Bal Harbour Mitigation
Artificial Reef Monitoring Program
Year 18
1999 – 2017

Progress Report and Summary

Submitted to the State of Florida Department of Environmental Protection
in partial fulfillment of the
Bal Harbour Consent Order - OGC Case No. 94-2842

Miami-Dade County
Department of Regulatory and Economic Resources
Division of Environmental Resources Management
Sara Thanner

TABLE OF CONTENTS

INTRODUCTION

This report provides information from an ongoing study of an artificial reef that was constructed as mitigation for impacts to natural reefs. A 20-year monitoring program was developed to assess the efficacy of the project as mitigation for natural reef impacts through the evaluation of colonization and succession of assemblages on two types of artificial reef materials, as well as comparisons to the adjacent natural reefs. The first five years of the project was previously documented (Thanner et al., 2006). Annual surveys from Years 6 through 9 were documented in progress reports submitted in April of 2007 (Y6 and Y7) and April of 2009 (Y8 and Y9). Bi-annual reports documenting Year 10, 12, 14, and 16 monitoring were submitted in April 2010, March 2012, October 2014, and December 2016 respectively. This report focuses on the monitoring results of Year 18 with a summary of the monitoring data to date.

PROJECT BACKGROUND

During the summer of 1990, a beach renourishment project was constructed in which approximately 400,000 cubic yards of sand from an offshore borrow area were deposited to renourish 1.4 km of shoreline in the town of Bal Harbour (Miami-Dade County, Florida). During the construction of this project, excessive sedimentation was discovered over 100,000 m^2 of reef adjacent to the borrow area (Blair et al. 1990). As a result, the Florida Department of Environmental Protection (FDEP) conducted an impact assessment including a 'lost service' evaluation of the impacted reef (Florida Department of Environmental Protection, 1994), and determined that 2,938 m^2 of artificial reef material would be required as mitigation. Subsequently, a consent order (FDEP OGC File No. 94-2842) was signed in December of 1994. The requirements of the consent order included the construction and deployment of the 2,938 m^2 of artificial reef material as mitigation, as well as a long-term biological monitoring plan to evaluate the success of the mitigation.

From Miami-Dade County north to St. Lucie Inlet in Martin County, the offshore reef system is comprised of a parallel series of low-relief carbonate ridges with a moderate amount of cryptic habitat. These natural reefs provide habitat for, and support a diverse assemblage of benthic and fish communities (Blair and Flynn, 1989; Goldberg, 1973; Lindeman, 1997; Moyer et al., 2003). The artificial reef (mitigation) was constructed in the sand plain between two of the parallel reef tracts. These parallel tracts are locally known as "Second Reef" (2R) and "Third Reef" (3R) (Figure 1). The natural reef study areas on 2R and 3R adjacent to the artificial reef site were not impacted in the Bal Harbour Renourishment Project. This artificial reef site is approximately 3.1 km offshore of Baker's Haulover Inlet, Miami-Dade County, at a depth of 20 m.

The design of the artificial reef included two major components: a multi-layer aggregation of natural limestone boulders surrounded by an array of prefabricated concrete modules. The boulder reef was constructed with approximately 8,000 tons of 0.9 m – 1.5 m diameter limerock boulders arranged in a north/south (N/S) rectangular configuration (approximately 46 m by 23 m), with a vertical relief ranging from 2.5 m – 3.5 m. A matrix of 176 prefabricated concrete and limerock modules was arranged in nine numbered columns (N/S) and 22 lettered rows (E/W) surrounding the rectangular boulder area (Figure 1). The artificial reef is located between Latitudes 25° 54.080' and 25° 54.180' North, and Longitudes 80° 05.365' and 80° 05.405' West.

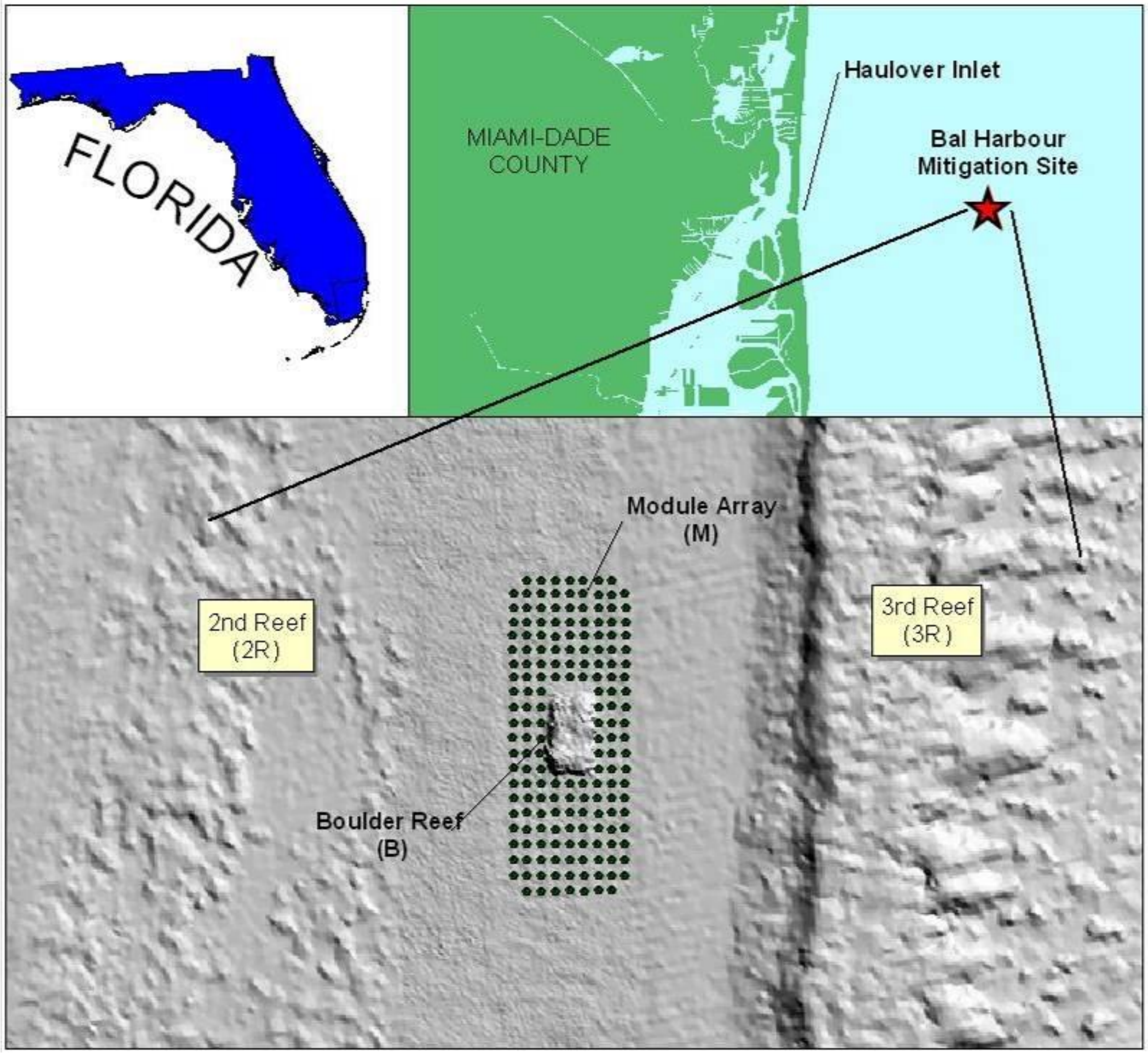

Figure 1—Location of Bal Harbour Artificial Reef Site with position of limerock boulders and modules.

The rows and columns were evenly spaced, approximately 8 m apart. The column number and row letter designations were utilized to provide a unique "x, y" coordinate identification for each module. The module design (Figure 2) consisted of five concrete culvert pipes in a "2-on-3" configuration secured onto a 1.8 m wide x 2.7 m long x 0.4 m thick concrete base. Limerock cobble was grouted onto the exterior of the pipes to provide a natural, rough surface to facilitate benthic recruitment. Overall 'as-built' height of each module was approximately 1.8 m; however, final in situ relief was between 1.3 m – 1.5 m due to subsidence in sand. The deployment of artificial reef modules and limerock boulders was completed in May of 1999.

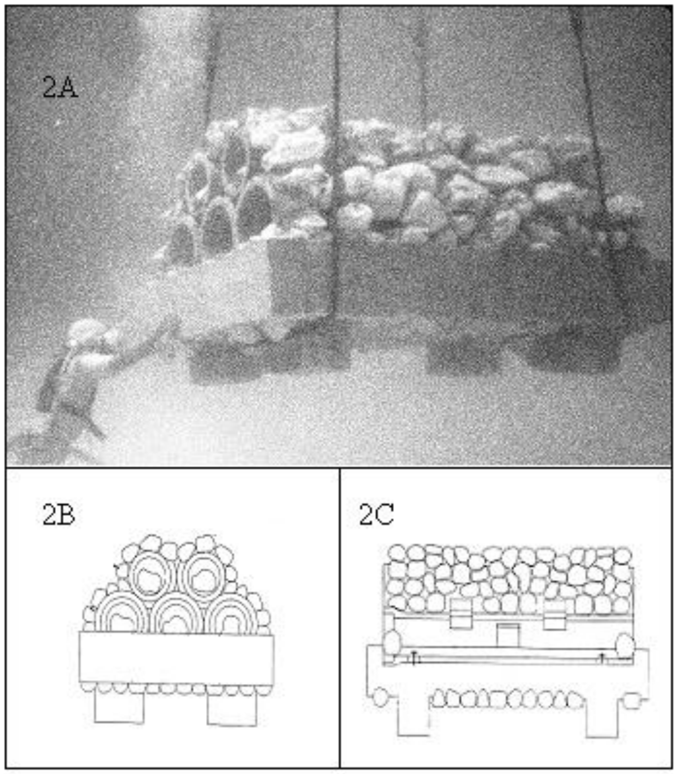

Figure 2—A) 1999 Photo of the module deployment; B) End view of module; C) Side view of module.

METHODS

Sampling Periods

The monitoring plan design included semiannual sampling of the benthic and fish assemblages on the artificial reef and the adjacent natural reef tracts (2R and 3R) for the initial five years post project construction (Table 1). For years 6-10, sampling was conducted on an annual basis. For the last ten years of the project, sampling will be conducted bi-annually. Sampling periods were initially sequentially numbered "S1" through "S10". Sampling periods are now referred to by year of sampling (i.e., Y6 = Year 6). During the recent Y18 sampling period, Hurricane Irma passed by Miami on September 10th, 2017. All fish surveys and the benthic monitoring on the modules were completed prior to the storm while the benthic monitoring for 2R, 3R, and boulders were completed after the storm.

Table 1—Sampling periods for Bal Harbour Artificial Reef Monitoring Project.

Sampling Period	Dates	Sampling Period	Dates	Sampling Period	Dates
Y0.5 (S1)	Oct-Dec 1999	Y4 (S8)	Sept 2003	Y10	July-Sept 2009
Y1 (S2)	July-Aug 2000	Y4.5 (S9)	Feb-April 2004	Y12	July-Sept 2011
Y1.5 (S3)	Feb-April 2001	Y5 (S10)	July 2004	Y14	July-Sept 2013
Y2 (S4)	Sept-Nov 2001	Y6	July-Sept 2005	Y16	July-Oct 2015
Y2.5 (S5)	Feb-April 2002	Y7	July-Sept 2006	Y18	July-Oct 2017
Y3 (S6)	July-Sept 2002	Y8	July-Nov 2007		
Y3.5 (S7)	Jan-April 2003	Y9	July-Oct 2008		

Benthic Assemblage Assessment

For the first five years of the project, the benthic sampling methodology involved random quadrat placement and subsequent identification and enumeration of sessile benthic organisms within each quadrat. During Year 4.5 and 5, a supplemental video transect methodology was also conducted. In Year 6, 7, 8, and 9 only the video transect methodology was implemented. In Y10, both random quadrat and video transect methodology were used in order to compare the current benthic assemblages with the first five years. In Y12, Y14, Y16, and Y18, a photo transect methodology was conducted as noted below.

The video transect methodology utilized is based on methodology used by Florida Wildlife Research Institute (FWRI) on the Coral Reef Evaluation and Monitoring Project (http://myfwc.com/research/habitat/coral/cremp/site-selection-monitoring/). However, as recommended and currently used by FWRI, a small point and shoot camera was used to ‘film’ the transects instead of the video camera starting in Y12. This allowed for less post processing and better image quality.

Three (3) stations were established approximately 10 m apart on each natural reef site—third reef (3R) and second reef (2R). The natural reef sites were chosen based on random GPS coordinates adjacent to the artificial reef site. For the module site (M), a row of eight (8) modules was randomly selected from the northern, middle, and southern area of the artificial reef site. Each row was one of the three replicate module stations. Due to the narrow width of the boulder field, the three (3) boulder stations (B) were established with a minimum of 5 m between one another.

Each station (M, B, 2R, 3R) is comprised of three transects, with each transect being approximately 20 m in length. Transects from Y4.5 through Y10 were filmed with a video camera and analyzed after post processing through frame grabbing software. In Y12 a new method was adopted. A high resolution digital camera (Canon Elph—12 megapixel in Y12, 16 megapixel in Y14 and Y16, and 20 megapixel in Y18) was positioned on a metal stand fixed at 40cm in height (Figure 3). Divers photographed the entirety of each transect using the small base of the stand and the chain as a reference. Images were then downloaded to the computer and then were available for analysis in “Coral Point Count with Excel Extension” (CPCe). The natural reefs yield approximately 210-280 images per station (60-100 per transect). Due to the extensive relief on the artificial reef material, the boulders yield approximately 250-300 images per station (80-105 images per transect) and the modules yield 340-350 per station (107-130 per transect) despite having similar planar area.

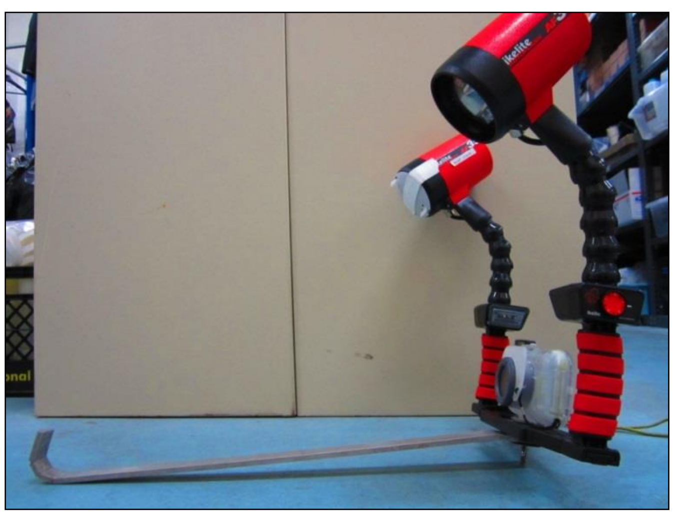

Figure 3—Point and shoot camera frame setup.

Image analysis was conducted using CPCe developed by Nova Southeastern University/National Coral Reef Institute (Kohler and Gill, 2006). This program randomly overlays 20 points on each image as it is opened. Substrate and taxa under each point were identified. After all the images were analyzed in CPCe, the data files were exported in an MS-Excel format for later analyses.

Fish Assemblage Assessment

On each natural reef site (2R and 3R), eight fish surveys were conducted during each sampling period. The survey locations were generally located near the benthic transects. The cinder block and rebar used to mark the benthic transects served as the "origin" for establishing the sampling locations. Randomly generated distances and bearings were used to navigate from the "origin" to the sampling location. An additional survey location would be determined by moving at randomly generated heading, for a distance such that the center points of the subsequent survey was a minimum of 15 m apart. During the first sampling period (Y0.5 / S1), 12 surveys were conducted on the artificial reef materials. Random row/column coordinates were generated for these fish surveys, and were distributed across the entire artificial reef. This resulted in a sampling of 10 modules locations and two boulder locations. Due to the apparent differences in fish assemblages on the materials, in subsequent samplings, the number of surveys on each material type was modified to ensure equivalent representation of modules and boulders (six surveys each).

Fish surveys were conducted utilizing a modified Bohnsack and Bannerot (1986) visual census technique. The fish assemblages within a 15 m-diameter vertical cylinder of water surrounding the sample location were assessed. In contrast to the stationary observer in the original Bohnsack-Bannerot method, the diver swam two slow concentric circles during the first five minutes of the survey, recording all species present within the cylinder. The first rotation was made around the perimeter with minimal disturbance to the species present within the cylinder. A second rotation was made at closer range to identify smaller, cryptic species that might otherwise be missed. For the remainder of the survey, the diver continued this rotational pattern enumerating and estimating the minimum, maximum, and mean size (in cm) of each fish species recorded during the initial five minutes of the survey. Species observed after the initial five minutes were also recorded. Additionally, station information, including habitat features and sampling conditions, was recorded.

Although comprehensive fish survey datasets include all species observed and recorded, 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. 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.

Statistical Analysis

The focus of this monitoring program was to document the changes in communities over time (especially on the new artificial reef materials) and determine to what extent the communities on the artificial reefs are similar to those of adjacent natural reefs. To achieve that goal, a combination of assessment methods, utilization of similarity indices, and clustering with multi-parameter scaling metrics were deemed appropriate for this evaluation. Multiple software applications were used to summarize and analyze the benthic and fish population data. Microsoft Excel was used to calculate summary statistics, graph results, and evaluate trends of the data and indices. "Primer-5 for Windows®" (Primer-E, 2002) multivariate statistical software was used to calculate diversity and evenness indices, Bray-Curtis similarity indices (Bray and Curtis, 1957), ordination clustering of the similarity data using non-metric multidimensional scaling (MDS) procedures, and similarity percentage breakdowns (SIMPER). The Shannon Diversity Index (H') was calculated as it incorporates species richness (S) as well as the relative abundances of species. 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. Relative numbers of individuals of each species also affects the value of H'. If only a small portion of species in the sample account for most of the individuals, 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. Higher values of J indicate the more evenly the individuals are spread among the different species. Bray-Curtis Similarity indices were calculated once 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 Shepard diagram (graphical representation of the association of the groups analyzed), 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. "SIMPER" analysis produces an average dissimilarity between samples and provides the percent contribution of each species to this dissimilarity.

RESULTS

Benthic Assemblages

This report summarizes the results from Y10-Y18 with the main focus being on the results from the Y18 monitoring through the evaluation of the relative percent cover of benthic groups with comparisons to previous year's results.

1. Assemblages on Natural Reefs

The benthic community components on the natural reefs showed relative consistency in the number of species and/or lowest possible taxonomic group throughout the study period (Tables 2 and 3). The one exception is the decline in the number of scleractian species observed on 3R during the last two sampling periods. The algal group remained the most abundant benthic organisms on the natural reefs in terms of percent cover (Tables 2 and 3). Octocorallia and porifera continue to be the next most abundant type benthic organisms on both second reef (2R) and third reef (3R) in terms of percent cover. In the three most recent sampling periods (Y14, Y16, and Y18), octocorals had a larger relative percent cover than porifera on both natural reefs. In Y18, the percent cover of the substrate, which includes non-biotic components such as bare pavement and sediment covered hardbottom, more than doubled that of previous years at both natural reef sites. On 2R, the percent cover of substrate was actually larger than the algal component.

Table 2—Number of taxa (species or lowest possible taxonomic group) and mean percent cover of major benthic categories on **second reef (2R)** identified in CPCe analysis during the last five sampling periods.

		Y10	**Y12**	**Y14**	**Y16**	**Y18**
Algae	# Taxa	8	9	10	9	**8**
	Mean % Cover	75.70	74.21	76.76	67.20	**40.98**
	Std. Dev.	5.96	5.00	4.94	3.68	3.88
Porifera	# Taxa	38	34	36	37	**36**
	Mean % Cover	8.68	9.18	5.98	7.62	**6.94**
	Std. Dev.	1.88	2.27	1.69	2.95	1.52
Octocorallia	# Taxa	11	9	10	10	**12**
	Mean % Cover	7.38	9.24	7.39	9.82	**7.50**
	Std. Dev.	1.98	3.03	2.16	3.95	1.47
Scleractinia	# Taxa	8	8	9	9	**8**
	Mean % Cover	0.23	0.35	0.25	0.25	**0.29**
	Std. Dev.	0.08	0.14	0.02	0.23	0.11
Substrate	Mean	7.82	6.86	8.85	14.73	**43.98**
	Std. Dev.	5.38	2.69	1.37	0.43	3.65

Table 3—Number of taxa (species or lowest possible taxonomic group) and mean percent cover of major benthic categories on **third reef (3R)** identified in CPCe analysis during the last five sampling periods.

		Y10	Y12	Y14	Y16	**Y18**
Algae	# Taxa	9	11	9	11	**8**
	Mean % Cover	77.17	74.00	73.28	65.22	**49.50**
	Std. Dev.	4.86	4.88	2.99	5.76	6.79
Porifera	# Taxa	32	37	35	33	**32**
	Mean % Cover	7.97	7.98	6.95	9.03	**6.57**
	Std. Dev.	0.88	0.56	0.98	2.76	0.39
Octocorals	# Taxa	10	10	7	11	**9**
	Mean % Cover	6.28	7.39	7.13	13.96	**14.71**
	Std. Dev.	0.49	0.09	0.26	2.21	4.21
Scleractinians	# Taxa	8	10	9	7	**6**
	Mean % Cover	1.17	1.00	1.11	0.88	**0.92**
	Std. Dev.	0.44	0.52	0.61	0.22	0.16
Substrate	Mean % Cover	6.89	9.14	10.97	10.23	**27.86**
	Std. Dev.	4.14	4.71	2.30	2.09	6.62

On 2R, turf algae still dominated the relative percent cover of the algal component as well as all biotic components in Y18 (Table 4). However, this was markedly lower than previous sampling periods. Likewise, the cover of blue-green algae and *Lyngbya* species decreased and when combined accounted for less than 1% cover whereas in the last sampling period (Y16) it accounted for over 15%. The encrusting octocoral, *Erythropodium caribaeorum*, had the highest percent cover of the octocorallia group on 2R. Consistent with the previous two sampling periods, porifera with the highest percent cover was *Xestospongia muta*. The percent cover of two abundant rope sponges, *Aplysina cauliformis* and *Amphimedon compressa*, decreased by more than half in Y18. Scleractinian cover remained low with the most abundant species being *Siderastrea siderea*. Within the substrate category, the percent cover attributed to sediment pockets and sediment covered hardbottom doubled and quadrupled respectively from Y16 to Y18. In Y18, 29.01% of 2R was sediment covered hardbottom while only 7.23% was in Y16.

Table 4—Mean relative percent cover (%) per sampling period for the highest contributors on **second reef (2R)** during the last five sampling periods.

		Y10	Y12	Y14	Y16	**Y18**
Algae	Turf	67.76	45.56	62.95	43.04	**36.88**
	Peysonnelia species	0.46	1.95	1.53	2.09	**1.63**
	Halimeda species	0.40	0.29	0.69	1.90	**1.04**
	Crustose coralline algae	0.33	0.96	0.32	1.14	**0.87**
	Blue-green algae	1.97	0.65	9.61	11.25	**0.48**
	Lyngbya species	4.73	24.70	0.44	7.69	**0.04**
Octocorallia	*Erythropodium caribaeorum*	0.06	0.02	0.39	1.99	**2.32**
	Eunicea species	0.27	1.43	2.23	2.48	**2.07**
	Unidentified octocoral	3.03	3.32	1.46	0.88	**1.53**
	Pseudopterogorgia species	0.25	0.10	0.46	0.62	**0.76**
	Briareum asbestinum	3.38	3.30	1.61	1.98	**0.34**
	Muricea species	0.04	0.02	0.05	0.06	**0.12**
	Muriceopsis species	0.29	0.84	1.07	1.54	**0.11**
Porifera	*Xestospongia muta*	1.34	1.49	1.72	1.57	**2.30**
	Unidentified porifera	2.20	1.59	0.57	0.90	**1.49**
	Niphates erecta	0.65	0.55	0.58	0.48	**0.45**
	Aplysina cauliformis	1.00	1.24	0.76	1.01	**0.35**
	Monanchora barbadensis	0.07	0.12	0.12	0.12	**0.26**
	Amphimedon compressa	0.39	0.47	0.26	0.54	**0.23**
	Spirastrella coccinea	0.08	0.17	0.05	0.34	**0.21**
Scleractinia	*Siderastrea siderea*	0.00	0.01	0.02	0.05	**0.09**
	Stephanocoenia intersepta	0.02	0.08	0.01	0.03	**0.07**
	Meandrina meandrites	0.10	0.14	0.06	0.02	**0.03**
	Montastraea cavernosa	0.02	0.06	0.08	0.00	**0.03**
	Orbicella faveolata	0.00	0.00	0.00	0.00	**0.03**
	Mycetophyllia aliciae	0.00	0.00	0.03	0.01	**0.03**
Substrate	Sand pocket	4.84	1.14	4.17	7.49	**14.91**
	Sediment covered hardbottom	2.98	5.72	5.23	7.23	**29.01**

Like on 2R, turf algae still dominated the relative percent cover of the algal component as well as all biotic components on 3R (Table 5). However, the turf coverage was lower than all previous sampling periods. Blue-green algae and *Lyngbya* species cover also declined and accounted for less than 1% cover combined while they had over 11% cover in Y16. Similar to the previous sampling period, octocorals with the largest percent cover included the encrusting species *E. caribaeorum* as well as *Pseudopterogorgia* species. Porifera with the highest percent cover included *X. muta* and unidentified poriferans. A large decrease was observed in the rope sponge *Iotrochota birotulata* from Y16 to Y18. Relative to scleractinians, *Montastraea cavernosa* had the highest relative percent cover followed *Porites astreoides* on 3R. Within the substrate category, the percent cover attributed to sediment pockets and sediment covered hardbottom doubled and quadrupled on 3R respectively from Y16 to Y18. In Y18, 22.63% of 3R was sediment covered hardbottom while only 5.59% was in Y16.

Table 5—Mean relative percent cover (%) per sampling period for the highest contributors on **third reef (3R)** during the last five sampling periods.

		Y10	Y12	Y14	Y16	**Y18**
Algae	Turf	69.78	51.43	66.48	50.70	**46.45**
	Halimeda species	0.77	0.84	0.67	1.69	**0.91**
	Coralline algae	0.19	0.38	0.31	0.34	**0.89**
	Peysonnelia species	0.29	0.89	0.66	0.56	**0.72**
	Blue-green algae	4.54	0.05	4.06	6.02	**0.45**
	Red filamentous algae	0.00	0.01	0.00	0.03	**0.04**
	Lyngbya species	0.79	20.19	0.26	5.49	**0.02**
Octocorallia	*Erythropodium caribaeorum*	0.04	0.12	1.99	6.14	**6.59**
	Pseudopterogorgia spp.	1.01	2.47	3.13	5.28	**6.12**
	Briareum asbestinum	3.49	3.40	0.91	1.03	**0.56**
	Eunicea species	0.25	0.13	0.25	0.69	**0.54**
	Unidentified octocoral	0.67	1.05	0.50	0.19	**0.35**
	Pseudoplexuara species	0.02	0.03	0.00	0.04	**0.27**
Porifera	*Xestospongia muta*	1.69	1.78	1.51	1.75	**2.10**
	Unidentified porifera	1.55	0.93	0.40	0.62	**0.95**
	Iotrochota birotulata	1.06	1.14	1.46	2.05	**0.38**
	Monanchora barbadensis	0.18	0.34	0.28	0.16	**0.37**
	Amphimedon compressa	0.54	0.28	0.31	0.68	**0.36**
	Niphates erecta	0.25	0.32	0.31	0.49	**0.36**
	Spirastrella cocinea	0.02	0.25	0.17	0.31	**0.31**
Scleractinia	*Montastraea cavernosa*	0.57	0.44	0.55	0.31	**0.42**
	Porites astreoides	0.22	0.25	0.22	0.32	**0.38**
	Stephanocoenia intersepta	0.00	0.01	0.00	0.00	**0.04**
	Siderastrea siderea	0.00	0.02	0.06	0.07	**0.03**
	Diploria labyrinthiformis	0.01	0.01	0.01	0.03	**0.03**
	Madracis decactis	0.03	0.00	0.01	0.01	**0.02**
	Orbicella faveolata	0.08	0.10	0.07	0.11	----
	Meandrina species	0.11	0.14	0.17	----	----
Substrate	Sand Pocket	3.92	3.18	5.39	2.34	**5.11**
	Sediment covered hardbottom	2.95	5.92	5.51	5.59	**22.63**

2. Assemblages on Artificial Reef Materials

The artificial reef materials showed relative consistency in number of taxa throughout the last five sampling periods (Table 6 and 7). Similar to 2R and 3R, the algae cover on the boulders decreased notably while the substrate cover increased in Y18. However, the algae and substrate percent cover remained more comparable to previous sampling periods on the modules. Similar to previous sampling periods, porifera had the next highest relative percent biotic cover on both artificial reef materials although the percentage did decrease for both since Y16. Octocorallia percent cover on both boulders and modules more than doubled between Y14 and Y16. In Y18, octocorallia cover remained similar on the boulders and increased slightly on the modules. Scleractinian cover increased slightly on the boulders but decreased slightly on the modules in the last sampling period.

Table 6—Number of taxa and mean percent cover in each major benthic category on the **boulders (B)** identified in CPCe analysis during the last six sampling periods.

Category		**Y10**	**Y12**	**Y14**	**Y16**	**Y18**
Algae	# Taxa	7	8	9	6	**5**
	Mean % Cover	85.25	81.85	84.32	79.39	**70.24**
	Std. Dev.	0.40	1.76	1.62	0.72	2.28
Porifera	# Taxa	29	36	40	33	**37**
	Mean % Cover	10.17	11.94	9.23	10.33	**8.48**
	Std. Dev.	0.95	0.76	1.44	0.42	1.63
Octocorallia	# Taxa	6	6	8	9	**8**
	Mean % Cover	1.62	1.77	1.41	3.20	**3.12**
	Std. Dev.	1.10	0.76	0.44	0.99	0.05
Scleractinian	# Taxa	17	21	21	23	**21**
	Mean % Cover	1.65	1.94	2.09	2.63	**3.09**
	Std. Dev.	0.09	0.09	0.32	0.30	0.16
Substrate	Mean % Cover	0.54	1.05	2.10	3.44	**13.93**
	Std. Dev.	0.32	0.61	1.52	1.16	2.37

Table 7—Number of taxa and mean percent cover in each major benthic category on the **modules (M)** identified in CPCe analysis during the last six sampling periods.

Category		Y10	Y12	Y14	Y16	Y18
Algae	# Taxa	4	7	8	6	**9**
	Mean % Cover	70.01	67.66	73.00	67.33	**67.66**
	Std. Dev.	1.77	2.59	2.10	2.18	1.03
Porifera	# Taxa	34	33	39	38	**36**
	Mean % Cover	26.36	26.12	20.50	21.45	**19.84**
	Std. Dev.	1.73	1.94	1.09	1.77	1.03
Octocorallia	# Taxa	3	6	8	8	**10**
	Mean % Cover	0.05	0.19	0.51	1.42	**1.91**
	Std. Dev.	0.05	0.16	0.39	0.83	1.10
Scleractinian	# Taxa	23	21	18	22	**19**
	Mean % Cover	1.74	2.21	2.40	3.92	**3.84**
	Std. Dev.	0.46	0.40	0.32	0.28	0.25
Substrate	Mean % Cover	0.47	0.70	0.98	3.23	**4.47**
	Std. Dev.	0.17	1.02	0.41	1.38	1.64

Table 8 shows the mean relative percent cover for the most common organisms on the boulders (B). Similar to the natural reef sites (2R and 3R), the turf algae component had the highest relative percent cover on the boulders within the algae category and overall. Porifera was the next highest cover relative percent cover on the boulders, with the most common being unidentified porifera *I. birotulata*, and *A. cauliformis*. While still abundant in Y18, the percent cover of *I. birotulata* decreased by nearly 3% from the previous sampling period. *Pseudopterogorgia* spp. and *Pseudoplexaura* spp. were the most abundant octocorals on the boulders. *Porites astreoides* and *S. siderea* continue to have the highest percent cover of the scleractinians. Also like the natural reefs, the percent cover attributed to sediment covered hardbottom quadrupled on the boulders from Y16 to Y18. In Y18, 13.91% of the boulders were sediment covered hardbottom while only 3.30% was in Y16.

Table 8—Mean relative percent cover (%) per sampling period for the highest contributors on the **boulders (B)** during the last six sampling periods.

		Y10	Y12	Y14	Y16	**Y18**
Algae	Turf	78.59	61.38	72.04	65.24	**62.63**
	Peysonnelia species	5.26	10.00	7.57	5.41	**4.41**
	Coralline algae	0.58	4.58	1.53	1.39	**2.32**
	Blue-green algae	0.79	0.12	3.06	6.47	**0.87**
	Lyngbya species	0.01	5.60	0.06	0.70	**0.01**
Porifera	Unidentified porifera	1.99	2.04	1.30	1.12	**1.84**
	Iotrochota birotulata	3.10	3.44	2.22	3.65	**0.77**
	Aplysina cauliformis	0.45	0.83	0.86	1.20	**0.71**
	Artemisina melana	0.24	0.29	0.19	0.26	**0.69**
	Monanchora barbadensis	0.21	0.34	0.32	0.31	**0.53**
	Ircinia campana	0.26	0.27	0.34	0.28	**0.36**
	Ircinia felix	0.40	0.28	0.26	0.26	**0.33**
	Cliona delitrix	0.07	0.20	0.22	0.21	**0.33**
	Smenospongia aurea	0.00	0.00	0.18	0.23	**0.31**
	Aiolochroia crassa	0.07	0.42	0.23	0.40	**0.31**
	Ircinia strobilina	0.07	0.34	0.33	0.14	**0.30**
Octocorallia	*Pseudopterogorgia* spp.	1.21	0.91	0.64	1.80	**1.35**
	Pseudoplexuara spp.	0.11	0.02	0.19	0.10	**0.46**
	Eunicea species	0.00	0.00	0.09	0.05	**0.39**
	Unidentified octocoral	0.11	0.45	0.24	0.63	**0.35**
	Muricea species	0.08	0.12	0.11	0.37	**0.28**
	Erythropodium caribaeorum	0.00	0.00	0.04	0.02	**0.17**
	Gorgonia ventalina	0.11	0.22	0.09	0.08	**0.10**
	Iciligorgia	0.00	0.00	0.00	0.03	**0.01**
	Briareum asbestinium	0.00	0.05	0.00	0.12	**0.00**
Scleractinia	*Porites astreoides*	0.71	0.53	0.66	0.64	**1.06**
	Siderastrea siderea	0.31	0.39	0.38	0.60	**0.75**
	Stephanocoenia intersepts	0.09	0.14	0.28	0.36	**0.43**
	Madracis decactis	0.15	0.21	0.22	0.28	**0.30**
Substrate	Sand pocket	0.20	0.06	0.01	0.40	**0.00**
	Sediment Dusting	0.34	0.96	2.09	3.30	**13.91**

The mean relative percent cover for the most common organisms on the modules (M) is shown in Table 9. Similar to the natural reef sites (2R and 3R) and the boulders, the turf algae component had the highest relative percent cover on the modules within the algae category and overall. The most abundant porifera on the modules in terms of percent cover was *I. birotulata* followed by unidentified porifera species. Unidentified octocorals and *Pseudopterogorgia* spp. were the most abundant octocorals on the boulders. *Porites astreoides* and *Madracis decactis* continue to be the scleractinian species with the highest relative percent cover on the modules. *Tubastrea coccinea*, a non-indigenous species, was observed again on the modules this sampling period but with a low percent cover (0.01%). The percent cover of sediment covered hardbottom did increase slightly from Y16 to Y18, but did not quadruple like the other three stations (2R, 3R, and Boulders).

Table 9—Mean relative percent cover (%) per sampling period for the highest contributors on the **modules (M)** during the last six sampling periods.

		Y10	Y12	Y14	Y16	**Y18**
Algae	Turf	62.91	46.74	58.03	49.72	**47.23**
	Blue-green algae	0.60	0.31	3.53	5.26	**9.24**
	Peysonnelia species	5.61	13.25	8.59	9.01	**7.23**
	Coralline algae	0.89	5.68	2.44	1.56	**2.82**
	Lyngbya species	0.00	1.65	0.26	1.75	**0.19**
Porifera	*Iotrochota birotulata*	6.61	7.45	5.80	6.98	**5.66**
	Unidentified porifera	4.66	3.45	1.33	2.54	**2.91**
	Monanchora barbadensis	0.91	1.12	1.27	0.86	**1.47**
	Niphates digitalis	1.25	1.10	0.93	1.18	**1.26**
	Aplysina cauliformis	0.16	0.41	0.46	1.09	**1.08**
	Diplastrella megastellata	1.01	1.91	1.37	0.57	**0.83**
	Ircinia felix	1.23	1.42	1.05	1.12	**0.81**
	Artemisina melana	1.42	1.50	0.76	0.78	**0.80**
	Niphates erecta	0.46	0.66	0.56	0.73	**0.73**
	Ircinia campana	0.81	1.00	0.92	0.83	**0.66**
	Niphates amorpha	0.09	0.22	0.18	0.30	**0.48**
	Ircinia strobilina	0.86	1.02	1.27	1.07	**0.45**
	Callyspongia vaginallis	0.82	0.68	0.59	0.50	**0.40**
Octocorallia	Unidentified octocoral	0.01	0.05	0.08	0.47	**0.49**
	Pseudopterogorgia species	0.00	0.04	0.03	0.16	**0.34**
	Muricea species	0.00	0.01	0.03	0.34	**0.23**
	Gorgonia ventalina	0.01	0.02	0.06	0.09	**0.23**
	Erythropodium caribaeorum	0.00	0.00	0.06	0.00	**0.21**
	Iciligorgia species	0.03	0.03	0.10	0.21	**0.19**
	Eunicea species	0.00	0.00	0.09	0.05	**0.12**
Scleractinia	*Porites astreoides*	0.80	0.88	1.30	1.77	**1.86**
	Madracis decactis	0.16	0.27	0.19	0.52	**0.56**
	Siderastrea siderea	0.23	0.19	0.22	0.29	**0.44**
	Stephanocoenia intersepts	0.08	0.16	0.05	0.19	**0.21**
	Montastraea cavernosa	0.05	0.13	0.13	0.30	**0.21**
Substrate	Sand pocket	0.01	0.03	0.02	0.02	**0.01**
	Sediment covered hardbottom	0.47	0.61	0.95	3.20	**4.45**

3. Artificial and Natural Reef Comparisons

The relative percent cover of benthic assemblages was used to generate Bray-Curtis similarity indices for the study areas. These indices were then used to evaluate patterns of change within each sampling site and between the artificial and natural reefs. Figure 4 depicts the level of similarity of the relative percent cover of benthic assemblages between the different sites monitored from Y5 through Y18 utilizing the transect methodology. The two natural reef sites (2R vs. 3R) showed a high level of similarity, varying between 75.1 to 78.8%. The comparisons of natural reefs (2R and 3R) and the artificial reef materials (B and M) showed a general increasing trend in similarity through Y8 with a decrease in Y9 followed by a slight increasing and subsequent leveling trend through Y16. During the last sampling period, 3R was more similar to the two artificial reef materials than 2R. The similarity between 2R and the boulders decreased notably in Y18. The boulders and 3R was the most similar artificial reef to natural reef comparison at 67.6%.

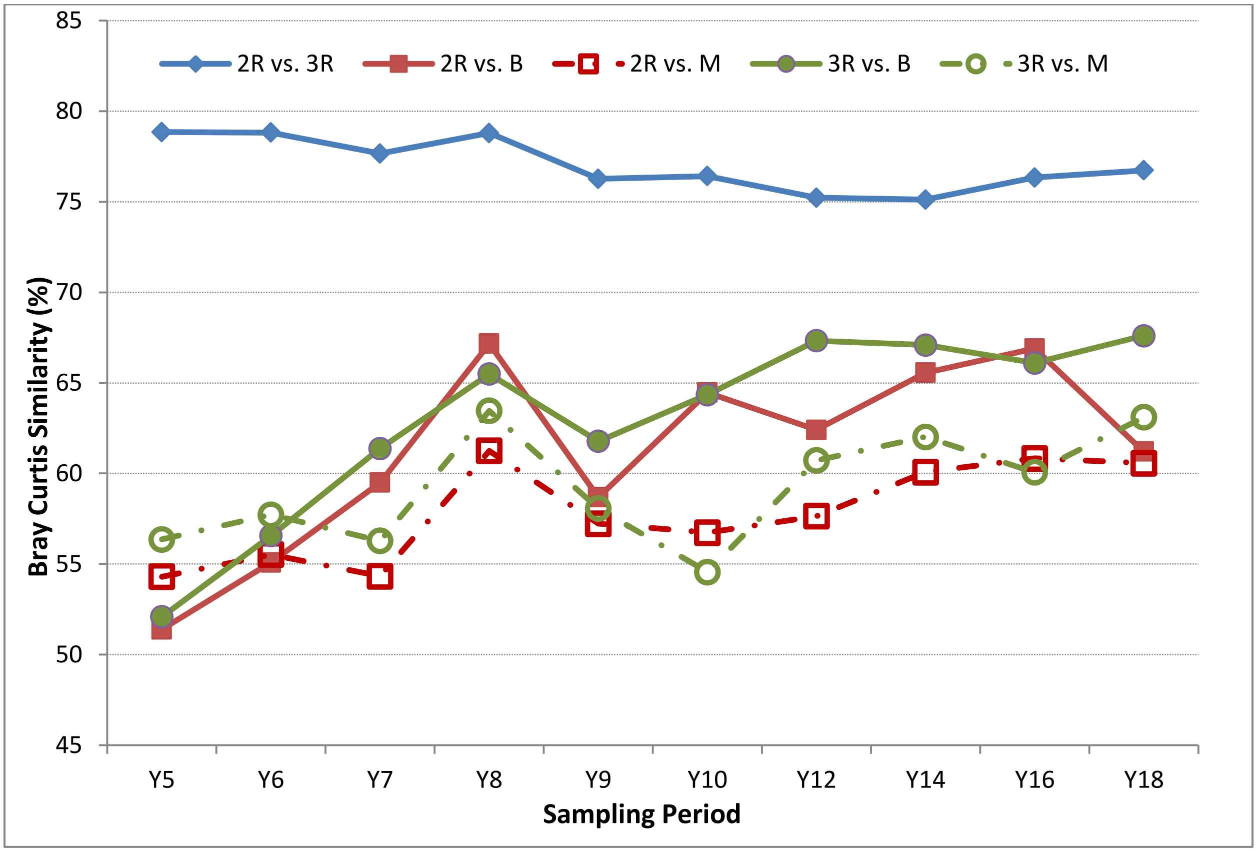

Figure 4—Bray-Curtis similarity levels between sites based on relative percent cover of benthic taxa and substrate. 2R=2nd Reef; 3R=3rd Reef; B=Boulders, M=Modules.

Greater insights into development and comparability of the different reef areas can be obtained from evaluation of assemblage and substrate components. Similarity percentage analysis (SIMPER; Primer-E software) was conducted on the last sampling period, Y18, to examine which substrate type or biological components (species/taxa subcategory) contribute the most to the differences between the sites during this sampling period (Table 10 and 11).

The largest contributor to the dissimilarity between the two natural reef sites (2R and 3R) was the absence of *P. astreoides* on 2R (Table 10). *Porites astreoides* was present during the species inventory at one of the three transects on 2R, but not with a large enough presence to be captured in the CPCe analysis. The octocorals, *Pseudopterogorgia* spp. (more abundant on 3R than 2R) and *Muriceopsis* species (more abundant on 2R than 3R) also contributed the dissimilarity between the two natural reef stations.

Table 10—Categories and/or species causing the dissimilarity between the two natural reef sites based on the Bray-Curtis Index for sampling period Y18. Species are listed in descending order according to the percent contribution to the dissimilarity.

		% Cover		Contribution %
		2R	3R	
2R vs. 3R	*Porites astreoides*	0.00	0.38	3.72
	Pseudopterogorgia species	0.76	6.12	3.02
	Muriceopsis species	0.11	0.00	2.75
	Hydroid species	0.00	0.10	2.63
	Plexaura species	0.08	0.00	2.51
	Scopalina ruetzleri	0.00	0.07	2.44

Inherent differences in the substrate are a large factor in differences in the natural and artificial reef sites relative percent covers. For example, along the natural reef several sand pockets or depressions in the hard bottom are observed (Table 11). These features are rare or absent on the boulders or modules.

Dissimilarities between the biotic components on the natural and artificial reef sites were associated mostly with *Xestospongia muta* and *Halimeda* species (Table 11). The large barrel sponge, *X. muta* has the largest relative percent cover of porifera on both natural reefs (Tables 4-5). *Xestospongia muta* was observed during the CPC analysis on the boulders during the Y14 sampling but not in Y16 or Y18 and does not yet have a large enough relative percent cover as to increase similarity. *Xestospongia muta* has yet to be observed on the modules. The encrusting octocoral species, *E. caribaeorum* and *B. asbestinum* are more common on the natural reefs than artificial reefs and also contribute to the differences in percent cover. Although the number and percent cover of octocorals have been increasing on both artificial reef materials, they are still below that of the natural reefs, the encrusting species in particular. During Y18, the stony coral (scleractinia), *P. astreoides*, was a major contributor to community differences between 2R and both artificial reef materials (B and M). Scleractinians were not a major contributor to the dissimilarity between 3R and both artificial reef materials.

Table 11—Categories and/or species causing the dissimilarity between the natural and artificial reef sites based on the Bray-Curtis Index for sampling period Y18. Species are listed in descending order according to the percent contribution to the dissimilarity.

		% Cover		Contribution %
		2R	B	
2R vs. B	Sand Pocket	14.91	0.00	5.18
	Xestospongia muta	2.30	0.00	3.25
	Porites astreoides	0.00	1.06	2.68
	Halimeda species	1.04	0.00	2.66
	Hydroid species	0.00	0.67	2.39
	Ircinia campana	0.00	0.36	2.04
	Briareum asbestinum	0.34	0.00	2.02
		3R	B	
3R vs. B	Sand Pocket	5.11	0.00	4.86
	Xestospongia muta	2.10	0.00	3.89
	Halimeda species	0.91	0.00	3.15
	Erythropodium caribaeorum	6.59	0.17	3.09
	Briareum asbestinum	0.56	0.00	2.8
	Cliona delitrix	0.00	0.33	2.45
	Undaria agaricites	0.00	0.12	1.92
		2R	M	
2R vs. M	Sand Pocket	14.91	0.01	3.93
	Xestospongia muta	2.30	0.00	2.96
	Porites astreoides	0.00	1.86	2.80
	Hydroid species	0.00	0.90	2.34
	Diplastrella megastellata	0.00	0.83	2.29
	Iotrochota birotulata	0.13	5.66	2.26
	Blue-green algae	0.48	9.24	2.19
		3R	M	
3R vs. M	*Xestospongia muta*	2.10	0.00	3.16
	Sand Pocket	5.11	0.01	3.09
	Diplastrella megastellata	0.00	0.83	2.51
	Dictyota species	0.00	0.83	2.51
	Erythropodium caribaeorum	6.59	0.21	2.44
	Blue-green algae	0.45	9.24	2.43
	Pseudopterogorgia species	6.12	0.34	2.13

4. Benthic Organism Health

The current survey methodology (percent cover analysis of transects) did not accurately document the health of the benthic organisms. Qualitatively, surveyors noted, paling, partially bleached, damaged and dislodged octocorals, paling, bleached, and diseased scleractinians, and discolored and possibly diseased or damaged porifera during the Y16 and Y18 sampling.

In Y16, paling and bleached encrusting octocorals, *E. caribaeorum* and *B. asbestinum* were observed on both 2R and 3R and numerous bleached *Muriceopsis* species were observed on 2R (Figure 5). The *Muriceopsis* species percent cover dropped from 1.54% in Y16 to 0.11% in Y18 possibly as a result of the bleaching observed in Y16. Paling and partial bleaching of the erect octocorals was not observed on the two natural reefs in Y18. Paling and bleaching was only observed in *E. caribaeorum* and to a much lesser degree than observed in Y16 (Figure 6). Bleaching octocorals were not observed on the two artificial reef materials in Y16 or Y18, but it should be noted that the boulders or modules have less octocoral cover than the natural reefs. In Y18, numerous octocorals on the natural reef were noted dislodged or damaged with broken branch tips (Figure 7). The natural reef stations were sampled a few weeks after Hurricane Irma and the dislodging and damage of the octocorals could be a result of the rough sea conditions.

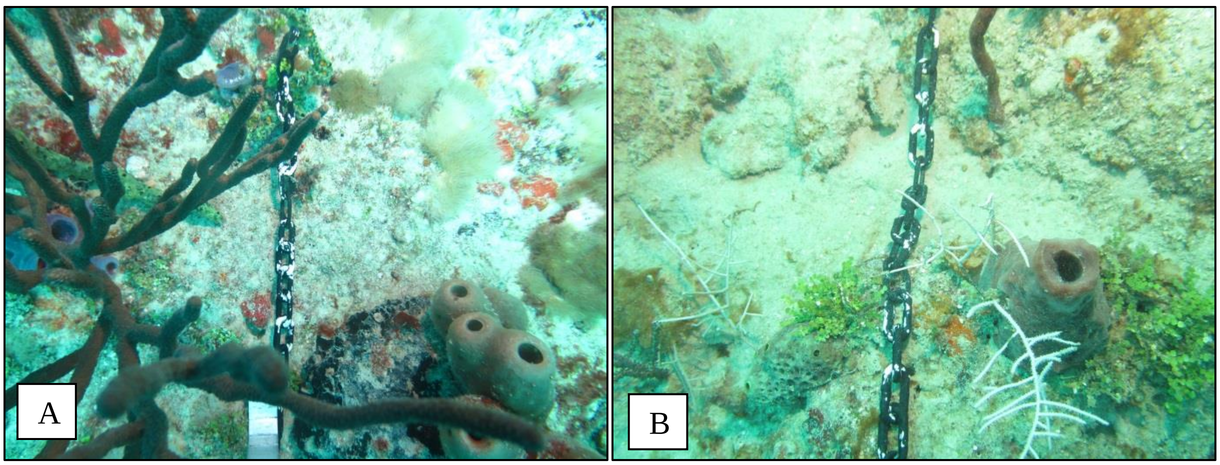

Figure 5—A). Pale and bleaching encrusting octocorals on 3R in Y16. B). Bleached *Muriceopsis* species on 2R in Y16.

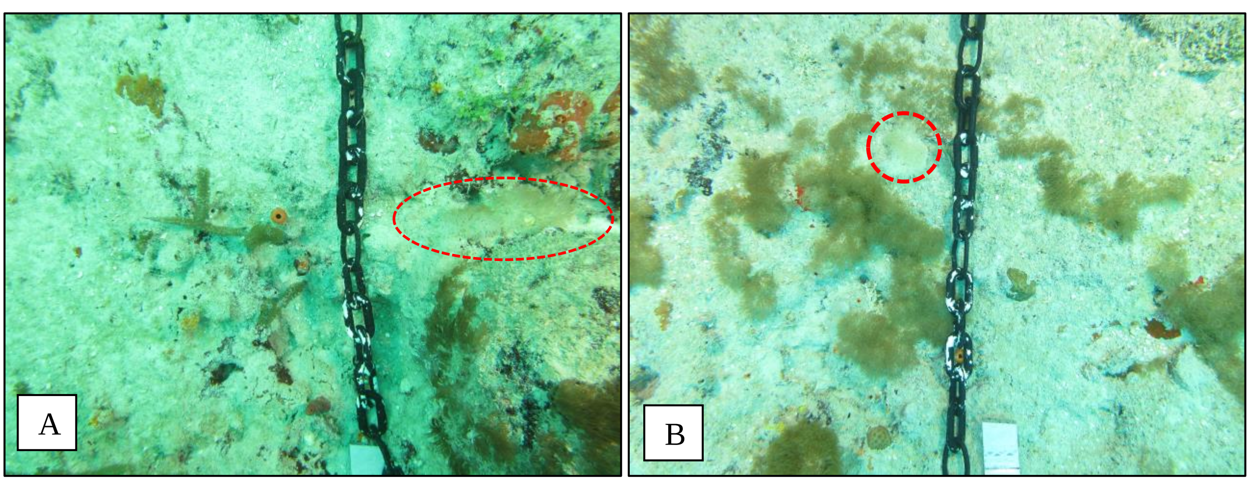

Figure 6—Pale and partially bleach *Erythropodium caribaeorum* on Y18. A). 2R. B). 3R

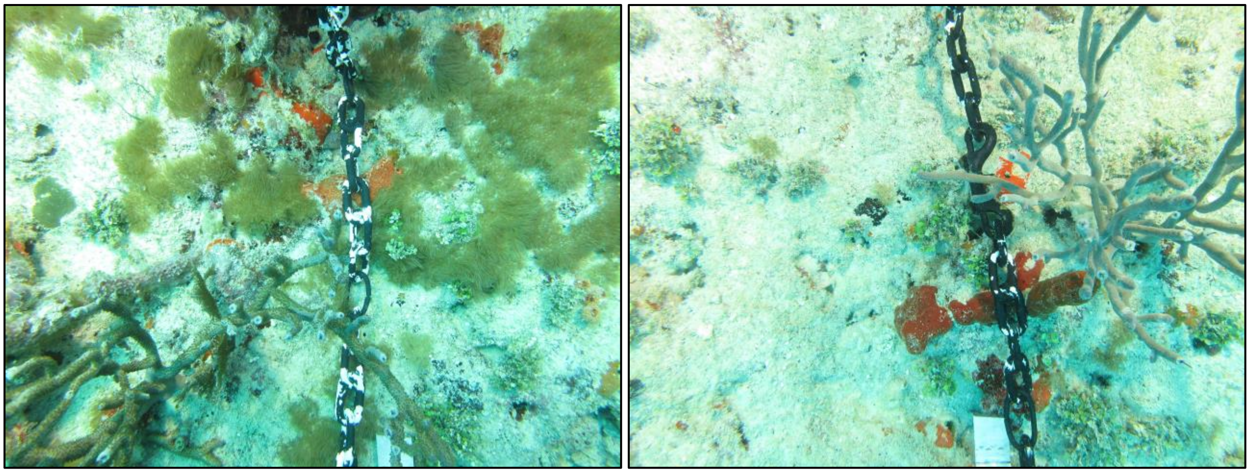

Figure 7—Damaged gorgonians with broken branch tips observed on the natural reefs during the Y18 sampling.

Prior to Y16, recently dead coral was not captured in the percent cover analysis. Although with very low coverage, three of the four sites had measurable percent cover of recently dead scleractinians in the Y16 sampling and two sites in Y18. In Y18, the boulders had 0.01% (±0.01) recently dead coral and the modules had 0.01% (±0.02). Although recently dead scleractinian cover was not captured in the CPCe analysis on 2R or 3R, paling, bleaching, disease, and recent mortality was observed at the two natural reef sites as well as the two artificial reef sites. Similar to Y16, each image from the transects was examined outside of the CPCe analysis in order to quantify the prevalence of unhealthy or stressed scleractinians. All visible scleractinians within the image and their health were recorded. Through this additional evaluation, an average of 40 colonies per station were observed on 2R, 83 on 3R, 635 on the boulders, and 439 on the modules. The average percentage of unhealthy colonies (partially bleached, completely bleached, diseased, or with recent mortality) ranged from 8-13%, depending on the station (Figure 8). An additional 19-25% of colonies were observed to be paling. Paling and unhealthy colonies were observed across multiple species including but not limited to *Agaricia fragilis*, *A. grahamae*, *A. lamarcki*, *Dichocoenia stokesii*, *Montastraea cavernosa*, *Orbicella faveolata*, *Porites astreoides*, *Pseudodiploria strigosa*, *Siderastrea siderea*, *Stephanocoenia intersepta*, and *Undaria agaricites* (Figure 9-13). Although on 2R and 3R, diseased scleractinians were not observed within the monitoring transects, diseased colonies were in the area immediately adjacent to the transects (Figure 9).

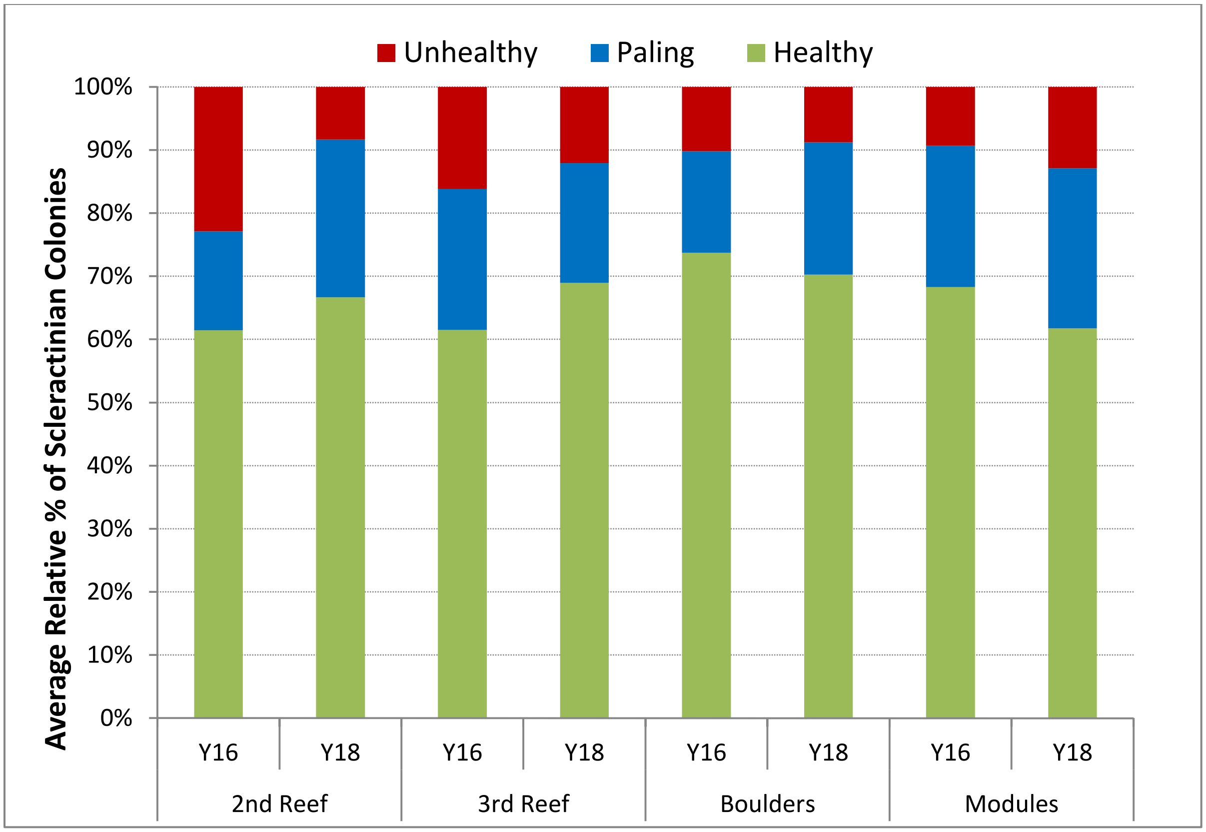

Figure 8—Average percent of healthy, paling, and unhealthy scleractinians colonies at each site during Y16 and Y18. Unhealthy colonies were partially bleached, completely bleached, diseased, and/or had recent mortality.

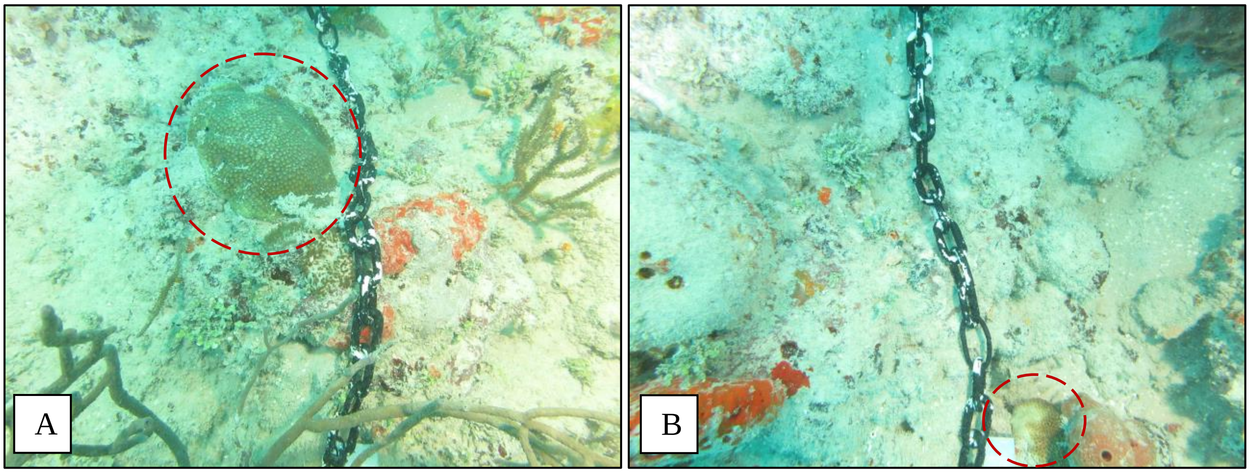

Figure 9—Stressed or unhealthy scleractinians observed along the monitoring transects on second reef (2R) in Y18. A). Paling *Orbicella faveolata*; B). *Stephanocoenia intercepta* with partial bleaching.

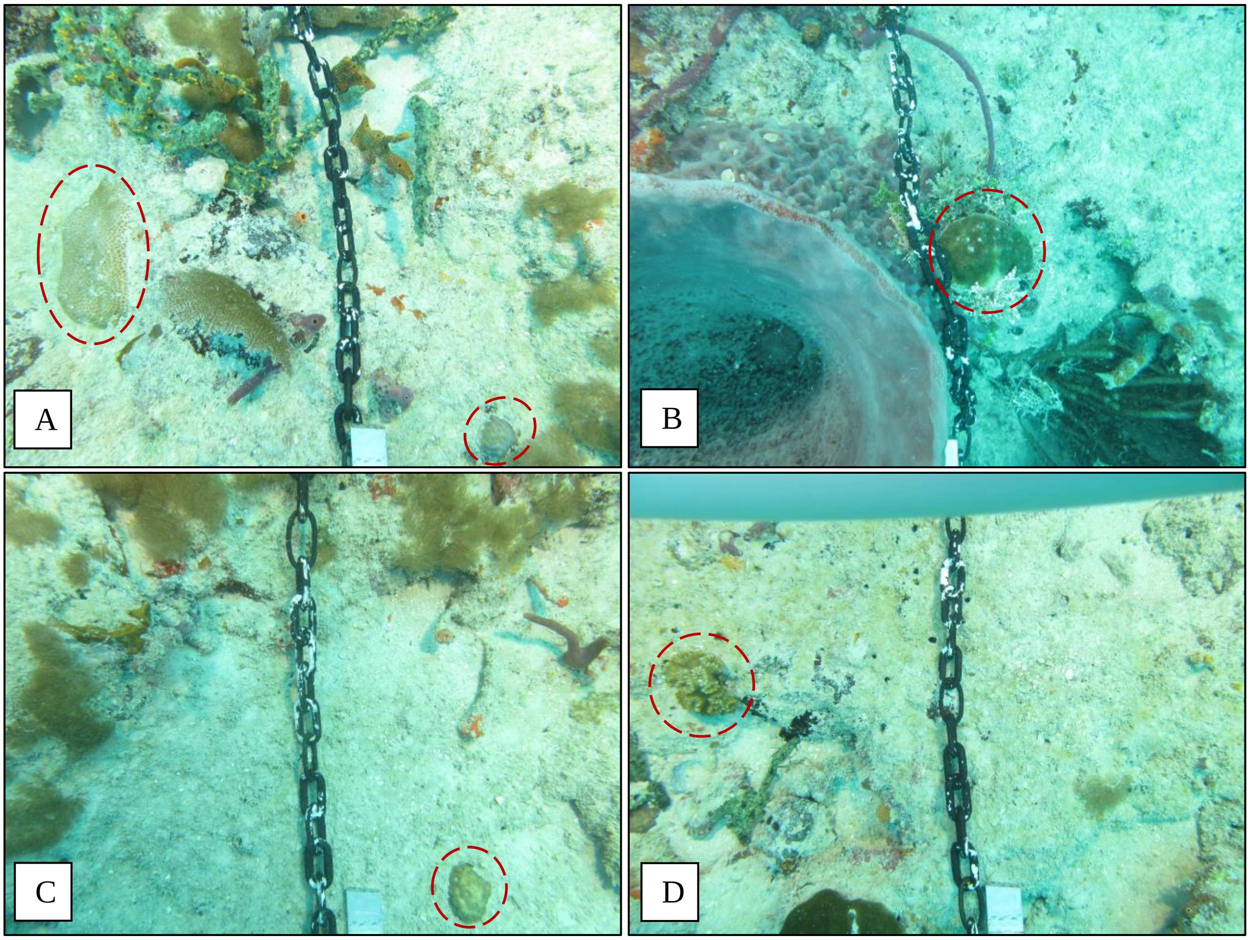

Figure 10—Stressed or unhealthy scleractinian colonies observed along the monitoring transects on third reef (3R) in Y18. A). *Siderastrea siderea* with patchy bleaching and *Montastraea cavernosa* with bleaching at the base; B). *Porites astreoides* with small bleached area; C.) Paling *M. cavernosa*; and D). Paling *Eusmilia fastigiata*.

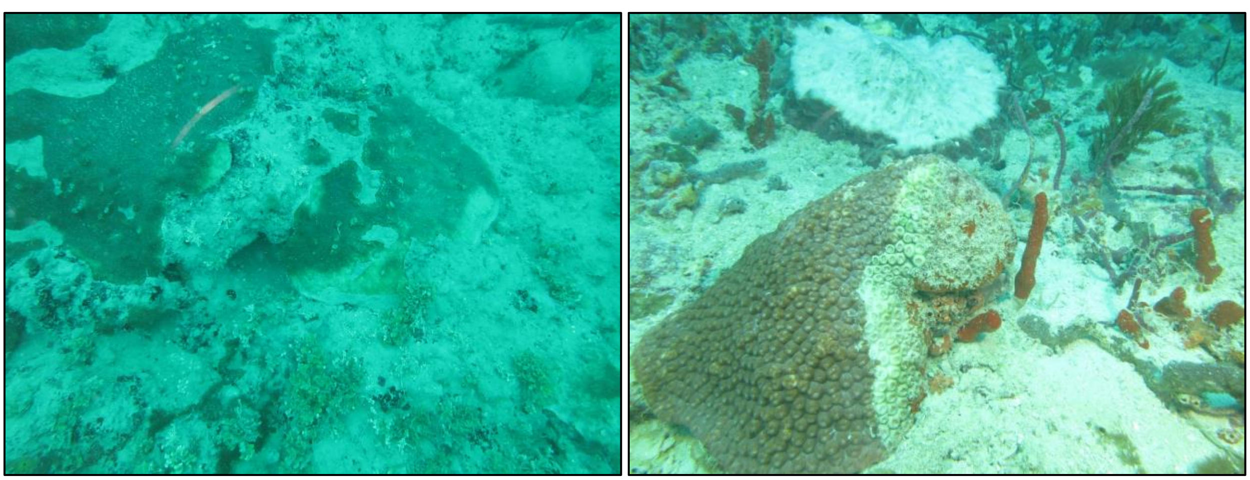

Figure 11—Diseased scleractinians adjacent to the monitoring transects on the natural reefs. A). *Orbicella faveolata* on 2R. B). *Montastraea cavernosa* on 3R.

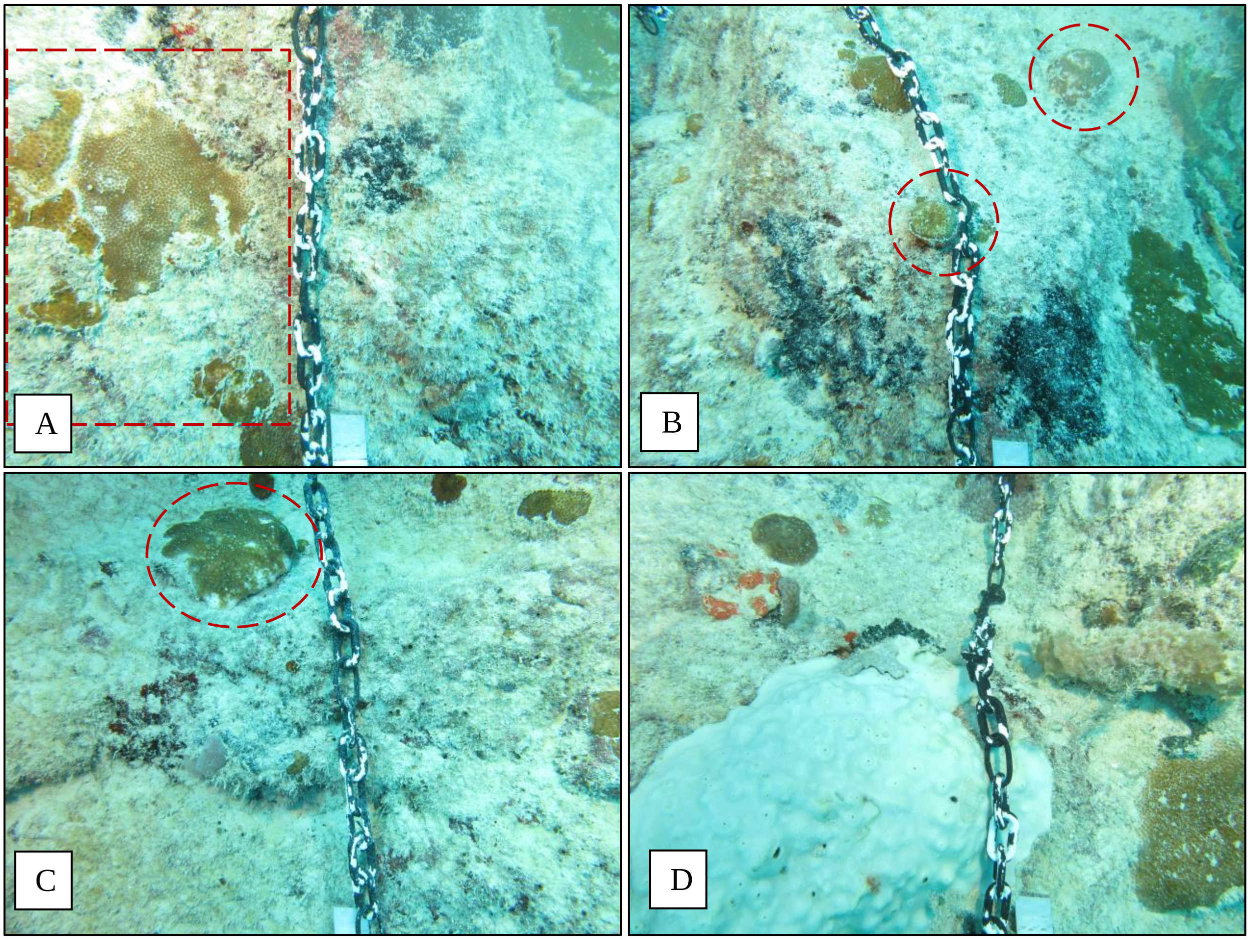

Figure 12— Stressed or unhealthy scleractinian colonies observed along the monitoring transects on the Boulders (B) in Y18. A and B). *Siderastrea siderea* and *Stephanocoenia intersepta* with partial bleaching and signs of disease; C). *S. siderea* with partial disease; D). Completely bleached or recently dead *Porites astreoides*.

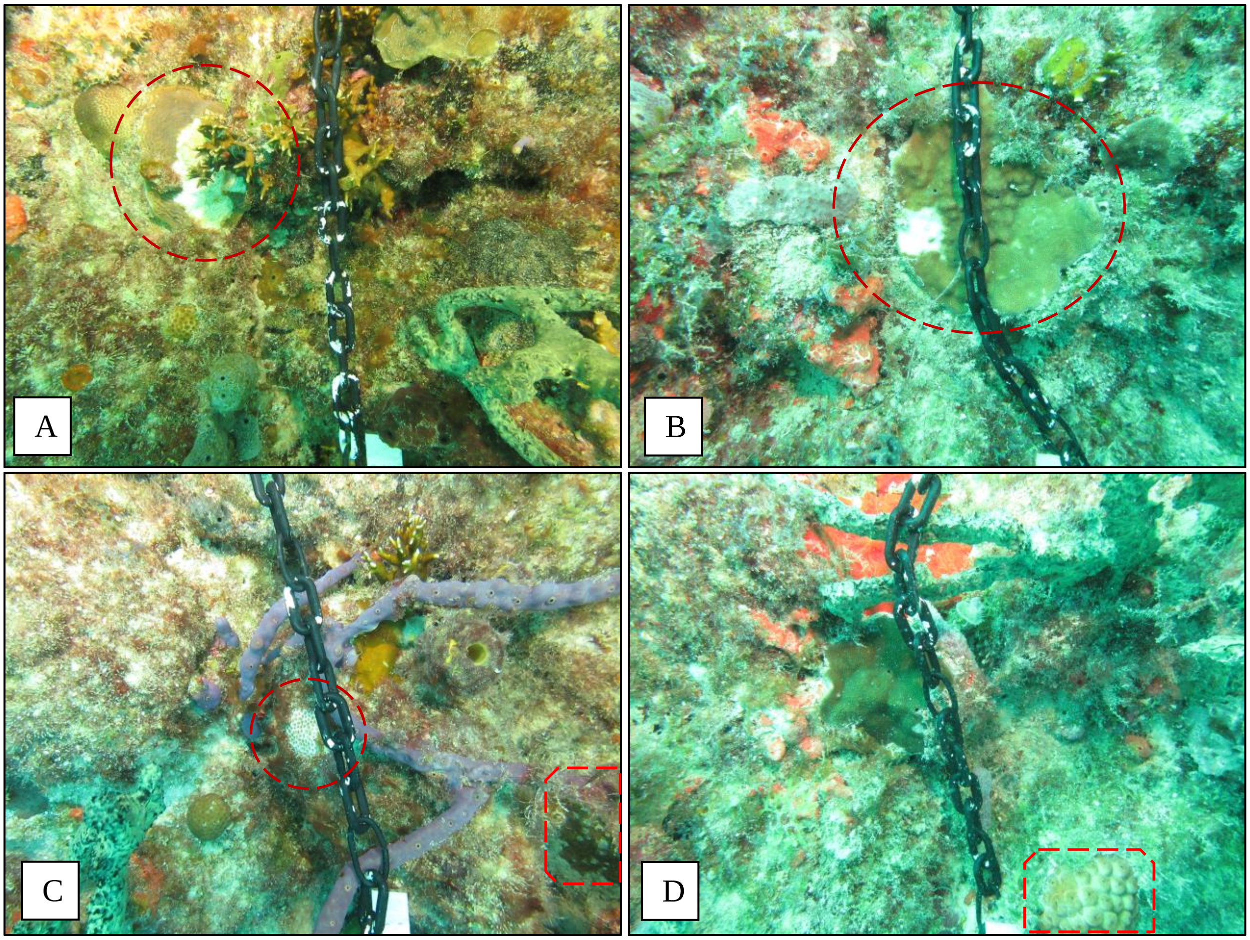

Figure 13— Stressed or unhealthy scleractinian colonies observed along the monitoring transects on the Modules (M) in Y18. A). *Undaria agaricites* with signs of disease and recent mortality; B). *Porites astreoides* with signs of disease and recent mortality; C). One *Siderastrea siderea* colony completely bleached (center) and one with signs of disease (bottom right); D). Paling and partially bleached *Montastraea cavernosa*.

In addition to observations on octocoral and scleractinian health, numerous porifera were noted with abnormal discoloration, possible disease, damage and mortality. Similar to octocorals and scleractinians, each image was reviewed and any sponge with discoloration or mortality was recorded. For *X. muta* only, healthy individuals were also recorded. *Xestospongia muta* was not observed on the two artificial reef materials. On the natural reefs, a total of 52 individual *X. muta* were observed at 2R of which only 40% appeared healthy. On 3R, 37 individual *X. muta* were observed of which only 32% appeared healthy. The remaining individuals appeared to be paling, have blotchy discoloration, and/or have tissue loss (Figure 14). It is unknown whether the mortality is a result of a disease or a physical loss due to shearing of the sponges during Hurricane Irma or a combination thereof. Numerous other porifera species were observed with discoloration and/or mortality. *Aplysina cauliformis* was the species with the most frequent discoloration and/or mortality observations across all sites (Figure 15). In Y18, the percent cover of *A. cauliformis* decreased at three of the four sites—2R, 3R, and boulders. Other porifera species with notable observations of discoloration and/or mortality included but are not limited to *Amphimedon compressa*, *Niphates erecta*, *N. digitalis*, and *Ircinia felix* (Figure 16).

Figure 14—*Xestospongia muta* at 2R (top row) and 3R (bottom row) observed with discoloration and tissue loss/damage.

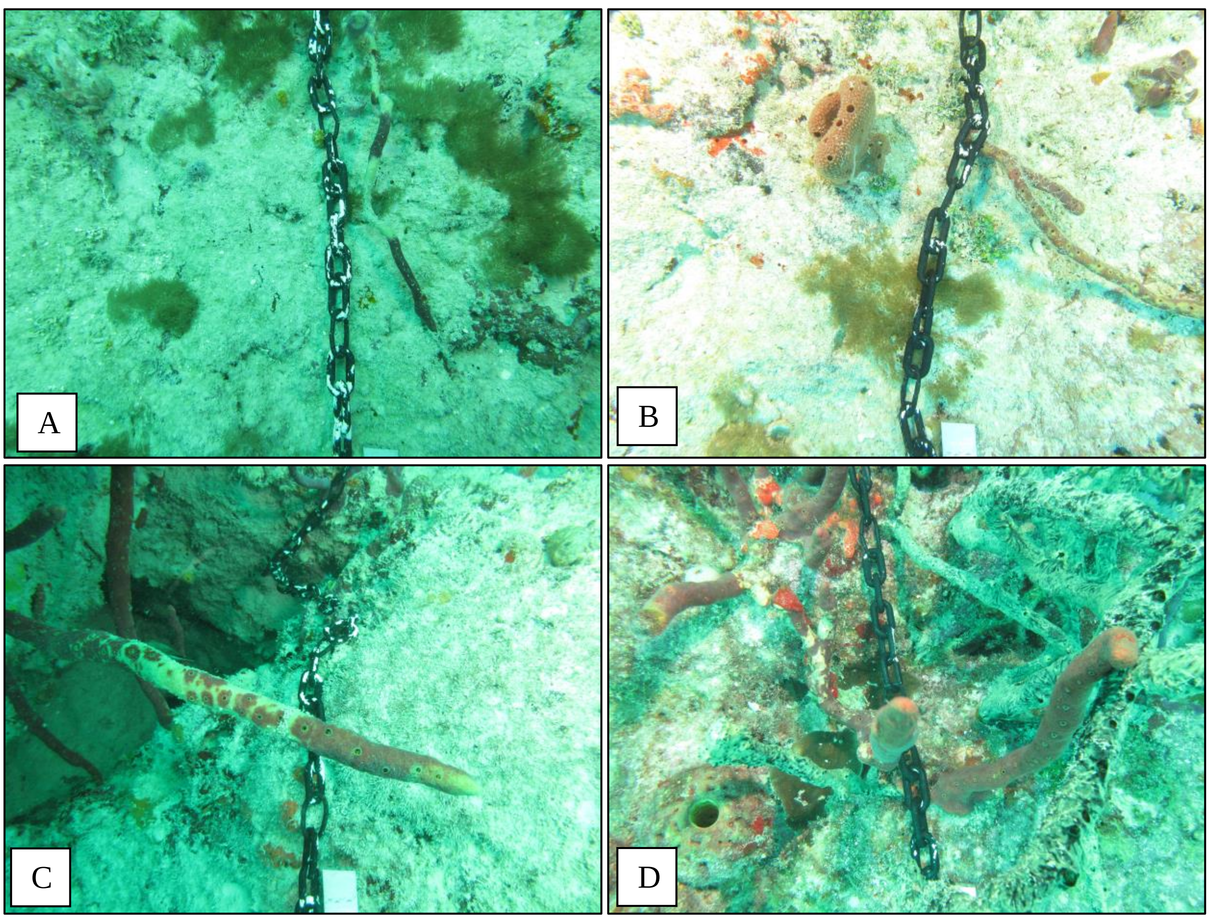

Figure 15—*Aplysina cauliformis* with patchy discoloration on 2R (A), 3R (B), Boulders (C), and Modules (D). Note tissue loss on *A. cauliformis* on 2R (A) and Modules (D).

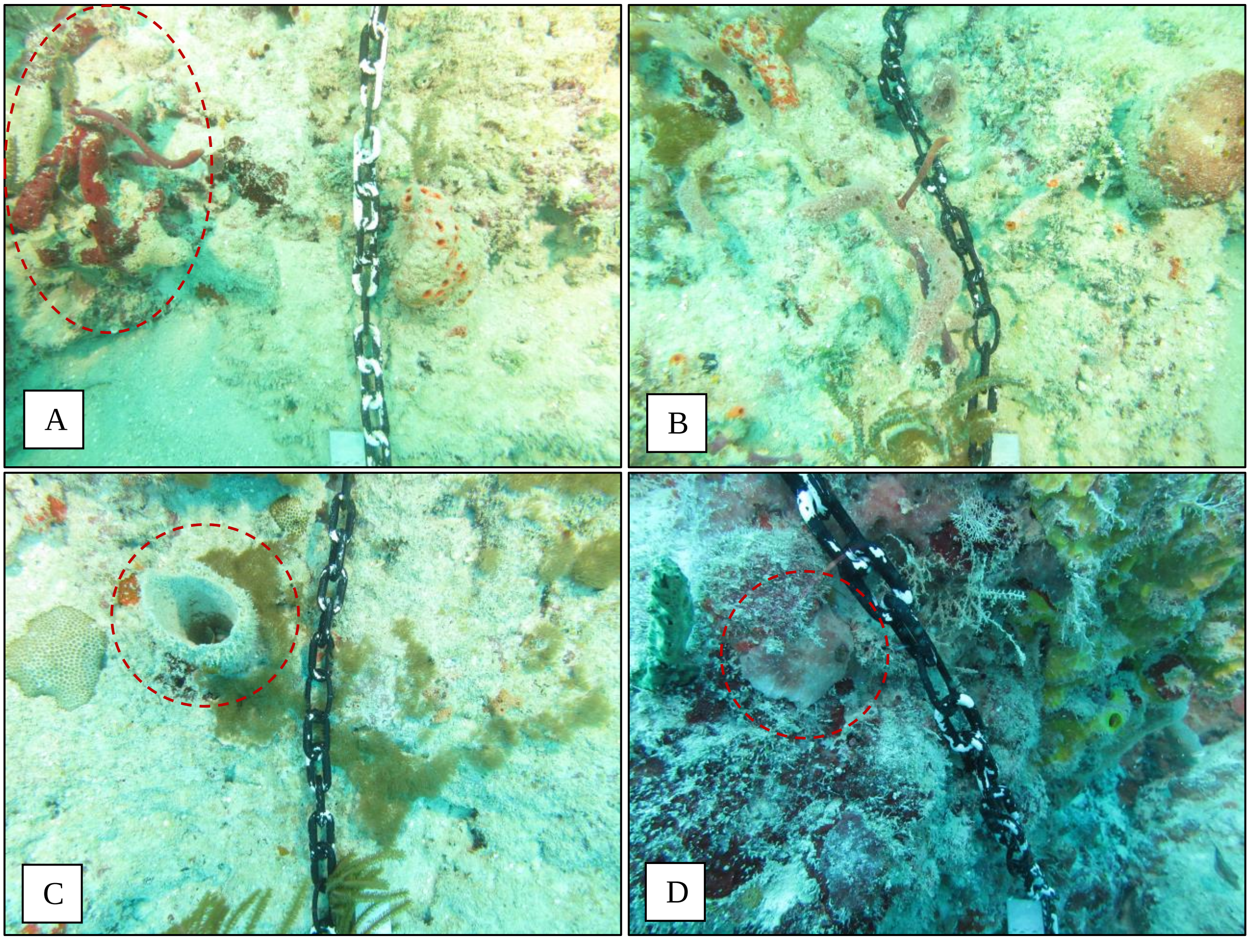

Figure 16—Porifera with discoloration and/or mortality observed during Y18. A). *Amphimedon compressa* on 2R with multiple areas of mortality; B). *Niphates erecta* on 3R with multiple areas of mortality; C). *Niphates digitalis* with mortality on the top portion of the vase on 3R; D). *Ircinia felix* with discoloration on the Modules.

Fish Assemblages

The monitoring results from the first five years (Y0.5 to Y5) of the Bal Harbour Mitigation Monitoring Project have been previously documented (Thanner et al., 2005) and Y6 through Y16 in the previously submitted progress and bi-annual reports. This report focuses primarily on the results from the fish surveys conducted in Y18 with some historical information for reference. Due to the high variability associated with 'transient' or 'visitor' species that may be in or on an area, only the 'resident' fish guild as classified by Bohnsack and others (1994) was used in the following comparison of the reefs and artificial reef materials. Although not factored into the data analysis, it is important to note that the invasive lionfish, *Pterois volitans*, was observed on the 2R, 3R, and boulders stations. The transient species, *Pseudupeneus maculatus* (Spotted goatfish), was also observed across all stations.

1. Species Richness, Diversity, and Evenness

The modules were represented by fewer resident fish species than the adjacent natural reefs and boulders in Y18 (Figure 17). Species richness has been generally highest on 3R across the majority of sampling periods. These differences can be attributed to the difference in substrate composition and relief. The module survey area is approximately 80-90% sand and the boulders were composed entirely of limerock boulders with extensive relief while the natural reef surveys only contained small isolated sand areas and had much lower relief. In Y18, five species were observed on both natural reefs yet were absent from the two artificial reef materials: *Chaetodon capistratus* (Four-eye butterflyfish), *Cryptotomus roseus* (Bluelip parrotfish), *Halichoeres cyanocephalus* (Yellowcheek wrasse), *Scorpaena plumieri* (Scorpionfish), and *Serranus tortugarum* (Chalk bass). Two species, *Chromis scotti* (Purple reeffish) and *Lutjanus synagris* (Lane snapper), were only observed on the artificial reef material and not the natural reefs. Similar to previous years, diversity measures were highest on the two natural reefs, 2R and 3R, followed by the modules. The lowest diversity and evenness measures were found on the boulders (H'=1.69, J'=0.44) (Figure 18).

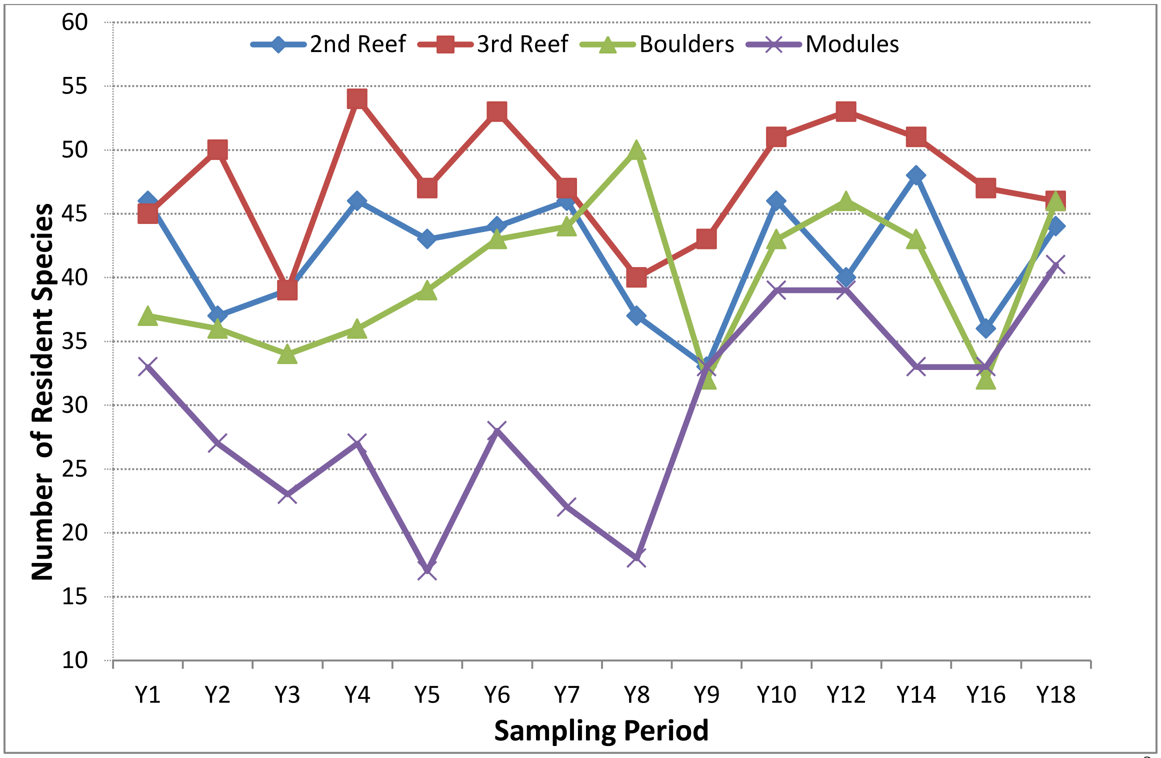

Figure 17—Number of resident fish species per annual sampling period. Total planar survey area was 1,414m^2 per sampling period for natural reefs and 1,056 m^2 for artificial reef materials.

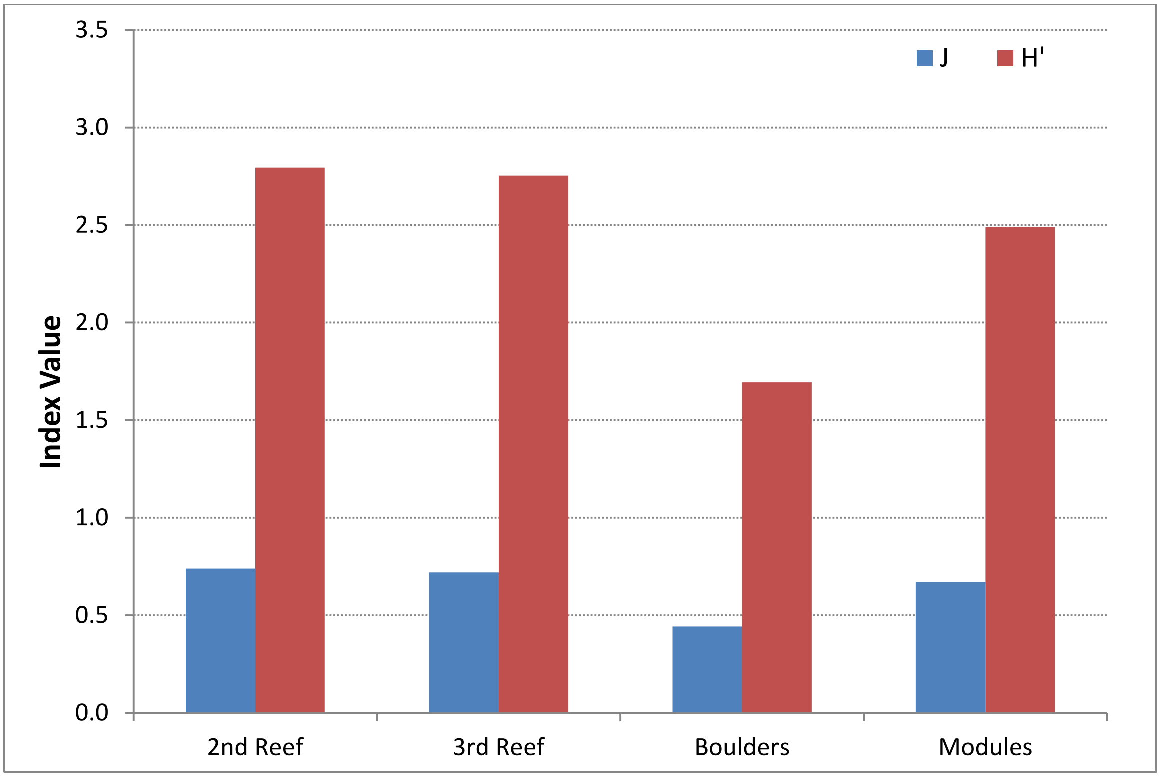

Figure 18—Mean Shannon Diversity Index (H') and Pielou's Evenness (J) measure for the resident fish assemblages on 2nd Reef, 3rd Reef, Boulders and Modules in Y18.

2. Abundance

Analysis of the resident fish assemblage shows abundance differs greatly when comparing the boulders and modules, as well as in the natural and artificial reef comparisons. The boulder site has consistently shown the highest mean resident fish abundances (Figure 19). In Y18, the mean abundance on the boulders was 1,349 individuals per survey, mainly comprised of large numbers of the masked goby, *Coryphopterus personatus* (767 ind. ±258) in the numerous void areas in between boulders as well as in large schools of tomtates, *Haemulon aurolineatum* (172 ind. ±254) and gray snappers, *Lutjanus griseus* (101 ind. ± 110). In Y18, the modules again had the lowest mean abundance of resident fish with higher abundance on 2R and 3R respectively.

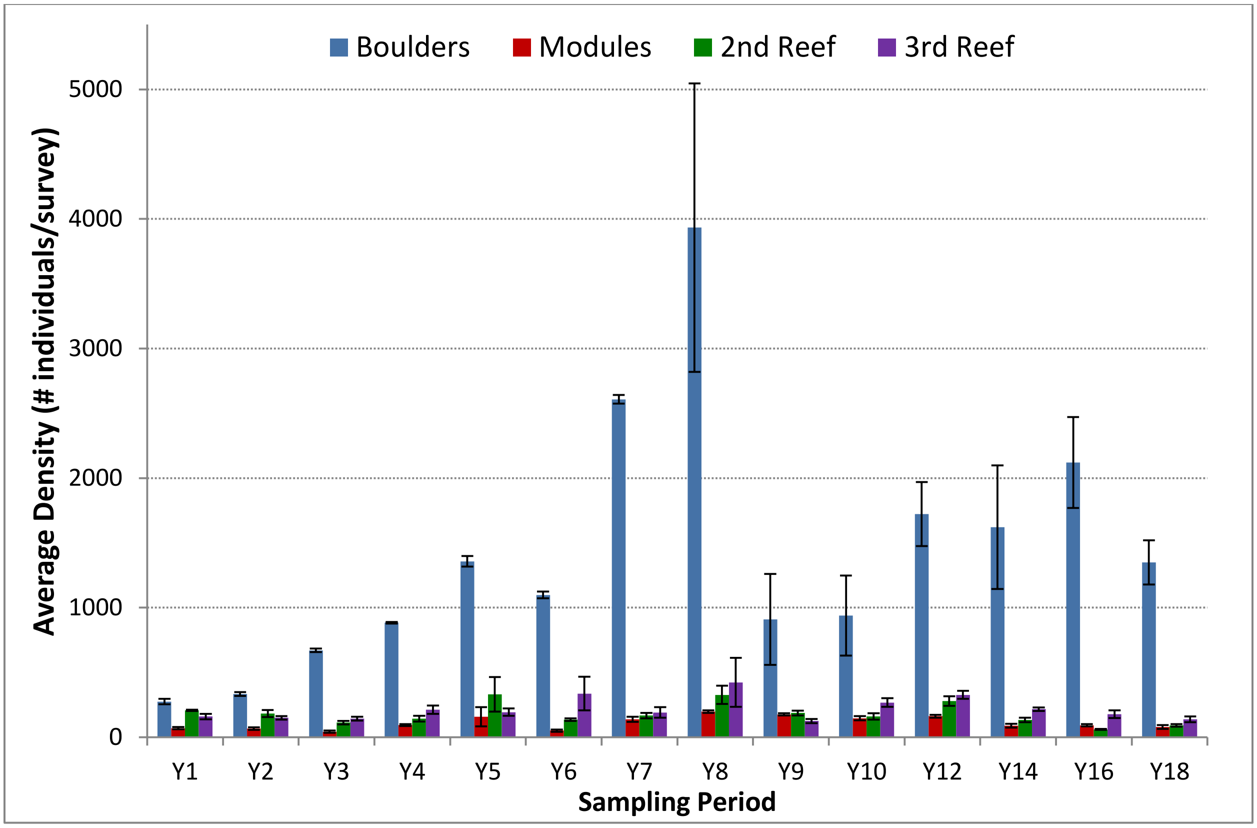

Figure 19—Mean density of resident fish assemblages at each site. Standard error bars plotted.

3. Major Taxonomic Family Constituents

In the last sampling period (Y18), the fish assemblages on the boulders and modules were dominated by the Gobiidae family largely attributed to large numbers of *C. personatus* (Figure 20). Haemulidae continue to have a high representation on the boulders mainly due to *H. aurolineatum* (tomtates) and *H. flavolineatum* (French grunts). The Lutjanidae family was also abundant on the boulders due to the presence of *L. griseus* (gray snappers). On 3R, Pomacentridae (damselfish) was the most abundant family. Labridae (wrasses) was also relatively abundant at both natural reef sites, 2R and 3R, as well as the modules; however, the contribution on the boulders was diminished by the total assemblage size. Scaridae (parrotfish) were major contributors to natural reef populations, but made up only 1.8% and 4.5% of boulder and module assemblages respectively. These differences in family constituents were also reflected in the Bray-Curtis indices values in Figure 21 and Table 11.

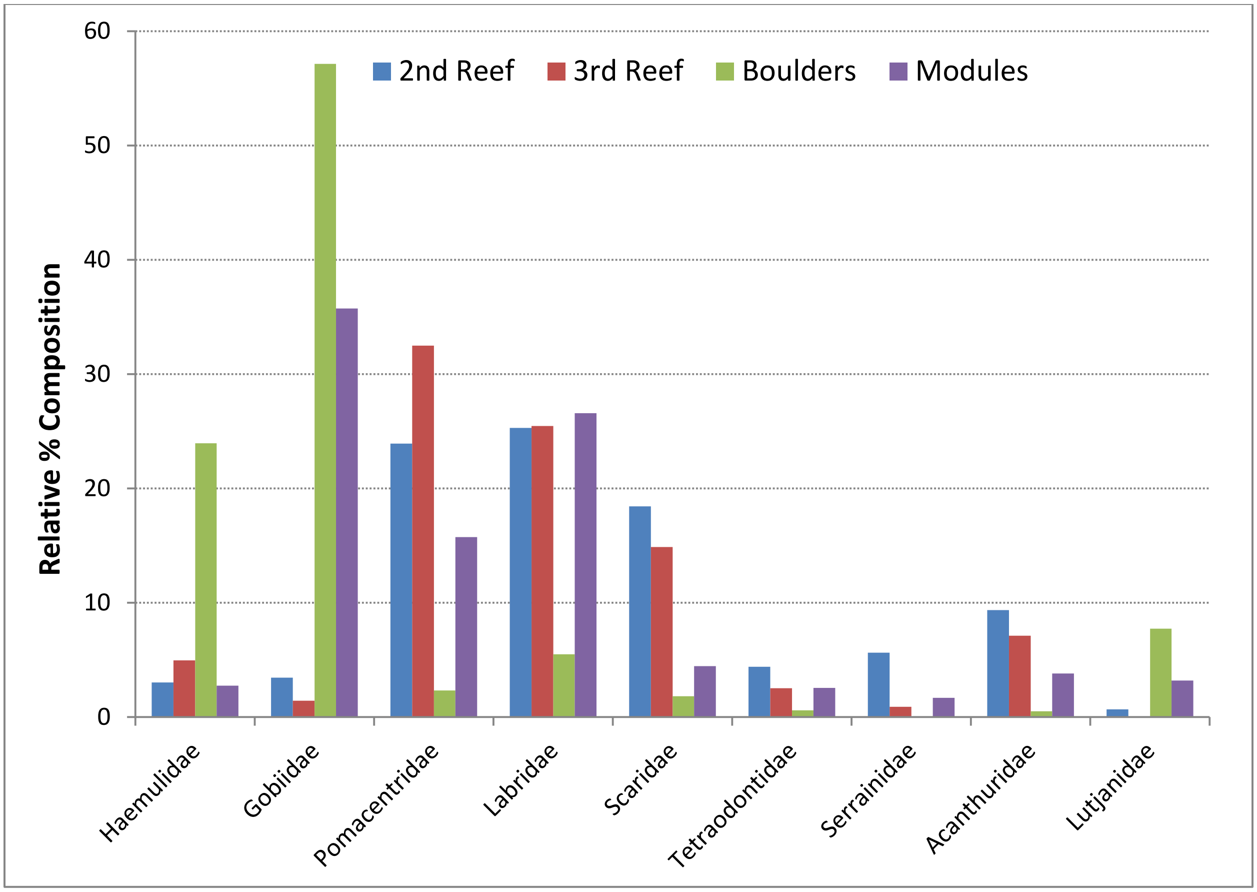

Figure 20—Percent composition (%) of individuals by major resident family constituents for Y18.

4. Similarity

Bray-Curtis Similarity Indices were calculated for the resident fish populations on all four sites in the study area. Figure 16 shows the MDS plot based on those values for the last five sampling periods (Y10, Y12, Y14, Y16, and Y18) while Table 12 shows the values for all annual sampling periods. Clear distinctions still remain between the fish assemblages on the natural and artificial reef sites, shown by the low stress value of the MDS plot (Figure 21). The two natural reef sites (2R and 3R) are clustered closer together than the other sites and in general maintained the highest level of similarity over the annual sampling events ranging from 59.0% to 72.9% similar (Figure 21 and Table 12). In Y18, 3R and the modules were as similar as the two natural reef comparisons boulders at 67.8%. Second reef (2R) and the boulders (B) showed the lowest similarity at 47.4%. The similarity levels between the natural reefs and the artificial reef material fish assemblages have fluctuated with no discernable trend. In general, the modules are more similar to the natural reefs than the boulders. The boulders and modules remain notably divergent from one another as well as from the natural reef sites.

SIMPER analysis of all surveys in Y18 showed the resident species responsible for the dissimilarity between the natural reefs and artificial reefs (Table 13). The greatest contributor to the dissimilarity between both 2R and 3R and the boulders and the modules was masked goby (*C. personatus*). Large numbers of *H. aurolineatum* were observed on the boulders but were absent from the natural reefs. Other grunts (*H. flavolineatum*, *H. chrysargyreum*, and *H. sciurus*) and the gray snapper (*Lutjanus griseus*) were also major contributors to the dissimilarity between the boulders and natural reefs sites. Several different species contributed to the dissimilarity between the natural reefs and the modules. In addition to the masked goby (*C. personatus*), the chalk bass (*Serranus tortugarum*) and the blue-lip parrotfish (*Cryptotomus roseus*) contributed to the difference between the modules and 2R and highhats (*Pareques acuminatus*) and the blue-lip parrotfish (*C. roseus*) contributed to the difference between the modules and 3R.

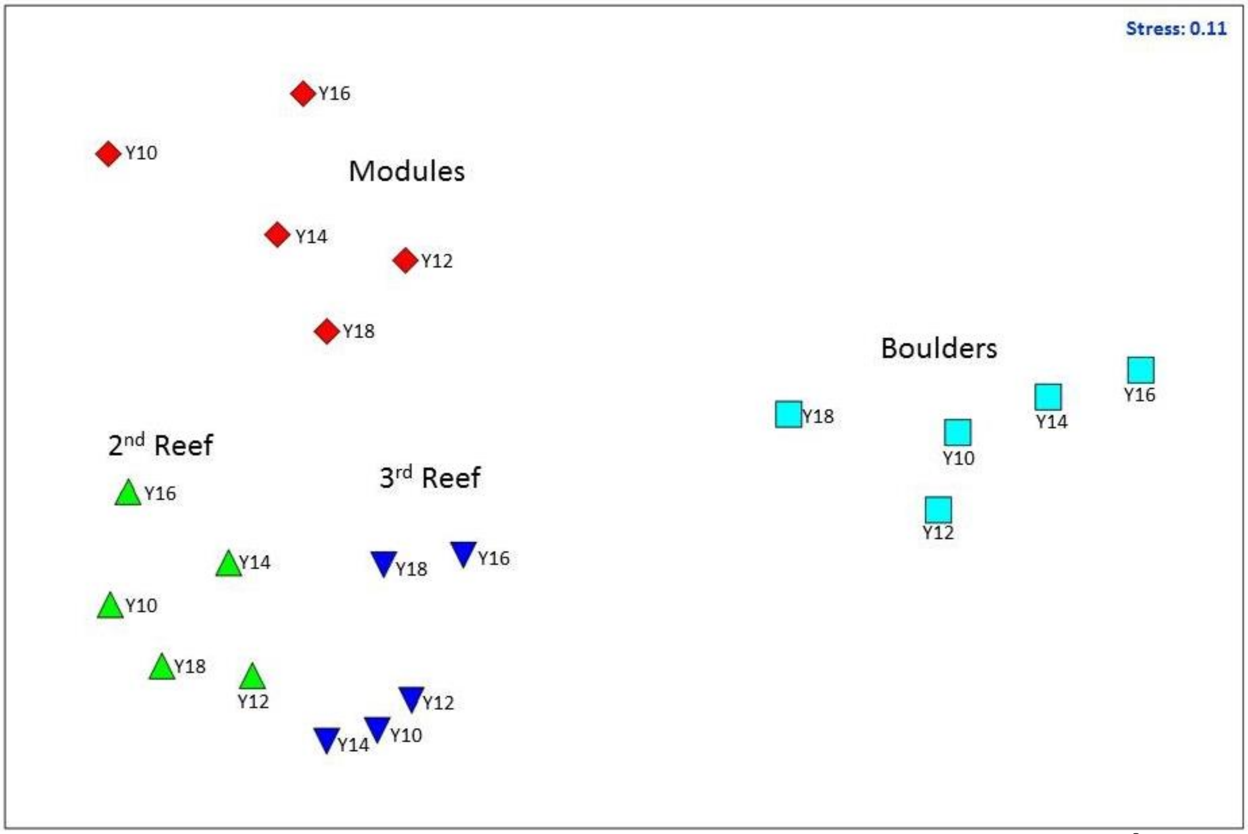

Figure 21—MDS Plot based on the Bray-Curtis indices for the mean resident fish density (individuals/m^2) for Y10, Y12, Y14, Y16, and Y18.

Table 12—Bray-Curtis Similarity Index (%) based on the mean abundance of each resident fish species per site. 2R=2nd Reef; 3R=3rd Reef; B=Boulders; M=Modules.

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y12	Y14	Y16	**Y18**
2R vs. 3R	72.1	67.0	70.7	68.2	72.9	68.3	72.9	63.8	71.4	60.3	72.5	65.7	59.0	**67.8**
2R vs. B	65.6	53.9	46.6	52.9	52.5	47.1	43.2	51.0	51.7	42.7	51.0	41.7	38.5	**47.4**
3R vs. B	51.7	57.5	57.2	58.5	54.4	54.9	48.9	54.7	48.8	47.0	52.3	44.9	46.1	**55.6**
2R vs. M	58.9	48.6	51.2	51.2	47.7	49.0	42.8	50.9	55.2	53.8	58.8	60.6	57.8	**57.6**
3R vs. M	53.6	48.4	41.0	48.2	41.4	47.2	43.6	45.0	56.7	51.6	56.9	57.7	55.3	**67.8**
B vs. M	56.6	58.7	49.9	50.1	47.7	44.0	43.9	35.8	49.1	42.5	51.7	42.6	38.2	**53.1**

Table 13—Resident species causing the dissimilarity between sites based on the Bray-Curtis Index for Y18. Species are listed in descending order according the percent contribution to the dissimilarity (%).

		Avg. Abundance		Contribution %
		2R	3R	
2R vs. 3R	*Chromis multilineata*	0	9	5.98
	Pareques acuminatus	0	9	5.88
	Abudefduf saxatilis	0	5	4.98
	Haemulon flavolineatum	0	3	4.45
	Haemulon sciurus	0	1	3.70
		2R	B	
2R vs. B	*Coryphopterus personatus*	0.4	767	7.88
	Haemulon aurolineatum	0	172	6.37
	Lutjanus griseus	0	101	5.58
	Haemulon flavolineatum	0	59	4.87
	Haemulon chrysargyreum	0	55	4.79
		3R	B	
3R vs. B	*Coryphopterus personatus*	0	767	10.48
	Haemulon aurolineatum	0	172	7.21
	Lutjanus griseus	0	101	6.32
	Haemulon chrysargyreum	0	55	5.43
	Chromis multilineata	9	0	3.49
		2R	M	
2R vs. M	*Coryphopterus personatus*	0	25	4.20
	Serranus tortugarum	3	0	3.76
	Cryptotomus roseus	3	0	3.72
	Lutjanus synagris	0	3	3.63
	Scarus iserti	2	0	3.26
		3R	M	
3R vs. M	*Coryphopterus personatus*	0.4	25	8.03
	Pareques acuminatus	9	0	6.18
	Cryptotomus roseus	4	0	5.19
	Lutjanus synagris	0	3	4.52
	Chromis cyanea	2	0	4.27
		B	M	
B vs. M	*Haemulon aurolineatum*	172	0	7.45
	Lutjanus griseus	101	0	6.53
	Coryphopterus personatus	767	25	6.23
	Haemulon chrysargyreum	55	0	5.61
	Haemulon flavolineatum	59	1	3.64

DISCUSSION

Artificial reefs have been utilized extensively as mitigation for natural reef impacts. It is important to understand the extent to which these “reefs” can effectively provide habitat similar to (i.e., mitigate for) natural reef areas. To gain an understanding of the extent to which these reefs can fulfill this role, an evaluation must be conducted of the overall biotic community (i.e., benthic and fish assemblages) colonizing and utilizing the mitigation reef materials with those of natural reef areas. Previous studies have documented that artificial substrates can provide habitat for benthic invertebrates and fish (Bohnsack et al., 1994; G.M. Selby and Associates, 1994, 1995a, 1995b; Russel et al., 1974; Walker et al., 2002). Additionally, a study by Arena et al. (2007) indicated that artificial (vessel) reefs may be a source of fish production rather than attracting fish away from neighboring natural reefs. A study by Perkol-Finkel and Benayahu (2005) in the Gulf of Eliat, Israel, suggested that it may take over ten years for an artificial reef community to become diverse and mature. Results from a study in the United Arab Emirates comparing a breakwater built in 1977 to nearby coral patches indicate higher coral cover on the breakwater and suggest that it may take three or more decades for coral communities on artificial reefs to develop enough for comparison with natural reefs (Burt et al., 2009). Another Perkol-Finkel and Benayahu study (2007) indicated that physical structure of the artificial reef plays an important role in recruitment comparisons to natural reef and therefore long term community composition. The study states that for restoration purposes, the artificial reef must have similar structural features to the natural reef. The Bal Harbour Mitigation Reef and adjacent natural reefs have substantial differences in their structural features with increased relief and rugosity on the mitigation reefs which may restrict true similarity between the sites. As noted in the trends within the benthic populations on the mitigation versus the natural reefs, the Bal Harbour Mitigation Reef appears to have reached a stable community structure. The similarity level of the mitigation reef with the natural reef may continue to increase over time with increased encrusting octocoral cover, for example, but never reach the similarity levels observed between the two adjacent natural reefs due to the innate differences in structure.

Data from the first 18 years of the monitoring program provide significant information on the efficacy of the Bal Harbour Mitigation artificial materials to serve as natural reef mitigation. Data throughout this study indicate that the local natural reefs support diverse and stable communities. This is reflected in the similar species richness and overall cover of the benthic assemblages on the second and third reef stations (Table 2-3), as well as in the relative consistency of the Bray-Curtis similarity values throughout the monitoring between these sites (similarity values range between 75.1 to 78.8%; Figure 4). The fish assemblages on the natural reefs had a greater variation over the years but showed relatively consistent Bray-Curtis values (between 59.0 to 72.9%; Table 12).

The increase in similarity in benthic assemblages on the natural and mitigation reefs was rapid for the first few years of sampling (Thanner et al., 2006). The level of similarity between the benthic assemblages on both the modules and boulders and natural reefs has showed a very slight increasing trend after the first five years although with some fluctuation between sampling periods (Figure 4; Sathe et al., 2010, Sathe et al., 2012, Thanner 2014, Thanner 2016). All sites maintain high percent cover of algae—primarily turf algae (Tables 2-9). Both artificial reef materials sustained higher percent poriferan cover than either natural reef site and were the second most abundant taxonomic group. In Y16, octocorallia cover increased on the boulders becoming third most abundant group followed by scleractinians and remained there in Y18. On the modules, octocorallia cover more than doubled in Y16 and increased slightly again in Y18, but remained the fourth most abundant group after scleractinians. On the natural reefs, octocorals were the second most abundant taxonomic group in Y18 followed by poriferans and then scleractinians consistent with prior sampling. The percent cover of scleractinians on both artificial reef materials have been comparable to that of or above both natural reefs since at least Y6. Although the octocorallia percent cover has increased, the octocoral communities on the natural and artificial reefs remain distinct. The main reason for the disparity between octocoral communities on the natural reefs and the artificial reefs can be attributed to a lower abundance of encrusting octocorals on the artificial reef materials.

In Y16, observations of paling and bleaching octocorals were observed. These observations continued in Y18 although qualitatively at a lesser extent. In Y18, erect gorgonians were noted with broken branch tips on the natural reefs (Figure 7). The cause of the damaged branches is unknown, but the sampling at the natural reefs occurred after the passing of Hurricane Irma and the damage could be storm related. Paling, bleaching, disease and recent mortality were recorded for scleractinian species across all four monitoring sites in Y16. These observations were consistent with other county sites and even region wide (Florida Reef Resilience Program 2015, Miami-Dade County 2015, Miami-Dade County 2016). These observations also continued in Y18. Completely bleached *P. astreoides* colonies were observed on the boulders and diseased colonies were observed at all sites. In Y18, numerous porifera species were also noted with discoloration and mortality mainly *X. muta* (Figure 14) and *A. cauliformis* (Figure 15). *Xestospongia muta* is observed on the natural reefs only and was sampled after Hurricane Irma which may have caused some of, if not all, the discoloration and mortality similar to post Irma observations in the Florida Keys National Marine Sanctuary (NOAA 2018). The discoloration and mortality in *A. cauliformis* was observed in the sampling both prior to Hurricane Irma on the modules and post Irma on 2R, 3R, and boulders. However, the only decline in the percent cover of *A. cauliformis* was observed at the stations sampled after Irma—2R, 3R, and boulders.

In general, resident fish populations demonstrated considerable variability. The fish assemblages on the natural reefs were less variable than those on the artificial reef materials. Species richness (Figure 17) and diversity and evenness measures (Figure 18) were generally higher on the natural reefs. Fish abundance on the boulders continues to be greater than the modules and natural reefs due to large numbers of *C. personatus* (masked goby) and *H. aurolineatum* (tomtates) (Figure 20, Table 13). Although the fish assemblages do share some measure of similarity, the fish populations on the artificial reef materials appeared to remain distinct in this study period. Increased relief and complexity is considered a fish 'attractant', and appears to play a role in the high densities of fish on the boulders; however, it is interesting to note that while the modules provide a two to three fold increase in relief compared to the adjacent reefs, the densities of fish are more comparable to the natural reef areas than the boulders.

CONCLUSION

Although the level of similarity between the natural and artificial reefs has increased during the initial years of the study, differences between natural and artificial reefs still remain 18 years later. In addition to the inherent differences in substrate, a significant contributor to the differences is the slow encrusting octocoral development on the artificial reef materials, as well as differences in porifera percent cover and composition. Widespread decline in scleractinian health was observed in Y16 and continued in Y18. Discoloration and mortality was also observed in a few porifera species in Y18. Fish assemblages on the artificial and natural reefs, on the other hand, have not demonstrated increases in similarity during this study. The similarity between sites does not appear to be converging over time, rather maintaining distinct separation after 18 years.

The artificial reef structures are providing habitat for diverse benthic and fish assemblages. Benthic assemblages have a moderately high level of similarity to the natural reefs in species composition and relative species representation, which may indicate that the artificial reef materials have developed communities that are comparable but not completely similar to the natural reef areas. Trends identified in the benthic data indicate a slight potential for continued convergence of the artificial and natural population constituents with continued development of the octocoral assemblages and a reduction and shift in poriferan assemblages. Fish assemblages on the artificial reef do share many species in common with the natural reef areas. Despite these similarities, however, the fish assemblages remain distinct between the natural and artificial reef materials especially due to the abundance of schooling fish on the boulders. Ultimately, physical differences between material types (i.e., shape, relief, availability of cryptic habitat, etc.) may limit the potential for these reefs to converge in similarity. It is anticipated that future monitoring results will provide additional insights as to the level to which the artificial reef materials are effective in serving as mitigation for the natural reef impacts.

LITERATURE CITED

Arena, P.T., L.K.B. Jordan, R.E. Spieler. Fish assemblages on sunken vessels and natural reefs in southeast Florida, U.S.A. 2007. Hydrobiologia 580: 157-171.

Blair, S.M. and B.S. Flynn. 1989. Biological monitoring of hard bottom reef communities off Dade County Florida: Community description. Diving for Science 1989: 9-24.

Blair, S.M., B.S. Flynn, T. McIntosh, L.N. Hefty. 1990 Environmental impacts of the 1990 Bal Harbour beach renourishment project: Mechanical and sedimentation impact on hard-bottom areas adjacent to the borrow area. Metropolitan Dade County, Florida Department of Environmental Resources. Technical Report 90-15. 46 pp.

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

____________, D.E. Harper, D.B. McClellan and M. Hulsbeck. 1994. Effects of reef size on colonization and assemblage structure of fishes at artificial reefs off southeastern Florida, USA. 1994. *Bull. Mar. Sci.* 55: 796-823.

Bray J.R. and J.T. Curtis. 1957. An ordination of the upland forest communities of Southern Wisconsin. *Ecol. Monog*. 27:325-349.

Burt, J., A. Bartholomew, P. Usseglio, A. Bauman, and P.F. Sale. Are artificial reefs surrogates of natural habitats for corals and fish in Dubai, United Arab Emirates? 2009. *Coral Reefs* 28: 663-675.

Clarke K.R. and R.M. Warwick R.M. 1994. Changes in Marine Communities: An Approach to Statistical Analysis and Interpretation: 1st edition. Plymouth Marine Laboratory. Plymouth, United Kingdom. 144p.

Consent Order. 1994. State of Florida Department of Environmental Protection vs. Dade County Board of County Commissioners. OGC File No. 94-2842.

G.M. Selby and Associates, Inc. 1994. Sunny Isles Artificial Reef Monitoring Project Eighth Quarterly Report—June 1994. Submitted to Miami-Dade County Department of Environmental Resources Management.

————. 1995a. Sunny Isles Artificial Reef Monitoring Project Twelfth Quarterly Report: January 1995. Submitted to Miami-Dade County Department of Environmental Resources Management.

————. 1995b. Sunny Isles Artificial Reef Monitoring Project Sixteenth Quarterly Report: September 1995. Submitted to Miami-Dade County Department of Environmental Resources Management.

Field J.G., K.R. Clarke, and R.M. Warwick. 1982. A practical strategy for analyzing multispecies distribution patterns. *Mar. Ecol. Prog. Ser*. 8: 37-52.

Florida Department of Environmental Protection. 1994. A Natural Resource Damage assessment for the Bal Harbor Beach Renourishment Project. Technical Economic Report, DEP-TER: 94-1. 19 pp.

Florida Reef Resilience Program. 2015. Florida Reef Resilience Program Disturbance Response Monitoring Quick Look Report: Summer 2015. 7 pp.

Goldberg, W. 1973. The ecology of the coral-octocoral communities off the southeast Florida coast: Geomorphology, species composition and zonation. Bull. Mar. Sci. 23:465-487.

Kohler, K.E. and S.M. Gill, 2006. Coral Point Count with Excel extensions (CPCe): A Visual Basic program for the determination of coral and substrate coverage using random point count methodology. *Computers and Geosciences*: 32 1259-1269.

Kruskal J.B. and M. Wish. 1978. *Multidimensional Scaling*. Sage Publications, Beverly Hills, California. 93 p.

Lindeman, K.C. 1997. Development of Grunts and Snappers of Southeast Florida: Cross-shelf distributions and effects of beach management alternatives. Ph.D. Dissertation 419 pp. RSMAS, Univ. of Miami.

Miami-Dade County. July 2015. 12 and 18 Month Monitoring of Scleractinians Relocated from Government Cut to a Natural Reef Recipient Site in Association with the Phase 3 Port of Miami/Government Cut Deepening Project. 50 pp.

Miami-Dade County. January 2016. Three Year Quantitative Post Construction Benthic Monitoring in Association with the Offshore Borrow Area utilized for Contract E: Miami-Dade Beach Nourishment. 20 pp.

Moyer R.P., B. Riegl, K. Banks, and R. Dodge. 2003. Spatial Patterns and ecology of benthic communities on a high-latitude south Florida (Broward County, USA) reef system. Coral Reefs 22: 447-464.

NOAA 2018. https://floridakeys.noaa.gov/whatsnew/releases/2018/20180110-noaa-and-partners-assess-reef-aid-recovery-following-irma.html.

Perkol-Finkel, S. and Y. Benayahu. 2005. Recruitment of benthic organisms onto a planned artificial reef: shifts in community structure one decade post-deployment. *Mar. Envi. Res*. 59: 79-99.

Perkol-Finkel, S. and Y. Benayahu. 2007. Differential recruitment of benthic communities on neighboring artificial and natural reefs. *Journal of Exp. Mar Bio.* 340: 25-39.

Russell, B.C., F.H. Talbot, and S. Domm. 1974. Patterns of colonization of artificial reefs by coral reef fishes. *Proc. Int. Coral Reef Symp., 2nd* : 207-215.

Sathe, M., S. Thanner, and S. Blair (Miami-Dade County). 2010. Bal Harbour Mitigation Artificial Reef Monitoring Program: Year 10 Progress Report and Summary. 39 pp.

Sathe, M., S. Thanner, and S. Blair (Miami-Dade County). 2012. Bal Harbour Mitigation Artificial Reef Monitoring Program: Year 12 Progress Report and Summary. 35 pp.

Thanner, S (Miami-Dade County). 2014. Bal Harbour Mitigation Artificial Reef Monitoring Program: Year 14 Progress Report and Summary. 29 pp.

Thanner, S (Miami-Dade County). 2016. Bal Harbour Mitigation Artificial Reef Monitoring Program: Year 16 Progress Report and Summary. 33 pp.

Thanner, S.E., T.L. McIntosh, and S.M. Blair. 2006. Development of benthic and fish assemblages on artificial reef materials compared to natural reef assemblages in Miami-Dade County, Florida. *Bull Mar Sci*. 78: 57-70.

Walker B.K., B. Henderson, and R. Spieler. 2002. Fish assemblages associated with artificial reefs of concrete aggregates or quarry stone offshore Miami Beach, Florida, USA. *Aquat. Living Resour.* 15: 95-105.