Bal Harbour Mitigation
Artificial Reef Monitoring Program
Year 10
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

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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 has been previously documented (Thanner et al., 2006). Years 6 through 9 were documented in progress reports submitted in April of 2007 (Y6 and Y7) and April of 2009 (Y8 and Y9). This report focuses on the monitoring results of Year 10 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 2938 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 2938 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.

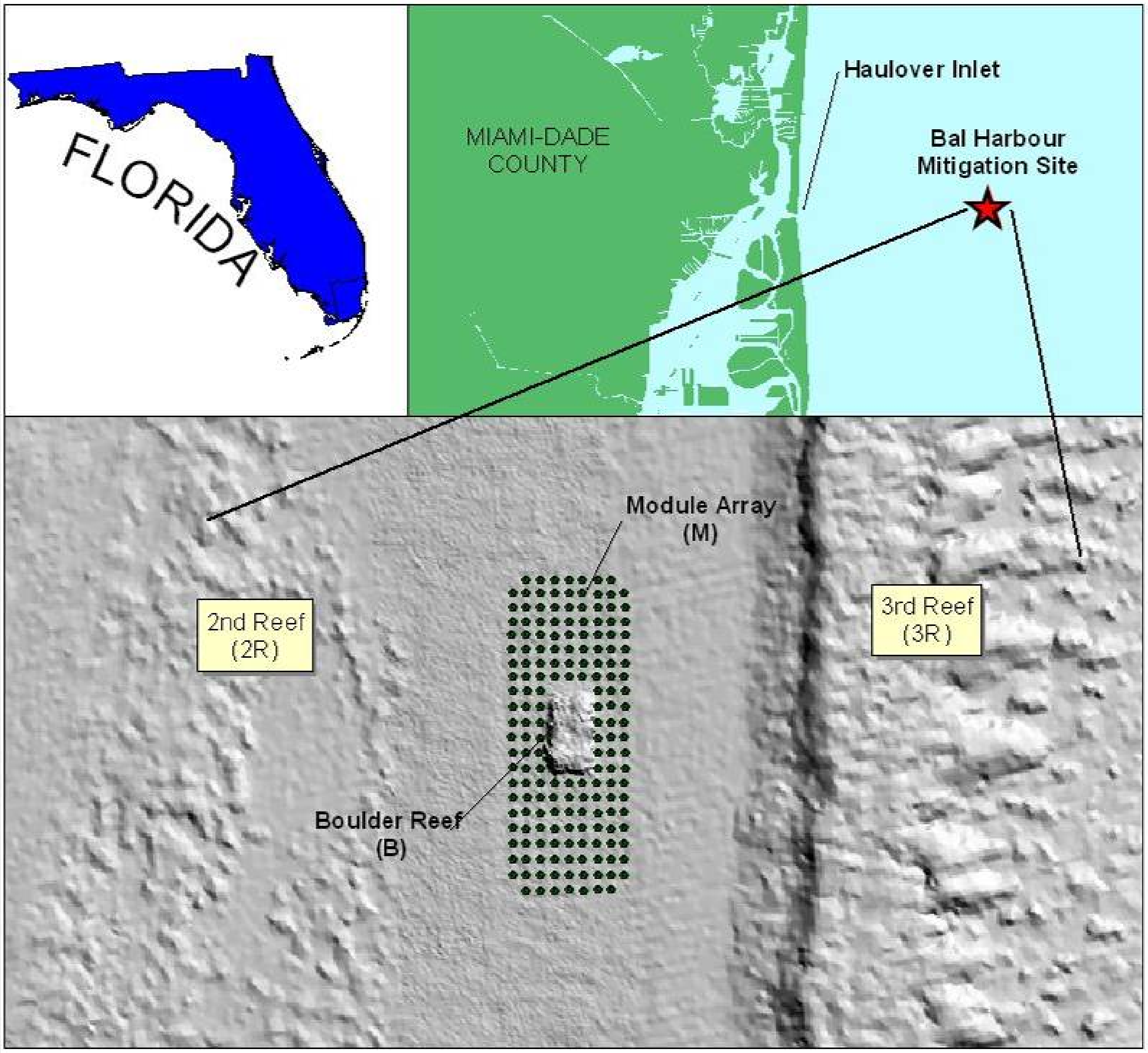

Figure 1—Location of Bal Harbour Artificial Reef Site with position of limerock boulders and modules.

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.

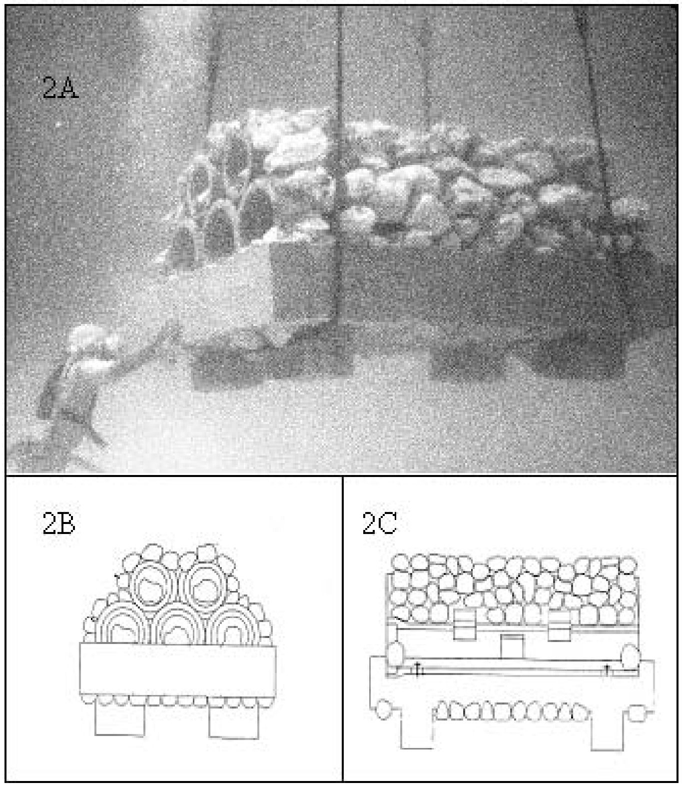

Figure 2—A) 1999 Photo of the module deployment; B) End view of module; C) Side view of module.

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).

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

Sampling Period	Dates
Y0.5 (S1)	Oct – Dec 1999
Y1 (S2)	July – Aug 2000
Y1.5 (S3)	Feb – April 2001
Y2 (S4)	Sept – Nov 2001
Y2.5 (S5)	Feb – April 2002
Y3 (S6)	July – Sept 2002
Y3.5 (S7)	Jan – April 2003
Y4 (S8)	Sep-03
Y4.5 (S9)	Feb –April 2004
Y5 (S10)	Jul-04
Y6	July-Sept 2005
Y7	July-Sept 2006
Y8	July-Nov 2007
Y9	July-Oct 2008
Y10	July-Sept 2009

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, supplemental video transect methodology was also conducted. In Year 6, 7, 8, and 9 only the video transect methodology was implemented. In Year 10, both random quadrat and video transect methodology were used in order to compare the current benthic assemblages with the first five years.

Random Quadrat Methodology—For each natural reef site (2R and 3R), 20 random sampling locations were selected for benthic habitat monitoring during the initial five years (Y0.5-Y5 / S1-S10) and again in the Y10 sampling effort. Randomly generated geographic coordinates on the reef crest, west (2R) and east (3R) of the artificial reef site, served as "origins for establishing the sampling locations. Randomly generated distances and bearings were used to navigate from the "origin" to the sampling location. Twenty sampling locations were also selected throughout the first four years of monitoring (Y0.5-Y4 / S1-S8) on the artificial reef site without distinguishing between the substrate types (i.e., modules or boulders). Sampling locations were determined by randomly selecting row/column coordinates from the artificial reef design matrix. Based on the design, 194 total potential monitoring locations existed within the site, with 176 representing module locations and 18 on the boulder substrate (Figure 1). The utilization of 20 samples on the natural and artificial reef was, by design, to compare the "reefs". However, by the fourth year of sampling, apparent consistent differences between communities of the artificial reef materials focused attention of the inequity of the sampling effort between the boulders and artificial reef modules. Although the total cumulative footprint of the modules (883 m^2) was roughly equivalent to the footprint of the boulders (1028 m^2), only 9% of the possible sampling points were on the boulders. Thus, module sampling locations were over-represented in the sampling. In the fifth year of monitoring (Y 4.5 / S9), modules and boulders received equivalent sampling efforts with 20 random sites selected on each.

At each sampling location, a $0.7m^2$ (1.0 m x 0.7 m) PVC quadrat was placed on the substrate. On the modules, quadrats were centrally oriented atop the module, along its long axis. On the natural reefs and boulder area, quadrats were oriented to the north at the predetermined random location. The 20 quadrats at each site yielded $14.0m^2$ planar area surveyed. For each quadrat in-situ mapping was conducted of all scleractinia, octocorallia, macro-porifera, macroalgae, and other sessile invertebrates to lowest possible taxonomic rank. Dimensions (major and minor axes) of all scleractinian corals were also recorded. In addition to the in-situ mapping of each quadrat, photographs were taken to serve as a permanent visual record of the quadrats and qualitative documentation of the development on the artificial reef material. Data utilized in the report were generated from the in-situ maps of the quadrats.

Video Transect Methodology—The video transect methodology utilized is based on methodology used by Florida Wildlife Research Institute on the Coral Reef Evaluation and Monitoring Project (http://research.myfwc.com/features/view_article.asp?id=30988). 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 year 4.5 through part of Y8 (October 2007) were filmed with a standard resolution Sony TRV950 camera in Amphibico underwater housing. During Y8 sampling (October 2007), the Sony TRV950 broke and the camera was replaced with a High Definition (HD) (16:9 picture format) Sony HDR-CX7. A convergent laser light system was used to maintain the camera at a uniform distance from the reef surface (40 cm). Artificial lights and red filters were used when necessary. Filming was conducted at a constant speed of about 4-5m per minute. RavenView™ image editing software was used to process the Y4.5 through Y8 video transects into abutting images (no more than 5% overlap). The HD format presented some problems for RavenView™ which is not currently configured to handle HD images. The HD images were eventually obtained, but were of similar quality to previous years' non-HD images. Year 8 2R, 3R, module and Y9 2R and 3R transects were filmed in standard resolution. Y8 boulder and Y9 module and boulder transects were filmed in HD, therefore, image quality differed slightly. In order to optimize image quality for analysis in Y9 and Y10, Pinnacle Studio 12™ was used to process the video transects into abutting images. The natural reefs yield approximately 220-250 images per station (70-90 per transect). Due to the extensive relief on the artificial reef material, the boulders yield approximately 300-380 images per station (90-150 images per transect) while the modules yield 360-530 per station (110-200 per transect) despite having similar planar area.

Image analysis was conducted using "Coral Point Count with Excel Extension" (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. Since transects filmed in HD were in a 16:9 ratio format, their images were wider than the standard definition 4:3 ratio format. Therefore, calibration of each image was conducted for all Y9 and Y10 transects to avoid overlap into the adjacent transect and maintain the standard image width of 40cm. The links of the transect chain, present in all images, was used for calibration, and all images were set to be a maximum of 40cm wide. 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 in or around 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

<u>Random Quadrat Methodology</u>

1. Assemblages on Natural Reefs

The benthic community components on the natural reefs showed relative consistency in their diversity and abundance throughout the study period. For all 11 sampling periods, porifera were the most abundant benthic organisms on the natural reefs (Table 2). A variety of porifera species including *Aplysina cauliformis*, *Niphates erecta*, *Ptilocaulis* species, *Scopalina ruetzleri* (previously reported as *Dictyonella ruetzleri*), *Monanchora barbadensis*, *Agelas wiedenmyeri* and *Dysidea etheria* were common on second reef (2R). *Aplysina cauliformis*, in particular, was consistently one of the most abundant species on 2R in ten out of eleven sampling periods. Third reef (3R), on the other hand, was dominated throughout the monitoring by two porifera species, *M. barbadensis* and *S. ruetzleri* (Table 3).

Octocorals were the second most abundant taxonomic group for both natural reefs (Table 2). *Briareum asbestinum* and *Eunicea* spp. were the most abundant octocorals on the natural reefs throughout the period of study. *Briareum asbestinum* was also consistently one of the most abundant organisms overall on 3R and occasionally on 2R (Table 3).

Table 2—Summary of the number of species (Spp) and number of individuals m^{-2} (density) of each benthic component observed at the natural reef sites. The "Other" category includes Actiniaria, Bivalvia, Coralimorphs, Ectoprocta, Milliporidae, Polychaetes, and Zoanthidea. Total survey area was $14m^2$ per site per sampling period. 2R= 2nd Reef; 3R= 3rd Reef.

Group	Site		Y1	Y2	Y3	Y4	Y5	Y10
Porifera	2R	Spp	33	36	40	43	34	**40**
		Density	45.36	48.57	57.43	52.64	42.64	**44**
	3R	Spp	32	31	38	38	32	**37**
		Density	38.64	30.64	43.93	46.07	41.36	**38.21**
Scleractinia	2R	Spp	10	10	8	10	10	**7**
		Density	2.29	0.57	2.79	1.71	2.36	**2.14**
	3R	Spp	8	8	13	10	11	**9**
		Density	2.43	1.71	2.5	2.64	2.5	**2.29**
Octocorallia	2R	Spp	7	10	8	10	6	**11**
		Density	7.43	8.21	6.14	13.36	11.86	**11.29**
	3R	Spp	8	11	7	11	8	**7**
		Density	6.57	13.36	13.71	17.5	12.93	**9.86**
Other	2R	Spp	2	4	3	2	3	**6**
		Density	0.36	0.93	0.5	0.36	1.29	**2.96**
	3R	Spp	4	5	6	3	4	**10**
		Density	1.5	1.6	1.71	1.86	1.93	**3.54**
			Organisms present but not enumerated					
Algae	2R	Spp	8	9	11	12	9	**11**
	3R	Spp	8	8	12	13	8	**12**
Hydroida	2R	Spp				1		**1**
	3R	Spp	1			1		**1**
Ascidiacia	2R	Spp	2	3	2		2	**4**
	3R	Spp	1	1	4	2	3	**4**
Total	2R	Spp	62	71	70	78	64	**80**
		Density	55.44	58.28	66.86	68.07	58.14	**65.50**
	3R	Spp	62	64	80	78	66	**80**
		Density	49.14	47.31	61.85	68.07	58.72	**58.89**

Table 3—Most abundant benthic species on the natural reefs. Overall density (individuals m^{-2}) and taxonomic group (P=Porifera, O=Octocorallia, S=Scleractinia) are listed in parenthesis. Total survey area was $14m^2$ per site per sampling period.

Period	2nd Reef	3rd Reef
Y1	*Aplysina cauliformis* (6.9, P)	*Monanchora barbadensis* (6.4, P)
	Ptilocaulis species (4.6, P)	*Briareum asbestinum* (4.7, O)
	Briareum asbestinum (4.5, O)	*Scopalina ruetzleri* (3.6, P)
Y2	*Aplysina cauliformis* (7.6, P)	*Briareum asbestinum* (8.5, O)
	Monanchora barbadensis (4.1, P)	*Scopalina ruetzleri* (3.9, P)
	Niphates erecta (3.6, P)	*Monanchora barbadensis* (3.8, P)
Y3	*Monanchora barbadensis* (7.4, P)	*Monanchora barbadensis* (8.9, P)
	Aplysina cauliformis (5.6, P)	*Briareum asbestinum* (8.1, O)
	Niphates erecta (4.2, P)	*Scopalina ruetzleri* (6.6, P)
Y4	*Aplysina cauliformis* (6.3, P)	*Briareum asbestinum* (12.1, O)
	Niphates erecta (4.6, P)	*Monanchora barbadensis* (8, P)
	Briareum asbestinum (4.5, O)	*Scopalina ruetzleri* (7.5, P)
Y5	*Niphates erecta* (6.2, P)	*Monanchora barbadensis* (8.4, P)
	Eunicea species (6.0, O)	*Briareum asbestinum* (8.3, O)
	Dysidea etheria (5.2, P)	*Scopalina ruetzleri* (5.6, P)
Y10	***Aplysina cauliformis* (4.6, P)**	***Monanchora barbadensis* (2.8, P)**
	***Agelas wiedenmyeri* (4.3, P)**	***Scopalina ruetzleri* (1.4, P)**
	***Briareum asbestinum* (3.7, O)**	***Eunicea species* (3.1, O)**

2. Assemblages on Artificial Reef Materials

As with the natural reef communities, porifera was the dominant organism group throughout the entire 10-year monitoring period on the artificial reef materials (Table 4). The most abundant porifera species were *Desmapsamma anchorata* (formerly reported as *Holopsamma helwigi)*, *Diplastrella megastellata*, *S. ruetzleri*, *M. barbadensis*, *Iotrochota birotulata*, and *Strongylacidon* species. *Desmapsamma anchorata* was the single most abundant species on the artificial reefs in Y1-Y5 (Table 5). However, in the most recent sampling periods, the density of *D. anchorata*, a 'pioneering' or opportunistic species, has decreased from a maximum density of 17.8 individuals m^{-2} in period Y3.5 to an average (on the modules and boulders combined) of 8.2 individuals m^{-2} in period Y10. *Monanchora barbadensis* on the modules surpassed that of *D. anchorata* by the last sampling period (Y10).

Scleractinian corals were the second most abundant group of benthic organisms on the artificial reef since two years after placement (Y2), mainly due to the presence of large numbers of juvenile *Siderastrea* spp. colonies. From three years after placement (Y3) to four years after placement (Y4), the density of scleractinian coral colonies nearly doubled (Table 4). *Siderastrea* *siderea* was the most numerous coral on both the modules and boulders and the most abundant species overall on the boulders in Y10 (Table 5).

Unlike the scleractinian corals, octocorals have not significantly colonized on the artificial reefs. Octocorals were only documented in two sampling periods before Y10 on the artificial reef materials, Y2.5 and Y4.5. In Y10, octocoral densities are starting to increase (Table 4).

The independent evaluation of the boulders and modules during periods Y4.5 and Y5 indicated differences in the benthic assemblages on the two types of artificial reef material. Overall, the modules supported more benthic species and higher densities than the boulders with two notable exceptions: In Y10, the boulders exhibited a numerically higher density of scleractinian corals despite the fact that the modules supported greater number of scleractinian species. The boulders also had more species and a higher density of octocorals (Table 4).

Table 4—Summary of the number of species (Spp) and number of individuals m^{-2} (Density) of each benthic component observed at the artificial reef site (AR=Artificial Reef; B=Boulders; M=Modules). Total survey area was 14m^2 per site per sampling period. The "Other" category includes Actiniaria, Bivalvia, Coralimorphs, Ectoprocta, Milliporidae, Polychaetes, and Zoanthidea.

		Joint AR Analysis (Random Mix of B and M)				**Separated AR Analysis**			
						B	**M**	**B**	**M**
Group		**Y1**	**Y2**	**Y3**	**Y4**	**Y5**	**Y5**	**Y10**	**Y10**
Porifera	Spp	15	17	27	24	23	24	**34**	**32**
	Density	15.07	40.86	57.07	73.57	39.86	82.07	**33.79**	**71.50**
Scleractinia	Spp	4	13	16	23	23	25	**18**	**22**
	Density	0.50	2.21	8.57	16.14	25.29	16.71	**28.50**	**26.79**
Octocorallia	Spp							**8**	**2**
	Density							**1.71**	**0.29**
Other	Spp	3	8	6	10	3	8	**8**	**13**
	Density	1.57	2.07	3.58	4.86	1.00	5.58	**2.18**	**13.93**
		Organisms Present But Not Enumerated							
Algae	Spp	8	9	8	10	9	8	**8**	**8**
Hydroida	Spp				1		1	**1**	**1**
Ascidiacia	Spp	4	7	6	6	2	6	**4**	**8**
Total	Spp	34	54.	63	74	61	72	**81**	**87**
	Density	17.14	45.14	69.21	94.57	66.14	104.36	**70.04**	**118.25**

Table 5—Three of the most abundant species on the artificial reef substrate. Overall density (individuals m^{-2}) and taxonomic group (P=Porifera, S=Scleractinia, B=Bryozoan) are listed in parenthesis. Total survey area was $14m^2$ per site per sampling period.

Period	Artificial Reef	
Y1	*Desmapsamma anchorata*(5.1, P)	
	Unidentified sponges (2.4, P)	
	Scopalina ruetzleri (1.9, P)	
Y2	*Desmapsamma anchorata*(13.7, P)	
	Iotrochota birotulata (5.2, P)	
	Strongylacidon species (3.6, P)	
Y3	*Desmapsamma anchorata* (11.1, P)	
	Diplastrella megastellata (8.4, P)	
	Monanchora barbadensis (7.4, P)	
Y4	*Desmapsamma anchorata*(15.1, P)	
	Diplastrella megastellata (13.0, P)	
	Iotrochota birotulata (7.5, P)	
	Boulders	Modules
Y5	*Desmapsamma anchorata* (13.0, P)	*Diplastrella megastellata* (15.1, P)
	Siderastrea siderea (10.9, S)	*Desmapsamma anchorata* (11.5, P)
	Scopalina ruetzleri (6.1, P)	*Monanchora barbadensis* (10.5, P)
Y10	***Siderastrea siderea* (7.3, S)**	***Monanchora barbadensis* (11.4, P)**
	***Siderastrea* species (6.4, S)**	***Desmapsamma anchorata* (9.9, P)**
	***Desmapsamma anchorata* (6.4, P)**	***Siderastrea siderea* (8.6, S)**

3. Artificial and Natural Reef Comparisons

Bray-Curtis similarity indices for the benthic assemblage densities were used to evaluate patterns of change within each sampling site over time and between the artificial and natural reefs. Figure 3 depicts the level of similarity of benthic assemblages between the different sites monitored through out the study using the random quadrat method. The two natural reef sites (2R vs. 3R) showed the highest level of similarity, fluctuating between 71.2 to 78.1%. The comparisons of natural reefs (2R and 3R) and the artificial reef (AR) showed a general increase in similarity through the first 3.5 years (Y3.5 / S7). The level of similarity between the artificial reef assemblages and both natural reef communities fluctuated between 45% and 61 % after that point and suggest a possible leveling off of the similarity curve (Figure 3).

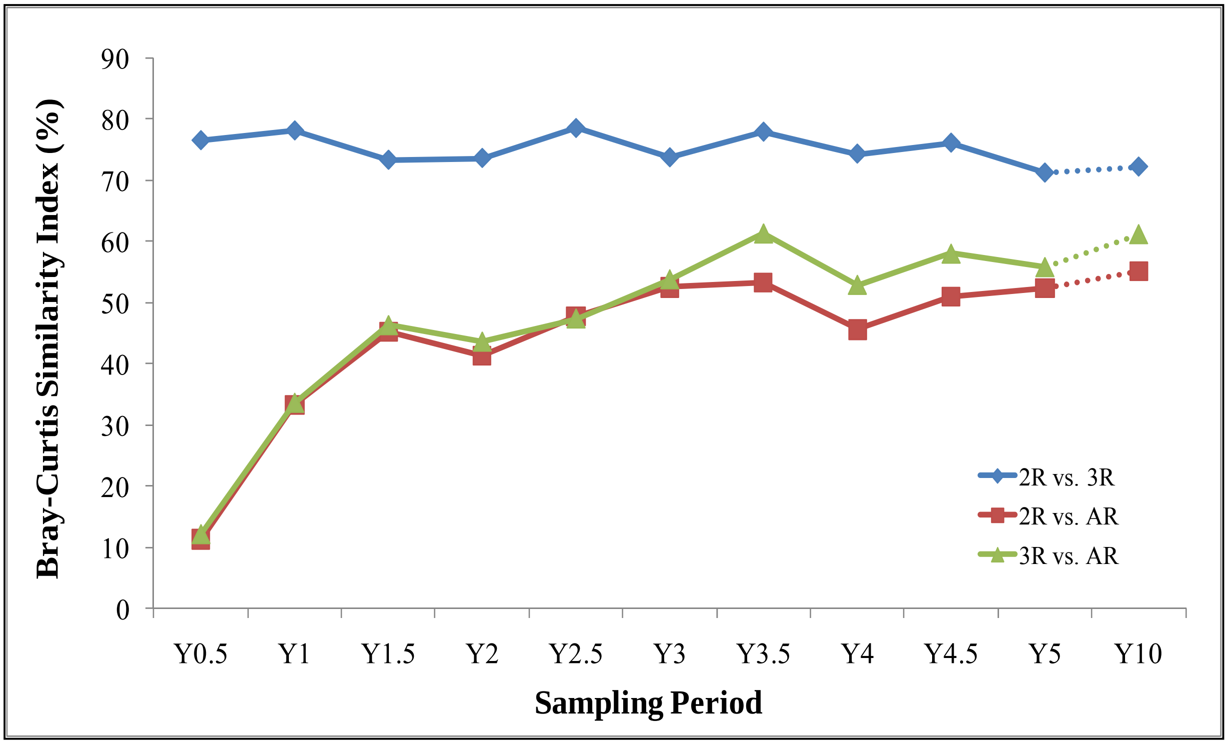

Figure 3—Bray-Curtis similarity levels between sites based on density (enumerated individuals of each species m^{-2}). Total survey area was $14m^2$ per site per sampling period. Note that in Y4.5, Y5, and Y10 the level of similarity between a natural and artificial reef is the mean individual similarity between the boulders versus natural reef and modules versus natural reef. 2R=2nd Reef; 3R=3rd Reef; AR=Artificial Reef.

The benthic communities were also compared through evaluation of their community components (i.e., scleractinian corals, octocorals, and porifera). The present status (Y10) of the composition of major benthic taxonomic group (based on number of individuals) is shown in Figure 4. As detailed in Table 2 and 4, as well as in Figure 4, porifera dominated both the natural and artificial reefs throughout the study period. Differences in component composition between the natural and artificial reefs were noted with respect to octocorals and scleractinian corals. On the natural reefs, octocorals were the second most abundant taxonomic group while their presence was extremely sparse on the artificial reef materials especially the modules. As previously mentioned, large numbers of juvenile scleractinian corals (<4cm) were recorded on the artificial reef materials in Y5 (S10) and, as a result, scleractinian corals were the second most abundant group on both the modules and boulders and continue to be in Y10. On the natural reefs, scleractinian corals were the third most abundant community component. The relative representation of major benthic components (based on number of individuals) has been consistent since the first sampling period (Y0.5 / S1) for the natural reefs and since the second year post placement (Y2 / S4) for the artificial reef materials.

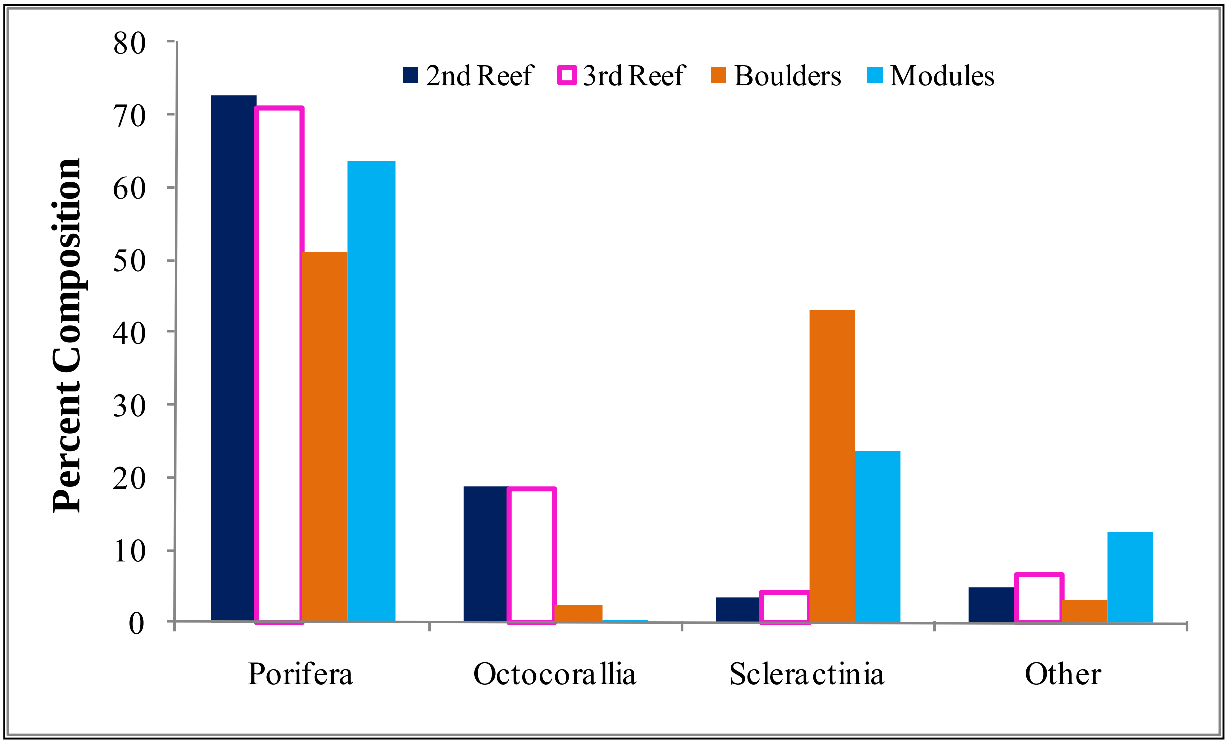

Figure 4—Mean relative percent composition (%) of benthic individuals by major taxonomic group for sampling period Y10. The "Other" category includes Actiniaria, Bivalvia, Coralimorphs, Polychaetes, and Zoanthidea.

Greater insights into development and comparability of the different reef areas can be obtained from evaluation of assemblage components. Of all the major benthic community components observed, octocoral assemblages showed the greatest disparity between the natural and artificial reef sites. The octocoral assemblage on the artificial reef materials and natural reef substrates are not comparable due to the lack of representation of this group on the modules and boulders especially encrusting octocorals such as *B. asbestinum*. In general, porifera and scleractinian corals showed the greatest similarity between the four sites.

The poriferan assemblages show more similarity to the natural reefs based on the Bray Curtis Similarity Index than the scleractinian corals comparisons (Table 6). However, the poriferan assemblages on the artificial reef material are still not as similar as the natural reefs are to themselves (2R vs. 3R). The dominance of *D. anchorata*, a pioneer species on the artificial reef, is a major factor in maintaining these differences. Although *D. anchorata* abundance has been declining in recent sampling periods, it is still one of the most abundant species on the artificial reefs. In contrast, on the natural reefs in Y10, *A. cauliformis* is the most abundant species on 2R and frequently found on 3R, but is sparse on the artificial reef materials (Table 3 and 5). The absence or presence of certain species highlights the differences that exist between the four sites.

Table 6—Bray-Curtis Similarity Index values (%) based on the density of each porifera species and each scleractinian corals species (Scler.). Note that in Y4.5, Y5, and Y10 the level of similarity between a natural and the artificial reef is the mean individual similarity between the boulders versus natural reef and modules versus natural reef 2R=2nd Reef; 3R=3rd Reef; AR=Artificial Reef.

		Y0.5	**Y1**	**Y1.5**	**Y2**	**Y2.5**	**Y3**	**Y3.5**	**Y4**	**Y.4.5**	**Y5**	**Y10**
Porifera	2R vs. 3R	83.2	85.9	80.2	80.5	83.3	82.4	86.0	80.9	82.5	75.9	**80.5**
	2R vs. AR	17.1	45.1	52.3	47.7	54.4	57.5	68.0	56.7	*56.4*	*61.3*	***67.5***
	3R vs. AR	18.7	42.8	51.3	53.7	54.7	61.4	67.8	65.0	*65.0*	*66.3*	***71.4***
Scler.	2R vs. 3R	68.0	54.1	56.8	62.8	73.0	46.1	44	53.1	55.7	54.7	**51.9**
	2R vs. AR		11.8	48.6	40.2	50.9	56.0	32.6	42.1	*49.1*	*45.2*	***38.8***
	3R vs. AR		18.9	61.8	31.6	56	54.3	68.4	44.1	*62.4*	*48.2*	***47.0***

Like the porifera assemblages, scleractinian corals on the artificial reef material have shown notable convergence to the natural reefs from periods Y.05-Y3 (Table 6). Since period Y3, the similarity between the natural and artificial reefs has fluctuated. In sampling period Y10, the 3R vs. AR comparison was 47.0%. In the same period, the 2R vs. AR comparison showed slightly lower similarity with 38.8% (Table 6).

Due to the importance of the scleractinian assemblages as reef builders, these assemblages were looked at further with respect to density, species richness, colony size, and percent cover. The number of scleractinian coral species recorded at the artificial reef site over all sampling periods showed a pattern of increasing species richness through Y4. During periods Y1.5 through Y2.5, the total number of scleractinian species increased to numbers comparable to adjacent natural reefs. From Y3 through Y10, the total number of species observed on the artificial reefs continued to increase to numbers well above those seen on the adjacent natural reef. In period Y10, the boulders and modules supported 18 and 22 different scleractinian coral species respectively, while 2R and 3R supported 7 and 9 respectively (Tables 2 and 4).

In contrast to the relatively consistent density of scleractinian corals observed on 2R and 3R, the density of scleractinian corals on the artificial reef materials has shown continual increase throughout the study period and most notably after Y3.5 (Figure 5). Density of scleractinian corals continues to increase through the last sampling period Y10 and is an order of magnitude greater than the density on either of the natural reefs (2R and 3R).

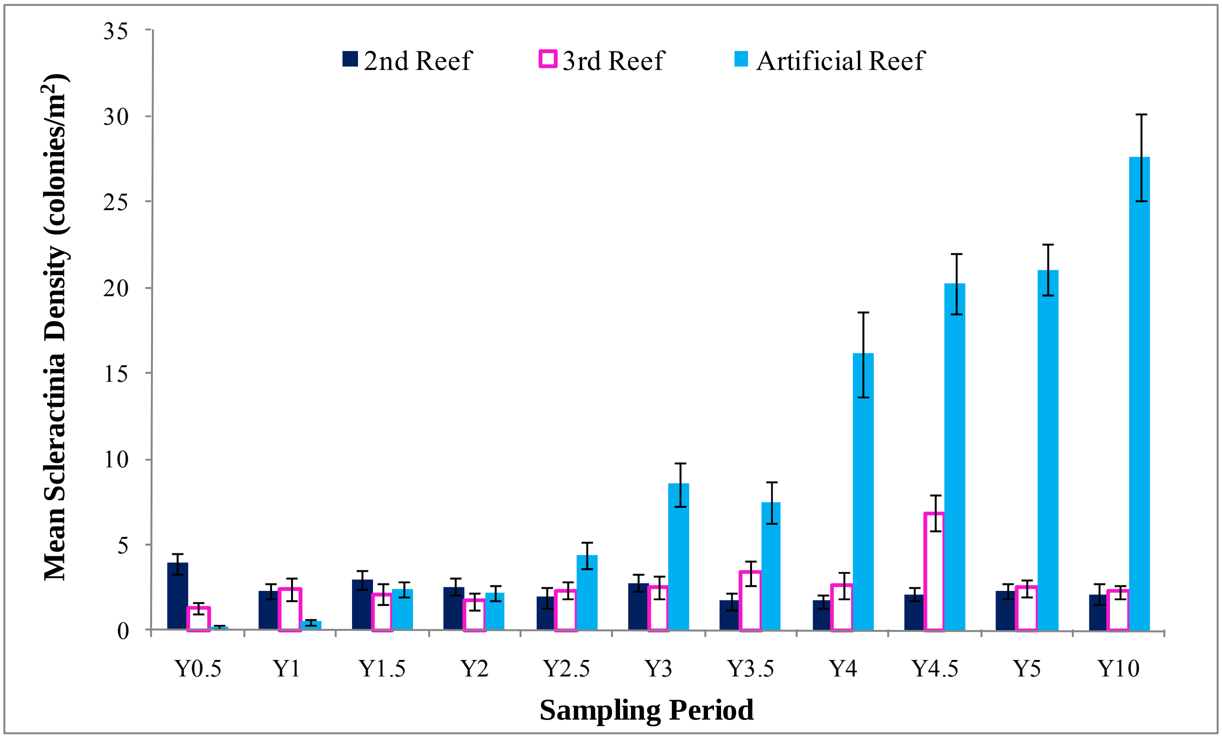

Figure 5—Mean density of scleractinian colonies. Standard error bars plotted. Total survey area was $14m^2$ per site per sampling period.

The mean size of the colonies of scleractinian corals on the artificial reef sites, are considerably smaller than those on the natural reefs. The mean colony size on the natural reefs shows a great deal of intra-site variability. For example, in the last sampling period (Y10), the mean colony size was 29.47 cm^2 (SE ±2.30, n=30) for 2R and 38.62 cm^2 (SE ±4.91, n=32) for 3R. The mean colony size on the artificial reef materials has been increasing and by the last sampling period (Y10) was 12.99 cm^2 (SE ±1.38, n=399) on the boulders and 14.66 cm^2 (SE ±1.36, n=375) on the modules. The colony size on the artificial reef materials has increased since the previous sampling period (Y5) from 4.79cm^2 (SE ±0.39, n=356) on the boulders and 8.75cm^2 (SE ±0.96, n=234) on the modules (Figure 6).

The scleractinian coverage on the artificial reef has continued to increase throughout the study period (Figure 7). It should be noted that the large coral cover on 3R in Y4.5 resulted from the presence of several large *Montastrea faveolata* and *M. cavernosa* colonies in the samples. This is additionally reflected in the greater variation noted in the samples (Figure 6). In the last sampling period, the scleractinian coral coverage for the artificial reef has exceeded the range of coverage on 2R and 3R with the exception of Y4.5.

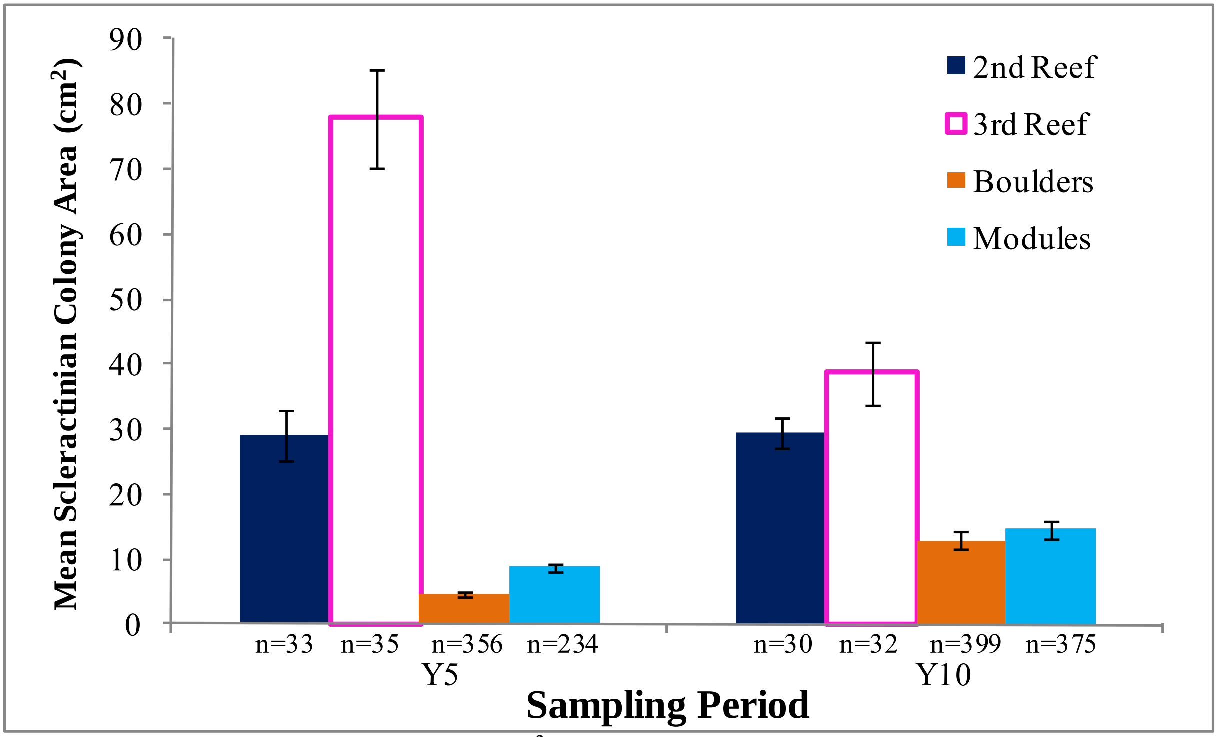

Figure 6—Mean scleractinian colony area (cm^2) in Y5 and Y10. Standard error bars plotted.

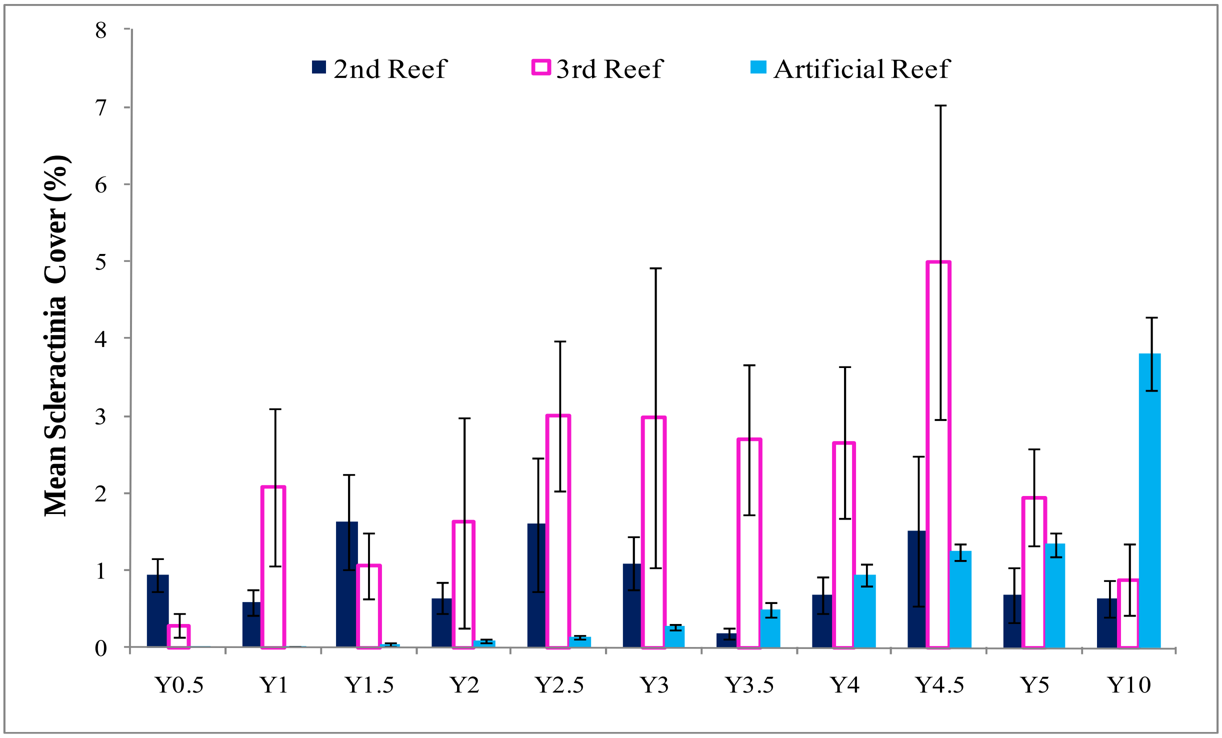

Figure 7—Mean scleractinian coverage (%). Standard error bars plotted. Total survey area was $14m^2$ per site per sampling period.

Video Transect Methodology

The video transect methodology was conducted from Y4.5 through Y10. This report summarizes the results from Y6 though Y10 with the main focus being on the results from the Y10 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 consistency in the number of species and lowest possible taxonomic group as well as the relative percent cover of benthic taxa throughout the study period (Tables 7, 8). The algal group was the most abundant benthic organisms on the natural reefs. Porifera and octocorallia continue to be the next most abundant type benthic organisms on both 2R and 3R in terms of percent cover.

Table 7 – Number of species (or lowest possible taxonomic group) in each major benthic category on the second reef (2R) and third reef (3R) identified in CPCe analysis.

	Y6		Y7		Y8		Y9		Y10	
Category	**2R**	**3R**	**2R**	**3R**	**2R**	**3R**	**2R**	**3R**	**2R**	**3R**
Algae	7	8	6	9	7	8	8	9	**8**	**9**
Porifera	32	32	34	33	29	31	33	29	**38**	**32**
Scleractinian	8	10	7	10	6	9	7	10	**8**	**8**
Octocorallia	6	9	7	8	7	5	6	8	**11**	**10**

Table 8—Relative percent cover (%) of major benthic taxa and substrate on second reef (2R) and third reef (3R) by sampling period. Benthic taxa other than those listed in the table were present, but collectively represented less than 0.4% relative cover. The "substrate" category refers to both barren hardbottom as well as sediment-covered areas.

		Y6		Y7		Y8		Y9		Y10	
Category	**Site**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Algae	2R	74.31	1.45	75.13	0.98	83.13	0.65	71.30	2.62	**75.70**	**5.96**
	3R	78.02	7.01	83.77	3.83	78.87	3.09	76.67	5.10	**77.17**	**4.86**
Porifera	2R	6.78	2.44	6.76	2.30	10.21	5.14	10.42	1.95	**8.68**	**1.88**
	3R	7.35	0.59	6.06	0.65	12.77	2.18	12.40	3.30	**7.97**	**0.88**
Octocorallia	2R	5.42	0.68	7.21	1.34	2.60	1.03	5.78	1.76	**7.38**	**1.98**
	3R	5.06	0.91	4.16	2.05	3.16	1.41	3.82	0.66	**6.28**	**0.49**
Scleractinia	2R	0.37	0.10	0.21	0.12	0.13	0.07	0.39	0.12	**0.23**	**0.08**
	3R	0.97	0.52	1.15	0.74	0.93	0.05	1.54	0.80	**1.17**	**0.44**
Milliporidae	2R	0.04	0.03	0.04	0.04	0.06	0.08	0.10	0.08	**0.10**	**0.01**
	3R	0.20	0.14	0.23	0.17	0.21	0.09	0.25	0.13	**0.29**	**0.21**
Substrate	2R	13.04	1.70	10.57	1.94	3.21	4.24	11.93	1.84	**7.82**	**5.38**
	3R	8.33	6.82	4.53	1.48	2.39	1.41	5.07	1.46	**6.89**	**4.14**

On 2R, turf algae dominated the relative percent cover of the algal component as well as all biotic components (Table 9). Blue-green algae cover was further classified in Year 10 with the identification of *Lyngbya* species amounting to 4.73% of the benthic cover. Although Lyngbya species were not distinguished from the larger blue-green algae component in Y9, an increase in *Lyngbya* species was observed in Y10 when visually comparing the video images between the two years (Figure 8). Y10 cover of blue-green algae was not as high as Y8 though. Unidentified erect gorgonians along with *B. asbestinum* had the highest percent cover of the octocorallia group on 2R. Porifera with the highest percent cover included unidentified sponges, *Xestospongia muta*, and *A. cauliformis*. *Meandrina meandrites*, *Stephanocoenia intersepts* and *Porites astreoides* had the highest relative percent cover of the scleractinian component (Table 9).

Table 9—Mean relative percent cover (%) per sampling period for the highest contributors on second reef (2R).

		Y6	Y7	Y8	Y9	Y10
Algae	Turf	64.86	65.2	63.8	68.53	**67.76**
	Total blue-green algae	7.24	6.86	10.16	0.85	**6.70**
	Lyngbya species	N/A	N/A	N/A	N/A	**4.73**
	Peyssonnelia species	0.08	0.57	1.09	0.73	**0.46**
	Halimeda species	1.77	1.28	0.53	0.43	**0.40**
	Coralline algae	0.01	0.15	1.63	0.07	**0.33**
	Macroalgae	0.26	1.08	5.84	0.67	**0.03**
Octocorallia	*Briareum asbestinum*	2.09	3.04	0.48	2.88	**3.38**
	Gorgonian (erect)	2.67	3.20	1.75	2.00	**3.03**
	Muriceopsis species				0.14	**0.29**
	Eunicea species	0.23	0.75	0.31	0.48	**0.27**
	Pseudopterogorgia species	0.31	0.14		0.23	**0.25**
Porifera	Unidentified Porifera	0.51	0.33	5.69	4.01	**2.20**
	Xestospongia muta	1.08	1.02	1.18	1.81	**1.34**
	Aplysina cauliformis	0.54	0.64	0.58	0.82	**1.00**
	Niphates erecta	0.66	0.88	0.55	0.62	**0.65**
	Pseudoceratina crassa	0.37	0.50	0.08	0.27	**0.50**
	Amphimedon compressa	0.33	0.32	0.35	0.36	**0.39**
	Desmapsamma anchorata	0.12	0.22	0.13	0.08	**0.35**
	Callyspongia tenerrima					**0.31**
	Niphates digitales	0.2	0.11	0.16	0.21	**0.29**
Scleractinia	*Meandrina meandrites*	0.12	0.04	0.03	0.12	**0.10**
	Stephanocoenia intersepta	0.05	0.08	0.01	0.09	**0.02**
	Porites astreoides	0.02	0.01			**0.02**
	Siderastrea siderea	0.02	0.01	0.04	0.05	**0.02**

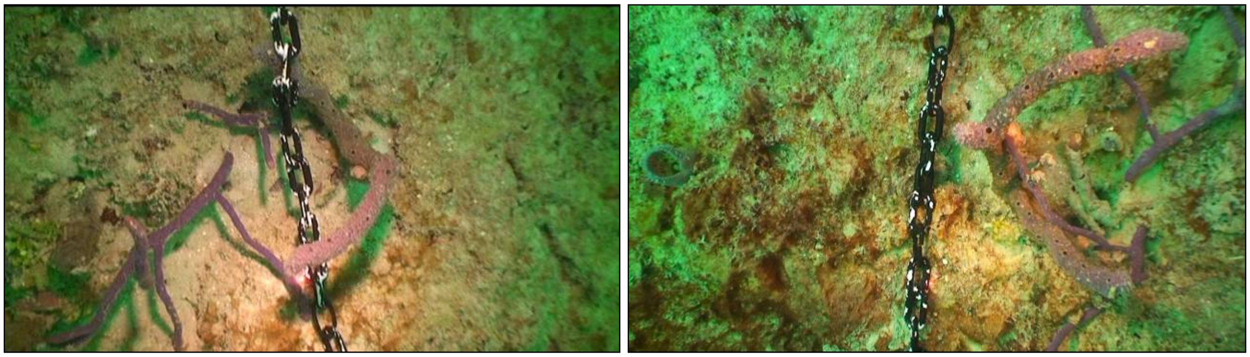

Figure 8–2R images from Y9 (on right) and Y10 (on left) illustrating a significant increase in blue-green algae (*Lyngbya* spp.).

As on 2R, turf algae dominated the relative percent cover on 3R (Table 10). Similar to 2R, the blue-green algae cover was higher in Y10 than the previous year (Y9) on 3R. Y10 and Y9 cover of blue-green algae was not as high as Y8. The lower blue-green algae cover in the last two years maybe attributed to the decline in cover of the blue-green algae species, *Lyngbya* species. Blue-green algae cover appears to fluctuate through the years and declined from Y8 to Y9 (Figure 9). Octocorals with the largest percent cover included *B. asbestinum* and *Pseudopterogorgia* species. Similar to 2R, the poriferan *X. muta,* had the largest relative percent cover on 3R. Porifera with the next highest percent cover included unidentified porifera and *I. birotulata*. Relative to scleractinians, *M. cavernosa* had the highest relative percent cover followed by *P. astreoides, M. meandrites,* and *M. faveolata* (Table 10).

Table 10—Mean relative percent cover (%) per sampling period for the highest contributors on third reef (3R).

		Y6	Y7	Y8	Y9	Y10
Algae	Turf	52.12	65.2	51.64	72.15	**69.78**
	Total blue-green algae	18.15	26.57	17.95	0.26	**5.33**
	Lyngbya species	N/A	N/A	N/A	N/A	**0.79**
	Macroalgae	3.45	4.78	8.25	0.59	**0.79**
	Halimeda species	3.83	1.68	0.56	0.84	**0.77**
Octocorallia	*Briareum asbestinum*	3.41	2.57	1.34	2.24	**3.49**
	Pseudopterogorgia species	0.14	0.04	0	0.37	**1.01**
	Gorgonian (erect)	1.01	1.14	1.72	0.81	**0.67**
	Plexaura flexuosa	0.08				**0.63**
	Eunicea species	0.07	0.17		0.19	**0.25**
	Plexaura species				0.13	**0.12**
	Gorgonia ventalina	0.11	0.01	0.04	0.01	**0.04**
Porifera	*Xestospongia muta*	1.55	1.35	0.88	1.84	**1.69**
	Unidentified Porifera	0.32	0.47	7.34	5.47	**1.55**
	Iotrochota birotulata	0.84	0.61	0.82	0.81	**1.06**
	Aplysina cauliformis	0.34	0.26	0.61	0.54	**0.75**
	Amphimedon compressa	0.37	0.35	0.27	0.47	**0.54**
	Niphates digitalis	0.47	0.25	0.27	0.46	**0.44**
	Niphates erecta	0.41	0.50	0.29	0.55	**0.25**
	Agelas conifera	0.16	0.23	0.14	0.27	**0.25**
	Strongylacidon species	0.22	0.36	0.27	0.15	**0.24**
Scleractinia	*Montastraea cavernosa*	0.60	0.51	0.49	0.55	**0.57**
	Porites astreoides	0.19	0.13	0.15	0.33	**0.22**
	Meandrina meandrites	0.03	0.28	0.19	0.32	**0.11**
	Montastraea faveolata	0.02	0.14		0.05	**0.08**

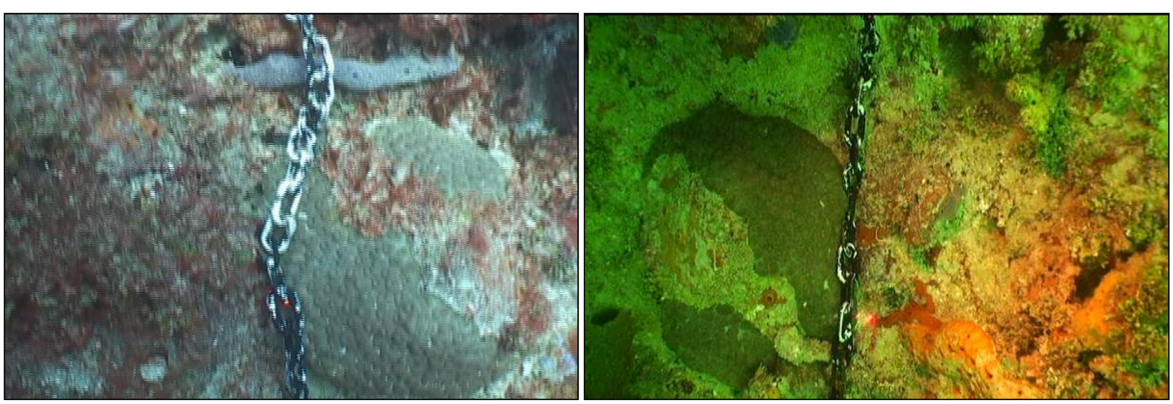

Figure 9—3R images from Y8 (on right) and Y9 (on left) illustrating a large decrease in blue-green algae (*Lyngbya* spp.) in Y9.

2. Assemblages on Artificial Reef Materials

The artificial reef materials showed relative consistency of number of species and lowest possible taxonomic group throughout the study period (Table 11). As with the natural reef communities, the algal component had the highest relative percent cover on both the boulders (B) and modules (M) (Tables 12). On both artificial reef materials, porifera had the next highest relative percent cover followed by scleractinia.

Table 11 - Number of species (or lowest possible taxonomic group) in each major benthic category on the Boulders (B) and modules (M) identified in CPCe analysis.

	Y6		**Y7**		**Y8**		**Y9**		**Y10**	
Category	**B**	**M**	**B**	**M**	**B**	**M**	**B**	**M**	**B**	**M**
Algae	4	6	7	6	9	6	6	4	**7**	**4**
Porifera	24	26	27	33	29	31	28	35	**29**	**34**
Scleractinian	15	14	12	20	23	18	19	19	**17**	**23**
Octocorallia	2	2	4	4	8	2	5	2	**6**	**3**

Table 12—Relative percent cover (%) of major benthic taxa and substrate on the boulders (B). The "other" benthic category includes Ascidiacia, Bivalvia, Gymnolaemata, Hydrozoa, and Polychaeta. The "substrate" category refers to both barren hardbottom as well as sand or sediment covered areas.

		Y6		**Y7**		**Y8**		**Y9**		**Y10**	
Category	**Site**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Algae	B	87.04	0.95	82.14	1.23	83.00	4.69	80.03	2.05	**85.25**	**0.40**
	M	74.89	0.4	74.29	2.54	79.01	1.51	72.18	1.36	**70.01**	**1.77**
Porifera	B	8.06	1.17	15.3	1.49	14.00	4.26	11.14	2.24	**10.17**	**0.95**
	M	19.57	0.36	21.89	2.53	18.83	1.31	24.12	0.47	**26.36**	**1.73**
Scleractinian	B	1.45	0.2	1.07	0.23	1.21	0.52	2.01	0.23	**1.65**	**0.09**
	M	1.09	0.23	1.02	0.26	0.80	0.22	1.46	0.38	**1.74**	**0.46**
Other	B	0.79	0.3	9.2	0.21	0.31	0.15	0.39	0.13	**0.60**	**0.25**
	M	0.74	0.2	0.9	0.39	0.32	0.11	0.69	0.21	**0.52**	**0.15**
Milliporidae	B	0.15	0.02	0.05	0.05	0.17	0.07	0.32	0.20	**0.16**	**0.11**
	M	0.45	0.15	0.35	0.25	0.61	0.04	0.88	0.31	**0.69**	**0.31**
Octocorallia	B	0	0	0.06	0.05	0.33	0.14	0.54	0.19	**1.62**	**1.10**
	M	0.02	0.02	0.09	0.05	0.02	0.02	0.04	0.04	**0.05**	**0.05**
Substrate	B	2.51	0.56	0.46	0.36	0.93	0.33	0.57	0.36	**0.54**	**0.32**
	M	3.24	0.41	1.46	0.07	0.32	0.26	0.55	0.54	**0.47**	**0.17**

Table 13 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. Porifera was the next highest cover, with the most common species being *I. birotulata*, unidentified porifera, and *D. anchorata*. Scleractinia had the third highest cover on the boulders, with *P. astreoides* and *S. siderea* showing the greatest cover of the 17 species identified through the coral point count methodology. Figure 10 shows representative video images of the benthic growth on the boulders in Y10.

Table 13—Mean relative percent cover (%) per sampling period for the highest contributors on the boulders (B).

		Y6	Y7	Y8	Y9	Y10
Algae	Turf	85.24	50.54	72.71	77.42	**78.59**
	Peysonnelia species	1.38	0.77	1.20	6.63	**5.26**
	Total Blue-green algae	0.42	0.58	5.18	0.10	**0.79**
	Coralline algae		0.26	3.26	0.87	**0.58**
Octocorallia	*Pseudopterogorgia* spp.		0.02	0.09	0.28	**1.21**
	Pseudoplexuara spp.				0.01	**0.11**
	Gorgonian (erect)			0.14	0.23	**0.11**
	Gorgonia ventalina		0.04	0.04	0.03	**0.11**
Porifera	*Iotrochota birotulata*	0.96	1.93	2.38	2.46	**3.10**
	Unidentified Porifera	0.71	0.87	6.25	3.55	**1.99**
	Desmapsamma anchorata	2.40	4.23	1.96	1.29	**1.14**
	Niphates digitalis	0.18	0.37	0.32	0.37	**0.56**
	Aplysina cauliformis	0.01	0.05	0.16	0.26	**0.45**
	Strongylacidon species	0.53	0.70	0.19	0.11	**0.40**
	Ircinia felix	0.61	0.52	0.40	0.40	**0.38**
	Ircinia campana	0.20	0.19	0.11	0.30	**0.26**
	Monanchora unguifera	0.26	0.16	0.21	0.26	**0.26**
	Artemisina melana				0.29	**0.24**
	Monanchora barbadensis	0.29	0.41	0.19	0.22	**0.21**
Scleractinia	*Porites astreoides*	0.43	0.48	0.41	0.70	**0.71**
	Siderastrea siderea	0.47	0.30	0.31	0.36	**0.31**
	Madracis decactis	0.03	0.03	0.05	0.12	**0.15**
	Stephanocoenia intersepts	0.20	0.05	0.08	0.08	**0.09**

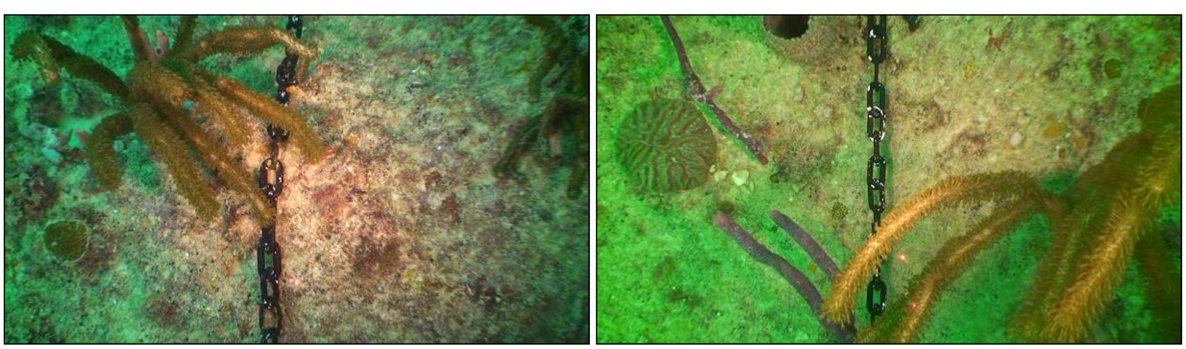

Figure 10 – Close up of benthic growth on the boulders in Y10.

The mean relative percent cover for the most common organisms on the modules (M) is shown in Table 14. The modules (M) were predominately covered by turf algae. The modules had a higher percent cover of porifera than the boulders with *I. birotulata,* unidentified porifera and *D. anchorata* showing the greatest cover. Other abundant porifera species in terms of relative percent cover on the modules includes *Artemisina melana* and *Niphates digitales*. Similar to the boulders, *P. astreoides* and *S. siderea* were the scleractinian species with the highest relative percent cover on the modules. Additionally, *Tubastrea coccinea*, a non-indigenous species, was observed for the first time on the modules in Y9 and again in Y10. Figure 11 shows a close up of benthic growth on the modules in Y10.

Table 14—Mean relative percent cover (%) per sampling period for the highest contributors on the modules (M).

		Y6	Y7	Y8	Y9	Y10
Algae	Turf	69.90	80.45	73.84	62.89	**62.91**
	Peyssonnelia species	3.54	2.81	1.43	7.77	**5.61**
	Coralline algae	0.05	0.08	0.56	1.46	**0.89**
	Total Blue-green algae	1.36	0.69	3.02	0.07	**0.60**
Octocorallia	*Iciligorgia* species					**0.03**
	Gorgonian (erect)	0.01			0.03	**<0.01**
	Gorgonia ventalina		0.05		<0.01	**<0.01**
Porifera	*Iotrochota birotulata*	1.40	2.46	4.99	5.40	**6.61**
	Unidentified Porifera	1.18	2.26	2.73	4.86	**4.66**
	Desmapsamma anchorata	5.02	6.22	3.13	2.57	**3.29**
	Artemisina melana				1.95	**1.42**
	Niphates digitalis	0.63	0.70	1.02	1.29	**1.25**
	Ircinia felix	1.27	0.99	1.06	1.16	**1.23**
	Diplastrella megastellata	0.33	0.38	0.87	0.42	**1.01**
	Monanchora barbadensis	2.04	1.23	0.18	0.49	**0.91**
	Ircinia strobilina	0.99	1.01	0.79	0.96	**0.86**
	Callyspongia vaginallis	0.23	0.39	0.62	0.59	**0.82**
	Ircinia campana	0.02	0.39	0.52	0.80	**0.81**
	Phorbus amaranthus	3.30	3.08	0.50	0.98	**0.68**
	Strongylacidon species	1.44	0.87	0.88	0.34	**0.57**
Scleractinia	*Porites astreoides*	0.34	0.36	0.40	0.62	**0.80**
	Siderastrea siderea	0.20	0.15	0.01	0.21	**0.23**
	Madracis decactis	0.11	0.15	0.07	0.15	**0.16**
	Agaricia agaricites	0.10	0.05	0.04	0.07	**0.10**

Figure 11—Close up of benthic growth on the modules in Y10.

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 12 depicts the level of similarity of the relative percent cover of benthic assemblages between the different sites monitored from Y6 through Y10. The two natural reef sites (2R vs. 3R) showed a consistent high level of similarity, varying between 76.26 to 78.79%. The comparisons of natural reefs (2R and 3R) and the boulders (B) and modules (M) have varied over the past four years, but maintained a general trend of increasing similarities through Y8 with more fluctuation in Y9 and Y10. The level of similarity between all artificial reef materials and both natural reefs increased from Y7 to Y8 and then decreased in Y9 and increased for the boulders in Y10. The boulders and 3R and 2R had the same similarity level in Y10 (64%).

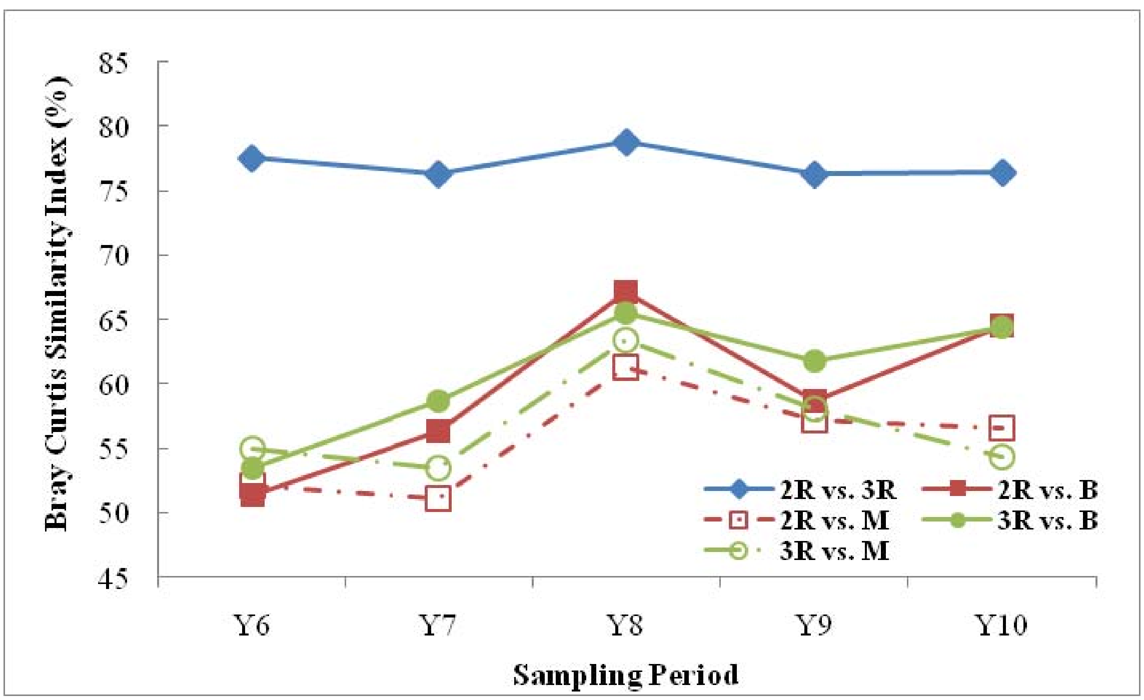

Figure 12—Bray-Curtis similarity levels between sites based on relative percent cover of benthic taxa and substrate. 2R=2nd Reef; 3R=3rd Reef; B=Boulders, M=Modules.

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, Y10, to examine which substrate type or biological components (species/ taxa subcategory) contribute the most to the differences between the natural and artificial reef sites (Table 13). Inherent differences in the substrate are a large factor in differences in the natural and artificial reef sites. For example, along the natural reef several sand pockets or depressions in the hard bottom are observed (Table 13). However, these features are rare or absent on the boulders or modules. Biotic components that caused dissimilarities between the natural and artificial reef sites included algal, octocoral, and sponge components. The natural reefs (2R and 3R) both had higher percent cover of the blue-green algae Lyngbya species than either artificial reef material (B and M). The octocoral assemblage on the artificial reef materials and natural reef substrates are only minimally comparable due to the lack of representation of this group on the modules and boulders. Qualitatively, the number and size of the erect octocorals are increasing on both artificial reef materials. However, encrusting octocorals abundant on the natural reefs such as *B. asbestinum* are extremely rare on the artificial reef material as shown in Table 13. Poriferan species also contribute to the differences between natural and artificial reef sites (Table 15). The large barrel sponge, *X. muta* has the largest relative percent cover of porifera on both natural reefs (Tables 9-10). However, *X. muta* has yet to be observed on either of artificial reef site. The relative percent cover of *D. anchorata* and *I. birotulata* also continues to be a factor in maintaining the differences between natural and artificial reefs. *Iotrochota birotulata* has the largest percent cover of porifera in Y10 on both artificial reefs (Tables 13-14). Although *I. birotulata* and *D. anchorata* are observed on the natural reef sites, they are a great deal less common. Stony corals (scleractinia) were not a major contributor to community differences on the natural versus artificial reefs, although species richness appeared to vary. Stony coral species richness (based on CPCe analysis) in Y10 was highest on the modules with 23 species and on the boulders with 17 species, while 2R and 3R had 8 species each (Tables 7, 11).

Table 15—Species causing the dissimilarity within the sites based on the Bray-Curtis Index for sampling period Y10. Species are listed in descending order according to the percent contribution to the dissimilarity.

		% Cover		Contrib. %
		2R	B	
2R vs. B	*Peyssonnelia* species	0.46	5.26	12.22
	Lyngbya species	4.73	0.01	12.04
	Sand Pocket	4.84	0.20	11.84
	Briareum asbestinum	3.38	0.00	8.62
	Iotrochota birotulata	0.06	3.10	7.75
	Gorgonian (erect)	3.03	0.11	7.45
	Sediment	2.98	0.34	6.72
		3R	B	
3R vs. B	*Peyssonnelia* species	0.29	5.26	14.44
	Blue-Green Algae	5.54	0.79	10.91
	Sand Pocket	3.92	0.20	10.80
	Briareum asbestinum	3.49	0.00	10.15
	Sediment	2.95	0.34	7.58
	Iotrochota birotulata	1.06	3.10	5.92
	Xestospongia muta	1.69	0.00	4.91

		% Cover		Contrib. %
		2R	M	
2R vs. M	*Iotrochota birotulata*	0.06	6.61	11.73
	Peyssonnelia species	0.46	5.61	9.22
	Sand Pocket	4.84	0.01	8.67
	Lyngbya species	4.73	0.00	8.48
	Briareum asbestinum	3.38	0.00	6.06
	Gorgonian (erect)	3.03	0.01	5.42
	Desmapsamma anchorata	0.35	3.29	5.26
		3R	M	
3R vs. M	*Iotrochota birotulata*	1.06	6.61	10.45
	Peyssonnelia species	0.29	5.61	10.03
	Blue-Green Algae	5.54	0.60	7.43
	Sand Pocket	3.92	0.01	7.37
	Briareum asbestinum	3.49	0.00	6.58
	Desmapsamma anchorata	0.00	3.29	6.20
	Unidentified Porifera	1.55	4.66	5.86

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 Y9 in the previously submitted progress reports. This report focuses primarily on the results from the fish surveys conducted in Y10 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 is used in the comparison of the reefs and reef materials as classified by Bohnsack and others (1994).

1. Species Richness, Diversity, and Evenness

The modules continue to be represented by fewer resident fish species than the adjacent natural reefs, however, in Y9 and Y10 the richness did approach 2R levels (Figure 13). This difference can be attributed to the difference in substrate composition and relief. The module survey area is approximately 80-90% sand while the natural reef surveys only contained small isolated sand areas and boulders surveys were composed entirely of limerock boulders with extensive relief. In Y9 and Y10 species richness decreased on the boulders to that similar to the modules. In the most recent sampling period (Y10), the boulders supported 39 different resident species while 2R supported 45 and 3R supported 48. The modules supported 38 different resident species in the last sampling period. In Y10, some of the species commonly observed on both natural reefs that were absent from the two artificial reef materials included *Halichoeres maculipinna* (Clown Wrasse), *Serranus tortugarum* (Chalk Bass), *Serranus tabacarius* (Tobaccofish), and *Holacanthus tricolor* (Rock Beauty). Diversity and evenness measures were highest on the 3rd reef (H'=3.14, J'=0.81) and lowest on the boulders (H'=1.93, J'=0.53). The second reef had a slightly higher diversity (H'=2.91, J'=0.76) and evenness compared to the modules (H'=2.65, J'=0.73) (Figure 14).

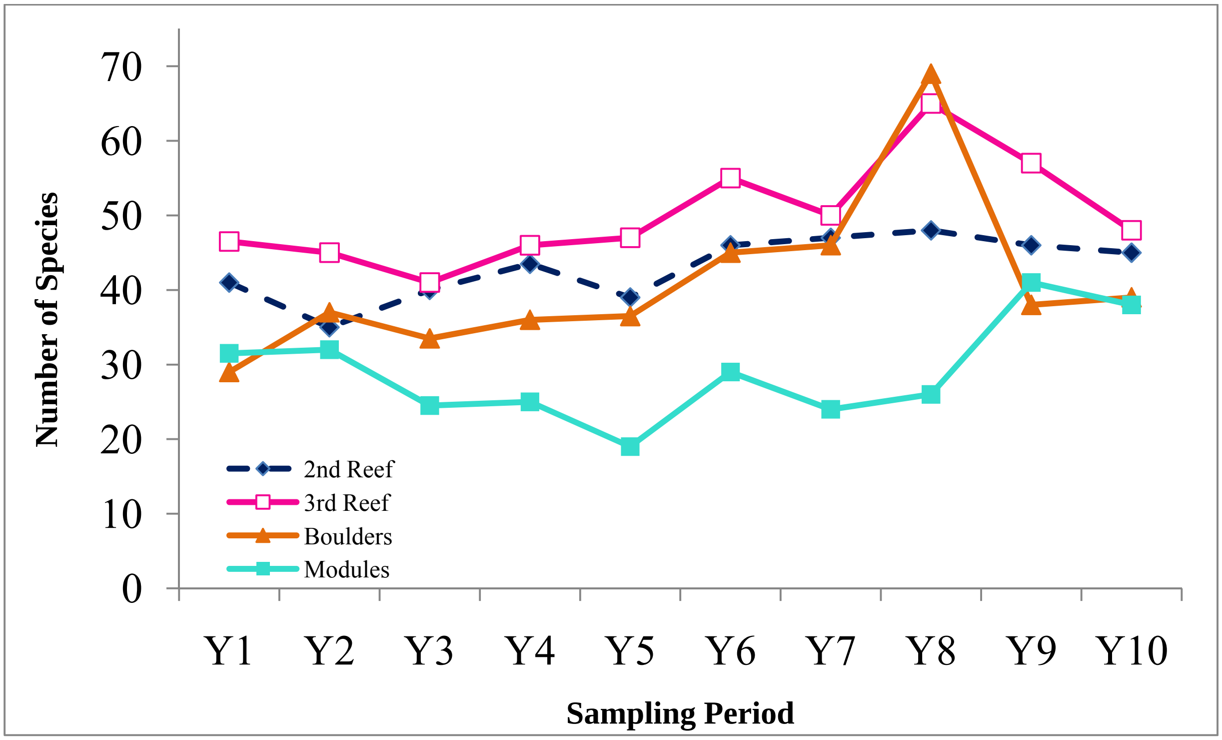

Figure 13—Number of resident fish species per annual sampling period (summer sampling). Total planar survey area was 1414m^2 per sampling period for natural reefs and 1056 m^2 for artificial reef materials.

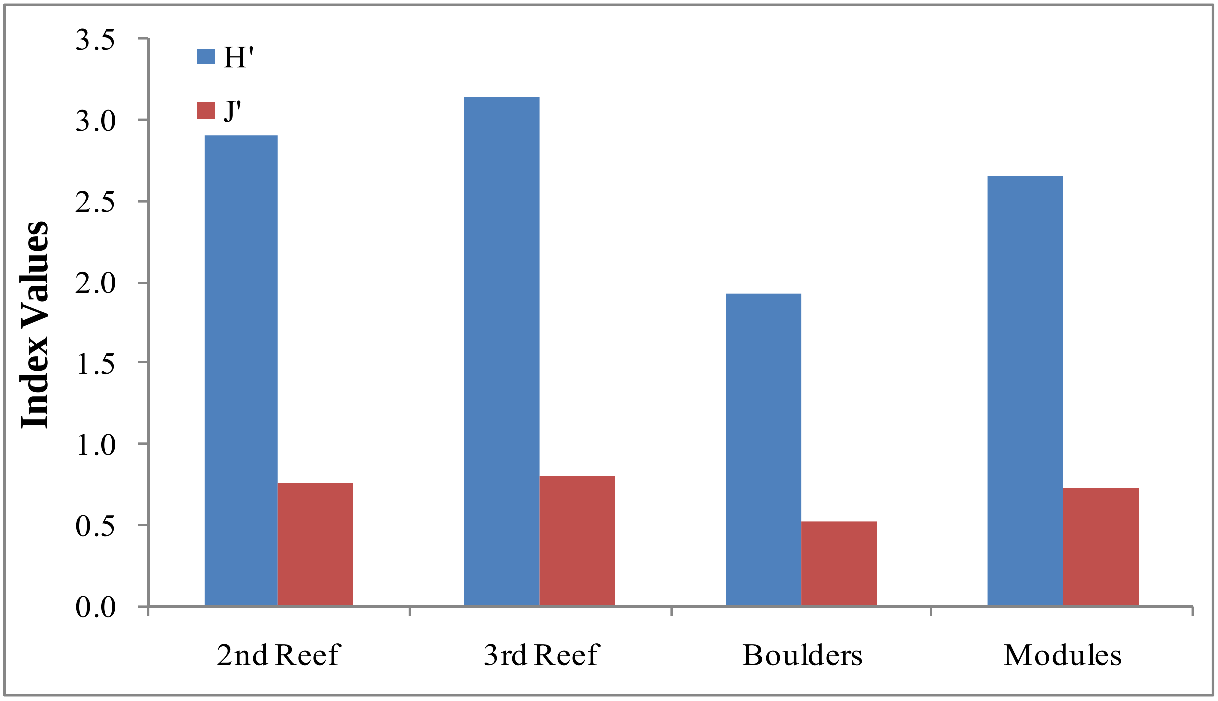

Figure 14 - Mean Shannon Diversity Index and Pielou's Evenness measure for the resident fish assemblages on 2nd Reef, 3rd Reef, Boulders and Modules. NOTE: Area of each survey = 176 m^2.

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 15). In Y10, the mean abundance on the boulders was 1490 individuals per survey, mainly comprised of large schools of *Haemulon aurolineatum* (490 ind. ±350.3) as seen in Figure 16 and large numbers of juvenile and adult *Coryphopterus personatus* (280 ind. ±480) in the numerous void areas in between boulders. In Y10 the modules had the lowest mean abundance of resident fish followed by 3R and 2R respectively.

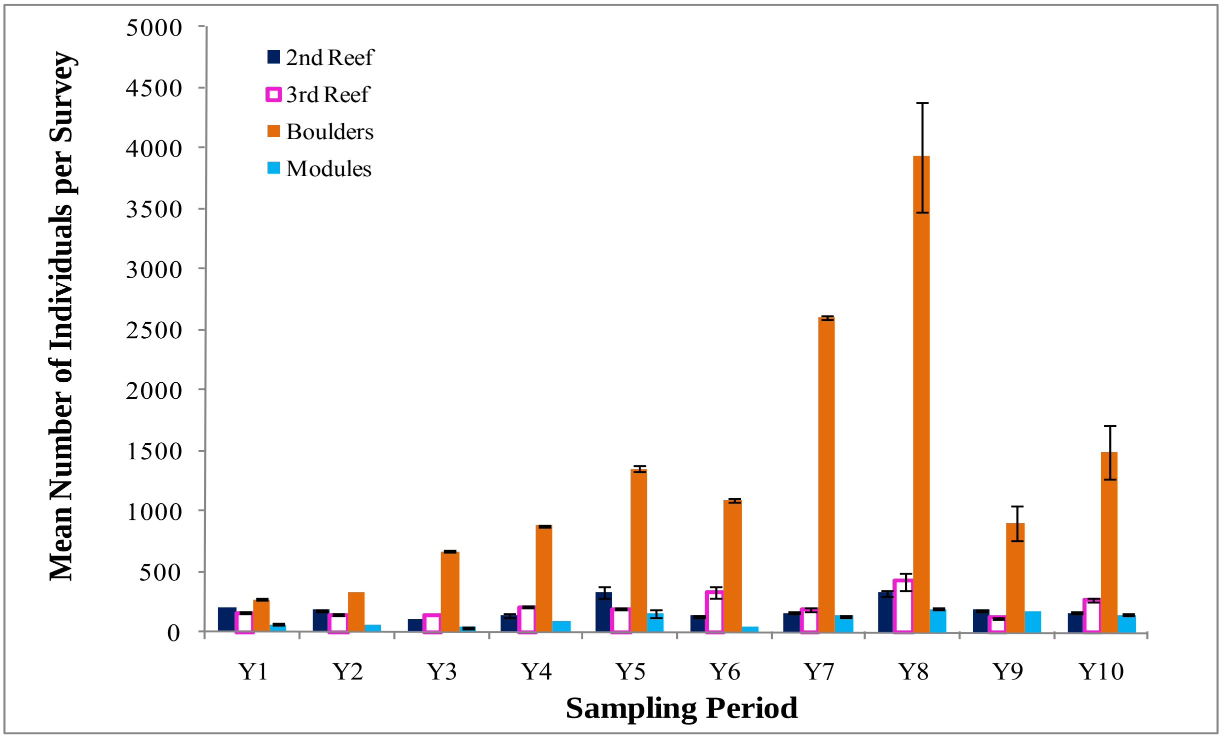

Figure 15—Mean abundance of resident fish assemblages. Standard error bars plotted.

Figure 16—Large school of *Haemulon aurolineatum* observed above the boulders in Y10.

3. Major Taxonomic Family Constituents

As of the last sampling period (Y10), Gobiidae had the highest overall representation on the modules (Figure 17). Dominance of Gobiidae family in module assemblage was attributed to large numbers of *C. personatus*. Haemulidae is the most abundant on the boulders. On 2R, Labridae is the most abundant while on 3R Pomacentridae was the most abundant. Labridae and Pomacentridae were relatively abundant at all sites, but the contribution on the boulders was diminished by the total assemblage size. Scaridae were major contributors to natural reef populations, but made up only 1.90% and 1.14% 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 16.

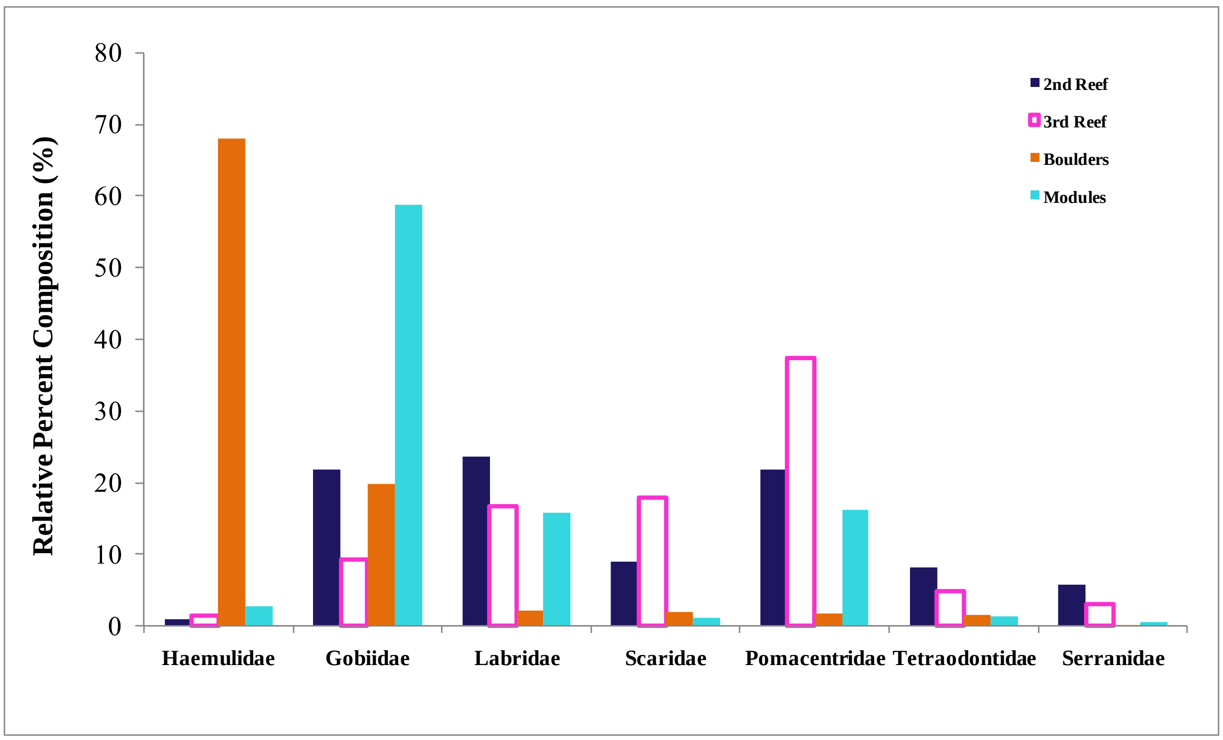

Figure 17—Percent composition (%) of individuals by major resident family constituents for Y10.

4. Size

Mean fish size (cm) appeared to increase over the sampling periods on the boulders (Figure 18). No discernable increasing or decreasing trends were seen on the natural reefs or the modules. One of the most common species on all sites, *Thalassoma bifasciatum* (Bluehead Wrasse), appeared to have an increasing mean size on the boulders as well as the modules but showed no discernable trends on the natural reefs (Figure 19). *H. aurolineatum*, a common species on the boulders and the modules, did not appear to be shifting in mean size through the sampling periods (Figure 20). However, adult *H. aurolineatum* were not observed on the modules in Y2—only 35 juveniles with an average size of 3 cm were recorded.

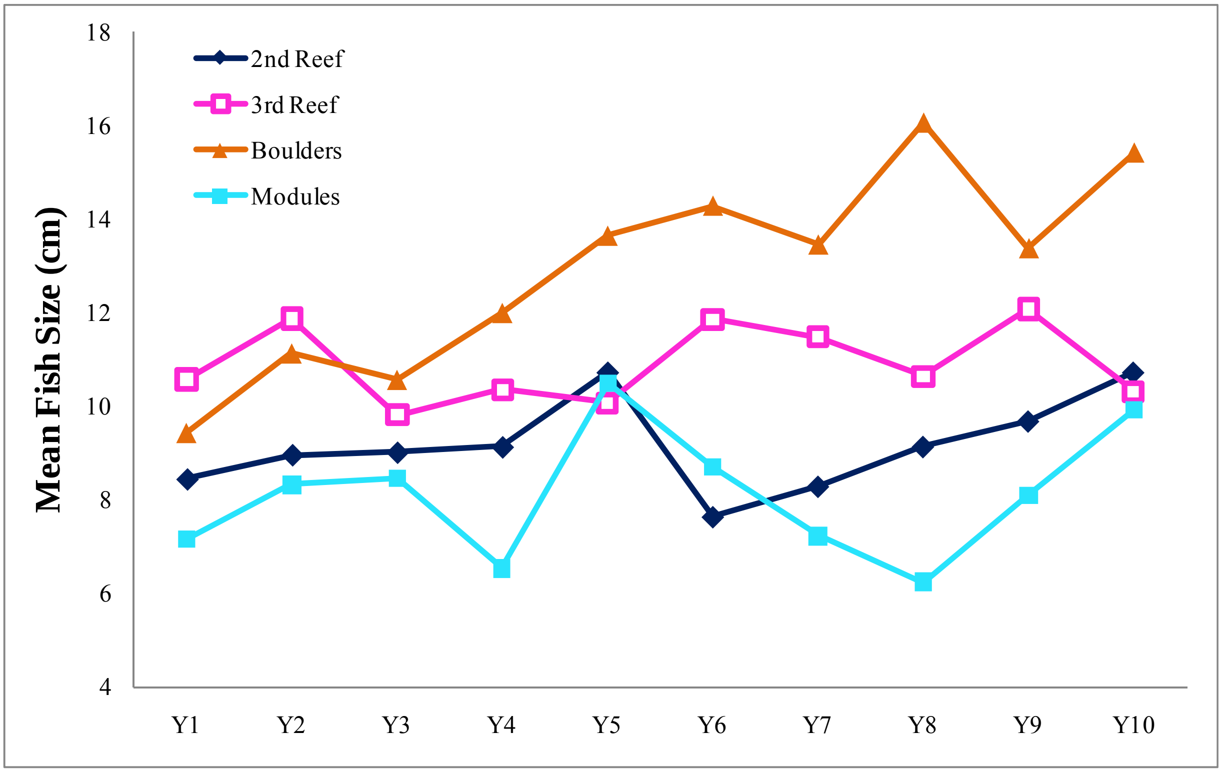

Figure 18—Mean fish size (cm) of resident fish assemblages.

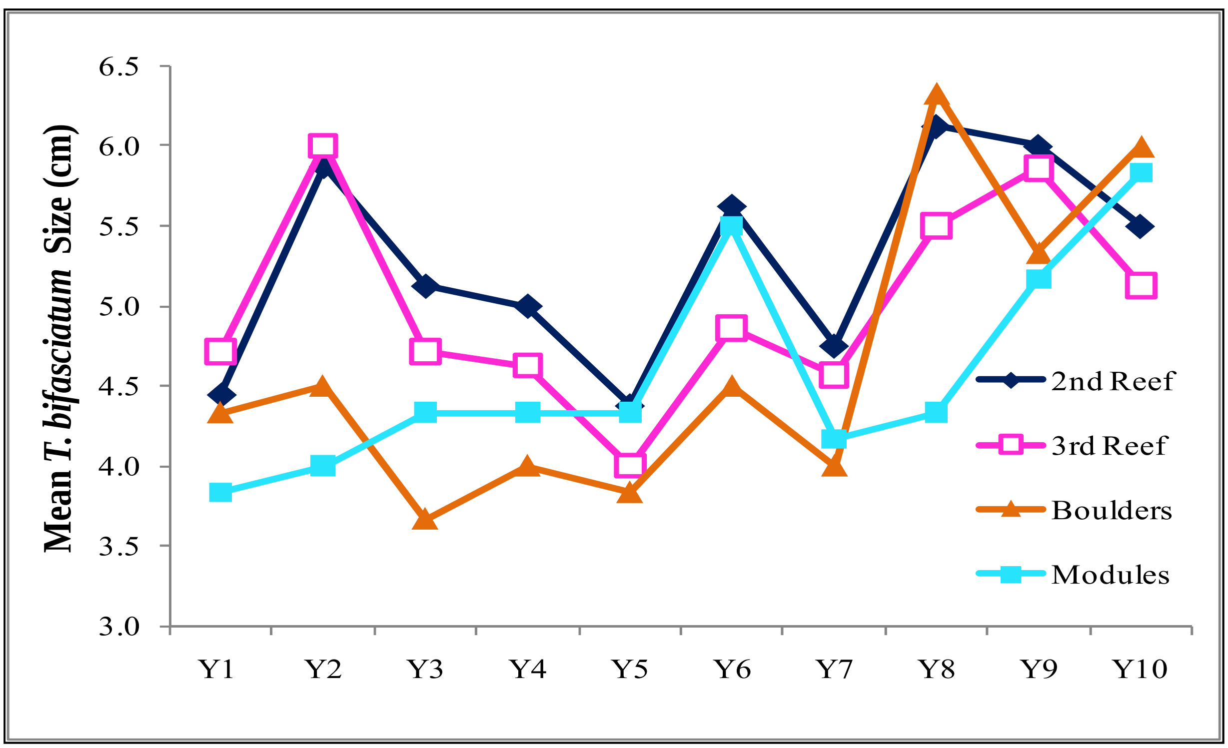

Figure 19—Mean size (cm) of a common resident fish species, Thalassoma bifasciatum, at all sites.

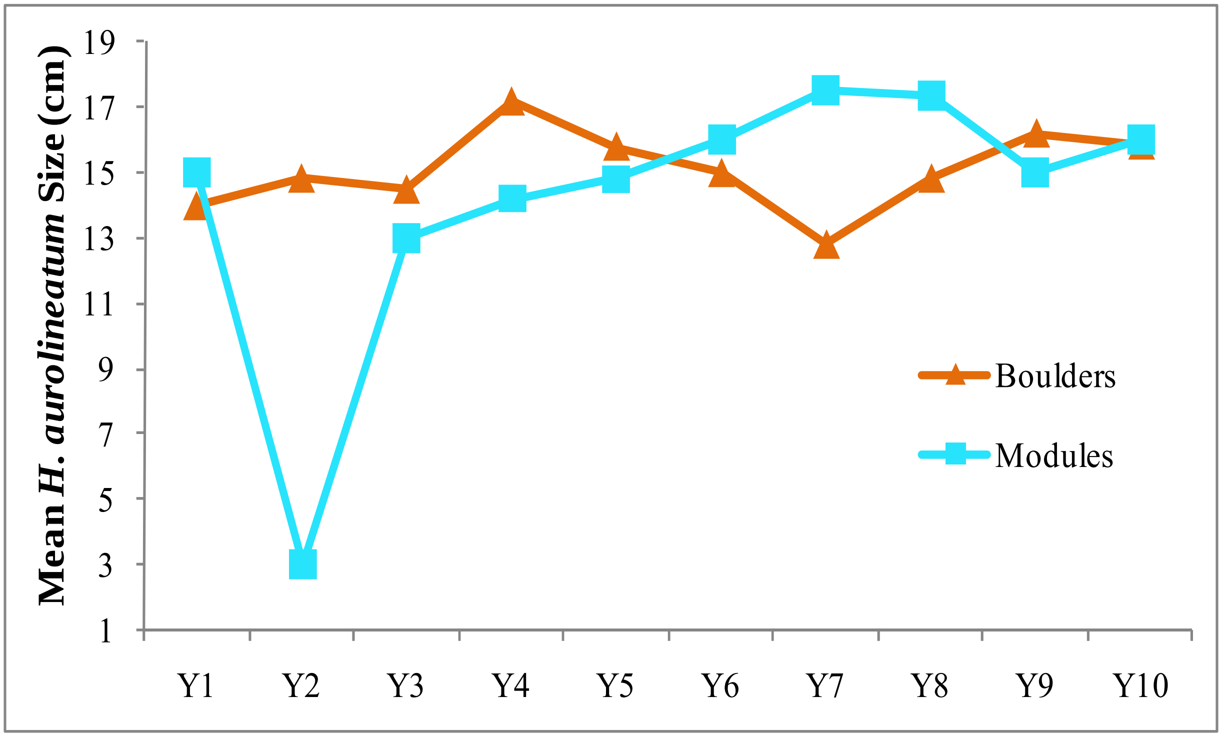

Figure 20—Mean size (cm) of a common resident fish species, Haemulon aurolineatum, on the Boulders and Modules.

5. Similarity

Bray-Curtis Similarity Indices were calculated for the resident fish populations on all four sites in the study area. Figure 20 shows the MDS plot based on those values for the last three sampling periods Y8, Y9, and Y10 while Table 7 shows the values for all annual sampling periods.

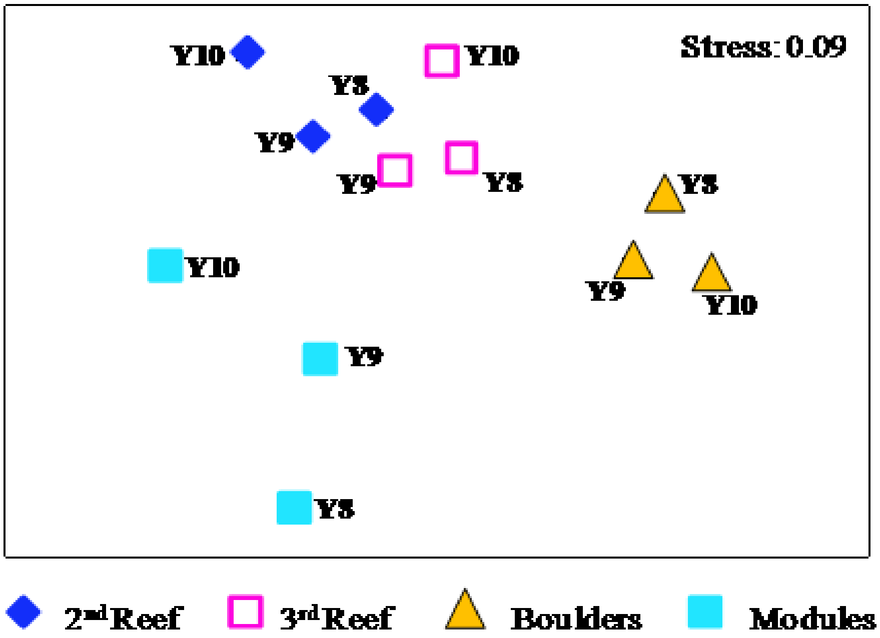

Figure 21—MDS Plot based on the BC indices for the mean resident fish density (individuals/m^2) for Y8, Y9, and Y10.

The two natural reef sites (2R and 3R) are clustered closer together than the other sites and maintained the highest level of similarity over the annual sampling events ranging from 57.7% to 72.5% similar (Figure 21 and Table 16). The natural reefs showed the lowest similarity to one another in this last sampling period (Y10) partially due to a larger abundance of *Stegastes partitus* and *Chromis multilineata* on 3R and larger abundance of *C. personatus* on 2R according to the SIMPER analysis (Table 17).

Table 16—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**
2R vs. 3R	71.6	66.6	70.1	67.9	72.5	67.0	71.3	69.1	68.6	**57.7**
2R vs. B	63.3	53.4	45.3	51.9	51.4	46.7	41.7	51.6	49.3	**41.7**
3R vs. B	49.7	57.0	56.3	58.0	53.3	53.8	47.9	60.2	51.7	**45.5**
2R vs. M	57.4	47.1	49.7	51.4	47.2	49.0	38.5	45.1	58.4	**52.1**
3R vs. M	52.5	53.3	39.9	48.3	40.6	47.0	41.1	45.6	57.9	**49.1**
B vs. M	53.8	57.0	48.0	49.7	45.9	45.6	43.6	39.3	48.3	**41.3**

Table 17—Species causing the dissimilarity within the sites based on the Bray-Curtis Index for sampling period Y10. Species are listed in descending order according the percent contribution to the dissimilarity (%).

		Avg. Abundance		%			Avg. Abundance		%
		2R	3R				B	M	
2R vs. 3R	*Stegastes partitus*	34.88	65.63	14.83	B vs. M	*Haemulon aurolineatum*	490.00	0.17	51.91
	Coryphopterus personatus	25.25	18.38	11.50		*Coryphopterus personatus*	186.67	66.00	11.83
	Chromis multilineatum	0.00	23.38	11.30		*Haemulon flavolineatum*	77.83	0.50	9.95
	Thalassoma bifasciatum	30.13	35.13	9.37		*Lutjanus griseus*	30.17	0.00	4.12
	Sparisoma atomarium	7.25	14.25	5.42		*Haemulon sciurus*	35.83	0.17	4.03
		2R	B				2R	M	
2R vs. B	*Haemulon aurolineatum*	0.00	490.00	50.12	2R vs. M	*Coryphopterus personatus*	25.25	66.00	32.47
	Coryphopterus personatus	25.25	186.67	10.67		*Stegastes partitus*	34.88	21.50	10.38
	Haemulon flavolineatum	0.00	77.83	9.66		*Thalassoma bifasciatum*	30.13	20.67	9.32
	Lutjanus griseus	0.00	30.17	3.97		*Coryphopterus glaucofraenum*	7.00	13.00	5.71
	Haemulon sciurus	0.00	35.83	3.91		*Canthigaster rostrata*	12.88	2.00	5.59
		3R	B				3R	M	
3R vs. B	*Haemulon aurolineatum*	0.00	490.00	45.52	3R vs. M	*Coryphopterus personatus*	18.38	66.00	19.19
	Coryphopterus personatus	18.38	186.67	9.19		*Stegastes partitus*	65.63	21.50	15.90
	Haemulon flavolineatum	3.38	77.83	8.29		*Chromis multilineatum*	28.38	0.00	9.64
	Stegastes partitus	65.63	10.83	6.59		*Thalassoma bifasciatum*	35.13	20.67	7.56
	Lutjanus griseus	0.00	30.17	3.53		*Sparisoma atomarium*	14.25	1.17	4.83

Clear distinctions still remain between the natural and artificial reef sites as is shown by the low stress value of the MDS plot (Figure 20). This is also apparent through the species richness (Figure 13), resident fish abundance (Figure 14), and major family composition (Figure 15) previously described. The boulders and modules remain notably divergent from one another as well as from the natural reef sites. The similarity levels between the natural reefs and the artificial reef materials have fluctuated with no discernable trend. The boulder site was only slightly more similar to the natural reefs than the modules from Y1 to Y8 in terms of mean resident fish abundance. The module site was more similar than the boulders to the natural reef sites in Y9 and Y10. SIMPER analysis of all surveys showed the species responsible for the dissimilarity between the natural reefs (2R and 3R) and the modules was *C. personatus* with a greater abundance on the modules. The large abundance of *H. aurolineatum* on the boulders was responsible for the dissimilarity between both reef sites and the boulders. *Haemulon aurolineatum* was also responsible for the difference between the boulders and the modules with a greater abundance on the boulders (Table 17).

DISCUSSION

Artificial reefs are increasingly being utilized 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. The degree to which the biotic communities on these artificial materials become similar to those on natural reefs has not been well demonstrated. Data from the first ten years of monitoring provides significant information on the efficacy of artificial materials to serve as natural reef mitigation.

Data from the ongoing monitoring program indicates that the local natural reefs support diverse and stable communities. This is reflected in the similar species richness, and overall densities of the benthic assemblages on the Second and Third Reef stations (Table 2), as well as in the relative consistency of the Bray-Curtis similarity values over time in comparisons between these sites (similarity values range between 71.2 to 78.79% depending on assessment method; Figures 3, 12). Similarly, the fish assemblages on the natural reefs showed relatively consistent Bray-Curtis values (between 66.6 to 72.5%; Table 16).

The level of similarity between the benthic assemblages on both the modules and boulders and natural reefs continued to increase up to Y8 but may be showing indications of stabilizing inY9 and Y10 (Figure 12). All sites maintain high percent cover of algae—primarily turf algae (Tables 13 and 14). Both artificial reef materials sustained higher percent poriferan cover than either natural reef site. On the natural reefs, octocorals were the second most abundant taxonomic group while scleractinian corals were the second most abundant group on the boulders and modules, primarily due to the presence of a large number of juvenile corals (Figure 4). Scleractinian density and colony size on the artificial reefs continued to rise in Y10 (Figure 5, 6). The percent cover of scleractinia on both the boulders and modules have been comparable to that of 3R and above that found on 2R throughout the last five sampling periods. The octocoral communities on the natural and artificial reefs though have remained distinct. The mean relative percent cover by octocorals was 7.38% and 6.28% respectively for 2R and 3R during the last sampling period Y10 (Table 8). Octocoral populations appear to be increasing on the boulders during the last three sampling periods with a large increase in Y10. The percent cover of octocorals on the boulders was 0.54% in Y9 and 1.62% in Y10 only 0.04% in Y9 and 0.06% in Y10 on the modules (Table 12). The reason for the disparity between octocoral communities on the natural reefs and the artificial reefs can be partially attributed to the lack of encrusting octocoral development on the artificial reef modules.

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 13) and diversity and evenness measures (Figure 14) were consistently higher on the natural reefs. Fish abundance on the boulders continues to be greater than the modules and natural reefs due to large schools of *Haemulon aurolineatum* (Tomates) (Figure 15 and 16). The fish assemblages on the boulders are dominated by the Haemulidae family and by the Gobiidae family on the modules (Figure 17). Mean fish size has increased on the boulders over the 10 years of monitoring (Figure 18). *Thalassoma bifasciatum* (Bluehead Wrasse) appears to be growing and perhaps reproducing on the artificial reef materials; however, *H. aurolineatum* (Tomtate) does not (Figures 19-20). 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. A portion of the variation seen the in artificial reef fish assemblage over time may be associated with the documented change (i.e., development) of the benthic assemblages. 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 comparable to the natural reef areas.

CONCLUSIONS

Although the level of similarity between the natural and artificial reefs has increased during the ten-year study, differences between natural and artificial reefs still remain after ten years. In addition to the inherent differences in substrate, a significant contributor to the differences is the slow octocoral development on the artificial reef materials, as well as differences in porifera composition. 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 ten years, and possibly showing divergence in similarity.

It does appear that 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 are developing communities that are comparable to the natural reef areas. Trends identified in the benthic data indicate potential for continued convergence of the artificial and natural population constituents with continued development of the octocoral 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. 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.

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