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A Comparison of Infaunal Community Structure Between Pre- and Post-Construction Sampling of Artificial FDOT Rock- Pile Reefs in Broward County, Florida

By

Joan Lorraine Guerra

Submitted to the Faculty of
Nova Southeastern University Oceanographic Center in partial fulfillment of the requirements for
the degree of Master of Science with a specialty in:

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Joan Lorraine Guerra

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Marine Biology

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Abstract

Artificial reefs (ARs) are generally created with the intention of increasing local fish populations, biodiversity and corresponding habitat productivity, most often in support of commercial and recreational uses (e.g., diving and fishing). Numerous studies have investigated the communities that develop on artificial reefs. By contrast, far less research has focused on the surrounding infaunal communities, which represent critical trophic resources for many species that populate both natural and artificial reefs, and which may be affected both by AR deployment and the organisms that subsequently recruit to them. This study compared infaunal organism abundances at four sites between the inner and middle reefs off Broward County, Florida, before deployment of a series of Florida Department of Transportation (FDOT) AR boulders in 2009 (pre-construction) and four years later in 2013 (post-construction). Samples consisted of sediment collected in hand-held core tubes taken on open sediment adjacent to the proposed ARs and along transects at distances 3 m and 7 m from the ARs post-construction. Sample depths ranged from 12.1 to 14.6 m. Analyses were carried out on organisms retained on a >0.5 mm sieve and identified to the lowest practical taxonomic level. Data consisted of abundances rather than densities, because pre-construction samples did not record sediment volume per core. A total of 159 taxa were identified, of which only 50 were identified to genus and 61 to species. Polychaete families Spionidae, Sabellidae, Syllidae, and Hesionidae, and sipunculan superfamily Phascolosomatidea dominated pre-construction samples. Polychaetes also dominated post-construction samples, with high relative abundances of Sabellidae and Hesionidae, but with increased proportions of bivalves and amphipods. Statistical analyses (PRIMER, PERMANOVA, and SIMPER) determined whether infaunal composition, richness and, diversity differed among samples by year, site and distance from AR boulders. A slight but statistically insignificant difference in species diversity appeared between 3- and 7-m distances between years. However, composition, richness, and diversity of infauna did not differ either between pre-and post-construction samples or by sample distance from the adjacent AR boulders. The increase in homogeneity among samples post-construction may reflect recovery following the disturbance created by AR deployment, or a response to different benthic conditions generated by AR deployment. As other studies have suggested that AR fauna may influence surrounding infaunal communities to distances greater than 7 m, and that conditions may not stabilize around ARs for up to ten years following deployment, additional sampling is recommended to determine the longer-term effects of the FDOT ARs on infauna and benthic habitat (e.g., sediment composition, water movement) and assist in determining best practices for future AR deployments (e.g., composition, structure, location).

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Introduction

Coral reefs support more species per unit area than any other marine environment and may harbor up to 8 million undiscovered species (Reaka-Kudla 1997; NOAA 2007). Maintaining reef health, structure, and diversity is of critical importance because reefs play multiple important roles, including but not limited to supporting fishery resources, providing coastal protection, and serving as local economic engines (Hodgson 1999; Bellwood et al. 2004).

Reefs are subject to numerous natural and anthropogenic impacts (Halpern et al. 2008, Hodgson 1999), and are currently declining worldwide due to global warming, ocean acidification (Hoegh-Guldberg et al. 2007), sedimentation and eutrophication, which can be caused by coastal development (Muday 2004). This decline has led to major efforts to conserve and expand reef areas. One such strategy involves the construction of artificial reefs (Rinkevich 2005; Perkol-Fenkel et al. 2006; Carr and Hixon 2015). Artificial reefs are deployed in Florida waters primarily to enhance fish biomass and populations to augment fishing opportunities that would reduce fishing effort and increase public access (Stone 1985; National Academy Press 1988). Sanders and Morgan (1976) define fishing effort as the product of fishing power per number of unit operations and is therefore the total effective area covered by gear during a given number of unit operations. Catch per unit effort is a measure of fish density. Increased fish densities and catch rates have been the overriding criteria for pronouncing artificial reefs as productive (Bohnsack 1989). The idea that supposedly unproductive sediment substrates can become highly productive fish habitat by deploying artificial reefs is based on the apparent additional food and shelter, and greater opportunities for recruitment, that such structures provide (Randall 1963; Ogawa 1973; Stone et al. 1979; Matthews 1985). Although the benthic infaunal communities in the sediment surrounding reefs are vital for maintaining reef health and trophic dynamics, they are often overlooked, so their response to artificial reef construction remains poorly understood (Ambrose and Anderson 1990).

Over the last several decades, considerable literature has focused on interactions between shallow (<30 m) hard substrates, both natural and artificial, and adjacent sediment substrates, following the recognition that substantial trophic linkages exist between them (e.g., Ogden & Buckman 1973; Parrish & Zimmerman 1977; Alongi 1989; Hueckel et al. 1989). Influences may be both physical and biological. Alterations in the direction, pattern and intensity of water movements around adjacent hard substrates may alter patterns of erosion, sedimentation, bedform structure, grain-size distributions, sorting and organic content, which in turn may have significant effects on resident infauna (Davis et al. 1982; Ambrose & Anderson 1990; DeFelice & Parrish 2001; Danovaro et al. 2002). The composition of artificial substrates (e.g., steel, tires) may induce faunal changes via chemical leaching (Fukunaga et al. 2008). Many fishes and some invertebrates forage beyond their reefal or rocky refuges, sometimes extensively (e.g., Ogden et al. 1973; Sale 1980; Parrish 1989; Frazer et al. 1991; Posey and Ambrose 1994; Bortone et al. 1998; Langlois et al. 2005), which may influence infaunal populations directly via predation, as well as indirectly via bioturbation (Dahlgren et al. 1999).

There have been conflicting studies about relationships between substrate habitats, adjacent sediments and the infaunal communities that reside in these areas. As examples, Barros et al. (2001) found that infaunal assemblages were richer and spatially more variable closer to rocky reefs, with lower infaunal densities and richness near an artificial reef relative to natural reefs, while infaunal abundances have been found to increase away from both natural (Posey & Ambrose 1994) and artificial (Bortone et al. 1998) reefs. On the other hand, several studies have found no clear variation in infauna with distance from hard substrates, either natural or artificial (e.g., Davis et al. 1982; Schlacter et al. 1998; Fukunaga & Bailey-Brock 2008). Langlois et al. (2006) agree that there is no consensus or a generalized conceptual model on how these variables mentioned above affect each other.

Individual studies have revealed that proximity to hard substrates affects different organisms differently. Predation by artificial reef-associated fishes decimated populations of an epifaunal soft-bottom sea pen, while densities of tube-building polychaetes *Diopatra* spp. increased adjacent to reefs (Davis et al. 1982). Densities of the polychaete *Prionospio pygmaeus* dropped, while those of *Spionophanes* spp. increased adjacent to an artificial reef (Ambrose & Anderson 1990). Langlois et al. (2006) found differing patterns between large (>4 mm) and small (<4->0.5 mm) macrofauna. Further, the range of proximity effects varied widely in different locations, from as little as a few meters to over 70 m (Ambrose & Anderson 1990; Barros et al. 2001), and even beyond 200 m in the case of epifaunal prey (Davis et al. 1982).

Variations with distance from natural hard substrates have been attributed to both predation (Posey & Ambrose 1994, Langlois et al. 2005) and physical disturbance (DeFelice and Parrish 2001). Cheung et al. (2009) attributed an observed decline in infauna to finer sediments and intensive trawling away from the reefs. Of course, an extensive literature relates infaunal assemblage composition and structure to a variety of factors independent of hard substrate proximity, e.g., sediment stability, wave exposure, particle size distribution, and predator disturbance (e.g., Aller and Dodge 1974; Hughes and Gamble 1977; St John et al. 1989; Etter and Grassle 1992; Morrisey et al. 1992). However, sediment composition may be affected by proximity to hard substrates, e.g., adjacent coarser sediments and greater scour (Davis et al. 1982; Ambrose & Anderson 1990). Also, the actual value of an artificial reef assemblage relative to the infaunal assemblage that it replaces depends on the size, extent and nature of the submerged structure, its proposed function (e.g., habitat and resource enhancement or restoration, recreation/ecotourism, erosion reduction), the length of time it has been in place, and the nature of both reef and surrounding assemblages and their interactions (Bortone et al. 1998; Fukunaga and Bailey-Brock 2008; Cheung et al. 2009). For example, Steimle et al. (2002) compared reef epifaunal versus sediment infaunal secondary production (kcal m^{-2} $y-^{1}$) and noted that reef production had to exceed that of infauna in terms of providing food to higher trophic levels in order for the local habitat to be considered enhanced.

Two previous studies have examined infaunal assemblages in Broward County waters as part of two major beach renourishment monitoring programs (Dodge et al. 1989, 1995). The focus was to monitor environmental problems associated with beach renourishiment. For example, resuspended sediment and the time it remains after construction have detrimental effects on the benthic community of sandy bottoms and nearby natural reefs. Although these studies did not investigate trophic dynamics or proximity effects of hard substrates, they provide a baseline for estimating background infaunal richness and diversity. The two studies combined recorded infaunal richness values of about 400 species at offshore stations (between the middle and outer reefs) and 250 species for inshore stations just beyond the toe of fill. Polychaetes dominated at both suites of stations (197 and 102 species, respectively), followed by crustaceans (81 and 51 species), chiefly amphipods.

The relative roles of various physical and biological processes in structuring, maintaining and changing soft-bottom benthic communities have generated some controversy (e.g., Gray, 1981; Thistle, 1981; Schoener, 1982; see also Lewin, 1986). Dodge et al. (1991) agreed that the extent of natural variability associated with the interactions among of these processes remains poorly understood for many marine environments, so that care must be taken in distinguishing between natural variability and the effects of anthropogenic disturbance. Natural sources, such as weather and predation, and anthropogenic influences affect a reef's viability. Potential major natural variations might include El Niño events, which may affect reef stability via reduced rainfall, increased sea temperature and lowering of sea levels (Cane 1983). Large, powerful waves from hurricanes and cyclones can break apart or flatten large coral heads and destroy their fragments (Barnes and Hughes, 1999; Jones and Endean, 1976). This will not usually destroy the entire reef, but growing coral maybe overrun by algae before it has a chance to reestablish. Anthropogenic influences, such as pollution from agricultural, urban and sewage runoff, and ship discharges, change seawater chemistry, increase turbidity, and introduce a wide variety of toxins. Fabricius' (2005) review provided information on these and other types of pollution that not only reduced coral recruitment, decreased richness of zooxanthellae in octocorals, reduced coral cover and decreased biodiversity, but increased bioerosion, macroalgal cover, and increased abundance of filter feeders. Mangrove communities have also been in decline due to human influence. Valiela et al. (2001) stated that the bulk of increasing losses of mangrove forests is due to maricultural practices.

South Florida is an excellent area in which to study possible effects of reef-associated communities, both natural and artificial, on adjacent infaunal communities because of their close mutual proximity. The region offers opportunities to study epifaunal and infaunal communities and their influence on the natural and artificial reef systems. The current project is part of a larger study investigating trophic interrelationships between fish assemblages associated with both artificial and nearby natural reefs and the surrounding soft-bottom infauna.

This thesis represents the first step of a planned multi-annual study, which proposes to assess how the structure and trophic relationships of the infaunal community change and influence nearby artificial reef fish assemblages over time. Peter-Finkel and Benayahu (2004) estimated that recognizing changes in artificial reef diversity may require a minimum of 10 years of study.

This thesis compares infaunal, benthic communities before and after the placement of a series of artificial boulder-pile reefs, and attempts to identify possible dependent factors contributing to any differences. Factors measured included year, site, distance from hard substrate, year vs. site, year vs. distance, site vs. distance, year vs. site vs. distance, and the nature of the original benthic communities either exterminated or displaced by artificial reef placement. This work represents a baseline for identifying impacts of a series of artificial boulder-pile reefs and their associated fish assemblages on adjacent natural infaunal communities.

$H_{o1:}$ Composition, richness and diversity of infauna does not differ between pre- and post- construction samples of the artificial reefs.

$H_{a1:}$ Composition, richness and diversity of infauna is higher after construction of artificial reefs.

$H_{o2:}$ Composition, richness and diversity of infauna does not vary, significantly with distance from adjacent artificial reef boulders.

$H_{a2:}$ Composition, richness and diversity of infauna varies, significantly with from adjacent artificial reef boulders.

Materials and Methods

Site Description

This study was carried out at sites ranging from ~1.43 to 1.53 km offshore on sediment substrates between the Inner and Middle Reefs off Broward County, Florida (Figure 1) (Table 1). Sediment core samples analyzed for infaunal community composition in this study represented a portion of a larger study that consisted of a total of 232 samples: 40 pre-construction and 192 post-construction, the latter taken at four artificial and four natural reef sites, 96 in 2013 and 96 in 2014.

Experimental Design

The sampling protocol differed slightly between pre- and post-construction sites. For this study, a total of 40 pre-construction sediment core samples was analyzed, ten at each of four sites where artificial reefs would be placed: five samples (A-E) in a circle 20 ft (6.1 m) from buoys marking proposed artificial reef sites 1, 3, 5 and 6 (30 Sep. 2009), and an additional five samples (F-J) per site in a circle ~3 m from each marker buoy (1 Oct. 2009) (Figure 2). The ten sediment samples, A-E and F-J, at each of the four artificial reef sites were each treated as replicate samples for the two distances for each site, for a total of 8 samples of 5 replicates each.

Each artificial reef was composed of 12 manufactured limestone boulders, each ~1 m^3, deployed at approximately the same locations as the pre-construction samples on 29 and 30 October 2009 by the Florida Department of Transportation under the supervision of Environmental Planning and Community Resilience Division and Florida Fish and Wildlife Commission. The four artificial boulder piles, chosen for this study were designated 1A, 3A, 5B, and 6A, corresponding to the preconstruction sample site names. These sites were closest to the Inner and Middle Reef tracts, ~275 m from the nearest natural reef outcrop except for 3A, which was 305 m.

Three parallel transects, each 2 m apart and designated North, Middle, and South, were established at each of the four artificial reef sites by hammering 3, 0.6-m rebar stakes into the substrate at distances of 0 and 10 m away from each artificial reef. Transects at sites 3A and 6A ran east to west from the artificial reef towards the Inner Reef, and transects for 1A and 5B ran west to east from the artificial reef towards the Middle Reef (Figure 3). Core samples were collected at 3-m and 7-m distances along each of the three transects per site totaling 24 post-construction samples. The three cores at a given distance per site were treated as replicates for a total of 8 samples of 3 replicates each.

Tables 1 and 2 list global positioning system (GPS) latitude and longitude for both pre-construction and post-construction artificial reef sampling sites. Depths recorded during sampling ranged from 12.1 to 14.6 m.

Field Methods

Sediment samples were collected using a stainless steel hand-held corer 10 cm in diameter x 18 cm deep (4 in x 7 in) (area= 471 cm2) while using SCUBA. Sediment was transferred underwater from the corer to a zippered plastic bag labeled with site designator, transect position (North, Middle, South), and distance. Airlifts transported the bags to the surface, where they were placed in ice-filled coolers aboard the boat. Excess water was decanted from each bag in the laboratory, and the bags were immediately refilled with 10% buffered formalin with Rose-Bengal vital stain. Preconstruction samples collected in 2009 had been left in formalin bags until 2012, when they were transferred to ethanol for this study. Some of these samples had become desiccated prior to transfer to ethanol but still contained stained specimens (Table 2). Each sediment sample was sieved through a 0.5-mm Nalgene screen, thoroughly rinsed twice in separate freshwater baths, and then funneled into 1-quart glass jars filled with 70% ethanol pending sorting. All preconstruction samples showed signs of specimen deterioration (e.g., broken specimens; crustaceans reduced to stained exoskeletons; unrecognizable parts of bodies). If the degraded organisms had features distinctive of known taxa, they were included in the abundance count. In September 2013, post-construction samples were collected along each transect at distances 3 and 7 m from each of the four artificial reefs, and treated following the same procedure as the preconstruction samples. Samples were sieved and transferred to ethanol between 48 and 72 hours following collection.

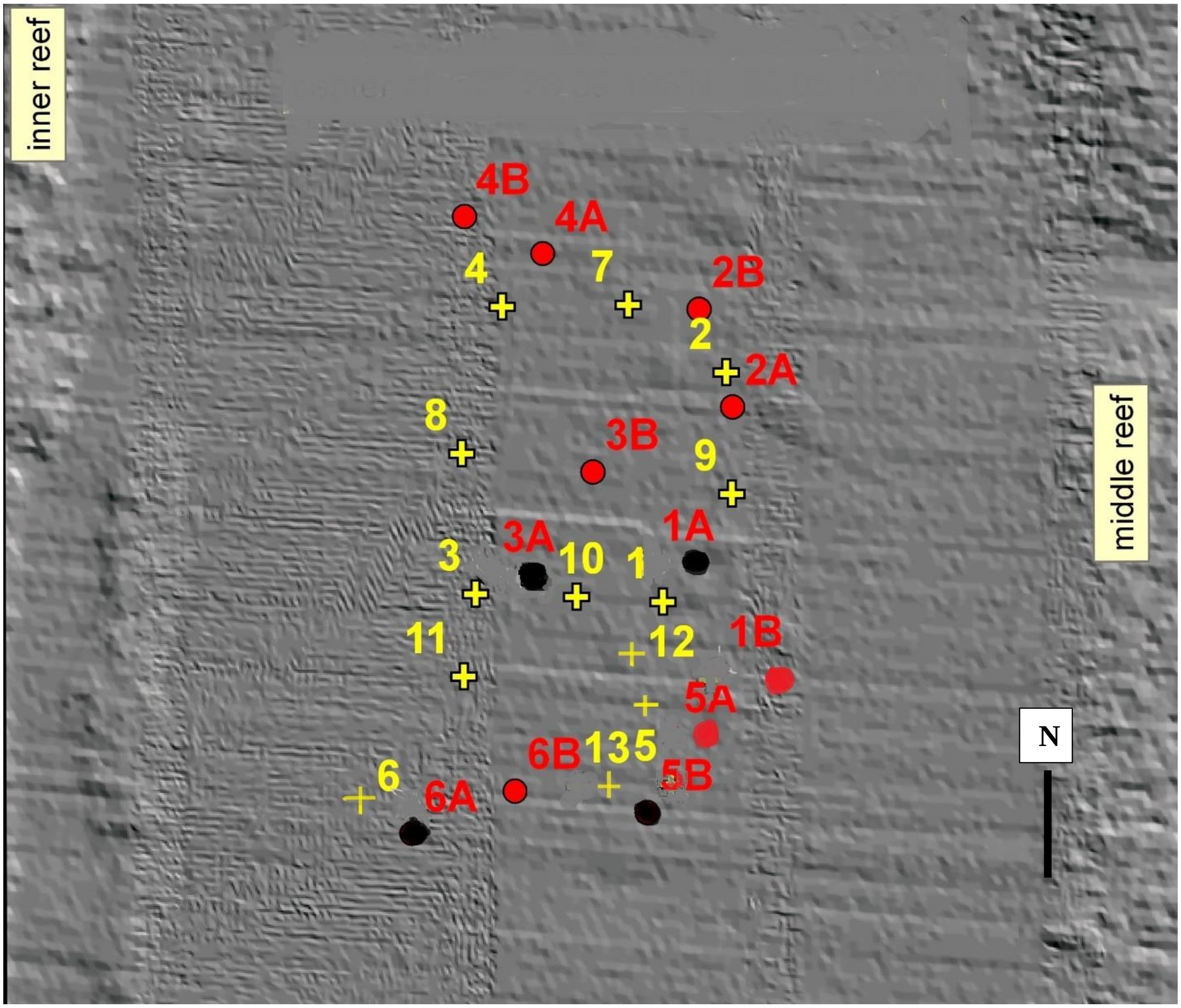


Figure 1. Map showing all pre-construction core samples sites (+) and locations of all FDOT artificial reefs in red dots. Black dots indicate sites from which samples were analyzed.

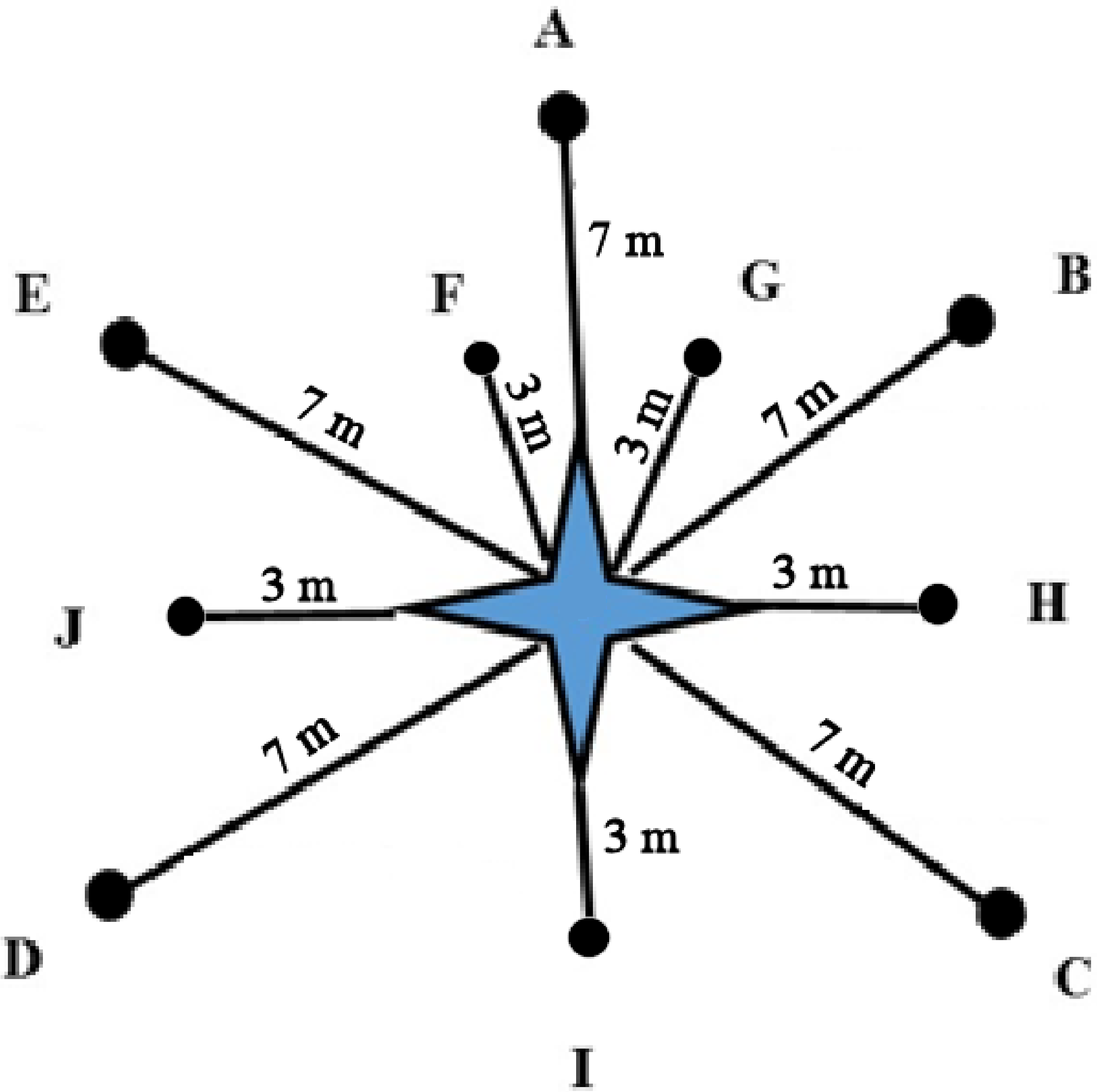


Figure 2. Diagram of pre-construction sampling technique. Marking buoy is represented by star with transects starting from the center and spreading out to their perspective distances. Core samples taken at the end of each transect, shown by black dots.

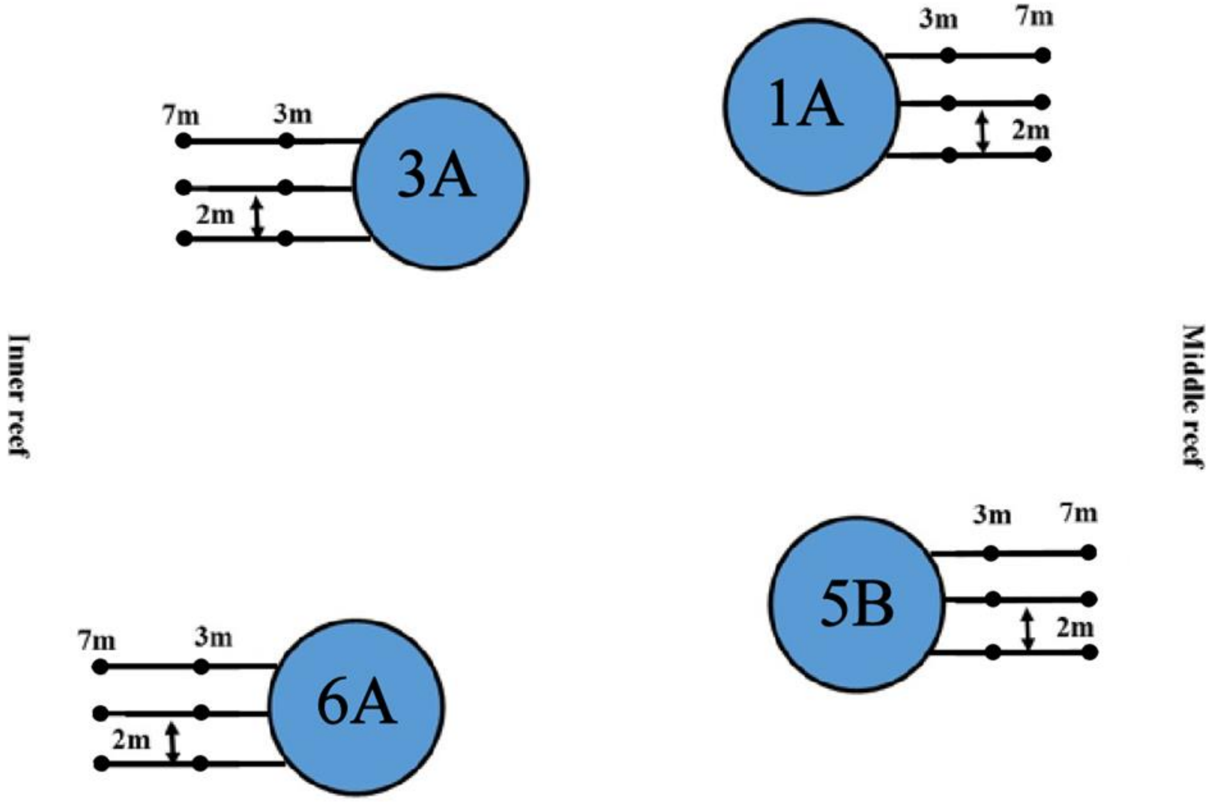


Figure 3. Schematic diagram of post construction samples and transect locations (black dots) for the four artificial reef sites. Distances between sites are not to scale.

Table 1. Global positioning system coordinates of preconstruction and post-construction sites.

GPS Coordinates					
Preliminary Construction Sites			**Artificial Reef Sites**		
	Latitude	Longitude		Latitude	Longitude
3	26°09.1829	80°05.1492	3A	26°09.1887	80°05.1449
6	26°09.1200	80°05.1691	6A	26°09.1148	80°05.1703
1	26°09.1799	80°05.0898	1A	26°09.1914	80°05.0944
5	26°09.1286	80°05.0879	5B	26°09.1201	80°05.0958

Table 2. Pre-construction samples taken in 2009 that were dry or moist but with no visible formalin when opened for analysis in 2013.

Preliminary Reef Sites	Samples with no visible formalin
3	3A, 3D, 3E, 3G, 3J
6	6A, 6B, 6C, 6D, 6F, 6I
1	1A, 1B
5	5D, 5E

Laboratory Methods

Approximately 1 tablespoon of sieved sample at a time was placed on a watch glass under a dissecting microscope and examined left to right in repeated horizontal rows, moving the examined sediment aside with a fine forceps. All invertebrates were placed in small vials containing 70% ethanol, closed with a cotton ball, and placed in a jar with 70% ethanol pending further identification. Excess ethanol in the initial sample jars was gently poured into a Petri dish lid to be examined thoroughly for floating specimens. For subsequent examination and identification, specimens were placed in 47-mm plastic Petri dishes, separated initially to major taxonomic group, and subsequently identified to lowest possible taxon. Most crustaceans and mollusks were identified to genus and species. Most polychaetes were identified to only family due to limited availability of taxonomic expertise. Nematodes and harpacticoid copepods were considered meiofauna and not sorted or identified.

Statistical analysis

The quantity of the sediment of the 2009 pre-construction core samples were not recorded during their collection: therefore, it was not possible to standardize or otherwise accurately examine differences in sample size (i.e., organism densities could not be calculated) and sampling effort. To compensate, this study applied statistical analysis that were reasonably unaffected by dissimilarities in sampling effort. Infaunal communities at each site, both pre- and post-construction, were compared using standard community indices, and univariate and multivariate methods.

Univariate methods

Two univariate indices were used in this study. Taxonomic richness (S) is the count of the number of taxa in a sample, and does not provide any information on abundance. It takes a minimum value of zero and theoretically has no upper bound. To measure relative abundance of the taxa in a sample, Pielou's eveness (J') was calculated. To test for both, each sample was analyzed using the DIVERSE routine in the PRIMER-E (v. 7). The calculation and distributional properties of these indices has been described elsewhere (e.g., see Magurran 2003). To calculate J' the following formula was used:

$$J' = \frac{H'}{\ln S}$$

where H' is the Shannon Diversity Index, calculated as:

$$H' = -\sum_{i=1}^{S} pi \ln pi$$

where S is the number of taxa in the sample, and p*i* is the proportion of individuals in a sample belonging to the *i*th taxon in that sample. Evenness (J') assumes values between 0 and 1. Values approaching zero indicate that some taxa are more abundant than others compared to values approaching 1, which indicate that all taxa are equally abundant in the sample.

These univariate community indices were imported into SPSS 19, and a General Linear Model (GLM) was used to test for effect of year (two levels: 2009, pre-construction vs. 2013, post-construction), sample site (four levels: sites 1A, 3A, 5A, 6B, with samples for each site replicated 6 or 10 times as described above), and distance along transect (two levels: 3 m and 7 m). The model was fully factorial and all factors were treated as fixed effects. The focus of this study was on the effect of artificial reef construction on infaunal community structure, making the year the primary factor of interest. Distance from artificial reef site was the second main effect of interest.

Multivariate methods

Pairwise Bray-Curtis similarity indices were calculated for each pair of samples in the dataset, using PRIMER-E (see http://www.primer-e.com/Primary_papers.htm). The Bray-Curtis similarity index was calculated as:

$$BCjk = 100\left\{1 - \frac{\sum_{i=1}^{p}|Yij - Yik|}{\sum_{i=1}^{p}(Yij + Yik)}\right\}$$

where BC*jk* is the Bray Curtis similarity between the *j*th and *k*th sample, Y*ij* is the abundance of taxon *i* in sample *j*, and Y*ik* is the abundance of taxon *i* in sample *k*. Note that the absolute value of the difference in the abundance of each taxon is used in the numerator, and that the index is multiplied by 100, so that BC*jk* can take values between 0 and 100. Values approaching 100 indicate that samples *j* and *k* are identical in both the taxa present and their relative abundances (i.e., the two samples have very similar communities in both taxonomic composition and abundances of each taxon). Conversely, values approaching zero indicate that the samples differ strongly in terms of which taxa are present and/or their relative abundances. The Bray Curtis similarity index can be biased by the presence of a few dominant taxa; this was addressed by using the square root of the abundance for all taxa in all calculations. Pairwise Bray Curtis similarity indices were calculated for all samples, yielding a triangular similarity matrix of the relative similarities across all pairs of samples. This matrix was used for all subsequent analyses except as noted below.

To determine what taxon was the most dominant in shaping the general community similarity patterns among all samples, a distance-based linear modelling (DistLM) procedure in PRIMER-E was performed using a stepwise addition process and adjusted Akaike Information Criteria (AICc, a statistic used to measure goodness of fit for a model) at each step to evaluate whether including a specific taxon improved the model. A permutation-based ANOVA (PERMANOVA) procedure in PRIMER-E was used to test for effect of year (i.e., before and after reef construction), site, and distance. A similarity permutations (SIMPER) analysis to identify the taxa that changed the most between 2009 and 2013 (i.e., before and after reef construction) was implemented. The results of the SIMPER analysis were imported into Excel and used to calculate the mean difference in abundance between 2009 and 2013 for these taxa. A sign test (available at http://graphpad.com/quickcalcs/binomial1.cfm) was used to determine whether there were more taxa that increased in abundance vs decreased following reef construction. A t-test (as per Zar 1998) was applied to determine whether the overall total change in abundance across all of the taxa identified by SIMPER was significantly different than zero.

Nonmetric multidimensional scaling (nMDS) was used to depict the Bray-Curtis similarity patterns among samples, and (where applicable) Pearson correlation vectors added to the ordination to illustrate among-sample differences in abundance for selected individual taxa.

To determine changes in community composition at higher taxonomic levels, abundance values in each sample were summed by class and phylum, and the above multivariate analyses were repeated.

Results

This study distinguished a total of 159 different taxa in both pre- and post-construction sites: 2 to the level of phylum, 5 to class, two to order, 42 to family, 50 to genus and 61 to species. Appendix A lists these taxa, as well as the taxonomic abbreviations used in all analyses and ordination graphs to maintain clarity. Appendices B and C list species identified from preconstruction and post-construction sites, respectively. Polychaete families Spionidae, Sabellidae, Syllidae, and Hesionidae, and sipunculan superfamily Phascolosomatidea dominated pre-construction samples. Polychaetes also dominated post-construction samples, with high relative abundances of Sabellidae and Hesionidae, but with increased proportions of bivalves and amphipods.

Table 3. Total organism abundance by site and distance, and abundance averaged for the five and three replicates per site preconstruction and post-construction, respectively.

		3 m		7 m	
	Site	**Total**	**Average**	**Total**	**Average**
Pre-Construction	1	285	57.0±5.6	493	98.6±21.2
	3	336	67.2±6.9	346	69.2±9.0
	5	211	42.2±6.1	350	70.0±9.0
	6	309	61.8±8.7	383	76.6±8.1
Post-Construction	1A	168	56.0±4.4	234	78.0±8.3
	3A	169	56.3±6.4	361	120.3±12.9
	5B	268	89.3±10.9	280	93.3±10.6
	6A	152	50.7±4.1	175	58.3±5.8

Average abundances per sample varied widely, ranging from 42.2±6.1 organisms at preconstruction site 5, 3 m, to 120.3±12.9 at post-construction site 3A, 7 m (Table 3). These values overlapped substantially among sites, distances, and years, although for any given site and year, average abundance at 7 m was at least slightly greater than at 3 m.

Univariate community indices

Community taxon richness (S) in samples ranged from 5 to 32, with a mean of 22.4±6.09 (std. dev.). The GLM including year, site, and distance as factors was not significant (GLM; R^2 0.302, df 1,15; F=1.357, p=0.208); there was no significant effect of year (df 1,1; F=881.153, p=0.190; eta squared 0.036), site (df 1,3; F=0.573, p=0.636; eta squared 0.035), but there was a slight but significant effect of distance from construction site (df 1,1; F=4.162, p=0.047, eta squared 0.081). Given the lack of significance of the overall model and the low effect size (i.e., eta squared), it is unlikely that taxonomic richness varied among samples. Community evenness (as Pielou's J') in samples ranged from 0.457 to 0.956 with a mean value of 0.855 and a standard deviation of 0.08. The mean value of J' closer to one indicated that each sample was dominated by one or more taxa. To identify these taxa, multivariate analyses were performed. The GLM including year, site, and distance as factors was not significant (GLM; R^2 0.292, df 1,15; F=1.291, p=0.245), a result similar to taxon richness. There was no significant effect of year (df 1,1; F=0.002, p=0.961, eta squared <0.001), site (df 1,3; F=1.343, p=0.272, eta squared 0.079), or distance from construction site (df 1,1; F=0.252, p=0.618, eta squared 0.005). These results indicated that all samples included approximately the same number of taxa, and featured similar dominance patterns.

Multivariate analyses

Permutation distance-based linear modelling identified a subset including 19 of the original 159 taxa that accounted for overall community similarity across all of the samples. The 19 taxa accounted for approximately 70% of the similarity patterns in the data (R^2=0.696; AICc = 467.2) and are listed in Appendix D. This analysis indicated that the taxa that were most important in driving overall community similarity were Hesionidae and Sabellidae (Polychaeta), Cardiidae (Bivalvia), *Aspidosiphon albus* (Sipuncula), and *Apseudes* sp. (Crustacea Tanaidacea).

Among-site Bray-Curtis similarity indices ranged from 0 to 67.3 with a mean overall similarity of 38.7±11.79 (std. dev). PERMANOVA indicated significant effects of year, site, and distance (Table 4). There was also a significant year-by-site interaction, indicating that the communities from at least one site did not vary between years, or exhibited a different response than the other sites. No other interactions were significant.

Table 4. Results of PERMANOVA on Bray-Curtis similarity indices.

Source	df	MS	Pseudo-F	p
Year	1	7705	4.388	0
Site	3	2972	1.692	0
Distance	1	2784	1.585	0.04
Year x Site	3	2412	1.373	0.02
Year x Distance	1	1117	0.636	0.91
Site x Distance	3	1809	1.03	0.41
Year x Site x Distance	3	1445	0.823	0.86

The pseudo-F values generated by the PERMANOVA (Table 4) can be interpreted as effect sizes (see http://www.primer-e.com/Primary_papers.htm), indicating that the factor that played the strongest role in structuring the infaunal assemblage among our samples was year (i.e., pre-construction vs. post-construction), followed by site and distance from reef. There was also a significant interaction between year and site, suggesting that infaunal assemblages in some samples did not change from 2009 to 2013, or changed in a different way. To examine this further, PERMANOVA was performed again, but with additional post-hoc tests to explore differences among individual sites in each year.

Table 5. Results of a post-hoc pairwise tests exploring community similarity among sites in 2009 of factor 'Year'.

Groups	T statistic	P
1A, 3A	1.3418	0.005
1A, 5B	1.6346	0.001
1A, 6A	1.6472	0.001
3A, 5B	1.2297	0.095
3A, 6A	1.3153	0.03
5B, 6A	1.1774	0.148

Table 6. Results of a post-hoc pairwise tests exploring community similarity among sites in 2013 of factor 'Year'.

Groups	T statistic	P
1A, 3A	1.0485	0.398
1A, 5B	1.2178	0.155
1A, 6A	0.95857	0.557
3A, 5B	1.2383	0.129
3A, 6A	1.3402	0.016
5B, 6A	1.3621	0.047

The results in Tables 5and 6 indicate that differences existed in community structure among the four sites in 2009 (pre-construction) but that these became less apparent in 2013 (post- construction), suggesting that that the sites became more homogeneous post-construction.

The primary objective of this study was to characterize infaunal assemblages pre- and post-construction. To achieve this end, SIMPER was performed to identify those taxa that differed the most in relative abundance before and after reef construction. SIMPER identified 89 taxa that changed. Table 7 shows partial results of SIMPER analysis. Twenty-five taxa accounted for 56.1% of the dissimilarity among samples collected in 2009 and 2013, with Sabellidae alone accounting for 6%. Subtracting the abundances between years indicated that most of these taxa (15 of 25) increased in abundance from 2009 to 2013. Other polychaetes involved in the increase in 2013 included Hesionidae, Syllidae, and Glyceridae, whereas others, such as Maldanidae, Spionidae and Pilargiidae, did not show positive values. Ostracoda, Amphipoda (both Crustacea) and Veneridae (Bivalvia) also showed positive values in this analysis.

Appendix A lists taxa identified by their code and ranks them by their percent contribution to the overall community similarity differences between years (Contrib %). Cumulative contribution is listed as well (Cum %). Note that these 25 taxa accounted for 56.1% of the dissimilarity between samples collected in 2009 and 2013. Taxa that increased in abundance post-construction are indicated in green, whereas those that decreased are indicated in red.

A sign test to determine whether more taxa increased than decreased among all 84 taxa identified by SIMPER (rather than just the top 25) found that 44 increased. This was not a significant departure from 50% (sign test, 2-tailed p=0.735), indicating that the number of taxa increasing in abundance did not differ from the number that decreased. A one-sample t-test performed on the net changes in abundance across all 89 taxa found that the mean change across all taxa was + 0.036: not significantly different from zero (t-test; df 1,83; t=1.196, p=0.235). The results indicated that, although infaunal community composition changed between years, abundances did not.

Table 7. Results of SIMPER analysis listing the 25 taxa that varied the most in abundance between years (pre- vs. post- construction).

	Group 2009	**Group 2013**			
Species	**Av. Abund**	**Av. Abun**	**DIFF**	**Contrib%**	**Cum.%**
SabeA	2.15	3.1	0.95	5.97	5.97
HesiA	2.35	3.37	1.02	3.63	9.59
SyllA	1.48	1.6	0.12	3.15	12.74
CardA	1.62	1.56	-0.06	2.96	15.7
SpioA	1.62	1.53	-0.09	2.74	18.44
albus	1.42	0.69	-0.73	2.67	21.11
GlycA	1.36	1.74	0.38	2.62	23.73
SyneB	1.84	1.47	-0.37	2.6	26.34
ApseA	1.64	1.19	-0.45	2.57	28.91
MyodA	0.44	0.96	0.52	2.15	31.06
CirrA	0.52	1.05	0.53	2.05	33.11
CapiA	0.87	0.58	-0.29	2.03	35.14
ParaA	1.07	1.14	0.07	2.01	37.15
parv	0.72	0.52	-0.2	1.96	39.11
darb	0.48	0.58	0.1	1.81	40.93
BemoA	0.67	0.73	0.06	1.81	2.73
pauc	0.07	0.75	0.68	1.7	44.44
SyneA	0.71	0.1	-0.61	1.63	46.07
NereA	0.36	0.61	0.25	1.58	47.65
LumbA	0.47	0.54	0.07	1.5	49.16
simps	0.41	0.67	0.53	1.48	50.64
misa	0.51	0.34	-0.17	1.48	52.12
MaldA	0.43	0.42	-0.01	1.38	3.5
PhylA	0.32	0.49	0.17	1.33	54.82
MooA	0.33	0.38	0.05	1.29	56.12

Figure 4 depicts the nMDS ordination plot of sample similarities, with individual samples labeled and disposed so that proximity implies similarity of infaunal community. The evenness (J') of various taxa can be seen for 2013 in this graph. Samples are also marked by a symbol indicating year of collection, and superimposed with Pearson correlation vectors corresponding to the taxa identified during the DistLM procedure above. Figure 5 is the same ordination plot, with individual samples marked with a symbol as above, labeled by collection site, and superimposed with vectors corresponding to those taxa identified during the SIMPER analysis. The two-dimensional stress value of 0.22 indicates that some distortion was needed to depict sample community patterns in two dimensions; however, the distinct clustering by year and (to a lesser extent, by site) remain apparent in the figures.

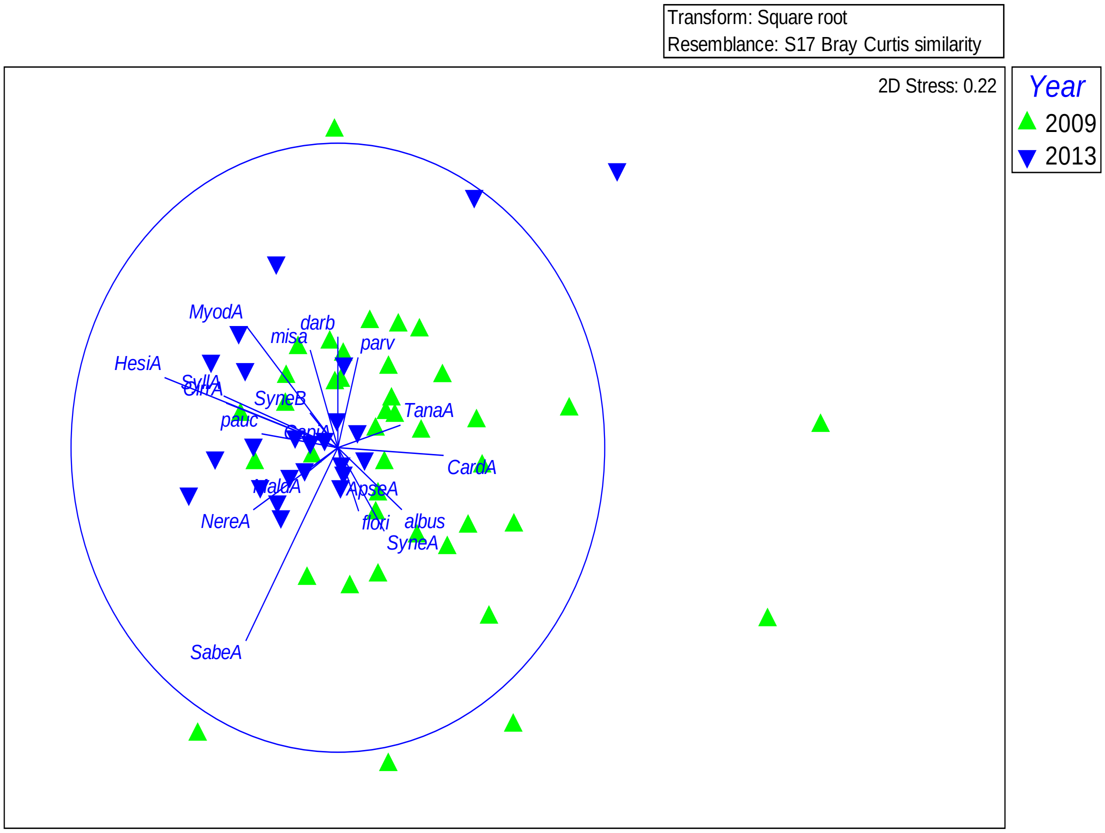


Figure 4. nMDS ordination plot of sample similarities, where proximity implies similarity of infaunal community.

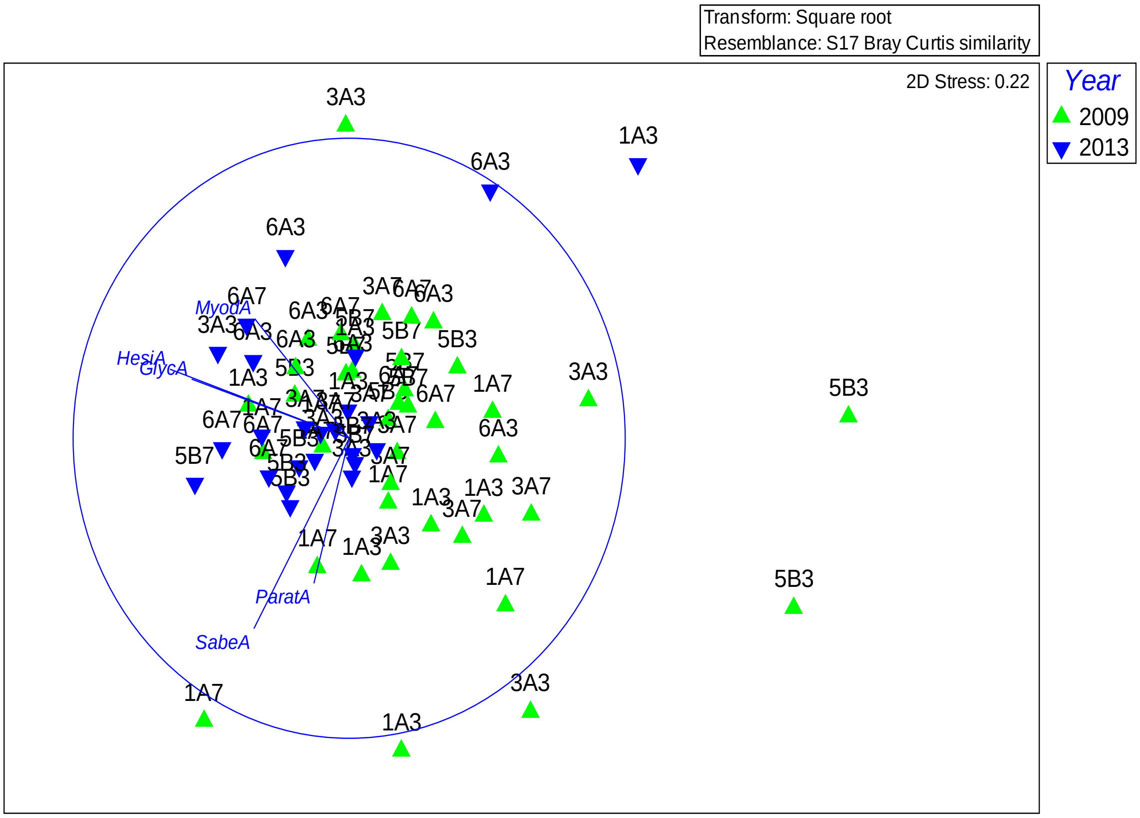


Figure 5. Same plot as above but collection site labeled with vectors to taxa identified during the SIMPER analysis.

Analysis by class detected a strong effect of year and distance from reef, but not of site (Table 8). There were no significant interaction terms. SIMPER analysis identified 9 classes accounting for 90.6% of the dissimilarity among samples between years, with Polychaeta (20.4%), Phascolosomatidea (13.3%) and Malacostraca (12.6%) accounting for 46.3% of the dissimilarity (Table 9).

Analysis by phylum also detected significant effects of year and distance, but not site (Table 10). SIMPER analysis indicated that Annelida and Sipuncula accounted for 31.2% and 21.4%, respectively, of the dissimilarity among sites between years (Table

11). Figure 6 reveals that 2013 samples were more clustered and less spread out than the 2009 samples, confirming the results of the SIMPER analysis.

Table 8. PERMANOVA by class. Green indicates strong effect and red no effect.

Source	Df	MS	Pseudo-F	p
Year	1	2455	5.0574	0
Site	3	667.4	1.375	0.15
Distance	1	1446	2.9796	0.01
Year x Site	3	756.5	1.5585	0.07
Year x Distance	1	132.4	0.27285	0.94
Site x Distance	3	363.5	0.74894	0.76
Year x Site x Distance	3	502.8	1.0359	0.43

Table 9. The nine classes SIMPER analysis identified with the most dissimilarity between years.

	Group 2009	**Group 2013**		
Species	**Av. Abund**	**Av. Abun**	**Contrib%**	**Cum.%**
Polychaeta	6.46	6.72	20.42	20.42
Phascolosomatidea	1.94	1.19	13.3	33.72
Malacostraca	2.57	2.42	12.62	46.34
Ostracoda	1.17	1.94	12.33	58.67
Bivalvia	2.32	2.54	11.28	69.95
Gastropoda	0.98	1.15	7.96	77.91
Scaphopoda	0.11	0.49	4.68	82.58
Leptocardii	0.36	0.23	4.2	86.78
Polyplacophora	0.09	0.39	3.82	90.59

Table 10. PERMANOVA by Phylum. Cell colors as in Table 8.

Source	df	MS	Pseudo-F	p
Year	1	889.2	2.8015	0.03
Site	3	364.1	1.1472	0.34
Distance	1	1016	3.2009	0.03
Year x Site	3	572.6	1.8042	0.06
Year x Distance	1	86.64	0.273	0.89
Site x Distance	3	210.1	0.6619	0.78
Year x Site x Distance	3	383.7	1.2089	0.27

Table 11. SIMPER analysis for phylum between years.

	Group 2009	Group 2013		
Phylum	Av. Abund	Av. Abun	Contrib%	Cum.%
Annelida	6.47	6.72	31.19	31.19
Sipuncula	1.98	1.19	20.4	51.58
Arthropoda	3.04	3.19	19.3	70.88
Mollusca	2.67	3.13	17.78	88.66
Chordata	0.36	0.23	6.4	95.06

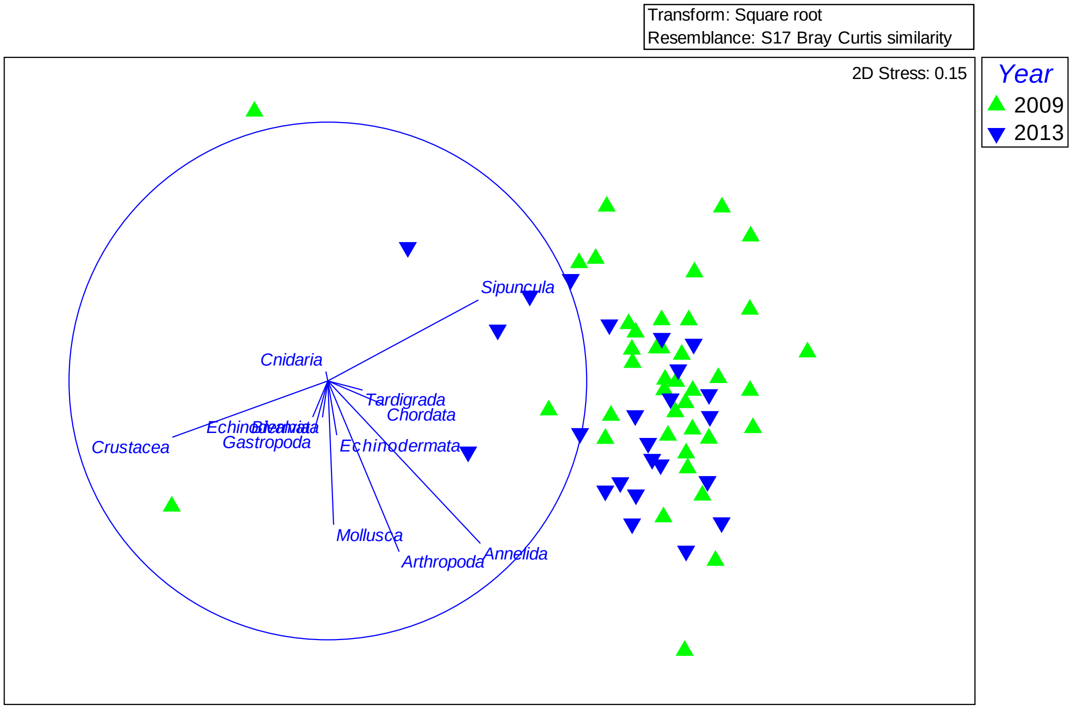


Figure 6. Graph showing that phyla Annelida and Sipuncula account for the greatest dissimilarity among sites and between years.

Figures 7 and 8 show that polychaetes accounted for 66% and 65% of organisms pre-construction and post-construction, respectively. Bivalvia was the next most influential group in both years (9.22% pre-construction and 10.44% post-construction) followed by Tanaidacea (6.74% pre-construction) and Amphipoda and Ostracoda (both 5.91% post-construction).

The majority of transects confirmed that polychaetes were the most abundant and ranged from 31 to 90% of organisms pre-construction and 30 to 80% post-construction. Polychaetes were not most abundant only in pre-construction area 5 in the 3-m samples along transects G and H. Transect 5G bivalves and polychaetes dominated equally at

42% while Bivalves dominated transect 5H at 57%. Polychaetes remained the most dominant group in all post-construction transects.

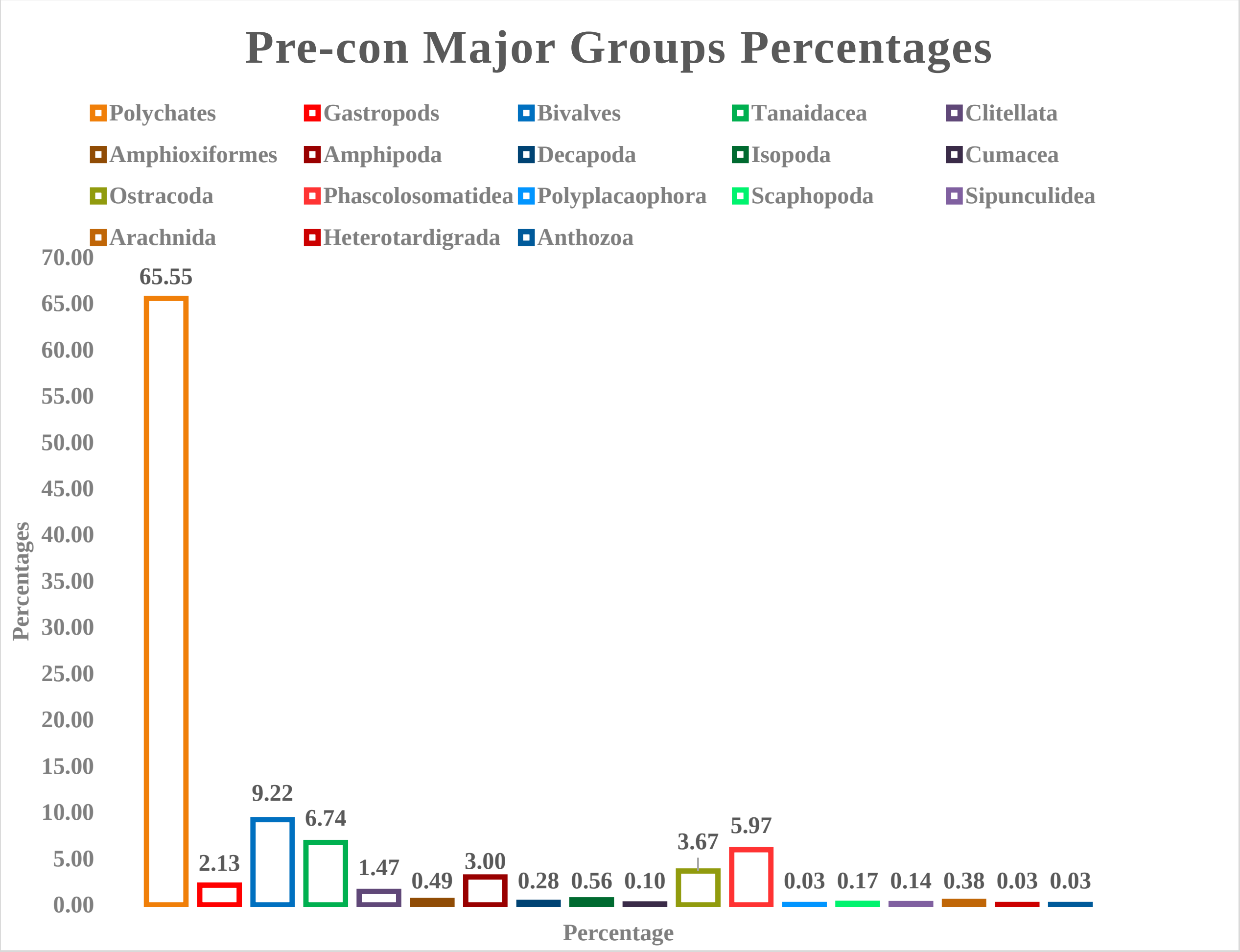


Figure 7. Pre-construction graph showing major groups.

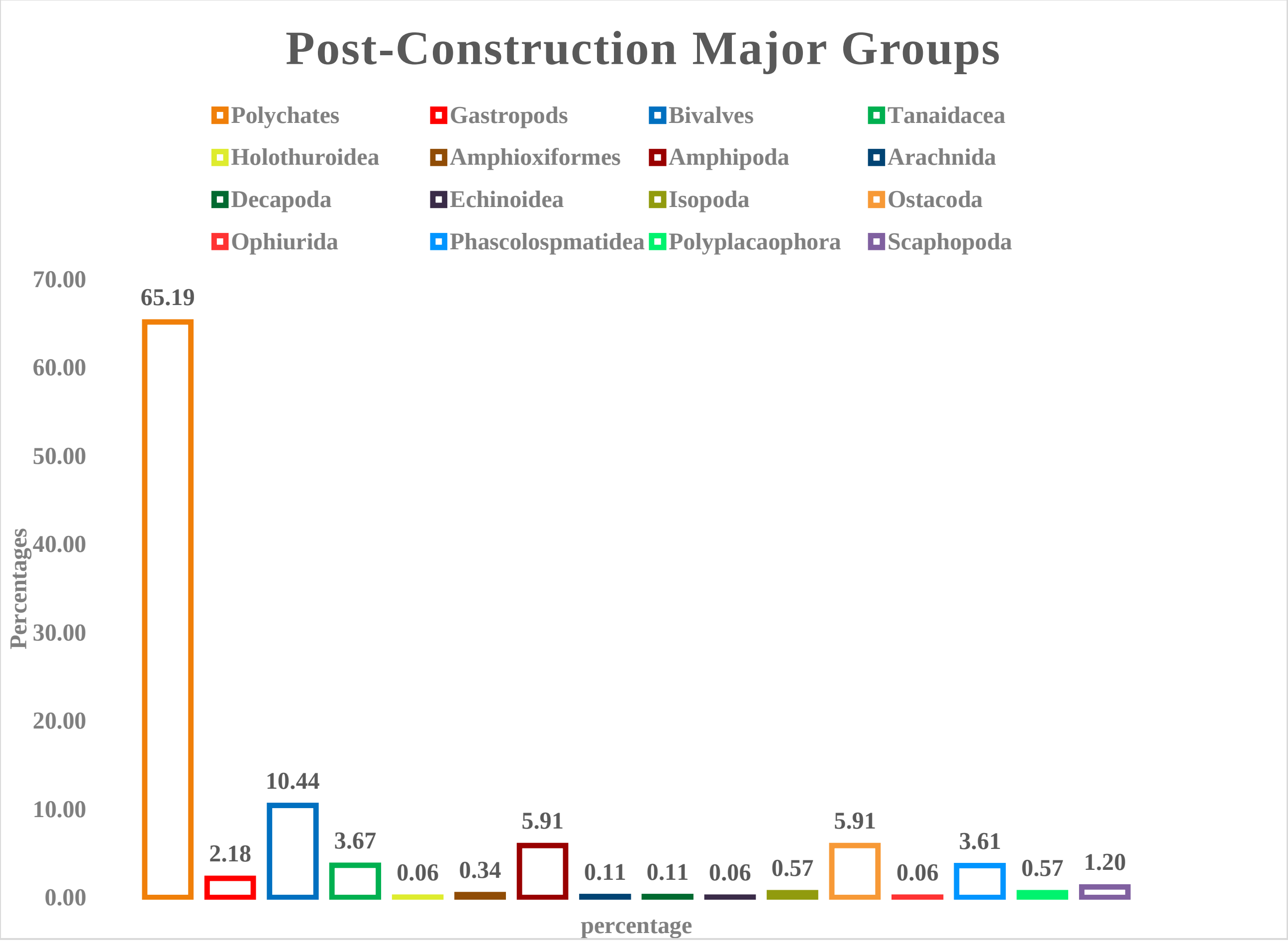


Figure 8. Major group percentages 2013 Post-Construction

Discussion

This study compared abundances of infauna in core samples taken before and after deployment of a series of artificial reef boulder piles between the Inner and Middle reef tracts off Broward County, Florida. The pre-construction and results between years are restricted to data based on relative abundances of taxa because the pre-construction samples taken by Broward County did not record sediment volume, which prevented calculation of organism densities. Although collection and treatment of samples remained otherwise the same for both efforts (sediment volumes were recorded in 2013), some circumstances differed between pre- and post-construction sampling, the latter carried out by NSU graduate students, that may have contributed to differences in results. First, although eight samples were taken in both years, the number of replicates per sample differed between years. In 2009, Broward County collected five cores at each distance (3 and 7 m) from each of the four proposed artificial reef sites. The five cores for a given distance were treated as replicates for that site (i.e., eight samples of five replicates each at four sites; total 40 cores). In 2013, cores were taken along three transects at each artificial reef site so that each sample consisted of three replicates at a given distance (3 and 7 m) from each reef (i.e., two samples of three replicates each at four sites; total 24 cores). Second, the pre-construction core samples were taken on open sandy sediment at the proposed sites for the artificial reefs (Figure 1). Distances to the nearest hard bottom ranged from ~275 to ~305 m. By contrast, post-construction core samples were taken four years after artificial reef deployment at distances no greater than 7 m from the hard substrates of the boulder piles. As a result, near-bottom water movement around the artificial reefs may have modified adjacent sediment deposition and composition by that time, perhaps modifying infaunal communities. In addition, pre-construction samples remained in original collection bags in formalin for four years before transfer to ethanol and analysis. As a result, 15 pre-construction samples (Table 2) contained no visible formalin when examined in 2013, which contributed to specimen deterioration and probable loss.

The results of univariate analyses (using DIVERSE routine in the PRIMER-E(v.7) found no significant differences in standard diversity indices (S, J',) among years, sites or distances. However, analyses that accounted for community structure found significant effects of year, site, and distance. Year was consistently the factor with the greatest effect size. The main change in community structure was increasing homogenization. Post-construction samples were much more similar in terms of relative abundances of the various taxa compared to pre-construction samples. Closer examination of the taxa responsible found that this effect was driven by changes in the abundance of several key taxa, most notably particular families of polychaetes, which increased in relative abundance from 2009 to 2013.

Multivariate statistical analysis (computed in PRIMER-E program; http://www.primer-e.com/Primary_papers.htm.) comparing species richness, diversity and abundance among sites (pre-construction vs. post construction sites, three meters vs. seven meters transect distances) found a slight change in species diversity between distances between years, but no other significant effects for any other diversity indices. SIMPER identified 89 taxa that changed between years, with the first 25 responsible for the difference. Of the 89 taxa, only 44 exhibited an increase, which was not a significant departure from 50%. These results indicated that there were compositional changes in the infaunal community between the years, though abundances did not change. This suggested that, at least four years after deployment, the artificial reefs had little to no effect on species diversity and richness. Thus, both null hypotheses, that composition, richness and diversity of infauna did not differ either between pre-and post-construction samples or by distance from the artificial reefs, could not be rejected.

Marine sediments constitute the largest habitat on Earth, covering roughly 80% of the ocean bottom (Lenihan and Michele 2001; Mybakken and Bertness 2005). The four taxonomic groups that dominate the macrofauna of these sediment communities are polychaetes, crustaceans, echinoderms and mollusks (Thorson1955; Nybakken and Bertness 2005). The current study agreed with Fabi et al. (2002), who also reported that polychaetes constituted the major taxa found in sediment surrounding artificial reefs, followed by mollusks and crustaceans. Similarly, previous studies that examined infauna offshore Broward County as part of beach renourishment monitoring programs (Dodge et al. 1989, 1995) reported that polychaetes dominated, followed by crustaceans, chiefly amphipods. Gravina et al. (1989) and Hutchings (1998) both stated that polychaetes have wide adaptive and reproductive capabilities, and this plasticity could lead to their resilience to change initiated by the establishment of an artificial reef.

Davis et al. (1982) stated that infaunal densities surrounding the artificial reefs should decrease due to increases in reef-associated fish populations. Somaschini et al. (1997) agreed and reported that disturbance in sandy bottom communities led to a decline in community diversity two years after establishment of an artificial reef. Hughes et al. (1984) mentioned that both disturbance and space availability were major factors affecting sand bottom community diversity.

Dodge et al. (1989, 1995) recorded combined infaunal richness values in sediment off Broward County of about 400 species for offshore stations (between the middle and outer reefs) and 250 species for inshore stations just beyond the toe of fill. Polychaetes dominated at both suites of stations (197 and 102 species, respectively), followed by crustaceans (81 and 51 species), chiefly amphipods. Both studies identified virtually all taxa to species level. The substantially lower total richness recorded in the current study, 159 taxa, is almost certainly due to a combination of fewer samples and less specific taxonomic identification. In addition, because the current study sampled between the inner and middle reefs (~12-14 m depth), the fauna is not directly comparable with the much shallower inshore (~4 m) and deeper offshore (~20 m) faunas sampled by Dodge et al. (1989, 1995). However, all three studies agreed on the dominant role of Polychaeta.

This study showed no significant changes between year and distances in the infaunal communities surrounding the ARs. However, Perkol-Finkel and Benayahu (2004) have suggested that any significant changes in the AR community would take at least ten years. It might therefore require a similar duration before surrounding infaunal communities might be affected. As a result, additional samples should be taken in the future to determine whether the infaunal communities change over a longer period. Such sampling may help determine whether these artificial reefs are suitably placed relative to the natural reef.

Bortone et al. (1998) stated that increasing the distance between an artificial reef and a natural reef should diminish any effect the artificial reef may have on the productivity of the natural reef. As artificial reefs are intended to increase fish productivity and restore damaged or lost habitats, their placement should avoid taking away resources from natural reef (Lonnstedt et al. 2014, NOAA 2007). However, Alevizon and Gorham (1989) state that artificial reefs can dramatically increase fish populations of selected species without negative impact on fishes dwelling in nearby habitats. The placement of ARs themselves maybe what disturbs the underlying and surrounding infaunal communities (Davis et al. 1982; Ambrose and Anderson 1990). Perkol-Fenkel et al. (2006) have suggested that particular suites of structural features may correspond to unique taxonomic composition and that an AR should have a variety of niches exhibiting different structural features in order to obtain a higher biodiversity. For this study, these changes may need to take more time than the four-year period given between the pre- and post-construction activities of this study to show any significant changes in infaunal communities.

The statistics results concluded that infaunal community composition became more homogenous by the end of 2013, though the groups of represented taxa shifted only slightly between sampling years. This suggests that the infauna may be moving to a more stable state, perhaps through a series of successions such as Connell and Slatyer (1977) described. However, it remains unknown whether the slight changes observed derived from local post-construction modifications of the sediment environment, interactions with fish newly associated with the artificial reefs, seasonality, storms or other factors.

The lack of significant changes in the infaunal community after placement of the artificial reefs also suggests that the trophic system has remained much the same as it was before deployment, and that reef productivity has not increased substantially. Therefore, additional sampling should be carried out until at least ten years post-construction, per Perkol-Finkel and Benayahu (2004), to identify any changes attributable to the artificial reefs. Ideally, samples should be taken more than once yearly to distinguish between longer-term and seasonal effects. If the artificial reefs were placed mainly to attract more fishes and increase biodiversity, it is important to track the surrounding infaunal community on which many of those fishes rely.

Appendix A. All taxa extracted from cores with levels of identification and abbreviations used for input in PRIMER.

Abbreviation	**Phylum**	**Class**	**Order**	**Family**	**Genus**	**Species**
TubiA	Annelida	Clitellata	Haplotaxida	Tubificidae	Unknown	A
EnchA	Annelida	Clitellata	Enchytraeida	Enchytraeidae	Unknown	A
AmphiA	Annelida	Polychaeta	Amphinomida	Amphinomidae	Unknown	A
AmphiB	Annelida	Polychaeta	Amphnomida	Amphnomidae	Unknown	B
EuniA	Annelida	Polychaeta	Eunicida	Eunicidae	Unknown	A
LumbA	Annelida	Polychaeta	Eunicida	Lumbrineridae	Unknown	A
LumbriA	Annelida	Polychaeta	Eunicida	Lumbrineridae	*Lumbrineris*	A
tetra	Annelida	Polychaeta	Eunicida	Lumbrineridae	*Lumbrineris*	*tetraura*
ScolA	Annelida	Polychaeta	Eunicida	Lumbrineridae	*Scoletoma*	A
OnupA	Annelida	Polychaeta	Eunicida	Onuphidae	Unknown	A
MooA	Annelida	Polychaeta	Eunicida	Onuphidae	*Mooreonuphis*	A
GlycA	Annelida	Polychaeta	Phyllodocida	Glyceridae	Unknown	A
amer	Annelida	Polychaeta	Phyllodocida	Glyceridae	*Glycera*	*americana*
capi	Annelida	Polychaeta	Phyllodocida	Glyceridae	*Glycera*	*capitata*
GlyA	Annelida	Polychaeta	Phyllodocida	Glyceridae	*Glycerella*	A
HemiA	Annelida	Polychaeta	Phyllodocida	Glyceridae	*Hemipodia*	A
HesiA	Annelida	Polychaeta	Phyllodocida	Hesionidae	Unknown	A
Vita	Annelida	Polychaeta	Phyllodocida	Hesionidae	*Gyptis*	*vitatta*
obsu	Annelida	Polychaeta	Phyllodocida	Hesionidae	*Oxydromus*	*obscurus*
NereA	Annelida	Polychaeta	Phyllodocida	Nereididae	Unknown	A
mira	Annelida	Polychaeta	Phyllodocida	Nereididae	*Ceratonereis*	*mirabilis*
Phol	Annelida	Polychaeta	Phyllodocida	Phyllodocidae	Unknown	A
Gene	Annelida	Polychaeta	Phyllodocida	Phyllodocidae	Unknown	B
PhylA	Annelida	Polychaeta	Phyllodocida	Phyllodocidae	Unknown	

AnaiA	Annelida	Polychaeta	Phyllodocida	Phyllodocidae	*Phyllodoce*	A
PhylB	Annelida	Polychaeta	Phyllodocida	Phyllodocidae	Unknown	B
SyneA	Annelida	Polychaeta	Phyllodocida	Pilargiidae	*Synelmis*	A
SyneB	Annelida	Polychaeta	Phyllodocida	Pilargiidae	*Synelmis*	B
SigA	Annelida	Polychaeta	Phyllodocida	Sigalonidae	Unknown	A
SyllA	Annelida	Polychaeta	Phyllodocida	Syllidae	Unknown	A
Sabe	Annelida	Polychaeta	Sabellida	Sabellidae	Unknown	
CapiA	Annelida	Polychaeta	Scolecida	Capitellidae	Unknown	A
CapiB	Annelida	Polychaeta	Scolecida	Capitellidae	Unknown	B
MaldA	Annelida	Polychaeta	Scolecida	Maldanidae	Unknown	A
MaldB	Annelida	Polychaeta	Scolecida	Maldanidae	Unknown	B
MaldC	Annelida	Polychaeta	Scolecida	Maldanidae	Unknown	C
ClymA	Annelida	Polychaeta	Scolecida	Maldanidae	*Axiothella*	A
opheA	Annelida	Polychaeta	Scolecida	Opheliidae	Unknown	A
ArmaA	Annelida	Polychaeta	Scolecida	Opheliidae	*Armandia*	A
Orbin	Annelida	Polychaeta	Scolecida	Orbiniidae	Unknown	
TaubA	Annelida	Polychaeta	Scolecida	Paraonidae	*Levinsenia*	A
ParaA	Annelida	Polychaeta	Scolecida	Paraonidae	Unknown	A
cerr	Annelida	Polychaeta	Scolecida	Paraonidae	*Aricidea*	*cerrutii*
phil	Annelida	Polychaeta	Scolecida	Paraonidae	*Aricidea*	*philbinae*
grac	Annelida	Polychaeta	Scolecida	Paraonidae	*Levinsenia*	*gracilis*
Mageb	Annelida	Polychaeta	Spionida	Magelonidae	Unknown	B
MagelA	Annelida	Polychaeta	Spionida	Magelonidae	*Magelona*	A
petf	Annelida	Polychaeta	Spionida	Magelonidae	*Magelona*	*pettiboneae*
SpioA	Annelida	Polychaeta	Spionida	Spionidae	Unknown	A
SpioB	Annelida	Polychaeta	Spionida	Spionidae	Unknown	B
ApopA	Annelida	Polychaeta	Spionida	Spionidae	*Prionospio*	A

CirrA	Annelida	Polychaeta	Terebellida	Cirratulidae	Unknown	A
CaulA	Annelida	Polychaeta	Terebellida	Cirratulidae	*Caulleriella*	A
TereA	Annelida	Polychaeta	Terebellida	Terebellidae	Unknown	A
HalaA	Arthropoda	Arachnida	Trombidiformes	Halacaridae	Unknown	A
Carp	Arthropoda	Malacostraca	Amphipoda	Chevaliidae	*Chevalia*	*carpenteri*
Leptac	Arthropoda	Malacostraca	Tanaidacea	Leptocheliidae	*Leptochelia*	
AmpiA	Arthropoda	Malacostraca	Amphipoda	Ampithoidae	Unknown	A
BemoA	Arthropoda	Malacostraca	Amphipoda	Aoridae	*Bemlos*	A
CaprA	Arthropoda	Malacostraca	Amphipoda	Caprellidae	Unknown	A
Capre	Arthropoda	Malacostraca	Amphipoda	Caprellidae	*Caprella*	
ChevA	Arthropoda	Malacostraca	Amphipoda	Chevaliidae	*Chevalia*	A
pans	Arthropoda	Malacostraca	Amphipoda	Haustoriidae	*Acanthohaustorius*	*pansus*
Amphide	Arthropoda	Malacostraca	Amphipoda	Kamakidae	*Amphideutopus*	
flor	Arthropoda	Malacostraca	Amphipoda	Phoxocephalidae	*Metharpinia*	*floridana*
PodoA	Arthropoda	Malacostraca	Amphipoda	Podoceridae	Unknown	A
AmphA	Arthropoda	Malacostraca	Amphipoda	Unknown	Unknown	A
vari	Arthropoda	Malacostraca	Cumacea	Bodotriidae	*Cyclaspis*	cf. sp.
CycloD	Arthropoda	Malacostraca	Cumacea	Bodotriidae	*Cyclaspis*	D
Pare	Arthropoda	Malacostraca	Decapoda	Albuneidae	*Albunea*	*paretii*
PersA	Arthropoda	Malacostraca	Decapoda	Leucosiidae	*Persephona*	A
PenaA	Arthropoda	Malacostraca	Decapoda	Penaeidae	Unknown	A
DecaA	Arthropoda	Malacostraca	Decapoda	Unknown	Unknown	A
Mag	Arthropoda	Malacostraca	Isopoda	Anthuridae	*Amakusanthura*	*magnifica*
AnthA	Arthropoda	Malacostraca	Isopoda	Anthuridae	Unknown	A
XenaA	Arthropoda	Malacostraca	Isopoda	Hyssuridae	*Xenanthura*	A
ParanA	Arthropoda	Malacostraca	Isopoda	Paranthuridae	Unknown	A
TanaA	Arthropoda	Malacostraca	Tanaidacea	Unknown	Unknown	A

ApseA	Arthropoda	Malacostraca	Tanaidacea	Apseudidae	*Apseudes*	A
KallA	Arthropoda	Malacostraca	Tanaidacea	Kalliapseudidae	Unknown	A
KalliA	Arthropoda	Malacostraca	Tanaidacea	Kalliapseudidae	*Kalliapseudes*	A
floriden	Arthropoda	Malacostraca	Tanaidacea	Kalliapseudidae	*Psammokalliapseudes*	*Floridensis*
LeptA	Arthropoda	Malacostraca	Tanaidacea	Leptognathiidae	Unknown	A
ParatA	Arthropoda	Malacostraca	Tanaidacea	Paratanaidae	*Paratanais*	A
Punct	Arthropoda	Ostracoda	Myodocopida	Cylindroleberididae	*Cylindroleberis*	*astropella*
louisi	Arthropoda	Ostracoda	Myodocopida	Cypridinidae	*Kornickeria*	
pauc	Arthropoda	Ostracoda	Myodocopida	Philomedidae	*Harbansus*	*paucichelatus*
darb	Arthropoda	Ostracoda	Myodocopida	Rutidermatidae	*Rutiderma*	*darbyi*
MyodA	Arthropoda	Ostracoda	Myodocopida	Unknown	Unknown	A
MyodB	Arthropoda	Ostracoda	Myodocopida	Unknown	Unknown	B
MyodG	Arthropoda	Ostracoda	Myodocopida	Unknown	Unknown	G
CrustA	Arthropoda	Crustacea unident.	Unknown	Unknown	Unknown	A
BranA	Chordata	Leptocardii	Amphioxiformes	Asymmetronidae	*Branchiostoma*	A
Ecop	Echinodermata	Echinoidea	Clypeasteroida	Mellitidae	*Encope*	sp.
HoloA	Echinodermata	Holothuroidea	Unknown	Unknown	Unknown	A
Amphiuridae	Echinodermata	Ophiuroidea	Ophiurida	Amphiuridae	*Amphiura*	
ThraA	Mollusca	Bivalvia	Anomalodesmata	Thraciidae	*Thracia*	A
luna	Mollusca	Bivalvia	Carditoida	Crassatellidae	Unknown	
dupl	Mollusca	Bivalvia	Carditoida	Crassatellidae	*Crassinella*	*dupliniana*
LimA	Mollusca	Bivalvia	Limoida	Limidae	*unknown*	A
scab	Mollusca	Bivalvia	Limoida	Limidae	*Ctenoides*	*scabra*
subo	Mollusca	Bivalvia	Limoida	Limidae	*Limatula*	*subovata*
LuciA	Mollusca	Bivalvia	Lucinoida	Lucinidae	Unknown	A
blan	Mollusca	Bivalvia	Lucinoida	Lucinidae	*Cavilinga*	
cren	Mollusca	Bivalvia	Lucinoida	Lucinidae	*Parvilucina*	*crenella*

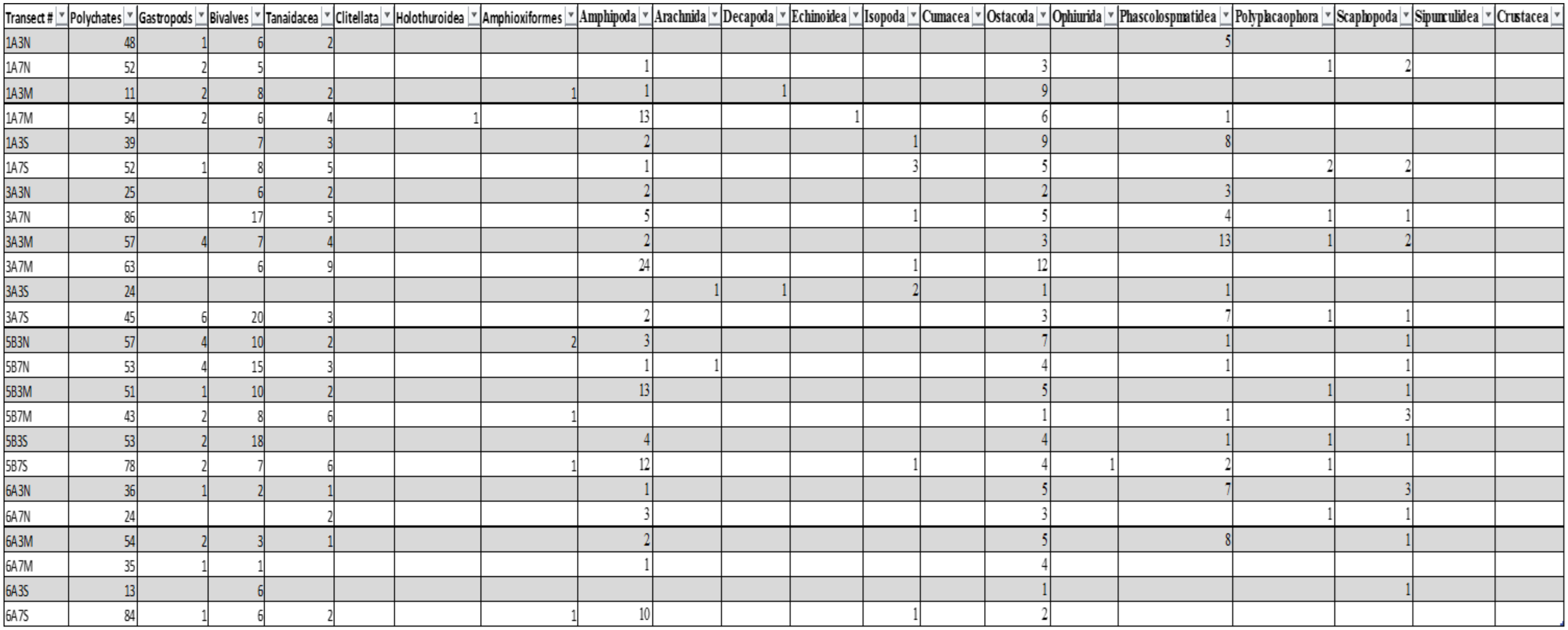
Vari	Mollusca	Bivalvia	Myoida	Corbulidae	*Corbula*	
VariA	Mollusca	Bivalvia	Myoida	Corbulidae	*Corbula*	A
decu	Mollusca	Bivalvia	Mytiloida	Mytilidae	*Crenella*	*decussata*
Pter	Mollusca	Bivalvia	Pterioida	Pteriidae	*Pteria*	
CardA	Mollusca	Bivalvia	Veneroida	Cardiidae	Unknown	A
floridana	Mollusca	Bivalvia	Veneroida	Laseidae	*Orobitella*	
lio	Mollusca	Bivalvia	Veneroida	Semelidae	*Abra*	*lioica*
nuca	Mollusca	Bivalvia	Veneroida	Semelidae	*Semlina*	*nucloides*
ErvA	Mollusca	Bivalvia	Veneroida	Semelidae	*Ervilia*	A
concen	Mollusca	Bivalvia	Veneroida	Semelidae	*Ervilia*	*concentrica*
Semel	Mollusca	Bivalvia	Veneroida	Semelidae	*Semelina*	
nite	Mollusca	Bivalvia	Veneroida	Tellinidae	*Tellina*	*nitens*
meriA	Mollusca	Bivalvia	Veneroida	Tellinidae	*Tellina*	A
TellA	Mollusca	Bivalvia	Veneroida	Tellinidae	Unknown	A
VeneA	Mollusca	Bivalvia	Veneroida	Veneridae	Unknown	A
mazy	Mollusca	Bivalvia	Veneroida	Veneridae	*Chione*	*mazycki*
Simps	Mollusca	Bivalvia	Veneroida	Veneridae	*Pitar*	
flori	Mollusca	Bivalvia	Veneroida	Veneridae	*Tivela*	*trigonella*
BivA	Mollusca	Bivalvia	Unknown	Unknown	Unknown	A
cerit	Mollusca	Gastropoda	Caenogastropoda	Cerithiidae	Unknown	
TurrA	Mollusca	Gastropoda	Caenogastropoda	Turritellidae	Unknown	A
succ	Mollusca	Gastropoda	Cephalaspidea	Haminoeidae	*Haminoea*	
RetuA	Mollusca	Gastropoda	Cephalaspidea	Retusidae	*Retusa*	A
RetuB	Mollusca	Gastropoda	Cephalaspidea	Retusidae	*Retusa*	B
PhenA	Mollusca	Gastropoda	Cycloneritimorpha	Phenacolepadidae	*Phenacolepas*	A
caro	Mollusca	Gastropoda	Littorinimorpha	Caecidae	*Caecum*	*carolinianum*
florid	Mollusca	Gastropoda	Littorinimorpha	Caecidae	*Caecum*	*floridanum*

pulc	Mollusca	Gastropoda	Littorinimorpha	Caecidae	*Caecum*	*pulchellum*
nitid	Mollusca	Gastropoda	Littorinimorpha	Caecidae	*Meioceras*	*nitidum*
Capul	Mollusca	Gastropoda	Littorinimorpha	Littorinidae	Unknown	
RissA	Mollusca	Gastropoda	Littorinimorpha	Rissoidae	*Rissoa*	A
RissoA	Mollusca	Gastropoda	Littorinimorpha	Rissoidae	*Rissoina*	A
NassA	Mollusca	Gastropoda	Neogastropoda	Nassariidae	*Nassarius*	A
nivea	Mollusca	Gastropoda	Neogastropoda	Olividae	*Oliva*	*nivea*
Simp	Mollusca	Gastropoda	Neogastropoda	Marginellidae	*Serrata*	
eburn	Mollusca	Gastropoda	Neogastropoda	Marginellidae	*Marginella*	*eburneola*
ovul	Mollusca	Gastropoda	Neogastropoda	Marginellidae	*Granulina*	*ovuliformis*
MargA	Mollusca	Gastropoda	Neogastropoda	Marginellidae	*Marginella*	A
OlivA	Mollusca	Gastropoda	Neogastropoda	Olividae	Unknown	A
BullA	Mollusca	Gastropoda	Cephalaspidea	Bullidae	Unknown	A
GastA	Mollusca	Gastropoda	Unknown	Unknown	Unknown	A
PolyA	Mollusca	Polyplacophora	Unknown	Unknown	Unknown	A
floridense	Mollusca	Scaphopoda	Dentaliida	Dentalidae	*Coccodentalium*	*carduus*
DentA	Mollusca	Scaphopoda	Dentaliida	Dentalidae	Unknown	A
Pret	Mollusca	Scaphopoda	Dentaliida	Dentalidae	*Antalis*	*pretiosum*
Laq	Mollusca	Scaphopoda	Dentaliida	Dentalidae	*Dentalium*	*laqueatum*
quad	Mollusca	Scaphopoda	Gadilida	Gadilidae	*Polyschides*	*quadratus*
carol	Mollusca	Scaphopoda	Gadilida	Gadilidae	*Polyschides*	*carolinus*
ScaphA	Mollusca	Scaphopoda	Unknown	Unknown	Unknown	A
Albus	Sipuncula	Phascolosomatidea	Aspidosiphonida	Aspidosiphonidae	*Aspidosiphon*	*albus*
Parv	Sipuncula	Phascolosomatidea	Aspidosiphonida	Aspidosiphonidae	*Aspidosiphon*	*parvulus*
misa	Sipuncula	Phascolosomatidea	Phascolosomatida	Phascolosomatidae	*Apionsoma*	*misakianum*
strom	Sipuncula	Sipunculidea	Golfingiida	Phascolionidae	*Phascolion*	*strombus*
nudas	Sipuncula	Phascolosomatidea	Phascolosomatida	Phascolosomatidae	*Phascolosoma*	

Appendix B. Pre-construction Major Groups

Transect #	Polychates	Gastropods	Bivalves	Tanaidacea	Clitellata	Holothuroidea	Amphioxiformes	Amphipoda	Decapoda	Isopoda	Cumacea	Ostracoda	Ophiurida	Phascolosomatidea	Polyplacaophora	Scaphopoda	Sipunculidea	Crustacea	Arachnida	Heterotardigrada	Anthozoa
1A	47	1	0		0		2							5							
1B	49	2	7	6				3	1			2		9							
1C	48	4	10	8																	
1D	28	4	2	9			1	1						14		1					
1E	206	1	4	3	2		2	2		1		6				1					
1F	45	1	1	2				4		2		5		1		1					
1G	47	1	9	1				2				5		5							
1H	162	5	9	9	3			6									2				
1I	50	3	15	3	1							2		4		2	2				
1J	35	1	1		1									4							
3A	40	1	3	4				2						4							
3B	33			4			1	3		1				5							
3C	42	4	8	14	6			7	3	1	1	8		5						1	
3D	35	3	3	4										4							
3E	56	1	8	9				4						6							
3F	24	2	5	3			1	1	1		1			2							
3G	53		10	1			1	1				13		6					5		
3H	14	1	1	5				1						9							
3I	32		7	17						1											
3J	103	2	10	7			1	7				4		3							
5A	42	2	11	8										5							
5B	53			9	2		1							11							
5C	29		4	4			1	1		2		2		5							
5D	25		6	7						1		2		7							
5E	26	2	12	5	12			4		2	1	13		7							
5F	27	1	9	8	5		1	1				2		9							
5G	3		3	1																	
5H	3		9	3										1							
5I	39		1	2								1		4							
5J	37	2	20	5	3		1	2		2		3		4							
6A	49	4	14	6				4		2		3		3							
6B	43	3	12	2				1				1		5							
6C	34	1	5	3				4	2			1		4					1		1
6D	70	6	5	5	4			8				5		1	1						
6E	34		8	6				2				8		1					3		
6F	70	1	18	1				5				7		3					1		
6G	20	2	2		2							3		3							
6H	30			1	1		1	1		1		1		2					1		
6I	29		8	2					1			4		7							
6J	64		4	6				9				4		3							

Appendix C. Post Construction Major Groups



Transect #	Polychates	Gastropods	Bivalves	Tanaidacea	Clitellata	Holothuroidea	Amphioxiformes	Amphipoda	Arachnida	Decapoda	Echinoidea	Isopoda	Cumacea	Ostacoda	Ophiurida	Phascolospmatidea	Polyplacaophora	Scaphopoda	Sipunculidea	Crustacea
1A3N	48	1	6	2												5				
1A7N	52	2	5					1						3			1	2		
1A3M	11	2	8	2			1	1		1				9						
1A7M	54	2	6	4		1		13			1			6		1				
1A3S	39		7	3				2				1		9		8				
1A7S	52	1	8	5				1				3		5			2	2		
3A3N	25		6	2				2						2		3				
3A7N	86		17	5				5				1		5		4	1	1		
3A3M	57	4	7	4				2						3		13	1	2		
3A7M	63		6	9				24				1		12						
3A3S	24								1	1		2		1		1				
3A7S	45	6	20	3				2						3		7	1	1		
5B3N	57	4	10	2			2	3						7		1		1		
5B7N	53	4	15	3				1	1					4		1		1		
5B3M	51	1	10	2				13						5			1	1		
5B7M	43	2	8	6			1							1		1		3		
5B3S	53	2	18					4						4		1	1	1		
5B7S	78	2	7	6			1	12				1		4	1	2	1			
6A3N	36	1	2	1				1						5		7		3		
6A7N	24			2				3						3			1	1		
6A3M	54	2	3	1				2						5		8		1		
6A7M	35	1	1					1						4						
6A3S	13		6											1				1		
6A7S	84	1	6	2			1	10				1		2						

Appendix D. Pre-construction Major Groups

Variable	AICc	SS(trace)	Pseudo-F	P	Prop.	Cumul.	res.df
+HesiA	481.99	11116	6.1649	0.001	9.04E-02	9.04E-02	62
+SabeA	479.5	7897	4.6368	0.001	6.43E-02	0.15469	61
+CardA	477.85	6188.5	3.8004	0.001	5.04E-02	0.20505	60
+albus	476.3	5782.6	3.7116	0.001	4.70E-02	0.2521	59
+ApseA	474.79	5508.6	3.6974	0.001	4.48E-02	0.29692	58
+SyllA	473.59	4883	3.4139	0.001	3.97E-02	0.33665	57
+flori	472.24	4899.4	3.5804	0.001	3.99E-02	0.37651	56
+darb	471.37	4175.1	3.1693	0.001	3.40E-02	0.41048	55
+CirrA	470.47	4093.6	3.2336	0.001	3.33E-02	0.44379	54
+SyneB	469.65	3886.6	3.1949	0.001	3.16E-02	0.47541	53
+MyodA	469.21	3408.5	2.9025	0.001	2.77E-02	0.50314	52
+MaldA	468.75	3359.3	2.9689	0.001	2.73E-02	0.53048	51
+SyneA	468.26	3310.8	3.0433	0.001	2.69E-02	0.55741	50
+misa	467.86	3160	3.0221	0.001	2.57E-02	0.58313	49
+CapiA	467.63	2956.4	2.9393	0.001	2.41E-02	0.60718	48
+pauc	467.45	2860.4	2.9599	0.001	2.33E-02	0.63045	47
+NereA	467.36	2744.1	2.958	0.001	2.23E-02	0.65278	46
+parv	467.36	2631.9	2.9577	0.001	2.14E-02	0.67419	45
+TanaA	467.19	2675.7	3.1506	0.001	2.18E-02	0.69597	44

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