Re-Evaluation of Module and Boulder Reefs: Miami-Dade County Artificial Reef Program 2019

FINAL REPORT

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ABSTRACT

Over the last 26 years, limerock boulder and module artificial reefs have been deployed offshore of Miami-Dade County for a variety of purposes including mitigation, fisheries enhancement, and recreational diving. This study sought to reexamine fish and benthic assemblages utilizing five limerock boulder reefs and two module reefs in Miami-Dade County. These reefs were first evaluated in previous FWC artificial reef monitoring grants from 2007-2009. The five boulder reefs evaluated included the Anchorage Boulder Reef (ANCB), Golden Beach Boulder Reefs (GDBB), Port of Miami Boulder Rows (PMBR), Port of Miami Boulder Piles (PMBP), and the Sunny Isles Mitigation Boulders (SIMB). The two module reefs were the Port of Miami A modules (PMAM) and the Sunny Isles Mitigation Modules (SIMM). Five reefs (PMBP, PMBR, SIMB, SIMM, and PMAM) were constructed with a broad goal to serve as mitigation reefs for dredging related impacts. One reef was constructed for fishery enhancement (ANCB) and one for both fishery enhancement and recreational diving opportunities (GDBB). This study demonstrated that all seven artificial reefs provide habitat that has supported abundant and diverse biological assemblages and have met the broad objectives for which they were deployed. The density of the fish assemblages increased in 2019 on ANCB, GDBB, and PMAM largely due to the abundance of grunts (Haemulidae), in particular *Haemulon aurolineatum* (tomtates), and decreased on the other sites due to fewer grunts and gobies (Gobidae). Other common reef fish families in both sampling periods were snappers (Lutjanidae), wrasses (Labridae), damselfish (Pomacentridae), and parrotfish (Scaridae). In general, more gamefish species were observed on the higher relief boulder reefs—GDBB, ANCB, PMBR, and PMAM. However, of those gamefish species with a regulated minimum size, only a few individuals were above the size and able to be harvested. In both sampling periods, benthic assemblages on all seven artificial reefs were dominated by turf algae coverage followed by soft coral (Octocorallia) on PMBP and PMBR and sponge (Porifera) species on the other five sites. Octocoral cover increased in 2019 on six of seven sites. Scleractian cover increased on all sites with the exception of PMAM at which a nearly 3% decline was observed due to loss of *Oculina diffusa*. Future artificial reef construction will be guided by results from this and prior grant monitoring. Both reef boulders and modules can provide suitable substrate for benthic assemblages but could be tailored toward modules if porifera cover is a priority. If fisheries enhancement is the project goal, higher relief boulders would be preferable and placing a large material footprint may minimize the dominance of large schools of grunts.

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INTRODUCTION

Artificial reefs are best known as a tool for fishery enhancement (Bohnsack and Sutherland 1985, Palmer-Zwahlen and Aseltine 1994, Pickering et al. 1998, Seaman 2000). However, during the last few decades, the uses of artificial reefs have expanded to include mitigation, habitat rehabilitation, habitat restoration, and habitat protection (Pickering et al. 1998). Seaman (2000) defined artificial reefs as objects, natural or human made, deployed purposefully on the seafloor to influence physical, biological, or socioeconomic processes related to living marine resources. Seaman’s definition has incorporated all such uses.

Over the last three decades, numerous artificial reefs, constructed from pre-fabricated concrete modules and boulders, have been deployed offshore of Miami-Dade County for a variety of purposes including mitigation, fisheries enhancement, and recreational diving. Through Florida Fish and Wildlife Conservation Commission (FWC) Grants #06121, #07015, and #08253, several of the Miami-Dade County module and boulder reefs were evaluated from 2006 to 2009 (Miami-Dade County 2007, Miami-Dade County 2008, and Sathe and Thanner 2009). This project surveyed benthic and fish assemblages on five different boulder reefs and two different module reefs which were evaluated through those three previous grants to document any changes in community structure over the last decade. Five of the monitored reefs were deployed as mitigation for coastal construction impacts, however, without definable goals to determine success. These sites include Sunny Isles Mitigation Reef- Boulders and Modules (SIMB and SIMM, respectively), Port of Miami A Modules (PMAM), and Port of Miami B Boulder Piles and Rows (PMBP and PMBR, respectively). One site, Golden Beach Boulders (GDBB) was deployed for general enhancement of recreational fishing and diving opportunities in the northern portion of the County. GDBB was not constructed for the enhancement of specific species, just a general high relief fishing and diving location. The purpose of the final site, Anchorage Boulders (ANCB), was simply for fisheries enhancement.

SITE DESCRIPTIONS

As noted above a total of seven artificial reefs were evaluated within five of Miami-Dade’s larger permitted sites (Figure 1). The seven artificial reefs have differing characteristics which are summarized in Table1 and described in more detail below.

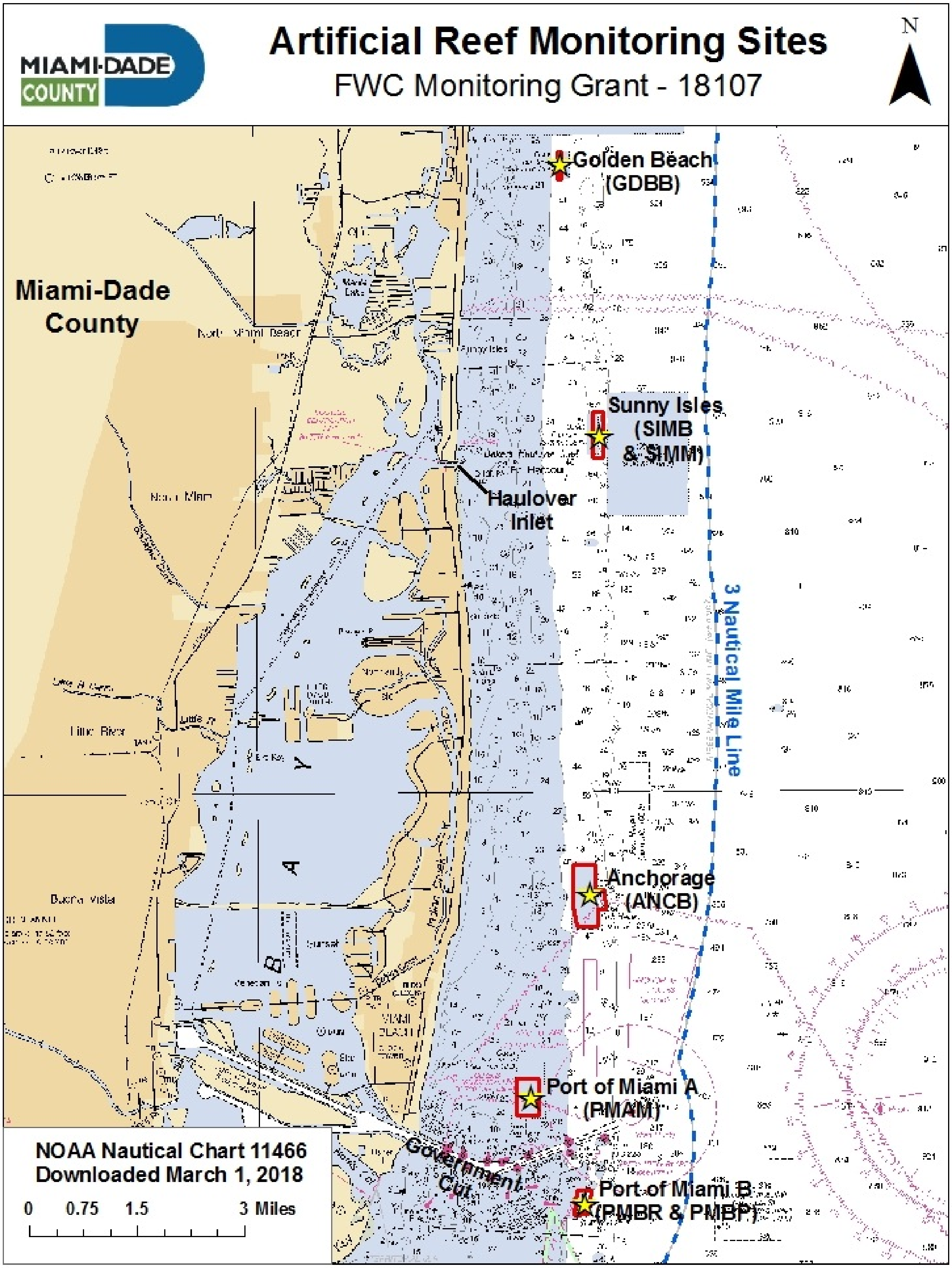

Figure 1. Location of the Golden Beach Boulders (GDBB), Sunny Isles Boulders (SIMB) and Modules (SIMM), Anchorage Boulders (ANCB), Port of Miami A Modules (PMAM), and Port of Miami B Boulders (PMBP and PMBR). See Figures 5-9 for detail site specific maps.

Table 1. Artificial reefs evaluated in FWC Grant #18107.

Site Name	Site Abbr.	Tons / Description	Approx. Footprint (m^2)	Depth (ft)	Max Relief (ft)	Year Deployed (Current Age)	Previous Grant Monitoring: FWC Grant #	Previous Grant Monitoring: Year	Previous Grant Monitoring: Age Then
Anchorage Reef—Boulders	ANCB	• 1,050 tons of limerock boulders deployed in 1 multi-layered row • Provide enhanced fishing opportunities	869	56	10	1995 (24)	06121	2007	11.5
Golden Beach Reef—Boulders	GDBB	• 850 tons of limerock boulders deployed in 3 multi-layered piles • Provide enhanced diving and fishing opportunities	520	43	13	2005 (14)	06121	2007	2
Port of Miami B—Boulder Piles Port of Miami B—Boulder Rows	PMBR PMBP	• 120,000 tons of limerock boulders deployed in multi-layered rows (11) and piles (35) • Mitigation for dredging impacts	59,950	45	10	1996 (23)	06121	2007	10.5
Sunny Isles Mitigation Reef—Boulders Sunny Isles Mitigation Reef—Modules	SIMB SIMM	• 1,500 tons of limerock boulders scattered in single layer along with 50 modules • Mitigation for dredging impacts	18,581*	68	5	1993 (26)	07015	2008	15
Port of Miami A – Modules	PMAM	• 495 modules deployed on 25’ centers • Mitigation for dredging impacts	32,516*	25	5	1996 (23)	08253	2009	13

*Inclusive of sand area between artificial reef material.

Anchorage Boulder Reef (ANCB): ANCB was deployed in 1995 with the objective of simply providing an enhanced fishing location. This reef consists of one row of multi-layered boulders approximately 40 m x 15 m (130 ft x 50 ft) (Figure 2). ANCB lies at a depth of 65 ft with up to 10 ft relief. Approximately 14 m (45 ft) northeast of the ANCB lies the Patricia (steel tug) and approximately 21 m (70 ft) southeast lies the Miss Karline (steel hull). Scattered steel antennae pyramids and concrete pieces are located south of the boulders beginning at about 38 m (130 ft) away. Natural hard bottom is approximately 183 m (600 ft) to the north-north west.

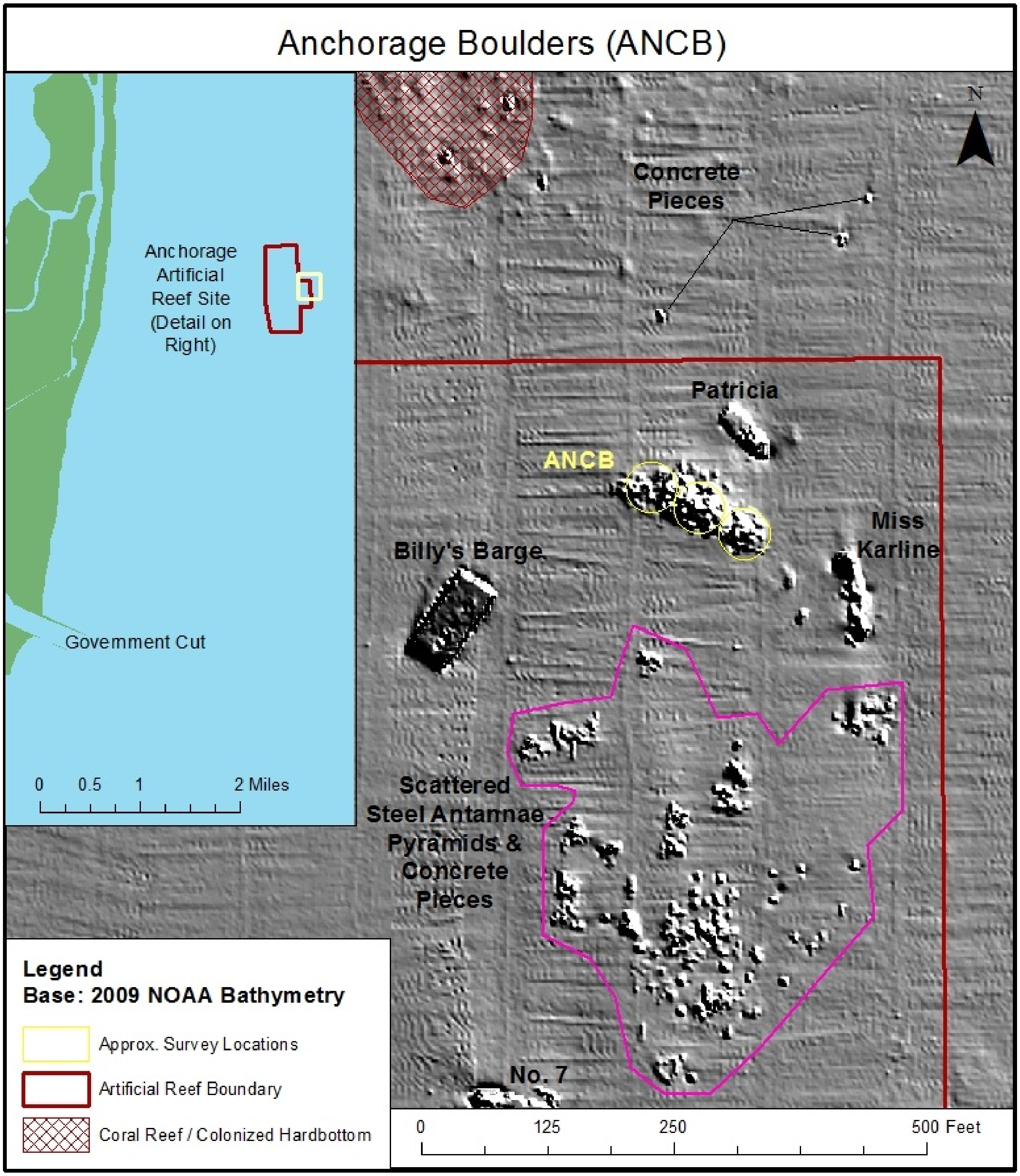

Figure 2. Anchorage Boulders (ANCB).

Golden Beach Reef—Boulders (GDBB): GDBB was deployed in 2005 to add shallow, high relief recreational fishing and diving opportunities in the northern part of Miami-Dade County. This is the youngest reef evaluated and comprised of three multi-layered boulder piles ranging in length from 14—20 m (45—65 ft) (Figure 3). The GDBB reef lies at a depth of 43 ft with up to 13 ft relief. Adjacent to the three boulder piles, 33 Reef Balls® clusters (217 individual reef balls) were deployed in between and surrounding the boulder piles from 2006 to date. Three reef ball clusters were deployed as part of school or scout projects. The remaining reef ball clusters were deployed as memorials by Eternal Reefs. The closest natural hard bottom to these artificial reefs is approximately 49 m (160 ft) to the west.

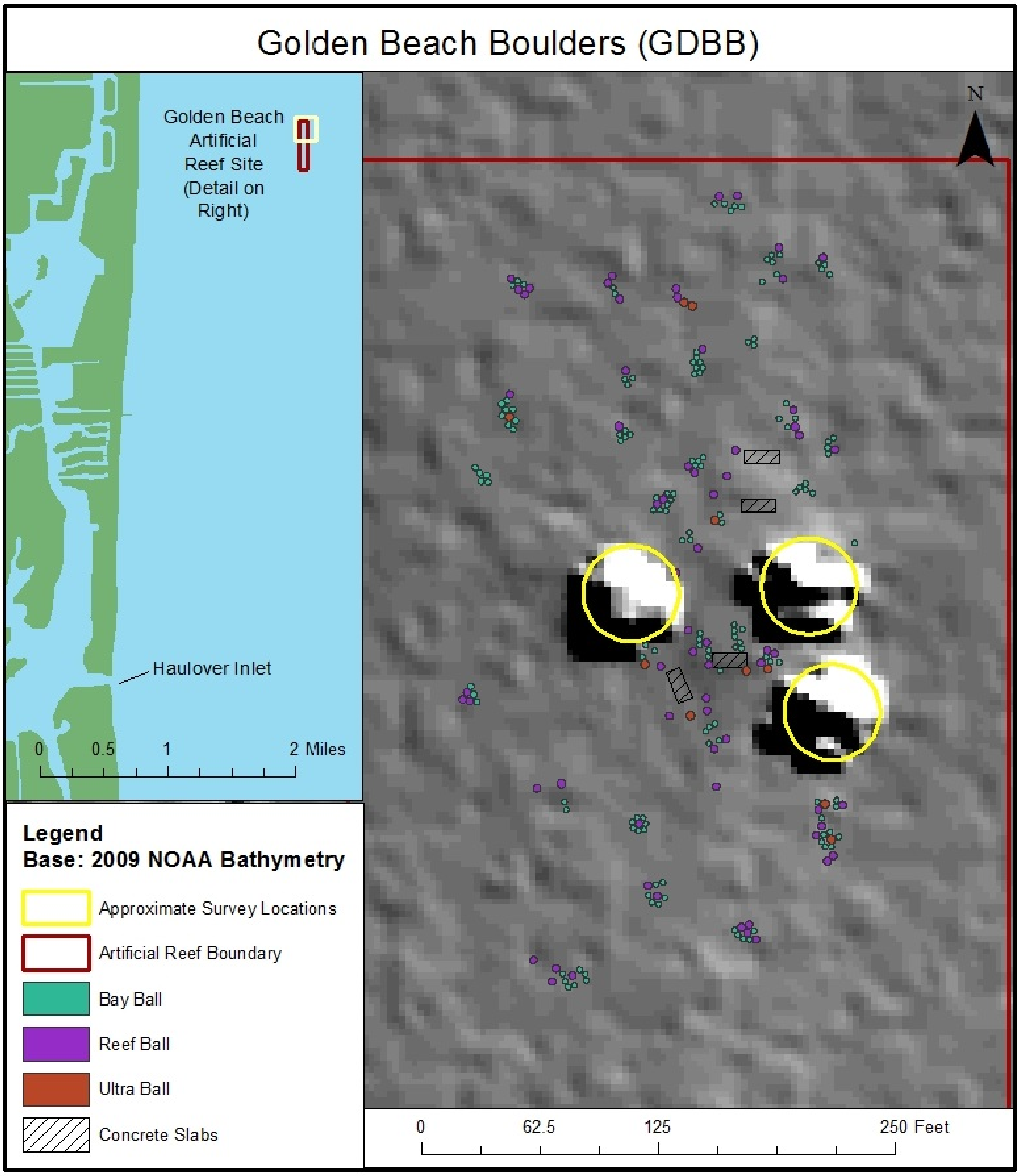

Figure 3. Golden Beach Boulders (GDBB).

Port of Miami Mitigation Site B - Boulder Rows (PMBR) and Piles (PMBP): The Port of Miami Site B material was deployed in 1996 as mitigation to offset impacts to high relief hardbottom communities by dredging for a Port of Miami expansion project. This site is comprised of multi-layered boulder rows and piles stretched across an area 500 m x 460 m (1600 ft x 1500 ft) (Figure 4). The 11 rows are each approximately 152 m x 15 m (500 ft x 50 ft) and the 35 piles are each approximately 27 m x 15 m (90 ft x 50 ft). South of this site, additional boulders were added in 2014 as mitigation for another phase of the Port of Miami Dredging Project. Spoil material (rubble from old Government Cut dredging projects) is located approximately 61 m (200 ft) to the north and the closest natural hard bottom area is 122 m (400ft) to the west.

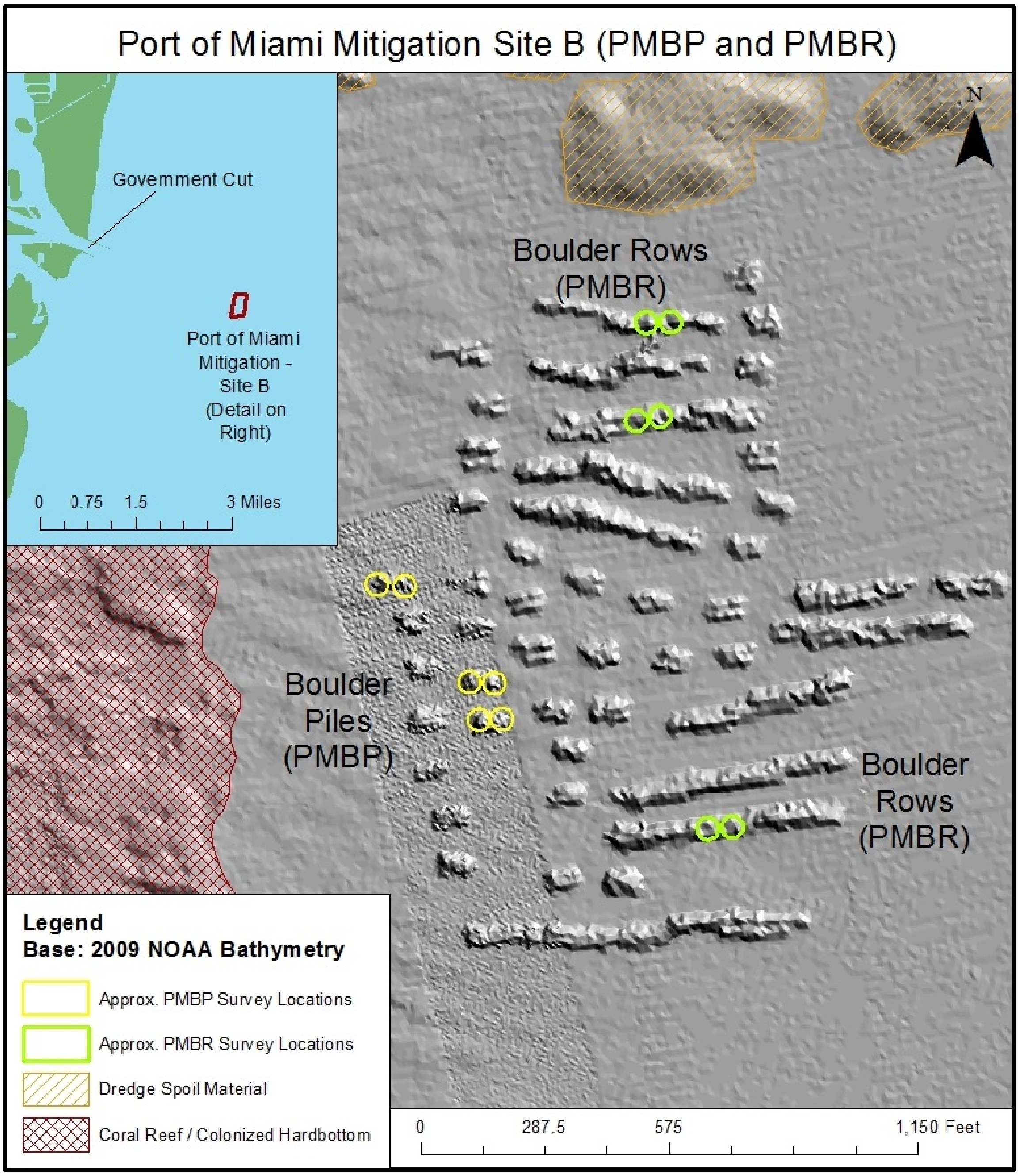

Figure 4. Port of Miami B Boulders (PMBP and PMBR).

<u>Sunny Isles Mitigation Reef - Boulders (SIMB) and Modules (SIMM):</u> Deployed in 1993, the Sunny Isles Offsite Mitigation Reef is the oldest reef evaluated. It was placed to offset impacts to low relief hardbottom communities by dredging for a beach renourishment project. Approximately 1,500 tons of limerock boulders were deployed scattered along an area 120 m by 190 m (394 ft x 623 ft) in a single-layer arrangement along with 50 modules (Figure 5). SIMB and SIMM lie at a depth of 68 ft with up to 5 ft relief. Three other artificial reefs are located within 40 m (130 ft) of the Sunny Isles Reef on the north and northwest side: Timothy Allen Reef Barge, C-one tug, and various concrete material. The closest natural hard bottom is approximately 40 m (130 ft) from the southwest corner.

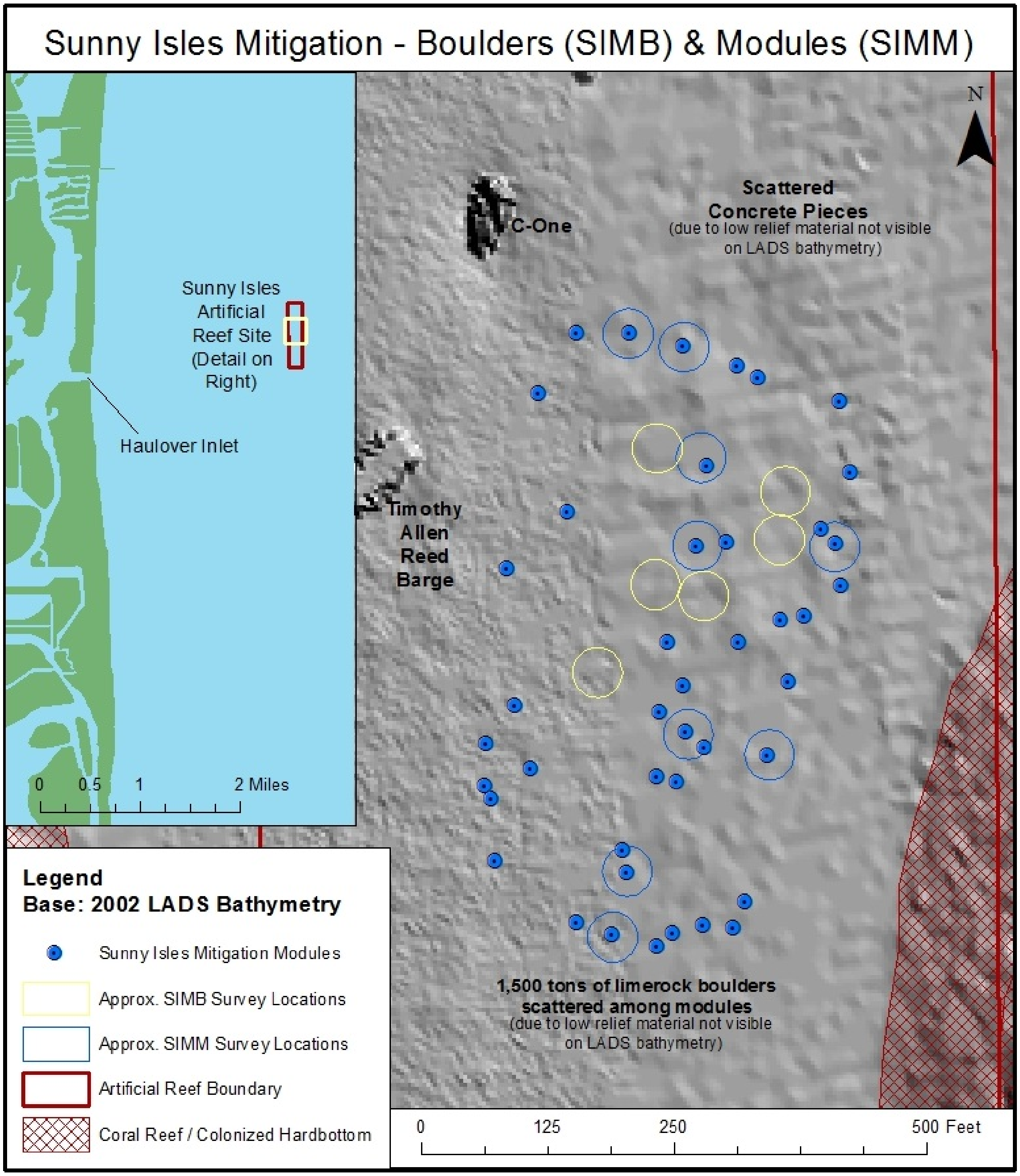

Figure 5. Sunny Isles Mitigation Reef –Boulders and Modules (SIMB and SIMM).

Port of Miami Mitigation Site A - Modules (PMAM): PMAM was deployed in 1996 as mitigation for impacts to low relief hardbottom communities by dredging for a Port of Miami expansion project. The modules evaluated are part of a group of 495 modules set on 7.6 m (25 ft) centers (Figure 6). PMAM lies at depth of 25 ft with up to 5 ft of relief. Immediately south of these modules are an additional 50 modules set on 30 m (100 ft) centers. Natural hard bottom is approximately 230 m (755 ft) to both the east and west of the modules.

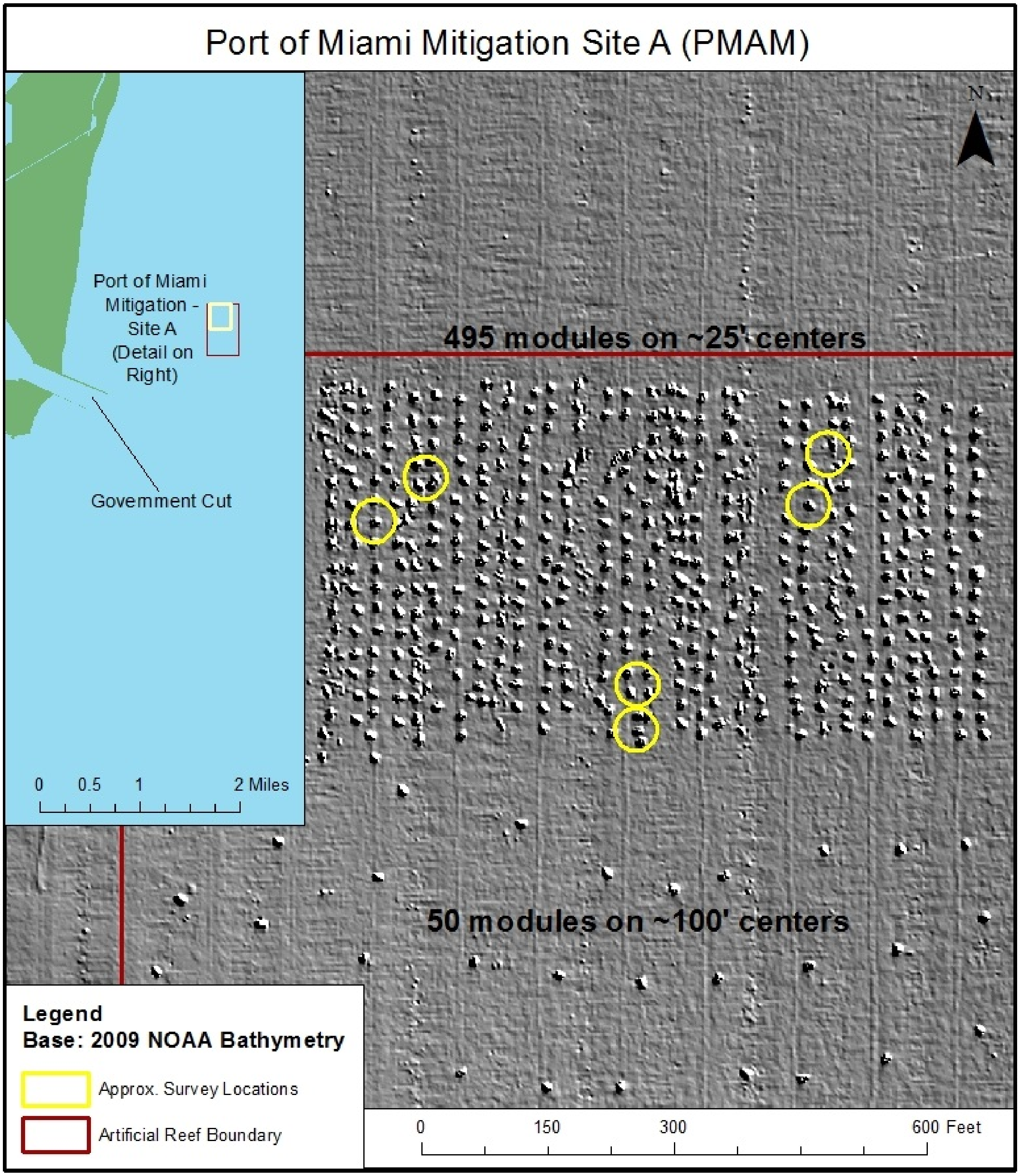

Figure 6. Port of Miami A modules (PMAM).

MATERIAL DESCRIPTIONS

All five **boulder** reefs (GDBB, SIMB, ANCB, PMBP, and PMBR) were constructed with quarried limerock which ranged between 0.9—1.8 m (3—6 ft) in diameter (Figure 7). The boulder reefs were multi-layered with several boulders stacked on one another with the exception of the SIMB which were deployed scattered in a single-layer (Figure 8).

Figure 7. Boulders on the barge prior to deployment at the Golden Beach Reef Site (GDBB) (photos taken 1/10/05).

Figure 8. Multi-layered boulder reef at the Anchorage Boulder Reef (top, photos taken 1/14/19) and single-layered boulder reef at Sunny Isles Mitigation Reef (bottom, photos taken 2/28/19).

Two of the evaluated artificial reefs (SIMM and PMAM) were comprised of **modules** which share a common design. The modules were constructed with a concrete slab base approximately 1.8 m x 2.7 m x 0.4 m (6 ft x 9 ft x 1 ft), on which three culvert pipes, either 12 in. or 18 in. diameter, were stacked in a "1-on-2" configuration (Figure 9). In both designs, small limerock pieces (6—9 in.) were grouted onto the exterior and at the open ends of the culverts to provide a natural, rough surface to facilitate benthic recruitment. The interior of the culverts remained hollow. Overall 'as-built' height of the two module types was approximately 1.5 m (5 ft), however, final in situ relief was between 0.9—1 .2 m (3—4 ft) due to subsidence in sand.

Figure 9. A) Module staged prior to deployment (photo date unknown); B) Module at Port of Miami Site A (left, photo taken 1/15/19); and C) Module at the Sunny Isles Mitigation Site (right, photo taken 2/25/19).

METHODOLOGY

Both the previous and current grant surveys utilized the same methodology as described below during the dates listed in Table 2

Table 2. Survey dates for fish surveys at each site during each grant period.

Site Name	Site Abbr.	Previous Grants	Current Grant (FWC 18107)
Anchorage Reef—Boulders	ANCB	Oct. 06 – Jan 07	Jan 19—March 19
Golden Beach Reef—Boulders	GDBB	Oct 06 – Jan 07	Jan 19—March 19
Port of Miami B—Boulder Rows	PMBR	Oct. 06 – Jan 07	Jan 19—March 19
Port of Miami B—Boulder Piles	PMBP	Oct. 06 – Jan 07	Jan 19—March 19
Sunny Isles Mitigation Reef—Boulders	SIMB	Nov 07—Jan 08	Feb 19—March 19
Sunny Isles Mitigation Reef—Modules	SIMM	Nov 07—Jan 08	Feb 19—March 19
Port of Miami A – Modules	PMAM	May 08—June 08	Jan 19—March 19

Fish surveys implemented the Bohnsack-Banerot (quick visual assessment) method (1986) with one modification. With the Bohnsack-Banerot method, each fish census is made within an imaginary vertical cylinder in the water column. The diameter of the cylinder is 15 m and the height of the cylinder extends from the substrate up to the surface (to the limits of visibility). For the standard Bohnsack-Banerot method, the survey is conducted from a stationary position in the center of the cylinder. For this study, the method was modified in that the surveyor did not remain stationary during the survey. The modified method consisted of a comprehensive listing of all fish species observed within the first five minutes of the survey by swimming around the perimeter of the cylinder and then a second smaller circle closer to the center of the cylinder. This modified method allows for a closer observation of smaller and cryptic species and more accurate species listing in lower visibility situations. Following the first five minutes, a count was made of the number of individuals of each previously noted species. In addition, the estimated size range (minimum, average, and maximum fork length in cm) of each species was recorded. Any new species observed after the first five minutes were listed, counted, and measured separately indicating the time interval they were observed—between 5-10 minutes or after 10 minutes.

Although the comprehensive fish survey datasets included all species observed and recorded during the full survey, fish assemblage analyses for this report were limited to those species characterized as the "resident" species or guild (Bohnsack et al. 1994). Resident species tend to remain at one site and are often observed on one or more consecutive surveys (Bohnsack et al. 1994). Other classifications such as "visitors" (only use the habitat for temporary shelter or feeding) and "transient" (roam over a wide area and appear not to react to the reef presence) were omitted from analysis unless otherwise noted in order to reduce the variability added by the inclusion of these classifications. Appendix 1 lists the fish species observed throughout both grant periods with their classifications.

The number of surveys was tailored to the specific reef site due to size to allow for independent, non-overlapping surveys and varied due to the number of rounds able to be completed with the different levels of grant funding (Table 3). A round was considered a separate visit to the same survey location usually three to four weeks later depending on weather conditions. All surveys, regardless of round, were averaged for analysis.

Table 3. Number of fish surveys conducted during the previous and current (2019) grant periods.

	Previous Grant			**2019 Grant**		
Site	**# Surveys / Round**	**# Rounds**	**Total # of Surveys**	**# Surveys / Round**	**# Rounds**	**Total # of Surveys**
ANCB	3	3	**9**	3	2	**6**
GDBB	3	3	**9**	3	2	**6**
PMBP	6	3	**18**	6	2	**12**
PMBR	6	3	**18**	6	2	**12**
SIMB	6	2	**12**	6	2	**12**
SIMM	9	2	**18**	9	2	**18**
PMAM	12	1	**12**	6	2	**12**

Benthic assemblages were assessed using a quadrat photo method. In the quadrat photo method, digital photographs were taken of non-overlapping quadrats at a fixed distance. Each quadrat was 40 cm x 50 cm (0.2 m^2). In the previous grant monitoring, 28.8m^2 of total area was surveyed at

ANCB, GDBB, PMBP, and PMBR, 40m^2 at SIMB and SIMM, and 102.2m^2 at PMAM. A total of 200 images or 40 m^2 were analyzed in 2019 at all sites. The images were analyzed through Coral Point Count Software developed by National Coral Reef Institute and Nova Southeastern University (Kohler and Gill 2006). This software overlays 20 random points on top of each image. The benthic organisms or substrate under each point were identified providing an estimate of relative percent cover of each benthic taxa or substrate.

Statistical analysis. To describe the benthic and fish assemblages on several boulder and module reefs throughout Miami-Dade County, basic descriptive statistics, similarity indices and non-parametric multi-dimensional scaling was used. Multiple software applications were used to summarize and analyze the benthic and fish population data. Microsoft Excel was used to calculate descriptive statistics and graph results of the data and indices. "Primer-5 for Windows®" (Primer-E, 2002) multivariate statistical software was used to calculate and display Bray-Curtis similarity indices (Bray and Curtis, 1957), similarity and evenness indices, as well as ordination clustering of the data using non-metric multidimensional scaling (MDS) procedures.

Summary statistics included total abundance, relative percent cover, number of species, and diversity. The Shannon Diversity Index (H') is the most commonly used diversity measure (Clarke and Warwick 1994). The value of the Shannon Index lies in its incorporation of species richness (S), or the total number of species, as well as the relative abundances of the species observed within a site. H' falls to zero when all the individuals in a population sample belong to the same species and increases as the number of species increases. The relative abundance of the species observed also affects the value of H'. If a few species in the sample account for most of the abundance, the value of H' will be lower than if all the individuals were distributed evenly among all the species. Pielou's Evenness measure (J) was also calculated because it expresses how evenly the individuals are distributed among the different species: the higher the value of J, the more evenly the number of individuals are spread among the different species.

Prior to the calculation of the Bray-Curtis indices, the data was fourth-root transformed in order to reduce the weight of the common species and incorporate the importance of both the intermediate and rare species (Field et. al 1982; Clark and Warwick 1994). The non-metric MDS analysis (Kruskal and Wish, 1978) generated a graph based on the calculated Bray-Curtis indices. The MDS analysis generates a "stress value" for each plot, which indicates the level of difficulty in representing the similarity relationships for all samples into a two-dimensional space. Clarke and Warwick (1994) state that a stress value ≤ 0.05 indicates a plot with excellent representation and minimal chance of misinterpretation, values from 0.05 to 0.10 correspond to a good ordination with slight chance of misinterpretation, values from 0.10 to 0.20 indicate a potentially useful plot, but have a greater chance of misinterpretation, and values between 0.20 and 0.30 are considered acceptable although conclusions should be crosschecked with other statistical measures. Plots associated with stress levels ≥ 0.30 represent a more or less arbitrary arrangement. One statistical measure that can be performed to cross-check and confirm the results of the MDS plot is a one-way pair-wise analyses of similarity, or ANOSIM (Clarke and Warwick 1994). ANOSIM is an analysis of similarities. ANOSIM produces an R statistic which correlates to how similar the samples are. This analysis produces a pairwise (between each combination of two samples) R statistics and p values. An R statistic of 1.00 indicates that samples are completely different while an R statistic of zero indicates samples are identical

(Clarke and Warwick, 1994). A non-parametric similarity of percentages analysis or SIMPER was also calculated (Clarke and Warwick 1994) to show which species contributed the most to the similarity or the dissimilarity between samples.

RESULTS

Fish Assemblages

Species Richness

Figure 10 shows the total number of fish species observed across all rounds on the five boulder and two module reefs during the current and previous grant monitoring surveys. The highest total number of species observed during the previous grant monitoring occurred at the two Port of Miami boulder reefs, PMBP and PMBR, with 67 and 66 species respectively. However, during the current monitoring, SIMM and GDBB had the highest total species richness with 64 and 60, respectively. The single layer boulders SIMB had the fewest species in the previous and current monitoring with 41 and 45 species respectively.

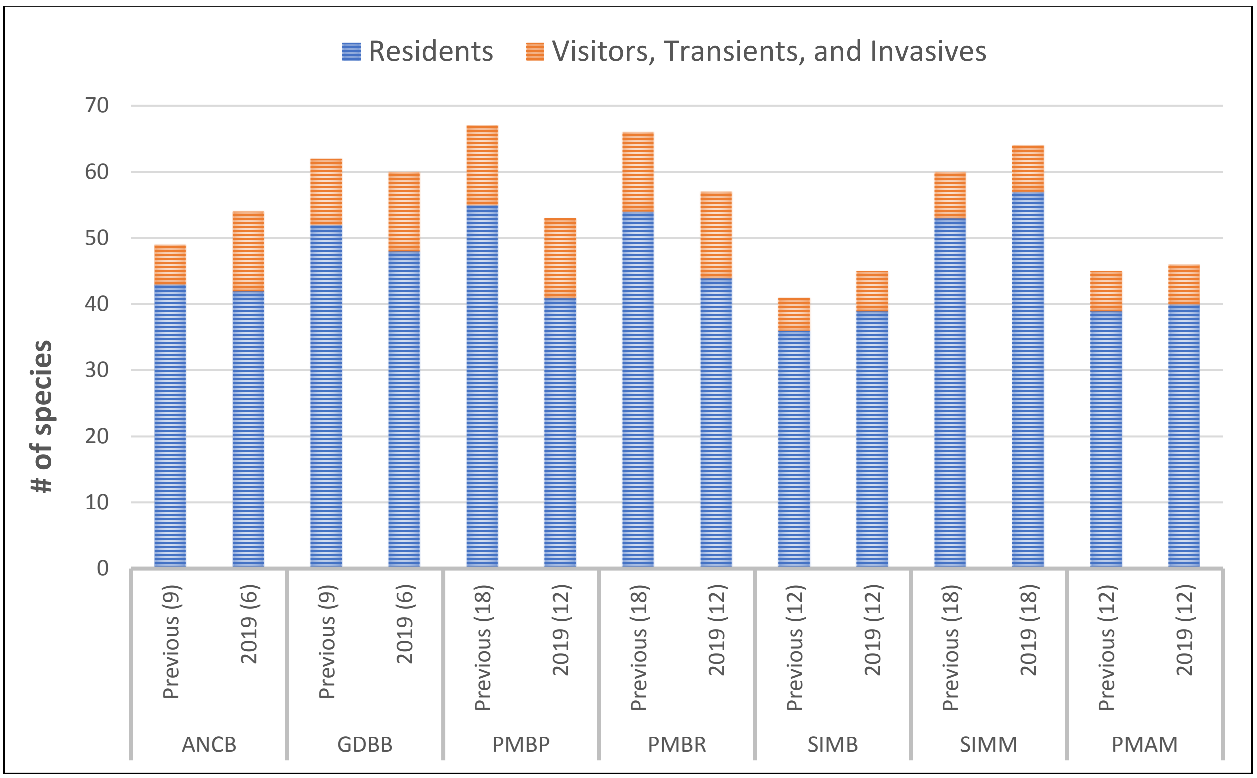

Figure 10. Total number of fish species observed across all surveys at five boulder and two module reefs. Note the number of surveys for each site may be different and are listed in parenthesis. Area of each survey = 176 m^2.

Diversity

The Shannon Diversity Index (H') and Pielou's Evenness measure (J') were calculated for the resident fish assemblages at each boulder reef. Figure 11 shows the average H' and J' values averaged across all surveys at each site per grant period. The two Port of Miami boulder sites (PMBP and PMBR) had the highest H' values as well as the highest J' value of all reefs during both grant periods, indicating a diverse fish assemblage. The lowest diversity and lowest evenness measure were observed at ANCB and GDBB during both grant periods. These two sites had large numbers of a single species *Haemulon aurolineatum* (Tomtates) which decreases the diversity and evenness measures.

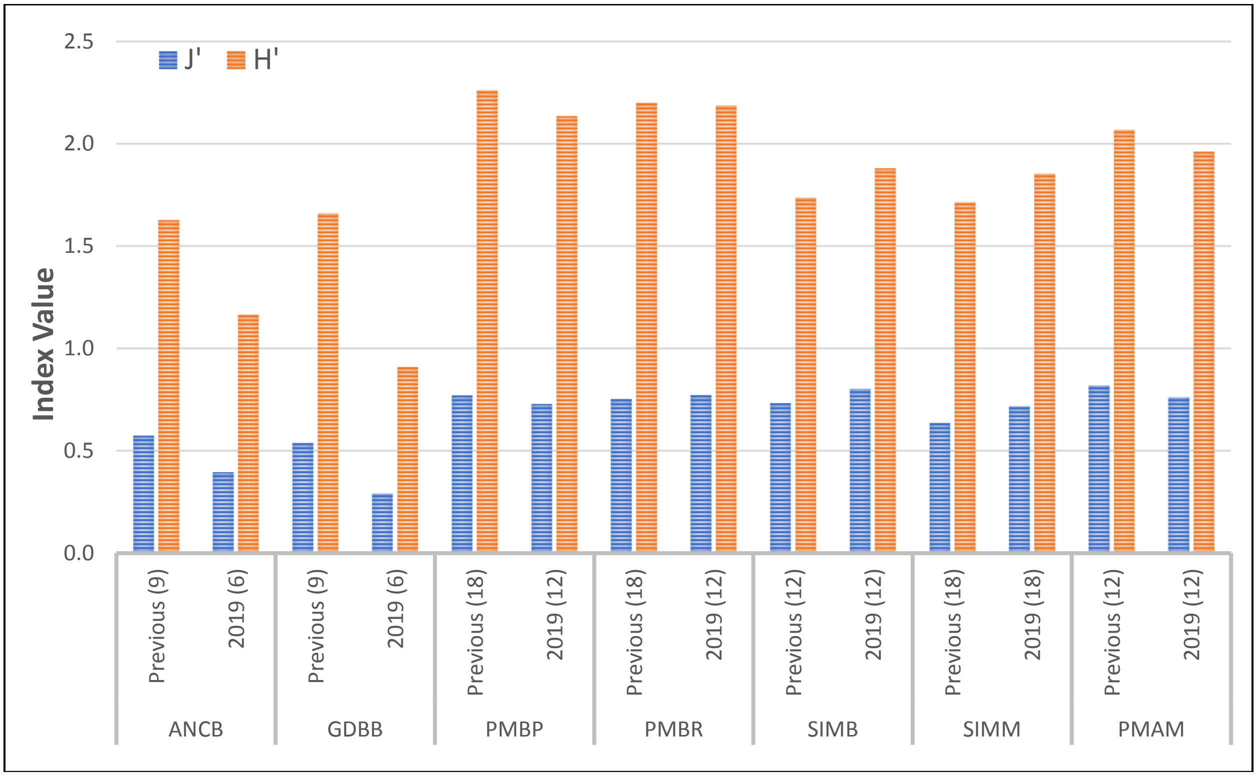

Figure 11. Average Shannon Diversity Index (H') and Pielou's Evenness measure (J') for the resident fish assemblages on each boulder reef. Note the number of surveys for each site may be different and are listed in parenthesis. Area of each survey = 176 m^2.

Density

Figure 12 shows the average resident fish density (individuals/m^2) across all surveys during each grant periods at the boulder and module reefs. For the same reason the diversity and evenness values were low at ANCB and GDBB, large schools of *H. aurolineatum* (Tomtates), the resident fish density was the highest at these two sites with an average of 8.91 individuals/m^2 across all surveys at ANCB and 14.87 individuals/m^2 at GDBB in 2019. The other four sites were observed with <2 individuals/m2 in both the previous and current grant monitoring. SIMM density was lower in 2019 as result of fewer *Coryphopterus personatus* (Masked goby).

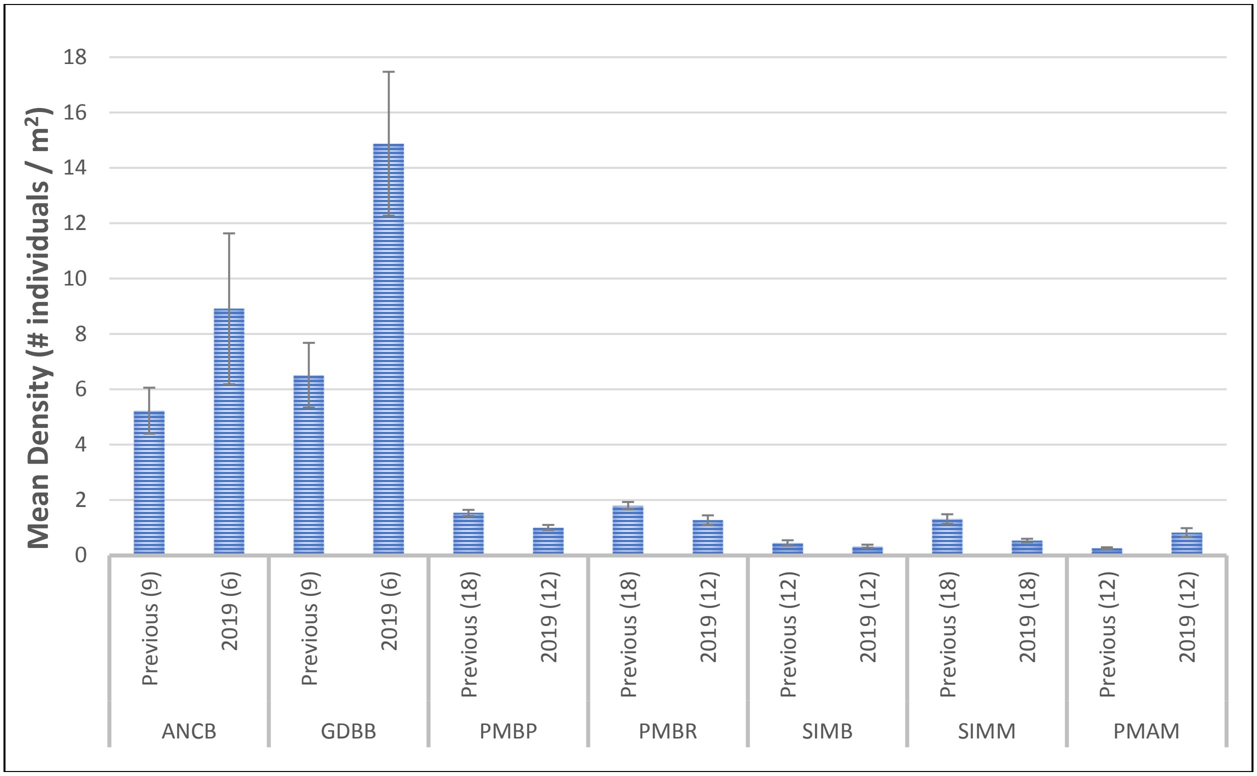

Figure 12. Average resident fish density (individuals/m^2) for each grant period at the five boulder and two module reefs. Standard deviation bars plotted. Note the number of surveys for each site may be different and are listed in parenthesis. Area of each survey = 176 m^2.

<u>Family Composition</u>

The relative percent composition by family for the seven evaluated reefs is shown in Figure 13. On two of the boulder reefs, ANCH and GDBB, in both the previous and current grant periods, a large percentage of the resident fish belonged to the Haemulidae (grunts) family. The percent composition by the Haemulidae family was primarily due to the large schools of *Haemulon aurolineatum* (Tomtates) present. Haemulidae was nearly absent on the low relief SIBB boulders. Instead this site was dominated by Labridae (wrasses) in both grant periods. Labridae were also common at the other six monitored sites. Pomacentridae, Gobiidae, Scaridae, and Tetraodontidae were also relatively abundant at all the sites, but on the ANCB and GDBB sites the percent composition was diminished by the total sample size and large number of Haemulidae individuals.

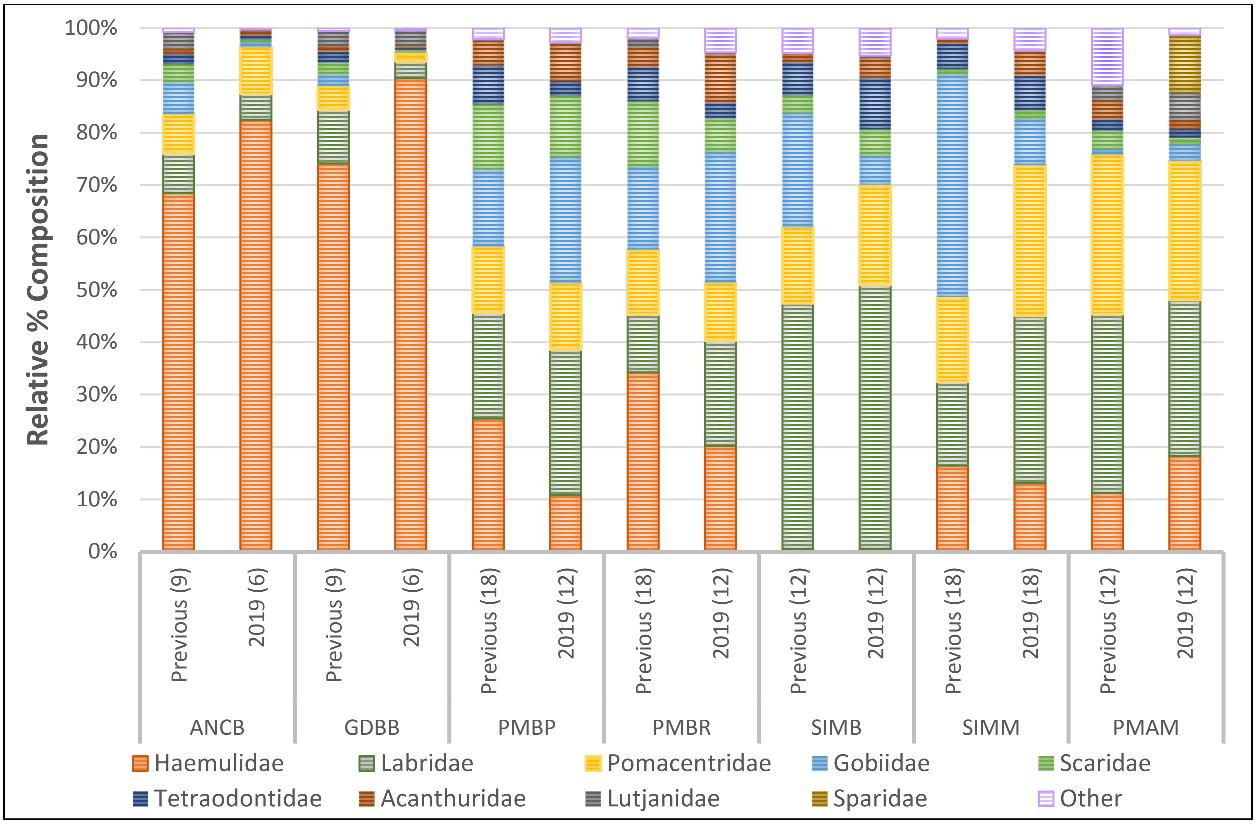

Figure 13. Average percent composition (%) of resident individuals by major family constituents across all survey at each site for each grant period. Note the number of surveys for each site may be different and are listed in parenthesis. Area of each survey = 176 m^2.

<u>Abundant species</u>

Haemulon aurolineatum (Tomtates) had the highest average density per survey at ANCB and GDBB with a large increase in the 2019 grant period accounting for the overall increase in density (Table 4, Figure 14). The density of *H. aurolineatum* was lower during the 2019 grant period than previously at the PMBP and PMBR boulder sites and absent on the low relief boulder site, SIMB, during both grant periods. Except for SIMB, *Haemulon sciurus* (Blue-stripped grunt), *H. flavolineatum* (French grunt), and *H. plumieri* (White grunt) of the Haemulidae family were observed at all boulder sites during both grant periods. *Lutjanus synagris* (Lane snapper) from the Lutjanidae family was abundant at ANCB in the previous grant monitoring but not the current monitoring. On the other hand, at GDBB *L. synagris* was more abundant in the 2019 monitoring than the previous grant monitoring. Common Labridae and Pomacentridae species during both grant periods included *Thalassoma bifasciatum* (Blue-head wrasse) and *Stegastes partitus* (Bicolor damsel). However, the density of *S. partitus* was lower during the 2019 grant monitoring at all boulder sites except ANCB. During the 2019 sampling, *Abudefduf saxatilis* (Sergeant Majors) from the Pomacentridae family was also very abundant at ANCB. Several Scaridae species were also consistently abundant across the four high relief boulders sites (ANCB, GDBB, PMBP, and PMBR) including *Sparisoma aurofrenatum* (Redband parrotfish), *Scarus taeniopterus* (Princess parrotfish), and *Scarus iserti* (Striped parrotfish). As with the *S. partitus* observations the abundance of these species were lower at many sites during the 2019 grant monitoring.

Table 4. Average density (number of individuals per survey) for the most abundant taxa on the five boulder reefs. Note the number of surveys for each site may be different and are listed in parenthesis.

		ANCB		GDBB		PMBP		PMBR		SIMB	
Family	**Species**	**Previous (9)**	**2019 (6)**	**Previous (9)**	**2019 (6)**	**Previous (18)**	**2019 (12)**	**Previous (18)**	**2019 (12)**	**Previous (12)**	**2019 (12)**
Acanthuridae	*Acanthurus bahianus*	4.4	5.8	6.6	4.8	5.6	3.7	5.7	3.9	0.9	0.1
	Acanthurus chirurgus	0.6	6.3	1.2	1.2	3.6	4.4	1.6	2.1	0.3	1.8
	Acanthurus coeruleus	3.9	3.8	4.1	3.7	3.8	4.8	4.7	14.6	0.2	0.3
Gobiidae	*Coryphopterus glaucofraenum*					0.1	0.2	0.3		8.8	1.3
	Coryphopterus personatus	55.7	10.8	23.9	0.7	39.6	42.7	50.2	55.4	8.3	1.0
Haemulidae	*Haemulon aurolineatum*	532.2	1167.5	737.2	2150.0	61.9	7.0	79.1	8.8		
	Haemulon flavolineatum	38.4	41.8	39.8	101.8	2.1	2.2	5.3	1.5	0.3	
	Haemulon plumieri	3.1	6.7	8.9	21.0	1.1	3.0	1.7	7.0		0.2
	Haemulon sciurus	41.1	54.5	56.3	27.0	2.3	6.3	19.1	27.9		
Labridae	*Halichoeres garnoti*	9.8	2.3	29.1	1.5	10.6	0.8	7.6	0.3	4.1	7.2
	Thalassoma bifasciatum	57.8	74.2	71.6	75.8	36.1	47.2	25.7	44.3	27.5	18.8
Lutjanidae	*Lutjanus griseus*		1.7	24.9	11.2	0.1		4.9	0.8		
	Lutjanus synagris	28.6	0.3	5.0	70.8	0.4	0.1	0.4			
Pomacentridae	*Abudefduf saxatilis*	31.0	102.7	5.0	16.8	2.7	5.9	7.0	11.8	0.1	0.8
	Stegastes partitus	31.9	32.2	28.2	16.2	23.7	14.8	24.0	11.3	11.5	9.2
Scaridae	*Scarus iserti*	4.3	2.8	5.4	5.5	8.7	6.8	6.8	3.7		0.2
	Scarus taeniopterus	10.8	0.7	7.1	0.5	10.6	1.8	12.0	2.5	0.4	0.1
	Sparisoma aurofrenatum	13.4	4.2	13.3	6.5	11.2	12.3	15.7	8.4	1.8	2.3
Tetraodontidae	*Canthigaster rostrata*	18.7	11.2	24.8	6.2	19.6	4.6	20.3	6.5	4.9	5.1

Figure 14. *Haemulon aurolineatum* (Tomtates) at ANCB (left, photo taken 3/3/19) and GDBB (right, photo taken 1/15/19) during the 2019 grant monitoring.

The most abundant species within the dominate families for the two module reefs are shown in Table 5. At the PMAM and SIMM, common species during both grant periods included *T. bifasciatum* (Blue-head wrasse) from the Labridae family and *S. partitus* (Bicolor damsel) from the Pomacentridae family. During the previous monitoring, *Coryphopterus personatus* (Mask goby, Gobiidae family), *H. aurolineatum* (Tomtates), and *H. flavolineatum* (French grunt) were abundant but were absent or present with smaller quantities in the 2019 monitoring. At the PMAM modules, *H. aurolineatum* (Tomtates) were abundant mainly as juveniles during the 2019 monitoring (Figure 15). *Archosargus rhomboidalis* (Seabream) from the Sparidae was also abundant during the 2019 sampling but not observed during prior grant monitoring.

Figure 15. Juvenile *Haemulon aurolineatum* (Tomtates) on the PMAM modules (photo taken 3/4/19).

Table 5. Average density (number of individuals per survey) for the two module reefs for the most abundant taxa. Note the number of surveys for each site may be different and are listed in parenthesis.

		SIMM		PMAM	
Family	**Species**	**Previous (18)**	**2019 (18)**	**Previous (12)**	**2019 (12)**
Acanthuridae	*Acanthurus bahianus*	0.9	0.7	0.4	1.3
	Acanthurus chirurgus	0.8	2.8	0.9	0.5
	Acanthurus coeruleus	0.3	0.9	0.3	0.8
Gobiidae	*Coryphopterus glaucofraenum*	8.8	0.6	0.2	0.9
	Coryphopterus personatus	89.3	6.3		1.5
Haemulidae	*Haemulon aurolineatum*	15.3		3.8	24.3
	Haemulon flavolineatum	12.0	4.3		0.3
	Haemulon plumieri	3.4	1.0		0.6
	Haemulon sciurus	0.3	0.2		0.5
	Haemulon sp. Juvenile		5.6		
Labridae	*Halichoeres bivittatus*			1.0	5.0
	Halichoeres garnoti	2.6	3.3		
	Thalassoma bifasciatum	33.2	25.9	13.3	38.2
Lutjanidae	*Lutjanus griseus*			1.1	5.9
	Lutjanus synagris				1.4
Pomacentridae	*Abudefduf saxatilis*	1.7	2.2	1.3	1.9
	Chromis cyaneus	3.4	0.6		
	Stegastes partitus	27.3	23.4	9.0	27.9
Scaridae	*Stegastes variabilis*	0.1	0.2	0.3	5.7
	Scarus iserti		0.2	0.3	
	Scarus taeniopterus	0.2	0.1	0.2	0.2
	Sparisoma aurofrenatum	1.9	1.2	0.6	1.6
Sparidae	*Archosargus rhomboidalis*				15.9
Tetraodontidae	*Canthigaster rostrata*	11.2	6.1	1.0	2.4

<u>Similarity</u>

Figure 16 shows the MDS plot graphically depicting the Bray-Curtis similarity values for the average density (number per survey) of resident fish species for each site during each grant monitoring period. PMAM, SIMB, and SIMM separate out from the other four sites most likely attributed to the differing reef structure-lower relief and spread out boulder and modules versus higher relief, more concentrated boulder reefs.

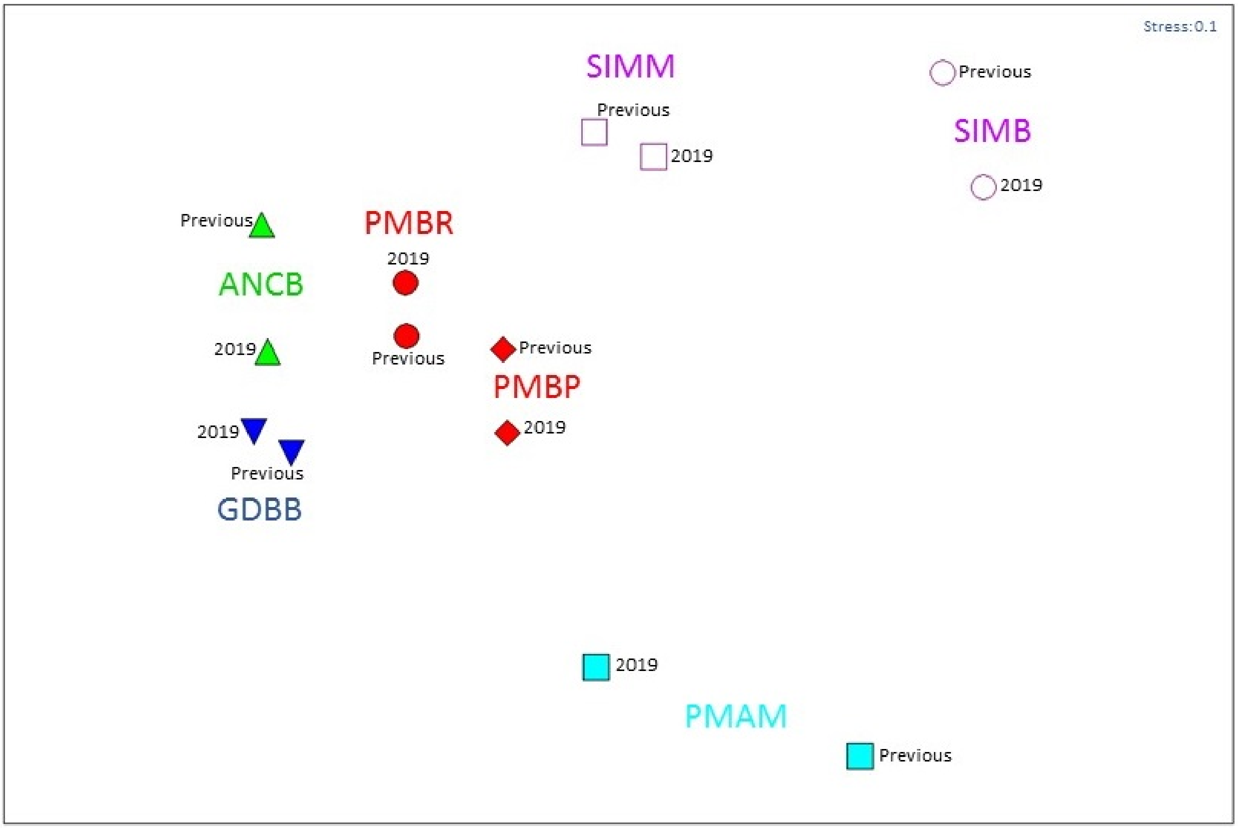

Figure 16. Multi-dimensional scaling (MDS) plot based on the Bray-Curtis Similarity values for the transformed average density (individuals per survey) of each resident fish species for each site during each grant period.

Figures 17 and 18 shows the MDS plot graphically depicting the Bray-Curtis similarity values based on the density of each resident fish species per survey between sampling periods at the boulder sites and modules sites respectively. The stress values for each plot are low or moderately low (≤0.24) indicating an accurate representation of the plot. At all sites, most surveys across both sampling periods are clustered close together indicating similar assemblages. The PMAM surveys show more distance between surveys and sampling periods indicating some greater differences or variability between the sampling periods. Table 6 summarizes Bray-Curtis similarity values and ANOSIM R values between grant. The low ANOSIM R value, ranging from 0.147 to 0.300, at the five boulders reefs indicated the fish assemblages surveyed in the previous grant are not significantly different than the assemblages observed in 2019. The comparison of the SIMM resident fish from the previous and current monitoring also had a low R value indicating similar assemblages. The PMAM modules, on the other hand, had a large R value (0.575) indicating some differences in the assemblages between the two grant monitoring periods.

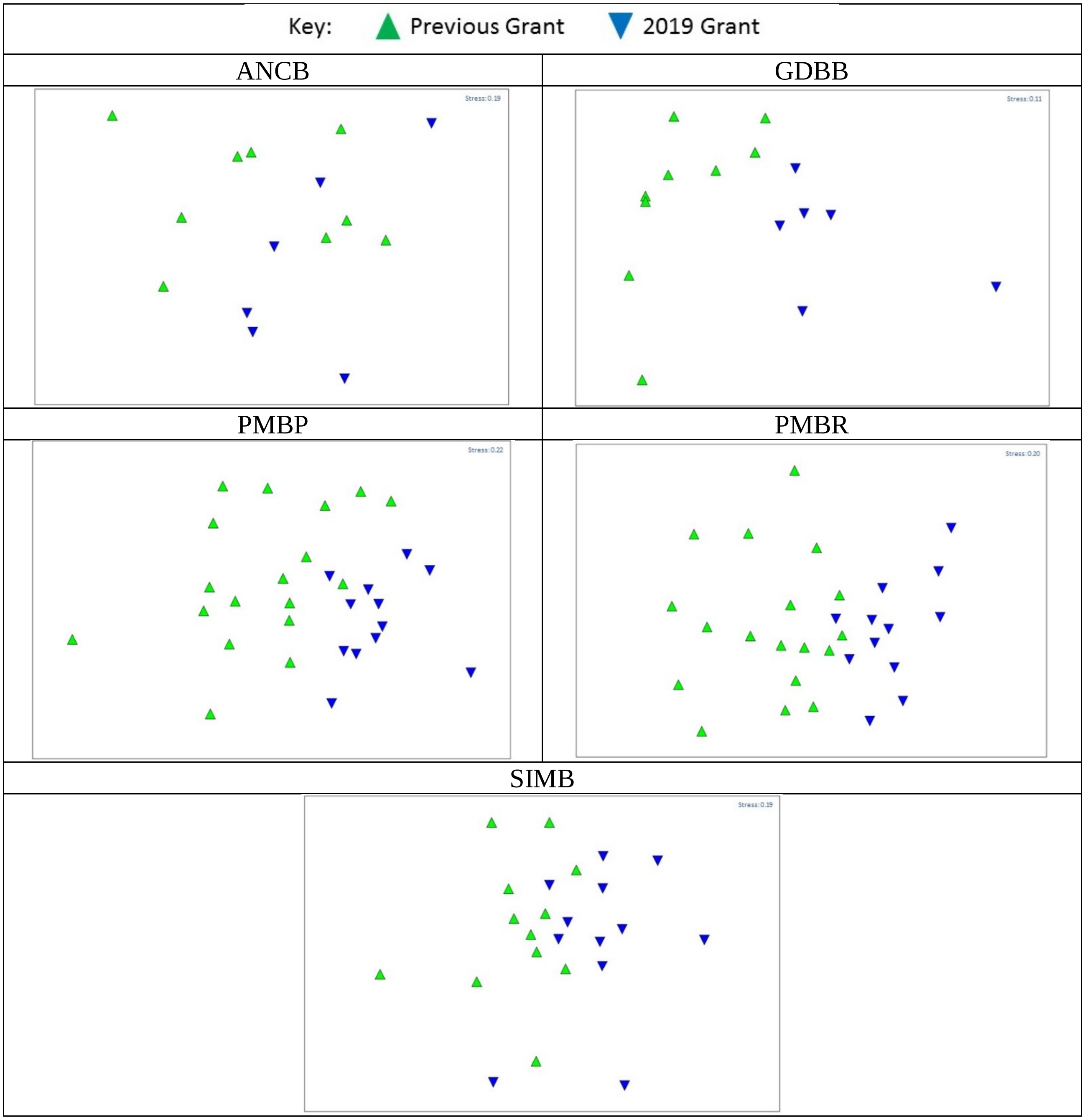

Figure 17. Multi-dimensional scaling (MDS) plot based on the Bray-Curtis Similarity values for the transformed resident fish species density for each survey at the five boulder sites.

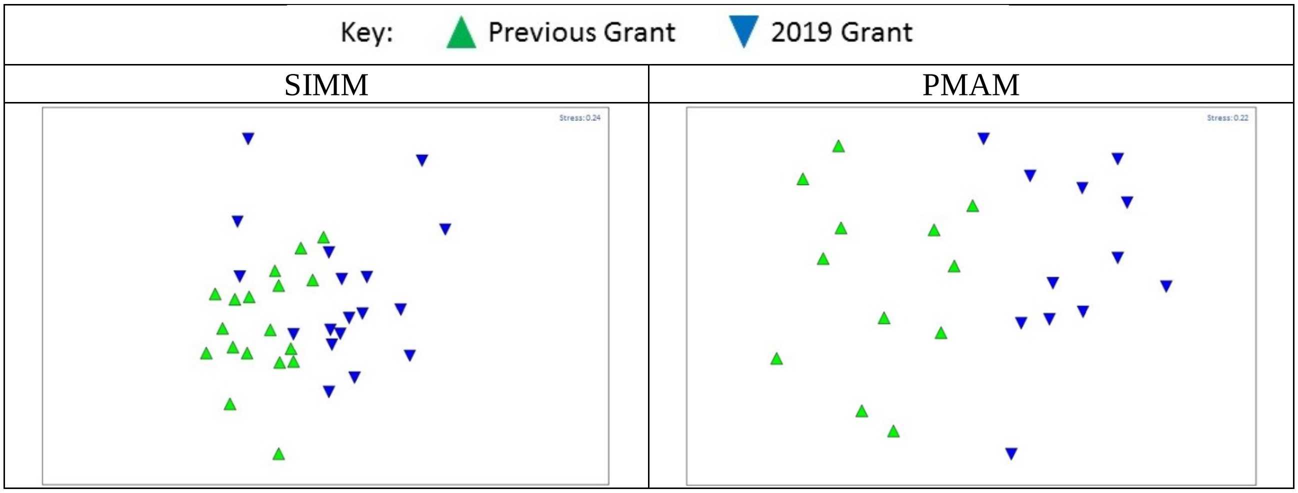

Figure 18. Multi-dimensional scaling (MDS) plot based on the Bray-Curtis Similarity values for the transformed resident fish species density for each survey at the module site.

Table 6. ANOSIM results for the comparison of the transformed resident fish density for each survey at each site between grant periods (previous vs 2019). An R statistic of 1.00 indicates the samples are completely different while 0.0 indicates samples are identical.

Type	Site	Average (%) Similarity	R value
Boulders	ANCB	57.9	0.147
	GDBB	55.5	0.390
	PMBP	56.3	0.299
	PMBR	53.9	0.300
	SIMB	49.1	0.149
Modules	PMAM	38.0	0.575
	SIMM	44.8	0.286

SIMPER analysis was conducted to determine what individual resident fish species contributed to the differences at each site between sampling periods and is summarized in Table 7 for the boulder sites and Table 8 for the module sites. At four of boulder sites (GDBB, ANCB, PMBP, and PMBR), varying average abundances of grunts (*H. aurolineatum*, *H. flavolineatum*, *H. chrysargyreum*, and *H. plumieri*) and snappers (*L. synagris* and *L. griseus*) species between sampling periods contributed the most to the dissimilarity between grant periods. In general, grunts were more abundant in 2019 at GDBB and ANCB than in previous grants, but lower in 2019 at PMBP and PMBR than previous grants. At the lower relief boulder site SIMB, gobies (*C. personatus*), wrasses (*Halichoeres maculipinna*), and parrotfish (*Sparisoma aurofrenatum*) contributed most the dissimilarity between sampling periods. Grunts (*H. aurolineatum*) and damselfish (*S. variabilis*) were more abundant in 2019 than the previous grant period at the module site PMAM. At PMAM, large schools of Seabream (*Archosargus rhomboidalis*) were also observed in 2019 but not in previous grants contributing to the dissimilarity between sampling periods. In previous grant monitoring, gobies (*C. personatus*) and grunts (*H.*

flavolineatum and *H. aurolineatum*) were more abundant on SIMM than in the current sampling contributing to dissimilarity.

Table 7. A similarity percentages analysis (SIMPER) on the transformed resident fish densities at the five boulders reefs that contributed the most to the dissimilarity between grant periods with the average abundance for each species per sampling period and their contribution the dissimilarity.

Site	Species	Previous Avg. Abundance	2019 Avg. Abundance	% Contribution
ANCB	*Haemulon aurolineatum*	532.2	1167.5	5.40
	Haemulon flavolineatum	38.4	41.8	4.94
	Coryphopterus personatus	55.7	10.8	4.72
	Haemulon chrysargyreum	2.8	21.2	4.21
	Lutjanus synagris	28.6	0.3	3.98
	Acanthurus chirurgus	0.6	6.3	3.48
GDBB	*Haemulon chrysargyreum*	4.6	50.3	5.77
	Haemulon aurolineatum	737.2	2150.0	5.17
	Lutjanus synagris	5.0	70.8	4.50
	Haemulon flavolineatum	39.8	101.8	3.76
	Lutjanus griseus	24.9	11.2	3.49
	Haemulon plumieri	8.9	21.0	3.38
PMBP	*Haemulon aurolineatum*	61.9	7.0	5.24
	Coryphopterus personatus	39.6	42.7	4.75
	Scarus taeniopterus	10.6	1.8	4.24
	Halichoeres garnoti	10.6	0.8	4.12
	Stegastes leucostictus	4.1	0.3	3.78
	Canthigaster rostrata	19.6	4.6	3.53
PMBR	*Coryphopterus personatus*	50.2	55.4	6.07
	Haemulon aurolineatum	79.1	8.8	5.30
	Haemulon plumieri	1.7	6.8	4.10
	Scarus taeniopterus	12.0	2.5	4.04
	Halichoeres garnoti	7.6	0.3	3.51
	Scarus iserti	6.8	3.7	3.43
SIMB	*Coryphopterus glaucofraenum*	8.8	1.3	5.91
	Halichoeres maculipinna	3.1	0.3	5.59
	Sparisoma aurofrenatum	1.8	2.3	5.01
	Acanthurus chirurgus	0.3	1.8	4.67
	Halichoeres bivittatus	1.3	2.8	4.65
	Canthigaster rostrata	4.9	5.1	4.36
	Chaetodon sedentarius	1.3	0.4	4.31

Table 8. A similarity percentages analysis (SIMPER) on the transformed resident fish densities at the two module reefs that contributed the most to the dissimilarity between grant periods with the average abundance for each species per sampling period and their contribution the dissimilarity.

Site	Species	Previous Avg. Abundance	2019 Avg. Abundance	% Contribution
SIMM	*Coryphopterus personatus*	89.3	6.3	8.37
	Haemulon flavolineatum	12.0	4.3	4.40
	Haemulon aurolineatum	15.3	0.0	4.25
	Coryphopterus glaucofraenum	8.8	0.6	3.82
	Myripristis jacobus	1.2	0.2	3.31
	Acanthurus chirurgus	0.8	2.8	3.30
PMAM	*Haemulon aurolineatum*	3.8	24.3	5.91
	Stegastes variabilis	0.3	5.7	4.77
	Balistes capriscus	1.9	0.0	4.31
	Lutjanus griseus	1.1	5.6	4.11
	Halichoeres bivittatus	1.0	5.0	4.01
	Archosargus rhomboidalis	0.0	15.9	3.86

Sportfish, Protected, and Invasive Species Abundance

Sport and regulated fish species were observed on the boulder and module reefs including jacks, groupers, snappers, and hogfish in the previous grant periods and in 2019. Table 9 summarizes the observation of sport and regulated fish species across all sites in the previous and current grant periods and whether the observed fish met the harvesting criteria according to FWC 2019 Atlantic Ocean regulations (https://myfwc.com/media/20441/quickchart.pdf). Appendix 2 through 8 summarize the sport and game fish observations at each of the seven sites while Figure 19 depicts some of the observed species. In the previous grant periods, a total of 24 different game or regulated fish species were observed while in 2019 only 18 were observed.

A few large jacks (*Seriola dumerili;* Greater Amberjack) were observed at the PMBP and PMBR in the previous monitoring, but all were smaller than the minimum size limit of approximately 71 cm (Appendix 4 and 5). In 2019, *S. dumerili* were only observed on PMAM and were again smaller than the minimum legal size (Figure 19C, Appendix 8). Smaller jack species were observed at multiple sites in both the previous sampling and in 2019. However, the overall percent occurrence and max size dropped notably for *Caranx ruber* (Bar jack) in 2019.

While not seen with high abundance, Hogfish, *Lachnolaimus maximus*, were observed at all sites during both sampling periods with similar average densities, percent occurrence, and sizes (Figure 19D, Table 9). Through all the observations in 2019, no individual was above the current legal size of approximately 40.6 cm (16”) although a single individual at both GDBB and SIMM were observed barely below the threshold at 40 cm, Appendix 3 and 7 respectively.

From the snapper family, one positive trend observed was the presence of *Lutjanus analis* (Mutton snapper) in 2019 that was absent at all station in prior grant monitoring (Table 9). In

2019, *L. analis* was observed at five of the seven sites. However, only a single *L. analis* individual above the legal size (45.7 cm) at PMBP (Appendix 4) was observed. *Lutjanus synagris* (Lane snapper), was observed with similar percent occurrence in the prior and current grant monitoring, but with a larger density in 2019 (Table 9). At five of the sites in 2019—*L. synagris* was observed in large schools at ANCB and GDBB (Appendix 2 and 3 respectively) and with fewer individuals at PMBP, PMBR, and PMAM (Appendix 4, 5, and 8 respectively). While *L. synagris* was observed at multiple sites, only a single individual at GDBB and PMBR was observed above the legal size (20.3 cm) in 2019 (Appendix 3 and 5, respectively). Observations of *L. griseus* (Gray snapper) were also common at multiple sites in the previous and current monitoring, however the density, percent occurrence, and mean size were all lower in 2019 (Table 9). In 2019, no *L. griseus* individuals were observed above the legal size (25.4 cm) although the upper size range of *L. griseus* at ANCB and GDBB were very close with a max size of 25 cm (Appendix 2 and 3, respectively). *Ocyurus chrysurus* (Yellowtail Snapper) was observed at all sites in 2019 with approximately a threefold increase in overall density and twice the overall percent occurrence (Table 9). The overall max size range was also larger in 2019 with legal size (30.5 cm or larger) individuals present at PMBP, PMBR, and SIMM (Appendix 4, 5, and 7 respectively).

Within the grouper family, *Epinephelus morio* (Red), *Mycteroperca microlepis* (Gag), and *M. phenax* (Scamp) were observed in previous grant periods but were not in 2019 (Table 9). *Cephalopholis cruentatus* (Graysby) were observed on all boulder and module reefs in both sampling periods except for SIMM in the previous monitoring (Table 9, Appendix 7). The overall percent occurrence of *C. cruentatus* was slightly higher in 2019, but mean size remained the same. Of the groupers with regulatory size limits, two of the four *Mycteroperca bonaci* (Black grouper) individuals were observed above legal size in 2019—one at ANCH and one at GDBB both at 64cm (Appendix 2 and 3 respectively).

Sphyraena barracuda (Great Barracuda) was not observed in previous grant samplings but was in 2019 (Table 9). Of the 4 individuals observed, two were within the harvestable slot size range 38.1-91.4 cm (15-36”) and one above the range at ANCB (Appendix 2). The fourth individual was observed on PMBR below the minimum slot size (Appendix 5).

The protected species *Epinephelus itajara* (Goliath grouper), was observed once at GDBB in the previous monitoring and once at SIMM in the 2019 monitoring (Figure 20). The Goliath grouper observed at SIMM was likely ‘visiting’ from the larger, high relief vessel artificial reefs to the north of the modules. The invasive Lionfish (*Pterois volitans*) was not observed during the previous grant monitoring but at least one individual was observed at all sites in 2019 ranging in size from 9—32 cm (Figure 21).

Table 9. Total, average density ($\bar{D}$), percent occurrence (P) per survey, average length ($\bar{L}$), and size range of sport and regulated fish across all sites throughout entire survey (not just first five minutes). Number of surveys per grant period is noted in parenthesis. Minimum size limit based on FWC Atlantic regulations as of April 2019. Harvestable codes: N = present but not above regulation size; Y = Present and at least one individual above regulation size; Y* = present with only bag limits; (Y) = present with no size or bag limits. In 2019, a single snapper (*Lutjanus* species) was unable to be identified to species but was above the legal minimum size for any snapper species and considered harvestable.

		Previous Grant (96)					**2019 Grant (78)**					**Minimum Legal Size cm / in**	**Able to Harvest in 2019 / # Ind.**
Family	**Species**	**Total**	**$\bar{D}$**	**P**	**$\bar{L}$ (cm)**	**Range (cm)**	**Total**	**$\bar{D}$**	**P**	**$\bar{L}$ (cm)**	**Range (cm)**		
Balistidae (Triggerfish)	*Balistes capriscus* (Gray Trigger)	25	0.26	12.5	20	12-25	30	0.38	1.3	19	18-25	30.5 / 12	N
Carangidae (Jacks)	*Caranx bartholomaei* (Yellow)	5	0.05	1.0	28	25-30	23	0.29	7.7	27	20-42	unreg.	(Y)
	Caranx crysos (Blue runner)	26	0.27	7.3	15	12-20	1	0.01	1.3	15	15-15	bag limit	Y*
	Caranx hippos (Crevalle)	8	0.08	2.1	23	6-45						unreg.	-
	Caranx ruber (Bar)	225	2.34	32.3	17	5-60	359	4.60	23.1	16	9-24	unreg.	(Y)
	Caranx species (unidentified)	43	0.45	3.1	36	7-60						unreg.	-
	Seriola dumerili (Amberjack)	11	0.11	2.1	50	50-55	24	0.31	2.6	36	30-42	71.1 / 28	-
	Seriola rivoliana (Almaco)	8	0.08	1.0	38	25-50	19	0.24	7.7	36	26-45	unreg.	(Y)
Labridae (Hogfish)	*Lachnolaimus maximus*	75	0.78	50.0	21	10-40	55	0.71	51.3	23	11-40	40.6 / 16	N
Lujanidae (Snappers)	*Lutjanus analis* (Mutton)						20	0.26	20.5	32	20-47	45.7 / 18	Y / 1
	Lutjanus apodus (Schoolmaster)	28	0.29	13.5	20	13-30	12	0.15	12.8	23	19-29	25.4 / 10	Y / 4
	Lutjanus campechanus (Red)	31	0.32	4.2	19	15-28						50.8 / 20	-
	Lutjanus griseus (Gray)	398	4.15	32.3	19	8-40	171	2.19	25.6	17	11-25	25.4 / 10	N
	Lutjanus jocu (Dog)	3	0.03	2.1	38	35-40						30.5 / 12	-
	Lutjanus mahogoni (Mahogany)	3	0.03	1.0	12	12-13						30.5 / 12	-
	Lutjanus species (unidentified)						1	0.01	1.3	60		unk	Y / 1
	Lutjanus synagris (Lane)	369	3.84	19.8	16	8-30	451	5.78	17.9	17	12-22	20.3 / 8	Y / 2
	Ocyurus chrysurus (Yellowtail)	46	0.48	26.0	20	8-30	131	1.68	55.1	20	9-35	30.5 / 12	Y / 5
	Rhomboplites aurorubens (Vermillion)	5	0.05	2.1	10	8-15						30.5 / 12	-
Rhincodontidae (Sharks)	*Ginglymonstoma cirratum*	1	0.01	1.0	140		3	0.04	3.8	119	55-183	137 / 54	Y / 1
Serranidae (Groupers)	*Cephalopholis cruentatus* (Graysby)	46	0.48	36.5	17	10-25	43	0.55	38.5	17	10-27	bag limit	Y*
	Epinephelus guttatus (Red hind)	6	0.06	4.2	18	12-28	1	0.01	1.3	21		bag limit	Y*
	Epinephelus morio (Red)	4	0.04	4.2	24	21-27						50.8 / 20	-
	Mycteroperca bonaci (Black)	1	0.01	1.0	100		4	0.05	5.1	55	45-64	61.0 / 24	Y / 2
	Mycteroperca microlepis (Gag)	8	0.08	6.3	21	7-28						61.0 / 24	-
	Mycteroperca phenax (Scamp)	15	0.16	11.5	21	8-30						50.8 / 20	-
Sphyraenidae (Barracuda)	*Sphyraena barracuda* (Great Barracuda)						4	0.1	5.1	73	50-105	38.1-91.4 / 15-36	Y / 2

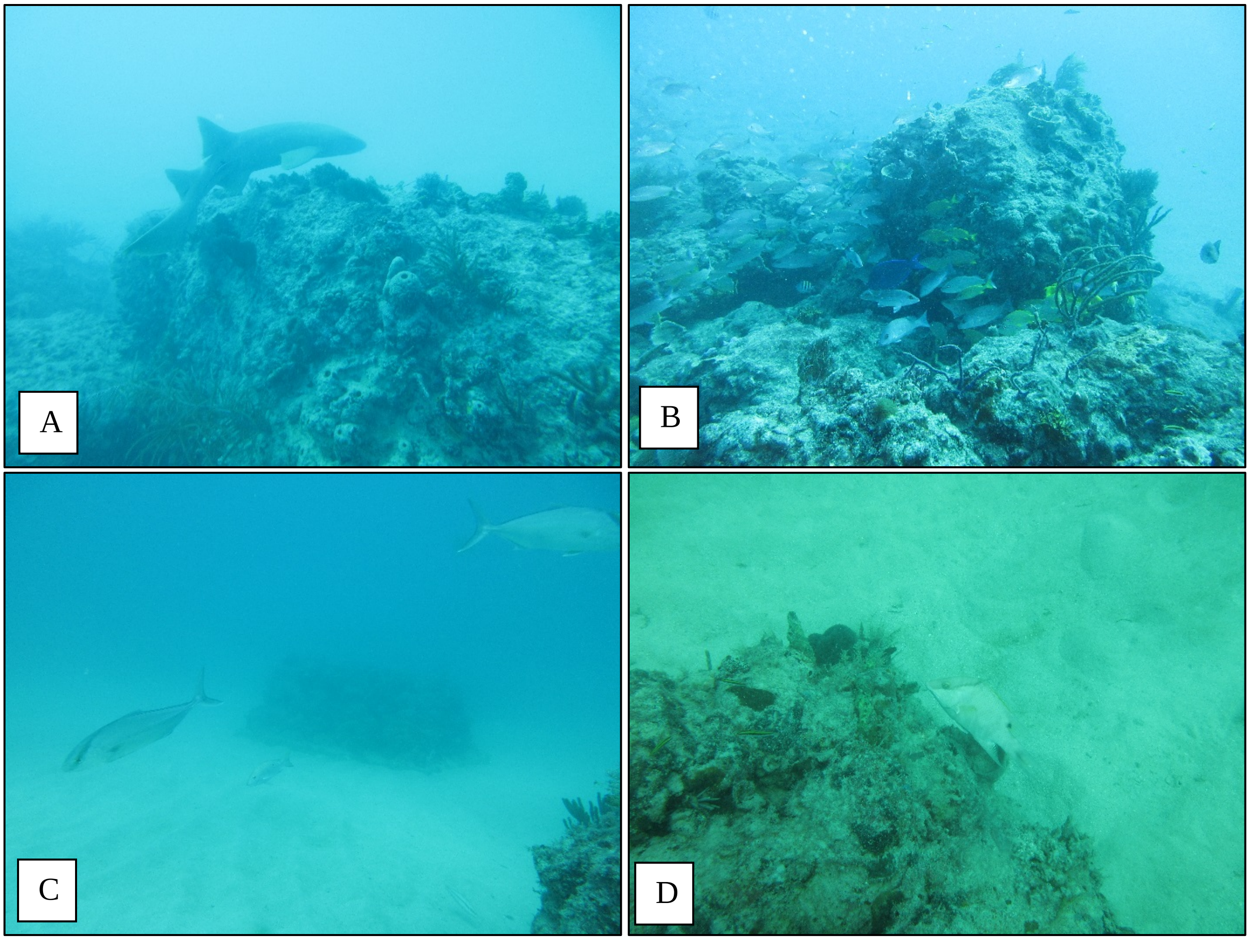

Figure 19. Sport and regulated fish observed during the 2019 grant period. A) *Ginglymonstoma cirratum* (nurse shark) at ANCB (photo taken 1/14/19). B). *Lutjanus griseus* (gray snapper) at GDBB among a variety of other species (photo taken 1/15/09). C). *Seriola dumerili* (Greater amberjack) with *Lutjanus analis* (mutton snapper) in background at PMAM (photo taken 1/15/19). D). *Lachnolaimus maximus* (hogfish) at PMAM (photo taken 3/4/19).

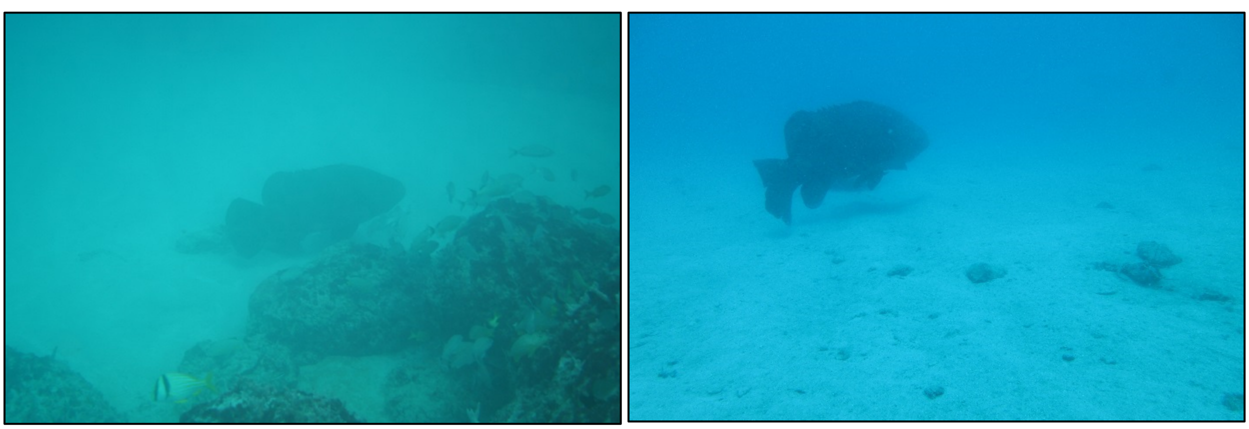

Figure 20. *Epinephelus itajara* (Goliath grouper) observed at GDBB (left, photo taken 1/30/07) in previous grant survey and at SIMM (right, photo taken 3/7/19) in current grant survey.

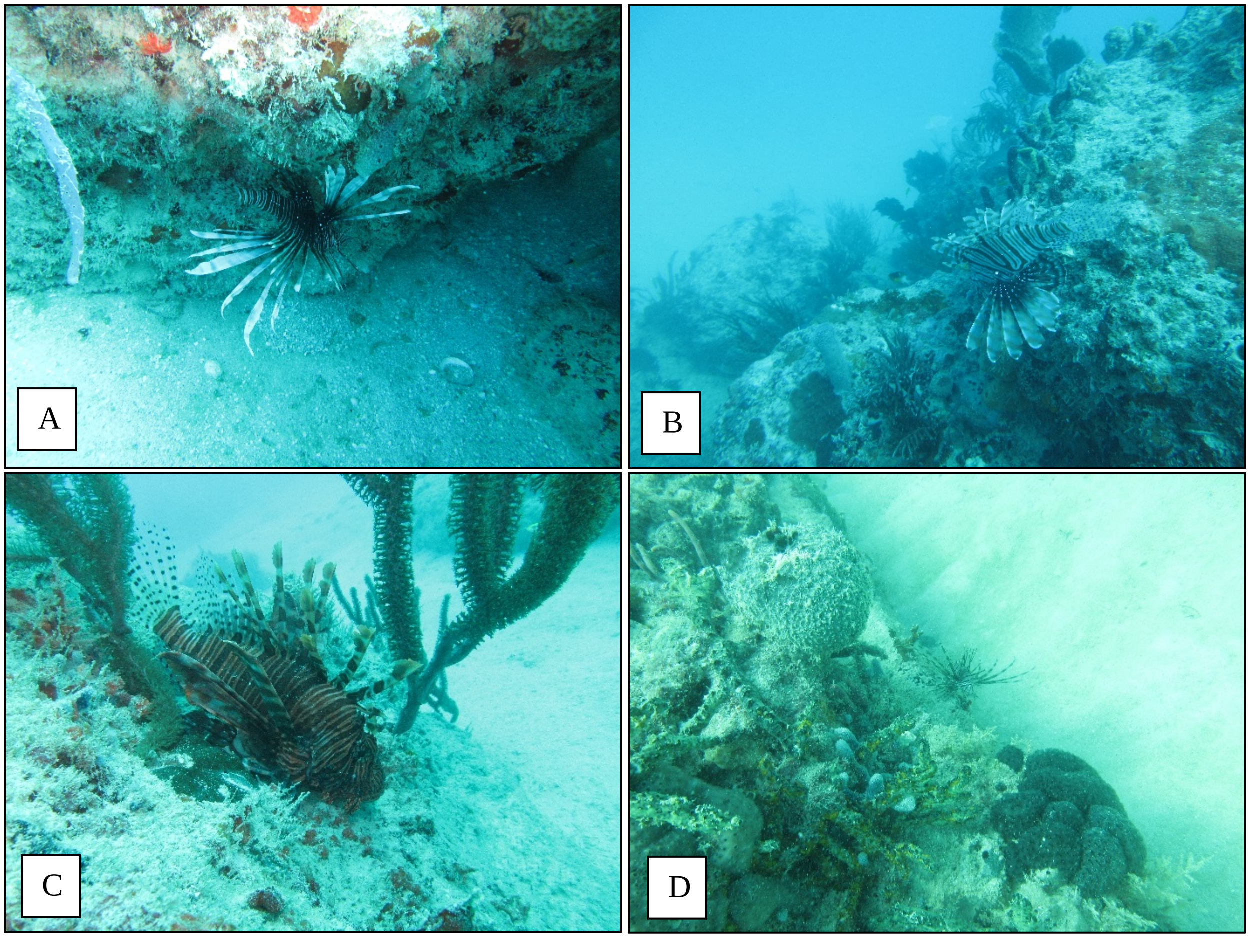

Figure 21. Invasive Lionfish (*Pterois volitans*) observed during 2019 sampling. A) GDBB (photo taken 1/15/09); B) PMBP (photo taken 1/17/09); C) SIMM (photo taken 2/25/19); and D) PMAM (photo taken 3/14/19).

Benthic Assemblages

The benthic assemblages were quantified through photogrammetric evaluation using Coral Point Count software (Kohler and Gill, 2006) from digital photography taken during the time periods specified in Table 2.

<u>Diversity</u>

The Shannon Diversity Index (H') and Pielou's Evenness measure (J') were evaluated for the percent cover of benthic assemblages at each boulder reef (Figure 22). In both the previous and 2019 monitoring, modules site SIMM maintained the highest H' value, 2.05 and 2.09 respectively. Conversely, the lowest diversity of all sites in both sampling periods was observed at ANCH, 0.88 and 1.36 respectively. All sites showed low J' values with respect to their benthic assemblages due to the overwhelming coverage of turf algae ranging from 54.13 to 83.7 percent cover (Table 11 and 12) that reduced the even distribution of benthic coverage.

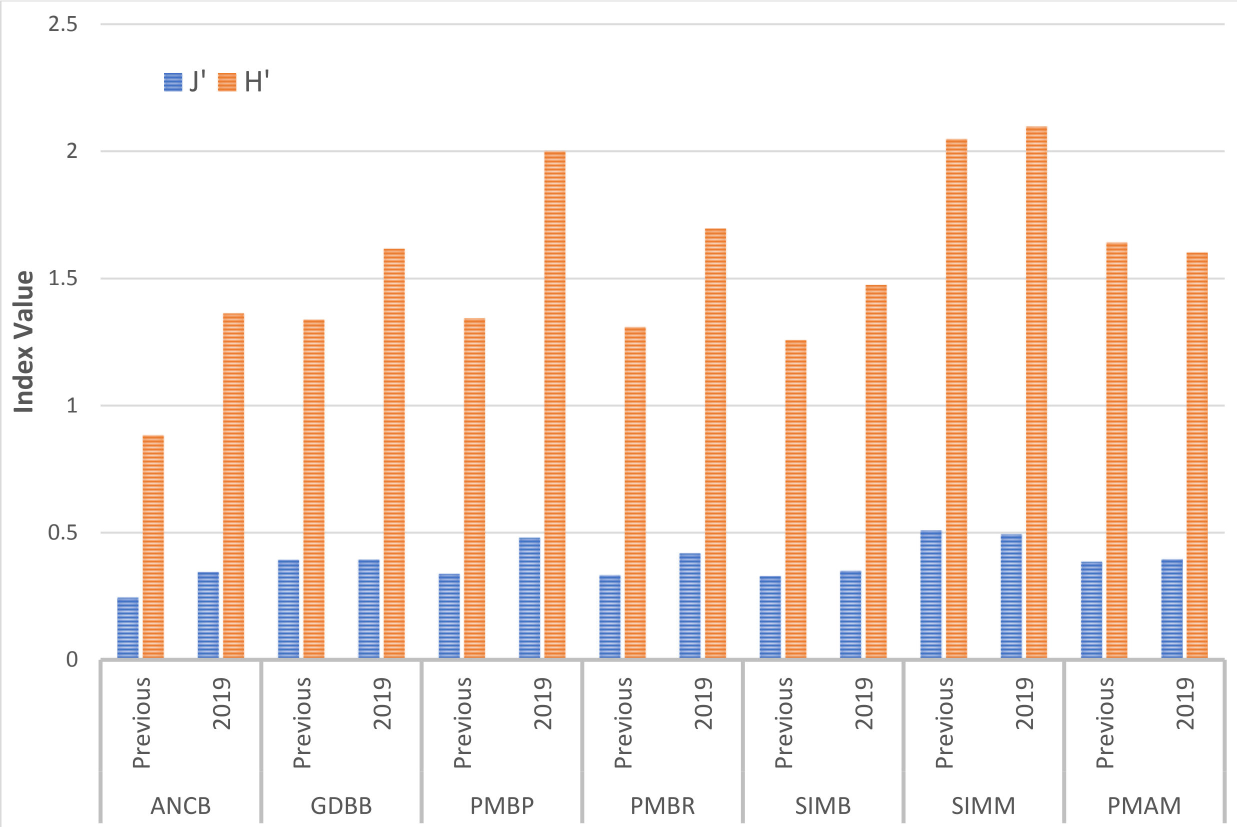

Figure 22. Shannon Diversity Index and Pielou's Evenness measure for each boulder reef. Note that in the previous grant monitoring, area surveyed varied: 28.8m^2 was surveyed at ANCB, GDBB, PMBP, and PMBR, 40m^2 at SIMB and SIMM, and 102.2m^2 at PMAM. In the 2019 grant sampling, 40m^2 was surveyed at each site.

Relative Percent Cover—Major categories

Table 10 shows the relative percent cover of the major benthic categories for the five boulder reefs studied. All five boulder reefs were dominated by algae cover in both sampling periods. Porifera were the second highest percent cover on all boulder sites except PMBP in the previous sampling and all sites except PMBP and PMBR in 2019. All boulder sites showed an increase in porifera percent cover in 2019 from the previous grant sampling except the low relief site SIMB. On PMBR in the previous sampling and on both PMBR and PMBP in 2019, octocorallia had the second highest percent cover, followed by porifera. In 2019, the octocoral cover increased by nearly 10% on PMBP (Figure 23). Octocoral cover was also moderately higher in 2019 on three other boulders sites—ANCB, GDBB, and SIMB. Scleractinian cover was also higher in 2019 at all five boulders sites, ranging from 2.26% to 5.14%. All sites had higher Milleporidae (fire coral) cover in 2019 than the previous sampling. The youngest site, GDBB, had the highest Ascidian (tunicate) coverage (3.38%) in the previous sampling which dropped to 0.06% in 2019 showing a shift in the colonization of the boulders.

Table 10. Relative percent (%) cover of major benthic categories at the five boulder sites. In previous grant monitoring, 28.8m^2 was surveyed at ANCB, GDBB, PMBP, and PMBR while 40m^2 was surveyed at SIMB. In the 2019 grant sampling, 40m^2 was surveyed at each site.

	ANCB		**GDBB**		**PMBP**		**PMBR**		**SIMB**	
Category	**Prev.**	**2019**	**Prev.**	**2019**	**Prev.**	**2019**	**Prev.**	**2019**	**Prev.**	**2019**
Algae	84.67	76.39	84.14	71.41	79.90	63.91	76.54	74.70	79.86	60.00
Porifera	12.43	15.72	10.68	16.80	10.49	11.81	5.14	8.65	12.67	9.92
Octocorallia	0.00	1.19	0.00	2.84	4.83	14.63	11.73	9.84	1.12	2.56
Scleractinia	1.14	2.74	0.04	2.26	3.57	5.14	4.04	4.27	1.69	2.98
Milleporidae	0.15	0.54	0.24	1.42	0.42	0.92	0.38	0.76	0.32	0.68
Zoanthidae	0.00	0.05	0.00	0.06	0.04	0.03	0.04	0.00	0.00	0.00
Ascidian	0.00	0.00	3.38	0.06	0.00	0.03	0.11	0.03	1.34	0.18
Other Live	0.63	0.30	0.08	0.00	0.49	0.24	0.23	0.03	2.20	0.29
Dead organisms	0.00	0.03	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.05
Substrate	0.99	3.04	1.45	5.15	0.27	3.24	1.79	1.73	0.80	23.34

Figure 23. Octocorallia abundance on PMBP in 2019 grant monitoring. Photos taken 2/4/19 (left) and 3/1/19 (right).

Table 11 shows the relative percent cover of the major benthic categories for the two module reefs studied. Both module sites were dominated by algae cover in both sampling periods. Porifera were the second highest percent cover on the module sites during both sampling periods with considerably higher cover than the boulders sites. On SIMM, milleporidae (fire coral) had the third highest cover in the previous grant monitoring and fourth highest in 2019. Octocorallia cover remains low on both module sites but cover was greater at both sites in 2019 than previous sampling. Scleractinian cover on both module sites was higher than octocoral cover in both sampling periods. SIMM showed a higher scleractinian cover in 2019, while PMAM showed a lower percent cover than in previous monitoring periods.

Table 11. Relative percent cover of major benthic categories at the module sites. In previous grant monitoring, 102.2m^2 was surveyed at PMAM and 40m^2 at SIMM. In the 2019 grant sampling, 40m^2 was surveyed at each site.

	SIMM		PMAM	
Category	**Prev.**	**2019**	**Prev.**	**2019**
Algae	64.74	59.89	74.75	71.88
Porifera	24.68	20.07	18.01	19.52
Octocorallia	0.40	2.97	0.04	0.62
Scleractinia	2.99	6.35	4.57	2.02
Milleporidae	5.28	4.66	0.80	0.49
Zoanthidae	0.08	0.39	0.09	0.24
Ascidaria	0.99	0.11	0.37	0.46
Other live	0.76	0.80	0.45	1.40
Dead organisms	0.00	0.11	0.64	0.00
Substrate	0.08	4.66	0.28	3.37

Relative Percent Cover—Algae, Porifera, and Octocorallia species

Table 12 lists the relative percent cover for the highest contributors within the three major taxonomic categories (Algae, Porifera, and Octocorallia) for the five boulders sites while Table 13 lists the highest contributor for the two modules sites. Turf algae dominated the algae percent cover component as well as all biotic components on both the boulder and modules sites. High algal coverage is common at other boulder, modules, and natural reef sites in Miami-Dade County (Thanner et. al 2006 and Thanner 2018).

Table 12. Relative percent cover for the highest contributors at the five boulder sites. In previous grant monitoring (Prev.), 28.8m^2 was surveyed at ANCB, GDBB, PMBP, and PMBR while 40m^2 was surveyed at SIMB. In the 2019 grant sampling, 40m^2 was surveyed at each site.

		ANCB		**GDBB**		**PMBP**		**PMBR**		**SIMB**	
		Prev.	**2019**	**Prev.**	**2019**	**Prev.**	**2019**	**Prev.**	**2019**	**Prev.**	**2019**
Algae	Turf	83.7	72.2	59.2	65.4	74.7	57.8	71.1	65.1	76.2	56.8
	Peysonnelia species	0.7	2.2	2.2	2.0	2.9	2.6	3.7	5.9	0.4	1.8
	Coralline algae	0.3	0.7		2.1	0.8	1.4	0.7	2.3	0.4	0.9
	Blue-green algae		1.3		1.9	1.3	1.9	0.6	0.8	2.4	0.5
Porifera	Porifera (unidentified)	0.88	3.88	1.30	3.96	0.95	2.95	1.29	2.13	3.11	2.32
	Desmapsamma anchorata	3.13	0.27	5.14	0.72	2.47	0.16	0.80	0.03	0.16	0.03
	Iotrochota birotulata	2.35	1.71	0.04	0.25	2.01	1.00	0.27	0.27	3.21	1.57
	Artemisina melana		3.44		2.95		2.73		2.54		0.76
	Cliona delitrix	0.59	0.92		1.09	0.38	0.73	0.15	0.51	1.10	0.78
	Diplastrella megastellata	0.15	0.79	2.20	0.14	0.19	0.08	0.15	0.05	0.46	0.16
Octocorallia	*Antillogorgia* spp.		0.03		1.11	2.89	4.43	9.25	2.30	0.08	0.47
	Gorgonian (unidentified)		0.22		0.11	0.34	4.14	1.33	3.22	0.37	0.42
	Muricea spp.		0.03			0.04	2.43		1.19		0.42
	Pseudoplexaura spp.		0.11			0.53	0.95	0.72	0.54	0.54	0.42
	Eunicea spp.		0.33		0.03	0.46	1.14	0.34	1.00		0.73
	Briareum asbestinum		0.08		1.14		0.43	0.04	0.89		

Table 13. Relative percent cover for the highest contributors at the two modules sites. In previous grant monitoring (Prev.), 102.2m^2 was surveyed at PMAM and 40m^2 at SIMM. In the 2019 grant sampling, 40m^2 was surveyed at each site.

		SIMM		**PMAM**	
		Prev.	**2019**	**Prev.**	**2019**
Algae	Turf	54.94	54.13	68.18	64.46
	Peysonnelia species	2.37	3.24	2.32	1.75
	Blue-green algae	3.08	0.25	2.02	4.10
	Coralline algae	4.09	2.27	1.30	1.46
Porifera	Porifera (unidentified)	6.63	5.35	2.41	3.77
	Iotrochota birotulata	4.66	2.02	3.49	5.69
	Artemisina melana		2.61	1.76	4.07
	Ircinia felix	1.16	0.28	1.98	1.19
	Monanchora barbadensis	1.95	2.11	0.28	
Octocorallia	Gorgonian (unidentified)	0.08	0.83		0.03
	Eunicea spp.		0.36	0.03	0.03
	Gorgonia ventalina	0.14	0.19		0.40
	Muricea spp.		1.03		

At all five boulders sites in 2019, Octocorallia *Antillogorgia* spp. (formerly *Pseudopterogorgia* spp.) and *Eunicea* spp. were observed with the largest percent cover of both genera observed on

PMBR followed by PMBP (Table 12). *Muricea* spp. and *Pseudoplexaura* spp. were two other Octocorallia species observed on four of the five boulders sites, again with the largest percentage of both genera observed on PMBR followed by PMBP. On GDBB, the encrusting octocoral *Briareum asbestinum* was also relatively abundant. A group of multiple, unidentified sponge species was the largest contributor to Porifera cover on four of the five boulder sites in 2019. *Artemisina melana*, a black encrusting sponge, was also abundant and was found at all five sites. In the previous sampling, *Desmapsamma anchorata* was abundant at GDBB. However, as GDBB has aged, the cover of this pioneering species has declined between sampling periods from 5.14% to 0.72% (Figure 24).

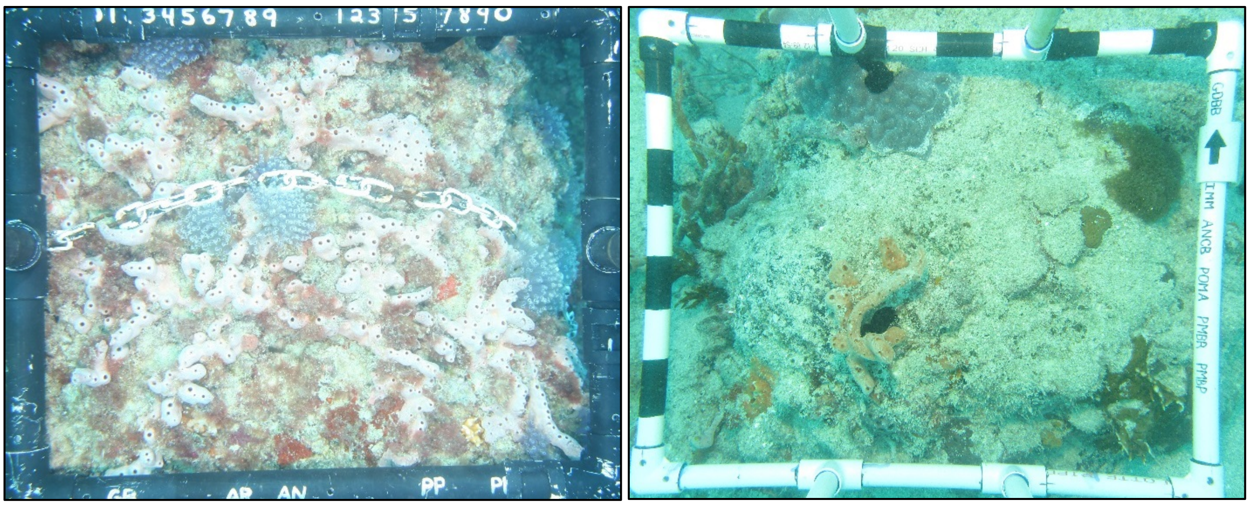

Figure 24. Photo quadrats from GDBB in the exemplifying high cover of *Desmapsamma anchorata* (pink rope sponge) in the previous grant monitoring (left, photo taken 4/24/07) and with lower cover of *D. anchorata* and more diverse benthic assemblage in the 2019 grant monitoring (right, photo taken 2/15/19).

At the module sites, Octocorallia species were less abundant than on the boulder sites (Table 13). In 2019, *Muricea* spp. had the largest octocoral percent cover on SIMM while *Gorgonia ventalina* had the greatest cover on PMAM. Porifera were more abundant on the modules than on the boulders. A group of multiple, unidentified sponge species was the largest contributor to Porifera cover on SIMM and *Iotrochota birotulata* had the greatest cover on PMAM in 2019. *Xestospongia muta*, a large barrel sponge common on natural reefs but generally absent from artificial reefs, was observed on SIMM in 2019 with a total of 0.17% cover (Figure 25).

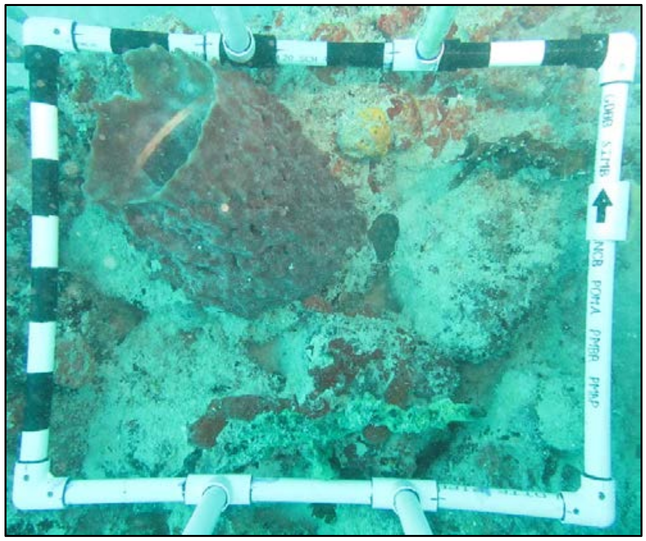

Figure 25. *Xestospongia muta* observed on SIMM in 2019 (photo taken 2/25/19).

<u>Relative Percent Cover—Scleractinian species</u>

The overall relative percent scleractinian cover at all five boulder sites (Table 10 and 14) and at one of the module sites (Table 10 and 14) was larger in 2019 than in previous surveys. The increase in scleractinian cover was largely due to increased cover of *Porites astreoides* and *Siderastrea siderea* cover at ANCB and GDBB and *S. siderea* and *Stephanocoenia intersepta* at PMBP. PMBR only showed a minor overall increase although *S. siderea* cover was 0.52% greater in 2019. At SIBB, small increases of 0.02% or less were observed across multiple species combining for an overall scleractinian cover increase. The module site SIMM saw a large increase in *P. astreoides* (1.74%) with smaller increases in cover of *Madracis decactis* and *S. siderea*. Overall, *Porites astreoides* had the highest percent cover of scleractinian species for all sites in both sampling periods with the exception of PMAM in the previous monitoring. In the previous sampling period, PMAM scleractinian cover was dominated by *Oculina diffusa*. However, *O. diffusa* cover declined from 2.90% to 0.03% in 2019 (Table 15, Figure 26). During the initial monitoring, boulder site GDBB was only two years old with one scleractinian species, *P. astreoides*. Now eleven species were identified through the point count analysis with a total of 2.26% cover. Two boulder sites had a notable presence of the invasive *Tubastraea coccinea* (Orange cup coral) in 2019—GDBB and PMBR (Table 14, Figure 27).

Table 14. Relative percent cover for all scleractinian species at boulder sites. In previous grant monitoring (Prev.), 28.8m^2 was surveyed at ANCB, GDBB, PMBP, and PMBR while 40m^2 was surveyed at SIMB. In the 2019 grant sampling, 40m^2 was surveyed at each site. Species observed in photo quadrats, but not captured in the point count cover analysis are indicated with an asterisk (*).

	ANCB		**GDBB**		**PMBP**		**PMBR**		**SIMB**	
	Prev.	**2019**	**Prev.**	**2019**	**Prev.**	**2019**	**Prev.**	**2019**	**Prev.**	**2019**
Agaricia agaricites	*	0.03		*	*	0.35	0.08	0.05	*	0.10
Agaricia fragilis	*	0.03			*	*	*	*	0.05	0.05
Agaricia species	0.04			0.03		0.08		0.03		
Colpophyllia natans	*	*		0.06	0.11		0.04	0.14		0.05
Dichocoenia stokesi	*	0.03		*	*	*	*	*	*	0.05
Diploria labyrinthiformis				0.11	0.08	0.05	0.15	0.16	0.05	0.34
Eusmilia fastigiata					0.04	0.03	0.04	0.08	*	
Favia fragum					0.08					
Madracis decactis	0.18	0.24		*	*	0.08	0.04	0.05	*	0.08
Meandrina meandrites	0.04	*		0.08	*	*	0.11		*	0.03
Montastraea cavernosa	*	0.11		0.03	*	0.19	0.08	0.11	*	0.05
Mycetophyllia aliciae					*	0.22	0.04	0.14	0.05	0.18
Orbicella species				*	0.04			0.14		
Porites astreoides	0.63	1.30	0.04	1.20	2.62	2.27	2.89	2.05	1.37	1.41
Porites porites		0.03		*	0.04	*	0.04	*	*	
Porites species						0.11				
Pseudodiploria strigosa	*	0.22		0.06	0.04	0.24	0.11	0.03		*
Pseudodiploria species				0.03						
Scolymia species		*	*			*		*	*	*
Siderastrea radians								*	*	
Siderastrea siderea	0.15	0.73	*	0.53	0.23	0.62	0.15	0.68	*	0.31
Siderastrea species						0.03		0.11		
Stephanocoenia intersepta	0.11	0.03		0.03	0.30	0.87	0.27	0.49	0.16	0.31
Tubastraea coccinea				0.11				0.03		
Total %:	**1.14**	**2.74**	**0.04**	**2.26**	**3.57**	**5.14**	**4.04**	**4.27**	**1.69**	**2.98**

Table 15. Relative percent cover for all scleractinian species at module sites. In previous grant monitoring (Prev.), 102.2m^2 was surveyed at PMAM and 40m^2 at SIMM. In the 2019 grant sampling, 40m^2 was surveyed at each site. Species observed in photo quadrats, but not captured in the point count cover analysis are indicated with an asterisk (*).

	SIMM		**PMAM**	
	Prev.	**2019**	**Prev.**	**2019**
Agaricia agaricites	*	0.17	0.06	0.05
Agaricia fragilis	0.08	*	*	
Agaricia species		0.08	*	
Colpophyllia natans			0.02	0.08
Dichocoenia stokesii	*		0.01	*
Diploria labyrinthiformis	0.23	0.30	0.01	*
Eusmilia fastigiata	*	0.03		*
Madracis decactis	0.17	0.75	0.01	
Meandrina meandrites	0.03	0.03	0.03	0.13
Montastraea cavernosa	0.03	0.30	0.01	0.03
Mussa angulosa	*			
Mycetophyllia aliciae	*	*		*
Mycetophyllia species	0.03			
Oculina diffusa			2.90	0.03
Orbicella species	0.03	0.03	0.02	
Porites astreoides	2.09	3.82	0.98	1.19
Porites porites			0.24	*
Pseudodiploria clivosa			*	0.19
Pseudodiploria strigosa	0.06	0.06	0.10	0.08
Scolymia species	*	0.03		
Siderastrea radians	*		0.03	
Siderastrea siderea	0.11	0.53	0.13	0.16
Solenastrea bournoni			*	*
Stephanocoenia intersepta	0.14	0.22	0.01	0.08
Total %:	**2.99**	**6.35**	**4.57**	**2.02**

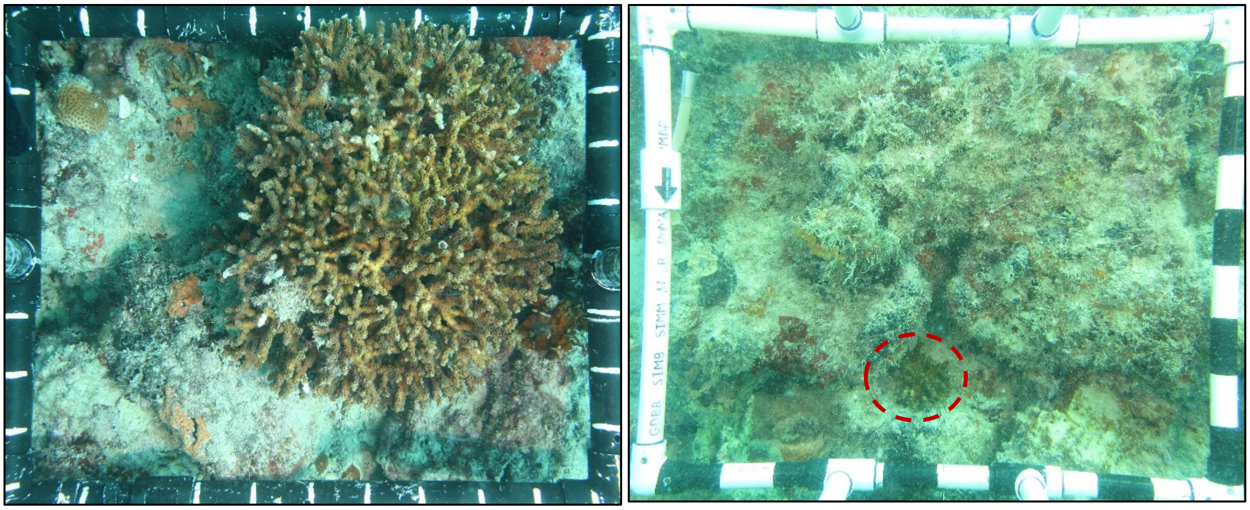

Figure 27. Large *Oculina diffusa* colony observed at PMAM in previous sampling (left, photo taken 6/4/09) and the largest colony observed in 2019 sampling (right, photo taken 3/4/19).

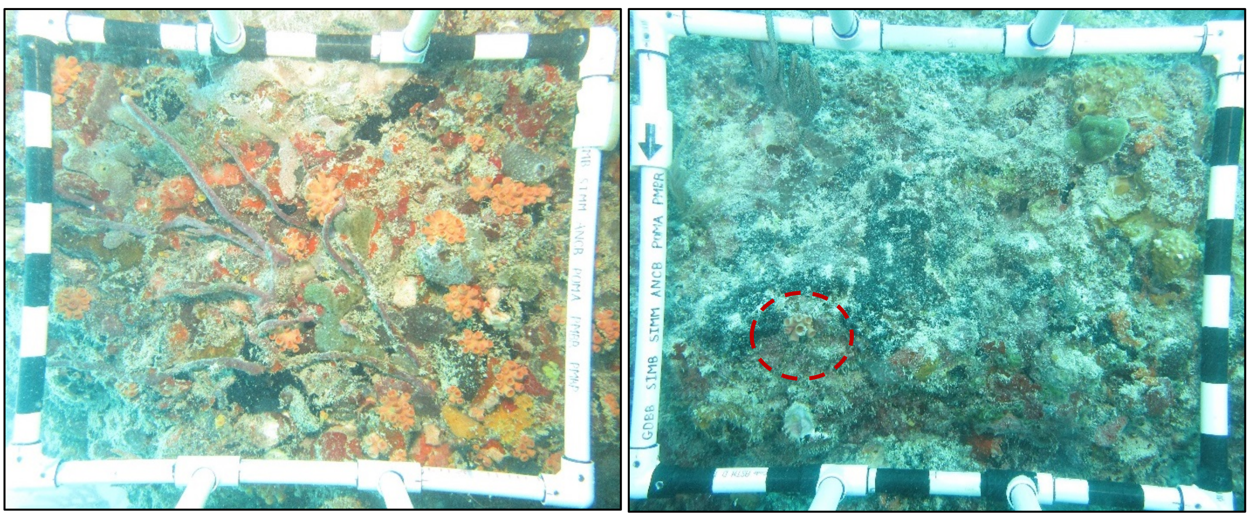

Figure 28. Invasive *Tubastraea coccinea* (orange cup coral) in 2019 at GDBB (left, photo taken 2/15/19) and PMBR (right, photo taken 3/1/19).

<u>Similarity</u>

Figure 29 shows the MDS plot graphically depicting the Bray-Curtis similarity values between sites and sampling periods for the relative percent composition of benthic species, substrate, and sand except for the previous sampling of GDBB. GDBB was only two years old during the previous sampling and as such showed the least similarity and greatest separation from the other sites. Therefore, it was removed from the plot to show the relationship of the other sites and sampling periods. In a portion of the previous sampling, the black encrusting sponge *A. melana* was not identified as a separate species but included with the group of unidentified sponges. For similarity comparisons, *A. mela* percent cover and unidentified sponge cover were combined to minimize any artificial differences caused by identification levels in the different sampling periods.

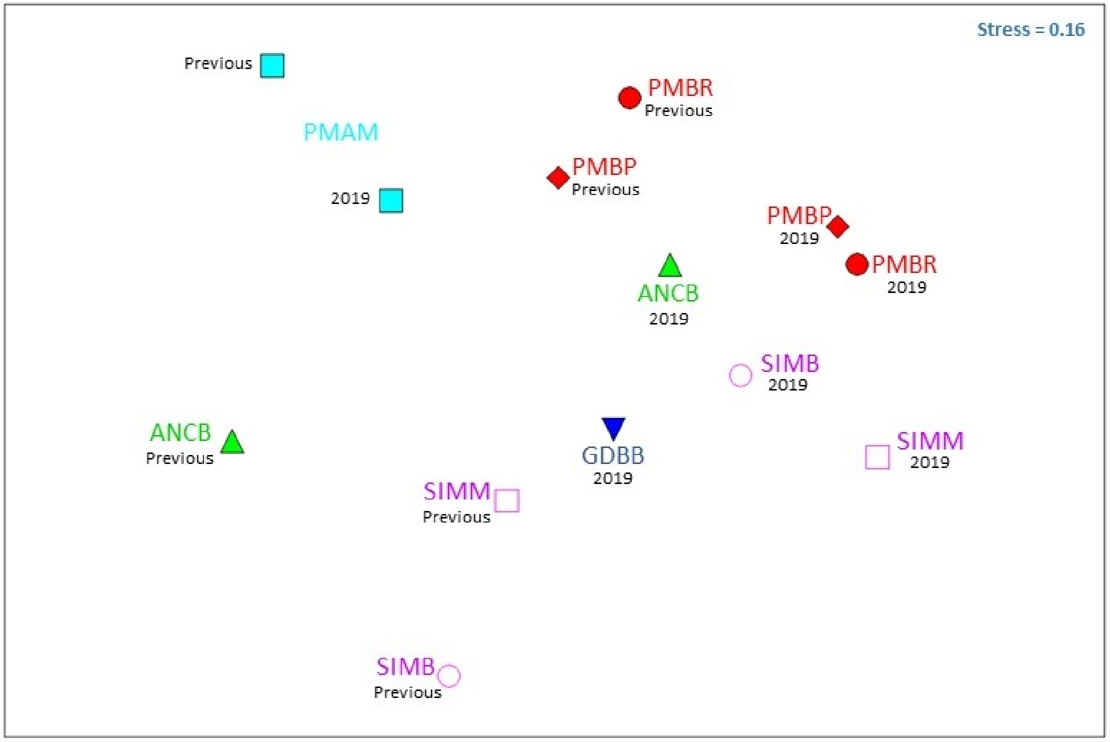

Figure 29. Multi-dimensional scaling (MDS) plot based on the Bray-Curtis Similarity values for the transformed relative percent composition of benthic species, substrate, and sand except for the previous sampling of GDBB. Note that in the previous grant monitoring, area surveyed varied: 28.8m^2 was surveyed at ANCB, GDBB, PMBP, and PMBR, 40m^2 at SIMB and SIMM, and 102.2m^2 at PMAM. In the 2019 grant sampling, 40m^2 was surveyed at each site.

The module site, PMAM, showed the greatest similarity between sampling periods at 72.8%. GDBB was least similar between sampling periods at 38.2%. Table 16 lists the species (or lowest possible taxonomic group) that caused the most dissimilarity at a given boulder site between sampling periods. Differing percent cover of a variety of algae (Blue-green, Coralline, unidentified macro, and *Wrangelia argus*) contributed the dissimilarity between sampling periods at all five boulders sites. A higher abundance of the sponge, *Diplastrella* species, on ANCB, PMBP, PMBR, and SIMB in the previous sampling than the 2019 sampling also contributed to the difference. GDBB was initially highly colonized by the tunicate *Clavelina* species in the previous sampling period with 2.47% cover (Figure 26 left), however, *Clavelina* species was not captured in the 2019 grant monitoring. On three of the boulder sites, PMBP, PMBR, and SIMB, the octocoral *Muricea* species had a higher cover in the 2019 sampling than the previous sampling accounting for some of the dissimilarity between sites. At SIMB in the previous sampling, *Filograna huxleyi*, a calcareous tube worm known as Sea Frost, was abundant with 1.61% cover, but was not observed in 2019 monitoring.

Table 17 lists the species (or lowest possible taxonomic group) which caused the most dissimilarity at a given module site between sampling periods. At SIMM, sponges *Diplastrella* species and *Ircinia campana* were more abundant in the previous sampling than 2019 and contributed the most to the dissimilarity between sampling periods. As previous noted (Table

14), a large decline in the cover of *O. diffusa* was observed between the two sampling periods and accounted for the most to the dissimilarity between the two samplings periods. The dead branches of *O. diffusa* covered in algae was also greater in the previous sampling period and contributed to the dissimilarity between sampling periods.

Table 16. A similarity percentages analysis (SIMPER) for the relative benthic species (or lowest possible taxonomic group) percent cover at the boulder reefs which contributed the most to the dissimilarity between grant periods. Percent cover for each species per sampling period and their contribution the dissimilarity is listed. Note that in the previous grant monitoring, area surveyed varied: 28.8m^2 was surveyed at ANCB, GDBB, PMBP, and PMBR, 40m^2 at SIMB. In the 2019 grant sampling, 40m^2 was surveyed at each site.

Site	Species	Previous % Cover	2019 % Cover	% Contribution
ANCB	Blue-green algae		1.33	4.75
	Diplastrella species	1.14		4.57
	Callyspongia vaginallis	0.51		3.74
	Smenospongia aurea		0.43	3.59
	Gorgonia ventalina		0.35	3.41
GDBB	*Wrangelia argus*	22.3		5.25
	Clavelina species	2.47		3.03
	Coralline algae		2.06	2.89
	Briareum asbestinum		1.14	2.5
	Pseudopterogorgia species		1.11	2.48
PMBP	*Diplastrella* species	1.25		3.87
	Briareum asbestinum		0.43	2.97
	Muricea species	0.04	2.43	2.95
	Smenospongia aurea		0.38	2.87
	Erythropodium caribaeorum		0.35	2.82
	Agaricia agaricites		0.35	2.82
PMBR	*Muricea* species		1.19	4.16
	Amphimedon compressa		0.27	2.88
	Macroalgae	0.27		2.87
	Diplastrella species	0.27		2.87
	Hydroid species	0.23		2.76
SIMB	*Filograna huxleyi*	1.61		4.11
	Eunicea species		0.73	3.38
	Diplastrella species	0.51		3.09
	Muricea species		0.42	2.94
	Siderastrea siderea		0.31	2.73

Table 17. A similarity percentages analysis (SIMPER) for the relative benthic species (or lowest possible taxonomic group) at the module reefs that contributed the most to the dissimilarity between grant periods. Percent cover for each species per sampling period and their contribution the dissimilarity is listed. Note that in the previous grant monitoring, area surveyed varied: 40m^2 was surveyed at SIMB and 102.2m^2 at PMAM. In the 2019 grant sampling, 40m^2 was surveyed at each site.

Site	Species	Previous % Cover	2019 % Cover	% Contribution
SIMM	*Diplastrella* species	1.98		4.21
	Ircinia campana	1.75		4.08
	Muricea species		1.03	3.57
	Zoanthid (unidentified spp.)		0.39	2.8
	Eunicea species		0.36	2.75
PMAM	*Oculina diffusa*	2.9	0.03	3.84
	Dead coral with algae	0.48		3.56
	Gorgonia ventalina		0.4	3.41
	Monanchora barbadensis	0.28		3.11
	Porites porites	0.24		2.97

DISCUSSION

Fish Assemblages

The fish surveys showed that the boulder and module reefs support a wide variety of fish species and numerous individuals (Figures 10-21, Tables 4-9). The most diverse and evenly distributed fish assemblages on the boulder reefs continue to be found on the boulder row and pile reefs at the Port of Miami Site B, PMBR and PMBP (Figure 11). The boulder material at the Port of Miami Site B cover a considerably larger area than the other four sites, collectively 59,950m^2 which is approximately twice as large as the PMAM and over 100 times larger than the smallest site, GDBB (Table 1). The lower resident fish density per survey at PMBR and PMBP (Figure 12) is related to the lower density of *H. aurolineatum* (Tomtate). Together PMBR and PMBP have an average *H. aurolineatum* (tomtates) density of 8 individuals per survey in 2019. Extrapolating that density across the entire site, the Port of Miami Site B site supported approximately 2,725 *H. aurolineatum* individuals. At the two smallest sites, ANCB and GDBB, substantial portions (74% and 82% respectively) of the fish were attributed to large schools of *H. aurolineatum* (Tomtate) as noted in Table 4 and seen in Figure 12. Based on the extrapolated average density of *H. aurolineatum* in 2019, ANCB and GDBB supported approximately twice the number of individuals across the entire site (5,764 and 6,342, respectively) than PMBP and PMBR. Overall, ANCB and GDBB supported over four times the resident fish density in 2019 (Figure 12). All boulder and module reefs supported fish from numerous other families besides Haemulidae. Some of the most abundant families included Gobiidae, Lutjanidae, Labridae, Pomacentridae, Scaridae, and Tetraodontidae (Figure 13 and Table 4 and 5).

Several gamefish species including jacks, groupers, snappers, and hogfish were observed on the boulder and module reefs (Table 9, Appendices 2-8). Both SIMB and SIMM had the fewest gamefish species observed in both sampling periods with five and six respectively in 2019. The greatest diversity of targeted species was found at GDBB in both sampling periods with 12 species observed in 2019 followed closely by ANCB and PMBR with 11 and PMBP and PMAM with nine. PMAM is a relatively low relief (<5 ft) artificial reef, and although nine gamefish species were observed on PMAM, only two were harvestable regulated only by bag limits. The other seven gamefish species had minimum size regulations which the observed individuals did not exceeded. This reef is shallower than the other sites at a depth of 25 ft and may serve as more of a transition habitat for intermediate sized fish. Although many factors are in play such as depth, location, and overall site size, the data indicates that scattered, lower profile (<5 ft) reefs like SIMB and SIMM do not provide the preferred habitat for as many gamefish species as the higher relief (>8 ft) artificial reefs. Even though several gamefish species were observed on the higher profile reefs, only a few individuals with regulated size limits were observed above the legal size (Table 9, Appendices 2-8). Similar observations have been documented in other fisheries-independent surveys on natural reefs in the region (Ferro et al. 2005 and Kilfoyle 2015) indicating the low number of legal sized fish is regional fisheries issue, not a reflection of the artificial reef design.

Benthic Assemblages

The evaluation of the benthic assemblages showed that the boulder and module reefs supported a variety of benthic taxa (Figure 22, Tables 10-15). Module site SIMM maintained the highest diversity and evenness measures in both the previous and 2019 sampling periods while the boulders site ANCB maintained the lowest diversity and evenness in both sampling periods. All sites were dominated by algae, in particular turf algae (Tables 10-13). It should be noted that while a large percentage of the bottom has ‘turf algae’, the ‘turf’ is composed of fine filamentous red and occasionally green algae. The ‘turf’ most often does not cover 100% of the area identified as turf, rather is a more open matrix of filaments. The second most abundant benthic component on six out of seven sites in the previous sampling and five of seven in 2019 sampling was Porifera (Tables 10-11). On PMBP in 2019 and PMBR in both sampling periods, octocorals were the second most abundant component (Table 10). In both sampling periods, the octocoral cover was higher at PMBP and PMBR than the other five sites.

Scleractinian species were observed on all sites with the highest coverage in 2019 on SIMM (6.35%) and the lowest on PMAM (2.02%) (Tables 10-11). *Porites astreoides* had the highest cover on all sites in 2019 increasing on five of the seven sites since the last sampling (Tables 14-15). Similar increasing trends in *P. astreoides* cover were noted on local natural reefs monitored through the Southeast Florida Coral Reef Evaluation and Monitoring Project (Walton et al. 2018). Despite the regional scleractinian coral tissue loss disease (SCTLD) that began offshore of Miami-Dade County in 2014, declines in overall scleractinian cover were only observed at PMAM (Table 15). However, the decline in scleractinian cover at PMAM is attributed to the loss of *O. diffusa* which is a species with low to no susceptibility to SCTLD according to the case study definition (FDEP 2018). PMAM is close to Government Cut which underwent a major dredging event from 2013-2015 which increased sedimentation and turbidity in the area. PMAM is also shallow and, therefore, more susceptible to wave energy and storms like Hurricane Irma which passed by in September 2017. The decline in *O. diffusa* could be related to the dredging, storms, and/or another cause but without pre and post event sampling the true reason behind the decline remains unknown. The benthic sampling methodology was chosen for consistency and comparability with the prior grant monitoring and may not have been optimal for detecting site level scleractinian changes, as cover of individual species is often less than 0.2%. The images from the two adjacent sites, PMBP and PMPR, were reviewed for the density of two species most susceptible to the SCTLD—*Meandrina meandrites* and *Dichocoenia stokesi* (FDEP 2018). Across both sites, a total of 17 *M. meandrites* colonies and 21 *D. stokesi* were observed in the previous photo quadrats while in 2019 only a total of five (5) colonies of each species were observed, indicating a decline in density. Possible evidence of the SCTLD disease was observed in whole colony mortality (Figure 28). However, identifying the cause and timing of coral mortality is made difficult by a lack of marked colonies, repeatable transects, and sampling several years after the initial disease outbreak.

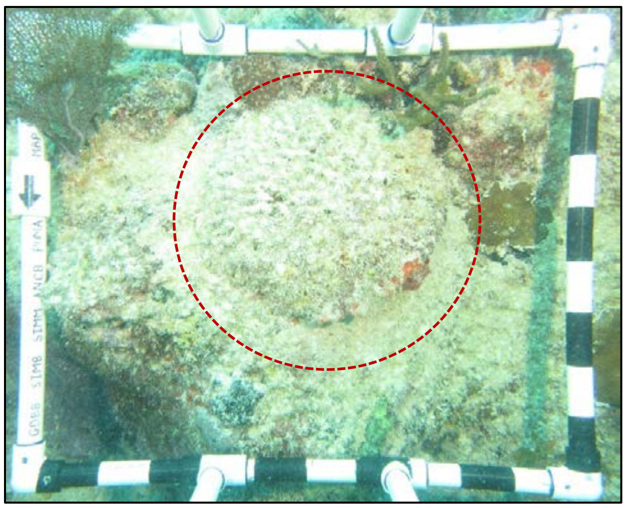

Figure 28. Dead scleractinian colony with algae growth.

The invasive *T. coccinea* (orange cup coral) was first observed by DERM staff on PMBR in 2003 (DERM unpublished) but was not documented in the data collected in 2007 as part of the previous grant monitoring (Miami-Dade County 2007). Qualitatively, the abundance does not seem to have increased at PMBR since the first sighting and currently only has a very low cover at 0.03%. *Tubastraea coccinea* was not observed on GDBB until in 2014 (DERM unpublished). At GDBB, the abundance has increased since the first observation predominately on the vertical surfaces. *Tubastraea coccinea* is now tied as the third most abundant scleractinian in terms of percent cover on GDBB with 0.11%. Future studies would be required to determine whether this increasing cover will continue at GDBB possibly outcompeting other benthic organisms that favor vertical surfaces.

Observations on Use and Marine Debris

While conducting the fish surveys and benthic photography, no recreational scuba diving was observed in the vicinity of the sites. Scuba diving activities have been reported on ANCB and

GDBB. Free diving and spear fishing have also been reported on the GDBB. The extent of diving activities at PMBR, PMBP, SIMB, SIMM, and PMAM is unknown. Recreational fishing was observed on PMBP and PMBR during this survey. Recreational and charter fishing vessels have been observed at all five boulder sites and module site SIMM in the past and monofilament fishing line, anchor line, and anchors is frequently found at these sites (Figure 29). Anecdotally, charter fishing has been most frequently observed over the Sunny Isles Artificial Reef Site where SIMM and SIMB are located and over the Anchorage Artificial Reef site where ANCB is located. Both the Sunny Isles and Anchorage Sites have multiple artificial reefs within them including high relief vessels. The Sunny Isles site is also located due east of the Haulover Inlet providing easy access. Both sites are just west of another, deeper (>100 ft) artificial reef site offering multiple fishing locations in close proximity. Both active and derelict commercial lobster traps (Figure 29E &F) and lines have also been found on and near the all sites. In general, marine debris is related to general boating and fishing activities not diving or snorkeling activities.

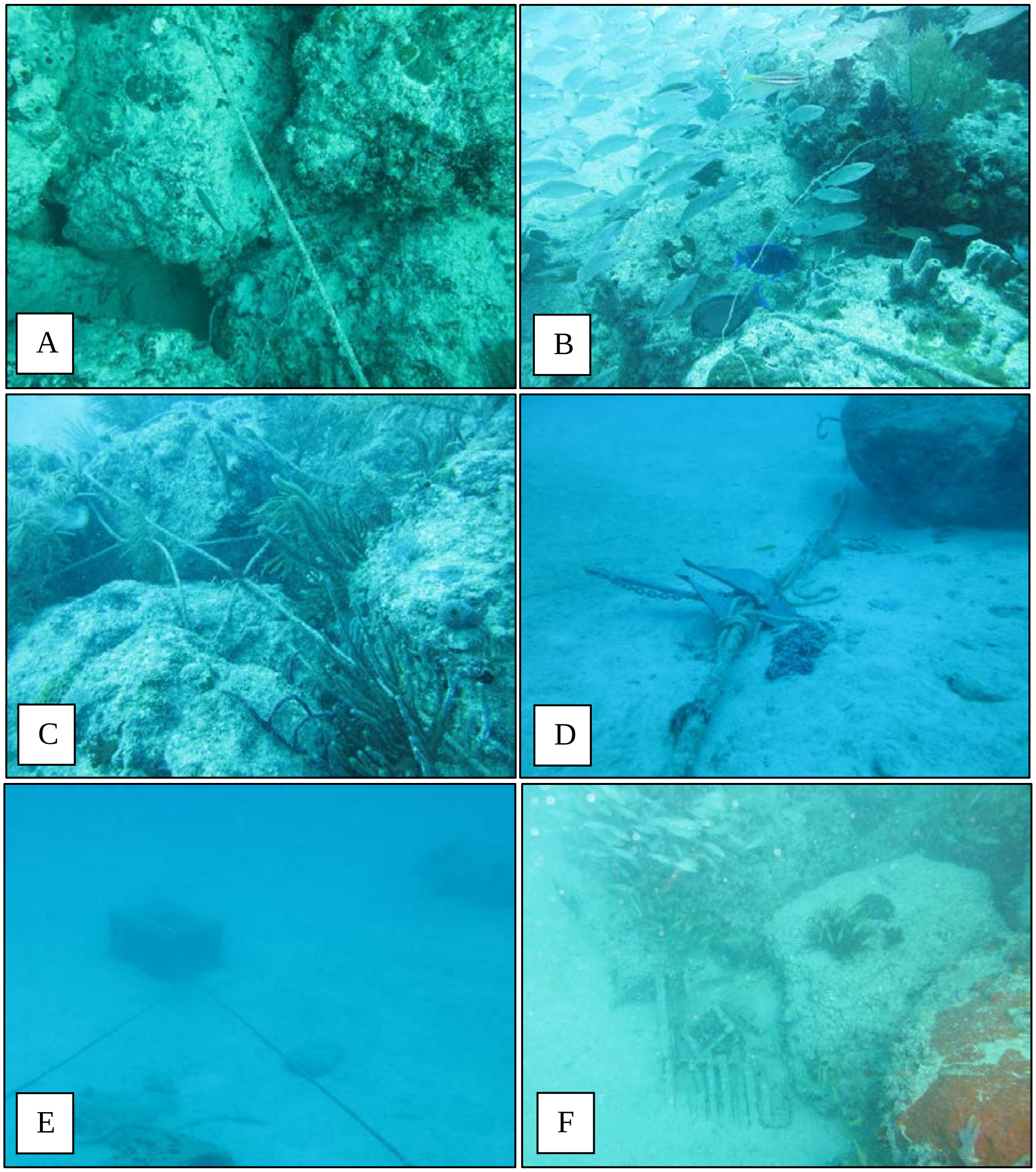

Figure 29. Marine debris observed in 2019. A) Line at ANCB; B) Line and monofilament at GDBB; C) Line at PMPR; D) Anchor and line at SIMB; E) Lobster trap at SIMB; and F) Broken up lobster trap at GDBB.

Artificial Reef Purposes

The seven artificial reefs evaluated were constructed with different purposes. Five were constructed as mitigation for coastal dredging impacts (SIMB, SIMM, PMBP, PMPR, and PMAM), one to enhance diving and fishing opportunities in northern Miami-Dade County (GDBB), and the last reef was deployed simply to provide an additional enhanced fishing location (ANCB). Based on the broad project objectives, each of artificial reefs succeeded a meeting the goals for which they were constructed as summarized below.

Anchorage Reef- Boulders (ANCB): The Anchorage Boulders were deployed to provide recreational fishing opportunities. Based on the data collected through this and prior grants, ANCB has been effective in meeting the objective for which it was constructed. Overall, ANCB supported high resident fish density (Figure 12) although with some shifts in family composition (Figure 13). Haemulidae increased while other common families including Labridae (wrasse), Gobidae (gobies), Scaridae (parrotfish), Tetraodontidae (pufferfish), and Lutjanidae (grunts) all decreased. Eleven gamefish species were observed in 2019 although with very few individuals were above the regulated minimum size. Similar observations have been made on fishery independent natural reef assessments and does not appear related to the design of the artificial reef.

Golden Beach Reef- Boulders (GDBB). The Golden Beach Boulders were deployed to provide recreational diving and fishing opportunities in northern Miami-Dade County. Based on the data collected through this and prior grants, GDBB has been effective in meeting the objectives for which it was constructed. The GDBB site was unique in that it was only two years old during the previous sampling. The 2019 reevaluation, when the reef was 14 years old, allowed for the comparison of early colonization to a more mature reef. Benthic community shifts were observed at GDBB in the 2019 sampling with a decreased abundance of ascidians (tunicates) and a pioneering sponge species *D. anchorata* as well as increased cover of scleractinians and octocorallia between the sampling periods. The benthic community continued to mature with increased porifera, octocoral, and scleractinian cover. Similar benthic successional transitions have been recorded on the Bal Harbour Mitigation Site (Thanner et. al 2006 and Thanner 2018) and the Sunny Isles Reef Restoration-Onsite Mitigation (Miami-Dade County 2003). Differences in the fish assemblages on GDBB were noticed as well. Haemulidae (grunts) density doubled and Lutjanidae (snappers) nearly doubled from the previous sampling period at GDBB. Conversely, the density of other common families including Labridae (wrasse), Pomacentridae (damselfish), Scaridae (parrotfish), Tetraodontidae (pufferfish), and Acanthuridae (surgeonfish/tangs) all decreased by a third to half from the previous sampling. Fluctuations in fish assemblages including large increases in Haemulidae abundance has also been observed at ANCB and throughout the long-term monitoring of the high relief boulders at the Bal Harbour Mitigation site (Thanner 2018). Determining whether fish assemblage changes are natural variations or linked to the develop of the reef would necessitate more frequent surveys beyond the scope of this study. Overall, GDBB did support the highest resident fish density (Figure 12) and highest richness of gamefish species (Appendix 3) in 2019. As such, GDBB provides a unique recreational diving and fishing opportunities in northern Miami-Dade County and has meet the goals for which is was constructed. Similar to ANCB, GDBB does provide a fishing location with recreationally important species; however, very few of those individuals were observed above the regulated minimum size. Similar observations have been made on fishery independent natural reef assessments and does not appear related to the design of the artificial reef.

Port of Miami Mitigation Site B -Boulder Piles (PMBP) and Rows (PMBR): The boulder piles and rows at Port of Miami B were deployed as mitigation for impacts to high relief natural reefs from port expansion dredging project. Specific mitigation success criteria were not outlined at the time of deployment and comparisons to nearby high relief natural reefs have not been made. With those caveats, PMBP and PMBR have met the broad objective of serving as a mitigation reef for dredging related impacts. The benthic assemblages are diverse with relatively high cover of octocorals, porifera, and scleractinians. The scleractinian cover on PMBP and PMBR is higher than what is typically found on natural reefs in the region (Gilliam et al. 2017 and Thanner 2018). Both the boulder piles and rows provided habitat for the most diverse fish assemblages of the sites evaluated. PMBP and PMBR lacked the large (1,000+ individuals) schools of Haemulidae (grunts) in 2019 which would be more similar to natural reef fish assemblages (Thanner 2018 and Arena et al. 2007). In addition to serving as a mitigation reef, these boulders serve as a recreational fishing location with eleven gamefish species observed collectively. Although, only a few individuals were above legal minimum size limits similar to other locations evaluated.

<u>Sunny Isles Mitigation Reef—Boulders and Modules (SIMB and SIMM):</u> The boulder and modules at the Sunny Isles Mitigation Reef were deployed as mitigation for impacts to low relief natural reefs from dredging for a beach renourishment project. Specific mitigation success criteria were not outlined at the time of deployment and comparisons to nearby high relief natural reefs have not been made. With those caveats, SIMB and SIMM have met the broad objective of serving as a mitigation reef for the dredging related impacts. The benthic assemblages are diverse with relatively high cover of octocorals, porifera, and scleractinians. SIMM had the highest porifera and scleractinian cover of all the artificial reefs evaluated and higher cover of both than what is typically found on natural reefs in the region (Gilliam et al. 2017 and Thanner 2018). Due to the lower relief (<3ft) and scattered arrangement of SIMB, the boulders supported a lower fish density including the complete absence of *H. aurolineatum* (tomtates) compared to the other artificial reef sites evaluated. However, the diversity of the fish assemblages was greater than that of the smaller, higher relief boulder reefs. SIMM had a little higher relief (< 4 ft) and provided more cryptic spaces resulting in slightly higher fish density than SIMB. The fish assemblages at SIMB and SIMM would be more comparable to a low relief patchy hardbottom and as such provided mitigation habitat similar to the impacted habitat meeting the broad goals for which they were deployed. Due to the lower relief and scattered placement SIMM and SIMB are not as effective in attracting large schools of fish.

<u>Port of Miami Site A – Modules (PMAM):</u> The modules at Port of Miami A were deployed as mitigation for impacts to low relief natural reefs from port expansion dredging project. Specific mitigation success criteria were not outlined at the time of deployment and comparisons to nearby low relief natural reefs have not been made. With those caveats, PMAM has met the broad objective of serving as a mitigation reef for dredging related impacts. Porifera cover remained high at PMAM during both sampling periods. Unfortunately, scleractinian cover dropped by over 50% in 2019 due to declines in *O. diffusa* for unknown reasons. Despite the decline the current cover of scleractinians is comparable to that typically found on natural reefs in the region (Gilliam et al. 2017 and Thanner 2018). However, the octocoral cover remains below that typically found on natural reefs (Gilliam et al. 2017 and Thanner 2018). PMAM supported numerous fish species with diversity and density greater than Sunny Isles Mitigation Reef (SIMB and SIMM), a deeper, low relief mitigation reef. Nine gamefish species were observed here in 2019, however, all those with size regulations were below the minimum legal size. PMAM provided mitigation habitat and met the broad goals for which there were deployed. Although due to wide placement of the modules is not as effective in attracting large schools of

fish. PMAM, as a result of its shallow location may also serve more as a transition habitat between nearshore juvenile habitat and deeper, offshore reefs than a recreational fishing location.

CONCLUSION AND MANAGEMENT RECOMMENDATIONS

Documenting and quantifying the biological assemblages on limerock boulder reefs is an important step in understanding the role boulder and module reefs play in artificial reef management. This study demonstrated that all seven reefs provide habitat that has supported abundant and diverse benthic and fish assemblages. Unfortunately, these artificial reefs have also been documented to support invasive species such as *T. coccinea* (orange cup coral) which have not been documented on nearby natural reefs and *P. volitans* (lionfish) which seems to prefer the greater relief provided by artificial reef structures.

Each reef has varying characteristics from depth, relief, and location (Table 1, Figure 1-9) and each reef exhibited some unique characteristics. Assessing these unique characteristics is essential in evaluating the success of current projects, planning future projects, and determining where further research and monitoring efforts are needed. As such, the following management recommendations are offered based on the data presented herein as well as general program observations and data gaps:

- Future artificial reef planning: Although many factors contribute to the success of each artificial reef (location, size, material, relief, etc.), the following are general guidelines for future artificial reef development within Miami-Dade County.
    - Mitigation artificial reefs should have more defined measures for determining success with comparisons to the representative habitats they are supposed to provide mitigation for.
    - To maximize fish density, high relief (>8 ft) boulder reefs with a relatively small footprints should be constructed (e.g., GDBB and ANCB).
    - To minimize dominance of large schools of grunts (mainly tomtates) and maximize fish diversity, evenness measures, and more even family composition, high relief (>8 ft) boulders reefs should be constructed with larger footprints (e.g., PMBP/PMBR).
    - To maximize the presence of gamefish species, higher relief reefs (>8 ft) should be constructed (although this will not guarantee gamefish will be large enough to be harvested).
    - To better mimic low relief natural reef/hardbottom habitat without a goal of fishery enhancement, low relief boulder and/or modules reefs should be constructed (e.g. SIMB/SIMM).
    - Both modules and boulders provide sufficient habitat for benthic settlement. However, modules have been documented with higher porifera cover and should be used if increased porifera cover is goal upon deployment.
- Biological Monitoring: Miami-Dade County currently conducts annual surveys on a subset of new artificial reefs (<10 years old). However, these surveys have been largely qualitative documenting species presence and approximate abundance (single, few, many,

abundant). Determining trends or changes with the broad annual survey methodology has limitations as does more detailed surveys decades apart. Therefore:

  - To better document and quantify changes in benthic assemblages, particularly important low cover scleractinian species, establishing long term monitoring stations and survey protocols should be considered at representative reefs based on material type, location, depth, and age.
  - Conducting more frequent, quantitative fish surveys (as opposed to just two surveys a decade apart) should also be evaluated to better capture annual variability and seasonal changes at the same representative sites.
  - Existing data needs to be analyzed further and/or new studies need to be undertaken to better identify:
    - Linkages between benthic and fish assemblages on different sites/materials as well as the same site over time.
    - Patterns in fish size classes between sites and survey periods.
    - Reasons for higher porifera cover on modules versus boulders when exterior surfaces of both are limerock and why the presences of the iconic barrel sponge *Xestospongia muta* which is common on natural reefs is rare on artificial reef materials.
    - Reasons for higher octocoral cover at PMBP and PMPR than other sites and why encrusting octocoral cover is lower on artificial reef material in general than natural reefs.
- Marine Debris: Marine debris including bottles, cans, monofilament, anchors, line (both from anchors and lobster traps), and derelict lobster traps are becoming an increasing issue at Miami-Dade County artificial reefs. Determining the negative effects, accumulation rates, and type of debris should be researched along with any differences in marine debris between reef types, depth and location in order to develop an effective marine debris management and removal strategy.
- The degree to which more robust and frequent monitoring can be implemented and the extent to which marine debris can be removed and minimized on artificial reefs in the future will largely depend on program funding and staff capacity and, therefore, likely and unfortunately limited.

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APPENDICES

- Appendix 1. Resident, Visitor, and Transient Fish Species Classifications
- Appendix 2. Sport and Regulated Fish Species at ANCB
- Appendix 3. Sport and Regulated Fish Species at GDBB
- Appendix 4. Sport and Regulated Fish Species at PMBP
- Appendix 5. Sport and Regulated Fish Species at PMBR
- Appendix 6. Sport and Regulated Fish Species at SIMB
- Appendix 7. Sport and Regulated Fish Species at SIMM
- Appendix 8. Sport and Regulated Fish Species at PMAM

Appendix 1. Classification of fish species (based on Bohnsak et. al, 1994).

Classification	Family	Species	Common Name
Resident	Acanthuridae	*Acanthurus bahianus*	Ocean surgeon
		Acanthurus chirurgus	Doctorfish
		Acanthurus coeruleus	Blue tang
	Apogonidae	*Apogon binotatus*	Barred cardinalfish
		Apogon species	Unidentified cardinal fish
	Aulostomidae	*Aulostomus maculatus*	Trumpetfish
	Balistidae	*Balistes capriscus*	Gray triggerfish
		Cantherhines macrocerus	Whitespotted filefish
		Cantherhines pullus	Orangespotted filefish
		Canthidermis sufflamen	Ocean triggerfish
	Blenniidae	*Blenny* species	Unidentified blenny
		Parablennius marmoreus	Seaweed blenny
	Chaenopsidae	*Acanthemblemaria aspera*	Roughhead blenny
		Emblemaria pandionis	Sailfin blenny
	Chaetodontidae	*Chaetodon capistratus*	Foureye butterflyfish
		Chaetodon ocellatus	Spotfin butterflyfish
		Chaetodon sedentarius	Reef butterflyfish
		Chaetodon striatus	Banded Butterflyfish
	Dasyatidae	*Dasyatis americana*	Southern stingray
	Diodontidae	*Diodon holocanthus*	Balloonfish
		Diodon hystrix	Porcupinefish
	Gobiidae	*Coryphopterus dicrus*	Colon goby
		Coryphopterus glaucofraenum	Bridled goby
		Coryphopterus personatus	Masked goby
		Coryphopterus punctipectophorus	Spotted goby
		Ctenogobius saepepallens	Dash goby
		Elacantinus oceanops	Neon Goby
		Gnatholepis thompsoni	Goldspot goby
		Ptereleotris calliurus	Blue goby
		Ptereleotris helenae	Hovering goby
	Haemulidae	*Anisotremus surinamensis*	Black margate
		Anisotremus virginicus	Porkfish
		Haemulon album	White margate
		Haemulon aurolineatum	Tomtate
		Haemulon carbonarium	Caesar grunt
		Haemulon chrysargyreum	Smallmouth grunt
		Haemulon flavolineatum	French grunt
		Haemulon melanurum	Cottonwick
		Haemulon parra	Sailor's choice
		Haemulon plumieri	White grunt
		Haemulon sciurus	Bluestriped grunt
		Haemulon species (juvenile)	Juvenile grunt species
	Holocentridae	*Holocentrus adscensionis*	Squirrelfish
		Holocentrus rufus	Longspine squirrelfish
		Myripristis jacobus	Blackbar soldierfish
	Kyphosidae	*Kyphosus sectarix*	Bermuda chub

Appendix 1 (Continued). Classification of fish species (based on Bohnsak et. al, 1994).

Classification	Family	Species	Common Name
Resident	Labridae	*Bodianus pulchellus*	Spotfin hogfish
		Bodianus rufus	Spanish hogfish
		Halichoeres bivittatus	Slippery dick
		Halichoeres cyanocephalus	Yellowcheek wrasse
		Halichoeres garnoti	Yellowhead wrasse
		Halichoeres maculipinna	Clown wrasse
		Halichoeres poeyi	Blackear wrasse
		Halichoeres radiatus	Puddingwife
		Lachnolaimus maximus	Hogfish
		Thalassoma bifasciatum	Bluehead wrasse
		Xyrichtys martinicensis	Rosy razorfish
		Xyrichtys splendens	Green razorfish
	Labrisomidae	*Labrisomus gobio*	Palehead blenny
		Malacoctenus triangulatus	Saddled blenny
	Lutjanidae	*Lutjanus analis*	Mutton snapper
		Lutjanus campechanus	Red Snapper
		Lutjanus griseus	Gray snapper
		Lutjanus jocu	Dog snapper
		Lutjanus mahogoni	Mahogany snapper
		Lutjanus species	Unidentifed snapper
		Lutjanus synagris	Lane snapper
	Monacanthidae	*Aluterus scriptus*	Scrawled filefish
		Stephanolepis hispidus	Planehead filefish
	Muraenidae	*Gymnothorax funebris*	Green moray
		Gymnothorax miliaris	Goldentail moray
		Gymnothorax moringa	Spotted moray
	Opistognathidae	*Opistognathus aurifrons*	Yellowhead jawfish
	Ostraciidae	*Acanthostracion polygonia*	Honeycomb cowfish
		Acanthostracion quadricornis	Scrawled cowfish
	Pempheridae	*Pempheris schomburgki*	Glassy sweeper
	Pomacanthidae	*Holacanthus bermudensis*	Blue angelfish
		Holacanthus ciliaris	Queen anglefish
		Holacanthus hybrid	Townsend angelfish
		Holacanthus tricolor	Rock beauty
		Pomacanthus arcuatus	Gray angelfish
		Pomacanthus paru	French angelfish
	Pomacentridae	*Abudefduf saxatilis*	Sergeant major
		Chromis cyaneus	Blue chromis
		Chromis insolatus	Sunshinefish
		Chromis multilineata	Brown chromis
		Chromis multilineatus	Brown chromis
		Chromis scotti	Purple reeffish
		Microspathodon chrysurus	Yellowtail damsel
		Stegastes adustus	Dusky damselfish
		Stegastes leucostictus	Beaugregory
		Stegastes partitus	Bicolor damselfish
		Stegastes planifrons	Threespot damselfish
		Stegastes variabilis	Cocoa damselfish

Appendix 1 (Continued). Classification of fish species (based on Bohnsak et. al, 1994).

Classification	Family	*Species*	Common Name
Resident	Scaridae	*Cryptotomus roseus*	Bluelip parrotfish
		Scarus guacamai	Rainbow parrotfish
		Scarus iserti	Striped parrotfish
		Scarus taeniopterus	Princess parrotfish
		Sparisoma atomarium	Greenblotch parrotfish
		Sparisoma aurofrenatum	Redband parrotfish
		Sparisoma chrysopterum	Redtail parrotfish
	Sciaenidae	*Equetus lanceolatus*	Jackknife fish
		Equetus punctatus	Spotted drum
		Odontoscion dentex	Reef croaker
		Pareques acuminatus	Highhat
		Pareques umbrosus	Cubbyu
	Scorpaenidae	*Scorpaena plumieri*	Scorpionfish
	Serranidae	*Diplectrum formosum*	Sand perch
		Epinephelus adscensionis	Rock hind
		Epinephelus cruentatus	Graysby
		Epinephelus guttatus	Red hind
		Epinephelus itajara	Goliath grouper
		Epinephelus morio	Red grouper
		Hypoplectrus chlorurus	Yellowtail hamlet
		Hypoplectrus gemma	Blue hamlet
		Hypoplectrus nigrricans	Black hamlet
		Hypoplectrus puella	Barred hamlet
		Hypoplectrus species	Unidentified/Tan hamlet
		Hypoplectrus unicolor	Butter hamlet
		Mycteroperca bonaci	Black grouper
		Mycteroperca microlepis	Gag
		Mycteroperca phenax	Scamp
		Serranus baldwini	Lantern bass
		Serranus tabacarius	Tobaccofish
		Serranus tigrinus	Harlequin bass
		Serranus tortugarum	Chalk bass
	Sparidae	*Archosargus rhomboidalis*	Sea bream
	Tetraodontidae	*Canthigaster rostrata*	Sharpnose puffer
		Sphoeroides spengleri	Bandtail puffer
Transient	Carangidae	*Decapterus punctatus*	Round scad
		Seriola dumerili	Greater amberjack
		Seriola rivoliana	Almaco Jack
	Carcharhinidae	*Carcharhinus plumbeus*	Sandbar shark
	Exocoetidae	*Hemiramphus brasiliensis*	Ballyhoo
	Mullidae	*Mulloidichthys martinicus*	Yellow goatfish
		Pseudupeneus maculatus	Spotted goatfish
	Urolophidae	*Urolophus jamaicensis*	Yellow stingray

Appendix 1 (Continued). Classification of fish species (based on Bohnsak et. al, 1994).

Classification	Family	*Species*	Common Name
Visitor	Carangidae	*Caranx bartholomaei*	Yellow jack
		Caranx crysos	Blue runner
		Caranx hippos	Crevalle jack
		Caranx ruber	Bar jack
		Caranx species	Unidentified jack
	Dasyatidae	*Dasyatis americana*	Southern stingray
	Echeneidae	*Echeneis naucrates*	Sharksucker
	Ephippidae	*Chaetodipterus faber*	Atlantic spadefish
	Labridae	*Clepticus parrai*	Creole wrasse
	Lutjanidae	*Lutjanus apodus*	Schoolmaster
		Ocyurus chrysurus	Yellowtail snapper
		Rhomboplites aurorubens	Vermillion snapper
	Ostraciidae	*Lactophrys bicaudalis*	Spotted trunkfish
		Lactophrys triqueter	Smooth trunkfish
	Rhincodontidae	*Ginglymonstoma cirratum*	Nurse shark
	Rhinobatidae	*Rhinobatos lentiginosus*	Atlantic guitarfish
	Scaridae	*Scarus coelestinus*	Midnight parrotfish
		Scarus coeruleus	Blue parrotfish
		Sparisoma rubripinne	Yellowtail parrotfish
		Sparisoma viride	Stoplight parrotfish
		Calamus bajonado	Jolthead porgy
		Calamus calamus	Saucereye porgy
		Calamus penna	Sheepshead porgy
		Calamus species	Unidentified porgy
	Sphyraenidae	*Sphyraena barracuda*	Barracuda
	Synodontidae	*Synodus intermedius*	Sand diver
Invasive	Scorpaenidae	*Pterois volitans*	Lionfish

Appendix 2. Total, average density ($\bar{D}$), percent occurrence (P) per survey, average length ($\bar{L}$**)**, and size range of sport and regulated fish at ANCB throughout entire survey (not just first five minutes). Number of surveys per grant period is noted in parenthesis. Minimum size limit based on FWC Atlantic regulations as of April 2019. Harvestable codes: N = present but none above regulation size; Y = Present and at least one individual above regulation size; Y* = present with only bag limits; (Y) = present with no size or bag limits.

ANCB	**Previous Grant (9)**					**2019 Grant (6)**					**Minimum Legal Size**	**Able to Harvest in 2019 /**
	Total	**$\bar{D}$**	**$\bar{P}$**	**$\bar{L}$ (cm)**	**Range (cm)**	**Total**	**$\bar{D}$**	**$\bar{P}$**	**$\bar{L}$ (cm)**	**Range (cm)**	**cm / in**	**# Ind.**
Carangidae (Jacks)												
Caranx bartholomaei (Yellow)						14	2.3	33	25	20-30	unreg.	(Y)
Caranx crysos (Blue runner)	21	2.3	22	18	15-20						bag limit	-
Caranx ruber (Bar)	83	9.2	56	19	10-30	184	30.7	100	16	9-23	unreg.	(Y)
Labridae (Hogfish)												
Lachnolaimus maximus	2	0.2	11	30	30	4	0.7	67	27	20-36	40.6 / 16	N
Lujanidae (Snappers)												
Lutjanus griseus (Gray)	67	7.4	44	18	10-40	20	3.3	33	21	18-25	25.4 / 10	N
Lutjanus synagris (Lane)	261	29.0	56	18	10-30	5	0.8	33	18	15-20	20.3 / 8	N
Ocyurus chrysurus (Yellowtail)						24	4.0	83	15	12-19	30.5 / 12	N
Rhomboplites aurorubens (Vermillion)	4	0.4	11	11	9-15			0			30.5 / 12	-
Rhincodontidae (Sharks)												
Ginglymonstoma cirratum (Nurse)						1	0.2	17	120		137 / 54	N
Serranidae (Groupers)												
Cephalopholis cruentatus (Graysby)	9	1.0	78	15	10-20	4	0.7	33	24	21-26	bag limit	(Y)
Epinephelus guttatus (Red hind)	1	0.1	11	12	12	1	0.2	17	21		bag limit	(Y)
Mycteroperca bonaci (Black)						1	0.2	17	64		61.0 / 24	Y / 1
Sphyraenidae (Barracuda)												
Sphyraena barracuda (Great Barracuda)						3	0.5	33	84	70-105	38.1-91.4 / 15-36	Y / 2

Appendix 3. Total, average density ($\bar{D}$), percent occurrence (P) per survey, average length ($\bar{L}$), and size range of sport and regulated fish at GDBB throughout entire survey (not just first five minutes). Number of surveys per grant period is noted in parenthesis. Minimum size limit based on FWC Atlantic regulations as of April 2019. Harvestable codes: N = present but none above regulation size; Y = Present and at least one individual above regulation size; Y* = present with only bag limits; (Y) = present with no size or bag limits.

GDBB	**Previous Grant (9)**					**2019 Grant (6)**					**Minimum Legal Size**	**Able to Harvest in 2019 /**
	Total	**$\bar{D}$**	**P**	**$\bar{L}$ (cm)**	**Range (cm)**	**Total**	**$\bar{D}$**	**P**	**$\bar{L}$ (cm)**	**Range (cm)**	**cm / in**	**# Ind.**
Balistidae (Triggerfish)												
Balistes capriscus (Gray Trigger)						30	5.0	17	19	18-25	30.5 / 12	N
Carangidae (Jacks)												
Caranx bartholomaei (Yellow)	5	0.6	11	28	25-30	2	0.3	33	31	20-42	unreg.	(Y)
Caranx hippos (Crevalle)	3	0.3	11	6							unreg.	-
Caranx ruber (Bar)	8	0.9	33	26	8-40	4	0.7	33	14	10-19	unreg.	(Y)
Caranx species (unidentified)	30	3.3	11	8	7-10						unreg.	-
Seriola rivoliana (Almaco)	8	0.9	11	38	25-50	17	2.8	83	36	26-45	unreg.	(Y)
Labridae (Hogfish)												
Lachnolaimus maximus	8	0.9	56	26	15-40	1	0.2	17	40		40.6 / 16	N
Lujanidae (Snappers)												
Lutjanus apodus (Schoolmaster)						2	0.3	33	28	27-29	25.4 / 10	Y / 2
Lutjanus campechanus (Red)	26	2.9	11	19	15-22						50.8 / 20	-
Lutjanus griseus (Gray)	224	24.9	89	20	8-30	68	11.3	67	20	14-25	25.4 / 10	N
Lutjanus jocu (Dog)	2	0.2	11	40	40						30.5 / 12	-
Lutjanus synagris (Lane)	82	9.1	22	13	10-25	426	71.0	83	16	12-22	20.3 / 8	Y / 1
Ocyurus chrysurus (Yellowtail)	1	0.1	11	19		17	2.8	67	21	12-27	30.5 / 12	N
Rhincodontidae (Sharks)												
Ginglymonstoma cirratum (Nurse)	1	0.1	11	140		1	0.2	17	55		137 / 54	N
Serranidae (Groupers)												
Cephalopholis cruentatus (Graysby)	3	0.3	33	19	16-20	2	0.3	33	18	17-19	bag limit	Y*
Mycteroperca bonaci (Black)	1	0.1	11	100		1	0.2	17	64		61.0 / 24	Y / 1
Mycteroperca microlepis (Gag)	6	0.7	44	20	7-28						61.0 /24	-
Mycteroperca phenax (Scamp)	7	0.8	44	22	8-30						50.8 / 20	-

Appendix 4. Total, average density ($\bar{D}$), percent occurrence (P) per survey, average length ($\bar{L}$), and size range of sport and regulated fish at PMBP throughout entire survey (not just first five minutes). Number of surveys per grant period is noted in parenthesis. Minimum size limit based on FWC Atlantic regulations as of April 2019. Harvestable codes: N = present but none above regulation size; Y = Present and at least one individual above regulation size; Y* = present with only bag limits; (Y) = present with no size or bag limits.

PMBP	**Previous Grant (18)**					**2019 Grant (12)**					**Minimum Legal Size**	**Able to Harvest in 2019 /**
	Total	**$\bar{D}$**	**P**	**$\bar{L}$ (cm)**	**Range (cm)**	**Total**	**$\bar{D}$**	**P**	**$\bar{L}$ (cm)**	**Range (cm)**	**cm / in**	**# Ind.**
Carangidae (Jacks)												
Caranx bartholomaei (Yellow)						7	0.6	17	25	22-27	unreg.	(Y)
Caranx crysos (Blue runner)	1	0.1	6	12							bag limit	-
Caranx ruber (Bar)	21	1.2	44	15	5-60	9	0.8	25	17	16-21	unreg.	(Y)
Caranx species (unidentified)	1	0.1	6	60							unreg.	-
Seriola dumerili (Amberjack)	3	0.2	6	50	50						71.1 / 28	-
Labridae (Hogfish)												
Lachnolaimus maximus	27	1.5	72	18	10-32	20	1.7	100	24	12-35	40.6 / 16	N
Lujanidae (Snappers)												
Lutjanus analis (Mutton)						4	0.3	25	37	25-47	45.7 / 18	Y / 1
Lutjanus apodus (Schoolmaster)	10	0.6	39	19	13-28	5	0.4	33	23	19-27	25.4 / 10	Y / 2
Lutjanus griseus (Gray)	3	0.2	11	20	20						25.4 / 10	-
Lutjanus mahogoni (Mahogany)	3	0.2	6	12	12-13						30.5 / 12	-
Lutjanus synagris (Lane)	11	0.6	28	15	12-20	2	0.2	17	19	18-19	20.3 / 8	N
Ocyurus chrysurus (Yellowtail)	15	0.8	28	19	8-30	27	2.3	100	21	15-31	30.5 / 10	N
Rhincodontidae (Sharks)												
Ginglymonstoma cirratum						1	0.1	8	183		137 / 54	N
Serranidae (Groupers)												
Cephalopholis cruentatus (Graysby)	14	0.8	61	18	10-25	10	0.8	50	18	12-23	bag limit	Y*
Epinephelus guttatus (Red hind)	1	0.1	6	28							bag limit	-
Mycteroperca phenax (Scamp)	1	0.1	6	12							50.8 / 20	-

Appendix 5. Total, average density ($\bar{D}$), percent occurrence (P) per survey, average length ($\bar{L}$**)**, and size range of sport and regulated fish at PMBR throughout entire survey (not just first five minutes). Number of surveys per grant period is noted in parenthesis. Minimum size limit based on FWC Atlantic regulations as of April 2019. Harvestable codes: N = present but none above regulation size; Y = Present and at least one individual above regulation size; Y* = present with only bag limits; (Y) = present with no size or bag limits. In 2019, a single snapper (*Lutjanus* species) was unable to be identified to species but was above the legal minimum size for any snapper species and considered harvestable.

PMBR	**Previous Grant (18)**					**2019 Grant (12)**					**Minimum Legal Size cm / in**	**Able to Harvest in 2019 / # Ind.**
	Total	**$\bar{D}$**	**P**	**$\bar{L}$ (cm)**	**Range (cm)**	**Total**	**$\bar{D}$**	**P**	**$\bar{L}$ (cm)**	**Range (cm)**		
Carangidae (Jacks)												
Caranx hippos (Crevalle)	5	0.3	6	40	30-45						unreg.	-
Caranx ruber (Bar)	106	5.9	44	14	8-40	160	13.3	50	17	10-24	unreg.	(Y)
Caranx species (unidentified)	12	0.7	6	40	35-45							
Seriola dumerili (Amberjack)	8	0.4	6	50	50-55						71.1 / 28	-
Seriola rivoliana (Almaco)						2	0.2	8	38	35-40	unreg.	(Y)
Labridae (Hogfish)												
Lachnolaimus maximus	17	0.9	72	18	10-40	9	0.8	50	18	12-27	40.6 /16	N
Lujanidae (Snappers)												
Lutjanus analis (Mutton)						1	0.1	8	33		45.7 / 18	N
Lutjanus apodus (Schoolmaster)	18	1.0	33	23	17-30	4	0.3	25	20	19-22	25.4 / 10	N
Lutjanus griseus (Gray)	89	4.9	50	20	13-30	12	1.0	33	15	11-22	25.4 / 10	N
Lutjanus jocu (Dog)	1	0.1	6	35							30.5 / 12	-
Lutjanus species						1	0.1	8	60		unk	Y / 1
Lutjanus synagris (Lane)	15	0.8	39	17	8-25	1	0.1	8	21		20.3 / 8	Y / 1
Ocyurus chrysurus (Yellowtail)	20	1.1	50	20	12-27	48	4.0	100	19	11-35	30.5 / 12	Y / 2
Rhomboplites aurorubens (Vermillion)	1	0.8	6	8							30.5 / 12	-
Serranidae (Groupers)												
Cephalopholis cruentatus (Graysby)	14	0.8	44	18	15-25	3	0.3	25	19	14-27	bag limit	Y*
Mycteroperca phenax (Scamp)	7	0.4	33	22	16-26						50.8 / 20	-
Sphyraenidae												
Sphyraena barracuda						1	0.1	8	50		38.1-91.4 / 15-36	N

Appendix 6. Total, average density ($\bar{D}$), percent occurrence (P) per survey, average length ($\bar{L}$), and size range of sport and regulated fish at SIMB throughout entire survey (not just first five minutes). Number of surveys per grant period is noted in parenthesis. Minimum size limit based on FWC Atlantic regulations as of April 2019. Harvestable codes: N = present but none above regulation size; Y = Present and at least one individual above regulation size; Y* = present with only bag limits; (Y) = present with no size or bag limits.

SIMB	**Previous Grant (12)**					**2019 Grant (12)**						**Able to**
											Minimum	**Harvest in**
	Total	**$\bar{D}$**	**P**	**$\bar{L}$ (cm)**	**Range (cm)**	**Total**	**$\bar{D}$**	**P**	**$\bar{L}$ (cm)**	**Range (cm)**	**Legal Size cm / in**	**2019 / # Ind.**
Carangidae (Jacks)												
Caranx ruber (Bar)	1	0.1	8	15							unreg.	-
Labridae (Hogfish)												
Lachnolaimus maximus	4	0.3	33	23	20-26	3	0.3	25	23	18-27	40.6 / 16	N
Lujanidae (Snappers)												
Lutjanus analis (Mutton)						3	0.3	17	31	27-32	45.7 / 18	N
Ocyurus chrysurus (Yellowtail)						1	0.1	8	15		30.5 /12	N
Serranidae (Groupers)												
Cephalopholis cruentatus (Graysby)	2	0.2	17	16	13-18	4	0.3	25	15	13-17	bag limit	Y*
Mycteroperca bonaci (Black)						1	0.1	8	45		61.0 / 24	N

Appendix 7. Total, average density ($\bar{D}$), percent occurrence (P) per survey, average length ($\bar{L}$), and size range of sport and regulated fish at SIMM throughout entire survey (not just first five minutes). Number of surveys per grant period is noted in parenthesis. Minimum size limit based on FWC Atlantic regulations as of April 2019. Harvestable codes: N = present but none above regulation size; Y = Present and at least one individual above regulation size; Y* = present with only bag limits; (Y) = present with no size or bag limits.

SIMM	**Previous Grant (18)**					**2019 Grant (18)**					**Minimum Legal Size cm / in**	**Able to Harvest in 2019 / # Ind.**
	Total	**$\bar{D}$**	**P**	**$\bar{L}$ (cm)**	**Range (cm)**	**Total**	**$\bar{D}$**	**P**	**$\bar{L}$ (cm)**	**Range (cm)**		
Carangidae (Jacks)												
Caranx ruber (Bar)	4	0.2	22	13	10-15	2	0.1	6	15	14-16	unreg.	(Y)
Labridae (Hogfish)												
Lachnolaimus maximus	10	0.6	39	25	15-36	13	0.7	50	24	11-40	40.6 / 16	N
Lujanidae (Snappers)												
Lutjanus analis (Mutton)						7	0.4	33	33	30-34	45.7 / 18	N
Ocyurus chrysurus (Yellowtail)	3	0.2	17	13	10-19	5	0.3	17	32	32-33	30.5 / 12	Y / 5
Serranidae (Groupers)			0									
Cephalopholis cruentatus (Graysby)	3	0.2	17	17	15-20	10	0.6	39	17	10-21	bag limit	Y*
Epinephelus guttatus (Red hind)	4	0.2	11	17	12-20							
Mycteroperca bonaci (Black)						1	0.1	6	45		61.0 / 24	N

Appendix 8. Total, average density ($\bar{D}$), percent occurrence (P) per survey, average length ($\bar{L}$), and size range of sport and regulated fish at PMAM throughout entire survey (not just first five minutes). Number of surveys per grant period is noted in parenthesis. Minimum size limit based on FWC Atlantic regulations as of April 2019. Harvestable codes: N = present but none above regulation size; Y = Present and at least one individual above regulation size; Y* = present with only bag limits; (Y) = present with no size or bag limits.

PMAM	**Previous Grant (12)**					**2019 Grant (12)**					**Minimum Legal Size**	**Able to Harvest in 2019 /**
	Total	**$\bar{D}$**	**P**	**$\bar{L}$ (cm)**	**Range (cm)**	**Total**	**$\bar{D}$**	**P**	**$\bar{L}$ (cm)**	**Range (cm)**	**cm / in**	**# Ind.**
Balistidae (Triggerfish)												
Balistes capriscus (Gray Trigger)	25	2.1	100	20	12-25						30.5 / 12	-
Carangidae (Jacks)												
Caranx crysos (Blue runner)	4	0.3	33	14	13-15	1	0.1	8	15		bag limit	Y*
Caranx ruber (Bar)	2	0.2	17	27							unreg.	-
Seriola dumerili (Amberjack)						24	2.0	17	36	30-42	71.1 / 28	N
Labridae (Hogfish)												
Lachnolaimus maximus	7	0.6	42	22	16-27	5	0.4	42	18	16-22	40.6 / 16	N
Lujanidae (Snappers)												
Lutjanus analis (Mutton)						5	0.4	33	27	20-30	45.7 / 18	N
Lutjanus apodus (Schoolmaster)						1	0.1	8	19		25.4 / 10	N
Lutjanus campechanus (Red)	5	0.4	25	19	15-28						50.8 / 20	-
Lutjanus griseus (Gray)	15	1.3	67	19	10-23	71	5.9	83	16	12-19	25.4 / 10	N
Lutjanus synagris (Lane)						17	1.4	33	16	14-17	20.3 / 8	N
Ocyurus chrysurus (Yellowtail)	7	0.6	58	23	14-30	9	0.8	50	15	9-21	30.5 / 12	N
Serranidae (Groupers)												
Cephalopholis cruentatus (Graysby)	1	0.1	8	17		10	0.8	58	17	10-23	bag limit	Y*
Epinephelus morio (Red)	4	0.3	33	24	21-27						50.8 / 20	-
Mycteroperca microlepis (Gag)	2	0.2	17	22							61.0 / 24	-