Martin County Artificial Reef Monitoring 2016-17

FINAL REPORT

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1.0 INTRODUCTION

The Martin County Artificial Reef Program has actively developed and managed the deployment of over 70 artificial reef structures since program establishment in 1972. There are currently four permitted offshore artificial reef sites (Donaldson, Sirotkin, Ernst, and South County) located in water depths ranging from 50 to 200 ft (15 to 60 m). Each permitted artificial reef site contains multiple deployments of artificial reef materials including bridge rubble, steel barges, prefabricated reef modules, concrete railroad ties, and large steel vessels such as the U.S.S. Rankin. In addition, Martin County has three nearshore and estuarine reef sites that were deployed in 2000 and consist of bridge pieces, predominantly pilings with some deck span pieces (Martin County, 2013). The goals of the Program are outlined in the 2013 Martin County Artificial Reef Management Plan (MCARP) developed in accordance with the guidelines provided in the State of Florida Artificial Reef Strategic Plan (FWC, 2003).

The purpose of this study is to compare fish and benthic communities associated with two offshore artificial reef sites in Martin County, Donaldson and South County permitted sites, to nearby natural reefs in the deep-ridge complex (**Figure 1**). The artificial reef deployments within these permitted sites range in age from two to eight years. Currently, there are no quantitative comparative studies of natural reefs and recreational artificial reefs in Martin County other than the nearshore reefs placed as hardbottom mitigation. The artificial reef and natural hardbottom community comparisons in this report will assess how proximity to natural hardbottom influences benthic and fish community composition, abundance, and diversity.

The coastal waters of Martin County lie in a zone of two overlapping biogeographical provinces, the warm temperate Carolinian and the tropical Caribbean (Gilmore et al., 1981, Hesperides Group, 2013). The benthic community in Martin County differs from Palm Beach, Broward, Miami-Dade and Monroe counties in that it is characterized by a lower diversity and density of scleractinian corals and octocorals (Walker and Gilliam, 2013). The fish assemblages of Martin County also differ from the three southeast Florida counties in that they are characterized by a decrease in tropical reef-associated species and an increase in more temperate, cold-water tolerant species (Gilmore et al., 1981, Fisco, 2016). Conducting quantitative surveys of the fish and benthic communities associated with artificial reefs using methods comparable to studies of natural reefs in Martin County should provide a better understanding of the role of artificial reefs in this highly variable biogeographic region.

This report presents the results of the 2016 benthic and fish assemblage surveys at the South County artificial reefs and locations along natural hardbottom at varying distances from the artificial reefs. In June 2008, six artificial reefs were deployed within the South County artificial reef area. In July and August 2014, six additional artificial reef structures were deployed northeast of the 2008 reefs. The location of the South County artificial reef site is designed to enhance demersal fish populations offshore of Martin County; the reef site is not as easily accessible to anglers as the other three artificial reef sites (Hesperides Group, 2013). The South County artificial reef site also contains natural hardbottom characterized as “Ridge Deep” (Walker and Gilliam, 2013) within the permitted artificial reef site; the natural hardbottom is approximately 600 to 700 ft (183 to 213 m) from the artificial reefs placed in 2014, and 1,250 to 2,300 ft (381 to 701 m) from the reefs placed in 2008. The locations of the South County artificial reefs and natural reef sites surveyed in 2016 are shown in **Figure 2.**

The results of this study are compared with the fish and benthic community data collected at Donaldson Reef in the summer and fall of 2015. The Donaldson Reef permit area is located about 3.2 NM (6 km) northeast of the St. Lucie Inlet and approximately 8.6 NM (16 km) from the South County artificial reef area (**Figure 1**). The purpose of the Donaldson artificial reef is enhancement of local recreational fisheries. The Donaldson Reef supports easily accessible dive destinations along with popular bottom fishing locations (Hesperides Group, 2013). This artificial reef site is located in depths where many important species of fishes in the grouper-snapper complex are found as juvenile or young adults (Hesperides Group, 2013). The South County and Donaldson artificial reefs are being managed similarly under the MCARP and consist of similar concrete material, but differ in depth, proximity to natural reef, and vertical relief. The MCARP does not restrict any activities on the sites, and management of both permitted sites consists of monitoring and maintenance. The MCARP requires monitoring of the artificial reefs for the first two years post deployment, then reef sites are monitored on a rotating annual schedule. Stability, subsidence, and relief are assessed at the artificial reefs along with general observations of fish populations and benthic fauna. Long-term maintenance is required and generally consists of removal of refuse and fouled fishing gear.

The MCARP intends to use the results of this study to evaluate the success of artificial reefs in achieving the goals of fishery enhancement and/or increased recruitment. Placement of artificial reefs within the limits of recreational diving and adjacent to natural hardbottom in the South County reef site presents a unique opportunity to evaluate the possible migration and concentration of economically important species at the artificial reefs. The potential for concentration of commercially desirable species could possibly increase fishing pressure on fish populations on both natural and artificial reefs. The use of a modified point count method (Bohnsack and Bannerot 1986, Brandt et al. 2009), similar to that used during the Reef fish Visual Census (RVC) surveys performed by the Southeast Florida Fishery-Independent Monitoring Program, allows the artificial reef data to be quantitatively compared to the RVC data collected on natural hardbottom. Comparisons between nearby natural reefs well within the home range of many snapper and grouper species, combined with comparisons to natural reefs at varying distances from the artificial structures, will begin to answer questions regarding effects of the artificial reefs on demersal fish species in Martin County.

The objectives of this grant were to determine if differences in the fish and benthic assemblage exist between the following groups:

1. Artificial reef deployments of different ages within the South County artificial reef area.
2. Artificial reefs within the South County artificial reef area and natural reefs at varying distances from the artificial reefs.
3. The Donaldson and the South County artificial reefs.
4. The Donaldson 2015 Year 2 post-deployment reefs and the South County 2016 Year 2 post-deployment reefs.

5. The South County artificial reef fish assemblage and the 2013-2015 Southeast Florida Coral Reef Initiative Reef fish Visual Censuses performed along the Ridge Deep habitat in Martin County.

Figure 1

Survey Locations at the Old and New Artificial Reefs in the Donaldson and South County Permitted Artificial Reef Sites

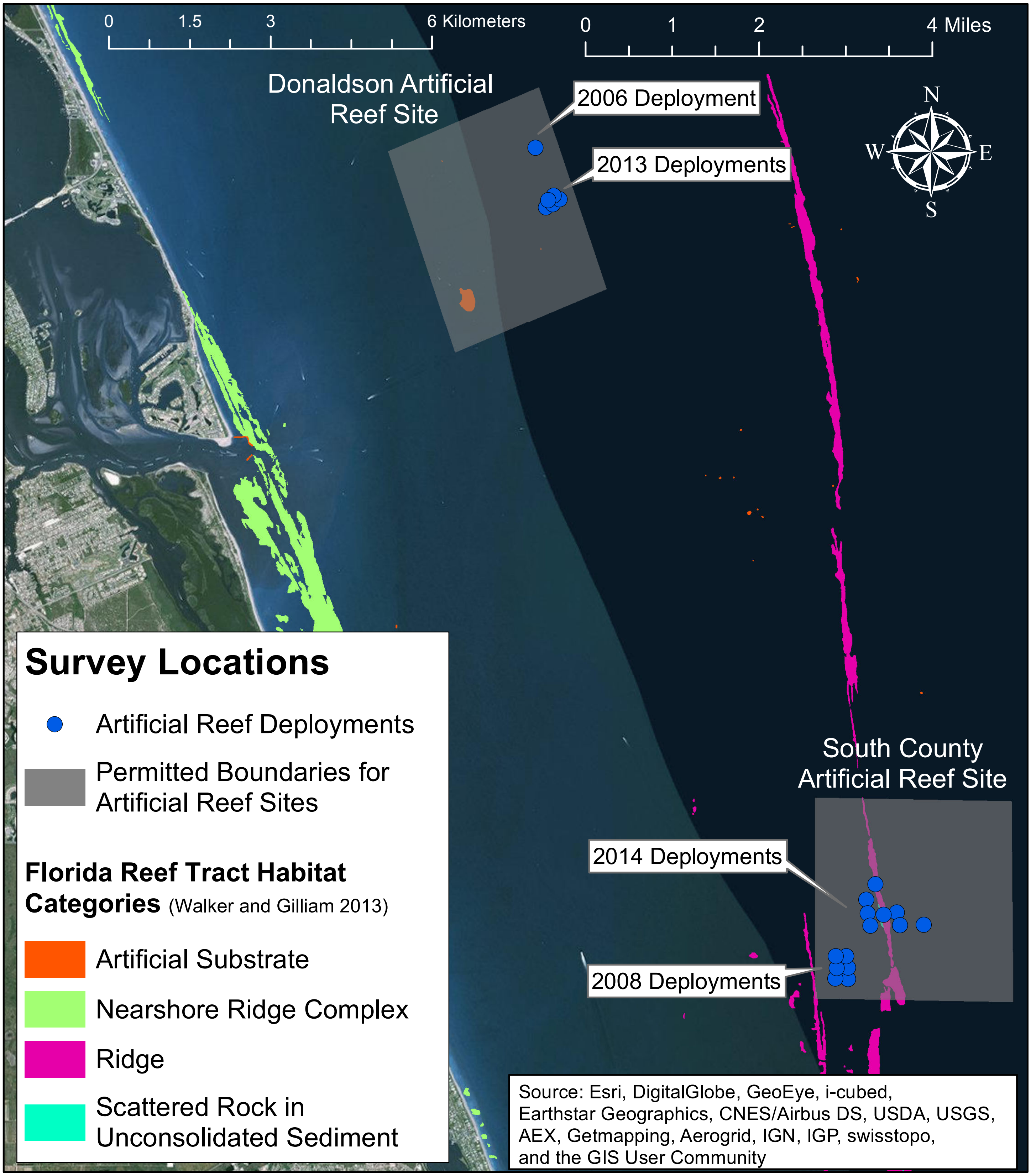


Figure 2
Martin County 2016 Artificial and Natural Reef Survey Locations

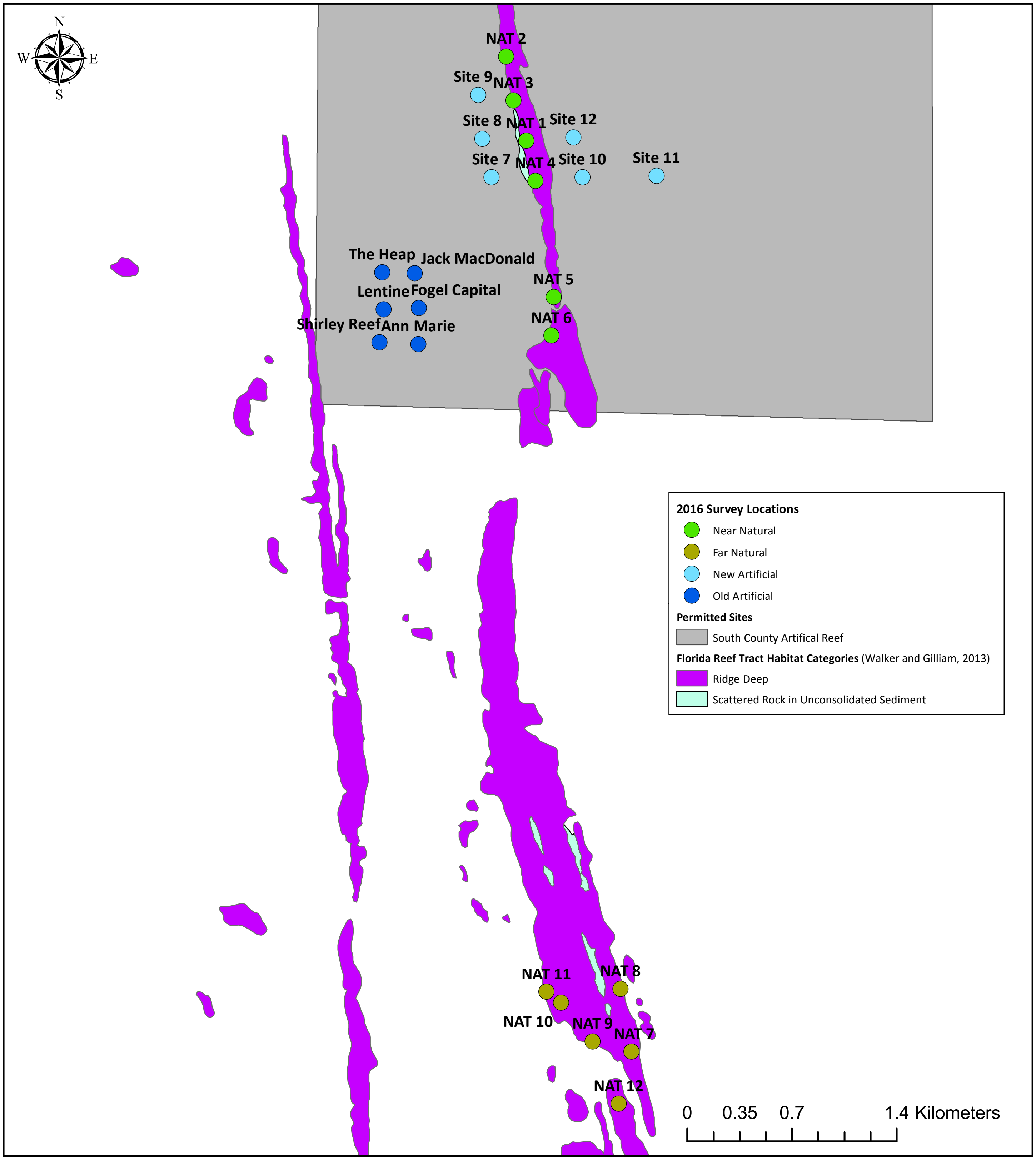
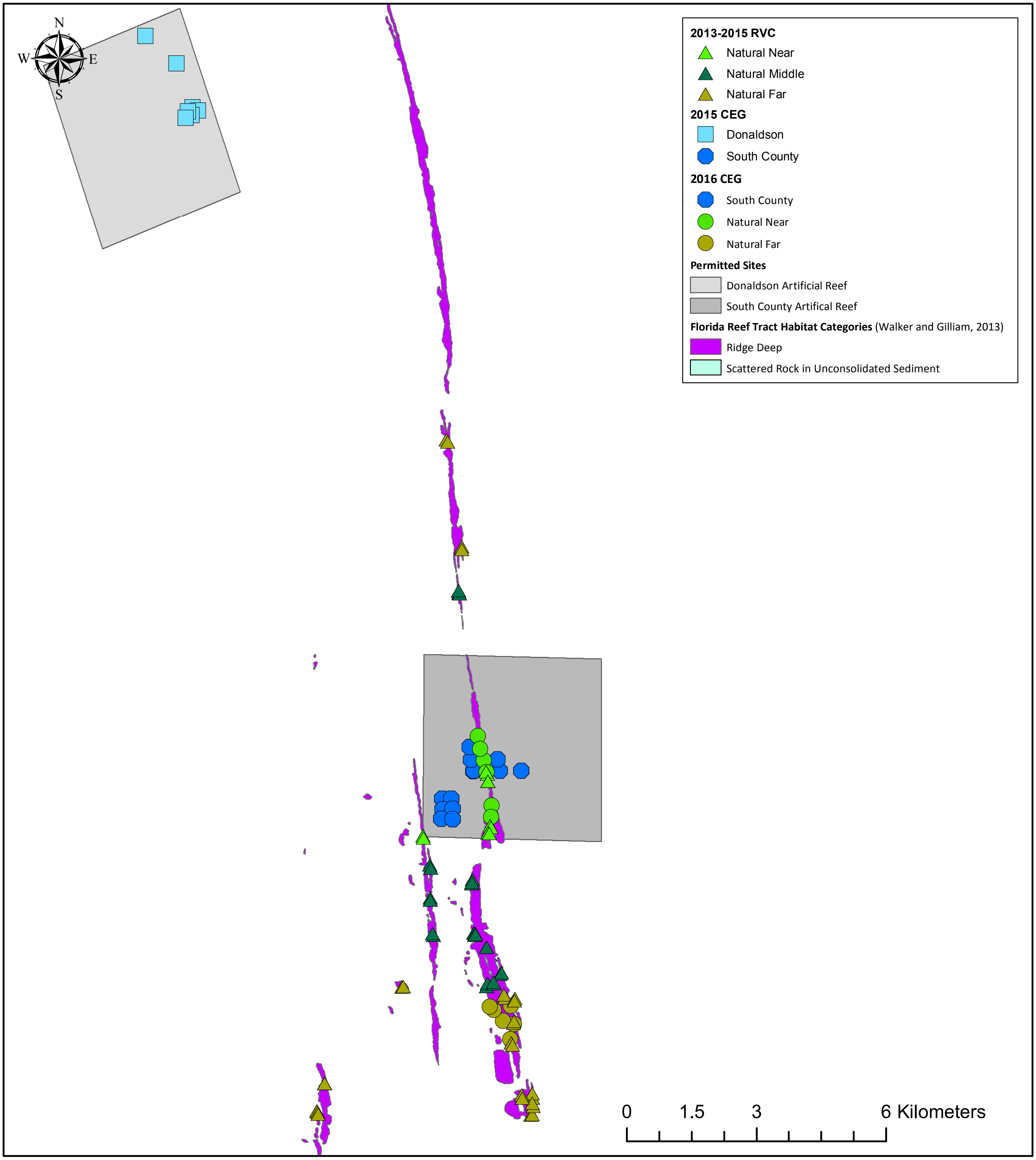


Figure 3

2013-2015 RVC Survey Locations and 2015 and 2016 Martin County Survey Locations in the Current Study



2.0 METHODS

2.1 Survey Locations

Locations of sites surveyed in 2016 are shown in **Figure 2**. Surveys focused on the South County artificial reef sites and natural reefs within the South County artificial reef site and south of the South County artificial reef site.

2.1.1 South County Artificial Reefs

The South County artificial reef site is close to the southern boundary of Martin County and is 4 mi^2 (10 km^2) in area. Water depths range from 55 to 120 ft (17 to 37 m). This site is located approximately 7.5 nmi (14 km) southwest of St. Lucie Inlet and is half way between St. Lucie Inlet and Jupiter Inlet. The South County site was developed as a fisheries enhancement site for Martin County reef fish populations, specifically for demersal reef fish species that are obligate hardbottom larval settlers (Hesperides Group, 2013). According to the MCAR, the goal of the South County site is to recruit larval and juvenile demersal fishes such as grouper and snapper species. Numerous patch reefs are to be deployed in this site with minimum placement distances of 738 ft (225 m) apart; previous studies have shown this distance diminishes competition between demersal reef fish assemblages and maximizes the link between benthic macroinvertebrate production and artificial reef systems (Bohnsack et al., 1994; Frazer and Lindberg, 1994; Lindberg, 1996).

Six artificial reef structures were deployed in the South County site in June 2008 in water depths of 68 to 70 ft (20 to 21 m). The 2008 reefs were the first set of deployments within the permitted site and are located in the southwestern corner of the South County artificial reef site. The primary reef material at these sites consists of concrete culvert pieces, deck sections, and concrete slabs (**Table 1**). Each reef consists of between 240 and 272 tons of material with a maximum relief of 9 ft (2.7 m) and covers approximately 0.4 acres (17,500 ft^2 or 1,600 m^2) of seafloor (Meeker and Dillon, 2010). Each of the six reefs was named in honor of the primary donor. The closest natural hardbottom habitat is a narrow ridge that lies within the artificial site, approximately 1,260 ft (385 m) to the west of the 2008 artificial reefs.

Six artificial reef structures were deployed in July and August 2014 to the east (3 sites) and west (3 sites) of the natural hardbottom ridge that runs through the central portion of the South County permitted site. Water depth at the sites during deployment was measured as approximately 72 ft (22 m); however, divers recorded depths of 91 ft (28 m) on the eastern side of Site 11 in 2016. The primary construction material consists of concrete culverts, slabs, and cylinders (**Table 1**).

Table 1. Summary of South County reefs with date of deployment, tonnage, and materials. Extra footprint notes are available for the Old (2008) deployments.

AGE	Name	Date Deployed	Tonnage (t)	Materials	Exta Notes
OLD	ANN MARIE	6/11/2008	260	170 concrete pipe segments, concrete slabs	0.4 acres; round with an irregular margin
	FOGEL CAPITAL	6/13/2008	245	125 concrete pipe segments, concrete slabs and pilings	0.5 acres; oval with a southeast-to-northeast axis
	THE HEAP	6/20/2008	268	26 demolished concrete bridge deck sections, concrete slabs, hershey kisses (cones), and culverts	0.4 acres; round with an irregular margin
	JACK MACDONALD	6/20/2008	272	44 demolished concrete bridge deck sections, concrete slabs, concrete culverts and pilings	0.5 acres; oval with a southeast-to-northwest axis
	LENTINE	6/13/2008	240	143 concrete pipe segments, concrete slabs, large cubes and pilings	0.4 acres; oval with a southeast-to-northwest axis
	SHIRLEY REEF	6/11/2008	249	148 concrete pipe segments, concrete slabs	0.4 acres; round with an irregular margin
NEW	Site 7	7/31/2014	490	200± concrete culverts, pipes	
	Site 8	8/3/2014	441	50± concrete culvert pieces, 50± Florida Power and Light poles and slabs	
	Site 9	8/14/2014	465	100± concrete culvert pieces	
	Site 10	8/7/2014	424	150± concrete culverts, 40± Florida Power and Light poles and slabs	
	Site 11	7/28/2014	424	100± concrete culvert pieces	
	Site 12	8/12/2014	490	30± concrete culvert pieces, 75± slabs, cylinders	

**Table sourced from Meeker and Dillon (2010) and US Army Corps of Engineers (2010).*

2.1.2 Natural Reef Sites

The natural hardbottom ridge that runs from north to south through the permitted South County artificial reef site is classified as "Natural Ridge – Deep" habitat according to the Florida Fish and Wildlife Conservation Commission (FWC) Unified Reef Tract Map. The natural reef habitat is approximately 600 to 700 ft (183 to 213 m) from the artificial reefs placed in 2014 and 1,250 to 2,300 ft (381 to 701 m) from the artificial reefs placed in 2008. Specifically, the ridge is located 650 ft (200 m) east of Sites 8 and 9, and 590 ft (180 m) west of Sites 10 and 12 (**Figure 2**). The southern (Far) natural sites were chosen at a minimum distance of 4 km from the artificial reef sites. This 4-km boundary was selected as a significant distance from the artificial reefs according to studies on the home ranges of members of the snapper-grouper complex (Beets & Hixon, 1994; Lembo et al., 1999; Kiel 2004; Lindberg et al., 2006).

Natural reef sites were selected to closely resemble the artificial reefs in maximum water depth and structural relief. Target locations were selected on the edge of the Ridge Deep formation from the FWC Unified Reef Tract Map. In the field, the survey crew used a boat fathometer to locate hardbottom relief that resembled the relief at the artificial reef sites.

2.1.3 Comparisons to Prior Studies

In the summer and fall of 2015, the South County artificial reef was sampled at Year 1 post-deployment, and the Donaldson artificial reef was sampled at Year 2 post-deployment; survey methods were similar to the current study. The 2016 Near natural sites NAT 1 and NAT 2 were in the same locations as the two natural sites sampled in 2015 (**Figure 3**). The 2015 data were analyzed with the 2016 data using multivariate analyses to identify potential differences in assemblages.

Data collected during the 2015 and 2016 surveys were also compared to the Southeast Florida Coral Reef Initiative's (SEFCRI) Reef fish Visual Census (RVC) surveys. The RVC project is a joint effort by partner agencies of SEFRCI with the majority of the funding provided by the NOAA Coral Reef Conservation Program. This monitoring program was established to assess reef fish resources of the Northern Florida Reef Tract. Surveys were conducted annually between Government Cut Inlet in Miami-Dade County and Port St. Lucie Inlet in Martin County. The robust dataset provides an opportunity to mine data to examine individual species and assemblage correlations with various abiotic and biotic variables (Kilfoyle et al., 2015). A total of 64 RVC samples were conducted between 2013 and 2015 in similar locations, water depth range, and habitat type to the natural reef sites sampled in the current study. **Figure 3** shows the locations of the RVC samples in relation to the 2015 and 2016 Martin County artificial reef sample locations. The RVC sample site was considered "Near" if the site was within 1 km of the artificial reef sites, "Middle" if it was located between 1 and 4 km from the artificial reef sites, and "Far" if it was between 4 and 8 km from the artificial sites.

2.2 Experimental Design

A stratified sampling design was used in this study to sample the fish and benthic assemblage at 24 locations. Treatment groups were assigned based on the type of reef (artificial or natural) and age or location of the reef (Old/New or Near/Far). The "Old" age class was assigned to artificial deployments from 2008. The "New" age class was assigned to recent artificial deployments from 2014. The "Near" location class was assigned to natural reef sites inside the South County artificial reef permitted site boundary. The "Far" location class was assigned to natural reef sites at least 4 km away from the South County artificial reef boundary. The sampling structure within each treatment group, location of each site, and sample date are shown in **Table 2**. The intended sampling strategy was to conduct 6 fish surveys and sample a minimum of 20 quadrats within each Type-Age/Location treatment group. An overall total of 24 point-count fish surveys were completed, and 88 benthic quadrats (0.5 m^2) were sampled in the 2016 surveys.

The August 2016 surveys (**Table 2**) were conducted during a period of upwelling that resulted in bottom temperatures that were colder than expected. Bottom temperature at NAT 3 was 67°F (19°C), and bottom temperature at NAT 9 was 72°F (22°C). Surface temperatures were as high as 83°F (28°C). The upwelling was not present during the September surveys; mean bottom temperature recorded during September was 82°F (27°C). The July 2015 surveys were also conducted during a period of upwelling that created bottom temperatures that were colder than expected. Bottom temperatures at reached a low of 68°F (20°C) while surface temperatures were 85°F (29°C). The upwelling seemed to decrease in intensity by the time of the August surveys; mean bottom temperature recorded during August was 75°F (24°C). Bottom temperatures during the final survey on November 8 had increased to a mean of 80°F (27°C). Occurrences of upwelling events may affect the species distribution (Pitts, 1999).

Table 2. Sample locations, date sampled, number of samples, and designated Type-Year/Location treatment group.

Type - Year/Location (Treatment)	Fish Survey N	Benthic Quadrat N	Individual Benthic Quadrat N	Site Name	Latitude (DD)	Longitude (DD)	Sample Date
OLD Deployed in 2008	6	23	4	ANN MARIE	27.07761	-80.03832	9/11/2016
			4	FOGEL CAPITAL	27.07954	-80.03829	8/23/2016
			4	THE HEAP	27.08144	-80.04050	9/11/2016
			4	JACK MACDONALD	27.08140	-80.03855	9/12/2016
			4	LENTINE	27.07946	-80.04041	8/23/2016
			3	SHIRLEY REEF	27.07770	-80.04067	8/22/2016
NEW Deployed in 2014	6	23	3	Site 7	27.08654	-80.03393	8/22/2016
			4	Site 8	27.08860	-80.03447	8/23/2016
			4	Site 9	27.09095	-80.03473	9/21/2016
			4	Site 10	27.08654	-80.02845	9/11/2016
			4	Site 11	27.08661	-80.02398	9/11/2016
			4	Site 12	27.08868	-80.02900	9/20/2016
NEAR Inside of permitted boundary	6	20	4	NAT 1	27.08849	-80.03184	8/23/2016
			3	NAT 2	27.09302	-80.03304	9/21/2016
			3	NAT 3	27.09065	-80.03260	8/22/2016
			3	NAT 4	27.08635	-80.03128	9/11/2016
			4	NAT 5	27.08012	-80.03019	9/21/2016
			3	NAT 6	27.07806	-80.03031	9/11/2016
FAR > 4km outside of permitted boundary	6	22	3	NAT 7	27.03969	-80.02551	9/20/2016
			3	NAT 8	27.04306	-80.02617	9/20/2016
			4	NAT 9	27.04024	-80.02784	8/23/2016
			4	NAT 10	27.04232	-80.02973	8/23/2016
			4	NAT 11	27.04290	-80.03062	9/21/2016
			4	NAT 12	27.03689	-80.02627	8/22/2016

**While the divers were dropped at the published artificial reef site locations, the exact Longitude and Latitude stated in this table were recorded at the diver's surface marker and may not represent exact survey locations due to strong currents at the time of the survey.*

2.3 Benthic Quadrat Assessments

2.3.1 Field Methods

Benthic assemblage monitoring was conducted *in-situ* using the Benthic Ecological Assessment for Marginal Reefs (BEAMR) method (Makowski et al., 2009). The BEAMR protocol evaluates physical habitat characteristics, percent cover of benthic functional groups, and stony coral and octocoral density. Visual estimates of planar percent cover are determined for 18 functional groups including sediment, bare hard substrate, macroalgae, turf algae, encrusting red algae, sponge, hydroid, octocoral, stony corals, tunicates, anemone, *Millepora* sp., sessile worm, worm rock, bivalve, bryozoan, zoanthid, and barnacle. Each functional group is assigned a percent cover ranging from 0% to 100%, and total functional group cover must equal 100%. If a functional group is present within a quadrat, it is assigned a minimum value of 1% cover. A 0.5 m^2 (0.7 m x 0.7 m) gridded quadrat was used for the survey, and a minimum of 10 m^2 were sampled at each Type-Age/Location treatment group. Quadrats were haphazardly distributed on at least three locations on hardbottom or surfaces of artificial structures at sites such that no location was sampled twice.

Under standard BEAMR protocol, maximum relief and maximum sediment depth measurements (to the nearest centimeter) are recorded within each quadrat. On the artificial reefs, sediment depth was generally zero, and vertical relief from the bottom (position of the quadrat to the sand) was recorded. All quadrats were assessed on horizontal or sub-vertical faces with upward exposure to sample a consistent habitat. The underside of ledges and other cryptic habitats were not assessed.

Common macroalgae were identified to genus level if present at 1% cover or greater within an individual quadrat, and assigned an individual percent cover. Octocorals and stony corals within quadrats were measured for a maximum height or diameter to the nearest centimeter. Octocorals were identified to genus level, and stony corals were identified to species level. Stony corals measuring less than 1 cm in diameter were recorded as 1 cm.

2.3.2 Data Analysis

Comparisons of percent cover of each benthic functional group between the four Type/Location treatments were first tested for normality using Shapiro-Wilk tests. Group variances were then tested using a Brown-Forsythe test. Normally distributed functional groups were compared using a univariate analysis of variance (ANOVA) with post-hoc Tukey HSD tests. For non-normal functional groups, appropriate transformations were attempted based on the shape of the data curve, but transformations could not normalize the groups. Therefore, analysis was conducted with the non-parametric Kruskal-Wallis ANOVA followed by post-hoc Multiple Comparison of Mean Ranks (MCMR). The MCMR test includes a built-in p-value adjustment for multiple comparisons. Statistical analysis was not conducted on rare functional groups as the dataset consisted primarily of zero values.

2.4 Fish Surveys

2.4.1 Field Methods

Fish survey methods were based on the stationary point count method outlined in Bohnsack and Bannerot (1986) and Brandt et al. (2009). Modifications to these methods were conducted to account for complexity of artificial reef habitat and lower visibility on some field days. The method and modifications are summarized here.

Traditionally, the Reef fish Visual Census (RVC) methodology requires two scientific divers to conduct concurrent surveys in adjacent 15-m cylinders (Brandt et al., 2009). The two surveys are then averaged to account for surveyor variability. Due to logistics of the present study, only one surveyor performed a fish count at each site. In order to assure statistical similarity between the two scientific divers conducting the fish surveys, both divers collected data concurrently at four sites. A paired t-test for density means was performed in Statistica® 12 (StatSoft Inc., 2013); no statistically significant differences were detected between the two fish surveyors. PRIMER-e statistical software was also used to examine differences in species richness between the two surveyors; no statistically significant differences in richness were found. Once the data were determined to be statistically similar, one of the two surveys from each of the four sites was randomly selected for analysis using the "=RAND" function in Microsoft Excel.

During the fish surveys, an imaginary cylinder extending from the seafloor to the vertical limit of visibility with a diameter of 15-m was assessed by the diver. The method calls for decreasing the size of the imaginary cylinder to 3 m if horizontal visibility is between 7.5 m and 3 m, but throughout the course of this study, visibility remained above 7.5 m. In the standard Bohnsack-Bannerot (1986) method, the survey is conducted from a stationary position in the center of the cylinder. In this study, the method was modified so that the surveyor did not remain entirely stationary during the survey. The surveyor recorded the start time of the sample on the datasheet, then proceeded to record all species observed within the first five minutes while rotating at their fixed position. Due to the complex nature of the habitat, divers were allowed to move slowly around the cylinder in order to view obstructed areas of the cylinder, but extensive searching of cavities or overhangs was not done during this period.

After five minutes had elapsed, abundance of each species was recorded along with the mean, minimum, and maximum fork lengths ("Avg", "Min" and "Max"). For all groupers, snappers and hogfish, every fish observed up to a maximum of ten fish were individually sized; if more than ten individuals of any of these species were present, the sizes of these species were recorded with estimated mean, minimum and maximum lengths. Concurrent with the species enumeration and length estimation, new species that were observed after the initial five-minute observation period and until completion of all data collection were also recorded, along with estimates of their abundance and minimum, mean, and maximum lengths. These species are noted as having been observed "Between 5 and 10 minutes" or "After 10 minutes", depending on the time elapsed at time of observation. During the survey, the final five minutes were used to search for new cryptic species located under overhangs or within cavities in the reef structure. Additionally, the benthic surveyors recorded all fish species present in the vicinity of the quadrat assessments. For consistency, each fish survey lasted a minimum of fifteen minutes. Divers were equipped with 1 m measuring sticks fitted with a 40-cm cross piece at one end, demarcated in 10-cm increments, to aid in both distance and fish size estimations. Environmental and habitat data were also recorded, including depth, water temperature, maximum relief, and substrate slope.

2.4.2 Data Analysis

Data analyses were performed at the species level with a few exceptions. To avoid confounding the presence/absence data for species richness calculations, juvenile Grunts (*Haemulon* spp.) were not considered a separate species if adult *Haemulon* spp. were recorded at the same site. Species lists were carefully reviewed by the surveyors to provide quality control for differences in identification between surveyors. As a result, abundances of several species were combined under a genus designation to account for possible surveyor differences and uncertainty in identification of highly similar species. The Mackerel and Round Scad (*Decapterus macarellus* and *D. punctatus*) were combined into *Decapterus* spp. The Saucereye, Whitebone, Littlehead and Sheepshead Porgy (*Calamus calamus, C. leucosteus, C. proridens* and *C. penna*) were combined into *Calamus* spp. The invasive Red and Devil Lionfish (*Pterois volitans/miles* complex) were combined into *Pterois* spp. The Whitefin Sharksucker and Sharksucker (*Echeneis neucratoides* and *E. naucrates*) were combined into *Echeneis* spp. The surveyors believe that no other species within the above genera were observed; however, the surveyors could not guarantee accuracy to the species level within these genera, especially under turbid conditions. Each of these genera is considered only once in species richness calculations.

The Shannon Diversity index provides a measure of assemblage diversity, accounting for number of species and abundance of each species; this index was calculated in PRIMER-e v6 (Clarke & Warwick 2001, Clarke & Gorley 2006). Species are included in the commercially important analyses if they are listed as a managed species under the Snapper Grouper Management Complex by the South Atlantic Fishery Management Council (South Atlantic Fishery Management Council, 2017).

All statistical analyses were performed using Statistica® 12 (StatSoft Inc., 2013). Fish abundance data from each Type/Location treatment were first tested for normality using a Shapiro-Wilk test. Data were right-skewed and were transformed using a logarithmic transformation. Group variances were then tested using a Brown-Forsythe's test; all comparisons met this assumption. Comparisons of fish abundance at the four Type/Location treatments were conducted using a one-way ANOVA and post-hoc Tukey HSD test. Comparisons between two treatments were conducted using a *t*-test (i.e. artificial vs. natural). Species richness was normally distributed and was compared using one-way ANOVA (for more than two factor levels) or *t*-tests (for two factor levels). Significant results are reported at alpha < 0.05, and all abundance values are reported as mean ± standard error (SE) unless otherwise stated.

The feeding guild of each species was determined based on the majority diet of the adult size class of each species from information available in published articles and on Fishbase (Froese and Pauly, 2016). "Invertivores" were defined as those that fed primarily on benthic and planktonic invertebrates and eggs, e.g. grunts and butterflyfish. For example, Fishbase states that Tomtate (*Haemulon aurolineatum*) "feeds on small crustaceans, mollusks, other benthic invertebrates, plankton and algae" (Froese and Pauly, 2016) so *H. aurolineatum* was considered primarily an invertivore. "Piscivore" was defined as a species that preys primarily on finfish such as snappers and groupers. "Herbivore" was defined as those that prey primarily on benthic algae such as damselfish and parrotfish.

For the multivariate analyses, abundance of each species was first transformed using log(x+1) to reduce the influence of common species. Transformed abundance values were then converted into resemblance matrices using Bray-Curtis similarity with a dummy variable of 1 and visually examined as non-metric multi-dimensional scaling (nMDS) plots using PRIMER-e (Clarke & Warwick 2001, Clarke & Gorley 2006). The similarity profile (SIMPROF) procedure was used to determine if there was significant structure within the data potentially caused by factors other than the pre-determined treatment groups. The contribution of individual species to the separation of clusters established using SIMPROF was determined using the similarity percentages (SIMPER) routine. This routine indicates which species were principally responsible for the groupings. The categorical variable of reef age/location (New, Old, Near, Far) was examined using analysis of similarities (ANOSIM).

3.0 RESULTS

3.1 Structural Summary

3.1.1 Artificial Reefs

The minimum and maximum recorded depths at each South County site along with maximum structural relief during the 2015 and 2016 surveys are shown in **Table 3**. The Old artificial reefs had noticeably less structural relief (average of 6.8 ft ± 0.8) than the New artificial reefs which averaged 11.2 ft ± 1.3 at the center of the piles. A general eastward trend of increasing depth is present with the westernmost Old artificial reefs ranging between 72 and 76 feet. The easternmost New artificial reef, Site 11, missed its intended deployment location and settled in a maximum depth of 91 ft. All artificial reefs contain numerous crevices, caves and other areas for sheltering, and the large diameter culverts often harbored large Goliath Grouper (*Epinephelus itajara)*.

There are substantial differences between several of the artificial reef depths at the time of deployment compared to depths recorded during the 2015 and 2016 diver surveys. During deployment, a fathometer was used from the boat on the surface of the water to measure water depth. During the 2015 and 2016 surveys, divers placed the depth gages of their dive computer on the seafloor to assess the maximum water depth at the time of the survey. Variability in annual maximum relief is possibly due to shifting sediments or changes in the location on the artificial reef at which the minimum and maximum depths were recorded.

A selection of structural images from the Old (2008) and New (2014) artificial reef deployments is shown in **Photos 1a** through **1d** and **Photos 2a** through **2d,** respectively. Photos of each Old artificial reef are provided in **Appendix B,** and photos of each New artificial reef are in **Appendix C**.

Table 3. Minimum and maximum depth of reef (ft) recorded by diver's depth gage at the South County artificial sites in 2016 and 2015, and minimum and maximum depths recorded from the boat at time of reef deployment.

AGE	Name	2016			2015			Deploy		
		Min Depth	Max Depth	Max Relief	Min Depth	Max Depth	Max Relief	Min Depth	Max Depth	Max Relief
OLD	ANN MARIE	69	73	4	67	74	7	63	68	5
	FOGEL CAPITAL	71	76	5	66	75	9	60	67	7
	THE HEAP	67	72	5	67	74	7	63	68	5
	JACK MACDONALD	65	74	9	65	74	9	63	70	7
	LENTINE	69	73	4	68	73	5	62	68	6
	SHIRLEY REEF	67	75	8	68	74	6	61	66	5
NEW	Site 7	60	76	16	61	72	11	55	72	17
	Site 8	61	74	13	58	71	13	-	-	-
	Site 9	66	75	9	61	72	11	-	-	-
	Site 10	67	79	12	65	74	9	-	-	-
	Site 11	80	91	11	81	88	7	-	-	-
	Site 12	73	79	6	66	76	19	-	-	-

Photos 1a-d. Photographs of the overall structure of the Old (2008) artificial reefs. a) Ann Marie taken September 11, 2016. b) Fogel Capital taken August 23, 2016. c) The Heap taken September 11, 2016. d) Shirley Reef taken August 22, 2016.

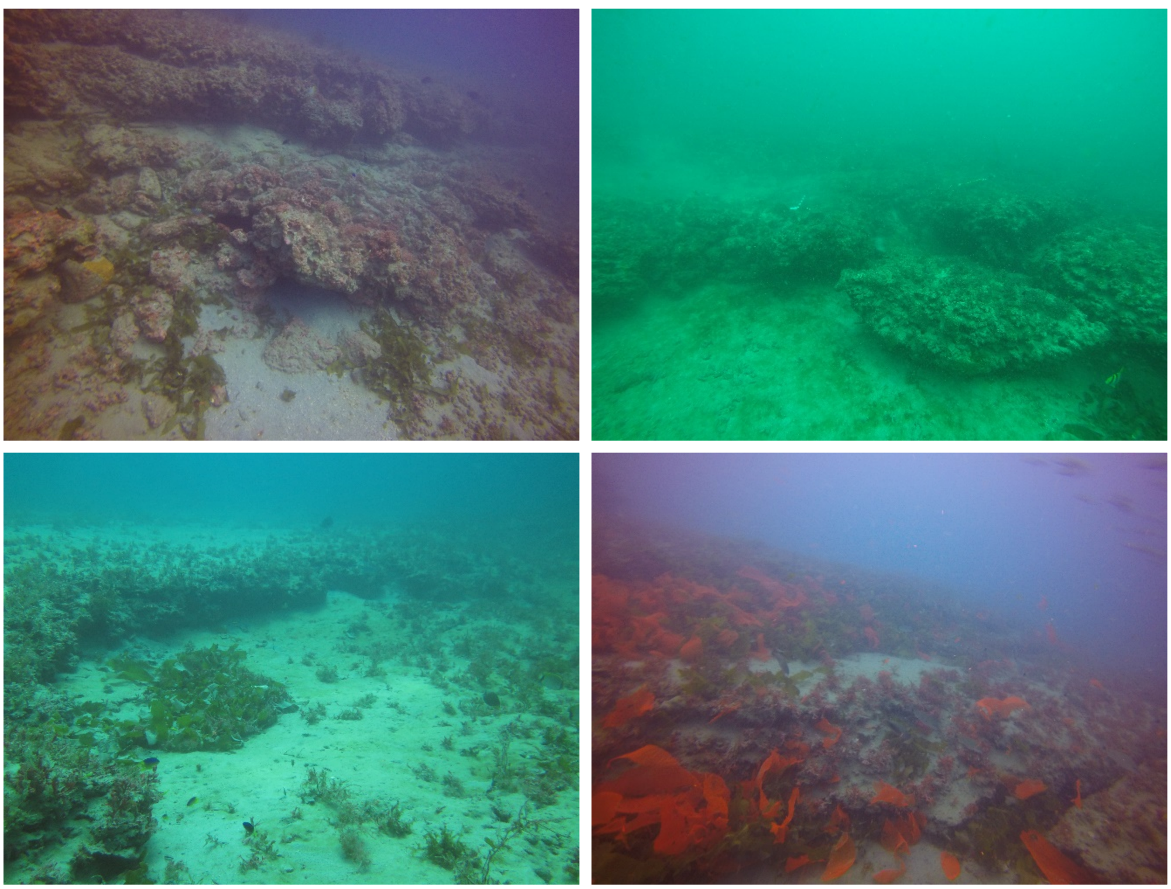
Photos 2a-d. Photographs of the overall structure of the New (2014) artificial reefs. a) Site 7 taken August 22, 2016. b) Site 8 taken August 23, 2016. c) Site 9 taken September 21, 2016. d) Site 10 taken September 11, 2016. d) Site 11 taken September 11, 2016.

3.1.2 Natural Reefs

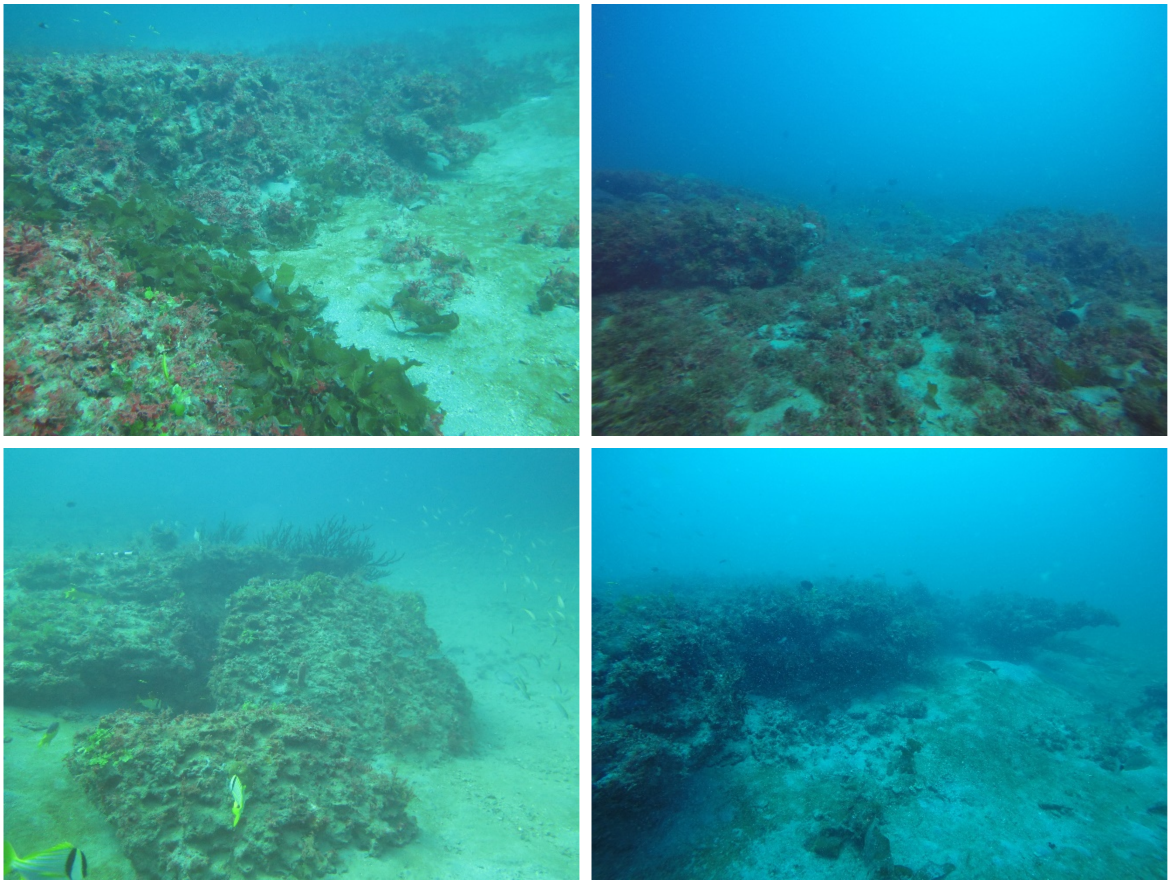
The minimum and maximum recorded depth at each natural reef site along with maximum relief are shown in **Table 4**. Average depth at the Far natural reefs was deeper (79.3 ft ± 1.6), and the Far natural reefs had relatively less relief (3.8 ft ± 0.5) compared to the Near natural reefs, which averaged 77.5 ft ± 0.5 in depth and had a mean relief of 5.7 ft ± 1.2. While high-relief reefs were targeted to create more analogous comparisons based on relief, the natural reefs are lower in vertical relief than the artificial reefs (average relief of 4.8 ft and 8.5 ft, respectively). Maximum water depths were similar between the natural reef and artificial reef sites. A selection of structural images from the Near natural reef sites are shown in **Photos 3a** through **3d,** and the Far natural reef sites are shown in **Photos 4a** through **4d**. **Appendix D** provides photographs from each Near natural reef site, and **Appendix E** contains photographs from each Far natural reef site.

Table 4. Minimum depth, maximum depth, and maximum relief (ft) recorded at the natural sites in 2016.

Location	Name	Min Depth	Max Depth	Max Relief
NEAR	NAT 1	68	78	10
	NAT 2	70	77	7
	NAT 3	74	77	3
	NAT 4	72	80	8
	NAT 5	74	76	2
	NAT 6	73	77	4
FAR	NAT 7	80	84	4
	NAT 8	80	83	3
	NAT 9	75	81	6
	NAT 10	74	76	2
	NAT 11	69	73	4
	NAT 12	75	79	4



Photos 3a-d. Photographs of the overall structure of the Near natural reef sites. a) NAT 2 taken September 21, 2016. b) NAT 3 taken August 22, 2016. c) NAT 5 taken September 21, 2016. d) NAT 6 taken September 11, 2016.



Photos 4a-d. Photographs of the overall structure of the Far natural reef sites. a) NAT 8 taken September 20, 2016. b) NAT 9 taken August 23, 2016. c) NAT 11 taken September 21, 2016. d) NAT 12 taken August 22, 2016.

3.2 Benthic Assemblage

3.2.1 South County Artificial and Natural Reefs

The benthic assemblage at the artificial and natural sites was dominated by macroalgae (33% and 27%, respectively) and turf algae (53 and 48%, respectively). The most abundant benthic invertebrates were sponges, hydroids, bryozoans, and tunicates (**Figure 4**). The dominant macroalgae at the Old and New artificial sites and the Near and Far natural reef sites are shown in **Table 5**. *Botryocladia, Bryothamion, Caulerpa, Codium, Dictyopteris, Dictyota, Galaxaura, Gracilaria, Halimeda* and *Lobophora* spp. were present at all treatments. The most common genera at all sites was *Gracilaria* sp.; this species was highest in abundance at the Old artificial reef sites (**Photo 5**, left). The New artificial reefs had high cover of *Bryothamnion*, *Galaxaura,* and *Sargassum* spp. (**Photo 5**, right). The natural reef sites contained high cover of *Dictyota* sp. The Near natural sites also contained high cover of *Amphiroa* sp. while Far natural reefs had higher percent cover of *Agardhiella* sp.

Significant differences in the cover of sediment, encrusting red algae, sponges, hydroids, and stony corals were found between treatment groups. Sediment cover was significantly lower on the New artificial sites than on all other treatment groups (**Table 6**); this is likely due to the higher level of structural complexity and vertical surfaces at the New artificial reefs. There was no difference in sediment cover between the Old artificial reefs and natural hardbottom sites. The Old artificial reefs contain numerous flat, horizontal concrete surfaces which have resulted in sediment accumulation on the reef structure.

Cover of encrusting red algae, sponges, and stony corals was significantly higher at the natural sites than at both the New and Old artificial reefs (**Photo 6**, **Table 6**). Encrusting red algae (crustose coralline algae) made up 2.8 ± 0.3% of the benthic community at the natural sites, and was as high as 8% in some individual quadrats (**Photo 7**). Overall cover of encrusting red algae at the artificial reef sites was 0.8 ± 0.2%. Although small sponges were common on the artificial reef sites, larger sponges such as the vase sponge *Ircinia campana* were frequently found at the natural reef sites (**Photo 6**, right). Stony coral cover was 1.0 ± 0.2% at the Near natural sites and 1.2 ± 0.2% at the Far natural sites, compared to 0.1 ± 0.1% at the Old artificial reefs and 0.04 ± 0.04% at the New artificial reefs.

Counts and size of each octocoral and stony coral colony at each treatment type are shown in **Table 7**. Stony corals, although small in size, were relatively common at the natural reef sites, *Siderastrea* sp. was numerically dominant. A total of 61 stony corals were recorded in quadrats at the natural sites; 42 (69%) of these were located at the natural sites located further away from the artificial reefs. The Far natural sites also had a higher diversity of coral species with 5 species compared to only 2 species (*Siderastrea radians* and *Siderastrea siderea*) at the Near natural sites. Three stony coral recruits were documented on the artificial reefs; a single *Siderastrea* sp. recruit was observed at the New deployment Site 10 and at the Old deployment Fogel Capital. A single *Oculina diffusa* recruit was observed on the old deployment Jack MacDonald. Octocorals were uncommon in the survey area. A single *Pterogorgia* sp. was recorded at Site 10 (New artificial) and at a single natural site close to the artificial reefs (NAT 6).

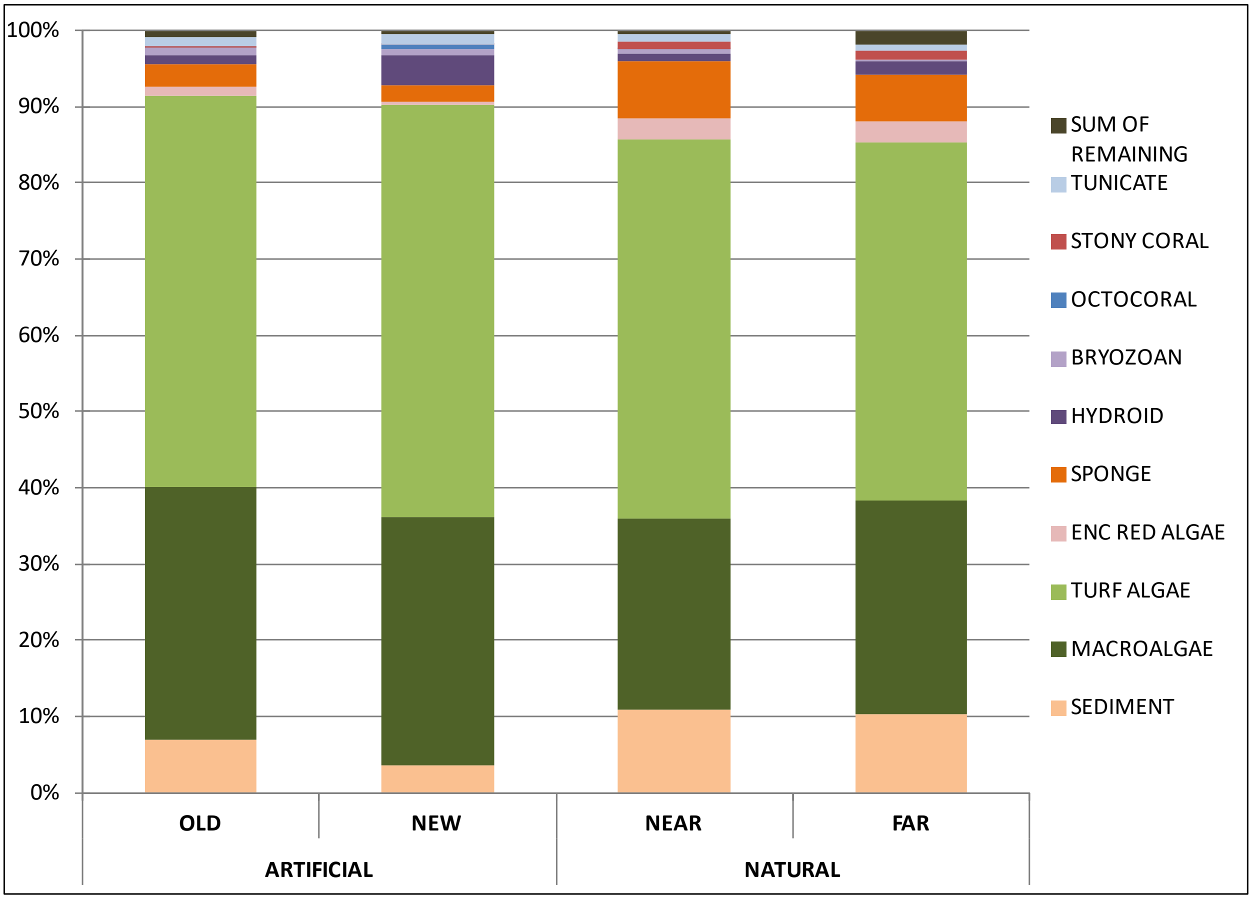


Figure 4. Percent cover of each benthic functional group at each treatment group (Old, New, Near and Far).

Table 5. Percent cover of each common macroalgae genus (only genera occurring at ≥ 1% cover in a single quadrat). Values with no standard error value (SE) were only found in a single quadrat.

Macroalgae Cover (Mean ± SE)				
Genus	**OLD**	**NEW**	**NEAR**	**FAR**
Agardhiella	2.3 ± 0.7	-	-	8.0
Amphiroa	1.7 ± 0.3	-	4.0	-
Botryocladia	2.3 ± 0.4	2.3 ± 0.5	2.4 ± 0.6	3.1 ± 0.4
Bryothamnion	2.3 ± 0.5	10.0 ± 3.1	2.0	3.0
Caulerpa	1.0 ± 0.0	6.0 ± 1.5	2.7 ± 1.1	3.0 ± 0.7
Ceramium	-	1.0	-	-
Champia	-	-	-	1.0 ± 0.0
Codium	1.0 ± 0.0	2.5 ± 0.6	3.0 ± 0.7	1.7 ± 0.2
Dasya	-	2.0	3.0	3.0 ± 1.0
Dictyopteris	2.9 ± 0.6	4.7 ± 0.8	3.3 ± 1.5	2.0 ± 0.5
Dictyota	3.3 ± 0.6	3.6 ± 1.2	5.2 ± 0.8	7.3 ± 1.1
Galaxaura	1.0 ± 0.0	7.8 ± 4.6	2.5 ± 0.5	4.0
Gelidiella	-	1.0	-	-
Gelidium	-	-	2.0	-
Gracilaria	15.4 ± 2.6	12.8 ± 2.2	10.4 ± 1.4	9.3 ± 1.3
Halimeda	3.0	1.6 ± 0.2	1.3 ± 0.3	2.5 ± 0.5
Halymenia	5.0	-	-	-
Hypnea	1.6 ± 0.2	1.7 ± 0.3	2.1 ± 0.3	3.7 ± 0.9
Jania	1.0 ± 0.0	3.2 ± 0.8	1.5 ± 0.3	2.4 ± 0.5
Lobophora	2.0	5.5 ± 1.9	1.5 ± 0.5	2.0
Polysiphonia	1.0	-	-	-
Rhodymenia	-	-	-	1.7 ± 0.7
Sargassum	7.3 ± 2.2	9.8 ± 1.8	2.6 ± 0.8	-
Solieria	-	-	-	1.0
Valonia	-	1.0	-	-
Wrangelia	-	1.5 ± 0.5	1.8 ± 0.5	1.5 ± 0.2

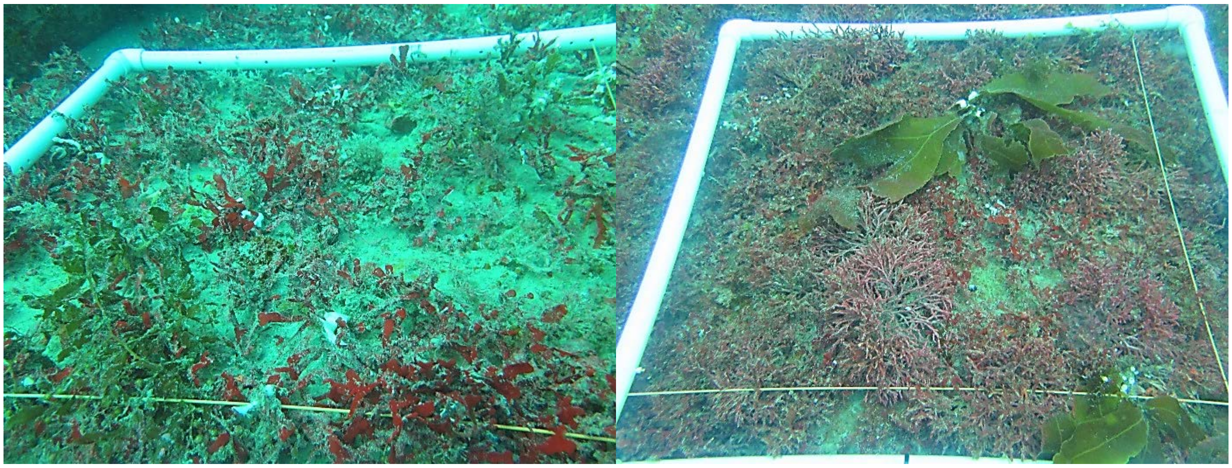


Photo 5. High cover of *Gracilaria* sp. at the Old artificial Ann Marie reef (left, taken September 11, 2016) and high cover of *Galaxaura* sp. at the New artificial reef Site 8 (right, taken August 23, 2016).

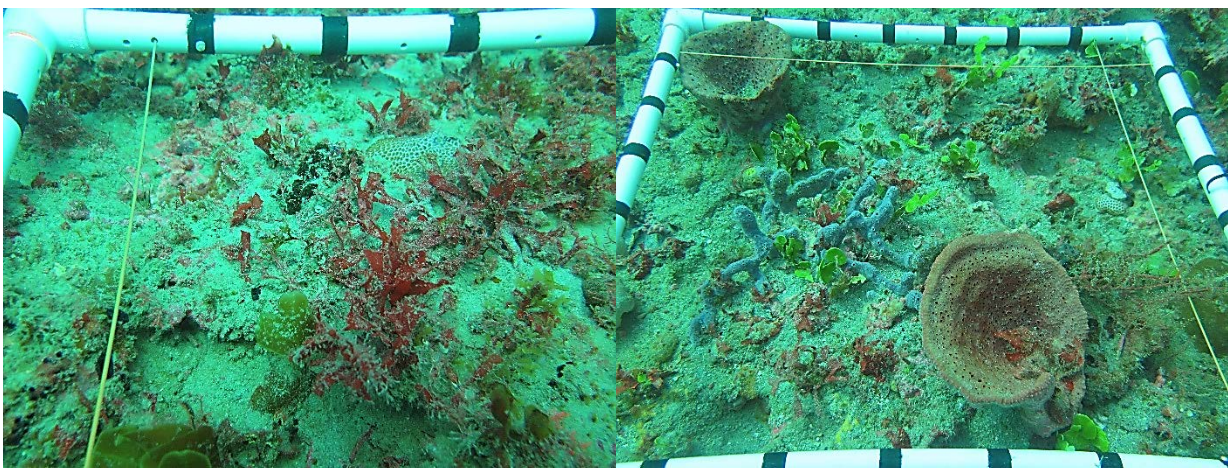


Photo 6. *Siderastrea siderea* with *Gracilaria* sp. at the Near natural site NAT 2 (left, taken September 21, 2016), large sponges with high cover of *Halimeda* sp. at the Far natural site NAT 11 (right, taken September 21, 2016).

Table 6. Results of statistical comparisons of percent cover of major functional groups among the four treatment types. Significant results indicated in red font. Natural Near N=20, Natural Far, N=22, Artificial Old, N=23, Artificial New N=23.

Functional Group	Test	Statistic	Overall p	Post-Hoc			
Sediment	Kruskal-Wallis	H=22.9	<0.001	***MCMR***	Natural_NEAR	Natural_FAR	Artificial_OLD
				Natural_FAR	1.000	-	-
				Artificial_OLD	0.918	0.575	-
				Artificial_NEW	0.001	<0.001	0.089
Macroalgae	ANOVA	F=1.8	0.163	-	-	-	-
Turf Algae	ANOVA	F=0.8	0.506	-	-	-	-
Enc Red Algae	ANOVA	F=9.4	<0.001	***Tukey HSD***	Natural_NEAR	Natural_FAR	Artificial_OLD
				Natural_FAR	1.000	-	-
				Artificial_OLD	0.021	0.020	-
				Artificial_NEW	<0.001	<0.001	0.533
Sponge	Kruskal-Wallis	H=38.2	<0.001	***MCMR***	Natural_NEAR	Natural_FAR	Artificial_OLD
				Natural_FAR	1.000	-	-
				Artificial_OLD	0.002	0.023	-
				Artificial_NEW	<0.001	<0.001	0.394
Hydroid	Kruskal-Wallis	H=10.9	0.012	***MCMR***	Natural_NEAR	Natural_FAR	Artificial_OLD
				Natural_FAR	1.000	-	-
				Artificial_OLD	1.000	1.000	-
				Artificial_NEW	0.242	0.017	0.158
Octocoral	Kruskal-Wallis	H=1.0	0.793	-	-	-	-
Stony Coral	Kruskal-Wallis	H=39.8	0.012	***MCMR***	Natural_NEAR	Natural_FAR	Artificial_OLD
				Natural_FAR	1.000	-	-
				Artificial_OLD	0.007	<0.001	-
				Artificial_NEW	0.003	<0.001	1.000
Tunicate	Kruskal-Wallis	H=3.1	0.371	-	-	-	-

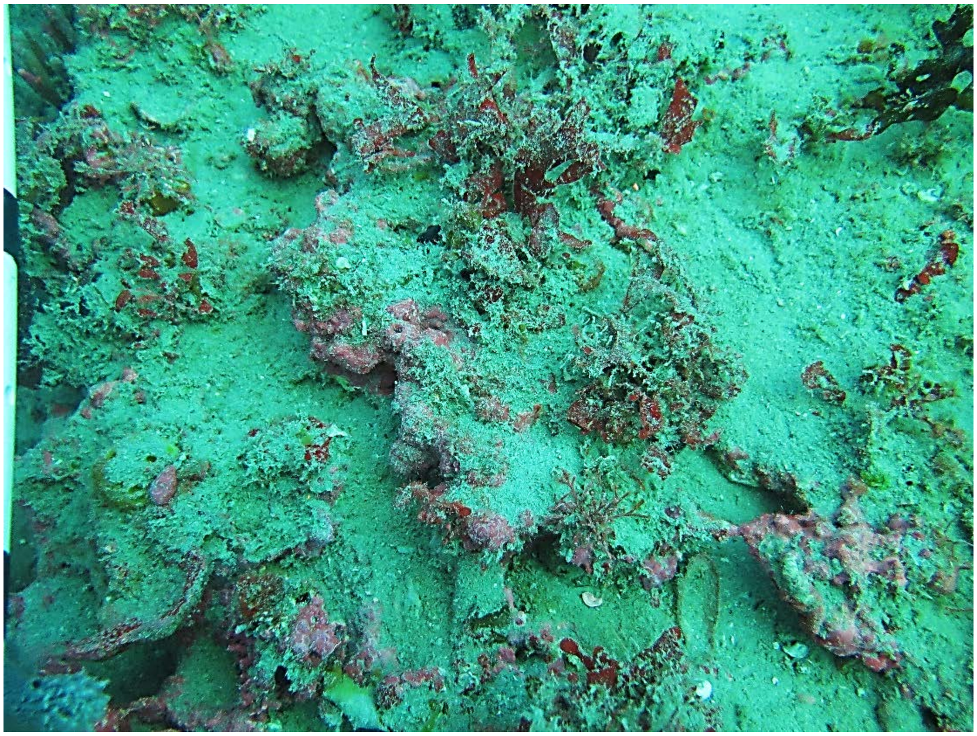


Photo 7. High cover of encrusting red algae at site NAT 4 (taken September 11, 2016).

Table 7. Counts and size (mean ± SE) of octocoral and stony coral colonies at each of the four treatment types.

	ARTIFICIAL-OLD		**ARTIFICIAL-NEW**		**NATURAL-NEAR**		**NATURAL-FAR**	
	Count	Size (Mean ± SE)	Count	Size (Mean ± SE)	Count	Size (Mean ± SE)	Count	Size (Mean ± SE)
Octocorals								
Carijoa sp.	-	-	3	10.0	-	-	-	-
Pterogorgia sp.	-	-	1	6.0	1	15.0	-	-
Stony Corals								
Agaricia agaricites	-	-	-	-	-	-	1	8.0
Oculina diffusa	1	2.0	-	-	-	-	3	8.7 ± 4.7
Porites astreoides	-	-	-	-	-	-	1	5.0
Siderastrea cf. *siderea*	1	1.0	1	1.0	6	3.0 ± 0.4	23	2.0 ± 0.2
Siderastrea radians	-	-	-	-	6	7.5 ± 1.2	3	3.3 ± 0.9
Siderastrea siderea	-	-	-	-	7	6.1 ± 0.8	11	10.6 ± 4.0

3.2.2 Comparison with 2015 Survey Data

Benthic community data from the 2015 surveys of the Donaldson and South County artificial reef areas were compared to data from the 2016 South County artificial reefs. The benthic community on all artificial reef structures is dominated by turf algae and macroalgae. There was no significant difference in macroalgae or turf algae cover between any of the Location/Age treatment groups shown in **Figure 5** (ANOVA, p>0.05 for both). The sum of the means for all faunal functional groups ranged from a high of 22.2% on the Old South County artificial reefs (2008 deployment, 7 years post-deployment) during the 2015 surveys to a low of 5.5% on the New South County artificial reefs (2014 deployment, 1-year post-deployment) during the 2015 surveys. Although it could be expected that overall faunal cover would increase with artificial reef age due to continued development of the biological community, the 2016 surveys on the Old artificial reefs in the South County site showed a total faunal cover of only 7.3% (compared to 22.2% the previous year which was attributed mostly to sponges, bryozoans, hydroids and tunicates).

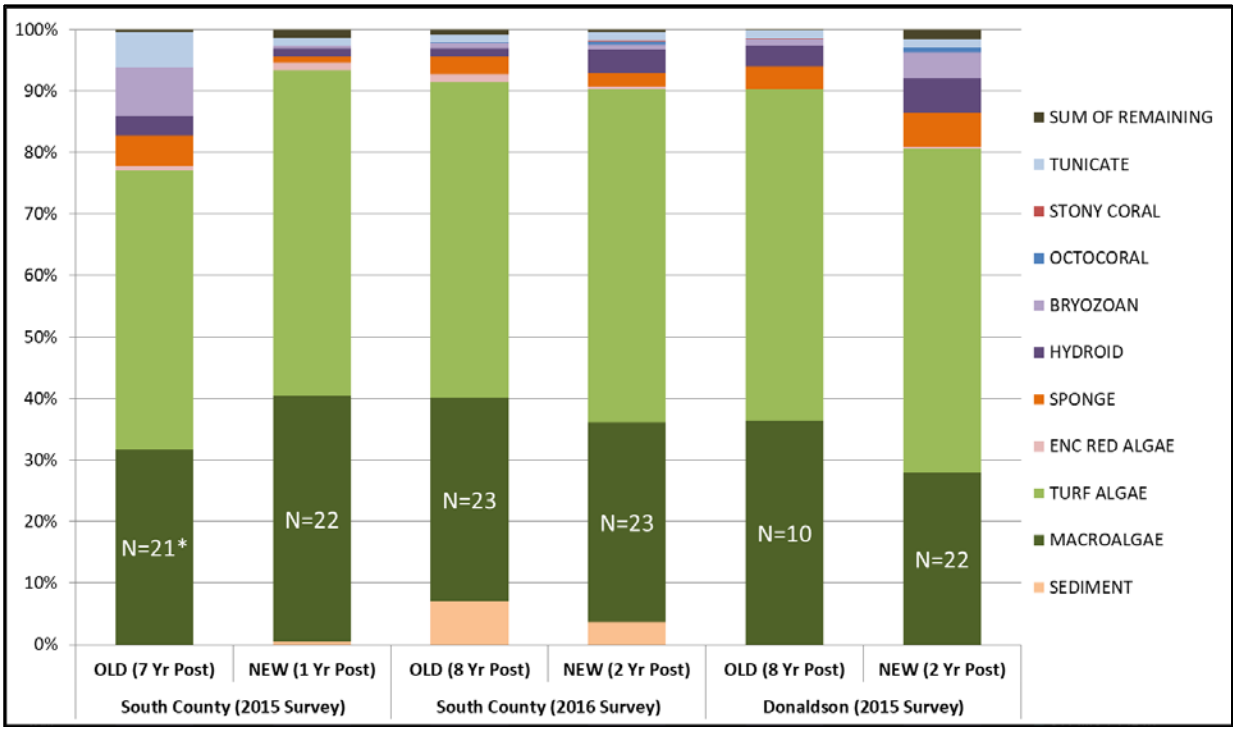


Figure 5. Percent cover of each benthic functional group at all artificial reef locations surveyed in 2015 and 2016 (Donaldson and South County, New and Old).

** Old South County reef deployments were surveyed in November 2015, which is outside of the seasonal sampling range of the 2016 surveys.*

Comparisons of benthic fauna cover were conducted between survey years (2015 and 2016) at South County Old (2008) and New (2014) artificial reefs to evaluate annual differences in the benthic community possibly related to reef age. On the Old South County deployments, there were significant decreases in the cover of hydroids (t-test, p=0.011), tunicates (t-test, p<0.001), and bryozoans (t-test, p<0.001) between 2015 and 2016. During the 2015 surveys, numerous colonies of feather hydroids (*Pennaria* sp.), *Amathia* sp. bryozoans, and white colonial encrusting tunicates (possibly *Didemnum* sp.) were observed. These species remained present, but were found in lower abundance in 2016. There was also a significant increase in sediment cover from 2015, when no sediment accumulation was observed, to a mean cover of 7.0 ± 2.0% in 2016 (*t*-test, p=0.002).

On the New South County deployments, there were no significant differences in cover of any benthic functional group between 2015 (Year 1 post-deployment) and 2016 (Year 2 post-deployment), except for encrusting red algae, which decreased significantly in cover from 1.2 ± 0.3% in 2015 to 0.4 ± 0.3% cover in 2016 (Mann-Whitney U, p<0.001).

Cover of benthic fauna groups was also compared between reefs of similar ages in the South County and Donaldson reef sites. These comparisons consisted of data from the New South County reefs at 2 years post-deployment (2016) and New Donaldson reefs at 2 years post-deployment (2015). Data from the PCL Shallow reef (Old Donaldson deployment) are included in **Figure 5**, but were not compared statistically to the Old South County artificial reef due to differences in sample size.

The only significant differences in the benthic community between the Donaldson and South County New artificial reefs at 2 years post-deployment were significantly higher cover of sponges (MWU, p<0.001) and hydroids (MWU, p<0.001) on the New Donaldson reefs (2013 deployment, surveyed in 2015) than on the New South County reefs (2014 deployment, surveyed in 2016). Sponge cover on the New Donaldson reefs in 2015 was 6.0 ± 0.9% versus 2.1 ± 1.0% on the New South County artificial reefs in 2016. Hydroid cover was 8.1 ± 1.8% on the New Donaldson deployments in 2015 and 4.0 ± 1.2% on the New South County deployments in 2016.

3.3 Nekton Assemblage

3.3.1 Artificial Reefs

Seventy-seven (77) fish species from 22 families were observed in 12 fish surveys on the South County artificial reefs. Mean abundance of each fish species observed on the Old (2008) and New (2014) artificial reefs is shown in **Table 8.** There were no significant differences in fish abundance (# of fish per survey) between the Old and New artificial reefs (*t*-test, p=0.321). Although it was not a significant difference, mean abundance at the Old artificial reefs was still nearly half of the abundance at the New deployments (1,721.0 ± 1,012.0 versus 3,194.0 ± 1,812.5 individuals per survey, **Figure 6**). The lack of significant difference is due to the high abundance of Scad Spp. (*Decapterus* spp.) and Tomtate (*Haemulon aurolineatum*) at only a few sites, with other sites having much lower abundance, causing a high level of variability between sites in each age treatment.

Decapterus spp. accounted for more than half of the abundance at both the Old and New artificial reef deployments (76.5% and 56.7% of the abundance respectively). *Decapterus* spp. are schooling bait fish that are highly associated with Goliath Groupers (*Epinephelus itajara*). Schools of *Decapterus* spp. are difficult to estimate in exact numbers, thus tend to inflate abundance estimations. When abundances are considered without the overwhelming number of *Decapterus* spp., differences in abundance between Old and New deployments are still not significantly different (*t*-test, p=0.382), though the difference is less than with *Decapterus* spp. included (404.3 ± 58.0 and 1,110.7 ± 610.6 respectively,

Figure 6). The abundance of individual fish species at each artificial survey location is provided in **Appendix A1**. Other than *Decapterus* spp., the most abundant fish species at the South County artificial reef sites were *H. aurolineatum* and Bluehead wrasse (*Thalassoma bifasciatum*).

Species richness and Shannon diversity index at each survey site are shown in **Table 9**. The New artificial reefs contained three more species overall than the Old artificial reefs (63 and 60, respectively). The natural hardbottom deep ridge that runs through the New artificial reef deployments could lead to higher abundance and overall species richness on the New artificial reefs (**Figure 2**). Thirteen species were exclusive to the Old artificial reefs, and 17 species were exclusive to the New artificial reefs. Of species exclusive to the New artificial reefs, two species, Brown Chromis (*Chromis multilineata*) and Dusky Damselfish (*Stegastes adustsus*) were also exclusive to the Near natural reef sites. Three other species, Ocean Surgeon (*Acanthurus bahianus*), Bar Jack (*Caranx ruber*), and Vermillion Snapper (*Rhomboplites aurorubens*), were in higher abundance at the Near natural sites than the Far natural sites (**Section 3.3.2**).

Species richness at an individual site ranged from 20 to 39. There was no significant difference in mean species richness between treatment groups (Old v. New, *t*-test, p=0.818). The highest diversity indices were recorded at the Old artificial reef sites; Fogel Capital and Lentine (2.16 and 2.07, respectively). The lowest species richness and lowest diversity were observed at the New deployment Site 7. Site 7 had the highest recorded relief and shallowest minimum depth of all artificial reef sites (**Table 3**).

Eighteen managed species were observed on the South County artificial reef sites; 14 species were observed on the Old deployments and 15 species on the New deployments (**Table 10**). *H. aurolineatum*, Grey Snapper (*Lutjanus griseus*), and Sheepshead (*Archosargus probatocephalus*) are three managed species recorded on all South County sites. Two members of the Serranidae family, Scamp (*Mycteroperca phenax*) and *E. itajara*, were present on every New artificial reef. *Mycteroperca phenax* only appeared on one of the Old artificial reefs while *E. itajara* was present at four Old artificial reefs.

A multi-dimensional scaling (MDS) plot showed no obvious separation in the structure of the fish assemblage between New deployments and the Old deployments (**Figure 7**). Analysis of similarities (ANOSIM) using deployment age as a factor (Old vs. New) demonstrated a significant difference in the fish assemblage (p=0.017). The SIMPER test showed that *Decapterus* spp. contributed to the significant differences between the New and Old artificial reef deployments. This genus was patchily distributed and created high variability in the structure of the fish assemblages at the artificial reefs (**Figure 8**). When *Decapterus* spp. are removed, fish assemblages at the Old and New artificial reefs are still significantly different (p=0.009), and a much clearer separation is seen in the MDS plot (**Figure 9**). Aside from *Decapterus* spp., the species contributing the most to differences between the Old and New artificial reef deployments are shown in **Table 11**. The New artificial reefs contained more commercially important species while the Old artificial reefs contained higher relative abundances of smaller damselfishes.

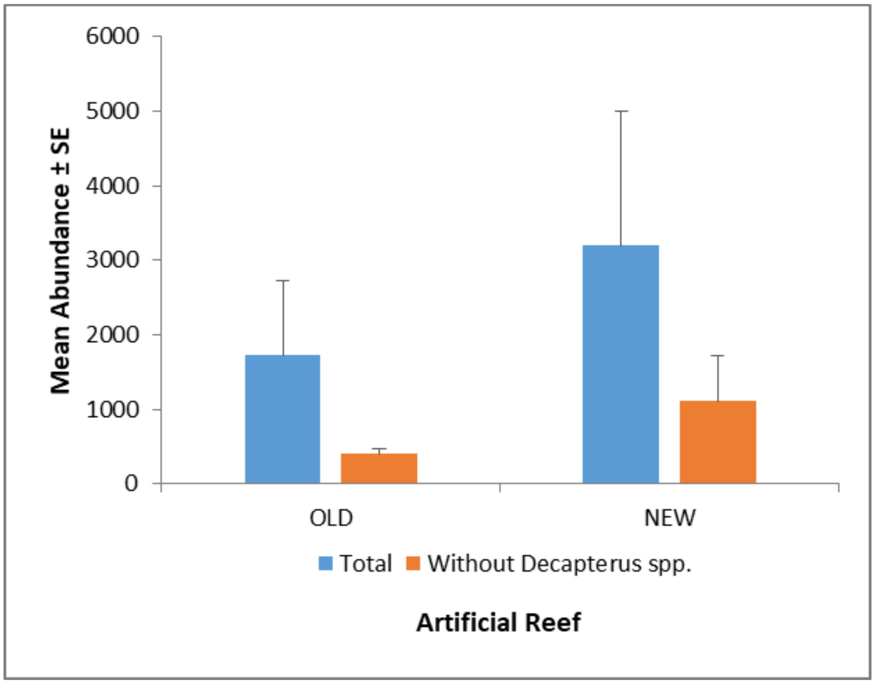


Figure 6. Mean fish abundance at the Old and New artificial reefs surveyed in the South County site in 2016, with and without *Decapterus* spp.

Table 8. Mean and relative abundance of fish species observed on the artificial reefs. RA= Relative abundance. SE= Standard Error.

			OLD		NEW	
Family	**Scientific Name**	**Common Name**	**Abundance ± SE**	**RA**	**Abundance ± SE**	**RA**
Acanthuridae	*Acanthurus bahianus*	Ocean Surgeon	-	-	0.5 ± 0.3	0.50
	Acanthurus chirurgus	Doctorfish	0.3 ± 0.2	0.33	1.2 ± 0.4	1.17
	Acanthurus coeruleus	Blue Tang	0.8 ± 0.3	0.83	0.8 ± 0.3	0.83
Apogonidae	*Apogon pseudomaculatus*	Twospot Cardinalfish	0.2 ± 0.2	0.17	-	-
Blenniidae	*Parablennius marmoreus*	Seaweed Blenny	-	-	0.3 ± 0.3	0.33
Carangidae	*Caranx crysos*	Blue Runner	8.8 ± 3.7	8.83	14.3 ± 6.3	14.33
	Caranx hippos	Crevalle Jack	-	-	3.3 ± 3.3	3.33
	Caranx ruber	Bar Jack	-	-	1.2 ± 0.8	1.17
	Decapterus spp.	Mackerel/Round Scad	1316.7 ± 1006.4	1316.67	2083.3 ± 1210.6	2083.33
	Elagatis bipinnulata	Rainbow Runner	-	-	1.8 ± 1.1	1.83
	Seriola rivoliana	Almaco Jack	0.2 ± 0.2	0.17	5.2 ± 1.9	5.17
	Trachinotus falcatus	Permit	0.2 ± 0.2	0.17	-	-
Centropomidae	*Centropomus undecimalis*	Common Snook	0.2 ± 0.2	0.17	-	-
Chaetodontidae	*Chaetodon sedentarius*	Reef Butterflyfish	0.8 ± 0.3	0.83	1.3 ± 0.4	1.33
Dasyatidae	*Dasyatis centroura*	Roughtail Stingray	0.2 ± 0.2	0.17	-	-
Echeneidae	*Echeneis* spp.	Sharksucker Spp.	0.2 ± 0.2	0.17	-	-
Gobiidae	*Coryphopterus dicrus*	Colon Goby	0.2 ± 0.2	0.17	-	-
	Coryphopterus glaucofraenum	Bridled Goby	1.3 ± 0.7	1.33	-	-
	Coryphopterus hyalinus/personatus	Masked/Glass Goby	35.5 ± 32.9	35.50	8.3 ± 8.3	8.33
	Gnatholepis thompsoni	Goldspot Goby	-	-	0.2 ± 0.2	0.17
Haemulidae	*Anisotremus surinamensis*	Black Margate	0.8 ± 0.3	0.83	0.5 ± 0.2	0.50
	Anisotremus virginicus	Porkfish	1.7 ± 0.4	1.67	0.5 ± 0.2	0.50
	Haemulon aurolineatum	Tomtate	232.5 ± 60.9	232.50	930.0 ± 621.5	930.00
	Haemulon plumierii	White Grunt	1.2 ± 0.3	1.17	-	-
	Haemulon spp.	Grunts, Juvenile/Unid	-	-	8.3 ± 8.3	8.33
	Haemulon striatum	Striped Grunt	-	-	3.3 ± 3.3	3.33

Table 8 cont. Mean and relative abundance of fish species observed on the artificial reefs. RA= Relative abundance. SE= Standard Error.

Family	Scientific Name	Common Name	OLD		NEW	
			Abundance ± SE	RA	Abundance ± SE	RA
Labridae	*Bodianus pulchellus*	Spotfin Hogfish	1.3 ± 0.5	1.33	1.2 ± 0.5	1.17
	Bodianus rufus	Spanish Hogfish	1.7 ± 0.5	1.67	0.7 ± 0.5	0.67
	Clepticus parrae	Creole Wrasse	2.2 ± 2.0	2.17	5.7 ± 2.7	5.67
	Halichoeres bivittatus	Slippery Dick	1.0 ± 0.5	1.00	0.3 ± 0.2	0.33
	Halichoeres garnoti	Yellowhead Wrasse	1.8 ± 0.4	1.83	0.5 ± 0.2	0.50
	Thalassoma bifasciatum	Bluehead	59.3 ± 3.2	59.33	64.2 ± 14.2	64.17
Labrisomidae	*Labrisomus nuchipinnis*	Hairy Blenny	0.2 ± 0.2	0.17	-	-
	Malacoctenus triangulatus	Saddled Blenny	0.5 ± 0.3	0.50	0.2 ± 0.2	0.17
Lutjanidae	*Lutjanus griseus*	Grey Snapper	10.3 ± 4.2	10.33	6.3 ± 1.9	6.33
	Lutjanus synagris	Lane Snapper	0.2 ± 0.2	0.17	0.7 ± 0.3	0.67
	Ocyurus chrysurus	Yellowtail Snapper	-	-	0.2 ± 0.2	0.17
	Rhomboplites aurorubens	Vermillion Snapper	-	-	9.3 ± 8.5	9.33
Mullidae	*Pseudupeneus maculatus*	Spotted Goatfish	0.2 ± 0.2	0.17	-	-
Pomacanthidae	*Holacanthus bermudensis*	Blue Angelfish	-	-	0.3 ± 0.2	0.33
	Holacanthus ciliaris	Queen Angelfish	0.3 ± 0.2	0.33	0.8 ± 0.3	0.83
	Holacanthus tricolor	Rock Beauty	0.2 ± 0.2	0.17	0.2 ± 0.2	0.17
	Pomacanthus arcuatus	Gray Angelfish	0.2 ± 0.2	0.17	-	-
Pomacentridae	*Abudefduf saxatilis*	Sergeant Major	0.8 ± 0.4	0.83	1.0 ± 0.5	1.00
	Chromis enchrysura	Yellowtail Reeffish	2.2 ± 1.2	2.17	3.8 ± 1.7	3.83
	Chromis insolata	Sunshinefish	1.5 ± 0.9	1.50	0.8 ± 0.5	0.83
	Chromis multilineata	Brown Chromis	-	-	0.2 ± 0.2	0.17
	Chromis scotti	Purple Reeffish	10.2 ± 4.1	10.17	6.2 ± 2.3	6.17
	Stegastes adustus	Dusky Damselfish	-	-	0.3 ± 0.3	0.33
	Stegastes leucostictus	Beaugregory	3.7 ± 1.3	3.67	0.7 ± 0.3	0.67
	Stegastes partitus	Bicolor Damselfish	3.2 ± 2.4	3.17	1.3 ± 0.8	1.33
	Stegastes planifrons	Threespot Damselfish	0.2 ± 0.2	0.17	0.2 ± 0.2	0.17
	Stegastes variabilis	Cocoa Damselfish	1.0 ± 0.4	1.00	1.3 ± 0.5	1.33

Table 8 cont. Mean and relative abundance of fish species observed on the artificial reefs. RA= Relative abundance. SE= Standard Error.

Family	Scientific Name	Common Name	OLD		NEW	
			Abundance ± SE	RA	Abundance ± SE	RA
Scaridae	*Cryptotomus roseus*	Bluelip Parrotfish	0.7 ± 0.5	0.67	0.3 ± 0.3	0.33
	Scarus iseri	Striped Parrotfish	1.3 ± 0.7	1.33	0.8 ± 0.8	0.83
	Sparisoma atomarium	Greenblotch Parrotfish	0.3 ± 0.2	0.33	0.5 ± 0.3	0.50
	Sparisoma aurofrenatum	Redband Parrotfish	0.5 ± 0.3	0.50	-	-
	Sparisoma radians	Bucktooth Parrotfish	0.5 ± 0.3	0.50	0.3 ± 0.3	0.33
	Sparisoma viride	Stoplight Parrotfish	-	-	0.5 ± 0.2	0.50
Sciaenidae	*Pareques umbrosus*	Cubbyu	0.5 ± 0.5	0.50	0.5 ± 0.3	0.50
Scorpaenidae	*Pterois volitans/miles*	Lionfish Spp.	1.2 ± 0.5	1.17	3.2 ± 1.3	3.17
	Scorpaena plumieri	Spotted Scorpionfish	0.7 ± 0.2	0.67	1.2 ± 0.6	1.17
Serranidae	*Cephalopholis cruentata*	Graysby	0.5 ± 0.2	0.50	0.3 ± 0.2	0.33
	Cephalopholis fulva	Coney	0.3 ± 0.3	0.33	0.2 ± 0.2	0.17
	Epinephelus itajara	Goliath Grouper	1.5 ± 0.7	1.50	2.7 ± 0.5	2.67
	Mycteroperca bonaci	Black Grouper	-	-	0.2 ± 0.2	0.17
	Mycteroperca phenax	Scamp	0.3 ± 0.3	0.33	1.8 ± 0.4	1.83
	Rypticus maculatus	Whitespotted Soapfish	0.7 ± 0.2	0.67	0.2 ± 0.2	0.17
	Schultzea beta	School Bass	-	-	0.3 ± 0.3	0.33
	Serranus annularis	Orangeback Bass	0.2 ± 0.2	0.17	0.2 ± 0.2	0.17
	Serranus baldwini	Lantern Bass	0.2 ± 0.2	0.17	-	-
	Serranus tigrinus	Harlequin Bass	0.2 ± 0.2	0.17	-	-
Sparidae	*Archosargus probatocephalus*	Sheepshead	2.2 ± 0.5	2.17	5.5 ± 3.0	5.50
	Calamus spp.	Porgy Spp.	0.7 ± 0.3	0.67	0.3 ± 0.2	0.33
Tetraodontidae	*Canthigaster jamestyleri*	Goldface Toby	1.0 ± 0.6	1.00	1.2 ± 0.5	1.17
	Canthigaster rostrata	Sharpnose Puffer	4.0 ± 1.3	4.00	2.3 ± 0.6	2.33
	Sphoeroides spengleri	Bandtail Puffer	-	-	0.7 ± 0.2	0.67
Mean Abundance (± SE)			1721.0 ± 1012.0		3194.0 ± 1812.5	
Overall Species Richness			60		63	

Table 9. Species richness, abundance, and Shannon diversity index at each artificial reef site.

Age	Site Name	Species Richness (S)	Abundance (N)	Shannon Diversity (H')
OLD	ANN MARIE	24	6726	0.31
	FOGEL CAPITAL	35	469	2.16
	THE HEAP	39	1019	1.25
	JACK MACDONALD	28	506	1.45
	LENTINE	32	329	2.08
	SHIRLEY REEF	20	1277	0.99
NEW	Site 7	21	920	0.65
	Site 8	33	692	1.52
	Site 9	34	1768	1.27
	Site 10	34	12116	0.71
	Site 11	29	888	1.39
	Site 12	32	2780	0.91

Table 10. Frequency of occurrence (% of surveys in which species occurred) of each managed fish species within the artificial reef sites.

Family	Scientific Name	Common Name	Frequency of Occurrence	
			OLD	NEW
Carangidae	*Caranx ruber*	Bar Jack	-	33.3
	Seriola rivoliana	Almaco Jack	16.7	83.3
	Caranx crysos	Blue Runner	66.7	66.7
	Trachinotus falcatus	Permit	16.7	-
Centropomidae	*Centropomus undecimalis*	Common Snook	16.7	-
Haemulidae	*Haemulon aurolineatum*	Tomtate	100.0	100.0
	Haemulon plumierii	White Grunt	83.3	-
Lutjanidae	*Lutjanus griseus*	Grey Snapper	100.0	100.0
	Lutjanus synagris	Lane Snapper	16.7	50.0
	Ocyurus chrysurus	Yellowtail Snapper	-	16.7
	Rhomboplites aurorubens	Vermillion Snapper	-	66.7
Serranidae	*Cephalopholis cruentata*	Graysby	50.0	33.3
	Cephalopholis fulva	Coney	16.7	16.7
	Epinephelus itajara	Goliath Grouper	83.3	100.0
	Mycteroperca bonaci	Black Grouper	-	16.7
	Mycteroperca phenax	Scamp	16.7	100.0
Sparidae	*Calamus* spp.	Porgy Spp.	50.0	33.3
	Archosargus probatocephalus	Sheepshead	100.0	100.0

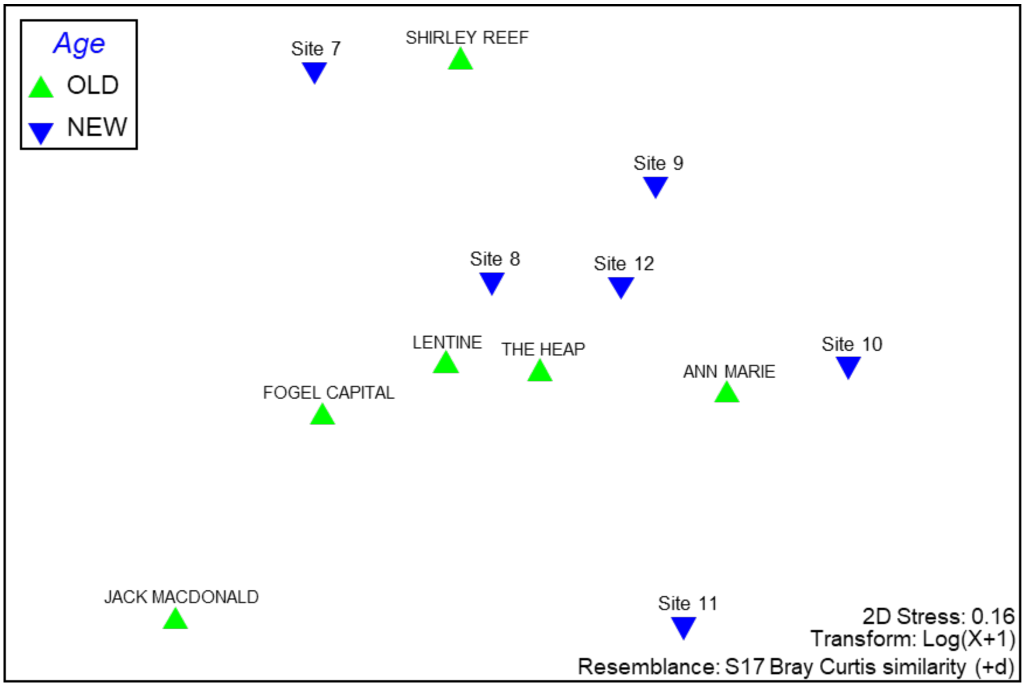


Figure 7. MDS plot of the fish assemblage at the artificial reef areas with reef age as the factor.

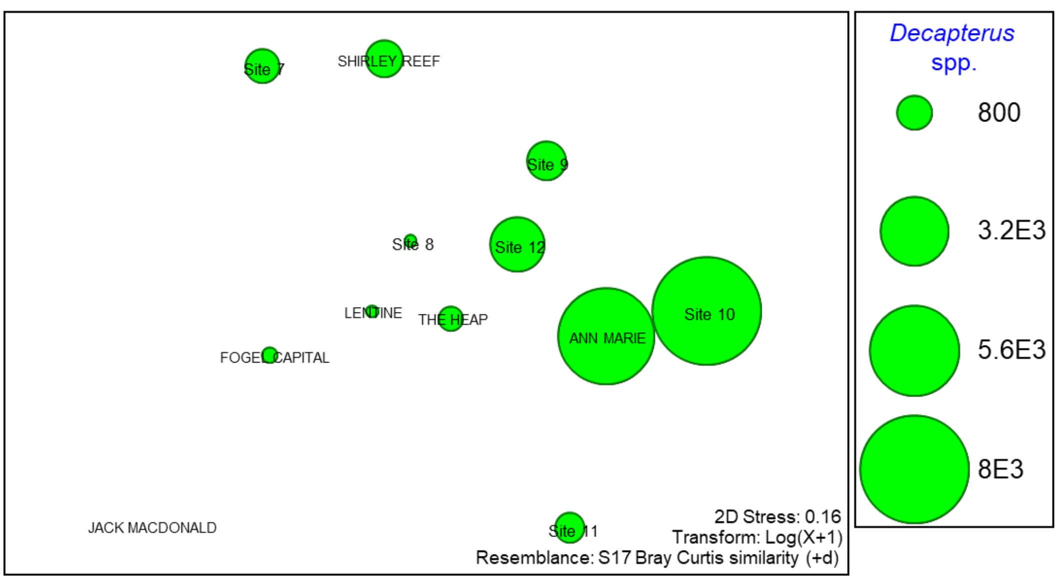


Figure 8. MDS plot from **Figure 7** with abundance of *Decapterus* spp. overlaid in the form of bubbles; larger bubbles correspond to higher abundance at that reef.

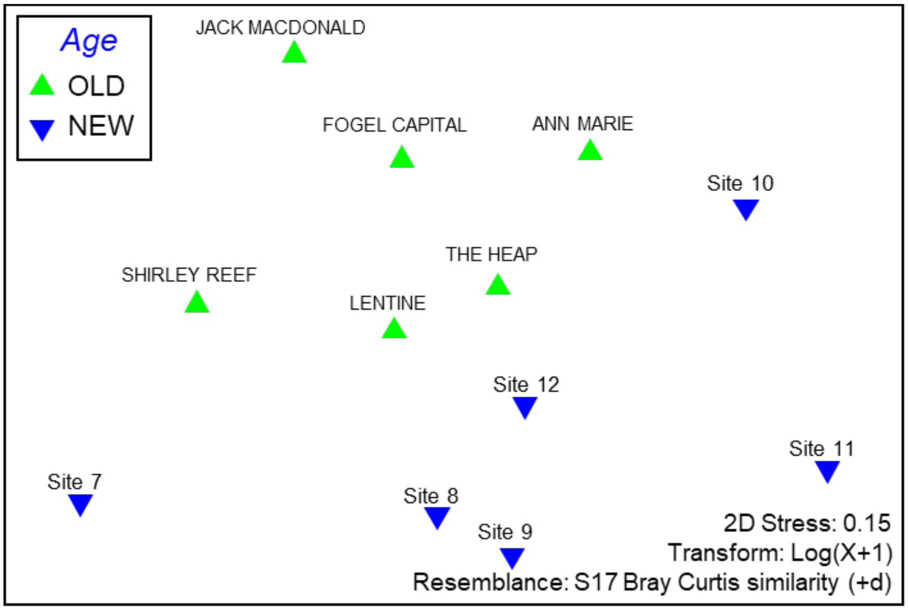


Figure 9. MDS plot of the fish assemblage without *Decapterus* spp. at the artificial reef areas with reef age as the factor.

Table 11. Species with highest contribution to differences (dissimilarity) in the fish assemblages at the Old and New artificial reefs with *Decapterus* spp. omitted. Species with a mean % dissimilarity of > 1.0% listed. Asterisks (*) indicate species with managed fisheries.

Scientific Name	Common Name	Higher Group	Mean % Dissimilarity	% Contribution
OLD v. NEW				
Coryphopterus hyalinus/personatus	Masked/Glass Goby	OLD	2.27	4.74
*Haemulon aurolineatum**	Tomtate	NEW	2.18	4.57
*Caranx crysos**	Blue Runner	NEW	1.99	4.17
*Seriola rivoliana**	Almaco Jack	NEW	1.76	3.67
Clepticus parrae	Creole Wrasse	NEW	1.58	3.30
Chromis scotti	Purple Reeffish	OLD	1.50	3.14
*Rhomboplites aurorubens**	Vermillion Snapper	NEW	1.26	2.63
Stegastes leucostictus	Beaugregory	OLD	1.25	2.61
Stegastes partitus	Bicolor Damselfish	OLD	1.11	2.32
Pterois volitans/miles	Lionfish Spp.	NEW	1.09	2.27
*Mycteroperca phenax**	Scamp	NEW	1.06	2.21
Chromis enchrysura	Yellowtail Reefish	NEW	1.05	2.19

3.3.2 Natural Reefs

A total of 98 fish species were observed from 29 families in the 12 fish surveys conducted on the natural reefs. Mean abundances of each fish species on the Near and Far natural reefs are listed in **Table 12.** There was no significant difference in fish abundance between the Near and Far natural reefs (*t*-test, *p*=0.524). While not significant, the Near natural reefs contained a higher overall mean abundance than the Far natural reefs (805.0 ± 494.4 versus 567.5 ± 412.1 individuals per survey, **Figure 10**).

The difference in abundance can be partially attributed to the very high abundance of Scad Spp. (*Decapterus* spp.) at three natural sites; two Near (NAT 1 and NAT 4) and one Far (NAT 11). When abundance data were analyzed without the presence of *Decapterus* spp., the difference in abundance between Near and Far natural reef sites was less evident (250.8 ± 72.4 versus 234.2 ± 81.4 individuals per survey, **Figure 10**). Abundances of individual fish species at each natural survey location are provided in **Appendix A2**.

Aside from *Decapterus* spp., the most abundant fish species on the Near natural reef sites were Tomtate (*Haemulon aurolineatum*), Bluehead wrasse (*Thalassoma bifasciatum*), and small reef-associated species including Chromis and Damselfish (*Chromis* and *Stegastes* spp.). The most abundant species on the Far natural reef sites were similar; *H. aurolineatum* and *T. bifasciatum* accounted for the majority of fishes (17.0% and 7.1% of the total mean abundance, respectively). The small Tetraodontid Sharpnose Puffer (*Canthigaster rostrata*) was more abundant on the Far natural reef sites than on the Near natural reef sites (1.6% versus 0.8% of the total abundance).

Species richness and Shannon diversity index at each survey site are shown in **Table 13**. The Near natural reef sites contained more species overall than the Far natural reef sites (84 versus 79, respectively). There were 14 species exclusive to the Far natural reef sites, and 19 species exclusive to the Near natural reef sites. Of species exclusive to the Near natural reef sites, Lane Snapper (*Lutjanus synagris*), Brown Chromis (*Chromis multilineata*), and Dusky Damselfish (*Stegastes adustus*) were also present in higher abundances at the New artificial reefs. Species richness at individual sites ranged from 24 to 46. There were no significant differences in mean species richness between each treatment group (Near and Far; *t*-test, *p*=0.875). Diversity indices at the Far sites were generally higher than those at the Near sites. Sites with the lowest diversity indices (NAT 4 and NAT 11) also contained relatively high species richness. This results from the overwhelming abundances of *Decapterus* spp. at these two sites, resulting in a high overall abundance, but lower assemblage diversity.

Twenty managed species were observed on the natural reef sites; 18 species were observed on the Near natural reef sites and 17 species on the Far natural reef sites (**Table 14**). Notable differences between the Near and Far natural reef sites include greater numbers of Blue Runner (*Caranx crysos*), and Vermillion Snapper (*Lutjanus aurorubens*) on the Near natural reef sites. Managed species on the natural reefs in the highest overall frequency were Grey Triggerfish (*Balistes capriscus*), *H. aurolineatum*, White Grunt (*Haemulon plumierii*), and Porgy Spp. (*Calamus* spp.).

Analysis of similarities (ANOSIM) using locations as a factor (Near vs. Far) showed that there were no significant differences in fish assemblages at the Near and Far natural reef sites (p=0.626). Therefore, a SIMPROF was run in order to determine if any other significant structures existed in the natural reef assemblage data. The SIMPROF divided communities into two significant clusters (A and B, **Figure 11**). SIMPER analysis showed that sites in cluster A contained consistently higher abundances of *H. aurolineatum*, Bicolor Damselfish (*Stegastes partitus*), *Decapterus* spp., and Purple Reeffish (*Chromis scotti*). Differences in the assemblage structure could be driven by the two sites in cluster B, NAT 5 and NAT 10, which have the lowest relief of the natural sites (**Table 4**). The remaining natural sites were grouped into cluster A. This might be due to high variability at these sites leading to a lack of the statistically significant differences to justify a separate cluster. Site NAT 6 is located relatively far away from the rest of cluster A (**Figure 11**) due to the school of Spotted Goatfish (*Pseudupeneus maculatus*) only present at this site.

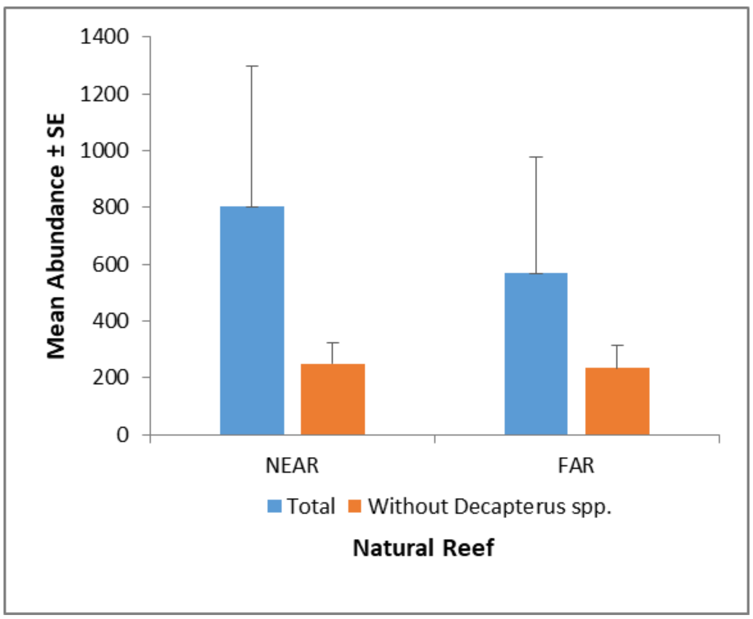


Figure 10. Mean fish abundance with all species and without *Decapterus spp.* at the Near and Far natural reef sites.

Table 12. Mean and relative abundance of fish species observed on the natural reef sites. RA= Relative abundance. SE=Standard Error.

Family	Scientific Name	Common Name	NEAR		FAR	
			Abundance ± SE	RA	Abundance ± SE	RA
Acanthuridae	*Acanthurus bahianus*	Ocean Surgeon	3.0 ± 1.2	3.00	0.2 ± 0.2	0.17
	Acanthurus chirurgus	Doctorfish	2.5 ± 0.8	2.50	4.0 ± 1.3	4.00
	Acanthurus coeruleus	Blue Tang	0.3 ± 0.3	0.33	0.2 ± 0.2	0.17
Apogonidae	*Apogon pseudomaculatus*	Twospot Cardinalfish	0.3 ± 0.3	0.33	0.3 ± 0.2	0.33
Balistidae	*Balistes capriscus*	Grey Triggerfish	3.5 ± 1.3	3.50	2.2 ± 0.7	2.17
Carangidae	*Carangoides bartholomaei*	Yellow Jack	0.3 ± 0.3	0.33	0.8 ± 0.8	0.83
	Caranx crysos	Blue Runner	5.3 ± 3.2	5.33	0.3 ± 0.2	0.33
	Caranx ruber	Bar Jack	1.0 ± 0.7	1.00	0.3 ± 0.2	0.33
	Decapterus spp.	Mackerel/Round Scad	554.2 ± 492.0	554.17	333.3 ± 333.3	333.33
	Seriola dumerili	Greater Amberjack	0.2 ± 0.2	0.17	-	-
	Seriola rivoliana	Almaco Jack	0.2 ± 0.2	0.17	0.3 ± 0.2	0.33
Chaenopsidae	*Emblemaria pandionis*	Sailfin Blenny	0.3 ± 0.3	0.33	-	-
Chaetodontidae	*Chaetodon ocellatus*	Spotfin Butterflyfish	0.7 ± 0.4	0.67	0.2 ± 0.2	0.17
	Chaetodon sedentarius	Reef Butterflyfish	1.7 ± 0.3	1.67	1.5 ± 0.3	1.50
Cirrhitidae	*Amblycirrhitus pinos*	Redspotted Hawkfish	-	-	0.2 ± 0.2	0.17
Echeneidae	*Echeneis* spp.	Sharksucker Spp.	-	-	0.2 ± 0.2	0.17
Gobiidae	*Coryphopterus dicrus*	Colon Goby	0.7 ± 0.5	0.67	-	-
	Coryphopterus glaucofraenum	Bridled Goby	3.5 ± 1.1	3.50	2.0 ± 0.9	2.00
	Coryphopterus hyalinus/personatus	Masked/Glass Goby	0.8 ± 0.8	0.83	1.0 ± 0.8	1.00
	Elacatinus oceanops	Neon Goby	0.2 ± 0.2	0.17	-	-
	Gnatholepis thompsoni	Goldspot Goby	0.8 ± 0.5	0.83	1.3 ± 0.6	1.33
Haemulidae	*Anisotremus surinamensis*	Black Margate	0.2 ± 0.2	0.17	-	-
	Anisotremus virginicus	Porkfish	1.7 ± 0.4	1.67	4.0 ± 2.4	4.00
	Haemulon aurolineatum	Tomtate	97.3 ± 61.2	97.33	96.5 ± 63.3	96.50
	Haemulon parra	Sailor's Choice	-	-	0.2 ± 0.2	0.17
	Haemulon plumierii	White Grunt	2.8 ± 1.9	2.83	1.7 ± 0.6	1.67
	Haemulon spp.	Grunts, Juvenile/Unid	-	-	2.0 ± 1.4	2.00

Table 12 cont. Mean and relative abundance of fish species observed on the natural reef sites. RA= Relative abundance. SE=Standard Error.

Family	Scientific Name	Common Name	NEAR		FAR	
			Abundance ± SE	RA	Abundance ± SE	RA
Kyphosidae	*Kyphosus sectatrix*	Chub	0.2 ± 0.2	0.17	-	-
Labridae	*Bodianus pulchellus*	Spotfin Hogfish	1.0 ± 0.6	1.00	0.3 ± 0.3	0.33
	Bodianus rufus	Spanish Hogfish	0.5 ± 0.3	0.50	0.8 ± 0.3	0.83
	Clepticus parrae	Creole Wrasse	0.8 ± 0.5	0.83	0.2 ± 0.2	0.17
	Halichoeres bivittatus	Slippery Dick	1.3 ± 0.8	1.33	2.7 ± 0.2	2.67
	Halichoeres garnoti	Yellowhead Wrasse	2.8 ± 1.2	2.83	5.2 ± 2.1	5.17
	Halichoeres maculipinna	Clown Wrasse	-	-	0.8 ± 0.4	0.83
	Halichoeres radiatus	Puddingwife	0.3 ± 0.2	0.33	0.2 ± 0.2	0.17
	Lachnolaimus maximus	Hogfish	0.5 ± 0.2	0.50	0.3 ± 0.2	0.33
	Thalassoma bifasciatum	Bluehead	36.2 ± 9.6	36.17	40.3 ± 7.7	40.33
	Xyrichtys splendens	Green Razorfish	-	-	0.5 ± 0.5	0.50
Lutjanidae	*Lutjanus analis*	Mutton Snapper	0.3 ± 0.3	0.33	0.2 ± 0.2	0.17
	Lutjanus griseus	Grey Snapper	2.0 ± 0.9	2.00	2.7 ± 1.7	2.67
	Lutjanus synagris	Lane Snapper	0.3 ± 0.2	0.33	-	-
	Ocyurus chrysurus	Yellowtail Snapper	-	-	0.3 ± 0.3	0.33
	Rhomboplites aurorubens	Vermillion Snapper	3.3 ± 2.0	3.33	0.2 ± 0.2	0.17
Monacanthidae	*Cantherhines pullus*	Orangespotted Filefish	0.3 ± 0.2	0.33	0.2 ± 0.2	0.17
Mullidae	*Pseudupeneus maculatus*	Spotted Goatfish	4.8 ± 3.1	4.83	0.5 ± 0.3	0.50
Muraenidae	*Gymnothorax miliaris*	Goldentail Moray	-	-	0.2 ± 0.2	0.17
	Gymnothorax moringa	Spotted Moray	0.3 ± 0.2	0.33	0.2 ± 0.2	0.17
Opistognathidae	*Opistognathus aurifrons*	Yellowhead Jawfish	-	-	1.5 ± 1.0	1.50
Ostraciidae	*Acanthostracion quadricornis*	Scrawled Cowfish	0.2 ± 0.2	0.17	-	-

Table 12 cont. Mean and relative abundance of fish species observed on the natural reef sites. RA= Relative abundance. SE=Standard Error.

Family	Scientific Name	Common Name	NEAR		FAR	
			Abundance ± SE	RA	Abundance ± SE	RA
Pomacanthidae	*Centropyge argi*	Cherubfish	0.2 ± 0.2	0.17	0.0 ± 0.0	0.00
	Holacanthus bermudensis	Blue Angelfish	0.3 ± 0.2	0.33	0.8 ± 0.3	0.83
	Holacanthus ciliaris	Queen Angelfish	0.7 ± 0.3	0.67	0.8 ± 0.4	0.83
	Holacanthus tricolor	Rock Beauty	0.5 ± 0.3	0.50	0.5 ± 0.2	0.50
	Pomacanthus arcuatus	Gray Angelfish	0.8 ± 0.5	0.83	0.5 ± 0.3	0.50
	Pomacanthus paru	French Angelfish	0.2 ± 0.2	0.17	0.8 ± 0.4	0.83
Pomacentridae	*Abudefduf saxatilis*	Sergeant Major	0.7 ± 0.4	0.67	0.5 ± 0.5	0.50
	Chromis cyanea	Blue Chromis	0.2 ± 0.2	0.17	0.2 ± 0.2	0.17
	Chromis enchrysura	Yellowtail Reeffish	11.8 ± 3.8	11.83	6.0 ± 2.8	6.00
	Chromis insolata	Sunshinefish	3.5 ± 1.1	3.50	3.0 ± 1.6	3.00
	Chromis multilineata	Brown Chromis	0.5 ± 0.3	0.50	-	-
	Chromis scotti	Purple Reeffish	8.7 ± 3.1	8.67	3.8 ± 1.4	3.83
	Microspathodon chrysurus	Yellowtail Damselfish	-	-	0.3 ± 0.3	0.33
	Stegastes adustus	Dusky Damselfish	0.8 ± 0.7	0.83	0.0 ± 0.0	0.00
	Stegastes leucostictus	Beaugregory	2.7 ± 1.5	2.67	1.8 ± 0.9	1.83
	Stegastes partitus	Bicolor Damselfish	14.8 ± 6.3	14.83	14.8 ± 6.5	14.83
	Stegastes planifrons	Threespot Damselfish	-	-	0.2 ± 0.2	0.17
	Stegastes variabilis	Cocoa Damselfish	1.3 ± 0.6	1.33	1.2 ± 0.6	1.17
Priacanthidae	*Heteropriacanthus cruentatus*	Glasseye	0.3 ± 0.3	0.33	0.2 ± 0.2	0.17
Scaridae	*Cryptotomus roseus*	Bluelip Parrotfish	-	-	0.2 ± 0.2	0.17
	Scarus iseri	Striped Parrotfish	0.2 ± 0.2	0.17	0.5 ± 0.3	0.50
	Sparisoma atomarium	Greenblotch Parrotfish	0.2 ± 0.2	0.17	0.8 ± 0.3	0.83
	Sparisoma aurofrenatum	Redband Parrotfish	0.2 ± 0.2	0.17	0.2 ± 0.2	0.17
	Sparisoma radians	Bucktooth Parrotfish	0.2 ± 0.2	0.17	0.5 ± 0.3	0.50
	Sparisoma rubripinne	Redfin Parrotfish	0.3 ± 0.2	0.33	0.2 ± 0.2	0.17

Table 12 cont. Mean and relative abundance of fish species observed on the natural reef sites. RA= Relative abundance. SE=Standard Error.

Family	Scientific Name	Common Name	NEAR		FAR	
			Abundance ± SE	RA	Abundance ± SE	RA
Sciaenidae	*Pareques acuminatus*	Highhat	0.2 ± 0.2	0.17	0.3 ± 0.3	0.33
	Pareques umbrosus	Cubbyu	4.8 ± 2.5	4.83	3.5 ± 2.1	3.50
	Sciaenidae spp.	Drum, Juvenile/Unid.	0.8 ± 0.8	0.83	-	-
Scombridae	*Euthynnus alletteratus*	Little Tunny	0.2 ± 0.2	0.17	-	-
Scorpaenidae	*Pterois volitans/miles*	Lionfish Spp.	0.8 ± 0.4	0.83	1.7 ± 0.3	1.67
	Scorpaena plumieri	Spotted Scorpionfish	0.7 ± 0.3	0.67	0.5 ± 0.2	0.50
Serranidae	*Cephalopholis cruentata*	Graysby	0.3 ± 0.3	0.33	0.5 ± 0.3	0.50
	Epinephelus itajara	Goliath Grouper	0.2 ± 0.2	0.17	0.2 ± 0.2	0.17
	Hypoplectrus spp.	Hamlet Juvenile/Unid	-	-	0.2 ± 0.2	0.17
	Hypoplectrus unicolor	Butter Hamlet	0.3 ± 0.2	0.33	-	-
	Liopropoma eukrines	Wrasse Bass	0.2 ± 0.2	0.17	-	-
	Mycteroperca phenax	Scamp	0.5 ± 0.3	0.50	0.2 ± 0.2	0.17
	Rypticus maculatus	Whitespotted Soapfish	0.5 ± 0.3	0.50	1.0 ± 0.3	1.00
	Schultzea beta	School Bass	0.2 ± 0.2	0.17	0.5 ± 0.3	0.50
	Serranus baldwini	Lantern Bass	0.2 ± 0.2	0.17	0.3 ± 0.2	0.33
	Serranus subligarius	Belted Sandfish	0.2 ± 0.2	0.17	-	0.00
	Serranus tabacarius	Tobaccofish	0.2 ± 0.2	0.17	-	-
	Serranus tigrinus	Harlequin Bass	0.2 ± 0.2	0.17	-	-
Sparidae	*Archosargus probatocephalus*	Sheepshead	0.5 ± 0.2	0.50	0.5 ± 0.3	0.50
	Calamus spp.	Porgy Spp.	1.8 ± 0.5	1.83	1.2 ± 0.5	1.17
Synodontidae	*Synodus foetens*	Inshore Lizardfish	0.2 ± 0.2	0.17	0.0 ± 0.0	0.00
Tetraodontidae	*Canthigaster jamestyleri*	Goldface Toby	0.2 ± 0.2	0.17	0.3 ± 0.2	0.33
	Canthigaster rostrata	Sharpnose Puffer	6.2 ± 2.8	6.17	8.8 ± 2.2	8.83
	Sphoeroides spengleri	Bandtail Puffer	-	-	0.2 ± 0.2	0.17
Mean Abundance (± SE)			805.0 ± 494.4		567.5 ± 412.1	
Overall Species Richness			84		79	

Table 13. Species richness, abundance, and Shannon diversity index at each natural reef site.

Location	Site Name	Species Richness (S)	Abundance (N)	Shannon Diversity (H')
NEAR	NAT 1	30	569	1.80
	NAT 2	44	596	1.52
	NAT 3	38	187	2.86
	NAT 4	31	3237	0.45
	NAT 5	34	122	3.00
	NAT 6	24	119	2.33
FAR	NAT 7	38	147	2.62
	NAT 8	34	128	2.99
	NAT 9	33	235	2.71
	NAT 10	29	73	2.88
	NAT 11	46	2625	0.94
	NAT 12	25	197	1.57

Table 14. Frequency of occurrence (% of surveys in which species occurred) of each managed fish species within the natural reef sites.

Family	Scientific Name	Common Name	Frequency of Occurrence	
			NEAR	FAR
Balistidae	*Balistes capriscus*	Grey Triggerfish	83.3	83.3
Carangidae	*Caranx crysos*	Blue Runner	66.7	33.3
	Caranx ruber	Bar Jack	33.3	33.3
	Seriola dumerili	Greater Amberjack	16.7	-
	Seriola rivoliana	Almaco Jack	16.7	33.3
Haemulidae	*Haemulon aurolineatum*	Tomtate	83.3	83.3
	Haemulon parra	Sailor's Choice	-	16.7
	Haemulon plumierii	White Grunt	66.7	83.3
Labridae	*Lachnolaimus maximus*	Hogfish	50.0	33.3
Lutjanidae	*Lutjanus analis*	Mutton Snapper	16.7	16.7
	Lutjanus griseus	Grey Snapper	66.7	50.0
	Lutjanus synagris	Lane Snapper	33.3	-
	Ocyurus chrysurus	Yellowtail Snapper	-	16.7
	Rhomboplites aurorubens	Vermillion Snapper	50.0	16.7
Scombridae	*Euthynnus alletteratus*	Little Tunny	16.7	-
Serranidae	*Cephalopholis cruentata*	Graysby	16.7	33.3
	Epinephelus itajara	Goliath Grouper	16.7	16.7
	Mycteroperca phenax	Scamp	33.3	16.7
Sparidae	*Calamus* spp.	Porgy Spp.	83.3	66.7
	Archosargus probatocephalus	Sheepshead	50.0	33.3

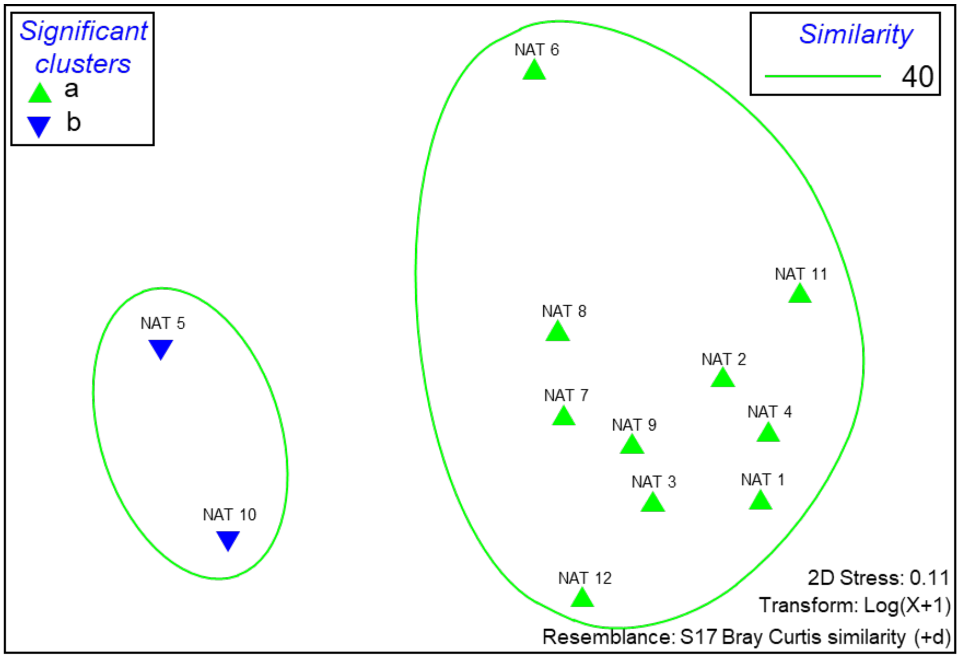


Figure 11. MDS plot of the fish assemblage at the natural reef sites overlaid with significant clusters determined by SIMPROF analysis.

3.3.3 Natural Versus Artificial

A one-way ANOVA showed an overall significant difference in abundance between treatment groups (New, Old, Near and Far, p=0.031). Post-hoc comparisons showed only one comparison (Far natural and New artificial) being significantly different (Tukey HSD, p=0.033). When Scad Spp. (*Decapterus* spp.) were removed from the analyses, the overall ANOVA was not significant (p=0.053). While the differences are not significant, the New artificial reef sites contained the highest mean fish abundance (3,194.0 ± 1,812.5), and the Far natural reef sites contained the lowest mean fish abundance (567.5 ± 412.1, **Figure 12**). The combined artificial reefs contained a significantly higher mean fish abundance than the combined natural reefs when analyzed with and without the *Decapterus* spp. (t-test, p=0.005 and p=0.009 respectively, **Figure 13**).

The Near natural reef sites contained the highest overall species richness (84 species) and the Old artificial reef sites contained the lowest (60 species). No significant differences were found in mean species richness between location/age treatment groups (ANOVA, p=0.584, **Figure 14**). Natural reefs contained more overall species than artificial reefs (98 versus 77 species). While it is a not a significant difference (t-test, p=0.162), there was a higher average number of species in natural reef habitats than artificial reef habitats (**Figure 15**).

The number of fish and minimum, maximum, and average fork lengths (cm) of commercially important species at each reef type are shown in **Table 15**. Overall, while natural reefs contained two more commercially important species than artificial reefs (20 and 18, respectively), artificial reefs contained over five times the number of commercially important fish than the natural reefs (7,423 and 1,368, respectively). Due to this discrepancy, it is difficult to directly compare fork lengths of species on the natural and artificial reefs. Of the species that were about equally abundant on both reef types, Blue Runner (*Caranx ruber*) showed an interesting trend of a larger range of fork lengths on the natural reef than on the artificial reefs, suggesting that natural reefs provide a better habitat for more life stages.

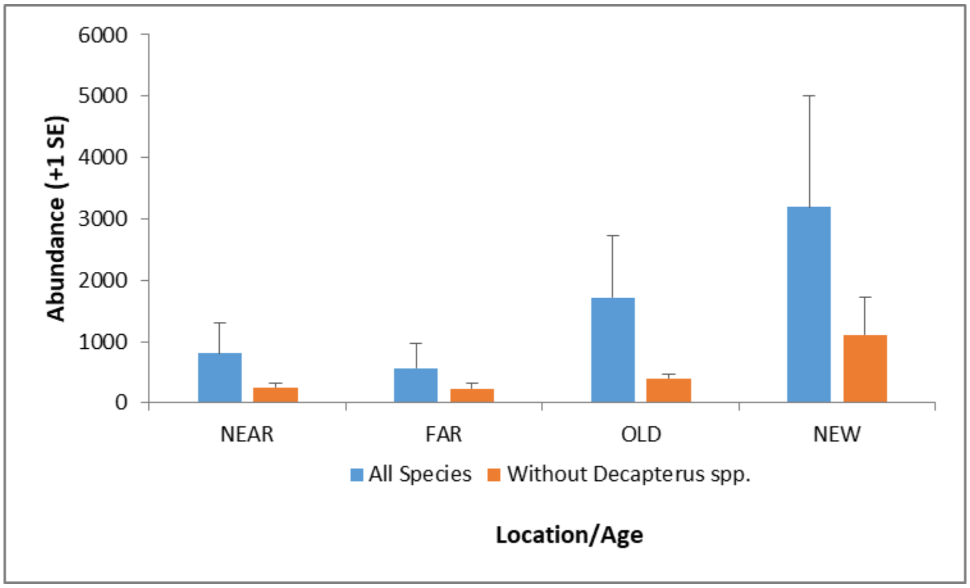


Figure 12. Mean abundances (+1 SE) of each reef location with and without *Decapterus* spp.

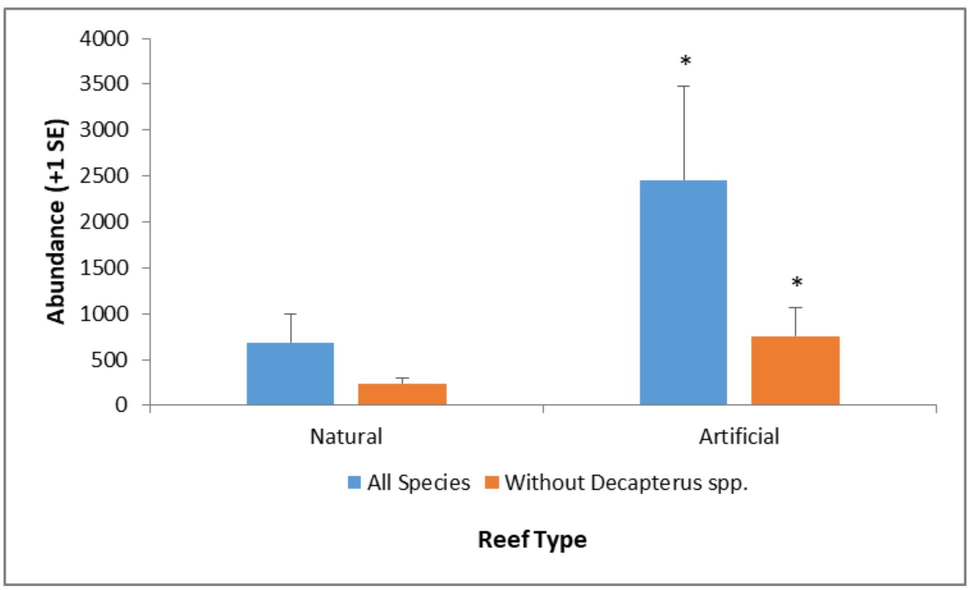


Figure 13. Mean abundances (+1 SE) of each reef type with and without *Decapterus* spp. Asterisk (*) indicates significant differences.

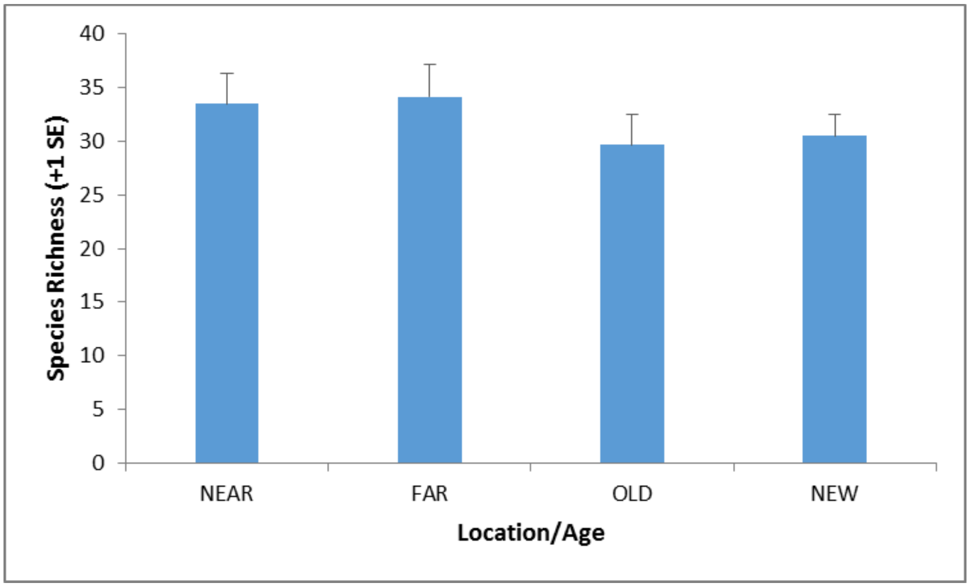


Figure 14. Mean species richness (+1 SE) of each treatment group.

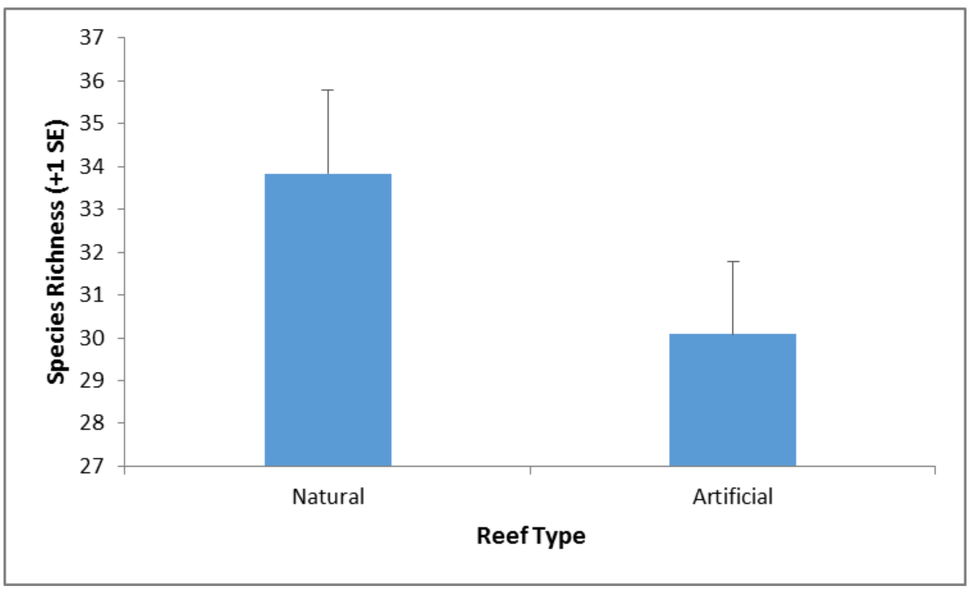


Figure 15. Mean species richness (+1 SE) of each reef type.

Table 15. Number (N), average size ± standard error (SE), minimum and maximum fork lengths in cm of each commercially important species at each reef type. Actual fork lengths are listed for species with 3 or fewer individuals observed.

Species	Common Name	Artificial				Natural			
		N	Average	Minimum	Maximum	N	Average	Minimum	Maximum
Archosargus probatocephalus	Sheepshead	46	37.1 ± 1.5	25	50	6	37.9 ± 3.5	28	53
Balistes capriscus	Grey Triggerfish	-	-	-	-	34	26.3 ± 1.9	18	41
Calamus spp.	Porgy Spp.	6	25.2 ± 1.1	22	28	18	26.5 ± 1.1	20	40
Caranx crysos	Blue Runner	139	33.1 ± 1.6	26	45	34	33.6 ± 2.8	20	50
Caranx ruber	Bar Jack	7	19.3 ± 0.8	17	23	8	30.6 ± 5.4	15	40
Centropomus undecimalis	Common Snook	1	76	-	-	-	-	-	-
Cephalopholis cruentata	Graysby	5	22.2 ± 1.5	18	27	5	19.3 ± 3.2	13	25
Cephalopholis fulva	Coney	3	20	15	30	-	-	-	-
Epinephelus itajara	Goliath Grouper	25	186.0 ± 10.5	120	280	2	-	180	190
Euthynnus alletteratus	Little Tunny	-	-	-	-	1	55	-	-
Haemulon aurolineatum	Tomtate	6975	19.3 ± 0.9	7	25	1163	19.9 ± 0.4	6	25
Haemulon parra	Sailor's Choice	-	-	-	-	1	28	-	-
Haemulon plumierii	White Grunt	7	22.9 ± 2.1	15	27	27	20.6 ± 2.0	10	33
Lachnolaimus maximus	Hogfish	-	-	-	-	5	33.0 ± 2.8	29	44
Lutjanus analis	Mutton Snapper	-	-	-	-	3	41	38	42
Lutjanus griseus	Grey Snapper	100	35.1 ± 1.5	25	48	28	33.1 ± 0.9	28	40
Lutjanus synagris	Lane Snapper	5	21.4 ± 2.1	17	25	2	-	20	28
Mycteroperca bonaci	Black Grouper	1	33	-	-	-	-	-	-
Mycteroperca phenax	Scamp	13	25.9 ± 2.1	16	34	4	36.5 ± 5.5	23	42
Ocyurus chrysurus	Yellowtail Snapper	1	22	-	-	2	-	25	25
Rhomboplites aurorubens	Vermillion Snapper	56	22.9 ± 2.7	15	28	21	26.0 ± 1.6	15	30
Seriola dumerili	Greater Amberjack	-	-	-	-	1	120	-	-
Seriola rivoliana	Almaco Jack	32	30.3 ± 1.7	25	40	3	25	24	27
Trachinotus falcatus	Permit	1	100	-	-	-	-	-	-

Fish assemblages at all four treatment types were dominated by invertivores (**Figure 16**). This is also true when *Decapterus* spp., an invertivorous genus, are removed (**Figure 17**). At all reef types except for New artificial sites, the second most abundant feeding guild were herbivores. At the New artificial reef sites, piscivores were relatively more abundant than herbivores (1.5% versus 0.7%, respectively). Even without *Decapterus* spp., invertivores comprised 93.5% of the assemblage at the New artificial reef sites due to 5,580 Tomtate (*H. aurolineatum)*; abundance was four times higher than at the Old artificial reefs and over nine times higher than at the Near and Far natural reef sites.

When analyzed by habitat type, the same pattern is true; assemblages are predominantly invertivores, with and without *Decapterus* spp. in the analysis (**Figures 18** and **19**). When looking at the assemblages without *Decapterus* spp., a clearer assemblage structure is evident. At the natural reef sites, 77.5% of the assemblage is invertivores; whereas at the artificial reef sites, invertivores make up 90.0% of the fish by abundance. This difference was again driven by the high number of *H. aurolineatum* present on the artificial reefs relative to natural reefs (6,975 versus 1,163 individuals, respectively). The presence or absence of piscivores can significantly affect the fish assemblage of both natural and artificial reefs. The natural reef sites contain a higher percentage of herbivores than piscivores (13.4% versus 9.1% of the fish by abundance, respectively). The herbivore assemblage on the natural reefs was dominated by the small Bicolor Damselfish (*Stegastes partitus*). The opposite is true for the artificial reef sites with piscivores outnumbering herbivores (5.1% versus 4.9% of the fish by abundance, respectively). The piscivore assemblage on the artificial reefs was dominated by the commercially important Blue Runner (*Caranx crysos*) and Grey Snapper (*Lutjanus griseus*).

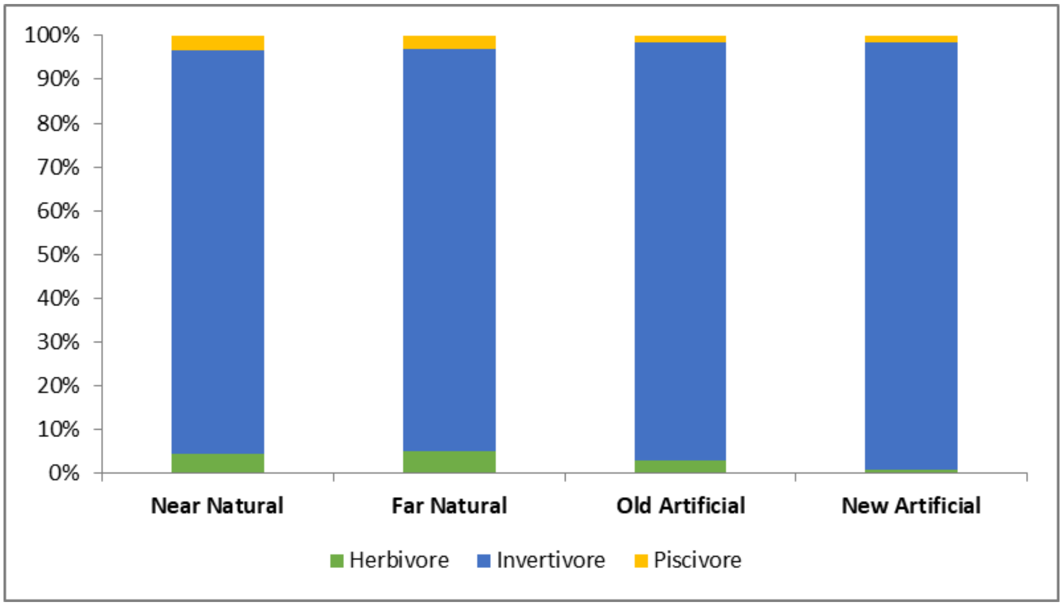


Figure 16. Percent of the fish assemblage (by abundance) consisting of herbivores, invertivores, and piscivores in the Near and Far natural reef sites and the Old and New artificial reefs.

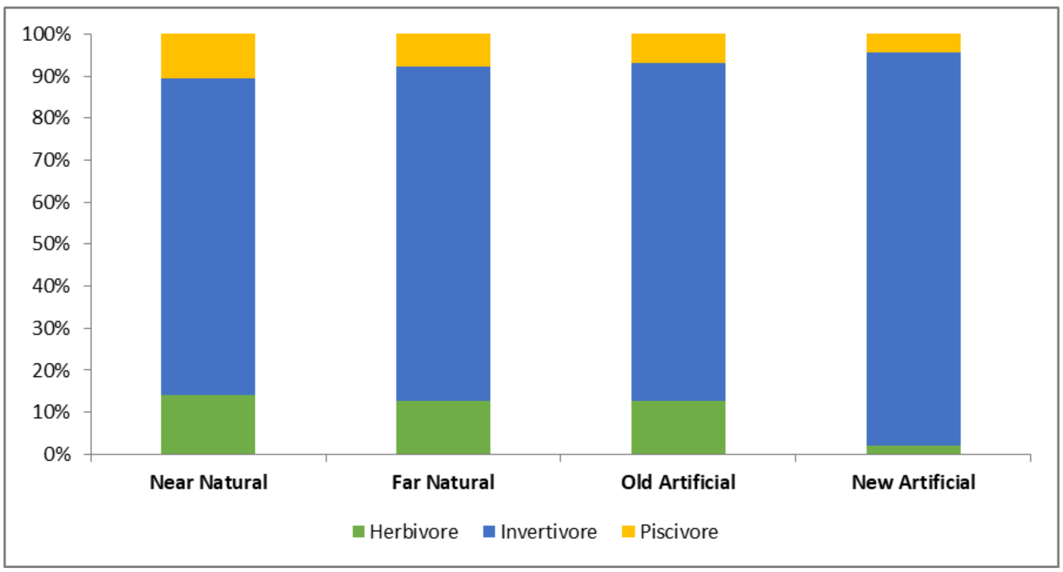


Figure 17. Percent of the fish assemblage (by abundance) excluding *Decapterus* spp. consisting of herbivores, invertivores, and piscivores in the Near and Far natural reef sites and the Old and New artificial reefs.

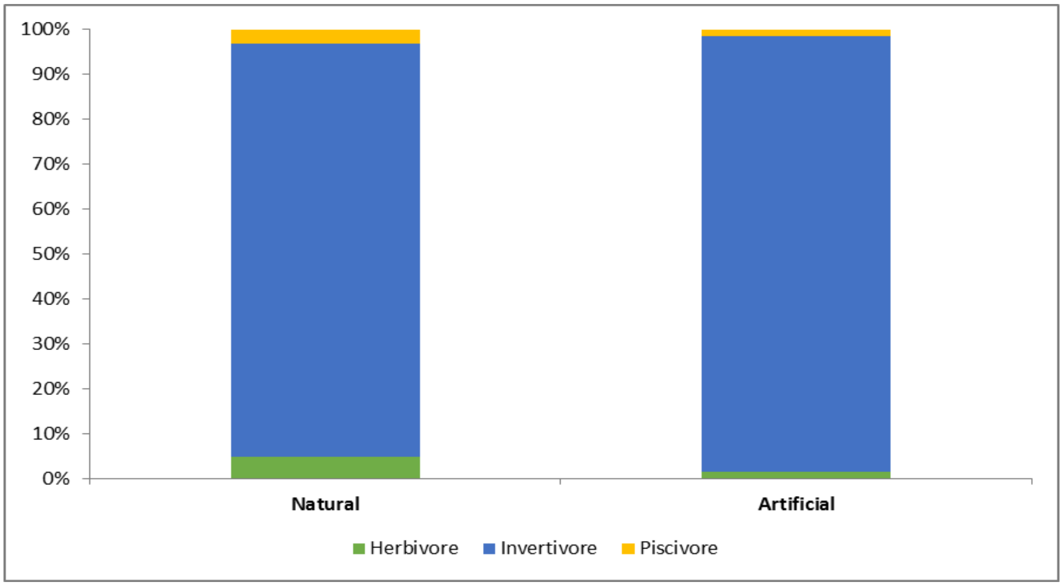


Figure 18. Percent of the fish assemblage (by abundance) consisting of herbivores, invertivores, and piscivores at the natural reef and artificial reef sites.

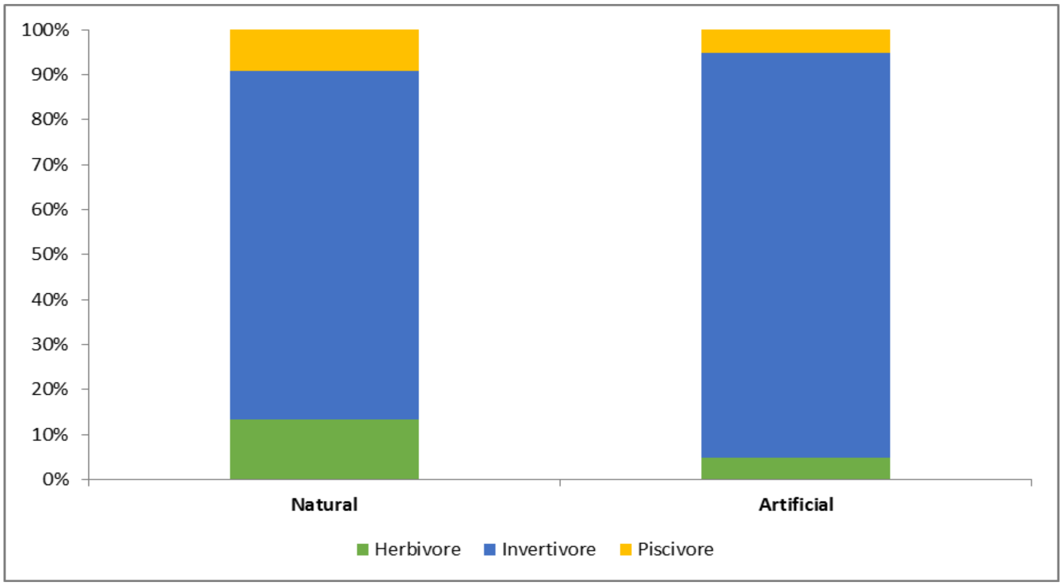


Figure 19. Percent of the fish assemblage (by abundance) excluding *Decapterus* spp. consisting of herbivores, invertivores, and piscivores in the natural reef sites and artificial reef sites.

Analysis of similarities (ANOSIM) using the categorical factor of reef age/location (New, Old, Near, and Far) showed that there were significant differences in fish assemblages between the four treatment groups (*p*=0.001, **Figure 20**). Pairwise comparisons indicated that fish communities at the Far natural and New artificial reef sites contained the most dissimilar assemblages (R stat=0.806). The second most dissimilar assemblages were between the Far natural and the Old artificial reef sites (R stat=0.493). The Near natural reef sites were also significantly different from both New (Global R stat=0.491) and Old (Global R=0.348) artificial reef sites, but the dissimilarity was not as strong. Species that had the highest contribution to the dissimilarity between each of the four treatment groups are listed in **Table 16**.

As **Figure 20** shows, the artificial sites clustered together at the bottom right of the MDS graph while the natural sites were more spread out in the top left. This clustering indicates that there were different fish assemblages on the natural and the artificial sites, and the artificial reefs are more similar to each other than the natural sites are to each other. An ANOSIM showed a significant difference between the natural and the artificial reefs (*p*=0.001). The top contributors to the difference between the natural and artificial reef sites are *Decapterus* spp., and the commercially important *H. aurolineatum*, *C. crysos*, and *L. griseus,* all were more abundant on the artificial reefs than on the natural reef sites. **Figure 21** shows the MDS plot of survey sites overlaid with abundances of commercially important species that had the greatest level of influence on the difference between natural and artificial reef sites. Conversely, the small, reef-associated *Stegastes* spp. and *Chromis* spp. and *Acanthurus* sp. showed higher abundance at the natural reef sites.

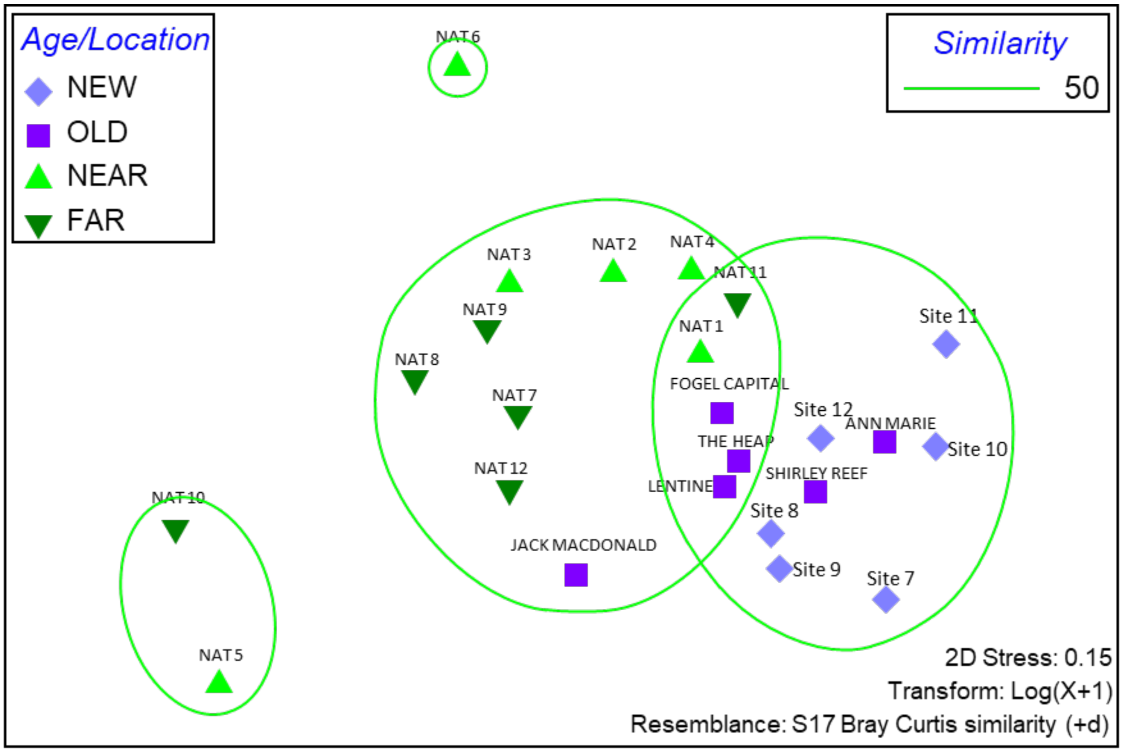


Figure 20. MDS plot based on abundance data of the fish assemblages at the natural and artificial reef sites with the age/location modifiers as factors overlaid with 50% similarity clusters.

Table 16. Species with the highest contribution to the differences (dissimilarity) in the fish assemblage at the New and Old artificial sites and Near and Far natural sites. Top 10 species listed. Asterisks (*) indicate species with managed fisheries.

Scientific Name	Common Name	Higher Group	Mean % Dissimilarity	% Contribution
NEAR v. OLD				
Decapterus spp.	Mackerel/Round Scad	Old	4.72	8.52
*Haemulon aurolineatum**	Tomtate	Old	2.23	4.03
Coryphopterus personatus/hyalinus	Masked/Glass Goby	Old	1.84	3.32
Stegastes partitus	Bicolor Damselfish	Near	1.83	3.30
Chromis insolata	Sunshinefish	Near	1.70	3.07
*Caranx crysos**	Blue Runner	Old	1.53	2.76
Chromis scotti	Purple Reeffish	Old	1.48	2.68
*Lutjanus griseus**	Grey Snapper	Old	1.42	2.56
*Balistes capriscus**	Grey Triggerfish	Near	1.40	2.52
Pseudupeneus maculatus	Spotted Goatfish	Near	1.27	2.28

Scientific Name	Common Name	Higher Group	Mean % Dissimilarity	% Contribution
FAR v. OLD				
Decapterus spp.	Mackerel/Round Scad	Old	5.54	10.16
*Haemulon aurolineatum**	Tomtate	Old	2.85	5.23
Coryphopterus personatus/hyalinus	Masked/Glass Goby	Old	1.90	3.48
Stegastes partitus	Bicolor Damselfish	Far	1.82	3.33
*Lutjanus griseus**	Grey Snapper	Old	1.73	3.16
*Caranx crysos**	Blue Runner	Old	1.71	3.14
Chromis scotti	Purple Reeffish	Old	1.42	2.60
Acanthurus chirurgus	Doctorfish	Far	1.36	2.49
Chromis enchrysura	Yellowtail Reeffish	Far	1.20	2.21
*Balistes capriscus**	Grey Triggerfish	Far	1.12	2.05

Scientific Name	Common Name	Higher Group	Mean % Dissimilarity	% Contribution
NEAR v. NEW				
Decapterus spp.	Mackerel/Round Scad	New	5.33	8.96
*Haemulon aurolineatum**	Tomtate	New	2.84	4.78
Stegastes partitus	Bicolor Damselfish	Near	1.78	3.00
*Caranx crysos**	Blue Runner	New	1.68	2.82
*Seriola rivoliana**	Almaco Jack	New	1.49	2.50
Chromis enchrysura	Yellowtail Reeffish	Near	1.33	2.24
*Balistes capriscus**	Grey Triggerfish	Near	1.33	2.23
Chromis scotti	Purple Reeffish	Near	1.33	2.23
Clepticus parrae	Creole Wrasse	New	1.32	2.22
*Rhomboplites aurorubens**	Vermillion Snapper	New	1.28	2.16

Scientific Name	Common Name	Higher Group	Mean % Dissimilarity	% Contribution
FAR v. NEW				
Decapterus spp.	Mackerel/Round Scad	New	6.62	10.81
*Haemulon aurolineatum**	Tomtate	New	3.34	5.45
*Caranx crysos**	Blue Runner	New	1.79	2.93
Stegastes partitus	Bicolor Damselfish	Far	1.74	2.83
*Seriola rivoliana**	Almaco Jack	New	1.48	2.41
Clepticus parrae	Creole Wrasse	New	1.40	2.29
*Lutjanus griseus**	Grey Snapper	New	1.38	2.26
*Archosargus probatocephalus**	Sheepshead	New	1.35	2.20
*Epinephelus itajara**	Goliath Grouper	New	1.25	2.03
Halichoeres garnoti	Yellowhead Wrasse	Far	1.21	1.98

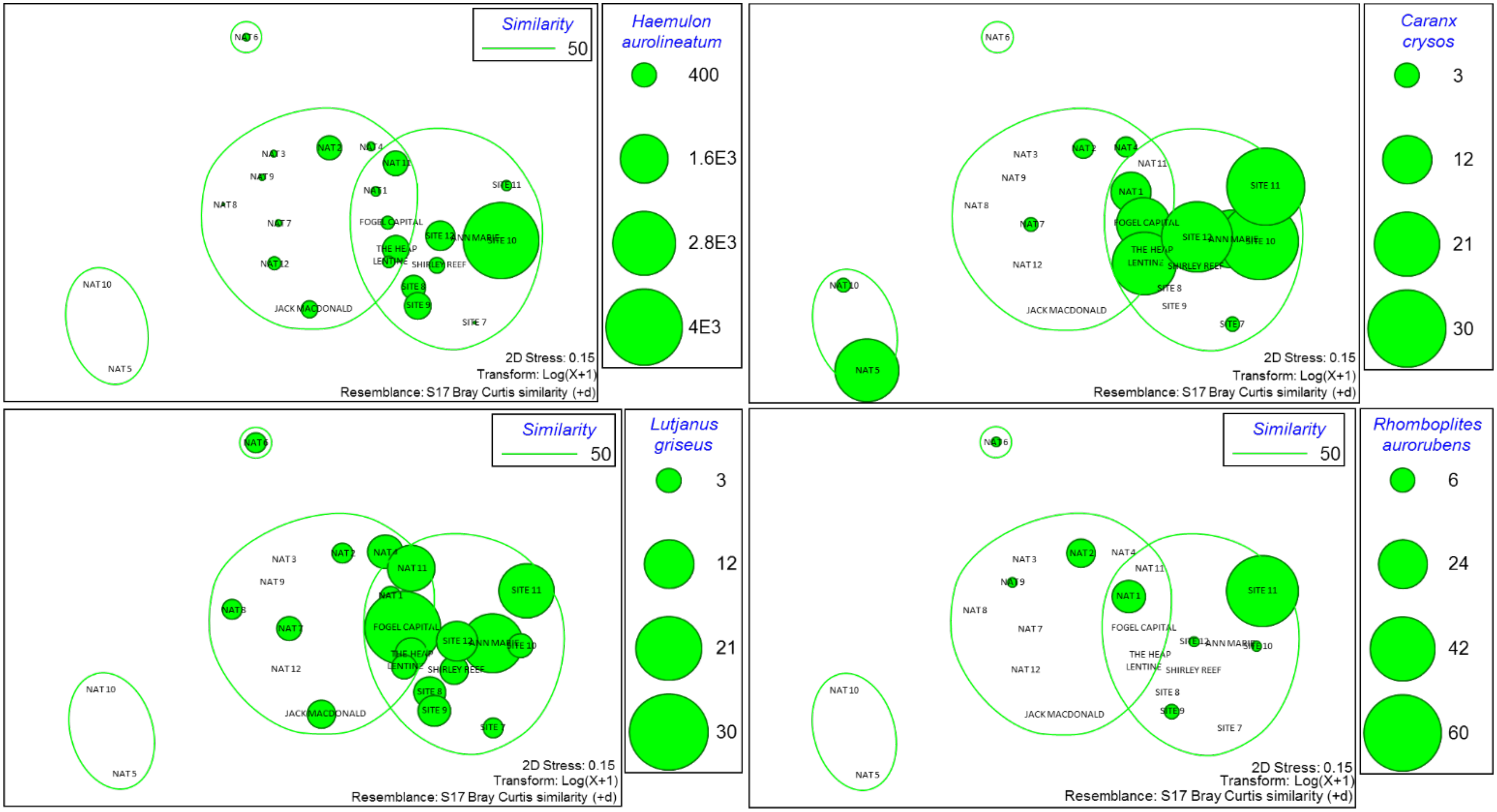


Figure 21. MDS plots from **Figure 20** with abundance of several commercially important species overlaid in the form of bubbles; larger bubbles correspond to higher abundance of *Haemulon aurolineatum* (top left), *Caranx crysos* (top right), *Lutjanus griseus* (bottom left), and *Rhomboplites aurorubens* (bottom right).

3.3.4 Nekton observed in benthic quadrats

Sixteen fish species were observed by the benthic surveyor while conducting quadrat assessments (**Table 17**). Six of these species were not recorded in the quantitative visual point count surveys at the site and are indicated in red text. While they were present at those sites, these species were not included in nektonic analyses because they were outside of the observer's cylinder. The most fish seen by the benthic surveyor was at the old artificial reef, The Heap. The Heap contained the highest species richness of all artificial reefs (**Table 9**).

Table 17. Species observed while conducting quadrat assessments. Species in red were not observed during visual point count observations.

Age/Location	Site	Quad	Scientific Name	Common Name	Number
OLD	Fogel Capital	3	*Thalassoma bifasciatum*	Bluehead	2
	The Heap	3	*Elacatinus oceanops*	Neon Goby	1
	The Heap	3	*Serranus annularis*	Orangeback Bass	1
	The Heap	3	*Pseudupeneus maculatus*	Spotted Goatfish	1
	The Heap	4	*Thalassoma bifasciatum*	Bluehead	1
	The Heap	3	*Cryptotomus roseus*	Bluelip Parrotfish	2
	The Heap	3	*Holacanthus ciliaris*	Queen Angelfish	1
	The Heap	3	*Halichoeres bivittatus*	Slippery Dick	1
	The Heap	3	*Ocyurus chrysurus*	Yellowtail Snapper	1
	Jack MacDonald	1	*Coryphopterus glaucofraenum*	Bridled Goby	1
	Jack MacDonald	2	*Coryphopterus glaucofraenum*	Bridled Goby	1
	Jack MacDonald	2	*Stegastes variabilis*	Coco Damselfish	1
	Jack MacDonald	3	*Serranus annularis*	Orangeback Bass	1
	Jack MacDonald	1	*Holacanthus tricolor*	Rock Beauty	1
	Jack MacDonald	2	*Rypticus maculatus*	Whitespotted Soapfish	1
NEW	Site 9	4	*Canthigaster rostrata*	Sharpnose Puffer	1
	Site 12	1	*Thalassoma bifasciatum*	Bluehead	1
	Site 12	1	*Canthigaster rostrata*	Sharpnose Puffer	1
NEAR	NAT 2	1	*Gymnothorax miliaris*	Goldentail Moray	1
	NAT 4	3	*Stegastes variabilis*	Coco Damselfish	1
FAR	NAT 7	1	*Stegastes partitus*	Bicolor Damselfish	1
	NAT 8	2	*Coryphopterus glaucofraenum*	Bridled Goby	1
	NAT 8	2	*Canthigaster rostrata*	Sharpnose Puffer	2
	NAT 9	2	*Canthigaster rostrata*	Sharpnose Puffer	1
	NAT 10	1	*Pomacanthus arcuatus*	Gray Angelfish Juvenile	1
	NAT 11	1	*Stegastes partitus*	Bicolor Damselfish	2
	NAT 11	3	*Stegastes partitus*	Bicolor Damselfish	1
	NAT 11	3	*Thalassoma bifasciatum*	Bluehead	1
	NAT 11	4	*Thalassoma bifasciatum*	Bluehead	5
	NAT 11	1	*Canthigaster rostrata*	Sharpnose Puffer	1

3.3.5 Comparisons with other Studies

The 2015 Martin County artificial reef monitoring program data were analyzed with the 2016 data using multivariate analyses. Generally, the natural reef sites clustered with the South County sites from 2015 and 2016 more than the 2015 Donaldson sites (**Figure 22**), indicating that the South County sites, which are closer to natural reefs, contain assemblages that are more similar to the natural reef. An ANOSIM showed that assemblages at the three locations were significantly different (p=0.001). The assemblages at Donaldson artificial reef sites were most dissimilar from the natural reef sites (R stat=0.695) and were also relatively dissimilar from the South County assemblages (R stat=0.551). The assemblages at the South County artificial reef and Natural reef sites were still significantly different from each other, but contained the most similar assemblages (R stat=0.496).

Table 18 shows the species with the highest contribution to the differences in the assemblages. Tomtate (*H. aurolineatum*) was a major contributor to the differences in assemblages between natural reefs and both Donaldson and South County artificial reefs, but did not contribute as much to the differences in assemblages between the two artificial reef sites. The artificial reefs at Donaldson are located further away from natural reefs and at shallower depths (45-56 ft) than the South County (72-91 ft) and natural reef sites (68-80 ft). Therefore, assemblages at these locations are expected to be significantly different.

The 2015 Year 2 post-deployment data from Donaldson were compared to the 2016 Year 2 post-deployment from South County. The reefs contained significantly different nekton assemblages (p=0.002, **Figure 23**). BJM 13 is separated from the majority of the Donaldson sites, likely because it was sampled in November 2015 while Donaldson North was sampled on July 23, 2015, and the remaining Year 2 Donaldson sites were sampled on August 11, 2015. A strong upwelling event occurred during the July 2015 surveys which had subsequently subsided by the November 2015 surveys. The species that contributed most to the differences are shown in **Table 19**. Species differences are consistent with those presented in **Table 18**; Donaldson had higher overall species richness and abundance. Inter-seasonal and inter-annual differences were also noted in the benthic communities between the two Year 2 post-deployment artificial reefs (**Section 3.2.2**).

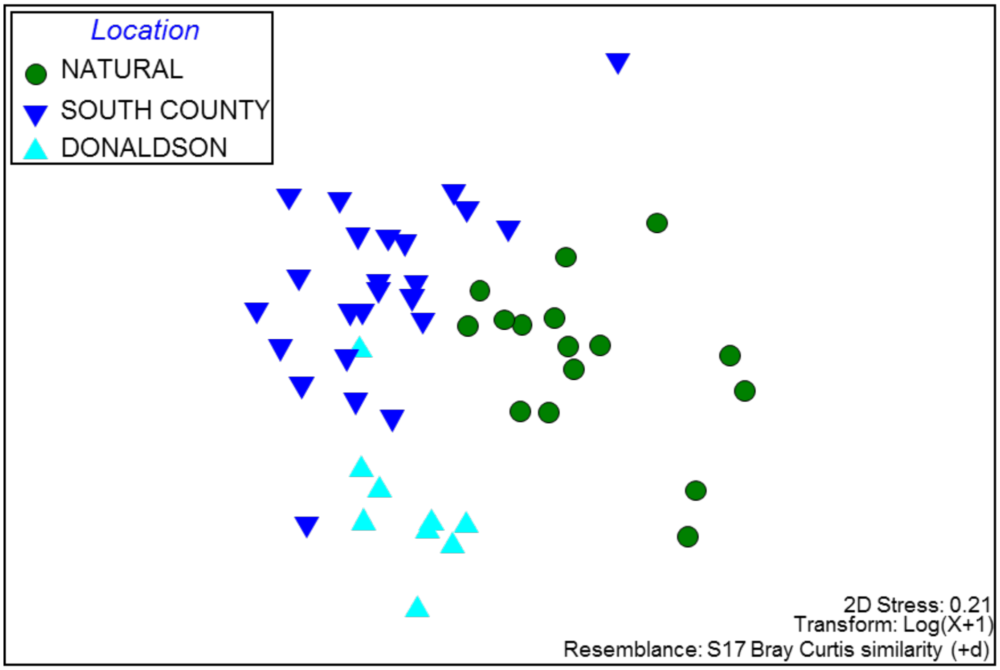


Figure 22. MDS plot based on abundance data of the fish assemblages at the natural and artificial reef sites from 2015 and 2016 with the habitat modifiers as factors.

Table 18. Species with the highest contribution to differences (dissimilarity) in fish assemblages at the Donaldson, South County and natural sites. Top 15 species listed. Asterisks (*) indicate species with managed fisheries.

Scientific Name	Common Name	Higher Group	Mean % Dissimilarity	% Contribution
South County v. Natural				
Decapterus spp.	Mackerel/Round Scad	South County	4.61	7.41
*Haemulon aurolineatum**	Tomtate	South County	2.90	4.67
Stegastes partitus	Bicolor Damselfish	Natural	2.12	3.41
Chromis enchrysura	Yellowtail Reeffish	Natural	1.91	3.07
Haemulan spp.	Grunts, Juvenile/Unid	South County	1.86	2.99
Chromis scotti	Purple Reeffish	South County	1.58	2.54
*Lutjanus griseus**	Grey Snapper	South County	1.53	2.46
*Caranx crysos**	Blue Runner	South County	1.45	2.34
Acanthurus chirurgus	Doctorfish	Natural	1.35	2.18
*Rhomboplites aurorubens**	Vermillion Snapper	South County	1.32	2.13
Stegastes leucostictus	Beaugregory	Natural	1.28	2.05
*Balistes capriscus**	Grey Triggerfish	Natural	1.26	2.03
Halichoeres bivattatus	Slippery Dick	Natural	1.18	1.90
Thalassoma bifasciatum	Bluehead	South County	1.16	1.87
Acanthurus bahianus	Ocean Surgeon	Natural	1.15	1.84

Scientific Name	Common Name	Higher Group	Mean % Dissimilarity	% Contribution
Donaldson v. Natural				
Haemulan spp.	Grunts, Juvenile/Unid	Donaldson	4.78	7.40
Parablennius marmoreus	Seaweed Blenny	Donaldson	2.59	4.02
Malacoctenus triangulatus	Saddled Blenny	Donaldson	2.38	3.68
Chromis enchrysura	Yellowtail Reeffish	Donaldson	1.88	2.91
*Haemulon aurolineatum**	Tomtate	Donaldson	1.83	2.84
Stegastes leucostictus	Beaugregory	Donaldson	1.82	2.82
*Caranx crysos**	Blue Runner	Donaldson	1.72	2.66
Halichoeres bivattatus	Slippery Dick	Donaldson	1.72	2.66
Stegastes variabilis	Cocoa Damselfish	Donaldson	1.65	2.55
Stegastes partitus	Bicolor Damselfish	Natural	1.54	2.39
*Seriola rivoliana**	Almaco Jack	Donaldson	1.32	2.05
Decapterus spp.	Mackerel/Round Scad	Natural	1.29	2.00
Anisotremus virginicus	Porkfish	Donaldson	1.29	2.00
Chromis scotti	Purple Reeffish	Natural	1.29	1.99
Sparisoma atomarium	Greenblotch Parrotfish	Donaldson	1.23	1.91

Scientific Name	Common Name	Higher Group	Mean % Dissimilarity	% Contribution
South County v. Donaldson				
Haemulan spp.	Grunts, Juvenile/Unid	Donaldson	3.96	6.54
Decapterus spp.	Mackerel/Round Scad	South County	3.51	5.79
Parablennius marmoreus	Seaweed Blenny	Donaldson	2.39	3.95
Chromis enchrysura	Yellowtail Reeffish	Donaldson	2.14	3.53
Malacoctenus triangulatus	Saddled Blenny	Donaldson	2.08	3.43
Stegastes leucostictus	Beaugregory	Donaldson	1.89	3.12
Halichoeres bivattatus	Slippery Dick	Donaldson	1.74	2.88
Chromis scotti	Purple Reeffish	South County	1.55	2.56
Anisotremus virginicus	Porkfish	Donaldson	1.55	2.56
Stegastes variabilis	Cocoa Damselfish	Donaldson	1.55	2.55
*Caranx crysos**	Blue Runner	Donaldson	1.52	2.50
Sparisoma atomarium	Greenblotch Parrotfish	Donaldson	1.21	2.00
Serranus subligarius	Belted Sandfish	Donaldson	1.17	1.93
Cryptotomus roseus	Bluelip Parrotfish	Donaldson	1.14	1.88
*Seriola rivoliana**	Almaco Jack	Donaldson	1.08	1.78

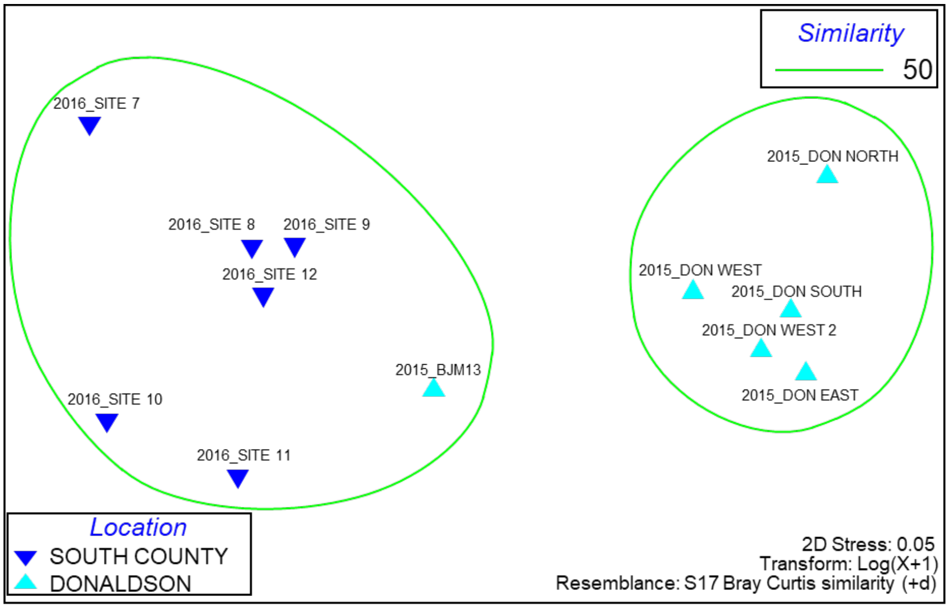


Figure 23. MDS plot based on abundance data of the fish assemblage at the 2015 Donaldson Year 2 post-deployment artificial reefs and the 2016 South County Year 2 post-deployment artificial reefs.

Table 19. Species with the highest contribution to differences (dissimilarity) in the fish assemblages at the Donaldson and South County Year 2 Post-deployments. Top 15 species listed. Asterisks (*) indicate species with managed fisheries.

Scientific Name	**Common Name**	**Higher Group**	**Mean % Dissimilarity**	**% Contribution**
Donaldson v. South County				
Decapterus spp.	Mackerel/Round Scad	South County	4.53	7.36
Haemulan spp.	Grunts, Juvenile/Unid	Donaldson	4.53	7.35
Parablennius marmoreus	Seaweed Blenny	Donaldson	2.80	4.55
Malacoctenus triangulatus	Saddled Blenny	Donaldson	2.31	3.74
Stegastes leucostictus	Beaugregory	Donaldson	2.02	3.27
Halichoeres bivattatus	Slippery Dick	Donaldson	1.99	3.23
Anisotremus virginicus	Porkfish	Donaldson	1.93	3.13
Chromis enchrysura	Yellowtail Reeffish	Donaldson	1.70	2.77
Sparisoma atomarium	Greenblotch Parrotfish	Donaldson	1.52	2.46
Stegastes variabilis	Cocoa Damselfish	Donaldson	1.42	2.30
*Caranx crysos**	Blue Runner	Donaldson	1.41	2.29
*Haemulon aurolineatum**	Tomtate	South County	1.39	2.25
Chromis scotti	Purple Reeffish	South County	1.33	2.15
*Centropomus undecimalis**	Common Snook	Donaldson	1.25	2.03
Stegastes partitus	Bicolor Damselfish	Donaldson	1.20	1.94

The Reef fish Visual Census (RVC) data from 2013-2015 were added to the multivariate analyses to explore possible differences in reef fish assemblages on natural reef sites closer to the artificial reefs compared to natural sites farther away. The northern limit of the RVC survey frame is the St. Lucie Inlet. Because the Donaldson artificial reef site is located north of St. Lucie Inlet and was found to be significantly different from the 2015-2016 South County artificial reefs assemblages, the 2015 Donaldson sites were excluded from these analyses. When data were analyzed by location, the South County artificial reef sites were tightly clustered together on the left side of the plot while the Near, Middle and Far natural reef sites were greatly intermixed and spread apart across the rest of the graph (**Figure 24**). When broken up into locations, the three categories of natural reef (Near, Middle and Far) were not as strongly significantly different from each other (R stat=0.075- 0.163, p=0.003-0.020) as they were from the South County artificial reefs (R stat=0.345-0.514, p=0.001).

The RVC data provide an interesting way to study the potential effects of artificial reef deployment near a natural reef edge. The RVC data include sites that were sampled prior to the 2014 deployment of the New South County artificial reefs. An ANOSIM was performed for all data by year and location. The Near natural sites showed an interesting trend of increasing similarities with the artificial sites in assemblage structure from 2013 (pre-construction) to 2016 (2 years post-construction) (**Table 20**, left). The 2013 and 2014 Near natural sites are spread further to the left of the MDS plot while the 2015 and 2016 Near natural sites are located closer to the 2015 and 2016 artificial reefs (**Figure 25**). The 2013 Near natural assemblages are also strongly significantly different from the 2016 Near natural assemblages (R stat=0.802, p=0.005, **Table 20**, right). The species that contributed most to the dissimilarity between Near natural reef fish assemblages in 2013 and 2016 are listed in **Table 21**.

The Near natural reef sites in 2013 contained relatively higher abundances of the commercially important Blue Runner (*Caranx crysos*), Grey Snapper (*Lutjanus griseus*) and Black Seabass (*Centropristis striata*). While *C. striata* was not observed in any of the 2016 surveys, both *L. griseus* and *C. crysos* were relatively more abundant on the artificial reefs than natural reefs in 2016 (**Table 16**). Conversely, *H. aurolineatum* and Scad Spp. (*Decapterus* spp.) were relatively more abundant on the Near natural reefs in 2016. This could indicate mixing of assemblages as the New artificial reefs became more established or possibly migration from the natural reefs to the artificial reefs.

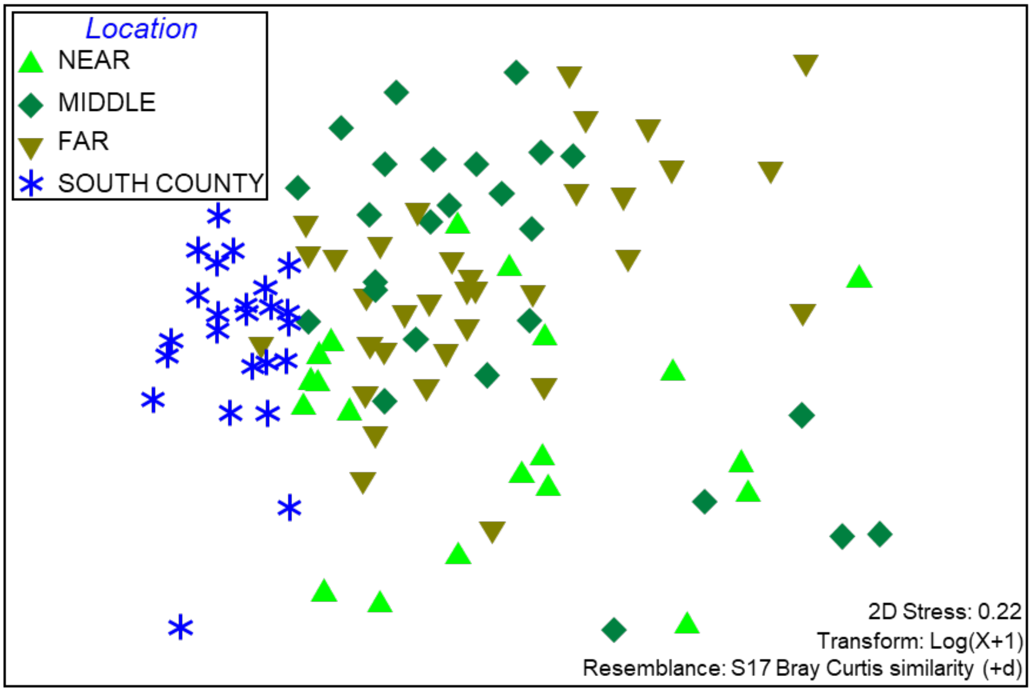


Figure 24 . MDS plot based on abundance data of the fish assemblage at the South County artificial reef sites and Near, Middle and Far natural reef sites (this study and RVC) with the locations as factors.

Table 20. ANOSIM results comparing the Near natural reef sites to the artificial (left) and Near natural (right) reefs by year. Significant differences are in red.

Near Natural v. Artificial	R stat	Significance
2013 Natural, 2015 Artificial	0.895	0.001
2013 Natural, 2016 Artificial	0.984	0.002
2014 Natural, 2015 Artificial	0.808	0.002
2014 Natural, 2016 Artificial	0.934	0.001
2015 Natural, 2015 Artificial	0.628	0.001
2015 Natural, 2016 Artificial	0.842	0.001
2016 Natural, 2015 Artificial	0.454	0.002
2016 Natural, 2016 Artificial	0.591	0.001

Near Natural v. Near Natural	R stat	Significance
2013 Natural, 2014 Natural	0	0.457
2013 Natural, 2015 Natural	0.425	0.024
2013 Natural, 2016 Natural	0.802	0.005
2014 Natural, 2015 Natural	0.258	0.100
2014 Natural, 2016 Natural	0.496	0.010
2015 Natural, 2016 Natural	0.094	0.152

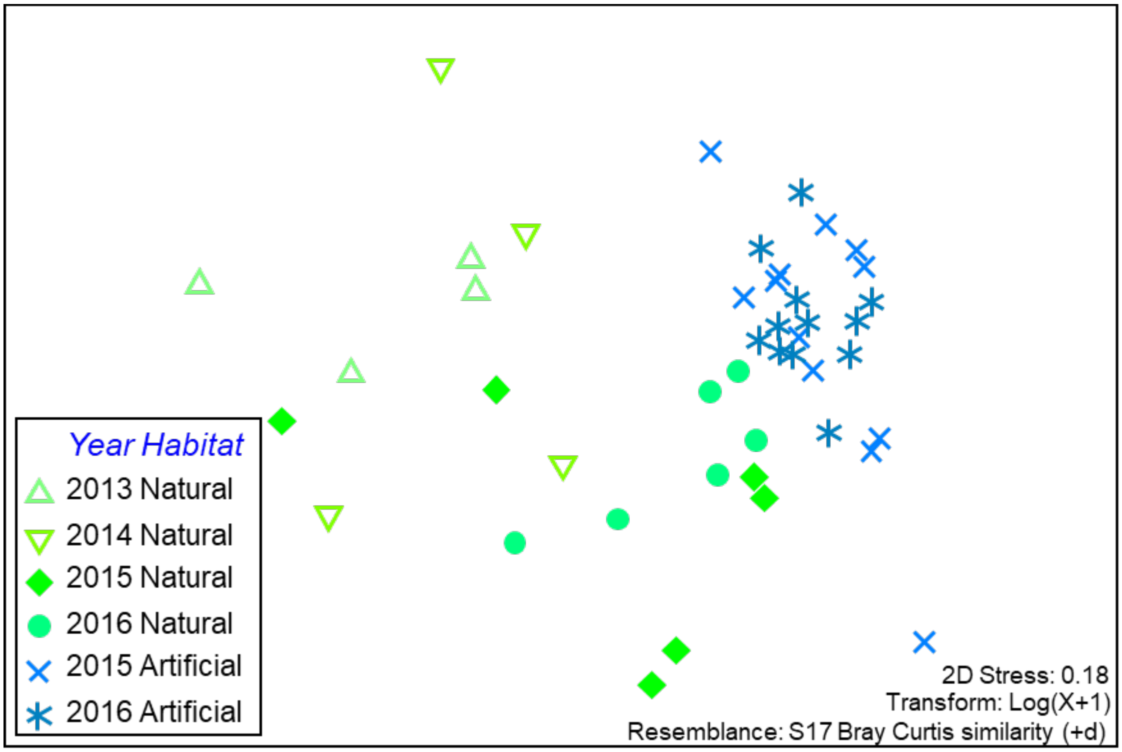


Figure 25. MDS plot based on abundance data of the fish assemblage at the South County artificial reefs and Near natural sites (this study and RVC) with year as the factor.

Table 21. Species with the highest contribution to differences (dissimilarity) in the fish assemblages at the Near natural reefs in 2013 and Near natural reefs in 2016. Top 15 species listed. Asterisks (*) indicate species with managed fisheries.

Scientific Name	Common Name	Higher Group	Mean % Dissimilarity	% Contribution
Near 2013 v. Near 2016				
*Haemulon aurolineatum**	Tomtate	2016	5.11	6.80
Thalassoma bifasciatum	Bluehead	2016	3.87	5.15
Decapterus spp.	Mackerel/Round Scad	2016	3.06	4.06
Stegastes partitus	Bicolor Damselfish	2016	2.54	3.38
Canthigaster rostrata	Sharpnose Puffer	2016	2.46	3.27
Chromis scotti	Purple Reeffish	2016	2.34	3.10
Chromis enchrysura	Yellowtail Reeffish	2016	2.20	2.92
*Caranx crysos**	Blue Runner	2013	2.14	2.85
*Lutjanus griseus**	Grey Snapper	2013	2.09	2.78
Pseudupeneus maculatus	Spotted Goatfish	2016	1.86	2.47
Coryphopterus glaucofraenum	Bridled Goby	2016	1.81	2.41
Pareques umbrosus	Cubbyu	2016	1.80	2.39
*Centropristis striata**	Black Seabass	2013	1.62	2.15
Chromis insolata	Sunshinefish	2016	1.54	2.05
Halichoeres garnoti	Yellowhead Wrasse	2016	1.52	2.02

4.0 DISCUSSION

Differences in assemblage structure between natural and artificial habitats are common (Carr and Hixon, 1997; Hackradt et al., 2011; Kilfoyle et al., 2013; Kojansow et al., 2013); however, this has not been previously documented on artificial reefs in Martin County. The location of the South County artificial reef deployments in close proximity to natural reef presents a unique opportunity to directly compare the artificial reefs with the nearby natural hardbottom assemblage. While high-relief natural reefs were targeted to enable the best comparisons, natural reef sites with similarly high relief to the artificial reefs were not always available. Average vertical relief on the natural reefs was almost half of the South County artificial reef sites in this study (4.8 ft ± 0.7 vs. 8.5 ft ± 1.1, 1.5 m ± 0.2 vs. 2.6 m ± 0.3 respectively) and one third of the Donaldson artificial reefs (14 ft, 4.3 m). Donaldson artificial reefs are located at a maximum depth of 59 ft (18.0 m) while natural reef sites and South County sites are located in similar water depths with a minimum depth of 68 ft (20.7 m). Differences in physical structures and distance from the natural reef can lead to significantly different nekton assemblages on the Donaldson Reefs, regardless of post-deployment age.

4.1 Benthic Assemblages

Overall, the benthic communities on the South County natural and artificial reefs were highly similar with no significant differences in cover of the two major functional groups, turf algae and macroalgae. These results suggest that differences in the fish community between natural and artificial reefs did not affect the cover of turf and macroalgal species during the 2016 surveys. However, during surveys in the same area in 2015, a higher abundance of Surgeonfish (*Acanthurus* spp.) was found on natural reefs, whereas significantly higher cover of macroalgae was found on the artificial reefs (CEG, 2016). During the 2015 surveys, only four natural sites were surveyed with a total of 13 quadrats compared to 42 quadrats on natural hardbottom in 2016. In addition, natural sites were surveyed in November 2015 in comparison to August 2016 in the current study. It is possible that seasonal abiotic differences resulted in lower cover of macroalgae (9.0 ± 1.6%) on natural hardbottom in 2015 compared to 2016 (overall average of 26.5 ± 2.2%).

The significantly higher cover of encrusting red algae at the natural reefs, also observed during the 2015 surveys, indicates that some differences in grazing pressure may exist between natural and artificial reefs that specifically affect encrusting coralline algae cover. High cover of encrusting red algae on the natural reefs may be due to increased grazing by species that were not included in the surveys such as urchins. Future surveys should include a standardized urchin count to better understand grazing differences between natural and artificial reefs.

Stony corals and octocorals were observed on the artificial reefs, but were found in very low abundance. Stony corals were relatively common on the natural reef. In a study comparing the benthic communities on natural and artificial reefs in Miami-Dade County, Thanner et al. (2006) found a similar relatively low abundance of stony corals and octocorals on the artificial reefs within the first six years of establishment. It is possible that the distance to the natural reef is too far, or that recruitment is hindered by epibiotic growth on the artificial structures, or there is increased predation pressure on the artificial structures. *Siderastrea radians*, a species commonly observed on the natural reefs, is a brooding coral that may have limited larval dispersal. The location of the New artificial deployments in closer proximity to the natural reef may enhance natural recruitment of this species, but this effect will likely not be noticeable for several years.

The overall lack of significant differences in cover of most faunal groups between artificial reefs of different ages and different locations (Donaldson and South County) indicates that the benthic community recruits rapidly on artificial structures in Martin County and is mostly similar to older artificial reefs within the first two years post-deployment. Thanner et al. (2006) found that the benthic assemblages on the artificial reefs in Miami-Dade County appeared to stabilize five years post-deployment. The most common differences observed between artificial reefs of different ages and locations in the present study were differences in cover of trace to low-cover benthic functional groups such as hydroids, tunicates, and bryozoans. Comparisons of benthic faunal groups at the Old South County artificial reefs from 2015 to 2016 show that cover of these groups can change significantly on both young and older artificial reefs. However, the Old South County artificial reefs were surveyed in November 2015 and August 2016; therefore, seasonal differences may account for some variability. Seasonal and annual variability in recruitment and growth likely outweigh any long-term differences in the community due to reef age.

Despite changes in the Old South County reefs between 2015 and 2016, there were no significant changes in the New South County artificial reef benthic community between 2015 and 2016 except for a small decrease in cover of encrusting red algae. This supports the observation that the benthic community develops quickly at the artificial reefs and reaches a stable state comparable to natural reefs except for stony coral and encrusting red algae cover.

The Donaldson artificial reefs at two years post-deployment were also very similar to the South County reefs at two years post-deployment. The only differences were sponge and hydroid cover, both were higher at Donaldson; however, the differences were relatively minor from a biological perspective (6.0 ± 0.9% versus 2.1 ± 1.0% sponge cover and 8.1 ± 1.8% versus 4.0 ± 1.2% hydroid cover). These results suggest that the location of artificial reefs in closer proximity to natural hardbottom in the South County artificial reef site does not likely have much influence on development of the majority of benthic functional groups. There are many factors that may contribute to differences in sponge and hydroid cover, including distance to natural reefs, annual variability between 2015 and 2016, and differences in water depth. It will likely take more time to determine if the location of the New South County artificial reefs in relatively close proximity (600 ft compared to 1,250 ft) to natural hardbottom enhances stony coral recruitment onto the reefs, or if long-term differences in the benthic community will develop at the 2014 South County deployments compared to the 2008 South County deployments.

4.2 Fish Assemblage

The overall goal of the South County artificial reef area is to provide recruitment space for obligate hardbottom species such as grouper and snapper with the ultimate goal of fisheries enhancement for reef fish populations. Results from this study show that there were significant differences in the fish assemblage at the artificial reefs and natural reef ridge. The natural reef sites contained higher overall species richness while the artificial reefs contained higher overall fish abundance. The natural sites located closest to the artificial reefs contained higher abundance and were more similar in assemblage structure to the artificial reefs than the Far natural sites. There were no significant differences in species richness or fish abundance between the New and Old artificial reefs, and the artificial reef sites cluster tightly together in MDS plots relative to natural reefs (**Figure 24**). These results indicate that, although there are persistent differences in the fish assemblages utilizing artificial reef habitat versus natural reef, there may be some mixing between the Near natural reef ridge and artificial reefs, creating populations on the Near natural reef that are more similar to the artificial reef assemblage. Between 2013 and 2016, the Near natural reefs showed relative increases in abundance of Tomtate (*Haemulon aurolineatum)* and Scad Spp. (*Decapterus* spp.); both were relatively more abundant on the artificial reefs than the natural reefs in 2016. The natural reefs had higher variability in their fish assemblages than the artificial reefs, while the artificial reef fish assemblages were consistently similar to each other. Deployment of artificial reefs near natural reefs may make the artificial reefs an extension of the existing natural hardbottom, providing possible enrichment of fish recruitment at the natural reefs (Danner et al., 1994; Pickering and Whitmarsh, 1997).

Comparing results from the current study to prior studies in Martin County further clarifies the extent of mixing which occurs between natural and artificial reef fish assemblages. The RVC surveys performed near the artificial reef sites show an interesting trend of mixing between natural and artificial assemblages. The RVC sites near the South County artificial reefs were highly dissimilar in 2013 before the New artificial reefs were deployed. The deployment of the New artificial reefs in the South County site occurred in the summer of 2014 at about the same time as the 2014 RVC surveys; fish assemblages were still highly different. After deployment of the New artificial reefs, fish assemblages on natural reefs near the artificial reefs in 2015 and 2016 became more similar to the South County artificial reef assemblages. Future comparisons between natural reef RVC data and artificial reef monitoring will help to show if mixing continues and similarities in assemblages increase or if there is a plateau in the level of mixing between reef types.

The fish assemblage on the South County artificial reefs was highly diverse with 77 species observed overall. The maximum number on a single reef was 39 species at The Heap. Review of previous monitoring reports from the 2008 deployments showed a high of 38 species in 2015 and a 36 species in 2009; both were also observed at The Heap. In 2015, the New artificial reefs contained 58 species overall, whereas the 2016 surveys recorded 63 species.

The fish assemblage on the natural reef sites was more diverse (98 species) than the artificial reefs. The maximum number of species observed on a single natural reef site was 46 species at site NAT 11. Site NAT 11 also contained the second highest fish abundance of the natural reef sites. NAT 11 is located far from the artificial reefs and is the shallowest natural sites sampled in this study. Although NAT 11 is located far from artificial reefs, the Near natural sites also had high abundances (highest abundance was at NAT 4) and species richness (higher at Near natural sites), and there were no significant differences in the fish assemblages based on the factor of distance (Near/Far). Higher species richness on natural reefs compared to artificial reefs has been recorded in other studies (Carr and Hixon, 1997; Kojansow et al., 2013). Even without the higher vertical relief typical of artificial reefs, natural reef structure provides a different level of complexity and refuge space than artificial habitats. Species richness results from Carr and Hixon (1997) and this study show that, even though the artificial reefs contain higher vertical relief and greater shelter availability, these features do not compensate for the greater structural complexity and natural forage base provided by corals and associated benthos of natural reefs.

The primary contributors to the difference between artificial reef and natural reef sites were the genera *Haemulon* (Grunt) and *Decapterus* (Scad). Both genera are commonly found in high abundance on artificial reefs. *Haemulon aurolineatum* are commonly reported in high abundance on artificial reefs and are often the first species to colonize new artificial structures. It is unclear why this species is attracted to artificial habitat and seems to settle onto artificial reefs in high density. *Haemulon aurolineatum* was a primary contributor to the difference between artificial and natural reefs in previous studies in south Florida (Walker et al. 2002; Thanner et al. 2006; Arena et al. 2007; Kilfoyle et al. 2013).

Juvenile *H. aurolineatum* are likely an important source of prey to resident predatory fish species due to their overwhelming abundance. Juvenile *Haemulon* spp. contributed greatly to fish abundance on the South County artificial reefs during the 2015 surveys. Conversely, juvenile *Haemulon* spp. were not observed at the Old artificial reefs in 2016 and only in small abundances on the New artificial reefs. The presence of *H. aurolineatum* could be highly dependent on annual recruitment success. Annual quantitative surveys of the artificial reefs could help to further clarify if recruitment success from the prior year contributes to high abundances of *H. aurolineatum*.

Fishes of the genus *Decapterus*, an important prey item of commercial and recreationally important species such as tunas, mackerels, sea basses and jacks (Grimes et al., 1982), dominated the artificial reef assemblages. *Decapterus* spp. are transient and highly aggregated, when present, they represent considerable biomass (Bohnsack et al., 1994). While these planktivores consume a wide variety of zooplankton throughout their lives, *Decapterus* spp. could have ecological importance as a predator on larvae and fish eggs, as well as a competitor for other planktonic food resources (Donaldson and Clavijo, 1994; Bohnsack et al., 1994). Although *Decapterus* spp. are frequently reported in high abundances on artificial reefs, spikes in fish abundance due to high numbers of this genera were also recorded on natural reefs in Martin County during the 2013 RVC surveys (Kilfoyle et al., 2015). The large difference in abundance between the Near and Far natural reef sites is partially attributed to the presence of *Decapterus* spp. Scad were present at two Near natural sites (NAT 1 and 4) and one Far natural site (NAT 11). Donaldson and Clavijo (1994) report that while Round Scad (*D. punctatus*) prefer artificial structures for predator avoidance (Rountree, 1989), there was no difference in the diets of *D. punctatus* between artificial and natural reefs in North Carolina. The authors suggest that placement of artificial reefs in proximity to natural reefs could increase the biomass of *D. punctatus*, which, in turn, could increase the biomass of many commercially important species due to proliferation of this important prey item (Donaldson and Clavijo, 1994).

The Goliath Grouper (*Epinephelus itajara*), the largest Grouper (Serranidae) in the Atlantic, were observed primarily on the artificial reef sites during this study. Adult *E. itajara* prefer high-relief artificial and natural reefs and regardless of life stage, show strong site fidelity to home sites (Koenig et al., 2011, Koenig et al., 2016), making them easy targets for commercial recreational fishing efforts. *Epinephelus itajara* aggregate on the coast of Southeast Florida in the late summer through early fall months to spawn (Koenig et al., 2011, Koenig et al., 2016). A total of 25 *E. itajara* individuals were observed on the artificial reefs in 2016. Overall, the New artificial reefs contained a higher relative abundance of *E. itajara* than Old artificial reefs, perhaps due to the relatively higher relief at the New artificial reefs. The only artificial reef site at which no individuals were observed was the Old artificial reef site, Jack Macdonald. While, the distinctive “boom” of *E. itajara* was heard by the surveyors at Jack Macdonald, strong currents and low visibility at the site during the survey did not allow for thorough investigation of the entire artificial reef site. Conversely, only two *E. itajara* individuals were observed on the natural sites in 2016; one at the Near natural site, NAT 1 and one at the Far natural site NAT 11. NAT 1 had the highest relief of all natural sites sampled in 2016. While the relief at NAT 11 was average for the natural reef sites, a large ledge was present to provide shelter. The higher relief and more intricate structures present at the artificial reefs may provide more opportunities to shelter these large Serranids.

The Blue Runner (*Caranx crysos*) is a commercially important predatory jack (Carangidae) species. The distribution of this species in the current study shows an interesting pattern that may be indicative of interactions between artificial reefs and nearby natural reef. *Caranx crysos* is a schooling pelagic carangid that was consistently a top contributor to the difference between treatments. *Caranx crysos* was found in higher abundance on the New artificial reefs and Near natural sites; the species was present on four of the six of the Old and New artificial reefs and Near natural reef sites, but only observed at two of the six Far natural sites. The length of *C. crysos* on the artificial reefs indicates that this species was likely attracted to the artificial structures rather than recruited, as length at maturity for *C. crysos* is estimated to be at about 22 to 24 cm (Goodwin and Finucane, 1985). Although no true juveniles were observed in this study, *C. crysos* spawn throughout the year with peaks in the summer months (Goodwin and Finucane, 1985; McMenney, et al., 1985; Brown et al., 2010). Conversely, some of the *C. crysos* observed on the natural reefs were most likely at an immature phase length, indicating that more of the life history of this species is spent on the natural reefs before being recruited to the artificial reefs. The species also shows a high degree of site fidelity with tagged fishes often detected at the same artificial site (Brown et al., 2010). Limited resources and competition on the artificial structures may have led to an increase of this species on the natural reefs that are near the new deployments.

The significant differences between the Donaldson and South County artificial reefs and natural reefs in Martin County show that various physical attributes (eg. location, proximity to natural reefs, vertical relief, etc.) contribute to the makeup of the nekton assemblages of this biogeographically diverse region, and each artificial reef is ecologically important regardless of age. This study will aid in future artificial reef site planning to improve conservation of commercially and recreationally important fish species.

5.0 CONCLUSIONS

The artificial reefs in Martin County support a diverse assemblage of fish and benthic invertebrates and provide additional hardbottom habitat to serve as a refuge for numerous commercially important fish species. Artificial reef deployments in the South County artificial reef site are located in close proximity to nearby natural hardbottom, and therefore it is likely that there is some degree of interaction with the natural hardbottom assemblage. The following summarizes the results of this study:

Benthic Community

- The benthic community on the New (2014) and Old (2008) artificial reef deployments was similar, indicating that benthic recruitment and succession on the New artificial reefs occurred relatively rapidly.
- There were no significant differences in cover of macroalgae and turf algae on artificial and natural reefs.
- Although stony corals and octocorals were observed on the artificial reefs, stony coral density remains significantly lower than on natural reefs.
- Consistently higher cover of encrusting red algae on the natural reefs in 2015 and 2016 indicates that some difference in grazing pressure likely exists between the two reef types. *Acanthurus* spp. were more common on natural reefs in 2015, but were not a major contributor to differences in 2016. Grazing pressure may be influenced by differences in urchin abundance between reef types.

Nekton Community

- The Old artificial reefs deployed in 2008 supported a diverse assemblage of fish; 60 species were recorded and 14 of these have managed fisheries. The New artificial reefs deployed in 2014 supported a slightly more diverse assemblage of fish; 63 species were recorded and 15 of these have managed fisheries.
- The artificial reefs had higher overall fish abundance while the natural reefs contained higher overall species richness. Differences were not statistically significant due to high variability.
- Near (inside permitted South County boundary) natural reef sites were more similar to artificial reefs than the Far (>4 km outside of permitted South County boundary) natural reef sites. Near natural reef sites contained higher species richness and abundance of fishes than the Far natural reef sites; differences were not statistically significant.
- Eighteen commercially protected species were found on the Near natural reefs and 17 were recorded on the Far natural reefs.
- Of the commercially and recreationally important species observed in the study, Blue Runner (*Caranx crysos*), Tomtate (*Haemulon aurolineatum*), and Grey Snapper (*Lutjanus griseus*) were

relatively more common on the artificial reefs while Grey Triggerfish (*Balistes capriscus*), and White Grunt (*Haemulon plumierii*) were relatively more common on natural reefs.

- There were significant differences in the fish assemblages at the artificial reefs and natural reef sites. Primary contributors to the difference between the artificial reefs and natural reef were Grunts (*Haemulon*) and Scad (*Decapterus*). Both genera are commonly found in high abundance on artificial reefs. The Bicolor Damselfish (*Stegastes partitus*) was more abundant on natural reefs than on artificial structures.
- Forty-one invasive Lionfish Spp. (*Pterois* spp.) were observed in this study. *Pterois* spp. were relatively more abundant on the artificial reefs (26 individuals) than the natural reefs (15 individuals).
- Twenty-seven Goliath Groupers (*Epinephelus itajara*) were recorded in this study. Twenty-five were present on the artificial reefs and two were recorded at the natural reef sites.
- The 2015 2-year post-deployment Donaldson Artificial reef sites had a significantly different fish assemblage compared to the 2016 2-year post-deployment South County artificial reefs.
- Increases in relative abundance of species such as Tomtate (*Haemulon aurolineatum*) and Scad Spp. (*Decapterus* spp.) indicate that fish assemblages on natural reefs nearest to the artificial reefs have been influenced by those on the artificial reefs in the two years since deployment of the New artificial reefs in 2014.

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Appendix A.

Fish Abundance at Each Survey Site.

Table A1. Fish species observed at each of the artificial reefs during the 2016 surveys.

			OLD (2008)						NEW (2014)					
Family	**Latin Name**	**Common Name**	**ANN MARIE**	**FOGEL CAPITAL**	**THE HEAP**	**JACK MACDONALD**	**LENTINE**	**SHIRLEY REEF**	**SITE 7**	**SITE 8**	**SITE 9**	**SITE 10**	**SITE 11**	**SITE 12**
Acanthuridae	*Acanthurus coeruleus*	Blue Tang	2	1	1	-	-	1	-	-	1	1	1	2
	Acanthurus bahianus	Ocean Surgeon	-	-	-	-	-	-	-	2	-	-	1	-
	Acanthurus chirurgus	Doctorfish	-	1	-	-	1	-	-	2	2	-	1	2
Apogonidae	*Apogon pseudomaculatus*	Twospot Cardinalfish	-	1	-	-	-	-	-	-	-	-	-	-
Blenniidae	*Parablennius marmoreus*	Seaweed Blenny	-	-	-	-	-	-	-	-	-	-	2	-
Carangidae	*Seriola rivoliana*	Almaco Jack	-	1	-	-	-	-	3	10	3	-	12	3
	Caranx crysos	Blue Runner	17	14	2	-	20	-	1	-	-	30	30	25
	Caranx hippos	Crevalle Jack	-	-	-	-	-	-	-	-	-	-	20	-
	Caranx ruber	Bar Jack	-	-	-	-	-	-	-	-	2	5	-	-
	Decapterus spp.	Mackerel/Round Scad	6300	150	400	-	100	950	800	100	1000	8000	600	2000
	Elagatis bipinnulata	Rainbow Runner	-	-	-	-	-	-	-	-	-	2	2	7
	Trachinotus falcatus	Permit	-	-	-	-	-	1	-	-	-	-	-	-
Centropomidae	*Centropomus undecimalis*	Common Snook	-	-	-	-	1	-	-	-	-	-	-	-
Chaetodontidae	*Chaetodon sedentarius*	Reef Butterflyfish	-	1	1	1	2	-	-	2	2	-	2	2
Dasyatidae	*Dasyatis centroura*	Roughtail Stingray	1	-	-	-	-	-	-	-	-	-	-	-
Echeneidae	*Echeneis naucrates*	Whitefine Sharksucker/Sharksucker	-	-	1	-	-	-	-	-	-	-	-	-
Gobiidae	*Coryphopterus glaucofraenum*	Bridled Goby	-	4	1	3	-	-	-	-	-	-	-	-
	Coryphopterus dicrus	Colon Goby	-	-	-	1	-	-	-	-	-	-	-	-
	Coryphopterus hyalinus/personatus	Masked/Glass Goby	-	4	-	200	3	6	-	-	50	-	-	-
	Gnatholepis thompsoni	Goldspot Goby	-	-	-	-	-	-	-	-	-	1	-	-
Haemulidae	*Anisotremus surinamensis*	Black Margate	1	2	1	-	1	-	-	-	1	-	1	1
	Anisotremus virginicus	Porkfish	2	2	3	2	1	-	-	1	-	1	1	-
	Haemulon aurolineatum	Tomtate	300	115	500	200	100	180	5	400	500	4000	75	600
	Haemulon plumierii	White Grunt	1	2	1	1	-	2	-	-	-	-	-	-
	Haemulon spp.	Grunts, Juvenile/Unid.	-	-	-	-	-	-	-	-	50	-	-	-
	Haemulon striatum	Striped Grunt	-	-	-	-	-	-	-	-	-	20	-	-
Labridae	*Thalassoma bifasciatum*	Bluehead	60	68	60	65	45	58	55	100	110	20	40	60
	Bodianus pulchellus	Spotfin Hogfish	-	3	-	2	2	1	1	3	-	1	2	-
	Bodianus rufus	Spanish Hogfish	2	1	3	1	3	-	-	3	-	-	-	1
	Clepticus parrae	Creole Wrasse	-	1	-	-	-	12	14	8	-	-	-	12
	Halichoeres bivittatus	Slippery Dick	-	2	1	3	-	-	1	-	-	-	1	-
	Halichoeres garnoti	Yellowhead Wrasse	2	2	2	-	3	2	1	-	1	-	-	1
Labrisomidae	*Labrisomus nuchipinnis*	Hairy Blenny	-	-	-	-	1	-	-	-	-	-	-	-
	Malacoctenus triangulatus	Saddled Blenny	1	2	-	-	-	-	-	-	-	1	-	-
Lutjanidae	*Lutjanus griseus*	Grey Snapper	18	28	5	4	3	4	2	5	5	3	15	8
	Lutjanus synagris	Lane Snapper	-	-	1	-	-	-	-	-	2	-	1	1
	Ocyurus chrysurus	Yellowtail Snapper	-	-	-	-	-	-	-	-	1	-	-	-
	Rhomboplites aurorubens	Vermillion Snapper	-	-	-	-	-	-	-	-	2	1	52	1
Mullidae	*Pseudupeneus maculatus*	Spotted Goatfish	-	-	-	1	-	-	-	-	-	-	-	-

Table A1 continued. Fish species observed at each of the artificial reefs during the 2016 surveys.

			OLD (2008)						NEW (2014)					
Family	Latin Name	Common Name	ANN MARIE	FOGEL CAPITAL	THE HEAP	JACK MACDONALD	LENTINE	SHIRLEY REEF	SITE 7	SITE 8	SITE 9	SITE 10	SITE 11	SITE 12
Pomacanthidae	*Holacanthus bermudensis*	Blue Angelfish	-	-	-	-	-	-	-	1	1	-	-	-
	Holacanthus ciliaris	Queen Angelfish	-	-	1	-	1	-	-	1	-	1	1	2
	Holacanthus tricolor	Rock Beauty	-	-	-	1	-	-	-	1	-	-	-	-
	Pomacanthus arcuatus	Gray Angelfish	-	-	1	-	-	-	-	-	-	-	-	-
Pomacentridae	*Stegastes leucostictus*	Beaugregory	2	3	2	4	1	10	-	-	1	1	-	2
	Abudefduf saxatilis	Sergeant Major	2	-	2	-	1	-	-	1	2	-	-	3
	Chromis enchrysura	Yellowtail Reeffish	-	8	2	2	1	-	2	2	4	1	12	2
	Chromis insolata	Sunshinefish	-	6	1	1	1	-	1	-	-	1	-	3
	Chromis multilineata	Brown Chromis	-	-	-	-	-	-	-	-	1	-	-	-
	Chromis scotti	Purple Reeffish	-	26	5	2	10	18	15	10	4	1	-	7
	Stegastes adustus	Dusky Damselfish	-	-	-	-	-	-	-	-	-	2	-	-
	Stegastes partitus	Bicolor Damselfish	-	2	-	-	2	15	-	2	-	1	-	5
	Stegastes planifrons	Threespot Damselfish	1	-	-	-	-	-	1	-	-	-	-	-
	Stegastes variabilis	Cocoa Damselfish	1	-	2	1	2	-	-	2	2	1	-	3
Scaridae	*Cryptotomus roseus*	Bluelip Parrotfish	-	-	1	-	3	-	2	-	-	-	-	-
	Scarus iseri	Striped Parrotfish	-	3	-	1	4	-	5	-	-	-	-	-
	Sparisoma atomarium	Greenblotch Parrotfish	-	-	1	1	-	-	-	1	2	-	-	-
	Sparisoma aurofrenatum	Redband Parrotfish	-	2	1	-	-	-	-	-	-	-	-	-
	Sparisoma radians	Bucktooth Parrotfish	-	-	1	2	-	-	-	-	-	2	-	-
	Sparisoma viride	Stoplight Parrotfish	-	-	-	-	-	-	1	1	1	-	-	-
Sciaenidae	*Pareques umbrosus*	Cubbyu	-	3	-	-	-	-	-	-	-	1	2	-
Scorpaenidae	*Pterois volitans/miles*	Lionfish Spp.	1	-	1	-	3	2	-	5	4	2	-	8
	Scorpaena plumieri	Spotted Scorpionfish	1	-	1	1	1	-	-	1	1	1	-	4
Serranidae	*Mycteroperca bonaci*	Black Grouper	-	-	-	-	-	-	-	1	-	-	-	-
	Cephalopholis cruentata	Graysby	1	1	1	-	-	-	-	-	1	-	-	1
	Cephalopholis fulva	Coney	-	-	2	-	-	-	-	-	-	-	1	-
	Epinephelus itajara	Goliath Grouper	5	1	1	-	1	1	2	1	4	4	3	2
	Mycteroperca phenax	Scamp	-	-	2	-	-	-	1	1	1	2	3	3
	Rypticus maculatus	Whitespotted Soapfish	1	-	1	1	-	1	-	-	-	1	-	-
	Schultzea beta	School Bass	-	-	-	-	-	-	-	-	-	2	-	-
	Serranus annularis	Orangeback Bass	-	-	-	1	-	-	-	1	-	-	-	-
	Serranus baldwini	Lantern Bass	-	-	-	-	1	-	-	-	-	-	-	-
	Serranus tigrinus	Harlequin Bass	-	1	-	-	-	-	-	-	-	-	-	-
Sparidae	*Calamus* spp.	Littlehead/Sheepshead/Saucereye/Whitebone	-	-	1	-	2	1	-	1	1	-	-	-
	Archosargus probatocephalus	Sheepshead	1	1	3	2	4	2	2	20	3	2	1	5
Tetraodontidae	*Sphoeroides spengleri*	Bandtail Puffer	-	-	-	-	-	-	-	1	-	1	1	1
	Canthigaster jamestyleri	Goldfaced Toby	-	4	1	1	-	-	-	1	1	2	3	-
	Canthigaster rostrata	Sharpnose Puffer	3	3	2	1	5	10	5	1	2	1	2	3

Table A2. Fish species observed at each of the natural reef sites during the 2016 surveys.

			NEAR						FAR					
Family	**Scientific Name**	**Common Name**	**NAT 1**	**NAT 2**	**NAT 3**	**NAT 4**	**NAT 5**	**NAT 6**	**NAT 7**	**NAT 8**	**NAT 9**	**NAT 10**	**NAT 11**	**NAT 12**
Acanthuridae	*Acanthurus coeruleus*	Blue Tang	-	2	-	-	-	-	1	-	-	-	-	-
	Acanthurus bahianus	Ocean Surgeon	1	3	5	8	1	-	-	-	1	-	-	-
	Acanthurus chirurgus	Doctorfish	2	1	-	3	3	6	3	9	5	-	5	2
Apogonidae	*Apogon pseudomaculatus*	Twospot Cardinalfish	-	-	2	-	-	-	1	-	-	1	-	-
Balistidae	*Balistes capriscus*	Grey Triggerfish	4	1	-	2	9	5	1	2	2	4	4	-
Carangidae	*Seriola rivoliana*	Almaco Jack	-	-	-	-	1	-	-	-	1	1	-	-
	Carangoides bartholomaei	Yellow Jack	-	-	-	-	2	-	-	-	-	-	5	-
	Caranx crysos	Blue Runner	8	2	-	2	20	-	1	-	-	1	-	-
	Caranx ruber	Bar Jack	-	2	-	-	4	-	-	-	1	-	1	-
	Decapterus spp.	Mackerel/Round Scad	325	-	-	3000	-	-	-	-	-	-	2000	-
	Seriola dumerili	Greater Amberjack	-	-	-	-	1	-	-	-	-	-	-	-
Chaenopsidae	*Emblemaria pandionis*	Sailfin Blenny	-	-	-	-	2	-	-	-	-	-	-	-
Chaetodontidae	*Chaetodon sedentarius*	Reef Butterflyfish	2	2	2	-	2	2	-	2	2	2	1	2
	Chaetodon ocellatus	Spotfin Butterflyfish	-	-	-	2	2	-	1	-	-	-	-	-
Cirrhitidae	*Amblycirrhitus pinos*	Redspotted Hawkfish	-	-	-	-	-	-	-	-	-	-	-	1
Echeneidae	*Echeneis naucrates*	Whitefine Sharksucker/Sharksucker	-	-	-	-	-	-	-	-	-	-	1	-
Gobiidae	*Coryphopterus glaucofraenum*	Bridled Goby	6	1	6	2	6	-	1	-	6	3	-	2
	Coryphopterus dicrus	Colon Goby	-	1	-	-	3	-	-	-	-	-	-	-
	Coryphopterus hyalinus/personatus	Masked/Glass Goby	5	-	-	-	-	-	-	1	5	-	-	-
	Elacatinus oceanops	Neon Goby	-	1	-	-	-	-	-	-	-	-	-	-
	Gnatholepis thompsoni	Goldspot Goby	2	-	-	-	3	-	-	2	4	1	1	-
Haemulidae	*Anisotremus surinamensis*	Black Margate	-	1	-	-	-	-	-	-	-	-	-	-
	Anisotremus virginicus	Porkfish	2	1	2	2	-	3	2	2	3	-	16	1
	Haemulon aurolineatum	Tomtate	62	400	28	54	-	40	30	3	26	-	400	120
	Haemulon parra	Sailor's Choice	-	-	-	-	-	-	-	-	-	-	1	-
	Haemulon plumierii	White Grunt	-	1	2	2	-	12	4	2	2	-	1	1
	Haemulon spp.	Grunts, Juvenile/Unid	-	-	-	-	-	-	-	4	-	8	-	-
Kyphosidae	*Kyphosus sectatrix*	Chub	-	1	-	-	-	-	-	-	-	-	-	-
Labridae	*Thalassoma bifasciatum*	Bluehead	42	70	35	50	10	10	40	25	53	19	70	35
	Bodianus pulchellus	Spotfin Hogfish	3	-	3	-	-	-	2	-	-	-	-	-
	Bodianus rufus	Spanish Hogfish	-	2	1	-	-	-	1	1	-	-	2	1
	Clepticus parrae	Creole Wrasse	3	-	2	-	-	-	-	-	-	-	-	1
	Halichoeres bivittatus	Slippery Dick	-	1	1	-	5	1	2	3	2	3	3	3
	Halichoeres garnoti	Yellowhead Wrasse	8	1	2	5	-	1	5	3	15	1	6	1
	Halichoeres maculipinna	Clown Wrasse	-	-	-	-	-	-	-	1	-	2	2	-
	Halichoeres radiatus	Puddingwife	-	1	-	-	1	-	-	-	-	-	1	-
	Lachnolaimus maximus	Hogfish	-	-	1	1	-	1	-	-	1	-	1	-
	Xyrichtys splendens	Green Razorfish	-	-	-	-	-	-	-	-	-	-	3	-

Table 2A continued. Fish species observed at each of the natural reef sites during the 2016 surveys.

			NEAR						FAR					
Family	**Scientific Name**	**Common Name**	**NAT 1**	**NAT 2**	**NAT 3**	**NAT 4**	**NAT 5**	**NAT 6**	**NAT 7**	**NAT 8**	**NAT 9**	**NAT 10**	**NAT 11**	**NAT 12**
Lutjanidae	*Lutjanus griseus*	Grey Snapper	2	2	-	6	-	2	3	2	-	-	11	-
	Lutjanus analis	Mutton Snapper	-	2	-	-	-	-	-	-	-	-	1	-
	Lutjanus synagris	Lane Snapper	-	1	-	-	-	1	-	-	-	-	-	-
	Ocyurus chrysurus	Yellowtail Snapper	-	-	-	-	-	-	-	-	-	-	2	-
	Rhomboplites aurorubens	Vermillion Snapper	11	8	-	-	-	1	-	-	1	-	-	-
Monacanthidae	*Cantherhines pullus*	Orangespotted Filefish	-	1	-	-	1	-	-	1	-	-	-	-
Mullidae	*Pseudupeneus maculatus*	Spotted Goatfish	-	5	1	3	-	20	-	2	-	-	-	1
Muraenidae	*Gymnothorax miliaris*	Goldentail Moray	-	-	-	-	-	-	-	-	-	1	-	-
	Gymnothorax moringa	Spotted Moray	-	-	1	-	-	1	1	-	-	-	-	-
Opistognathidae	*Opistognathus aurifrons*	Yellowhead Jawfish	-	-	-	-	-	-	1	-	-	2	6	-
Ostraciidae	*Acanthostracion quadricornis*	Scrawled Cowfish	-	-	-	-	1	-	-	-	-	-	-	-
Pomacanthidae	*Holacanthus bermudensis*	Blue Angelfish	-	-	1	1	-	-	1	-	1	1	2	-
	Centropyge argi	Cherubfish	-	-	1	-	-	-	-	-	-	-	-	-
	Holacanthus ciliaris	Queen Angelfish	-	-	2	1	-	1	-	2	1	-	2	-
	Holacanthus tricolor	Rock Beauty	1	2	-	-	-	-	1	1	-	-	1	-
	Pomacanthus arcuatus	Gray Angelfish	1	-	-	1	-	3	-	-	-	1	2	-
	Pomacanthus paru	French Angelfish	-	1	-	-	-	-	2	-	-	1	2	-
Pomacentridae	*Stegastes leucostictus*	Beaugregory	10	3	2	-	1	-	2	2	6	-	1	-
	Abudefduf saxatilis	Sergeant Major	-	2	-	2	-	-	-	-	-	-	3	-
	Chromis cyanea	Blue Chromis	-	-	-	1	-	-	-	-	-	-	-	1
	Chromis enchrysura	Yellowtail Reeffish	24	12	20	12	3	-	3	20	5	2	2	4
	Chromis insolata	Sunshinefish	6	5	4	6	-	-	1	5	10	-	-	2
	Chromis multilineata	Brown Chromis	-	-	1	2	-	-	-	-	-	-	-	-
	Chromis scotti	Purple Reeffish	15	11	18	8	-	-	1	3	5	-	10	4
	Microspathodon chrysurus	Yellowtail Damselfish	-	-	-	-	-	-	-	-	-	-	-	2
	Stegastes adustus	Dusky Damselfish	-	4	-	-	-	1	-	-	-	-	-	-
	Stegastes partitus	Bicolor Damselfish	14	25	10	40	-	-	20	-	36	2	30	1
	Stegastes planifrons	Threespot Damselfish	-	-	-	-	-	-	-	-	-	-	-	1
	Stegastes variabilis	Cocoa Damselfish	-	-	3	-	3	2	1	-	-	1	4	1
Priacanthidae	*Heteropriacanthus cruentatus*	Glasseye	-	-	-	2	-	-	-	-	-	1	-	-
Scaridae	*Cryptotomus roseus*	Bluelip Parrotfish	-	-	-	-	-	-	-	-	-	1	-	-
	Scarus iseri	Striped Parrotfish	-	1	-	-	-	-	1	2	-	-	-	-
	Sparisoma atomarium	Greenblotch Parrotfish	-	-	-	-	1	-	1	1	2	1	-	-
	Sparisoma aurofrenatum	Redband Parrotfish	-	-	1	-	-	-	-	-	1	-	-	-
	Sparisoma radians	Bucktooth Parrotfish	-	-	1	-	-	-	-	2	-	-	1	-
	Sparisoma rubripinne	Redfin Parrotfish	-	1	-	-	-	1	-	-	-	-	1	-

Table 2A continued. Fish species observed at each of the natural reef sites during the 2016 surveys.

Family	Scientific Name	Common Name	NEAR						FAR					
			NAT 1	NAT 2	NAT 3	NAT 4	NAT 5	NAT 6	NAT 7	NAT 8	NAT 9	NAT 10	NAT 11	NAT 12
Sciaenidae	*Pareques umbrosus*	Cubbyu	-	4	15	9	-	1	1	6	13	-	1	-
	Pareques acuminatus	Highhat	-	-	-	1	-	-	-	2	-	-	-	-
	Sciaenidae spp.	Drum, Juvenile/Unid.	-	-	-	-	5	-	-	-	-	-	-	-
Scombridae	*Euthynnus alletteratus*	Little Tunny	1	-	-	-	-	-	-	-	-	-	-	-
Scorpaenidae	*Pterois volitans/miles*	Lionfish Spp.	-	2	1	-	2	-	1	2	1	2	1	3
	Scorpaena plumieri	Spotted Scorpionfish	-	-	1	-	1	2	1	1	-	1	-	-
Serranidae	*Serranus subligarius*	Belted Sandfish	-	-	1	-	-	-	-	-	-	-	-	-
	Cephalopholis cruentata	Graysby	-	2	-	-	-	-	-	-	2	-	1	-
	Epinephelus itajara	Goliath Grouper	1	-	-	-	-	-	-	-	-	-	1	-
	Hypoplectrus spp.	Hamlet Juvenile/Unid	-	-	-	-	-	-	1	-	-	-	-	-
	Hypoplectrus unicolor	Butter Hamlet	-	1	1	-	-	-	-	-	-	-	-	-
	Liopropoma eukrines	Wrasse Bass	-	-	-	-	1	-	-	-	-	-	-	-
	Mycteroperca phenax	Scamp	2	-	1	-	-	-	1	-	-	-	-	-
	Rypticus maculatus	Whitespotted Soapfish	-	-	1	-	2	-	1	-	1	2	1	1
	Schultzea beta	School Bass	-	-	1	-	-	-	-	-	-	-	2	1
	Serranus baldwini	Lantern Bass	-	-	-	-	1	-	1	-	-	1	-	-
	Serranus tabacarius	Tobaccofish	-	-	-	-	1	-	-	-	-	-	-	-
	Serranus tigrinus	Harlequin Bass	1	-	-	-	-	-	-	-	-	-	-	-
Sparidae	*Calamus* spp.	Littlehead/Sheepshead/Saucereye/Whitebone	2	-	4	2	2	1	1	2	1	3	-	-
	Archosargus probatocephalus	Sheepshead	-	1	-	1	1	-	-	1	2	-	-	-
Synodontidae	*Synodus foetens*	Inshore Lizardfish	-	1	-	-	-	-	-	-	-	-	-	-
Tetraodontidae	*Sphoeroides spengleri*	Bandtail Puffer	-	-	-	-	-	-	-	-	-	-	1	-
	Canthigaster jamestyleri	Goldfaced Toby	-	-	-	-	1	-	-	1	-	-	1	-
	Canthigaster rostrata	Sharpnose Puffer	3	4	3	6	20	1	5	10	18	4	11	5

Appendix B.

Photographs from the Old (2008) Artificial Sites.

Ann Marie

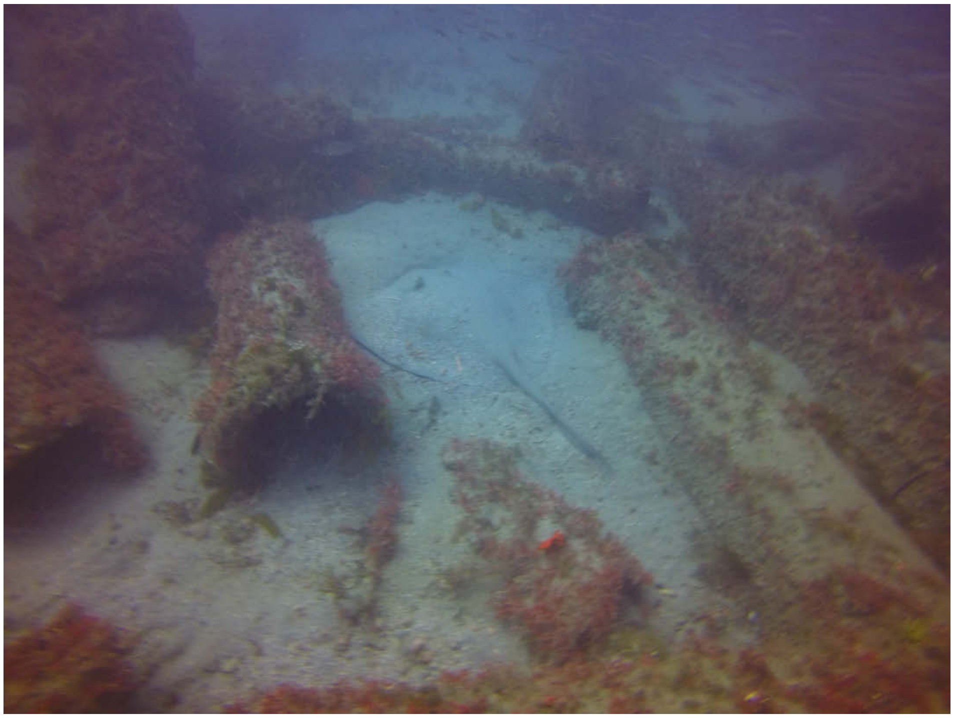

Photo 1. Roughtail Stingray (*Dasyatis centoura*) on Ann Marie Reef. Photo taken September 11, 2016.

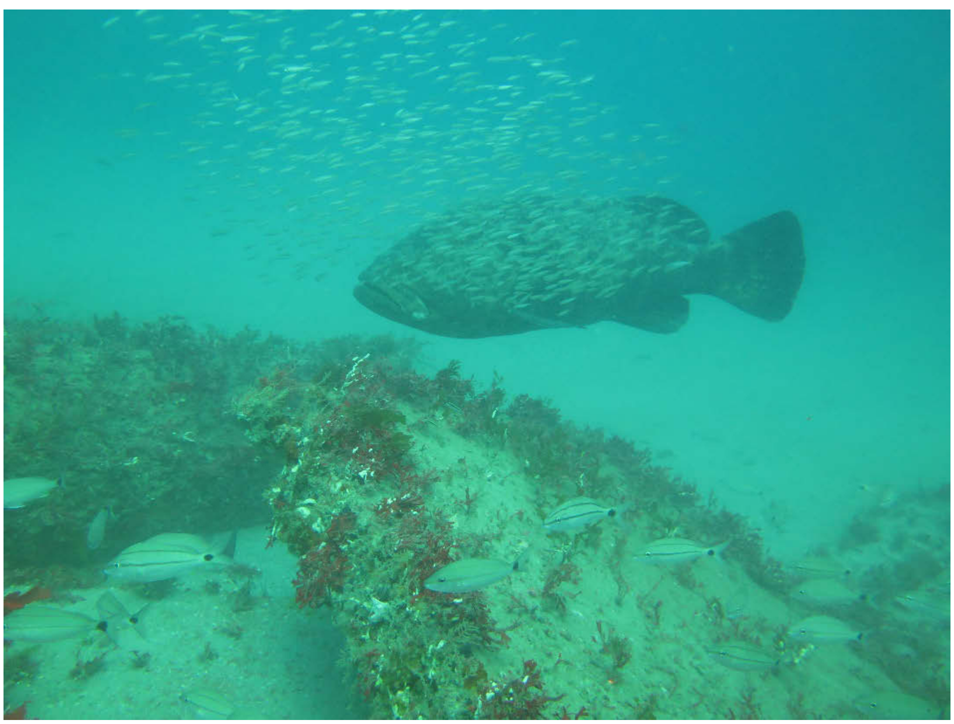

Photo 2. Goliath Grouper (*Epinerphelus itajara*) on Ann Marie Reef. Photo taken September 11, 2016.

Fogel Capital

Photo 3. Structure of Fogel Capital Reef. Photo taken August 23, 2016.

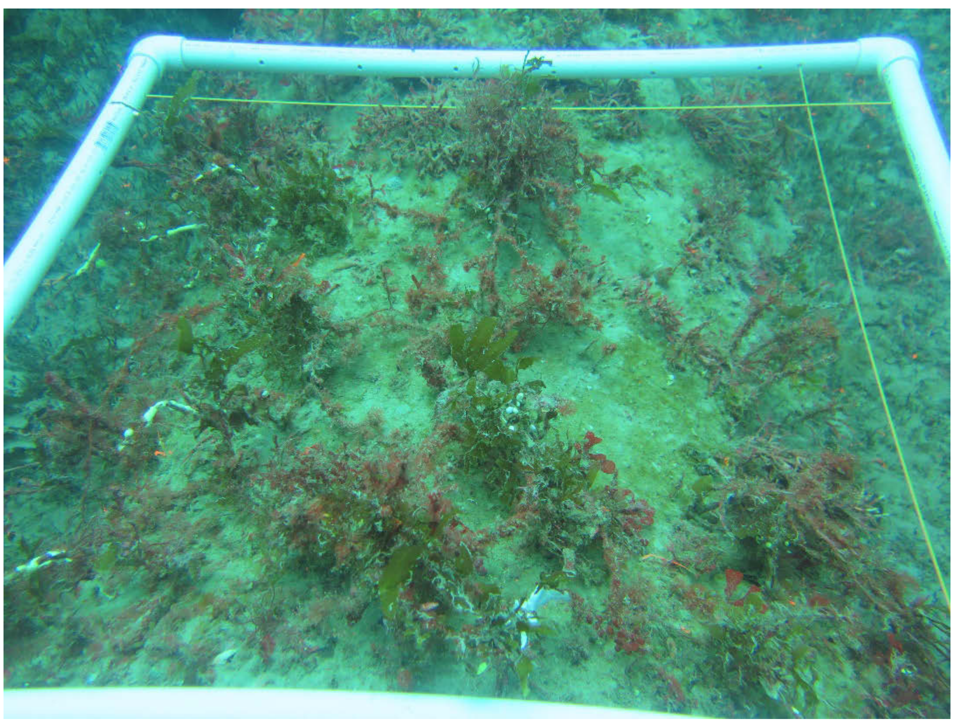

Photo 4. Benthic Quadrat on Fogel Capital Reef. Photo taken August 23, 2016.

The Heap

Photo 5. Structure of The Heap Reef with Tomtate (*Haemulon aurolineatum*) and Gray Snapper (*Lutjanus griseus*). Photo taken September 11, 2016.

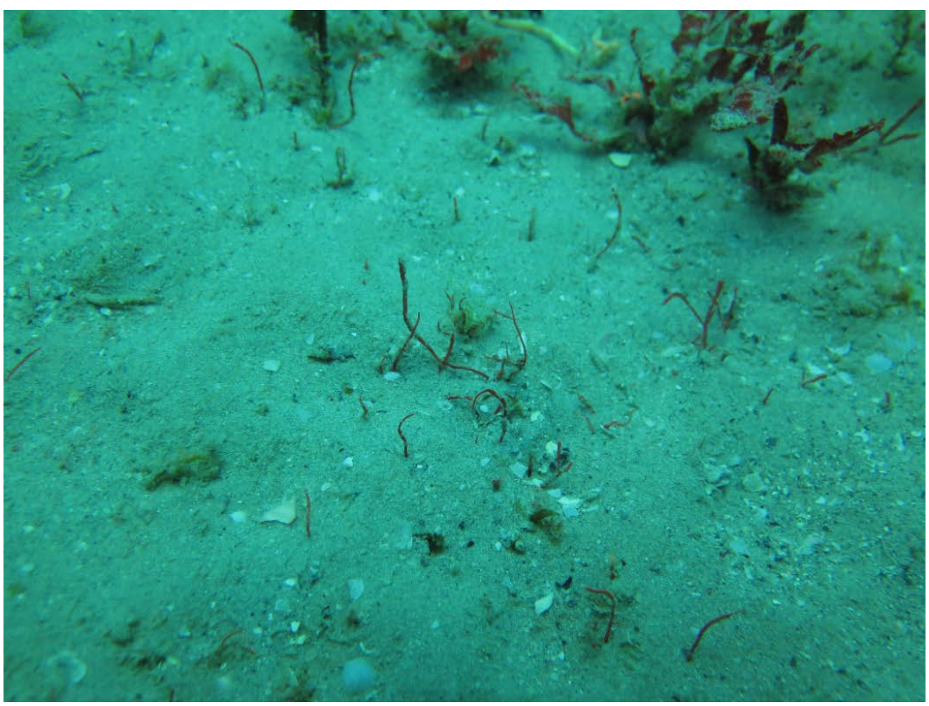

Photo 6. Red macroalgae in a benthic quadrat on The Heap Reef. Photo taken September 11, 2016.

Jack MacDonald

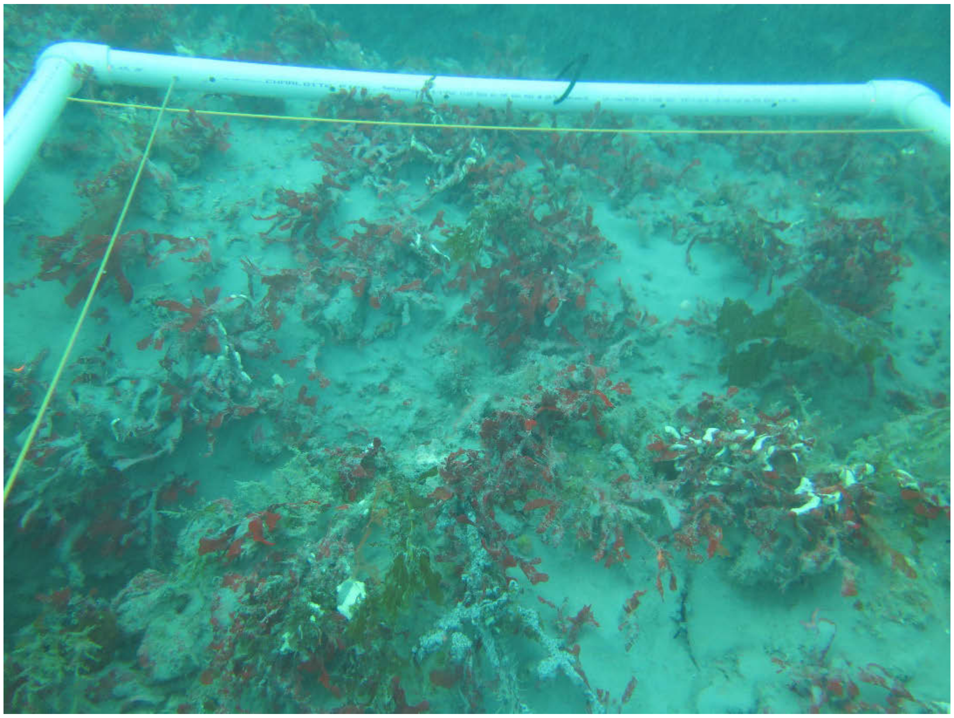

Photo 7. Benthic quadrat on Jack MacDonald Reef. Photo taken September 12, 2016.

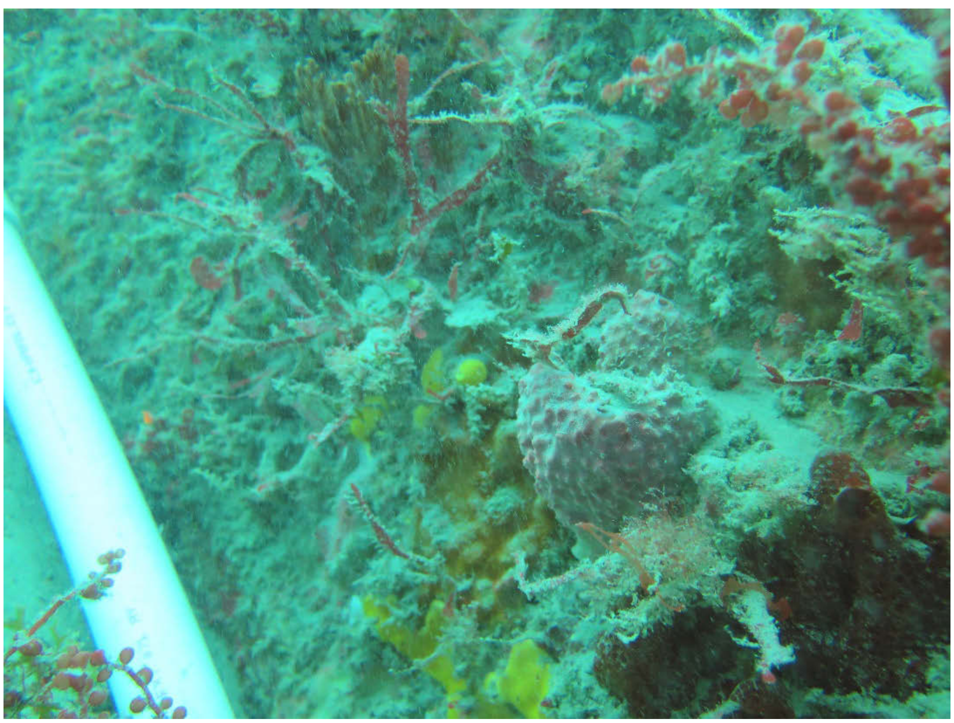

Photo 8. Sponge in benthic quadrat on Jack MacDonald Reef. Photo taken September 12, 2016.

Lentine

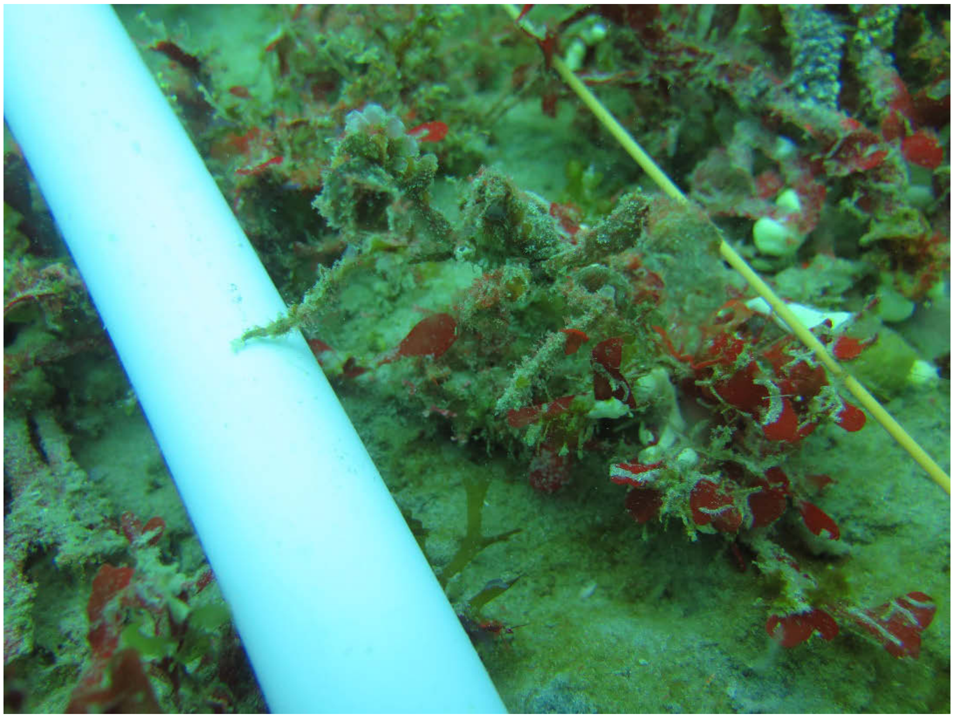

Photo 9. Crab sp. in benthic quadrat on Lentine Reef. Photo taken August 23, 2016.

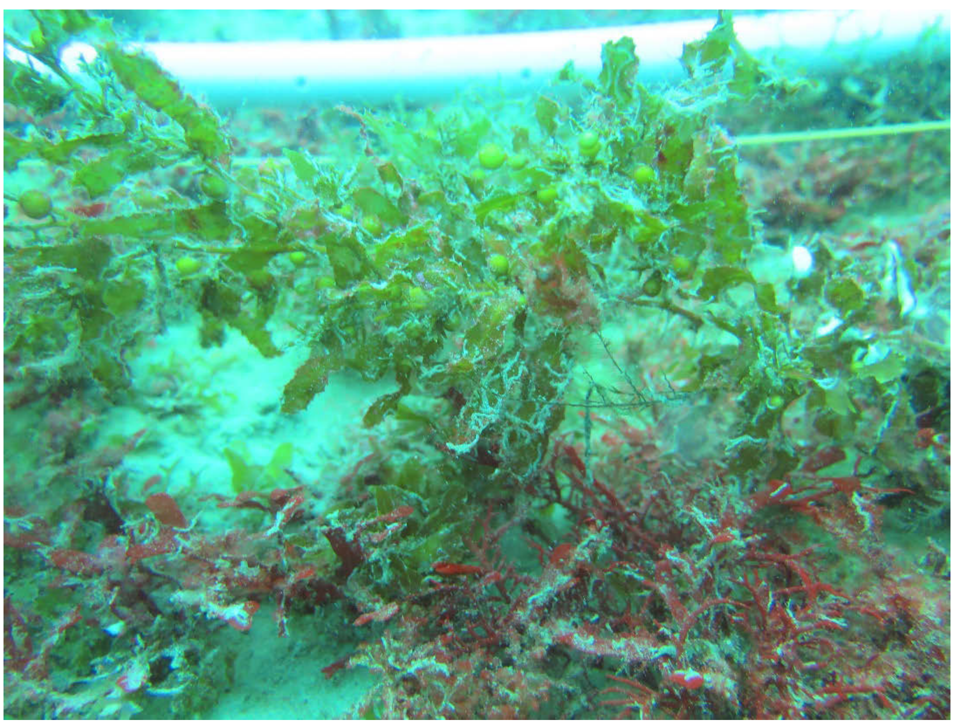

Photo 10. *Sargassum* sp. present in a benthic quadrat on Lentine Reef. Photo taken August 23, 2016.

Shirley

Photo 11. Permit (*Trachinotus falcatus*) on Shirley Reef. Photo taken August 22, 2016.

Photo 12. Structure of Shirley Reef. Photo taken August 22, 2016.

Appendix C.

Photographs from the New (2014) Artificial Sites.

Site 7

Photo 1. Structure of Site 7 Reef. Photo taken on August 22, 2016.

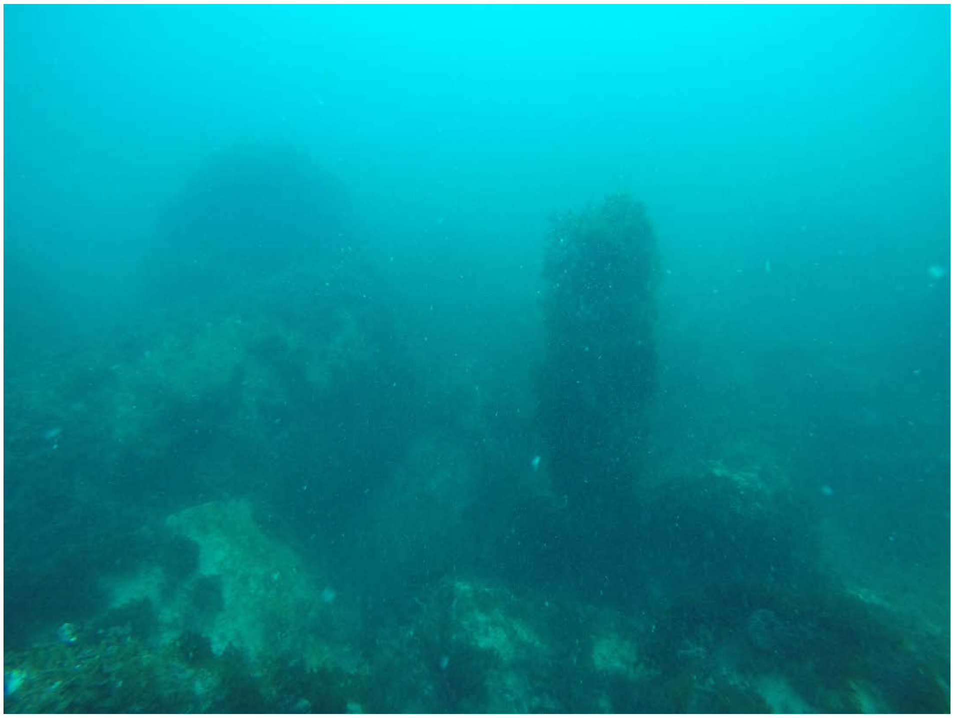

Photo 2. Structure of Site 7 Reef. Photo taken on August 22, 2016.

Site 8

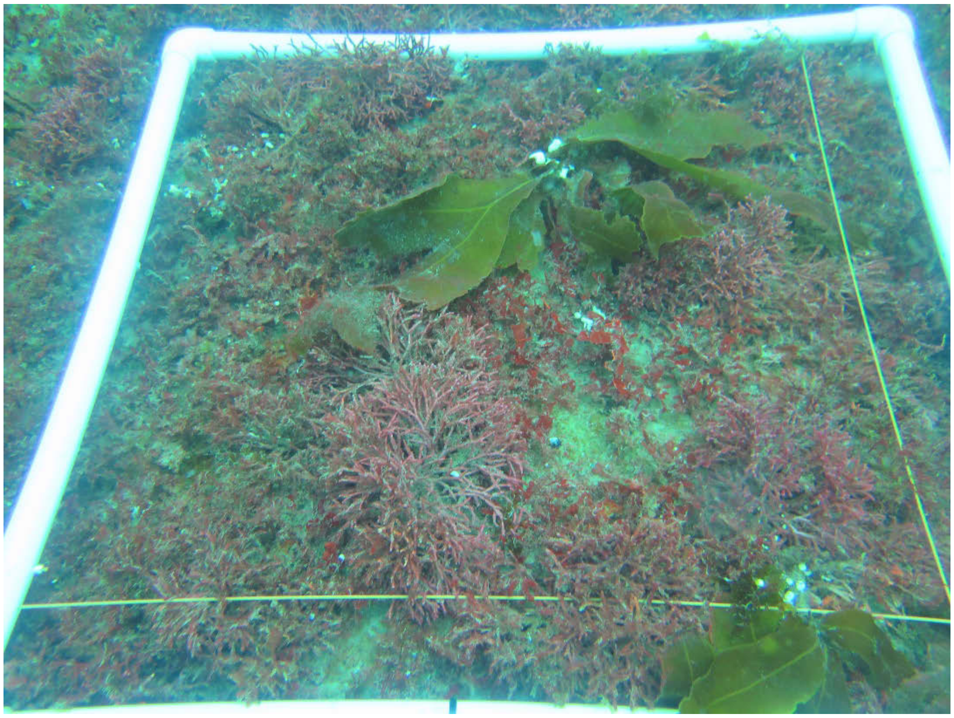

Photo 3. Benthic quadrat on Site 8 Reef. Photo taken August 23, 2016.

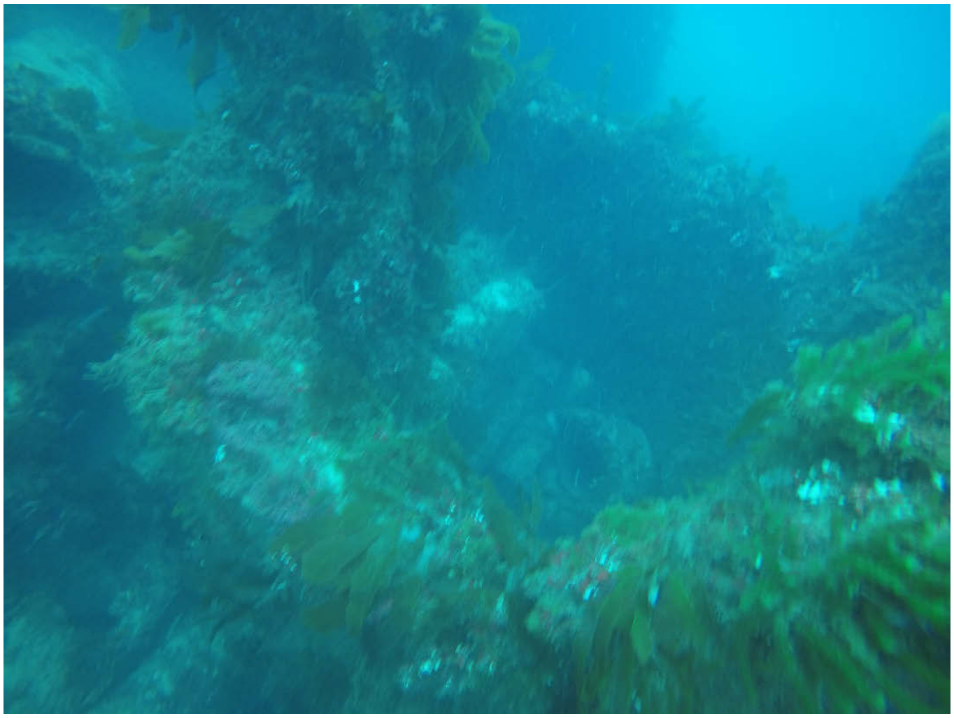

Photo 4. Structure of Site 8 Reef. Photo taken August 23, 2016.

Site 9

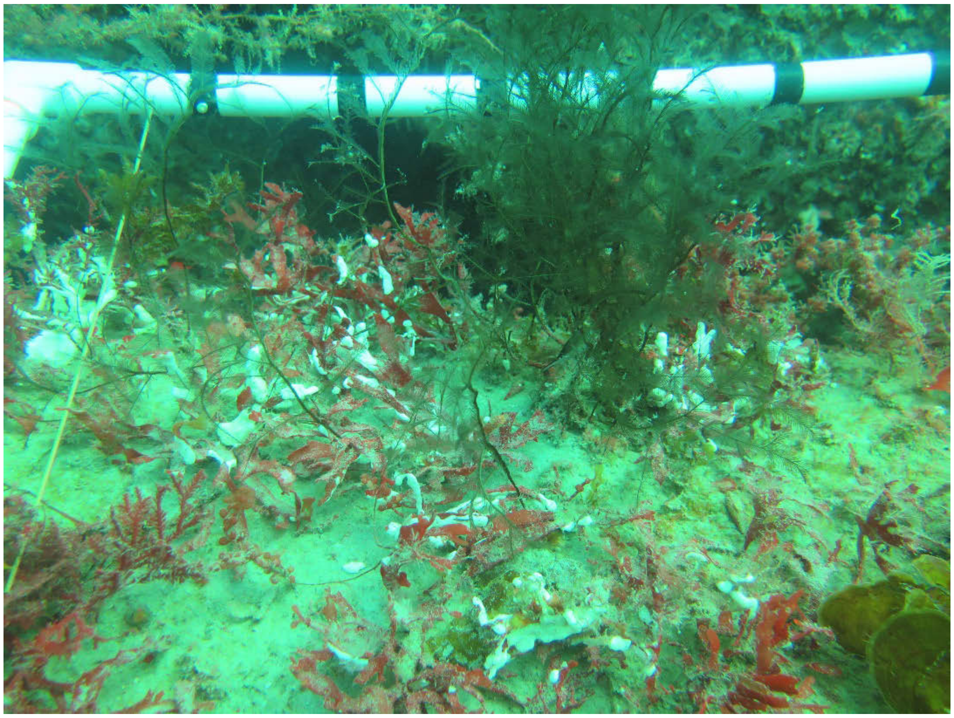

Photo 5. Hydroid sp. in a benthic quadrat on Site 9 Reef. Photo taken September 21, 2016.

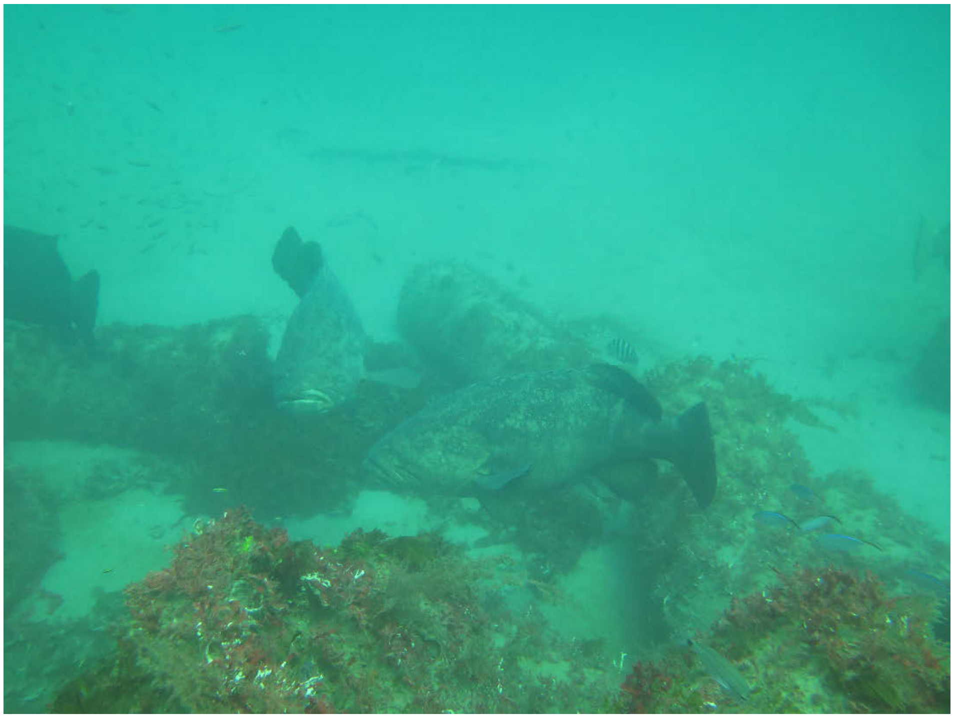

Photo 6. Goliath Grouper (*Epinepheluls itajara*) on Site 9 Reef. Photo taken September 21, 2016.

Site 10

Photo 7. Structure of Site 10 Reef. Photo taken September 11, 2016.

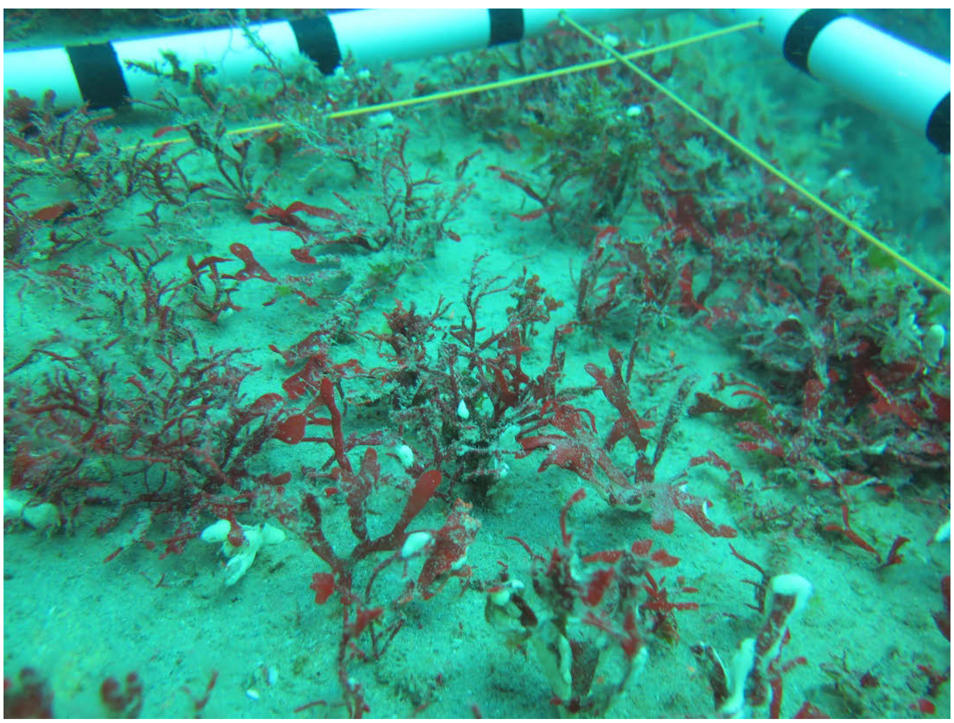

Photo 8. *Gracilaria* sp. in a benthic quadrat on Site 10 Reef. Photo taken on September 11, 2016.

Site 11

Photo 9. Tomtate (*Haemulon aurolineatum*) on Site 11 Reef. Photo taken September 11, 2016.

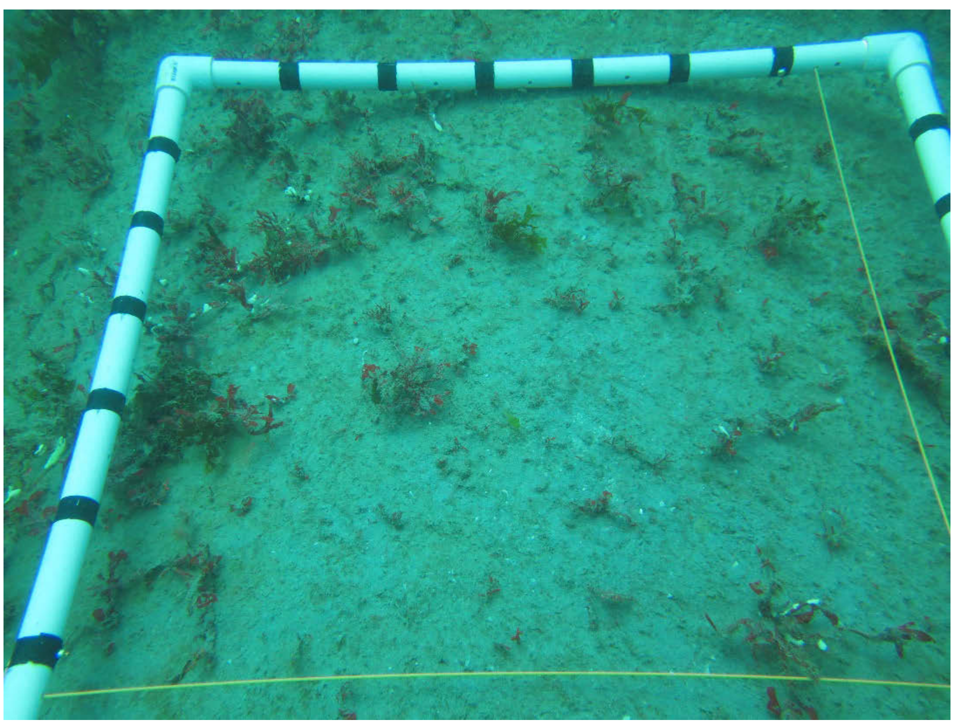

Photo 10. Benthic quadrat on Site 11 Reef. Photo taken September 11, 2016.

Site 12

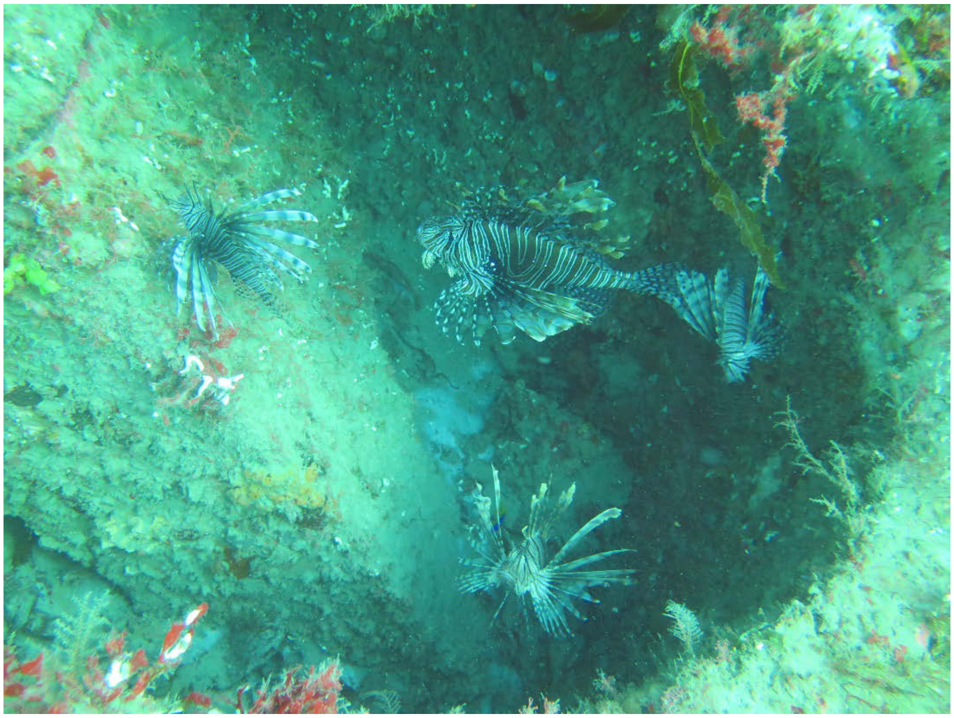

Photo 11. Lionfish spp. (*Pterois* spp.) on Site 12 Reef. Photo taken on September 20, 2016**.**

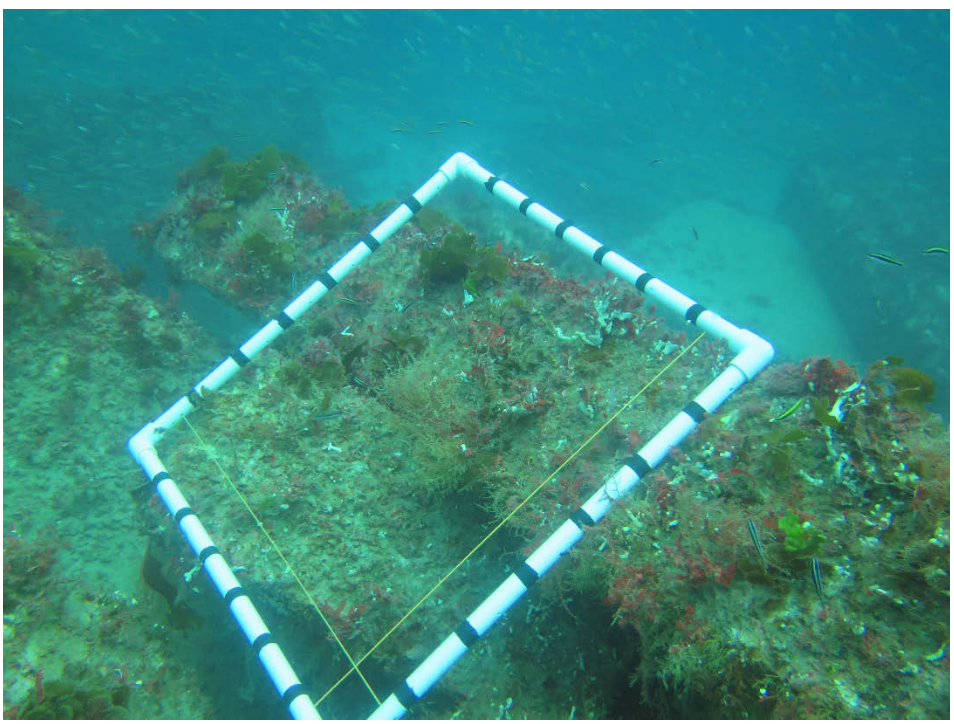

Photo 12. Benthic quadrat on Site 12 Reef. Photo taken September 20, 2016.

Appendix D.

Photographs from the Near Natural Sites.

Natural 1

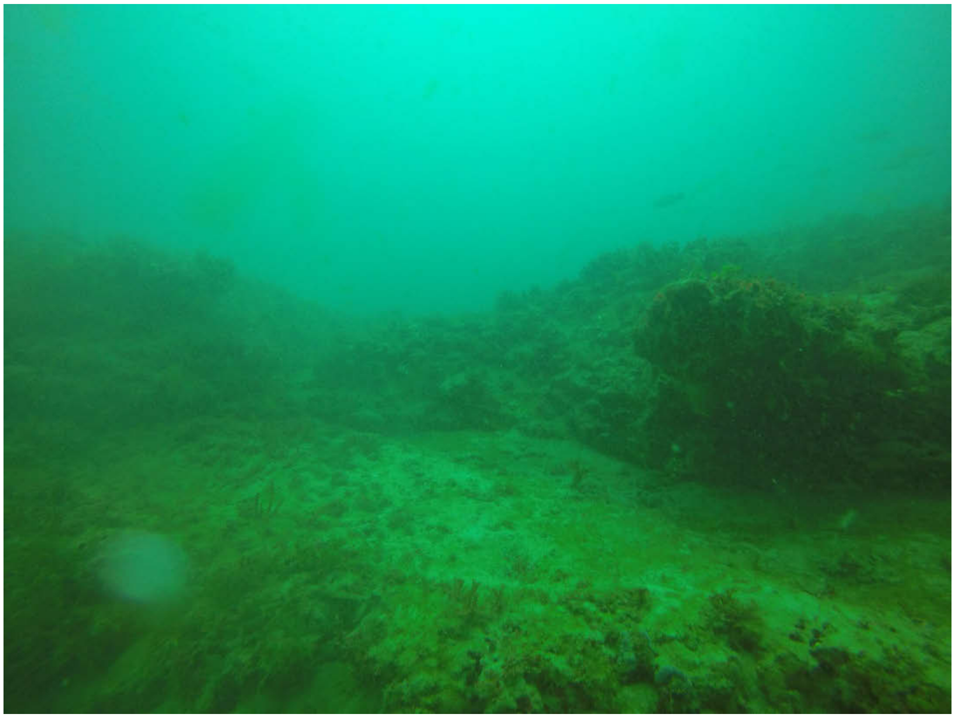

Photo 1. Structure of Natural 1. Photo taken August 23, 2016.

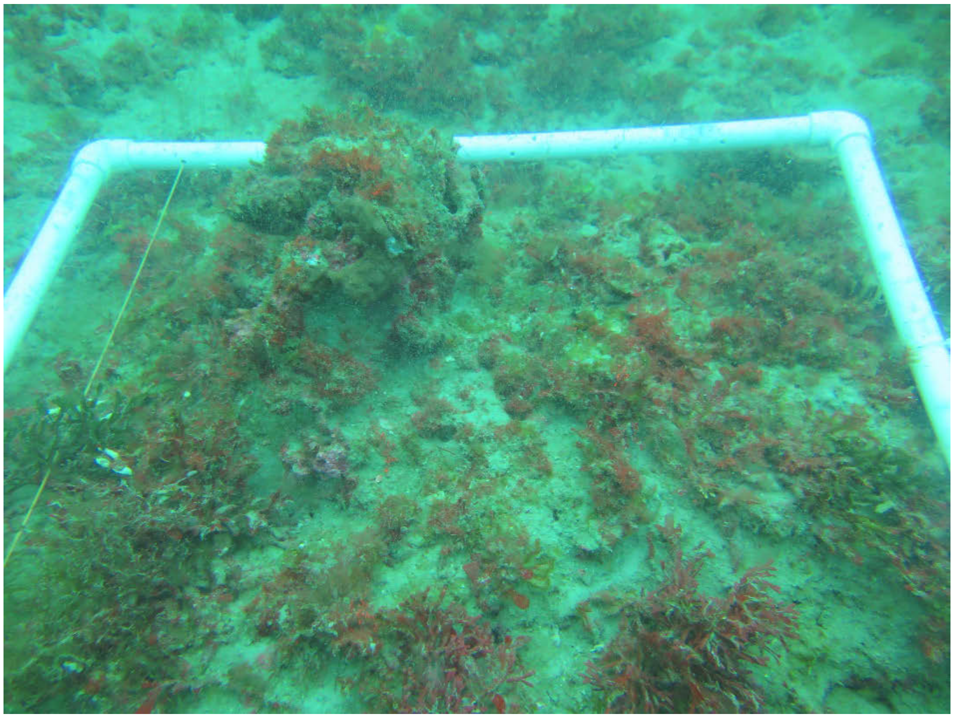

Photo 2. Benthic quadrat on Natural 1. Photo taken August 23, 2016.

Natural 2

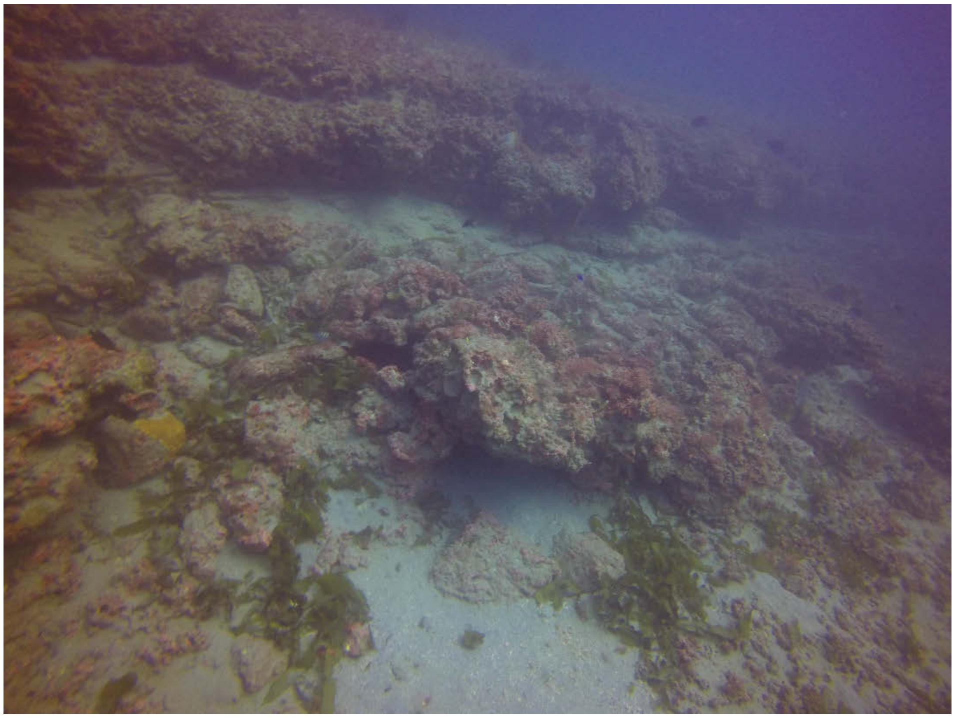

Photo 3. Structure of Natural 2. Photo taken September 21, 2016.

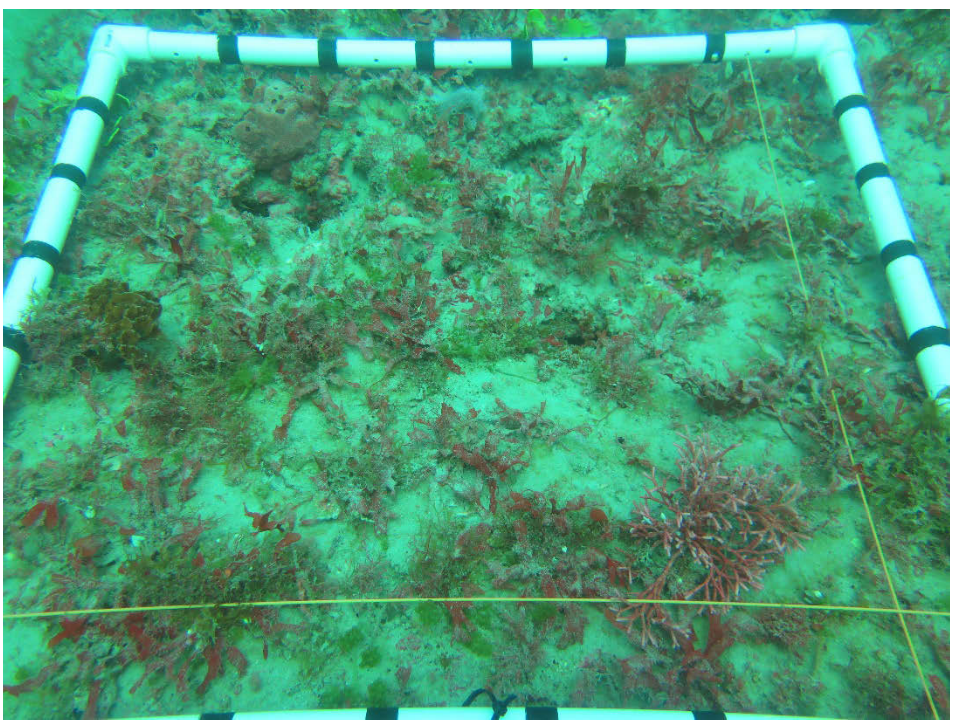

Photo 4. Benthic quadrat on Natural 2. Photo taken September 21, 2016.

Natural 3

Photo 5. Structure of Natural 3. Photo taken August 22, 2016.

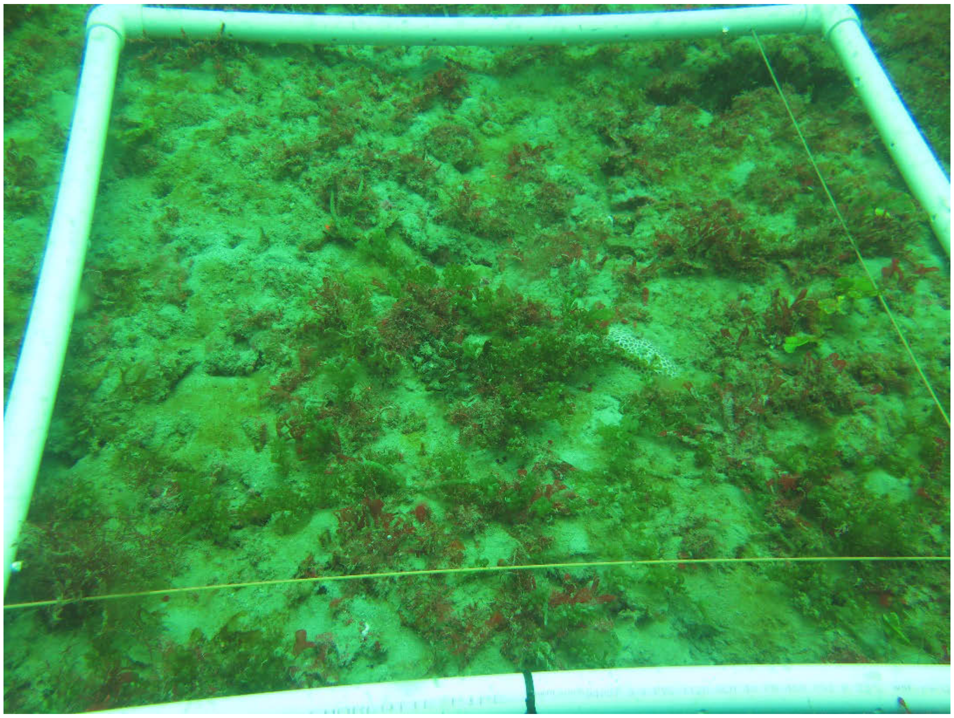

Photo 6. Benthic quadrat on Natural 3. Photo taken August 22, 2016.

Natural 4

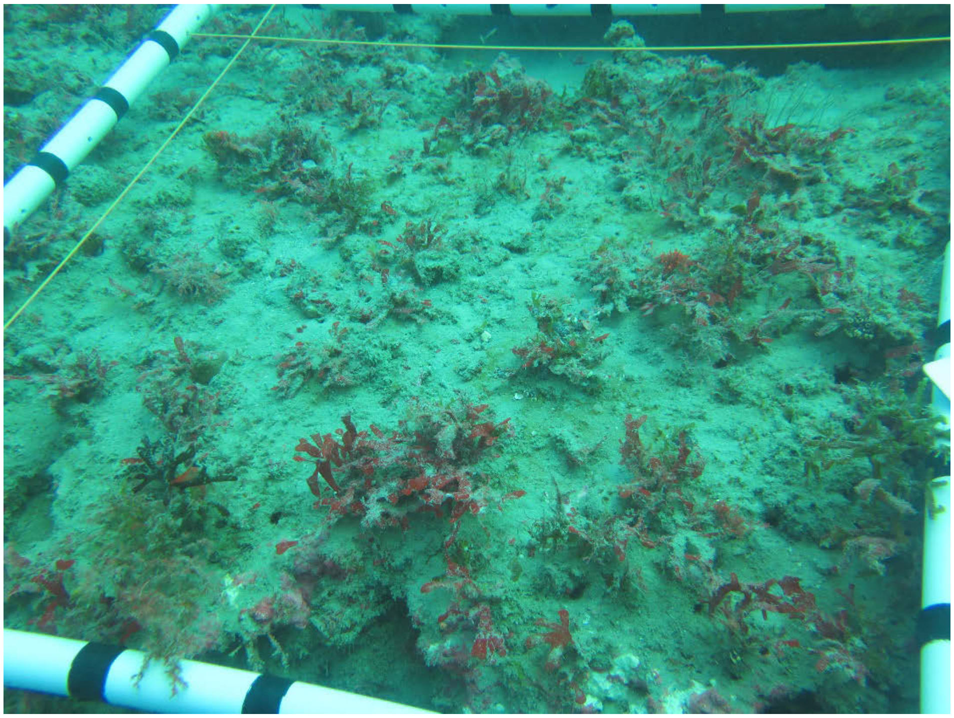

Photo 7. Benthic quadrat at Natural 4. Photo taken on September 11, 2016.

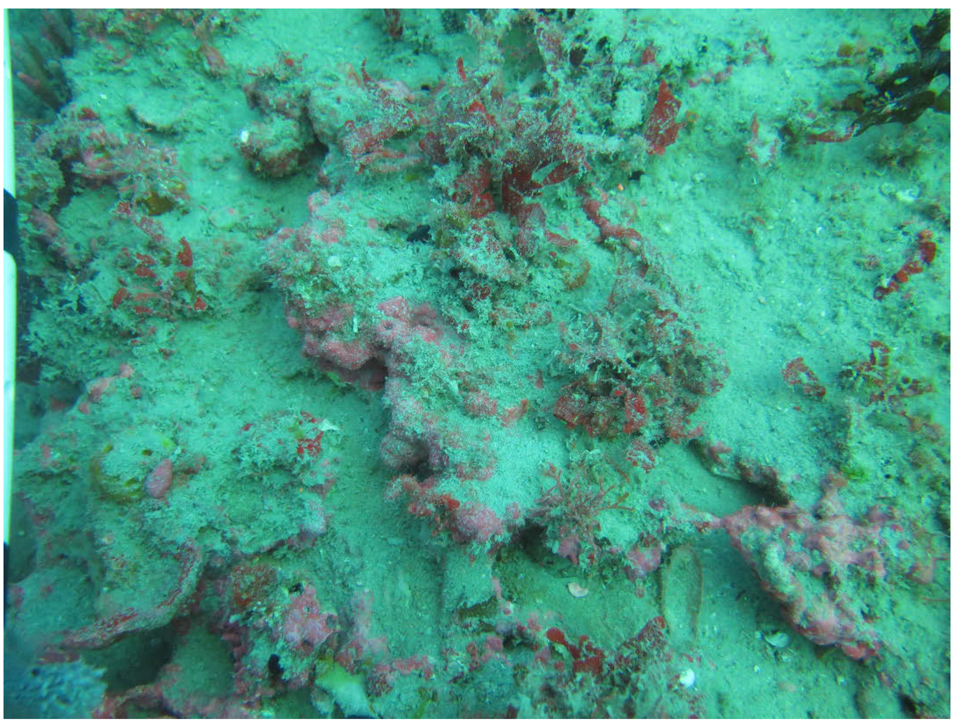

Photo 8. Calcareous Coralline Algae in a benthic quadrat at Natural 4. Photo taken on September 11, 2016.

Natural 5

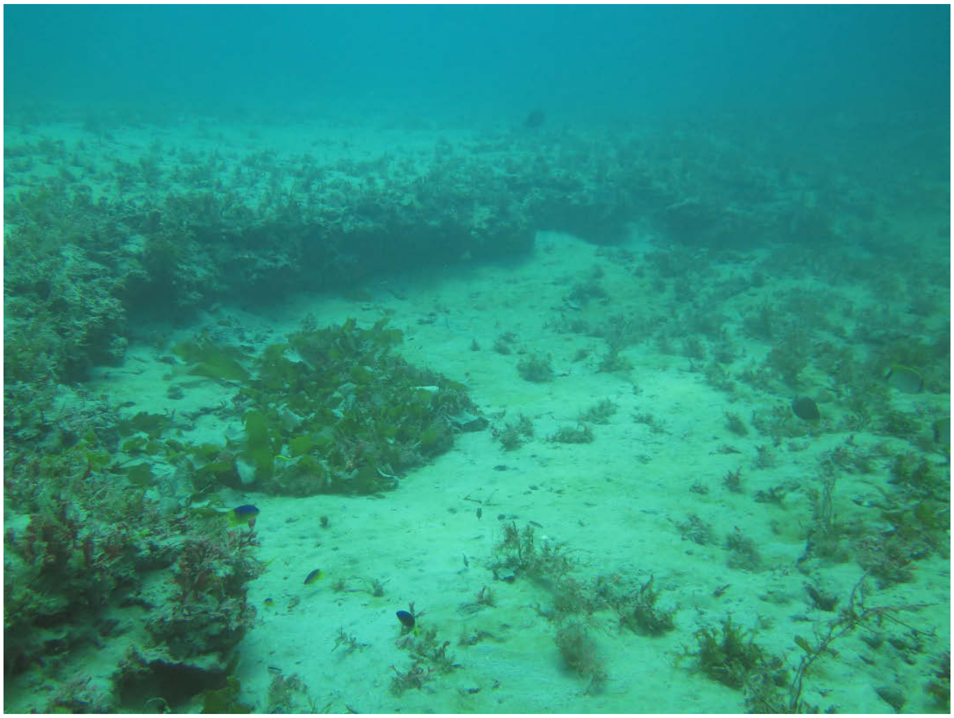

Photo 9. Structure of Natural 5. Photo taken September 21, 2016.

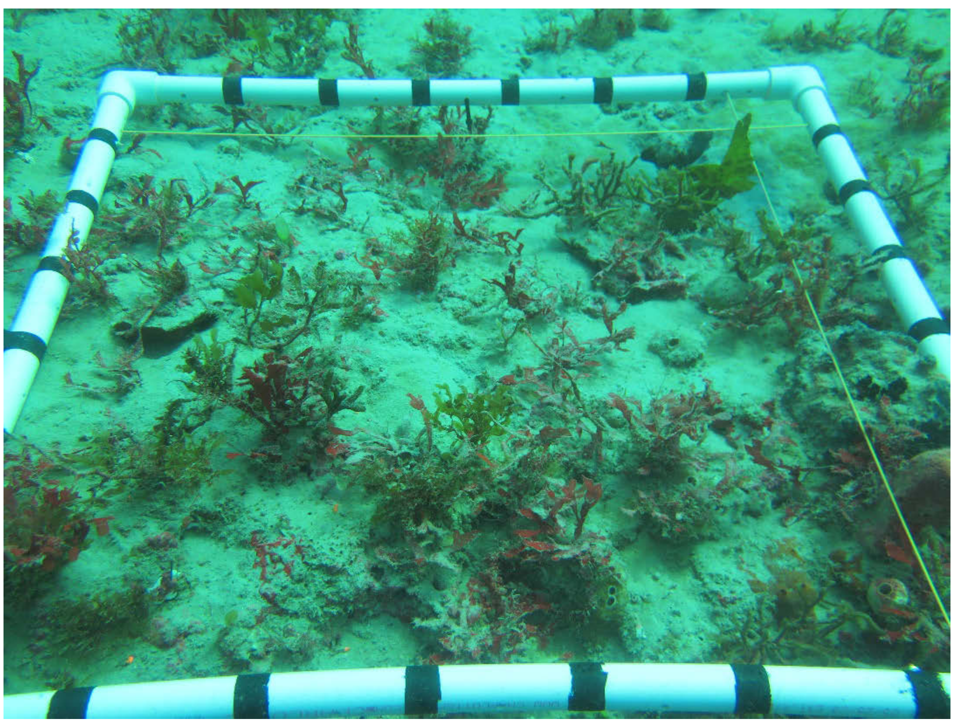

Photo 10. Benthic quadrat at Natural 5. Photo taken September 21, 2016.

Natural 6

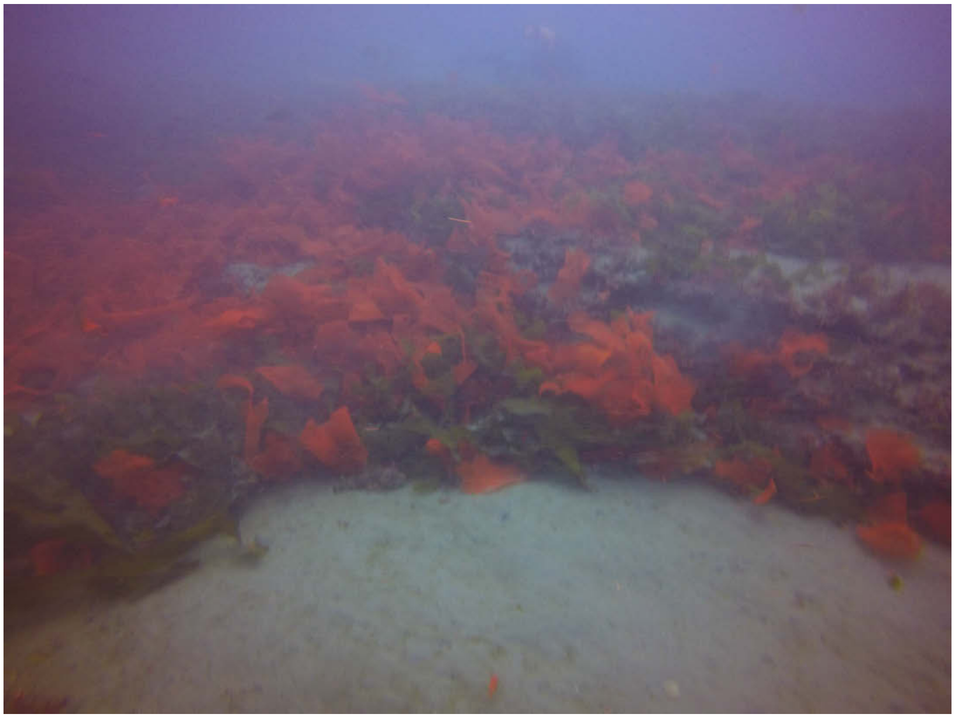

Photo 11. Structure at Natural 6. Photo taken September 11, 2016.

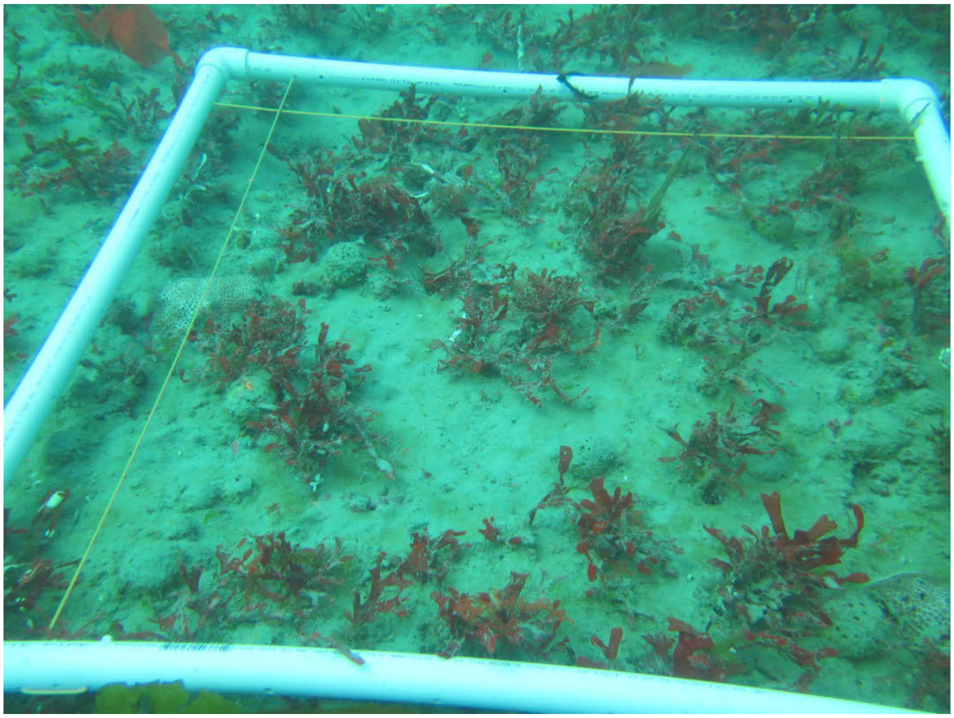

Photo 12. Benthic quadrat on Natural 6. Photo taken September 11, 2016.

Appendix E.

Photographs from Far Natural Sites.

Natural 7

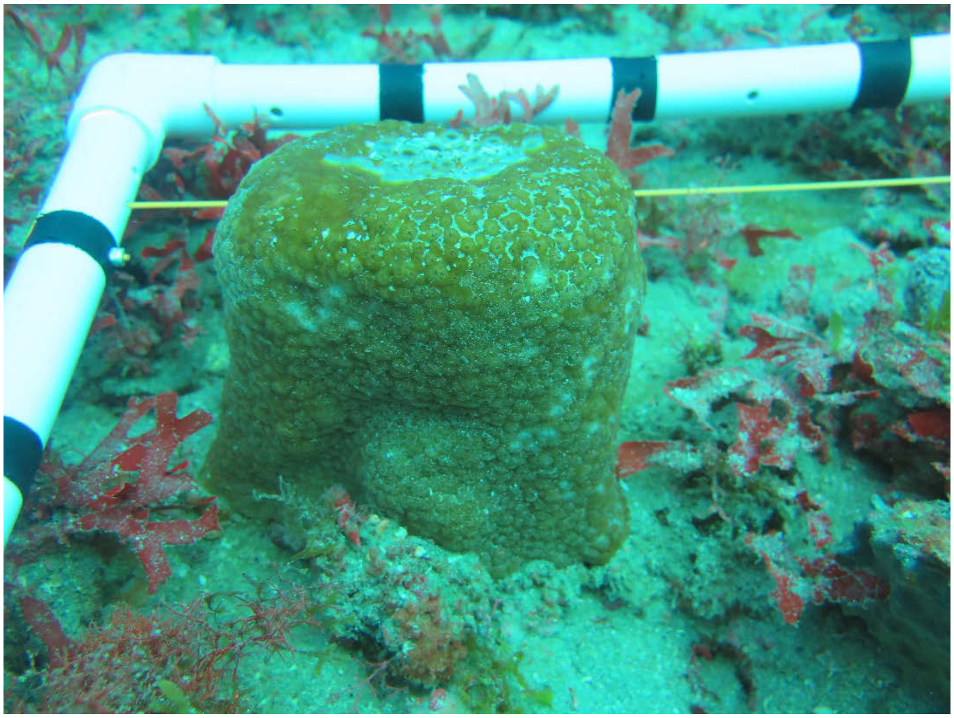

Photo 1. Sponge in a benthic quadrat at Natural 7. Photo taken September 20, 2016.

Photo 2. Lionfish sp. (*Pterois* sp.) at Natural 7. Photo taken September 20, 2016.

Natural 8

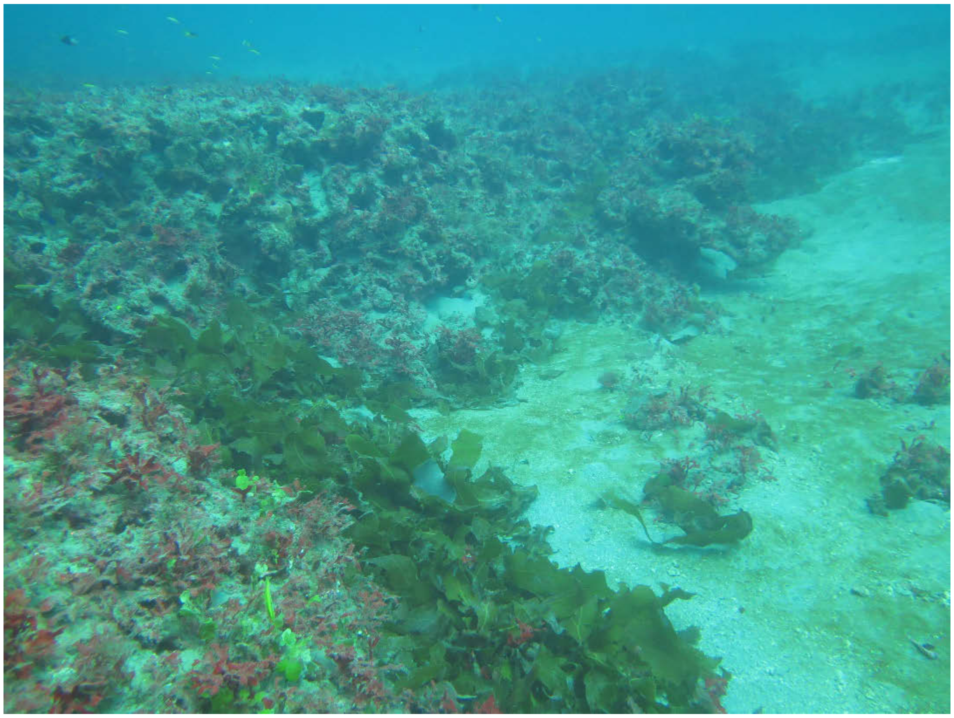

Photo 3. Structure at Natural 8. Photo taken September 20, 2016.

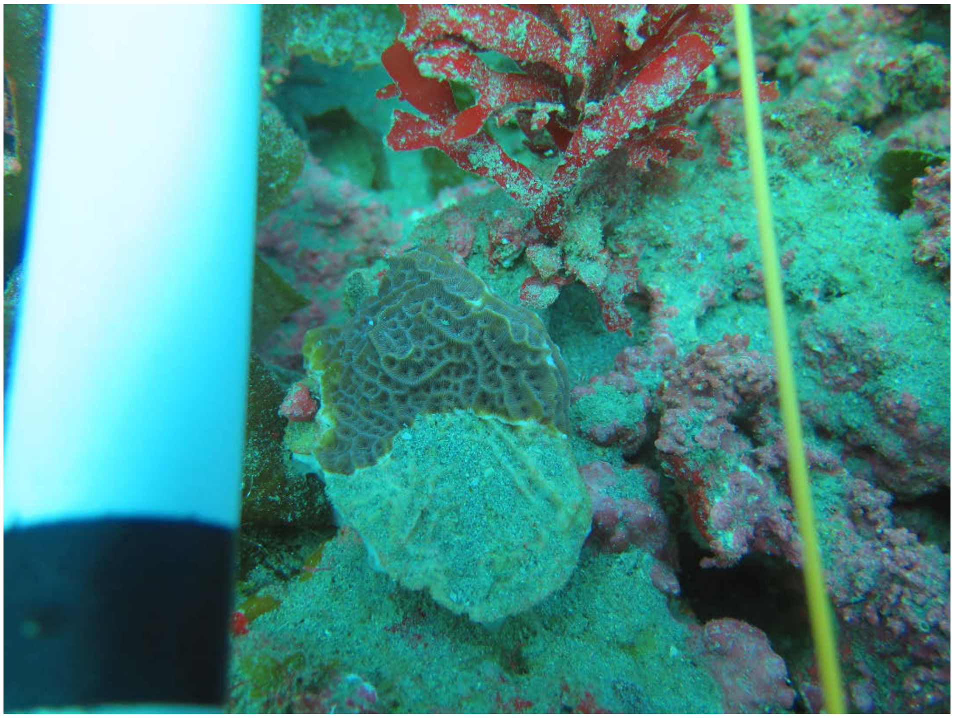

Photo 4. Lettuce coral sp. (*Agaricia* sp.) present in a benthic quadrat at Natural 8. Photo taken September 20, 2016.

Natural 9

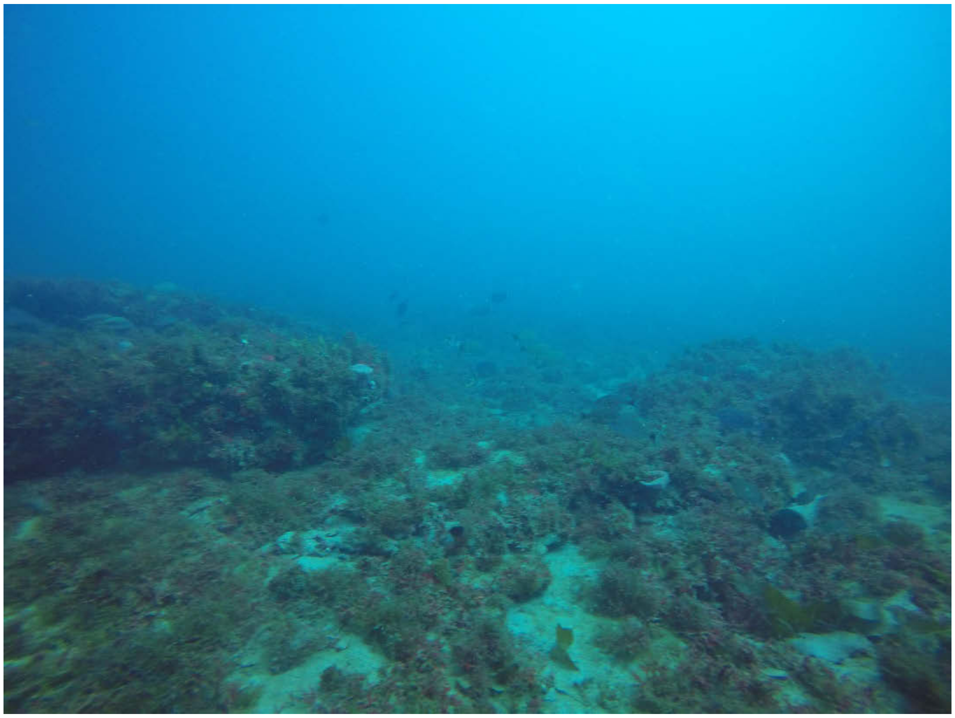

Photo 5. Structure at Natural 9. Photo taken August 23, 2016.

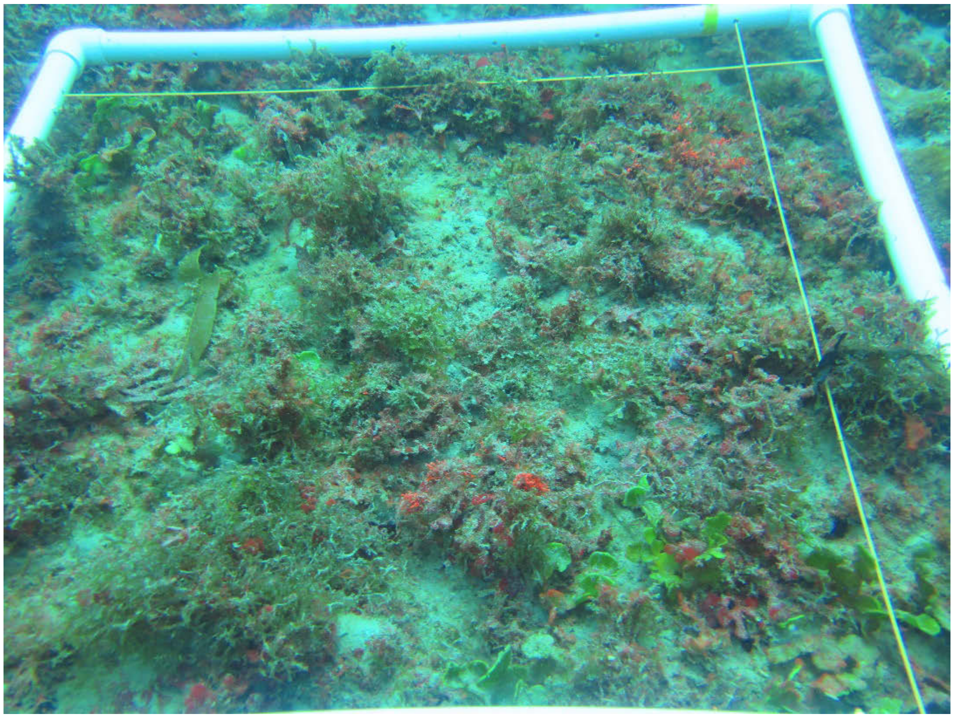

Photo 6. Benthic quadrat at Natural 9. Photo taken August 23, 2016.

Natural 10

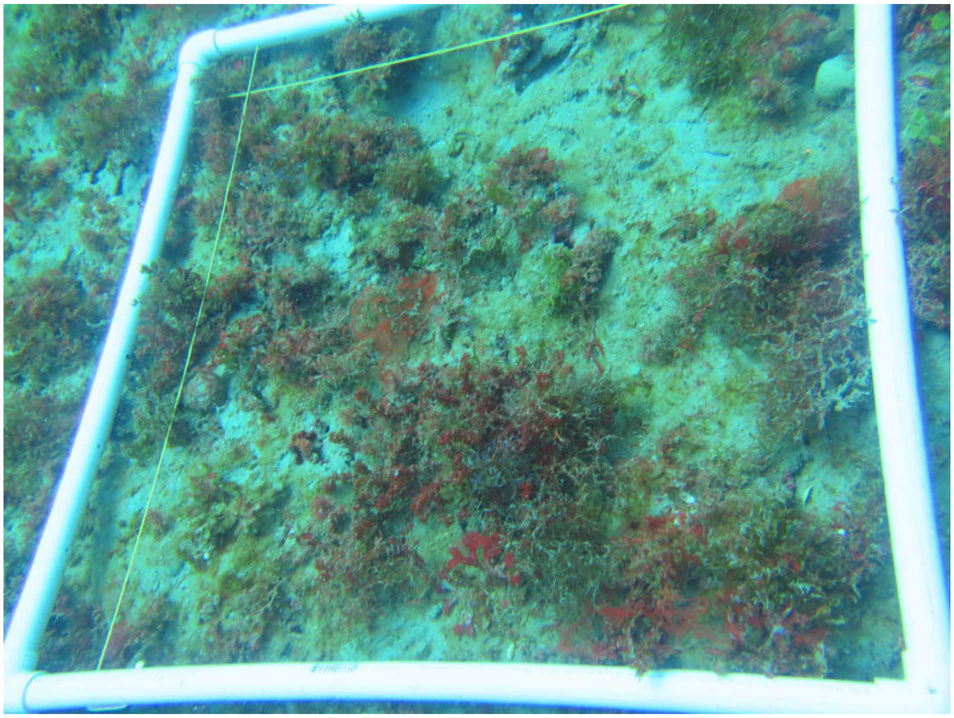

Photo 7. Benthic quadrat at Natural 10. Photo taken August 23, 2016.

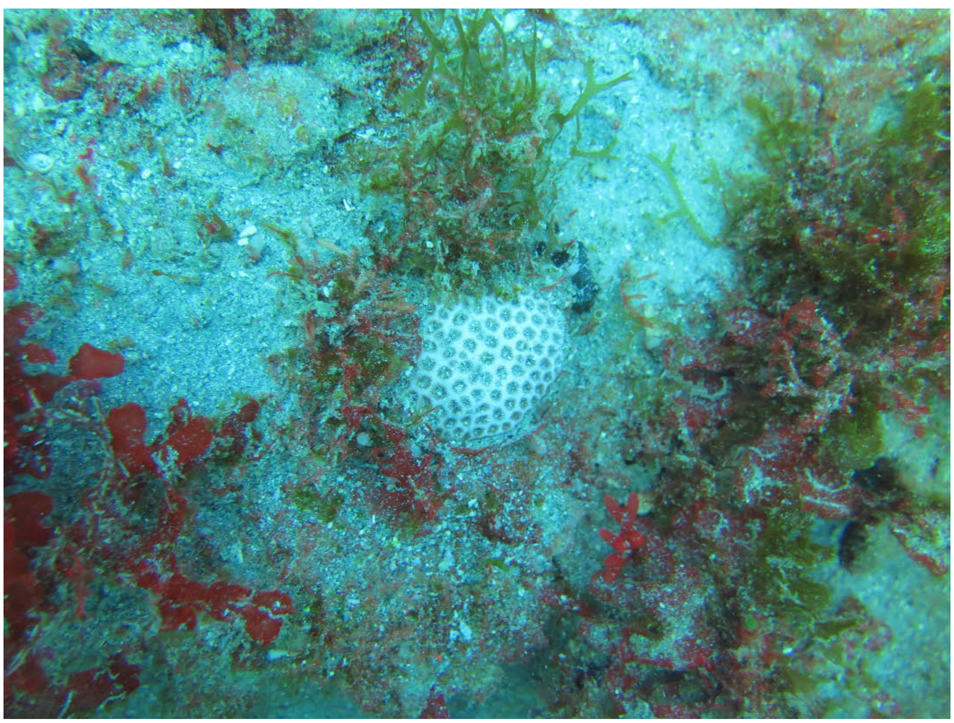

Photo 8. Lesser Starlet Coral (*Siderastrea radians*) in a benthic quadrat at Natural 10. Photo taken August 23, 2016.

Natural 11

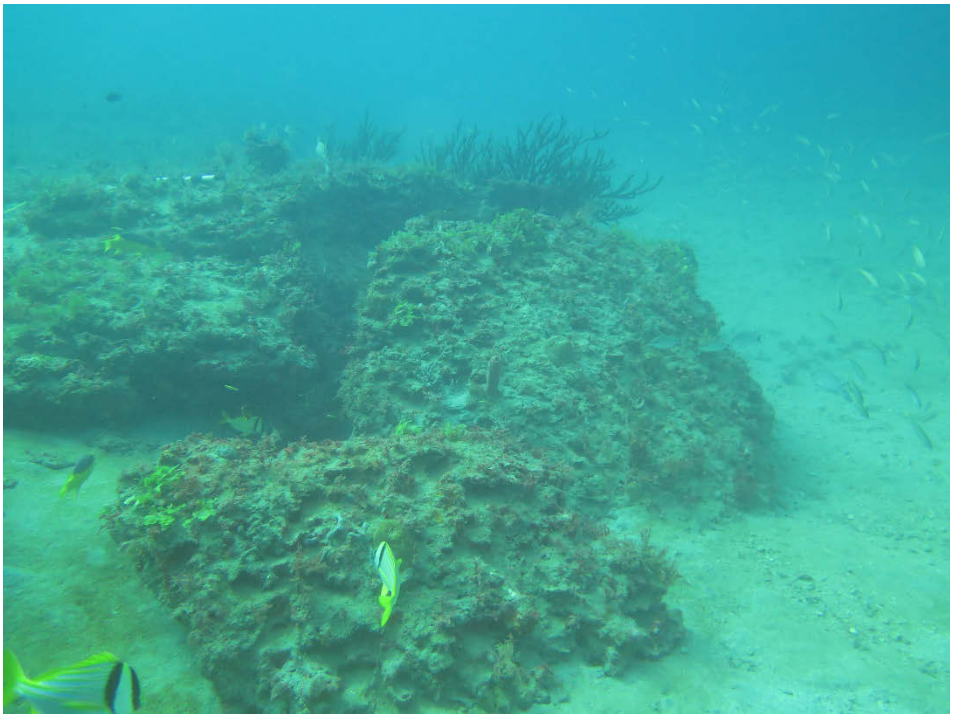

Photo 9. Structure at Natural 11. Photo taken September 21, 2016.

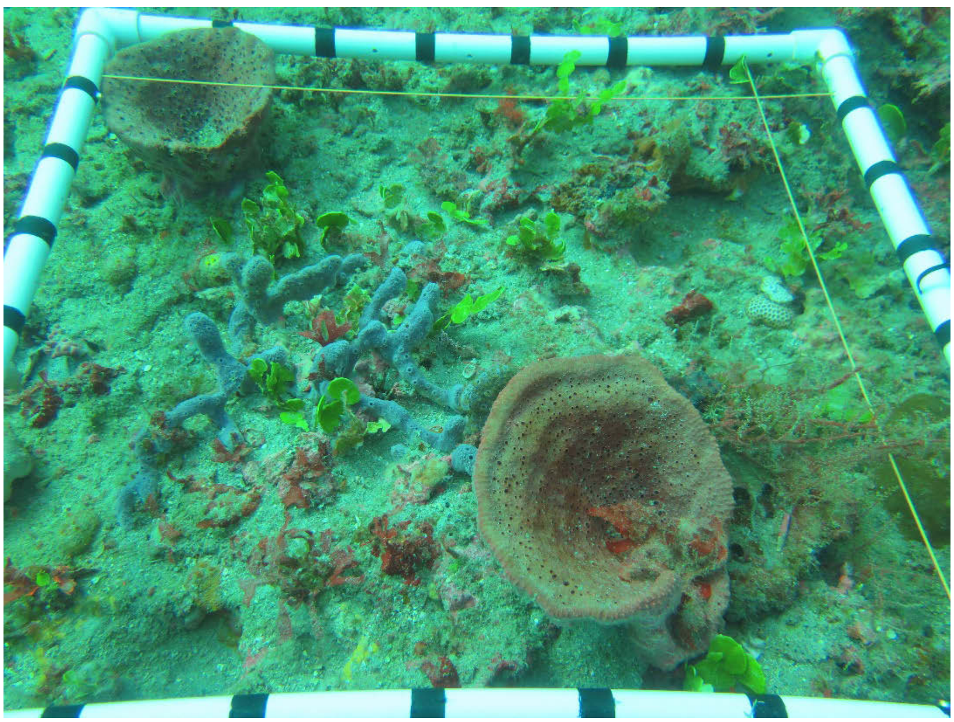

Photo 10. Benthic quadrat at Natural 11. Photo taken September 21, 2016.

Natural 16

Photo 11. Structure at Natural 12. Photo taken August 22, 2016.

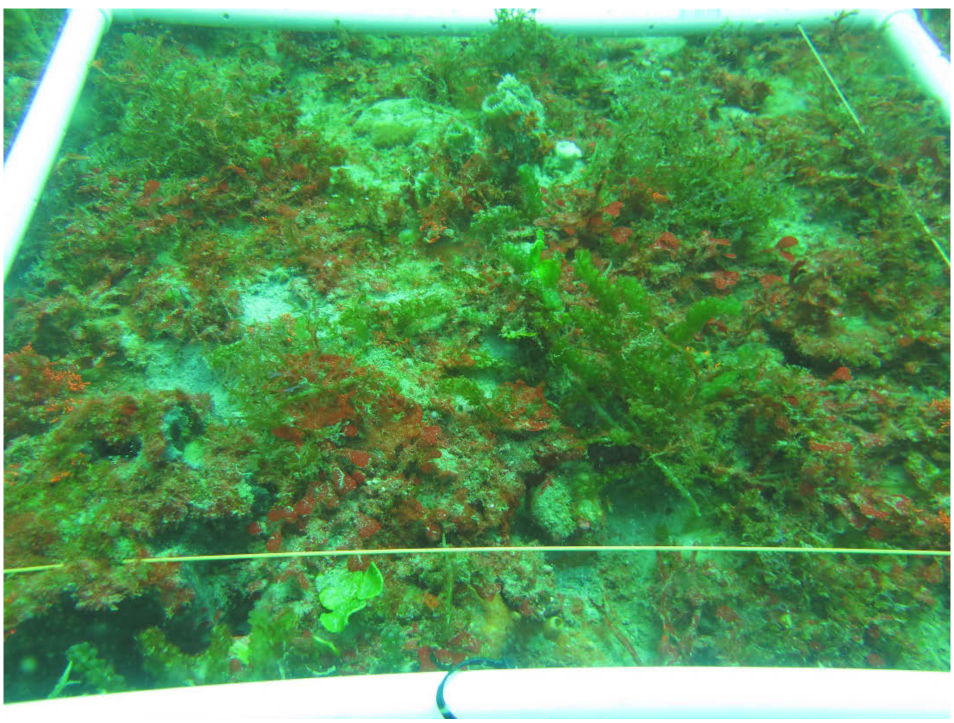

Photo 12. Benthic quadrat at Natural 12. Photo taken August 22, 2016.

Appendix F.

Curriculum vitae for the survey participants.

Adrienne Carter, Senior Marine Scientist/
Dive Safety Officer
Coastal Eco-Group, Inc.
665 SE 10th St. Suite 104
Deerfield Beach, FL 33441
Email: acarter@coastaleco-group.com

Coastal Eco-Group Inc.

YEARS OF EXPERIENCE
Total: 14

YEARS WITH CURRENT FIRM
Total: 8

EXPERIENCE
Biological Monitoring of Hardbottom Habitats in Southeast Florida

Lake Worth Lagoon Seagrass Monitoring and Mapping

Coral Relocation and Transplant Success Monitoring

Hardbottom Impact Assessment and Mitigation Planning

NEPA Documentation and Compliance

GIS and Aerial Photography Interpretation of Hardbottom

Environmental Permitting and Regulatory Support

EDUCATION

- M.Sc. / Marine Biology / 2007 / Nova Southeastern University Oceanographic Center, Dania Beach, FL.
- B.Sc. / Biology / Marine Science / 2002 / Stony Brook University, Stony Brook, NY.

PROFESSIONAL REGISTRATIONS

- International Society for Reef Studies
- Southeast Florida Coral Reef Initiative
- American Academy of Underwater Sciences

CERTIFICATIONS

- 2016- Emergency First Responder and DAN Oxygen Administration
- 2013- SDI Open Water Scuba Instructor
- 2008- UMAM Uniform Mitigation Assessment Method
- 2007- MMS Certified Marine Mammal & Listed Species Observer
- 2004- PADI Enriched Air Nitrox Diver
- 2003- PADI Advanced and Rescue Diver

EMPLOYMENT HISTORY

- Senior Scientist, Coastal Eco-Group, Inc., Deerfield Beach, FL, 2009 – present
- Marine Scientist, Coastal Planning & Engineering, Boca Raton, FL, 2006 - 2009
- Research Assistant, National Coral Reef Institute, Nova Southeastern University Oceanographic Center, Dania Beach, FL, 2003 – 2006

RELEVANT CEG EXPERIENCE

<u>Biological Monitoring, Benthic Habitat Mapping/Characterization, and Impact Assessments</u>**:** Biological assessments and resource delineation of nearshore hardbottom, offshore reef, artificial reef and submerged aquatic vegetation habitats including flora and fauna identification, *in situ* sessile biotic cover analyses, coral relocation and success monitoring, coral stress evaluations, UW video/photography, GIS and sedimentation analyses for the following projects:

- Martin County Artificial Reef Program (2016)
- Bathtub Beach/Sailfish Point Beach Nourishment Project, Martin County, FL (2010-2016)
- North, Central and South Boca Raton Beach Renourishment Projects, Palm Beach County, FL (2010–2016)

- Palm Beach Island Beach Management Agreement Annual Hardbottom Mapping and Monitoring (2014-2016)
- Town of Palm Beach Historic Nearshore Hardbottom Delineation/Aerial Analysis and GIS Development for the Beach Management Agreement Study Area (2012-2016)
- Town of Palm Beach, Phipps Ocean Park Beach and Dune Restoration Project Biological Monitoring Program, Palm Beach County, FL (2009–2016)
- Ocean Ridge Shore Protection Project, Palm Beach County, FL (2012–2016)
- Port of Palm Beach Slip 3 Replacement Project -Coral Harvest and Relocation to the 0.8 Acre Mitigation Artificial Reef (2013-2014)

NEPA Documentation/Compliance and Environmental Permitting:
Development of NEPA Environmental Assessments, Biological Assessments, and environmental permitting support for the following projects:

- North County Comprehensive Shore Protection Project, Palm Beach County, FL (2016)
- Port Everglades Sand By Pass Project, Broward County, FL (2014-2016)
- North and South Boca Raton Beach Renourishment Projects, Palm Beach County, FL (2009–2013)
- Ocean Ridge Shore Protection Project, Palm Beach County, FL (2011-2012)
- Rybovich Riviera Beach Marine Facility Project, Palm Beach County, FL (2010-2014)
- Long Key State Park Beach Restoration Project, Monroe County, FL (2011-2012)
- South Amelia Island Shoreline Stabilization Project, Nassau County, FL (2010-2011)

Seagrass Surveys/SAV Assessments:

- Palm Beach County Lake Worth Lagoon Fixed Transect Seagrass Monitoring, Palm Beach, FL (2011-2015)
- Rybovich Riviera Beach Marine Facility Project, Submerged Aquatic Vegetation Mapping and EFH Assessment, Palm Beach County, FL (2010-2012)
- Riviera Beach Waterfront Municipal Marina Submerged Aquatic Habitat Mapping, Palm Beach County, FL (2009)
- Long Key State Park Beach Restoration Project, Monroe County, FL (2009–2010)

Biological Data Analysis/Technical Report Writing:
Quality control and assessment of observer inter-variability of benthic digital video transect data using point-count software; benthic community univariate and multivariate statistical analyses in the evaluation of project-related effects utilizing Statistica, GraphPad, Primer V6, Matlab, and other statistical software packages:

- Bathtub Beach/Sailfish Point Beach Nourishment Project, Martin County, FL. Annual Monitoring Reports for permit compliance (2010-2016)
- North, Central and South Boca Raton Beach Renourishment Projects, Annual Monitoring Reports for permit compliance, Palm Beach County, FL (2009–2017)
- Town of Palm Beach, Reach 7 0.8-Acre Mitigation Artificial Reef Monitoring Program, Palm Beach County, FL (2010-2011)
- City of Hollywood Beach Nourishment Project Construction Biological Monitoring of Nearshore Hardbottom Survey Reports (2012-2016)
- Ocean Ridge Shore Protection Project, Palm Beach County, FL (2011-2013)

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YEARS OF EXPERIENCE
Total: 7

YEARS WITH CURRENT FIRM
Total: 1

EXPERIENCE
Fish Population Assessments/Reef Fish Visual Census Surveys

Biological Monitoring of Hardbottom Habitats in Southeast Florida

Lake Worth Lagoon Seagrass Monitoring and Mapping

Coral Relocation and Transplant Success Monitoring

Lake Worth Lagoon Benthic Macroinvertebrate Identification

Marine Mammal Docent

Small Boat Captain and Operations

EDUCATION

- M.S./Marine Biology & Coastal Zone Management/2016/Nova Southeastern University Oceanographic Center, Dania Beach, FL.
  Thesis: Reef fish spatial distribution and benthic habitat associations on the southeast Florida reef tract.
- BA/Marine and Freshwater Sciences/2008/Colgate University, Hamilton, NY

PROFESSIONAL REGISTRATIONS

- American Academy of Underwater Sciences
- Florida Association of Environmental Professionals

CERTIFICATIONS

- 2011 - PADI Enriched Air Nitrox Diver
- 2011 - PADI Adventure and Rescue Diver
- 2011 - AAUS Scientific Diver
- 2011 - Emergency First Responder and DAN Oxygen Administration

EMPLOYMENT HISTORY

- Marine Scientist, Coastal Eco-Group, Inc., Deerfield Beach, FL, August 2016 – present
- Research Assistant, National Coral Reef Institute, Nova Southeastern University, Dania, FL, 2012-2016
- Sea Turtle Specialist I, Broward County Sea Turtle Conservation Program, Broward County, FL, 2016
- Animal Care and Education Docent, Marine Mammal Center, Sausalito, CA, 2006-2011

<u>Fish Monitoring</u>

- Rybovich Riviera Beach Marine Facility Project, Fish Identification and Census, Palm Beach County, FL (2016)
- Martin County artificial and natural reef fisheries-independent surveys (2016)
- Bathtub Beach/Sailfish Point Beach Nourishment Project, Fish Identification and Census, Martin County, FL (2017)

<u>Hardbottom Monitoring, Benthic Habitat Mapping/Characterization, and Impact Assessment</u>
Biological surveys and benthic resource delineation of nearshore hardbottom, offshore reef, and submerged aquatic vegetation habitats including coral and sponge fate tracking, coral stress evaluations, video/still photography, reef edge mapping, and sedimentation monitoring for the following projects:

- Lake Worth Lagoon Fixed Transect Seagrass Monitoring, Palm Beach County, FL (2016)
- Palm Beach Island Beach Management Agreement 2016 annual survey and Year 1 post-construction survey for the 2015 Mid-Town Beach Nourishment Project, Town of Palm Beach, FL (2016)
- 2016 Town of Palm Beach Reaches 7/8 Beach Nourishment Project, Palm Beach County, FL (2016)
- 2013 South Boca Raton Beach Nourishment Project, Year 2 post-construction survey, City of Boca Raton, Palm Beach County, FL (2016-2017)
- 2017 Central Boca Raton (Segment 2) Beach Nourishment Project- pre-construction, during-construction, and post-construction sedimentation surveys of offshore reefs adjacent to borrow site, City of Boca Raton, Palm Beach County, FL (2016-2017)
- 2016 Broward County Segment 2 Beach Nourishment Project Immediate Post-Construction sedimentation survey and nearshore edge mapping (2016)
- Broward County Nearshore Hardbottom Monitoring Program for Natural Variability nearshore hardbottom edge mapping surveys and GIS (2016-17)
- 2016 Bathtub Beach Sailfish Point Beach Nourishment Project, Immediate Post-Construction sedimentation surveys, Martin County, FL (2016- 2017)

<u>Relevant Biological Data Analysis/Technical Report Writing</u>
Software Packages: ArcGIS< Primer V6, STATISTICA 10, and other statistical software packages used for univariate and multivariate analyses.

- 2016 CAP 1135 Benthic Macroinvertebrate Study Lake Worth Lagoon, FL Report (2016-2017)
- 2016 Martin County Artificial Reef Program Monitoring Report (2016-2017)
- 2015 Martin County Artificial Reef Program Monitoring Report (2016)

RELEVANT NOVA SOUTHEASTERN UNIVERSITY EXPERIENCE
<u>Fish Monitoring</u>
Reef Fish Visual Census and Roving Diver Surveys in Florida.

- South East Florida Coral Reef Initiative Reef Fish Visual Census (RVC) surveys, Miami-Dade, Broward, Palm Beach and Martin County, FL (2012-2016)
- FDEP-CRCP Southeast Florida Fisheries-Independent Monitoring Program, Dry Tortugas National Park, FL (2012, 2014, 2016)
- NSUOC Annual Monitoring sites (2012)
- NSU-FAU Cable Monitoring project (2014-2016)
- NSUOC Boat Basin Artificial Reef Monitoring (2014-2016)
- Preserved larval through mature specimen Identification (2012-2013)

<u>Biological Data Analysis/Technical Report Writing</u>
Software Packages: Primer V6, STATISTICA 10, and other statistical software packages used for univariate and multivariate analyses.

- Marine Biological Monitoring in Broward County, Florida: Year 13 (2012) Annual Report. (2013)
- Southeast Florida Coral Reef Fishery-Independent Baseline Assessment Summary Reports (2013-2017)

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EDUCATION

M.S., Biological Sciences, Florida Atlantic University, 2000

B.S., Marine Biology, FAU, 1996

B.A., University of Pennsylvania, 1992

YEARS OF PROFESSSIONAL EXPERIENCE

22

YEARS WITH CURRENT FIRM

12

PROFESSIONAL AFFILIATIONS

Southeast Florida Coral Reef Initiative Team Member (SEFCRI), 2003-2012, Vice-Chair (2013-2017)

South Florida Water Management District Water Resources Advisory Commission, 2011-2013

International Coral Reef Society

American Academy of Underwater Sciences

EXPERIENCE

- Biological Monitoring of Coral Reef, Hardbottom, and Seagrass Habitats in Southeast Florida
- Hardbottom and Seagrass Impact Assessment and Mitigation Planning
- Environmental Permit Application Preparation and Processing
- Environmental Compliance
- NEPA Documentation & Compliance
- Coral Relocation and Transplant Success Monitoring
- GIS and Aerial Photography Interpretation of Hardbottom
- Environmental Permitting and Regulatory Agency Liaison

EMPLOYMENT HISTORY:

- President, Coastal Eco-Group, Inc., Deerfield Beach, FL- November 2005 – present
- Senior Scientist II, PBS&J, Inc., Jacksonville, FL- October 2004 – March 2006
- Research Assistant II, Harbor Branch Oceanographic Institute, Marine Nutrient Dynamics Laboratory, Fort Pierce, FL- September 2004 – August 2005
- Environmental Specialist III, Florida Department of Environmental Protection- Bureau of Beaches & Coastal Systems, Tallahassee, FL, October 2002 – September 2004
- Senior Marine Biologist, Coastal Planning & Engineering, Inc., Boca Raton, FL, April 1997 – October 2002

PROFESSIONAL EXPERIENCE:

Ms. Miller, President and Principal Scientist, has over 22 years of professional experience in environmental planning and permitting, project management, NEPA assessments and document preparation, and marine and estuarine ecological surveys, including hardbottom, mangrove and submerged aquatic vegetation mapping, monitoring, impact analysis, and mitigation design/implementation in association with dredging and shore protection projects throughout Florida. Prior to establishment of Coastal Eco-Group in 2005, Ms. Miller was employed as an Environmental Specialist with the FDEP, Bureau of Beaches and Coastal Systems, where she conducted the regulatory and ecological review of joint coastal and environmental resource permits and provided technical expertise for monitoring program design and seagrass mitigation.

REPRESENTATIVE CEG PROJECTS:

2010, 2013/14 North and South Boca Raton Beach Nourishment Projects, and 2016/17 North Boca Raton Segment II Project, City of Boca Raton, Palm Beach County, FL

Project Manager and Principal Scientist in charge of biological assessments, NEPA documentation, endangered species surveys and critical habitat assessments, hardbottom data analyses and impact analysis, and reporting and permit compliance for the 2010, 2013/2014, and 2016/17 beach nourishment projects. Provided regulatory and resource protection agency coordination services and developed a cost effective and ecologically appropriate sedimentation monitoring plan to allow authorization of a 400-ft buffer distance to adjacent reef habitats during dredging of offshore borrow sites; Responsible for technical reports in compliance with FDEP and USACE permit requirements.

2010 Bathtub Beach Restoration Project and 2016/17 Bathtub Beach Sailfish Point Nourishment Project, Immediate through Year 3 Post-Construction Biological Monitoring of Nearshore Hardbottom, Martin County, FL, 2010- present. Principal Scientist and Project Manager for the biological monitoring of the 2010 and 2016/17 beach nourishment projects. Responsibilities include nearshore hardbottom edge mapping, biological monitoring surveys of permanent transects, sediment monitoring, and wormrock reef surveys involving 3-D laser scanning to measure accretion and erosion of the wormreef in relation to the adjacent dry beach. Developed adaptive management approach to the nearshore monitoring program which resulted in modifications to achieve overall cost saving without compromise to biological data collection and analysis. Primary Author and Project Manager for the Biological Assessment and Environmental Assessment for the 2016 Bathtub Beach/Sailfish Point Nourishment Project, including development of a cumulative effects review template for overlapping project elements at St. Lucie Inlet. Principal Scientist for 2014 seagrass mapping of the inlet flood shoal borrow areas and recommendations for impact avoidance and monitoring protocols for dredging.

Lake Worth Lagoon Fixed Transect Seagrass Monitoring Program: Annual Monitoring Surveys, 2011-2017 and 2013 Lake Worth Lagoon Seagrass Mapping Project, Palm Beach County
Principal Scientist for annual seagrass surveys of permanent fixed transects in the Lake Worth Lagoon for Palm Beach County Department of Environmental Resources Management. Primary Author of annual cumulative reports which examine long-term trends in seagrass distribution. Provided recommendations for new field protocols to evaluate sediment characteristics, habitat suitability, and potential patch migration of *Halophila* spp. Principal Scientist and Project Manager for the 2013 Seagrass Mapping Project; Primary Author of the 2013 mapping report which analyzed changes in seagrass cover/extent between 2007 and 2013 by sub-basin/reach based on extensive ground-truthing of 1,508 sites.

2015 Structural Stabilization and Rehabilitation of the Spar Orion and the Clipper Lasco Grounding Sites, Broward County, FL, 2014-2016. Project Manager and Lead Scientist responsible for post-grounding biological surveys. Conducted multiple biological and ESA listed species surveys to verify existing site conditions and identify alternatives to stabilize and/or remove unconsolidated rubble from the grounding sites. Provided construction oversight of reef stabilization, restoration and rehabilitation activities to ensure compliance with project specifications.

Port of Palm Beach Slip 3 Orphan Coral Relocation Project, Palm Beach County, FL, 2013-2016.
Project Manager and Lead Scientist for regulatory agency coordination and coral relocation for impact avoidance. USACE project permit required relocation of stony corals greater than 10 cm in diameter for impact avoidance. Through co-ordination with regulatory agencies, secured the use of orphan corals from the slip walls (all corals less than 10 cm) for use in the coral nursery mitigation program for the Town of Palm Beach. Over 500 orphan corals were transplanted from to the offshore coral nursery in 2013. Cost effective monitoring was developed by combining the Port's monitoring requirement with the Town's coral nursery program, avoiding long-term survivorship monitoring costs to the Port and reducing field survey requirements using innovative low-cost monitoring techniques to demonstrate transplantation success.

Town of Palm Beach Biological Services Consultant, Palm Beach County, FL, 2009- present.
Project Manager and Lead Scientist for the 2014 Mid-Town Beach Nourishment Project and Palm Beach Island Beach Management Agreement and Biological Monitoring Program; and Primary Author/Developer of the Town's mitigation program for nearshore hardbottom impacts from beach nourishment. Deputy Project Manager and Lead Scientist for biological monitoring, data analyses, impact evaluation, and permit-required reporting for nearshore hardbottom habitats for the 2010 Mid-Town Beach Nourishment Project, Phipps Ocean Park Beach and Dune Restoration Project, and Palm Beach Harbor Dredging Program Mitigation Reef Monitoring and Coral Transplantation Pilot Project (2009-2013).

Port Everglades Sand Bypass Project, Broward County, FL, 2006 – present.
Project Manager/Principal Author of the 2008 and 2015 NEPA regulatory Environmental Assessments and Biological Assessments for Section 7 ESA compliance. The sand bypass project was re-designed in 2014 to avoid confined blasting techniques. Primary Author of the UMAM hardbottom mitigation evaluation and innovative Mitigation Plan for impacts to nearshore hardbottom rubble-dominated communities at the spoil shoal. Responsibilities include environmental permitting support and coordination with State and Federal regulatory and resource protection agencies

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YEARS OF EXPERIENCE
Total: 12

YEARS WITH CURRENT FIRM
Total: 3.5

EXPERIENCE
Biological Monitoring of Hardbottom Habitats in Southeast Florida

Lake Worth Lagoon Seagrass Monitoring and Mapping

Coral Relocation and Transplant Monitoring

Coral Nursery Development, Coral Histological Analysis and Fecundity

Fish Population Assessments/ Reef Visual Census Surveys

EDUCATION

- M.S./Marine Biology/ Nova Southeastern University Oceanographic Center, Dania Beach, FL, 2015
- B.S. Biology/Zoology w/ High Honors 2001/University of Maryland, College Park, MD

EMPLOYMENT HISTORY

- Marine Scientist, Coastal Eco-Group, Inc., Deerfield Beach, FL (August 2012 – present)
- Research Assistant, Nova Southeastern University Oceanographic Center, (October 2009 – May 2013)
- Senior Biologist, National Aquarium Institute, Baltimore, MD (2002-2009)
- Water Quality Analyst, National Aquarium Institute, Baltimore, MD (2004)

RELEVANT EXPERIENCE

Fish Monitoring

Reef Fish Visual census surveys of reef fish in Palm Beach County and Broward County, FL

- FDEP-CRCP Southeast Florida Fisheries-Independent Monitoring Program (2012-2013)
- Martin County artificial reef fisheries-independent surveys (2015-2016)

Biological Monitoring and Benthic Habitat Mapping/Characterization**:**

- Palm Beach Island Beach Management Agreement Annual Hardbottom Mapping and Monitoring (2014-2016)
- 2016 Bathtub Beach Sailfish Point Nourishment Project, Pre-Construction Hardbottom Mapping and Characterization (2014-2015)
- 2014/2015 North and Central Boca Raton Beach Nourishment Projects- Pre-Construction, During, and Immediate Post-Construction Monitoring (2014-2015)
- 2013 South Boca Raton Maintenance Project, Immediate through Year 2 Post Construction Monitoring, Palm Beach County, FL (2013-2016)
- 2010 Bathtub Beach Restoration Project, Years 2 and 3 Post Construction Monitoring, Martin County, FL (2012-2015)
- 2012 City of Hollywood Beach Nourishment Project, Years 1 -3 Post-Construction Biological Monitoring Survey of Nearshore Hardbottom, Broward County, FL (2013-2016)
- 2013 Pensacola Beach Nourishment Project, Escambia County, FL (2013)
- 2015/2016 Martin County Artificial and Natural Reef Benthic Assessments

Seagrass Surveys/SAV Assessments:

- 2013 Lake Worth Lagoon Seagrass Groundtruthing, Palm Beach County, FL (2012-2014)
- Palm Beach County Lake Worth Lagoon Fixed Transect Seagrass Monitoring, Palm Beach, FL (2013-2015)
- 2016 Bathtub Beach Sailfish Point Nourishment Project, Pre-Construction seagrass mapping on the St. Lucie Inlet shoal (2014-2015)

Coral Histology and Nursery:

- Town of Palm Beach Coral Nursery Mitigation Project- coral relocation, fecundity, survival monitoring, statistical analyses, and report development (2014-2016)
- Proficient with sample preservation, embedding, sectioning and staining techniques
- Performed microscopic analysis on histological and gross coral tissue samples for fecundity analysis
- Established and maintained offshore and land-based coral nurseries for propagation and transplantation of *Acropora cervicornis*.
- Proficient with coral collection, transportation, fragmentation and attachment techniques
- Monitored health and condition of donor and transplanted colonies
- Monitored coral transplants and nursery colonies for gamete production and spawning activity, including gamete collection and larval rearing

Statistical Analysis/Technical Report Development

- 2014/2015 North and Central Boca Raton Beach Nourishment projects- Sedimentation Impact Analyses for Offshore Borrow Area (2014-2015)
- Piping Plover Foraging Habitat Evaluation Monitoring, Town of Hilton Head Island, SC, Port Royal Sound Shoreline Restoration Project- Years 2 and 3 Post-Construction (2014-2016)
- Martin County Artificial Reef Program 2015 and 2016 Monitoring Report

NEPA Documentation/Compliance and Environmental Permitting
Development of NEPA Environmental Assessments and Biological Assessments

- 2013 Pensacola Beach, FL Beach Nourishment Project (2013)
- 2015/16 Town of Hilton Head Island Beach Nourishment Project, Hilton Head, South Carolina (2014/15)
- 2015 FDEP Structural Stabilization and Rehabilitation of the Spar Orion and Clipper Lasco Grounding Sites, Environmental Assessment and Biological Assessment (2014)

RELEVANT NATIONAL AQUARIUM EXPERIENCE

Marine, Estuarine, and Freshwater Scientific Collection Activities**:**
Collected fish and invertebrate specimens for educational display using SCUBA, seine net, or fishing equipment. Identification of flora and fauna in Chesapeake Bay watershed, including tidal marsh, stream, and beach habitats.

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YEARS OF EXPERIENCE

Total: 6

OFFICE LOCATION

Deerfield Beach, FL

PROFESSIONAL AFFILIATION

American Academy of Underwater Sciences

EXPERIENCE RELEVANT TO RFP

- Biological Monitoring of Hardbottom Habitats in Southeast Florida
- Benthic Habitat Mapping and Characterization
- GIS and Aerial Photography Interpretation of Hardbottom
- NEPA and Section 7 Documentation & Compliance

EDUCATION

- M.S., Marine Biology / 2013 Nova Southeastern University Oceanographic Center, Dania Beach, FL
- M.S., Coastal Zone Management / 2013 Nova Southeastern University Oceanographic Center, Dania Beach, FL
- B.S., Marine Biology / 2009 Texas A&M University at Galveston, Galveston, TX

PROFESSIONAL REGISTRATIONS

- American Academy of Underwater Science

CERTIFICATIONS

- 2016 – CPROX1st AED Administrator
- 2011 - PADI Rescue Diver Certification

EMPLOYMENT HISTORY:

- Staff Scientist, Coastal Eco-Group, Inc., Deerfield Beach, FL - June 2013 – present
- Staff Scientist, Pinnacle Group International, Boca Raton, FL- August 2012 – June 2013
- Volunteer Scientist, U.S. Geological Survey (USGS), Nova Southeastern University Oceanographic Center, Dania Beach, FL – June 2010 – October 2010
- Volunteer Scientist, National Oceanic and Atmospheric Administration (NOAA), St. Croix, U.S. Virgin Islands – June – September 2010

RELEVANT EXPERIENCE

Biological Monitoring, Benthic Habitat Mapping/Characterization, and Impact Assessments**:** Biological assessments and mapping/characterization of nearshore hardbottom, offshore reef, and submerged aquatic vegetation habitats including flora and fauna identification, *in situ* sessile biotic cover analyses, video/still photography and sedimentation analyses for the following projects:

- 2010 Bathtub Beach Restoration Project and 2016/17 Bathtub Beach/Sailfish Point Beach Nourishment Project, Martin County, FL (2013-present)
- Martin County Artificial Reef Program (2015-2016)

- 2016 Broward County Segment II Beach Nourishment Project (2016-present)
- Broward County Nearshore Hardbottom Edge Monitoring Program, Natural Variability Study (2014-present)
- 2016 Phipps Ocean Park Beach Nourishment Project, Town of Palm Beach, FL (2015-present)
- 2016 Longboat Pass Navigational Maintenance Dredging and Beach Disposal Project, Pre-Construction and Year 1 Post-Construction Survey, Town of Longboat Key (2015- present)
- Pipeline Corridor Hardbottom Mapping, Charlotte County Erosion Control Project (2015-2016)
- 2013 and 2016 South Boca Raton Beach Nourishment Projects, City of Boca Raton, FL (2013-present)
- 2015 Mid-Town Beach Nourishment Project and Beach Management Agreement, Town of Palm Beach, FL (2013-present)
- 2010 North Boca Raton Beach Nourishment Project and 2014/2016 North and Central Boca Raton Beach Nourishment Projects (2013-present)
- 2012 City of Hollywood Beach Nourishment Project, Years 1-3 Post-Construction Biological Monitoring Survey of Nearshore Hardbottom (2013-2015)
- Ocean Ridge Shore Protection Project, Palm Beach County, FL (2013-2014)
- Town of Palm Beach Mitigation Artificial Reef Siting Field Investigations, Palm Beach County, FL (2013)

<u>Seagrass Surveys:</u>

- Old Port Cove Dredge Hole Seagrass Mitigation Site Annual Monitoring, Lake Worth Lagoon, Palm Beach County, FL (2016-2017)
- Lake Worth Lagoon Annual Fixed Transect Seagrass Monitoring, Palm Beach County, FL (2013-2017)
- 2013 Lake Worth Lagoon Seagrass Mapping Project, Palm Beach County, FL (2013-2014)
- Rybovich Riviera Beach Marina Submerged Aquatic Vegetation Delineation, Palm Beach County, FL (2013)

<u>Biological Data Analysis/Technical Report Writing for Permit Compliance</u>
Assisted in the development of technical reports including data compilation, GIS, and analyses for the following projects:

- 2010 Bathtub Beach Restoration Project, Year 3 Post-Construction Monitoring, Annual Report, Martin County, FL (2013)
- 2010 North and South Boca Raton Beach Renourishment Projects, Year 3 Post-Construction Annual Monitoring Reports, Palm Beach County, FL (2013-2014)
- 2012 City of Hollywood Beach Nourishment Project, Years 1-3 Annual Post-Construction Biological Monitoring Reports (2013-2016)
- Palm Beach County, Lake Worth Lagoon Groundtruthing Verification of 2007 Seagrass Maps, Palm Beach, FL (2013)
- 2013 and 2014 Lake Worth Lagoon Fixed Transect Seagrass Monitoring Reports, Palm Beach, FL (2013-2015)