID, heading, and depth were recorded for each location. A total of seven repetitive photostations were deployed in 2015. One still frame for each repetitive station was then extracted from the high definition video for further processing.

In 2015, a SubAtlantic Mohawk 18 ROV, owned by National Marine Sanctuary Foundation (NMSF) and FGBNMS, and operated by University of North Carolina at Wilmington - Undersea Vehicle Program (UNCW-UVP), was used. The ROV was equipped with an Insite Pacific Mini Zeus II HD video camera with two Deep Sea Power & Light 3100 LED lights, an ECA Robotics five-function all-electric manipulator, and two parallel spot lasers set at 10 cm in the video frame for use as a scale.

Data Processing

Qualitative summaries of each still frame image from the high definition video were conducted using Adobe Illustrator, ImageJ, and Microsoft® Excel®. Key features were identified in each image and outlined using a color coded key Illustrator (Figure 6.3). Measurements of key stony coral, octocoral, and black coral specimens were made using ImageJ and the reference scale lasers. Qualitative summaries were recorded for comparisons in subsequent years, to document the loss, reduction, expansion, or gain of key features and changes in general condition. Key biological features were assigned a code using the first two letters of the genus and species name, along with a unique number for the image (for example, StIn_1 = *Stephanocoenia intersepta* colony 1).

Figure 6.3. Mesophotic photostation M01. Key features are outlined and identified.

Results

A total of seven repetitive mesophotic photostations were installed and photographed in 2015. Depth of the stations ranged from 35.8 – 54.7 m; average station depth was 48.1 m. Qualitative summaries of each station were produced (Table 6.1).

Table 6.1. Repetitive photostation M01 - M08 descriptions.

Station	Depth (m)	Bearing (Degrees)	Latitude (DD)	Longitude (DD)	Site Description
M01	39.9	130	28.16541692	-94.29867017	Coral (StIn_1) *Stephanocenia intersepta*: 50.3 x 30.4 x 12.4 cm. No bleaching present. (PoAs_1) *Porites asteroides*: 10.8 x 4.1 x 2.0 cm. Approximately 20% hard bottom covered in macroalgae and remaining consists of rubble.
M02	54.7	90	28.15705383	-94.30259167	Octocoral (HyW_1) white *Hypnogorgia* sp.: 50 x 96 cm. Black coral (Stic_1-2) sea whips. Poor visibility. 100% hard bottom.
M03	51.2	0	28.159424	-94.304477	Sponges (IrW_1-4) white *Ircinia* sp.. (IrB_1-12) brown *Ircinia* sp., and (NiEr_1-4) *Niphates erecta* with gastropods. Black coral sea fans (BCSF_1): 20 x 3 cm (BCSF_2): 24 x 10 cm. Black coral sea whips. 100% cover of trawl net on hard bottom.
M04	52.4	225	28.16206665	-94.30651668	Sponges (IrW_1) white *Ircinia* sp.: 25 x 7 x 8 cm, (IrW_2) white *Ircinia* sp.: 16 x 8 x 4 cm. (IrB_1-2), and brown *Ircinia* sp.. Black coral sea fan (BCSF_1). 100% hard bottom.
M05	53.6	0	28.16922285	-94.28722273	Octocorals (HyW_1-2) white *Hypnogorgia* sp.. (HyR_1) red *Hypnogorgia* sp.: 28 cm in height. (HyG_1) gold *Hypnogorgia* sp.. Black coral sea whip (Stic_1). 100% hard bottom.
M06	49.1	270	28.172475	-94.28981667	Black coral (BCSF_1) sea fan: 25 x 29 cm and (Stic_1-3) sea whips. Sponges (NiEr_1-2) *Niphates erecta* and (IrB_1) brown *Ircinia* sp.. 100% hard bottom
M07	NA	NA	NA	NA	Lost marker during descent
M08	35.8	225	28.16431783	-94.29793817	Coral (StIn_1) *Stephanocenia intersepta:* 58.6 x 48.3 x 4 cm. No bleaching present. (StIn_2) *Stephanocenia intersepta*: 32.6 x 18.0 x 3 cm. Sponge *Neofibularia nolitangere*. 80% hard bottom covered in macroalgae and rubble.

Discussion

Mesophotic repetitive photostations were a new addition to the long-term monitoring program at Stetson Bank. Site selection proved challenging as sites required sufficient visibility for imagery of the key features and adequate habitat to deploy the marker. Additional factors, including hurricanes and fishing or anchoring impacts may cause the markers to move, making them difficult to relocate. Additional sites may be selected during the 2016 field season, dependent on the success of relocating sites installed in 2015.

A variety of sites were selected in 2015. Key biological features included stony corals (M01 and M08), octocorals (M02 and M05), black corals (M06), and sponges (M03 and M04). Qualitative comparisons of the loss, reduction, expansion, or gain of key features and changes in their general condition will be assessed over the subsequent years. In addition, two sites with similar biological communities were selected, but one location was established on hard bottom habitat (M04) and the other on hard bottom habitat encased in a shrimpers trawl net (M03). These sites will also be qualitatively assessed for the loss, reduction, expansion, or gain of key features and changes in their general condition in subsequent years, with a focus on the effect the trawl net has on the stability of the community.

Challenges and Resolutions

- Sites to deploy repetitive station markers were limited due to poor visibility, location of debris hazards, and eroded patch reef structure all restricting potential locations to deploy station markers.
    - Sites with sufficient visibility for the ROV operators to work and where the habitat was conducive to placement of a marker were selected. Fewer markers were deployed than intended due to the limited number of sites identified as suitable and harboring interesting features to monitor.
- Placement of repetitive markers required greater logistical planning than initially thought. On several occasions, the marker was positioned correctly, but the extra float release mechanism did not function as expected and/or the 1.8 m of wire rope did not fully deploy.
    - Additional time was taken to improve the release mechanism for the extra float. For sites where the float did not release as expected, additional time was taken with the ROV to release the trapped float. For sites where the 1.8 m of cable did not deploy as expected, small amounts of light duty painters tape were used and are expected to disintegrate over time, releasing the remainder of the cable.

- One complete repetitive station marker, intended for M07, was lost as the ROV transited to the seafloor due to a malfunction with the ROV manipulator.
    - For future deployments, the manipulator arm will be manned for the duration of dive, where the operator can hold the jaw control closed.
- Capturing a downward facing image of the repetitive site will not result in the same image being captured between years.
    - Forward facing video was captured of each site, with 10 cm lasers in the field of view. The compass heading that best captured the features the site was established to monitor were recorded for each site. This imagery should be repeatable between years, but will alter the methods called out in the SOP to evaluate the sites over time. The new method will not allow repeatable and accurate areal measurement of the colonies.
- Acoustic beacons were incompatible with the ROV communication systems.
    - The two acoustic beacons that were intended for deployment at selected repetitive station markers were not deployed as they were incompatible with the ROV communication system. While the ROV operators were consulted in this purchase, the acoustic beacons identified to purchase were miscommunicated. All acoustic beacons were returned to the purchasing company. In following ROV cruises, we plan to utilize the ROV mounted sonar system to aid in locating repetitive station markers.

7. MESOPHOTIC RANDOM TRANSECTS

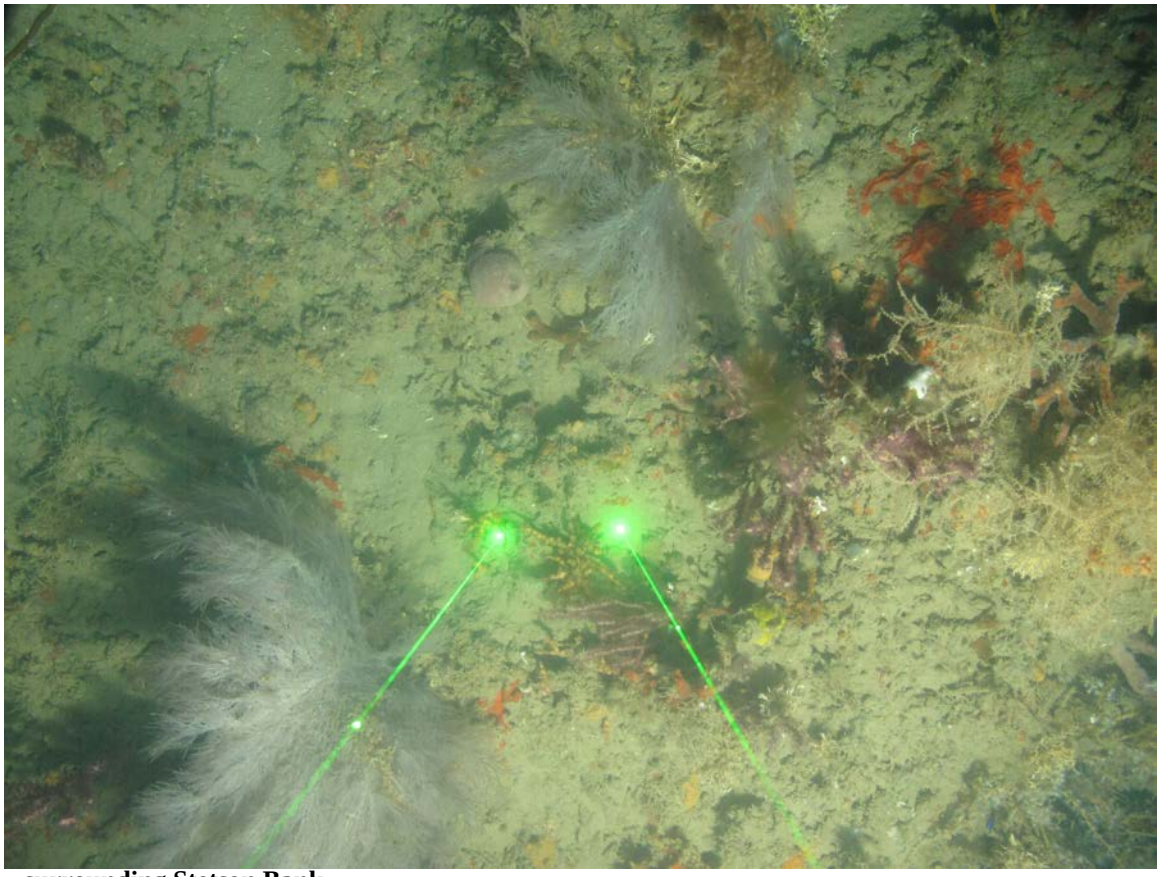


Photo: FGBNMS/UNCW-UVP

surrounding Stetson Bank.

Introduction

A minimum of 15 random transects were conducted annually using a stratified random sampling design. Sites were selected on potential mesophotic habitat, identified using bathymetric data. Transects were conducted using a downward facing still camera mounting to an ROV. These transects were analyzed to assess community composition and coral density.

Methods

Field Methods

Bathymetric data was processed in ESRI's ArcGIS® to highlight potential mesophotic habitat. Two meter resolution bathymetry raster was imported into ArcMap® and focal statistics calculated for range within a 2 x 2 cell rectangle. Cells with a range >1 m were identified as potential habitat. Area shallower than 33.5 m was removed. The raster was then converted to a polygon feature. In 2015, thirty surveys were randomly distributed within the polygon. Each point, representing the start location of transects, was generated using the tool 'create random points', with a minimum of 30 m between sites (Figure 7.1).

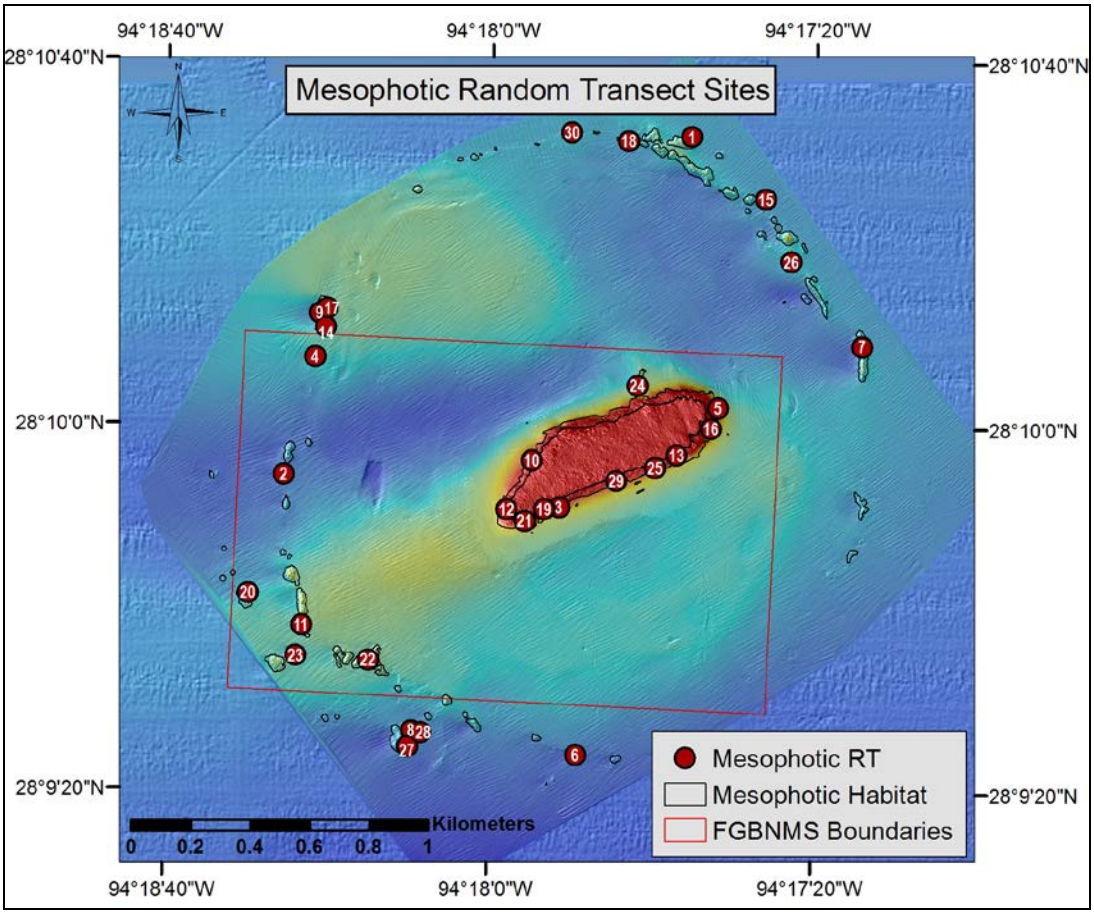


Figure 7.1. Mesophotic random transect locations for 2015.

Surveys were conducted using an ROV with a downward facing still camera and two lasers for size scale in the frame. Transects started at each of the random drop sites and continued for 10-minutes along hard bottom habitat. The ROV traveled at 1 m above the bottom, at a speed of 0.5 knots, taking downward facing still images every 30 seconds during the transect.

In 2015, the same ROV system as described in Chapter 6 Methods was used. The ROV was also equipped with a Kongsberg Maritime OE14-408 10mp digital still camera, OE11-442 strobe, and two Sidus SS501 50mW green spot lasers set at 10 cm in the still camera frame for scale.

Data Processing

Images were processed to remove silted, shadowed, out of focus, or soft bottom images. From the remaining images, a minimum of nine and a maximum of 11 images were randomly selected for processing. If a transect did not have at least nine useable images, it was removed from the analysis. The size of each image was calculated in ImageJ and recorded in Microsoft® Excel®. Colony counts for cnidarian species of interest (stony

corals, octocorals, black corals, and soft corals) were conducted for each image and recorded. Colony counts were calculated for each species, summed across transects, divided by the transect area, and presented as density per 100 m^2.

Percent cover of the images was analyzed using CPCe. A total of 500 points were randomly overlaid on each transect, with an equal number of points on each photo of the transect. The benthic species lying under these points were identified. Microsoft® Excel® spreadsheets were created automatically via CPCe using customized coral code files pertinent to the benthic species in the mesophotic zone in this region.

Organisms positioned beneath each random dot were identified to lowest possible taxonomic group for Cnidaria, Porifera, and macroalgae (algae longer than approximately 3 mm, included thick algal turfs); other organisms were identified to the phylum level; substrate was characterized as rubble, soft bottom, fine turfs, and bare rock. Summary data were grouped into substrate or phylum level categories. Families of interest from the cnidarian phyla were expanded to family groupings and summarized. Bleaching, paling, fish biting, and other disease or damage were recorded as "notes," providing additional information for each random point.

In percent cover analysis, as transects differed in area, weighted cover was used in analysis. To obtain weighted cover, percent cover was multiplied by the area captured in the image. This was then converted to relative percent cover for data summarized by habitat.

Cnidarian density data were projected spatially as pie charts following the Methods in Chapter 2.

Results

A total of 30 mesophotic random transects were conducted in 2015. Depth of the stations ranged from 35.6 – 57.6 m, with an average station depth of 49.9 m. Two distinct habitats were observed: mesophotic reefs with coralline algae (coralline algae reef) and mesophotic reefs without coralline algae (deep reef) (Figure 7.2). Results were grouped by habitat type.

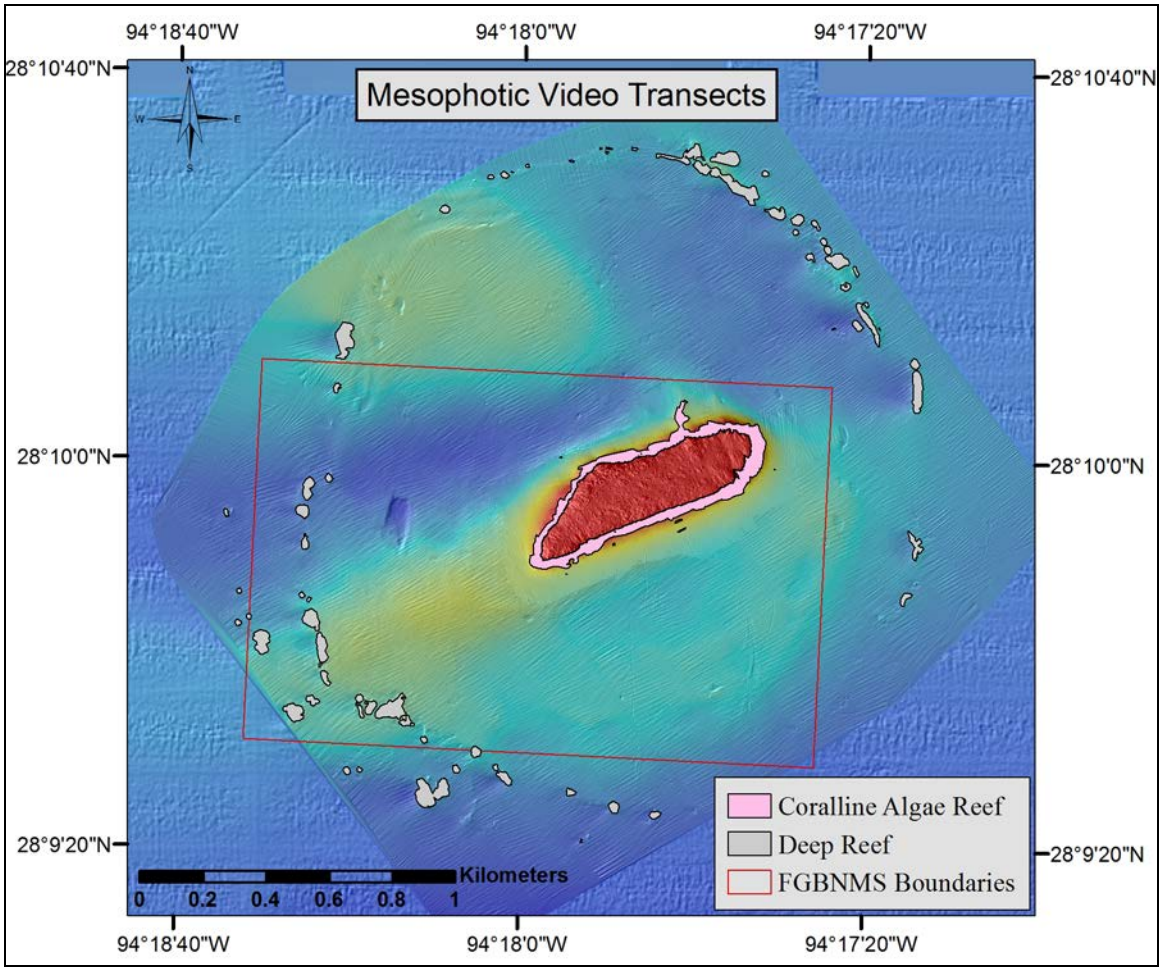


Figure 7.2. Location of coralline algae reef and deep reef habitats.

Relative percent cover in both habitats was dominated by bare substrate in the form of rubble, soft bottom, or hard bottom habitat (Table 7.1). However, rubble was seen more frequently in coralline algae reef habitat than deep reef habitat, and soft bottom was seen more frequently in deep reef habitat than coralline algae reef habitat.

Table 7.1. Percent cover of substrate and biota by habitat.

Habitat	Coralline Algae Reef (Relative % Cover)	Deep Reef (Relative % Cover)
Rubble	31.9	0.7
Soft bottom	9.4	32.1
Hard bottom	52.7	44.6
Biota	37.9	23.4

A total of 10 phyla comprised the recorded biota in both habitats (Figure 7.3). Coralline algae reefs were dominated by Rhodophyta, comprising 11.0% cover, primarily due to the abundance of crustose coralline algae in these habitats. Deep reefs were dominated by Cnidaria, comprising 13.8% cover.

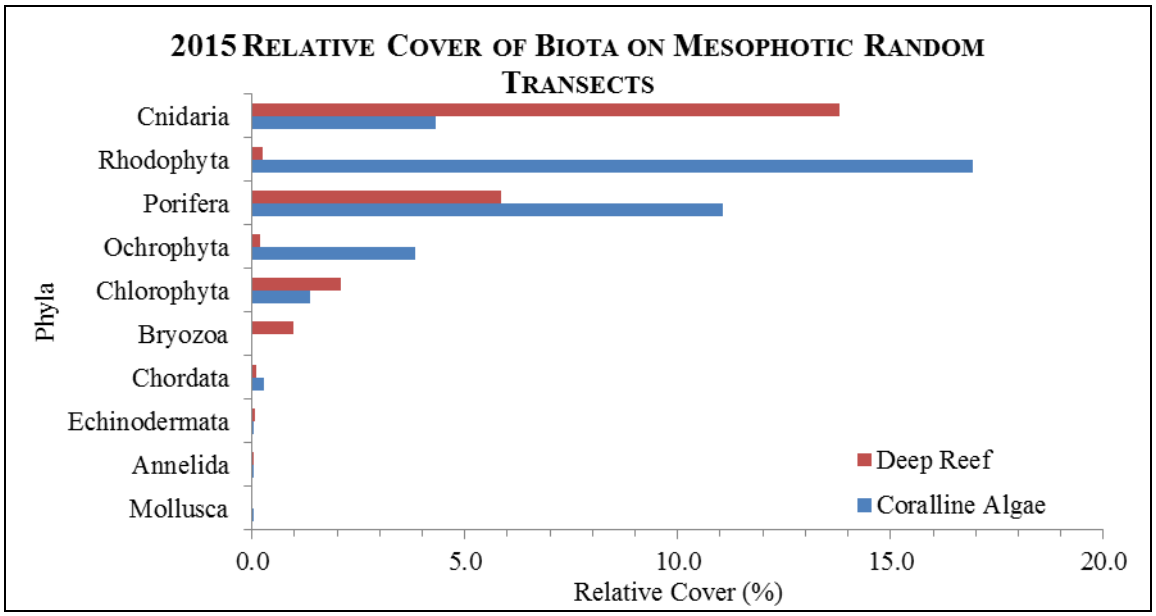


Figure 7.3. Relative percent cover of phyla.

Of the cnidarian species of interest, species were summed to family level. A total of eight families were recorded (Figure 7.4). Coralline algae reefs were dominated by Astrocoeniidae, at 0.7% cover, due to the prevalence of *S. intersepta*. Deep reef was dominated by Antipathidae, comprising 3.0% cover, due to the prevalence of a black coral sea fan, potentially *Antipathes atlantica/gracilis*.

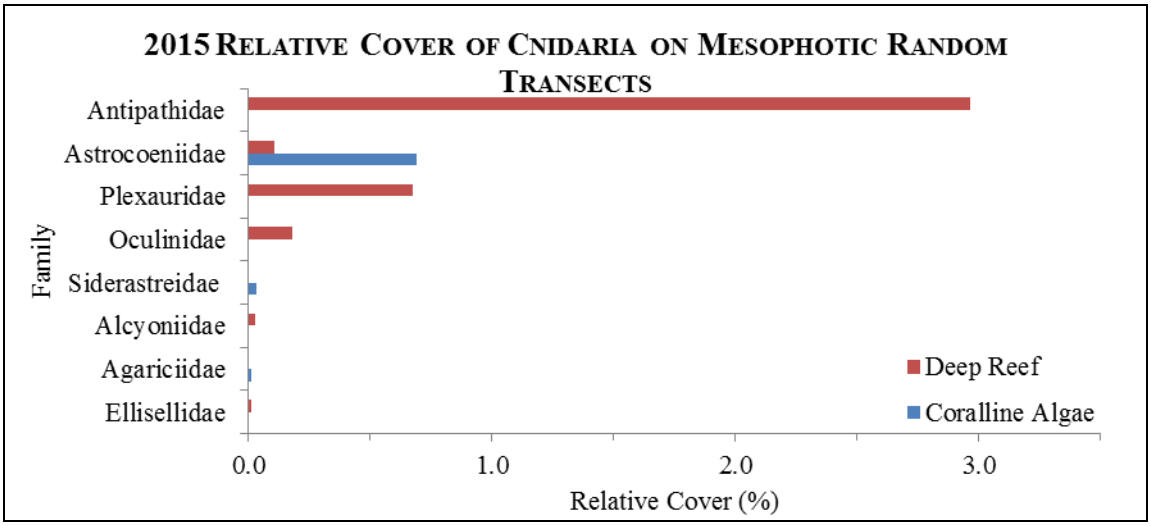


Figure 7.4. Relative percent cover of cnidarian families of interest.

Density of colonies varied between habitat types, with a total of 11 families recorded (Figure 7.5). The densest family in deep reef was Antipathidae with a mean of 3.57 individuals per m^2 (± 0.48 SE), which were entirely absent from coralline algae reefs. The densest colonies in coralline algae reef was Astrocoeniidae at 1.35 individuals per m^2 (± 0.57 SE).

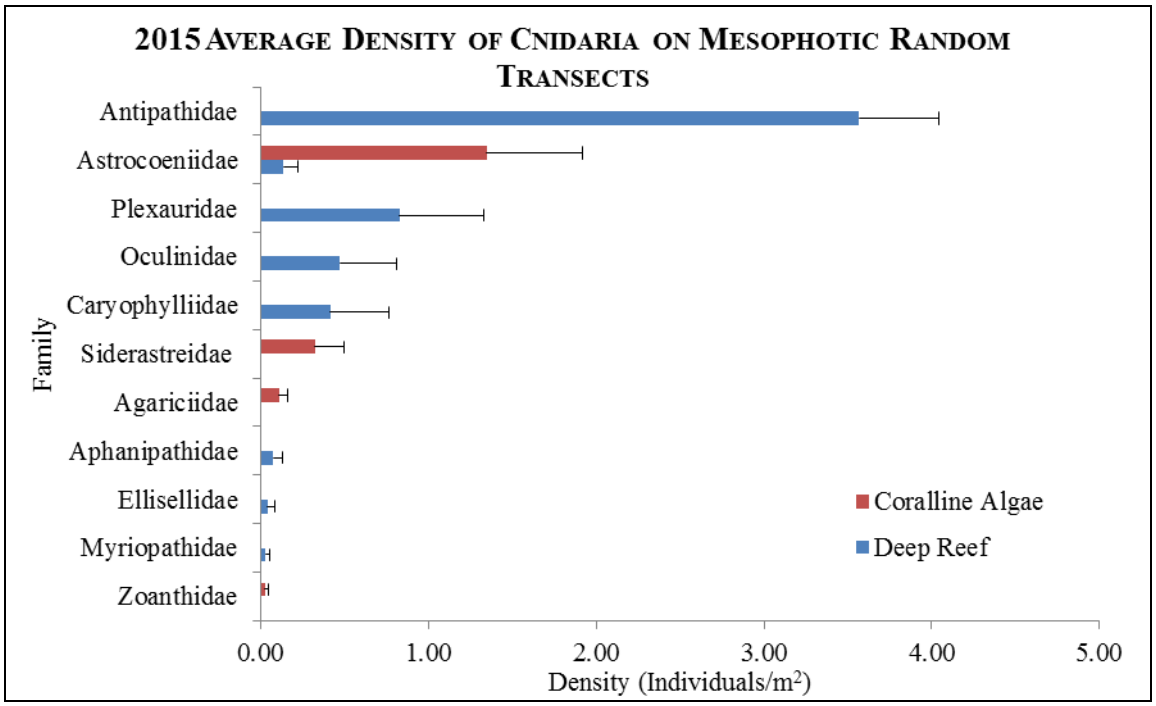


Figure 7.5. Colony density of family per 100m^2.

When colony density (grouped by family) was projected spatially, additional trends were observed (Figure 7.6). Surveys in coralline algae reef habitat showed that the eastern portion of the reef was dominated by Astrocoeniidae colonies, while the western portion of the reef was dominated by both Astrocoeniidae and Siderastreidae colonies. Surveys on deep reef habitat were primarily dominated by Antipathidae colonies, though some differences were evident to the east.

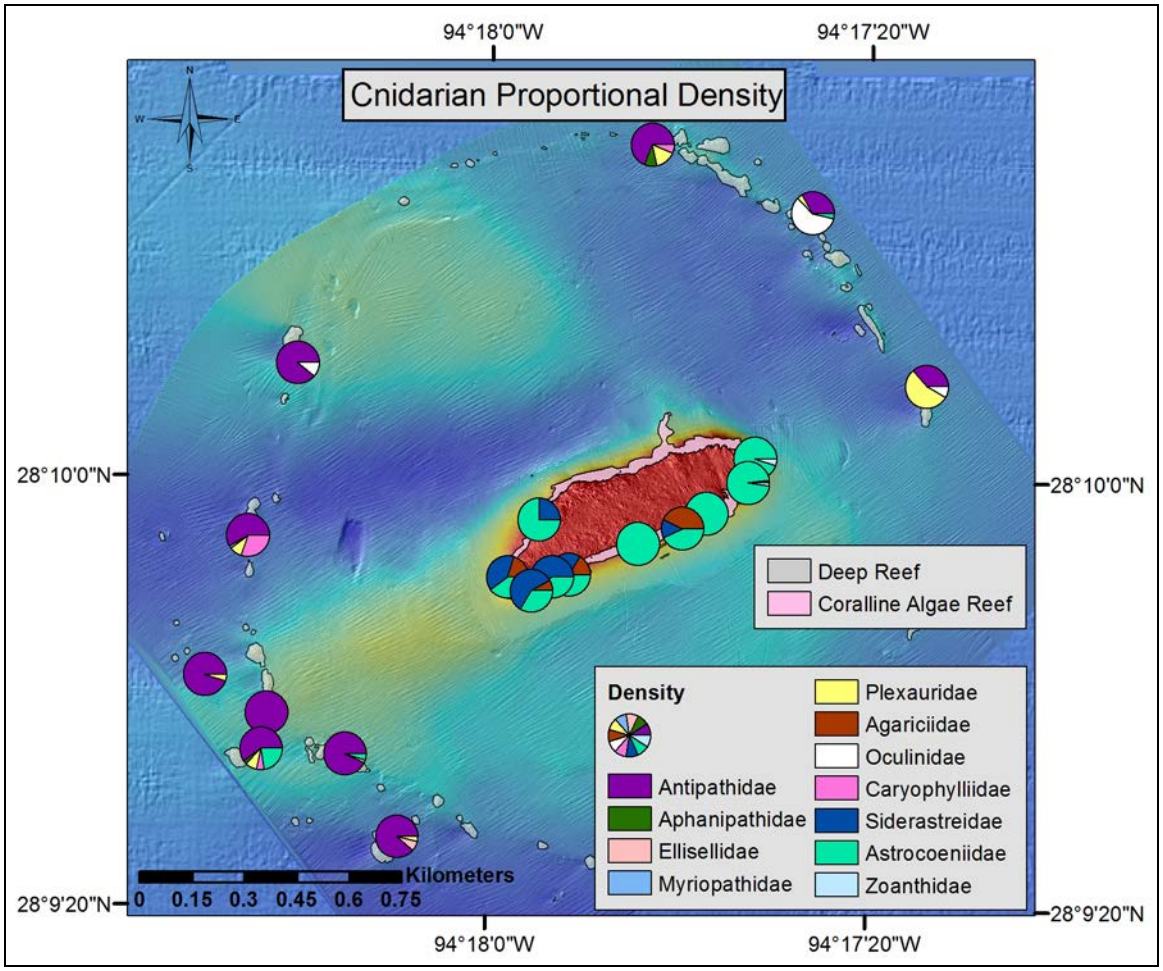


Figure 7.6. Spatial projection of mesophotic cnidarian family density. Each pie chart represents the location at which a survey was conducted and the proportion of density represented by each family of interest.

Discussion

Mesophotic ecosystems are a critical component of Stetson Bank. Two distinct habitat types were encountered in this study, each with different communities. Coralline algae reef habitat was defined by the presence of abundant crustose coralline algae, which was reflected in the relative cover of Rhodophyta. Cnidarians in coralline algae habitat were the third most dominant phyla, of which the Astrocoeniidae family comprised the highest

cover and greatest density. Deep reef habitat, defined by the presence of deep-sea and mesophotic corals, was dominated by the Cnidarian phyla, of which both cover and density were dominated by Antipathidae, primarily due to the abundance of a black coral sea fan, potentially *A. atlantica/gracilis*.

Interesting spatial trends were observed within coralline algae reef habitat. The western portion of the main reef feature has a high density of Siderastreidae. Notes from these observations identified that *S. radians* contributed largely to the high densities. This species were not abundant on similar habitat on the eastern portion of the main reef feature, which was instead dominated by Astrocoeniidae (*Madracis brueggemanni*). The eastern portion of deep reef habitat found higher densities of octocorals from the Plexauridae and Oculinidae families. The community spatial differences are potentially due to different local conditions, such as turbidity, which was anecdotally noted to be greater in the eastern deep reef habitat than other locations.

It was noted that most *S. radians* and *S. intersepta* colonies observed in the coralline algae reef habitat were small in size (<5 cm). In other parts of the Caribbean region, *S. radians* colony size ranges are reported from 10 – 30 cm and *S. intersepta* colony size ranges are reported from 15 – 76 cm (Humann and Deloach 1992). Therefore, the small colonies observed may represent coral recruits or colonies with stunted growth due to the sub-optimal environmental conditions for coral growth at Stetson Bank.

While density analysis collected data on both rare and abundant cnidarian species of interest, percent cover, evaluated via point counts, can miss rare species. This was reflected in the number of families observed in each analysis during the study period: 10 families were found in density analysis and seven in percent cover analysis. The additional families captured in the density analysis included small cup coral species (Caryophylliidae), small bottle brush shaped black corals (Myriopathidae), and one small fan shaped black coral (Aphanipathidae).

Challenges and Resolutions

- Some images from random transects had air bubbles in the image due to air being trapped around the camera lens of the ROV and no method to remove the trapped air.
    - The area affected by the air bubble is small (<2% of the image). When points fell in this area, if identification could not be made due to distortion, they were noted as No Data, removing them from analysis. They are not anticipated to have a significant impact on the data.
- Following methods identified in IA E14PG00052, complete percent cover analysis of mesophotic random transect images was called for. This resulted in excessive data processing time of approximately 20 mins per image, with ~11 images per transect, resulting in ~3 hr. 40 min per transect. With minimum of 15 transects annually, this resulted in ~ 55 hrs. of processing time.

- We compared this method with a 500 point count for each transect. When summed to major categories, little difference was observed in the percent cover of benthic fauna between the methods. The results were compared using a Bray-Curtis similarity matrix (Bray and Curtis 1957), and found to be >90% similar for all transects. However, the Complete Cover method produced higher species richness values than the 500 Point. Upon further examination, the 500 Point method did not capture rare species with low overall percent cover, including solitary cup corals. While the 500 Point method captures lower species richness overall, we do not feel this will impair the quality of the data presented in the long-term monitoring study. The purpose of this study, as identified in the interagency agreement, is to monitor community ecology to detect change, with a view toward identifying cause of change. The 500 Point method evaluated provides the level of information needed to study the community, and produces similar results to the Complete Cover method. However, the 500 Point method will take 1/10 of the processing time of the Complete Cover method. Images for 2015 were processed using the 500 Point method with the support of individual colony counts to capture rare and cryptic stony, octo, black, and soft coral species.

8. MESOPHOTIC FISH SURVEYS

Photo: FGBNMS/UNCW-UVP

Lionfish, Big-Eye, Rock Hind, Yellowtail Reeffish, Vermilion Snapper, and Red Snapper utilizing mesophotic reef habitat with a discarded boat anchor and rope.

Introduction

To examine fish community composition and changes over time, belt transect visual fish censuses were conducted at random locations in the mesophotic habitat surrounding Stetson Bank, in conjunction with mesophotic random transects. These surveys were used to characterize and compare fish assemblages.

Methods

Field Methods

Fishes were visually assessed by ROV using belt transect methods discussed in Chapter 7 Methods. Observations of fishes were restricted to the field of view of the ROVs high definition video camera. All fish species observed were recorded, counted, and sized using mounted scale lasers in the field of view of the ROV. Fork length was binned into eight groups; 0 – 5 cm, 5.1 – 10 cm, 10.1 – 15 cm, 15.1 – 20 cm, 20.1 – 25 cm, 25.1 – 30 cm, 30.1 – 35 cm, and >35.1 cm, where each individual's size was recorded. Each survey required 10 minutes to complete. Surveys began in the early morning (after 0700), and were repeated throughout the day until dusk. Each survey represented one sample.

The surveys were conducted in conjunction with mesophotic random transects, where the survey starting location was selected using a stratified random sampling design (see Chapter 7 Methods). At least fifteen surveys were conducted in mesophotic habitat. During the 2015 sampling period, 30 fish surveys were conducted.

In 2015, the same ROV system described in Chapter 6 Methods was used. This ROV was also equipped with an ORE transponder to collect ROV position information with ORE TrackPoint II.

Data Processing

Fish survey data were entered into a Microsoft® Excel® database by the surveyor in real time. Entered data were later checked by for quality and accuracy prior to processing by another person, utilizing high definition video of the survey. Data were processed using the same methods described in Chapter 3.

Transects where visibility was restricted to less than 5 m^2 in the field of view were removed from analysis. These transects exhibited low species richness and may not be representative of the habitat due to the limited visibility preventing species identifications. Additionally, transects >25% soft bottom habitat were removed from analyses.

Area of each survey was calculated by importing ROV track data, recorded every two seconds, into ArcMap®. The line data was smoothed using PAEK algorithm and a smoothing tolerance of 10 m. Line length was then calculated in WGS83 UTM15 for the 10 minute transect. Distance was multiplied by the maximum horizontal distance in the field of view, where field of view was determined using forward facing dual lasers

measured at the furthest point in the field of view. Measurements were calculated using ImageJ.

Post-hoc analysis of benthic transects in Chapter 7 revealed two distinct habitat types: deep reef and coralline algae. Fish surveys were analyzed as a whole, but also grouped by habitat type identified by the associated benthic transect in Chapter 7.

Statistical Analyses

See statistical analyses outlined in the Methods of Chapter 3.

Results

Thirty mesophotic fish surveys were conducted in 2015 (Figure 8.1). After removing transects with limited visibility or >25% soft bottom, 17 transects were analyzed. Greater turbidity was observed in the eastern portion of the deep reef, hence the lack of useable surveys in those locations. Depth of transects ranged from 35.6 – 57.6 m, with an average station depth of 49.0 m. Total species richness from all surveys was 53, and total family richness from all surveys was 24. Average species richness overall was 17 (± 1.3 SE), and average family richness overall was 11 (± 0.6 SE). Both average species and family richness was greater in coralline algae reef habitat (20 ± 0.9 SE; 11 ± 0.6 SE) than deep reef habitat (13 ± 2.1 SE; 9 ± 1.1 SE).

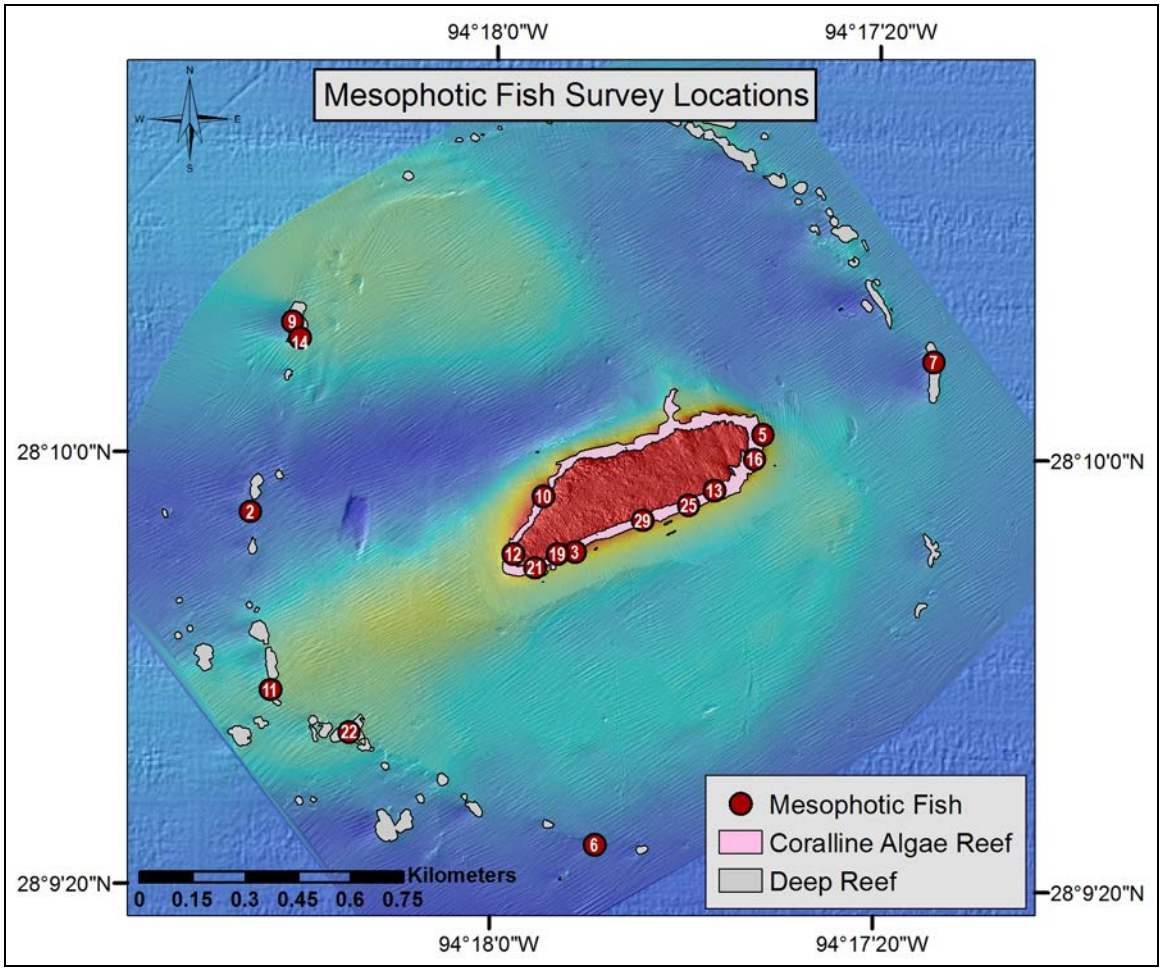


Figure 8.1. Location of mesophotic fish surveys.

Sighting Frequency and Occurrence

The most frequently sighted species in the mesophotic habitat at Stetson Bank in 2015 was Spotfin Hogfish (*Bodianus pulchellus*). Rank occurrence of the top 10 most frequently sighted species was calculated (Table 8.1).

Table 8.1. Sighting frequency of the 10 most observed mesophotic fish species. Grouped by habitat type, where bold text indicates species that were among the 10 most frequently seen species in all habitat types.

(Family Name: Species Name (Common Name - Trophic Guild) Species ID	Sighting Frequency (%)		
	All Surveys	Deep Reef	Coralline Algae Reef
Labridae: *Bodianus pulchellus* (Spotfin Hogfish-I)	88.2	71.4	100.0
Pomacentridae: *Chromis enchrysura* (Yellowtail Reeffish-I)	88.2	71.4	100.0
Lutjanidae: *Lutjanus campechanus* (Red Snapper-P)	76.5	100.0	60.0
Chaetodontidae: *Chaetodon sedentarius* (Reef Butterflyfish-I)	76.5	42.9	100.0
Epinephelidae: *Epinephelus adscensionis* (Rock Hind-I)	70.6	28.6	100.0
Pomacanthidae: *Holacanthus bermudensis* (Blue Angelfish-I)	64.7	57.1	70.0
Tetraodontidae: *Canthigaster rostrata* (Sharpnose Puffer-I)	64.7	14.3	100.0
Scorpaenidae: *Pterois volitans/miles* (Lionfish-P)	58.8	85.7	40.0
Pomacentridae: *Stegastes variabilis* (Cocoa Damselfish-H)	58.8	0.0	100.0
Pomacentridae: *Chromis scotti* (Purple Reeffish-PL)	58.8	0.0	100.0
Haemulidae: *Haemulon aurolineatum* (Tomtate-I)	35.3	85.7	0.0
Lutjanidae: *Rhomboplites aurorubens* (Vermilion Snapper-P)	35.3	85.7	0.0
Carangidae: *Seriola dumerili* (Greater Amberjack-P)	47.1	71.4	30.0
Epinephelidae: *Mycteroperca phenax* (Scamp-P)	41.2	71.4	20.0
Priacanthidae: *Priacanthus arenatus* (Bigeye-PL)	35.3	57.1	20.0
Pomacanthidae: *Pomacanthus paru* (French angelfish-I)	52.9	14.3	80.0
Holocentridae: *Holocentrus adscensionis* (Squirrelfish-I)	52.9	14.3	80.0

Species were considered “rare” if they were recorded in less than 20% of all surveys. “Prevalent” species were recorded in ≥20% of surveys. Over all surveys, a total of 24 species were characterized as “rare,” while 29 species were characterized as “prevalent.” Most shark and ray species were considered ‘rare’ throughout the Caribbean (REEF 2014). One Sandbar Shark (*Carcharhinus plumbeus*) and several Southern Stingray (*Dasyatis americana*) were recorded in mesophotic fish surveys at Stetson Bank during this study period, but all were considered “rare” in sighting frequency.

Density

Average fish density for all surveys was 31 individuals per 100 m^2 (± 9.2 SE). In deep reef habitat, Tomtate (*Haemulon aurolineatum*) and Vermilion Snapper (*Rhomboplites aurorubens*) had the greatest average density, with 21.2 individuals per 100 m^2 (± 17.6 SE) and 20.2 individuals per 100 m^2 (± 8.4 SE), respectively (Table 8.2). In coralline algae reef habitat, Yellowtail Reeffish (*Chromis enchrysura*) and Sunshinefish (*Chromis insolata*) had the greatest average density, with 4.9 individuals per 100 m^2 (± 2.2 SE) and 2.3 individuals per 100 m^2 (± 0.8 SE), respectively.

Table 8.2. Average density (individuals/100m^2) of the 10 densest mesophotic fish species. Grouped by habitat type, ± standard error, where bold text indicates species that were among the 10 densest species in all habitat types and dashes indicate that the species was not observed in that habitat

(Family Name: Species Name (Common Name - Trophic Guild) Species ID	Density (Individuals/100m2)		
	All Surveys	Deep Reef	Coralline Algae Reef
Haemulidae: *Haemulon aurolineatum* (Tomtate-I)	8.7 ± 7.4	21.2 ± 17.6	<0.1 ± 0.0
Lutjanidae: *Rhomboplites aurorubens* (Vermilion Snapper-P)	8.3 ± 4.1	20.2 ± 8.4	<0.1 ± 0.0
Pomacentridae: *Chromis enchrysura* (Yellowtail Reeffish-I)	3.4 ± 1.4	1.3 ± 0.7	4.9 ± 2.2
Lutjanidae: *Lutjanus campechanus* (Red Snapper-P)	1.4 ± 0.4	1.9 ± 0.9	1.1 ± 0.4
Pomacentridae: *Chromis insolata* (Sunshinefish-PL)	1.4 ± 0.6	0.1 ± 0.1	2.3 ± 0.8
Pomacentridae: *Stegastes variabilis* (Cocoa Damselfish-H)	1.2 ± 0.5	-	2.1 ± 0.8
Pomacentridae: *Chromis scotti* (Purple Reeffish-PL)	0.9 ± 0.4	-	1.5 ± 0.6
Labridae: *Thalassoma bifasciatum* (Bluehead-I)	0.6 ± 0.3	-	0.9 ± 0.5
Carangidae: *Seriola rivoliana* (Almaco Jack-P)	0.4 ± 0.4	1.0 ± 0.9	<0.1 ± 0.0
Labridae: *Bodianus pulchellus* (Spotfin Hogfish-I)	0.4 ± 0.1	0.3 ± 0.1	0.5 ± 0.1
Scorpaenidae: *Pterois volitans/miles* (Lionfish-P)	0.3 ± 0.1	0.5 ± 0.2	0.1 ± 0.0
Epinephelidae: *Mycteroperca phenax* (Scamp-P)	0.2 ± 0.1	0.4 ± 0.2	<0.1 ± 0.0
Priacanthidae: *Priacanthus arenatus* (Bigeye-PL)	0.2 ± 0.1	0.4 ± 0.2	<0.1 ± 0.0
Carangidae: *Seriola dumerili* (Greater Amberjack-P)	0.2 ± 0.1	0.3 ± 0.1	0.1 ± 0.1
Pomacentridae: *Stegastes partitus* (Bicolor Damselfish-H)	0.4 ± 0.2	<0.1 ± 0.0	0.6 ± 0.3
Tetraodontidae: *Canthigaster rostrata* (Sharpnose Puffer-I)	0.4 ± 0.1	<0.1 ± 0.0	0.6 ± 0.1
Pomacanthidae: *Pomacanthus paru* (French angelfish-I)	0.3 ± 0.1	<0.1 ± 0.0	0.4 ± 0.1

Biomass

Average biomass in all surveys was 3172.2 g/100 m^2 (± 1061.7 SE). Tomtate and Vermilion Snapper have the greatest average biomass in deep reef habitat, with 2204.8 g/100 m^2 (± 1845.4 SE) and 1315.4 g/100 m^2 (± 596.5 SE), respectively (Table 8.3). In coralline algae habitat, Greater Amberjack (*Seriola dumerili*) and Red Snapper (*Lutjanus campechanus*) have the greatest average biomass, with 389.5 g/100 m^2 (± 224.6 SE) and 317.9 g/100 m^2 (± 107.6 SE), respectively.

Table 8.3. Average biomass of the top 10 mesophotic fish species. Grouped by habitat type, ± standard error, where bold text indicates species that were among the 10 densest species in all habitat types and dashes indicate that the species was not observed in that habitat type.

Family Name: Species Name (Common Name - Trophic Guild Species ID	Biomass (g/100m2)		
	All Surveys	Deep Reef	Coralline Algae Reef
Haemulidae: *Haemulon aurolineatum* (Tomtate-I)	907.9 ± 774.2	2204.8 ± 1845.4	-
Lutjanidae: *Rhomboplites aurorubens* (Vermilion Snapper-P)	541.6 ± 284.9	1315.4 ± 596.5	-
Carangidae: *Seriola dumerili* (Greater Amberjack-P)	506.9 ± 162.8	674.5 ± 236.0	389.5 ± 224.6
Lutjanidae: *Lutjanus campechanus* (Red Snapper-P)	395.6 ± 109.1	506.6 ± 220.9	317.9 ± 107.6
Carangidae: *Seriola rivoliana* (Almaco Jack-P)	282.0 ± 230.0	619.8 ± 554.1	45.6 ± 39.2
Epinephelidae: *Mycteroperca phenax* (Scamp-P)	86.9 ± 37.3	170.1 ± 79.1	28.7 ± 19.3
Pomacanthidae: *Pomacanthus paru* (French angelfish-I)	82.3 ± 33.2	2.8 ± 2.8	137.9 ± 49.9
Scorpaenidae: *Pterois volitans/miles* (Lionfish-P)	66.1 ± 17.8	83.6 ± 25.9	53.9 ± 24.6
Carangidae: *Caranx crysos* (Blue runner-P)	58.7 ± 47.3	-	99.8 ± 79.5
Serranidae: *Hyporthodus nigritus* (Warsaw Grouper-P)	42.0 ± 42.0	102.0 ± 102.0	-
Balistidae: *Balistes capriscus* (Gray triggerfish-I)	21.8 ± 10.8	30.1 ± 24.2	15.9 ± 8.3
Pomacanthidae: *Holacanthus bermudensis* (Blue Angelfish-I)	38.1 ± 12.3	24.1 ± 9.9	47.9 ± 19.6
Epinephelidae: *Epinephelus adscensionis* (Rock Hind-I)	21.9 ± 5.9	2.8 ± 1.8	35.2 ± 7.5
Balistidae: *Balistes capriscus* (Gray triggerfish-I)	21.8 ± 10.8	30.1 ± 24.2	15.9 ± 8.3
Priacanthidae: *Priacanthus arenatus* (Bigeye-PL)	13.5 ± 6.4	30.0 ± 13.4	1.9 ± 1.4

Trophic Guilds

Species richness within trophic guilds was calculated overall and by habitat type (Table 8.4). Invertivores possessed the greatest average species richness overall, with 10 species (± 0.9 SE) comprising the guild, and herbivores possessed the lowest average species richness overall, with one species (± 0.3 SE) comprising the guild.

Table 8.4. Average mesophotic fish species richness within trophic guilds.

Trophic Guild	All Surveys	Deep Reef	Coralline Algae Reef
Planktivore	2 ± 0.3	1 ± 0.3	3 ± 0.3
Piscivore	4 ± 0.6	5 ± 0.8	3 ± 0.6
Invertivore	10 ± 0.9	1 ± 0.3	12 ± 0.6
Herbivore	1 ± 0.3	<1 ± <0.1	2 ± 0.3

The contribution of each trophic guild to the observed density and biomass overall and by habitat was calculated (Table 8.5). In deep reef habitat, piscivores and invertivores contributed most to observed density of fishes (50.0 % and 48.8 %, respectively). In coralline algae reef habitat, invertivores contributed the most to observed density (50.6 %), while piscivores contributed the least (13.6 %). Observed biomass in both deep reef and coralline algae reef habitat was primarily comprised of piscivores (59.7 % and 85.8 %, respectively).

Table 8.5. Percent contribution of mesophotic fish trophic guild to density and biomass.

Trophic Guild	Density (% Contribution)			Biomass (% Contribution)		
	All Surveys	Deep Reef	Coralline Algae Reef	All Surveys	Deep Reef	Coralline Algae Reef
Planktivore	9.1	1.1	19.8	0.7	0.6	1.5
Piscivore	35.8	50.0	13.6	63.3	59.7	85.8
Invertivore	49.9	48.8	50.6	35.6	39.5	11.1
Herbivore	5.3	0.1	15.9	0.4	0.2	1.6

The three species contributing the most to observed density (Table 8.6) and biomass (Table 8.7) within each habitat type and from each trophic guild were calculated.

Table 8.6. Percent contribution of mesophotic fish density of the top three species to trophic guild. Grouped by habitat type, where bold text indicates species that were among the three densest species in all habitat types

Trophic Guild	(Family Name: Species Name (Common Name - Trophic Guild) Species ID	% Contribution to Trophic Density		
		All Surveys	Deep Reef	Coralline Algae Reef
H	**Acanthuridae: *Acanthurus chirurgus* (Doctorfish-H)**	3.5	100.0	2.1
	Pomacentridae: *Stegastes variabilis* (Cocoa Damselfish-H)	73.1	-	74.1
	Pomacentridae: *Stegastes partitus* (Bicolor Damselfish-H)	22.7	-	23.0
I	Haemulidae: *Haemulon aurolineatum* (Tomtate-I)	56.1	88.8	-
	Pomacentridae: *Chromis enchrysura* (Yellowtail Reeffish-I)	21.9	5.6	49.8
	Labridae: *Bodianus pulchellus* (Spotfin Hogfish-I)	2.7	1.0	5.4
	Labridae: *Thalassoma bifasciatum* (Bluehead-I)	3.6	-	9.7
	Tetraodontidae: *Canthigaster rostrata* (Sharpnose Puffer-I)	2.4	0.1	6.4
P	Lutjanidae: *Rhomboplites aurorubens* (Vermilion Snapper-P)	74.4	82.5	-
	Lutjanidae: *Lutjanus campechanus* (Red Snapper-P)	12.8	7.8	59.4
	Carangidae: *Seriola rivoliana* (Almaco Jack-P)	3.9	4.0	2.4
	Carangidae: *Caranx crysos* (Blue runner-P)	2.0	-	20.5
	Carangidae: *Seriola dumerili* (Greater Amberjack-P)	1.5	1.2	4.2
PL	Priacanthidae: *Priacanthus arenatus* (Bigeye-PL)	7.2	79.0	1.1
	Epinephelidae: *Paranthias furcifer* (Atlantic Creolefish-PL)	8.8	11.0	8.6
	Pomacentridae: *Chromis insolata* (Sunshinefish-PL)	47.6	10.0	50.8
	Pomacentridae: *Chromis scotti* (Purple Reeffish-PL)	31.0	-	33.7

Table 8.7. Percent contribution of mesophotic fish biomass of the top three species from each trophic guild. Grouped by habitat type and overall, where bold text indicates species that were among the three densest species in all habitat types.

Trophic Guild	(Family Name: Species Name (Common Name - Trophic Guild) Species ID	% Contribution to Trophic Biomass		
		All Surveys	Deep Reef	Coralline Algae Reef
H	**Acanthuridae: *Acanthurus chirurgus* (Doctorfish-H)**	58.5	100.0	37.2
	Acanthuridae: *Acanthurus coeruleus* (Blue Tang-H)	36.2	-	54.8
	Pomacentridae: *Stegastes variabilis* (Cocoa Damselfish-H)	4.3	-	6.5
I	Haemulidae: *Haemulon aurolineatum* (Tomtate-I)	80.3	94.9	-
	Balistidae: *Balistes capriscus* (Gray triggerfish-I)	1.9	1.3	5.4
	Pomacanthidae: *Holacanthus bermudensis* (Blue Angelfish-I)	3.4	1.0	16.2
	Pomacanthidae: *Pomacanthus paru* (French angelfish-I)	7.3	0.1	46.6
	Epinephelidae: *Epinephelus adscensionis* (Rock Hind-I)	1.9	0.1	11.9
P	Lutjanidae: *Rhomboplites aurorubens* (Vermilion Snapper-P)	27.0	37.4	-
	Carangidae: *Seriola dumerili* (Greater Amberjack-P)	25.2	19.2	40.8
	Carangidae: *Seriola rivoliana* (Almaco Jack-P)	14.0	17.6	4.8
	Lutjanidae: *Lutjanus campechanus* (Red Snapper-P)	19.7	14.4	33.3
	Carangidae: *Caranx crysos* (Blue runner-P)	2.9	-	10.5
PL	**Priacanthidae: *Priacanthus arenatus* (Bigeye-PL)**	63.6	45.2	2.0
	Epinephelidae: *Paranthias furcifer* (Atlantic Creolefish-PL)	1.1	0.2	0.3
	Pomacentridae: *Chromis insolata* (Sunshinefish-PL)	<0.1	<0.1	<0.1
	Ptereleotridae: *Ptereleotris helenae* (Hovering dartfish-PL)	0.1	-	<0.1

Size-Frequency

Size frequency, using relative abundance, was calculated for all surveys and for each trophic guild (Table 8.6). In all surveys combined, 42.7% of individuals were 15-20 cm. A similar pattern was found in the piscivore and invertivore guilds. However, planktivores and herbivores were dominated by <5 cm individuals.

Table 8.6. Relative abundance (%) of individuals in each size category.

Size Category (cm)	All Surveys	Planktivore	Piscivore	Invertivore	Herbivore
<5	28.1	78.2	0.0	29.0	95.5
5-10	3.6	4.6	0.0	5.8	0.9
10-15	11.3	14.0	19.2	7.1	0.9
15-20	42.7	2.0	42.4	54.9	0.9
20-25	3.7	1.3	7.5	1.9	1.4
25-30	6.3	0.0	18.6	0.5	0.5
30-35	2.9	0.0	8.5	0.2	0.0
>35	1.5	0.0	3.7	0.5	0.0

Dominance Plots

When averaged for all samples, dominance plots (abundance-biomass curve) *w* values were slightly positive, 0.12 (± 0.03 SE) overall. Deep reef habitat had mean *w* statistic close to zero, while coralline algae reef habitat was slightly positive (0.01 ± 0.05 SE; 0.20 ± 0.03 SE).

Spatial Analysis

When surveys were projected spatially, general trends in species distributions were observed. The density of each trophic guild at each survey site was projected (Figure 8.2). During this study period, density of piscivores was noticeably greater in the deep reef habitat surrounding the main feature of Stetson Bank, primarily due to the density of Vermillion Snapper. Conversely, invertivore density was higher around the main feature of the bank in coralline algae habitat due to the density of Yellowtail Reeffish.

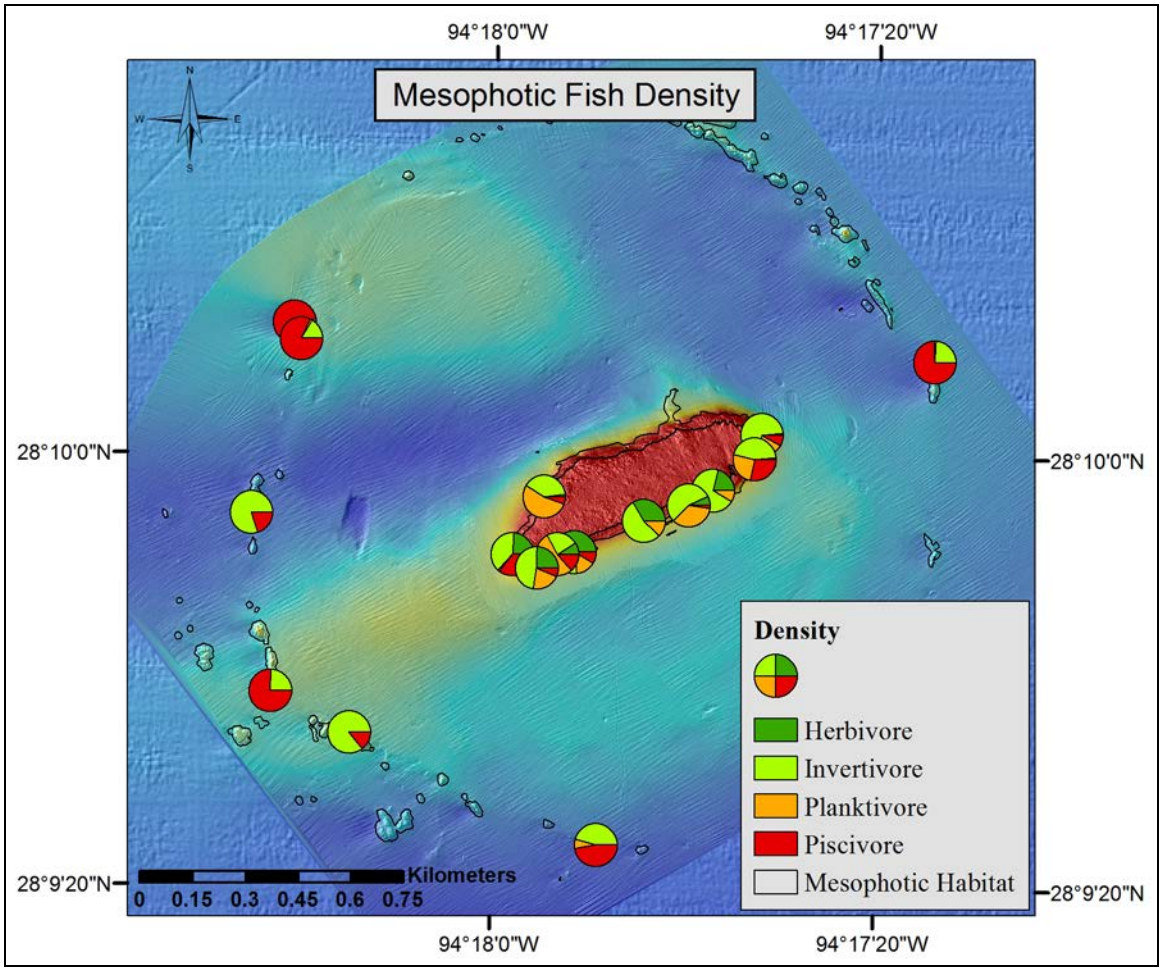


Figure 8.2. Spatial projection of mesophotic fish trophic density. Each chart represents the location at which a survey was conducted.

The biomass of each trophic guild at each survey site was also projected (Figure 8.3). During this study period, overall biomass of piscivores was dominant in all surveys. However, different species were responsible for the piscivore biomass dominance in deep reef habitat (Vermilion Snapper) and coralline algae reef habitat (Greater Amberjack).

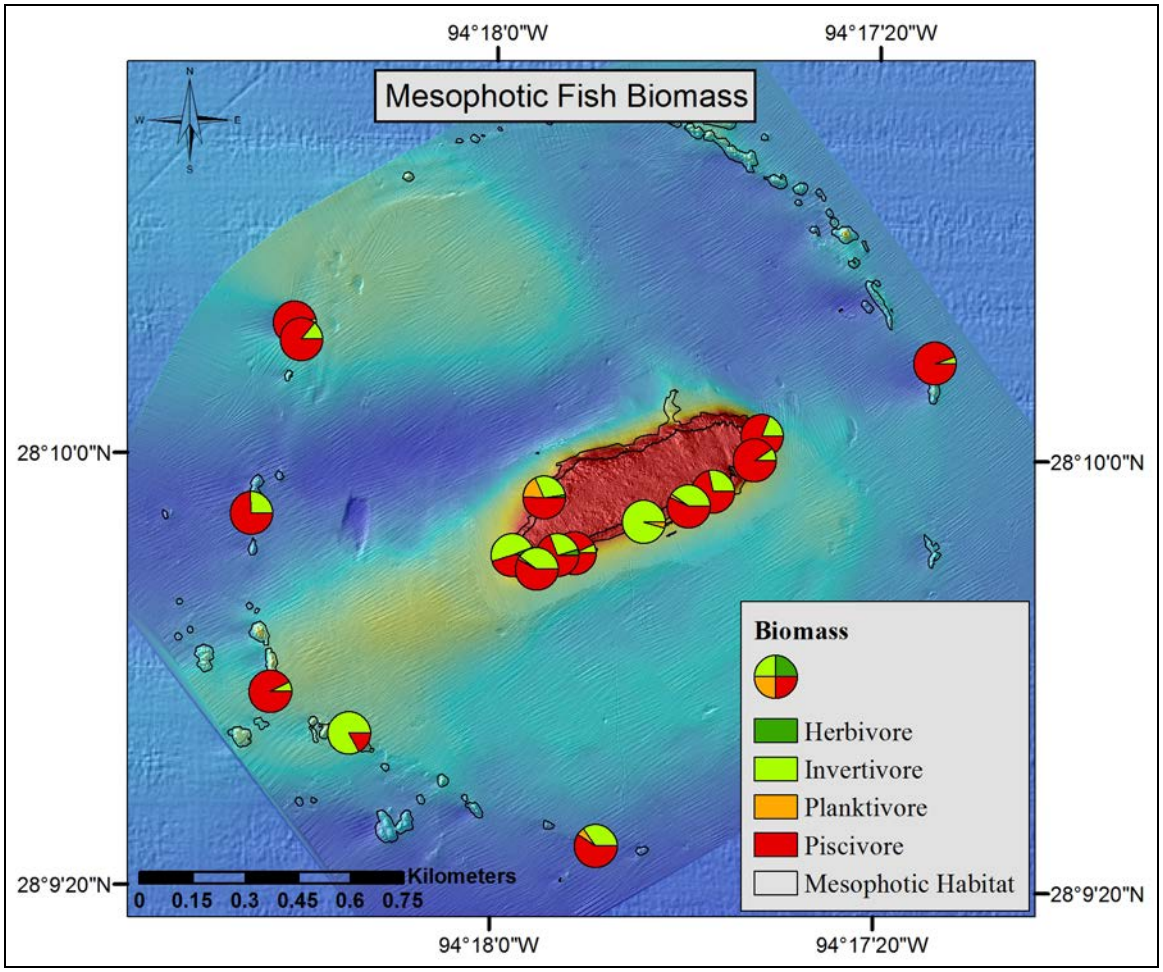


Figure 8.3. Spatial projection of mesophotic fish trophic biomass. Charts represents the location at which a survey was conducted.

Discussion

This data collection period represents the first quantitative mesophotic fish surveys conducted at Stetson Bank to date. Fish communities are considered an important component in monitoring programs as they can be indicators of ecosystem health (Sale 1991). The addition of mesophotic fish communities to this monitoring program will enable researchers and managers to better understand, monitor, and track changes in these deeper communities.

While direct comparison is not possible due to the different methods employed, these deeper communities were notably different to shallow bank crest communities. They were heavily dominated in both density and biomass by piscivorous fishes, and lacking in herbivorous fishes.

Fish in mesophotic habitat at Stetson Bank were dominated by medium sized individuals (15-20 cm), which account for over 50% of all recorded individuals. Abundance-Biomass Comparisons indicated the mesophotic fish community at Stetson Bank appears to be equally balanced between abundance and biomass in deep reef habitat, but coralline algae reef habitat is slightly biomass dominant.

Spatial analysis highlights the importance of mesophotic patch reefs for piscivorous fishes, both in density and biomass. The central feature of the bank was dominated by piscivore biomass, but harbored greater densities of invertivores.

On the bank crest of Stetson Bank, SCUBA divers have reported Lionfish since 2011. This study period represents the first records of lionfish in mesophotic fish surveys at Stetson Bank. The invasion of this exotic species is of particular concern due to their voracious appetite, high fecundity, and apparent low number of predators. While biomass and density of lionfish appeared low, they were recorded as the eighth most frequently sighted species on all surveys.

Continued monitoring of fish communities at Stetson Bank will help establish the degree of natural variation occurring in the community, allowing for more sensitive analysis to detect significant changes from the normal variation of the fish assemblage. Overall, the mesophotic fish community was variable and comprised of both commercially and recreationally valuable fish species.

Challenges and Resolutions

- Random fish surveys were challenging in low visibility habitats due to fish hiding before coming into the field of view of the camera and lack of water clarity making identifications difficult.
    - Additional surveys were conducted, to ensure a minimum of 15 surveys with sufficient visibility for fish surveys. Image size was calculated for each transect by taking a still frame from each transect, where field of view was calculated using the scale lasers at the furthest point from the ROV in the field of view. ImageJ was used to measure the size of the image. This information was plotted against species richness for each transect with a logistic trend line (Figure 8.4). The point at which the curve began to asymptote was selected as the minimum image size: $5m^2$.

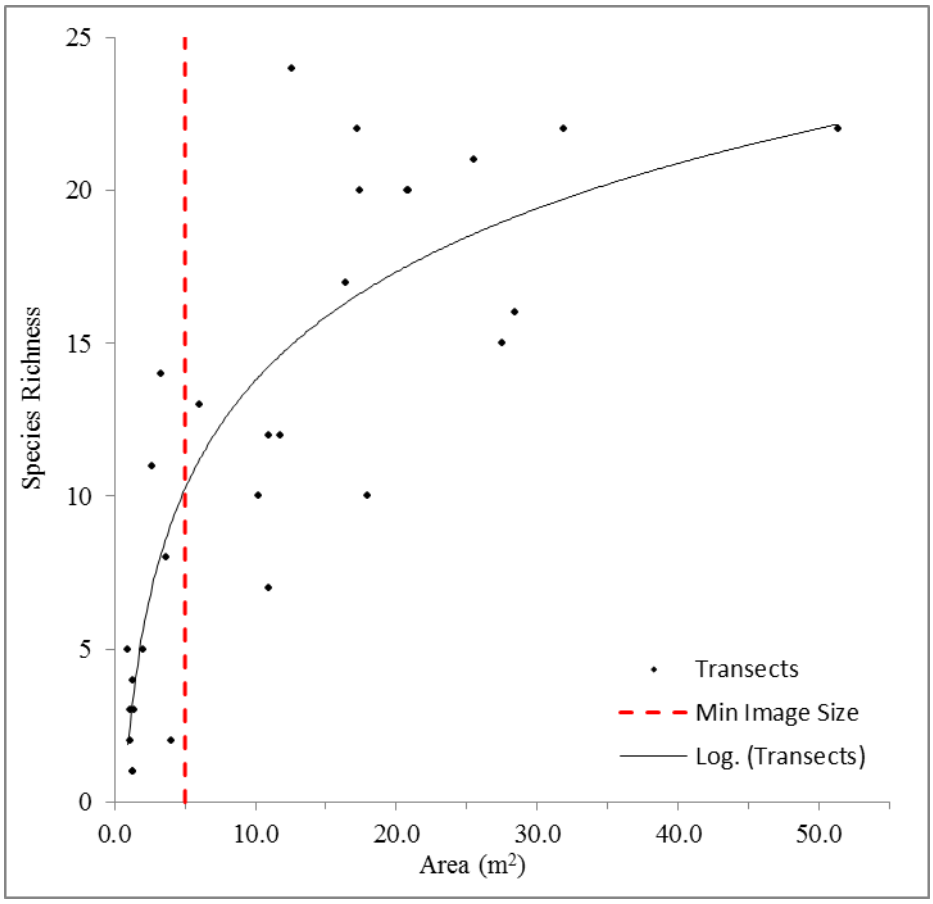


Figure 8.4. Mesophotic fish species accumulation curve. Species richness plotted against field of view from all mesophotic fish surveys conducted with ROV.

9. MESOPHOTIC WATER TEMPERATURE

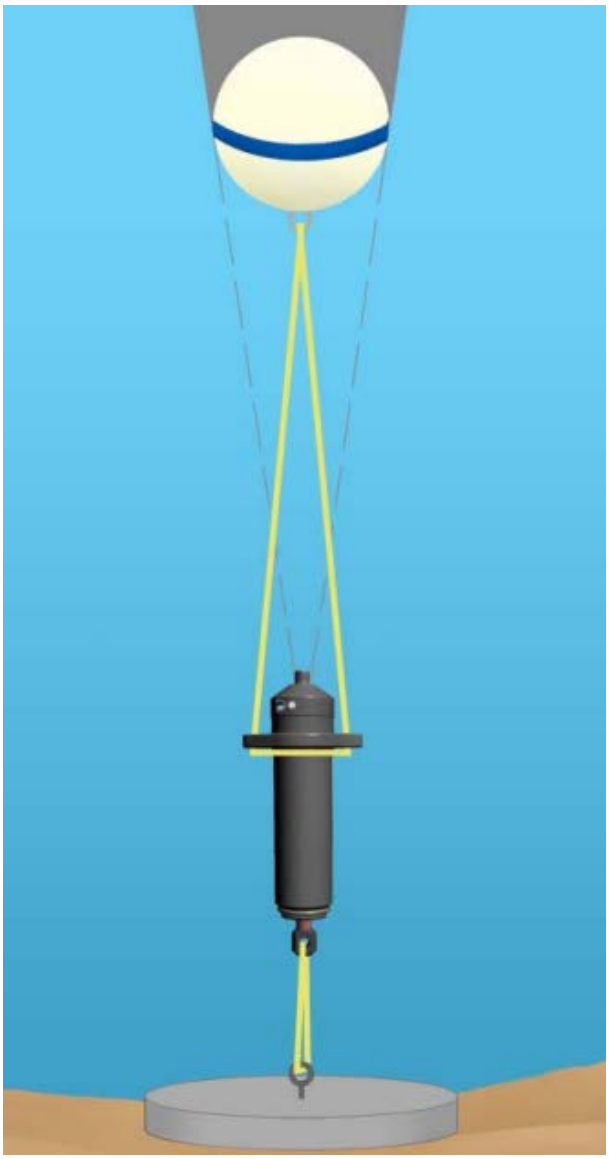


Photo: VEMCO

Introduction

Water temperature loggers were deployed at Stetson Bank in July, 2015, to collect water temperature data every hour. Two instruments were deployed on a single acoustic release system, one at 54 m and one at 44 m (Figure 9.1).

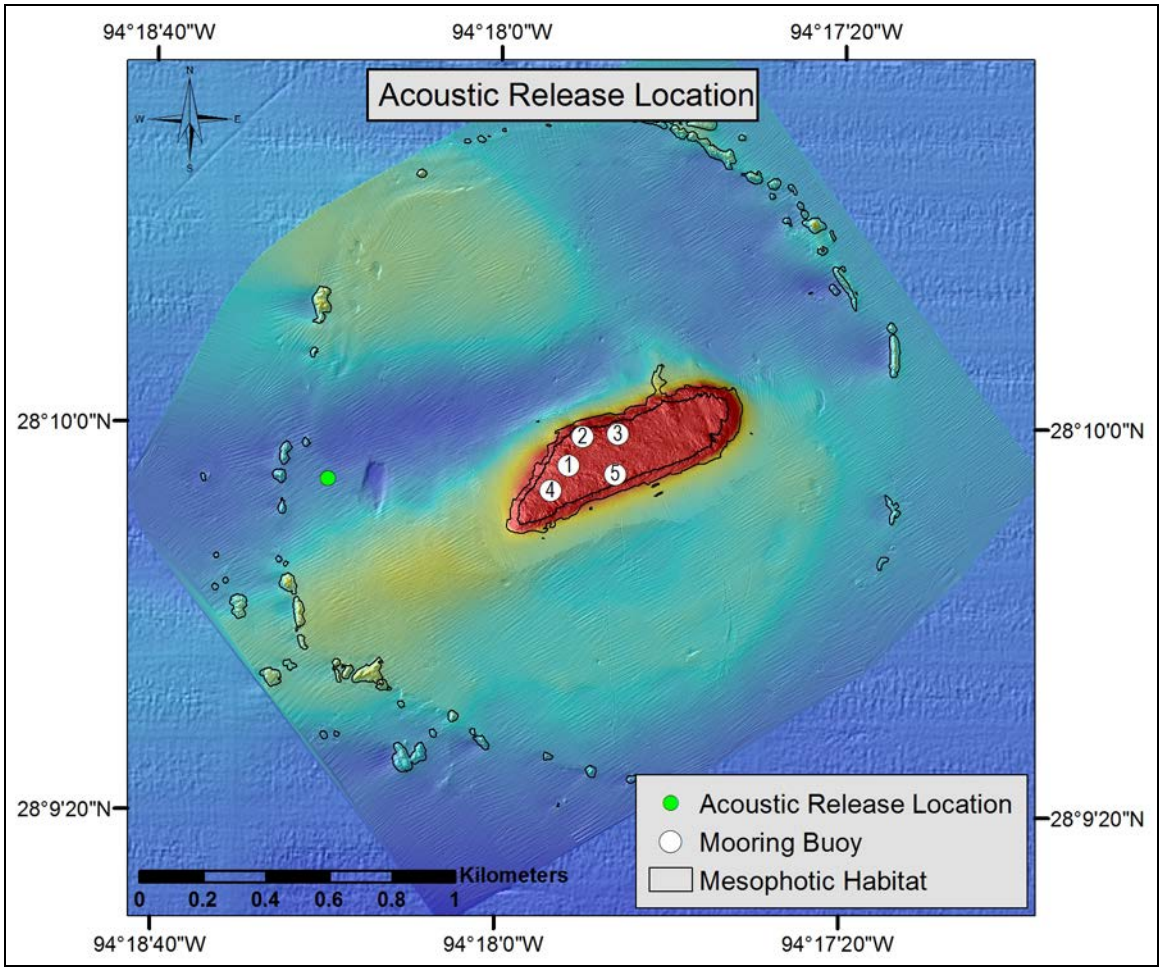


Figure 9.1. Location of the acoustic release system. System holds instruments at 54 m and 44 m to record water temperature every hour.

Methods

Field Methods

Acoustic Release System

Both instruments were deployed on an acoustic release system to allow easy deployment and retrieval, without the need for an ROV. A VEMCO VR2AR, in conjunction with a VR100 receiver, was used as the acoustic release system. In addition to the acoustic release system, the instrument can record and log water temperature. The VR2AR was

deployed using a concrete block connected to the releasing lug on the VR2AR. A hard trawl float (18 lbs. buoyancy) was connected to the receiver of the VR2AR via 10 m of wire rope.

Temperature Loggers

The VEMCO VR2AR was deployed at 54 m and used to record temperature at that depth. A Onset® Computer Corporation HOBO® Pro v2 U22-001 thermograph was attached to the wire rope 10 m above the VR2AR. Both instruments were set to record temperature hourly. Every six months the instrument will be collected, downloaded, maintained, and redeployed.

Data Processing

Temperature data obtained from loggers were downloaded and processed every six months. The twenty-four hourly readings obtained each day were averaged into one daily value and recorded in a database. Separate databases were maintained for each type of logger.

Results

No data are available at this time.

Discussion

Water temperature is one of many factors that can affect species composition and health. Generally, it is thought that temperature stability increases with depth. Divers deploy reef-based instruments to a maximum depth of 40 m. These mesophotic instruments expand the temperature array off the main reef feature at Stetson Bank to a maximum depth of 54 m. Temperature fluctuations at these sites will help researchers better understand the mesophotic environment at Stetson Bank and observe potential upwelling events.

Challenges and Resolutions

- When instrument retrieval was attempted on 11/3/2015, surface communication with the system indicated that the instrument was no longer vertical in the water column, laying horizontally on the seafloor. A release was attempted, and executed by the instrument, but the instrument did not rise to the surface. Other instrument status information indicated excellent battery life, low memory usage, and good communication to the surface unit.
    - It is presumed something has happened to the flotation of the instrument that holds it vertical in the water column and provides the flotation to return the instrument to the surface. The instrument is designed for

deployments lasting 14 months. All other information indicates the instrument is in good condition and can continue to collect data and communicate with the surface unit for an additional six months. We will wait until the 2016 mesophotic data collection cruise, when we will have the ROV onsite. At that time we will investigate the status of the instrument and attempt to retrieve it using the ROV.

10. VIDEO OBSERVATIONS AND NOTES

Photo: Marissa Nuttall/FGBNMS

Small reef fish schooling around high relief pinnacles at Stetson Bank.

Introduction

Three 100 m permanent video transects locations were established on the bank crest, covering both flat and high relief features, in addition to locations of high coral cover. As time permitted, video transects were conducted in the mesophotic habitat, traversing the extent of the bank and associated patch reef features. These transects were conducted for general condition observations.

Methods

Field Methods

Bank Crest Video Transects

Three 100 m permanent transects were installed at Stetson Bank. Each transect was marked using 12" stainless steel eyebolts drilled and epoxied into the reef at 25 m increments along the transect. Each eyebolt was labeled with a cattle tag denoting the transect number and the eyebolt position along the transect. Transect start locations were surveyed and will be added to the site maps. Before videoing, a line was laid between the eyebolts to mark the transect.

In 2015, video surveys were recorded along each transect, starting from eyebolt A, and ending at eyebolt E. Video was recorded using a Canon® VIXIA® HF G10 HD video camera in a Light and Motion® Stingray® housing with a Light and Motion® Fathoms® 90 degree super wide dome port.

A plumb bob was secured to the front of the camera housing with 2 m of scope between the camera housing and the plumb bob. The diver swam along the transect line, following the line with the plumb bob. The camera was maintained at a 45^{o} angle to the reef during filming.

Mesophotic Video Transects

Four 2500 m north-south and four 2500 m east-west transect lines were drawn in ArcMap (Figure 10.1). Transects covered the complete extent of the bank feature and associated patch reefs. An ROV was used to follow the transect line, collecting forward facing video during transects. Annotations were recorded during the ROV dive. Habitat, benthic biota, fish community, and general notes were recorded and binned into five minute intervals. Transects were conducted as time permitted.

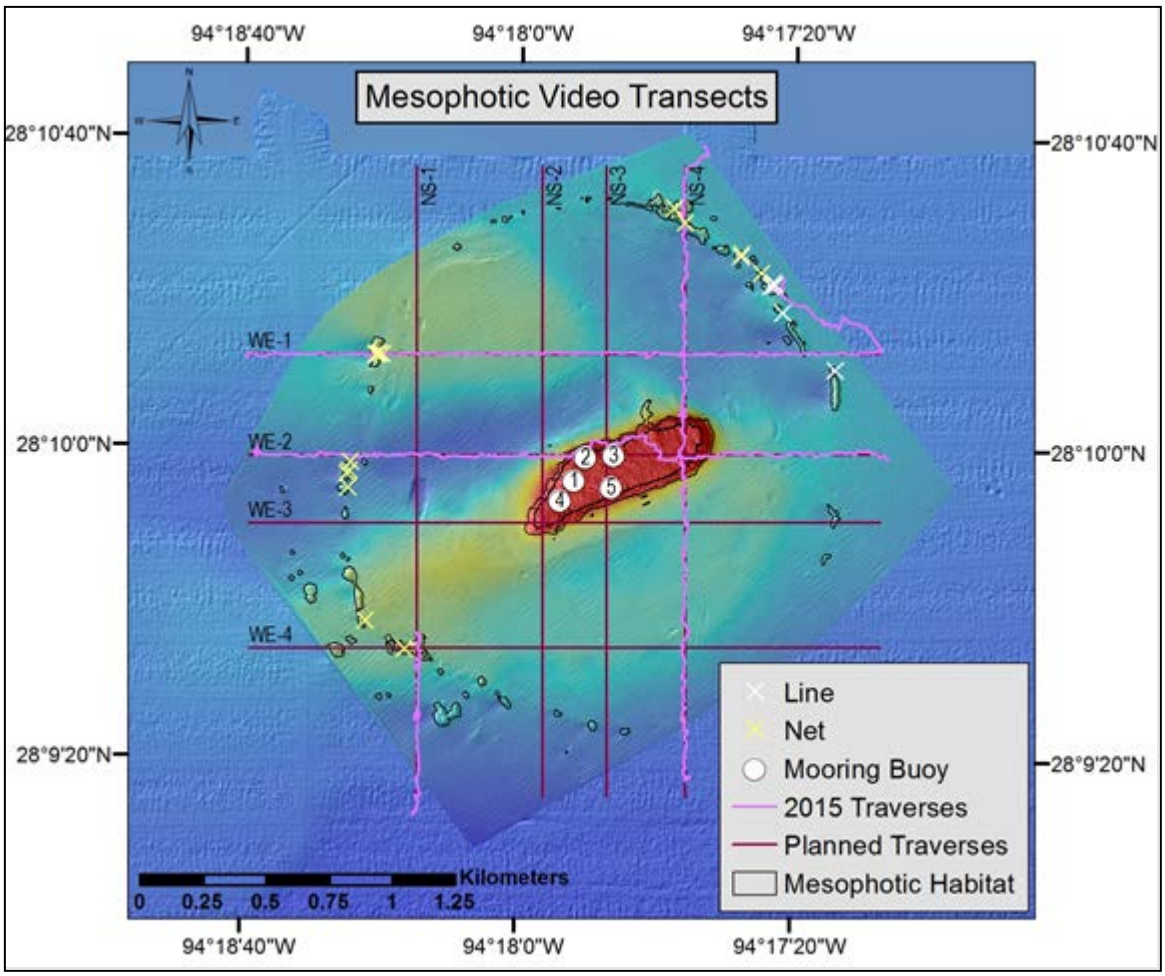


Figure 10.1. Location of mesophotic video transects.

In 2015, the same ROV system described in Chapter 6 Methods was used.

General Observations

General observations of interest were recorded throughout the field work. Observations of biology, geology, marine debris and operations were made and recorded as notes on each transect.

Data Processing

Notes and observations were made from each transect and recorded in Microsoft® Excel®. Notes were reviewed for interesting or important information.

Results

Bank crest video transects captured moderate densities of Long-Spined Sea Urchins, in addition to sponge and coral colonies. Sponges and corals appeared to be in good health with no notable impacts.

A total of 3.25 mesophotic video transects were completed in 2015 (Table 10.1). Transects covered a variety of habitats; mesophotic patch reefs, soft bottom pits and burrows, and shallow reef. Observations noted several previously unknown marine debris locations (trawl nets) and low relief rubble patches with mesophotic and deep-sea corals.

Table 10.1. Mesophotic video transects completed.

Transect Name	Direction
WE-1	East to West
WE-2	West to East
NS-4	North to South
NS-1	South to North (1/4 transect completed)

General observations on the shallow reef cruise included observations of Sandbar Sharks, Manta Rays, Loggerhead Sea Turtles, Common Octopus, location of *P. strigosa* coral heads, and location of potential lobster dens. Divers also noted an apparent reduction in macroalgae. On the mesophotic cruise, researchers observed Sandbar and Blacktip Sharks and Lionfish. Visibility was noted to be variable around the reef, but appeared best in the morning hours.

Discussion

Several interesting observations were made during the 2015 field season. New marine debris locations will be recorded for GIS mapping. *P. strigosa* and lobster den locations will be added to the sites maps. Observed macroalgae reduction in June 2015 was of particular interest, and continued monitoring of the status of macroalgae on the reef will be conducted, when possible, on quarterly water quality cruises through 2016 (a subsample of ~30 of the shallow reef repetitive photostations will be marked and photographed, as time and conditions permit).

Conclusions

This report summarizes the findings from the annual monitoring conducted at Stetson Bank in 2015. Both bank crest and mesophotic habitat were surveyed in this study period.

The bank crest of Stetson Bank has been monitored for over 20 years. While repetitive photostations do not capture the entire reef community, this form of benthic monitoring has been conducted annually on the reef since 1993, and documented a significant shift from sponge-coral community to algal community over that time. Data from this study period indicated a potential reduction in macroalgae cover, increasing the availability of open substrate for potential colonization. This finding was also supported in random transect data.

Although water column temperatures warmed quickly early in the year, this study period did not record water temperatures on the bank crest exceeding 30^{o}C. However, salinity declines in July may indicate potential runoff events. While no direct water samples were collected during the time period of reduced salinity, all nutrient samples in 2015 were below detectable limits. Carbonate chemistry indicates that this area, despite its proximity to the land, more closely resembles an open ocean setting, and acts as a net CO_2 sink.

Mesophotic benthic habitats at Stetson Bank where quantitatively surveyed for the first time in 2015. Results from this analysis show two distinct habitats were encountered, each with a unique biotic community. While biota cover was low on mesophotic reefs in general, density of select stony coral species, including potential coral recruits, was high on mesophotic reefs with coralline algae (coralline algae reef), and density of black coral species was high on mesophotic reefs without coralline algae (deep reef).

While a direct comparison is not possible due to the different methods used, fish communities between the bank crest and mesophotic habitat appear to be very different. The mesophotic habitat appears to be an important location for piscivorous fishes while the bank crest supports a greater proportion of invertivorous fishes. The dominant species observed in mesophotic habitat at Stetson Bank are commercially and recreationally valuable species.

Several challenges were encountered during this study period, particularly with mesophotic monitoring tasks. Visibility proved to be the greatest challenge in completing field work. The 2016 field season will allow further refinement of these techniques and retrieval of malfunctioning equipment.

To date, this monitoring program represents one of the longest running monitoring efforts of a northern latitude coral community. An ongoing monitoring program at Stetson Bank is essential to monitor the drivers of ecosystem variation and change in the northern Gulf of Mexico. Continued monitoring will continue to document changes in the condition of the reef and will be useful for management decisions and future research.

References

Aronson R.B. and W.F. Precht. 2000. Herbivory and algal dynamics on the coral reef at Discovery Bay, Jamaica. Limnology and Oceanography 45:251–255.

Bates, NR, Best MHP, Neely K, Garley R, Dickson AG, and Johnson RJ. 2012. Detecting anthropogenic carbon dioxide uptake and ocean acidification in the North Atlantic Ocean. Biogeosciences, 9: 2509-2522.

Bonaldo RM, Bellwood DR. 2011. Spatial variation in the effects of grazing on epilithic algal turfs on the Great Barrier Reef, Australia. Coral Reefs 30(2): 381-390.

Bohnsack JA, Bannerot SP. 1986. A stationary visual census technique for quantitatively assessing community structure of coral reef fishes. NOAA Technical Report NMFS 41. 15pp.

Bohnsack JA , Harper DE. 1988. Length-weight relationships of selected marine reef fishes from the southeastern United Station and the Caribbean. NOAA Technical Memorandum NMFS-SEFC-215. 37pp.

Bray JR, Curtis JT. 1957. An ordination of upland forest communities of southern Wisconsin. Ecological Monographs 27:325-349.

Carpenter RC, Edmunds PJ. 2006. Local and regional scale recovery of *Diadema* promotes recruitment of scleractinian corals. Ecol Lett 9:268–277.

Clarke KR. 1990. Comparison of dominance curves. Journal of Experimental Marine Biology and Ecology 138:143-157.

DeMartini EE, Friedlander AM, Sandin SA, Sala E. 2008. Differences in fish-assemblage structure between fished and unfished atolls in the northern Line Islands, central Pacific. Marine Ecology Progress Series 365: 199-215.

Diaz-Pulido G, Garzon-Ferreira J. 1997. Seasonal variation of algal cover in rock coral reefs on the Tayrona park, Colombian Caribbean. America Zoologist 37(5):35A.

Diaz-Pulido G, Garzon-Ferreira J. 2002. Seasonality in algal assemblages on upwelling-influenced coral reefs in the Colombian Caribbean. Botanical Marina 45: 284-292.

Edmunds PJ and Carpenter RC. 2001. Recovery of *Diadema antillarum* reduces macroalgal cover and increases abundance of juvenile corals on a Caribbean reef. Proceedings of the National Academy of Sciences 98:5067–5071.

Friedlander A, DeMartini E. 2002. Contrasts in density, size, and biomass of reef fishes between the northwestern and the main Hawaiian Islands: the effects of fishing down apex predators. Marine Ecology Progress Series 230:253–264.

Froese, R. and D. Pauly. Editors. 2016. FishBase. World Wide Web electronic publication. Accessed 2/22/2016. www.fishbase.org

Hixon M, Beets J (1993) Predation, prey refuges, and the structure of coral-reef fish assemblages. Ecological Monographs 77–101.

Jackson JBC, Donovan MK, Cramer KL, Lam VV (editors). 2014. Status and Trends of Caribbean Coral Reefs: 1970-2012. Global Coral Reef Monitoring Network, IUCN, Gland, Switzerland.

Johnson MA, Embesi JA, Eckert RJ, Nuttall MF, Hickerson EL, Schmahl GP. *In Press*. Persistence of Coral Assemblages at East and West Flower Garden Banks, Gulf of Mexico. Coral Reefs.

Johnston MA, Nuttall MF, Eckert RJ, Embesi JA, Slowey NC, Hickerson EL, Schmahl GP. 2015. Long-term monitoring at East and West Flower Garden Banks National Marine Sanctuary, 2011–2012, volume 1: technical report. U.S. Dept. of Interior, Bureau of Ocean Energy Management, Gulf of Mexico OCS Region, New Orleans, Louisiana. OCS Study BOEM 2015-027. 194 p.

Knowlton N, Jackson J.. 2008. Shifting Baselines, Local Impacts, and Global Change on Coral Reefs. PLoS Biol 6:e54.

Kohler K.E. and 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: 1259–1269.

Kramer PA .2003. Synthesis of coral reef health indicators for the western Atlantic: results of the AGRRA program (1997–2000). Atoll Res Bull 496:1–57.

Meade R.H.. 1995. Contaminants in the Mississippi River. US Geological Survey Circular 1133, 140 pp.

Mumby PJ, Hedley JD, Zychaluk K, Harborne AR, Blackwell PG. 2006. Revisiting the catastrophic die-off of the urchin *Diadema antillarum* on Caribbean coral reefs: fresh insights on resilience from a simulation model. Ecol Model 196:131–148.

Mumby PJ, Hastings A, Edwards HJ. 2007. Thresholds and the resilience of Caribbean coral reefs. Nature 450:98–101.

Odum E, Odum H (1971) Fundamentals of ecology. Saunders Philadelphia.

Sale PF. 1991. The ecology of fishes on coral reefs. Academic Press, Inc., San Diego, California. 754 pp.

Sandin S, Smith J, DeMartini E, Dinsdale E, Donner S, Friedlander A, Konotchick T, Malay M, Maragos J, Obura D.. 2008. Baselines and degradation of coral reefs in the northern Line Islands. PLoS ONE 3:e1548.

Singh A, Wang H, Morrison W, Weiss H. 2012. Modeling fish biomass structure at near pristine coral reefs and degradation by fishing. Journal of Biological Systems. 20(1): 21-36.

Takahashi T, Sutherland SC, Wanninkhof R, Sweeney C, and others. 2009. Climatological mean and decadal change in surface ocean pCO_2, and net sea–air CO_2 flux over the global oceans. Deep Sea Research Part II: Topical Studies in Oceanography 56:554-577.

Wang H, Morrison W, Singh A, Weiss H. 2009. Modeling inverted biomass pyramids and refuges in ecosystems. Ecological Modeling 220(11):1376-1382.

Zimmer B, Duncan L, Aronson RB, Deslarzes KJP, Deis D, Robbart ML, Precht WF, Kaufman L, Shank B, Weil E, Field J, Evans DJ, Whaylen L. 2010. Long-term monitoring at the East and West Flower Garden Banks, 2004–2008. Volume I: Technical report. U.S. Dept. of the Interior, Bureau of Ocean Energy Management, Regulation, and Enforcement, Gulf of Mexico OCS Region, New Orleans, Louisiana. OCS Study BOEMRE 2010-052. 310 p.

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