NEW BENTHIC METHODOLOGY (BEAMR) REVOLUTIONIZES BIOLOGICAL ASSESSMENT OF PROJECT EFFECTS AND ARTIFICIAL REEF EFFICACY: AN EXAMPLE FROM BROWARD COUNTY SEGMENT III

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ABSTRACT

Coastal Planning & Engineering, Inc. developed a methodology referred to as Benthic Ecological Assessment for Marginal Reefs (BEAMR). Many reef communities in Florida's coral habitat are best described as marginal *i.e.*, marginal in terms of impoverished community condition and biogeographic limits. CPE identified the need for an *in situ* method specifically tailored to characterize these marginal habitats. The result is a synthesis of well-established reef assessment methods with selected parameters that have proven most useful for assessment and community change detection, and are scalable to the sampling intensity requirements of different projects. These data are often required by agencies, and since BEAMR is more rigorous than AGRRA, a BEAMR dataset frequently satisfies agency RAI(s) as well. The major benefits of a single method are applicability to all benthic assessment projects, and simplification of training, data management, and analyses.

Segment III of the Broward County Shore Protection Project placed approximately 1.92 million cubic yards of sand and impacted 7.6 acres of nearshore hardbottom. As mitigation, the Florida Department of Environmental Protection (FDEP) required the placement of 3.60 x 10^{-2} km^2 (8.9 acres) of mitigative artificial reef to be constructed before the anticipated construction of the beach nourishment project. The biological monitoring of the natural hardbottom and artificial reef associated with this project was designed to be one of the most comprehensive studies of the potential impacts of beach nourishment projects and employed some of the most rigorous methodologies in the history of beach nourishment. A total of fifty-six 30-m transects were monitoring on the natural, artificial, and control hardbottom habitats. The data from this monitoring plan has allowed for the evaluation of the efficacy of the mitigative artificial reef as a replacement for natural hardbottom lost due to beach construction and

the effect of beach construction activity on the nearshore natural hardbottom benthic community.

KEY WORDS – BEAMR, artificial reef, marginal reef, nourishment, benthic monitoring

INTRODUCTION

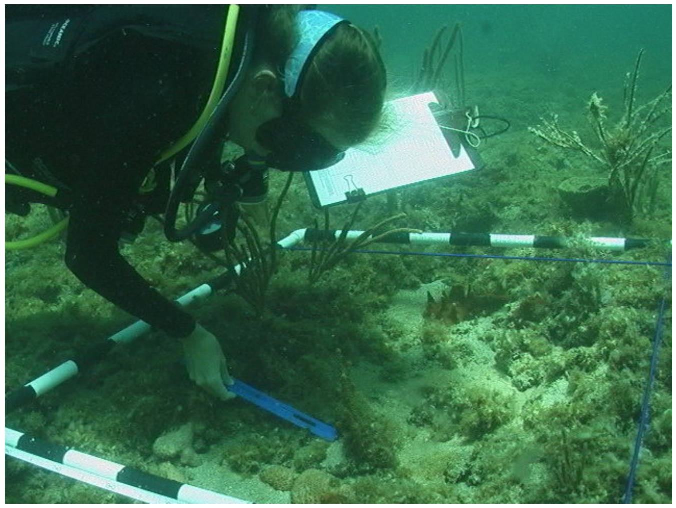
The Marine Science and Biological Research Department of Coastal Planning & Engineering, Inc. (CPE) developed a benthic biological assessment method referred to as Benthic Ecological Assessment of Marginal Reefs (BEAMR). Many reef communities in Florida's coral habitat are best described as "marginal". CPE identified the need for an *in situ* method specifically tailored to characterize these marginal habitats.

Development of BEAMR Methodology

The term "marginal" describes coral reefs and coral communities that occur either close to environmental thresholds for coral survival or in areas characterized by "sub-optimal" or fluctuating environmental conditions. They are regions which reflect the effects of steady-state or long-term average environmental limitations (Perry and Larcombe, 2003; Guinotte *et al.,* 2003). This can include, but is not limited to, settings characterized by high or low temperatures, salinities, or nutrient levels, or by low light penetration. In southeast Florida, marginal reefs are defined by impoverished community conditions and biogeographic limits. Broward County is a high-latitude reef community in the midst of potential anthropogenic and natural stressors such as thermal stress, pollution, increased fresh water discharge, periodic ship groundings, and extensive coastal urbanization (Vargas-Ángel *et al.,* 2003). Most methodologies tailored for 'classic' coral reefs do not collect enough data for meaningful change-detection analyses on marginal reef habitats.

The basic monitoring methods of benthic habitat include: line-intercept, belt-transect, and quadrat sampling. Line-intercept can give percent cover and spatial distribution of organisms, belt-transect can give percent cover and abundance but not spatial distribution, and quadrat sampling can give all three. Each methodology is useful for a specific task but quadrat sampling is ideal to fully characterize a benthic community. The method most commonly used for benthic assessment in Florida is the Atlantic and Gulf Rapid Reef Assessment (AGRRA). AGRRA is a comprehensive biological assessment technique which combines all three monitoring methods (line, belt, and quadrat). It is excellent for unknown areas and large scale surveys and depends heavily on coral, algae, and fish data to characterize reef habitat. However, corals are not a key component of marginal reefs; therefore, a key habitat quality indicator for AGRRA is missing.

Key habitat quality indicators of marginal reefs are not well known because each habitat is subject to variations in physical and biological characteristics; this forced an abandonment of reliance on indicator organisms in the design of BEAMR. Instead BEAMR measures everything visible from a birds eye view (Photograph 1) above the quadrat and pools organisms by functional group (sessile only). This generalization allows BEAMR to be efficient on any marginal reef. Macroalgae and coral are further broken down to genus and species. An example of a BEAMR datasheet is presented in Figure 1. Physical parameters, relief and sediment depth, are also measured. For detailed BEAMR methodology see Lybolt and Baron (2006).



Photograph 1. BEAMR methodology conducted by a CPE marine biologist.

Sample Name or #	2.5	List macroalgae Genus List every coral colony ~and coral condition(s)	% cover max size (cm)
Max Relief (cm)	4	Hypnea	1
Max Sediment Depth (cm)	1	Gracilaria	1
Sessile Benthos…	**% Cover**		
Sediment- (circle all: sand shell mud)	20		
Macroalgae- Fleshy+Calcareous	3		
Turf- algae+cyanobacteria (circle all: g r b)	60		
Encrusting Red Algae	0	S. hyades	14
Sponge	2	S. siderea	5
Hydroid	0		
Octocoral	0		
Stony Coral	1		
Tunicate	0		
Bare Hard Substrate	14		
other-…	0		
Total Must = 100%			

Figure 1. Example BEAMR datasheet (for 1 quadrat).

Broward County Shore Protection Project

Segment III of the Broward County Shore Protection Project (SPP) is located between Port Everglades and the Broward/Miami-Dade County line. The project fill area in Segment III is approximately 10.97 kilometers (6.8 miles) in length. The project provided beach renourishment for the majority of the Segment III shoreline including John U. Lloyd State Park, Dania Beach, and Hollywood/Hallandale shorelines. Beach fill extended from Florida Department of Environmental Protection (FDEP) monuments R-85.7 (Port Everglades) to R-92 within John U. Lloyd State Park, and from R-99 (Dania Beach Pier) to R-128 (Dade County line) (Figure 2). The estimated sand fill volume for Segment III is approximately 1.92 million cubic yards of sand.

The placement of sand during nourishment activities and subsequent equilibration of the beach fill was predicted to result in the burial of approximately 3.07×10^{-2} km^2 (7.6 acres) of nearshore hardbottom and biological resources, including direct burial of 3.64×10^{-3} km^2 (0.9 acres) of hardbottom in John U. Lloyd State Park and 4.45×10^{-3} km^2 (1.1 acres) of wormrock habitat in Hollywood. Due to the projected burial of natural hardbottom areas, the FDEP required the placement of 3.60×10^{-2} km^2 (8.9 acres) of mitigative artificial reef (Figure 3). The artificial reef was constructed as one layer of limestone boulders (4-6 feet [1.2-1.8 meters] in maximum diameter) placed in the nearshore zone in approximately 4 to 6 meters mean water depth. Construction of the mitigative artificial reef was completed twenty months before construction of the beach nourishment project.

In order to assess the efficacy of the mitigative artificial reef and the effects from beach construction on the nearshore natural hardbottom, biological monitoring was conducted on fifty-six 30-m transects using 1-m^2 quadrats spaced 2.5 meters apart for a total of 12 quadrats per transect. The 56 transects include 24 natural hardbottom transects, 27 artificial reef transects, and 5 control transects.

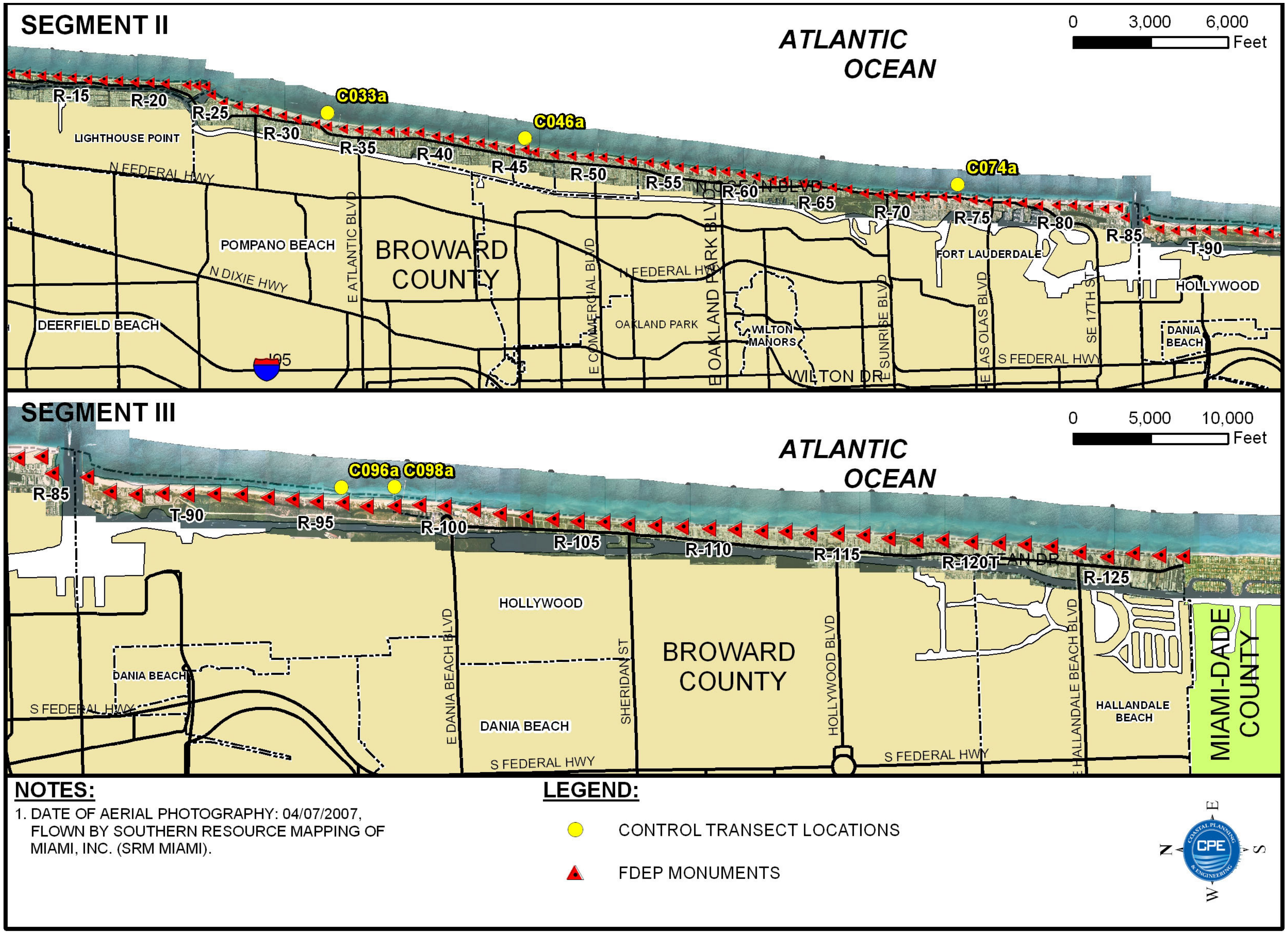


Figure 2. Location map of Broward County Shore Protection Project control transects in Segments II and III.

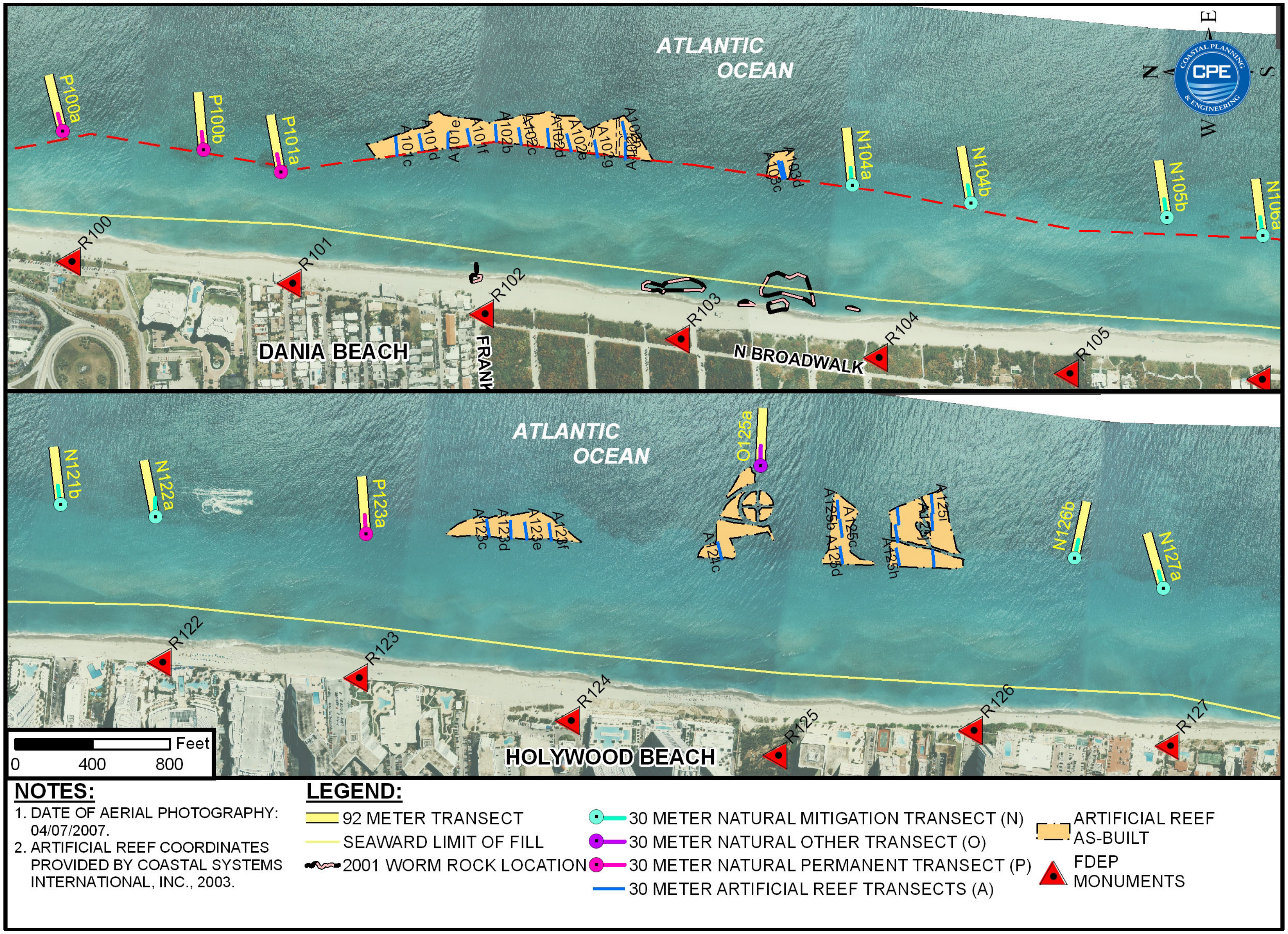


Figure 3. Location of artificial reef and associated transects in Segment III.

RESULTS

The results discussed here are limited to functional group level data analyses. Data analysis consisted of non-parametric analyses using PRIMER-E (v6) statistical package (Clarke and Warwick, 2001; Clarke and Gorley, 2006). Statistical significance was determined at $\alpha = 0.05$ (95% confidence interval) and all reference to "significance" has been determined through statistical analysis.

The Mitigative Artificial Reef versus the Adjacent Natural Hardbottom

The mitigative artificial reef was monitored 9, 12, 18, 24, 36, and 48 months post-mitigation construction (herein referred to as post-mitigation). Twenty-seven artificial reef transects were monitored in conjunction with 24 natural hardbottom transects in order to assess the efficacy of the mitigation reef as replacement habitat for anticipated impact from beach construction. Figure 3 presents the location of the artificial reefs in Segment III.

Temporal Analyses of Artificial and Natural Site Types

The change in biotic community composition was analyzed to examine the progress of the mitigative artificial reef. Sediment was removed from the dataset in order to determine where significantly different changes in the biotic community occurred. The dataset was standardized by total and then log(x+1) transformed in order to reduce the contribution of highly abundant taxa (functional groups) and to strengthen that of the less abundant ones. The transformed data was then analyzed for similarity using a Bray-Curtis similarity matrix. A multi-dimensional scaling (MDS) ordination was generated from the similarity matrix for the artificial (A) and natural (N, O, and P) reef communities over time (Figure 4a). Each data point in Figure 4a represents the functional group community of one transect at one point in time. Data point location is based on its similarity to the rest of the data points; those closest together have the highest similarity.

Figure 4a presents a distinct clustering of artificial reef data points by monitoring event. This is expected since each monitoring event represents a longer "soak time" than the previous event, allowing for further community growth. However, the 36- and 48-Post events are tightly clustered together, an indication that community growth has slowed as a function of time. The natural hardbottom ordination does not appear to cluster as clearly based on time. An analysis of similarity (ANOSIM) was used to determine if the monitoring events can be significantly differentiated for each site type at $\alpha = 0.05$. ANOSIM results reveal an R statistic and a significance level (p-value). The R statistic falls between 0 (no differences) and 1 (significantly different). The global R statistic for the artificial reef was 0.690 the global p was < 0.001. This indicates significant differences between monitoring events. The global R statistic for the natural hardbottom was relatively low at 0.312, whereas the global p-value was < 0.001. This can occur because the p-value is dependent on the sample size and when the possible permutations are high as they are in this case, biologically trivial differences may become statistically significant when the 'power' is large. In these instances, the R statistic is the more useful output to interpret (Clarke and Gorley, 2006).

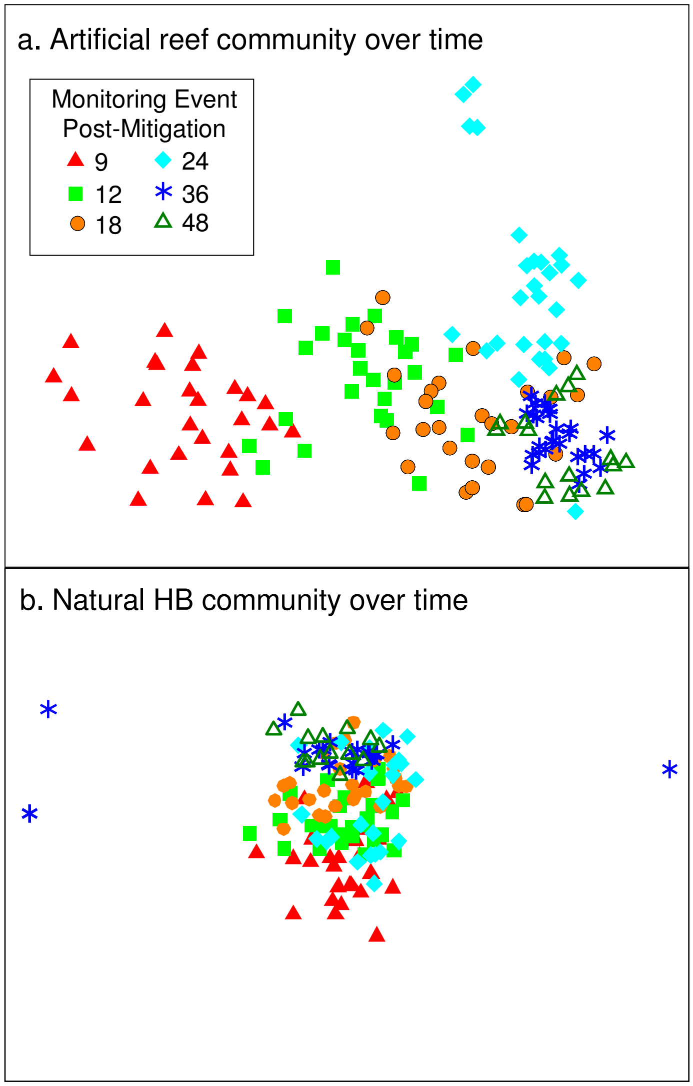


Figure 4. MDS ordination of transect-level biotic functional group mean percent cover on the a. artificial reef and b. natural hardbottom (HB) transects over time.

Spatial Analyses of Artificial versus Natural Site Types

Multi-dimensional scaling (MDS) ordinations were generated from the Bray-Curtis similarity matrix for each monitoring event to display the growing similarity between the artificial reef and natural hardbottom communities over time (Figures 5a – 5e). The MDS figures are defined by transect type to clearly represent the differentiation between the data points of each site type (natural and artificial). An ANOSIM proved the natural hardbottom community to be significantly different from the artificial reef community at each monitoring event. Although the transect types remained significantly different at each monitoring event, the R statistic decreased from 0.607 (9-month post-mitigation) to 0.569 (48-month post-mitigation); this indicates an increase in community similarity over time.

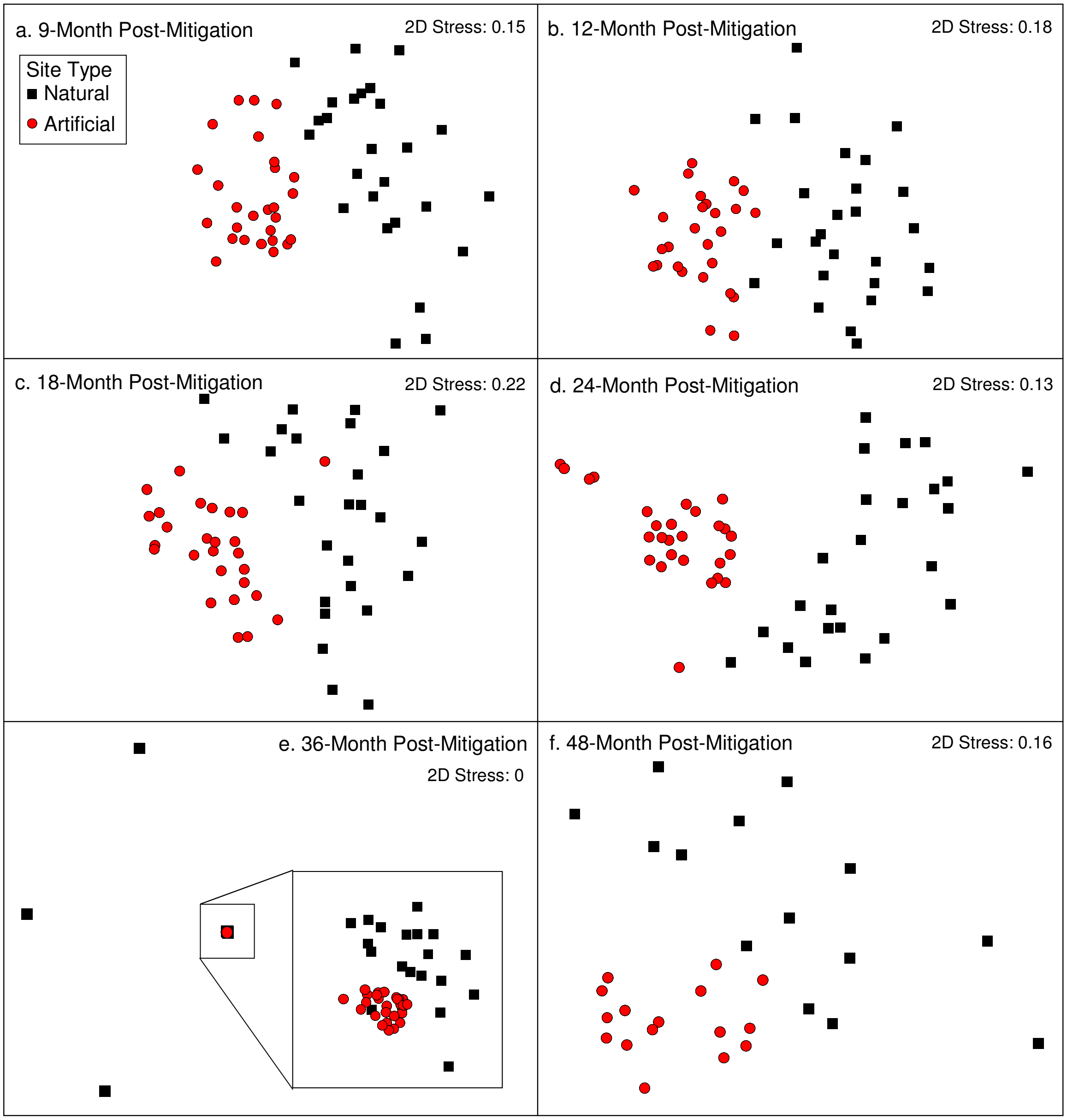


Figure 5. MDS ordinations displaying artificial reef and natural hardbottom similarity for a. 9-month, b. 12-month, c. 18-month, d. 24-month, e. 36-month, and f. 48-month post-mitigation based on biotic functional group mean percent cover from BEAMR.

Effects of Beach Construction

The natural hardbottom adjacent to the Segment III project area was monitored pre-, mid-, and post-construction using the BEAMR methodology. Five control transects were monitored in conjunction with 12 experimental transects in order to assess the effects of beach construction on the nearshore natural hardbottom. These transects were monitored monthly for 18 months post-construction.

Non-parametric multivariate analyses were applied to the functional group data to determine if significant differences ($\alpha = 0.05$) existed over time and space in the nearshore 30 meters of hardbottom habitat. The MDS ordination in Figure 6a takes into account all control (C) and experimental transects (O and P). It is defined by the factor *construction phase* (pre-, mid-, and post-construction) in order to present a picture of transect similarity in relation to the phase of beach construction. Figure 6b is the same MDS ordination as Figures 6a with the application of a 2-dimensional bubble plot defined by the variable *sediment cover*; the larger the bubble, the higher the average percent cover of sediment for that transect at a specific monitoring event. The bubble plot presents the influence of sand cover in transect similarity.

A second-stage community analysis was applied to the dataset to compare the time-series at each transect, which were previously designated as a control or experimental transect type. If the temporal pattern between transect types could be differentiated, it would imply that a localized variable, such as beach construction, had affected one type and not the other regarding functional group cover. The results of the second-stage analysis (MDS and ANOSIM) indicated that the transect types could not be significantly differentiated and follow a similar temporal pattern (Figure 7). This leads to the conclusion that although a disturbance signal was apparent, beach construction did not change the temporal pattern of the experimental transects enough to make it significantly distinct from the temporal pattern of the control transects.

Each experimental transect was examined independently to determine change in the biotic benthic community over time. Table 1 displays the percent similarity between pre-construction conditions (average of 8-pre and 2-pre) to 0-, 6-, 12-, and 18-month post-construction for all experimental transects based on Cluster analysis with Similarity Profile (SIMPROF). The biotic benthic community on 6 of the 12 experimental transects could not be significantly differentiated from pre-construction conditions by 18 months post-construction; the other six remained significantly different.

Based on these analyses, it can be concluded that increased sediment cover adversely affected the functional group-level of the benthic community; however, the present state of the benthic community is that of progressive recovery.

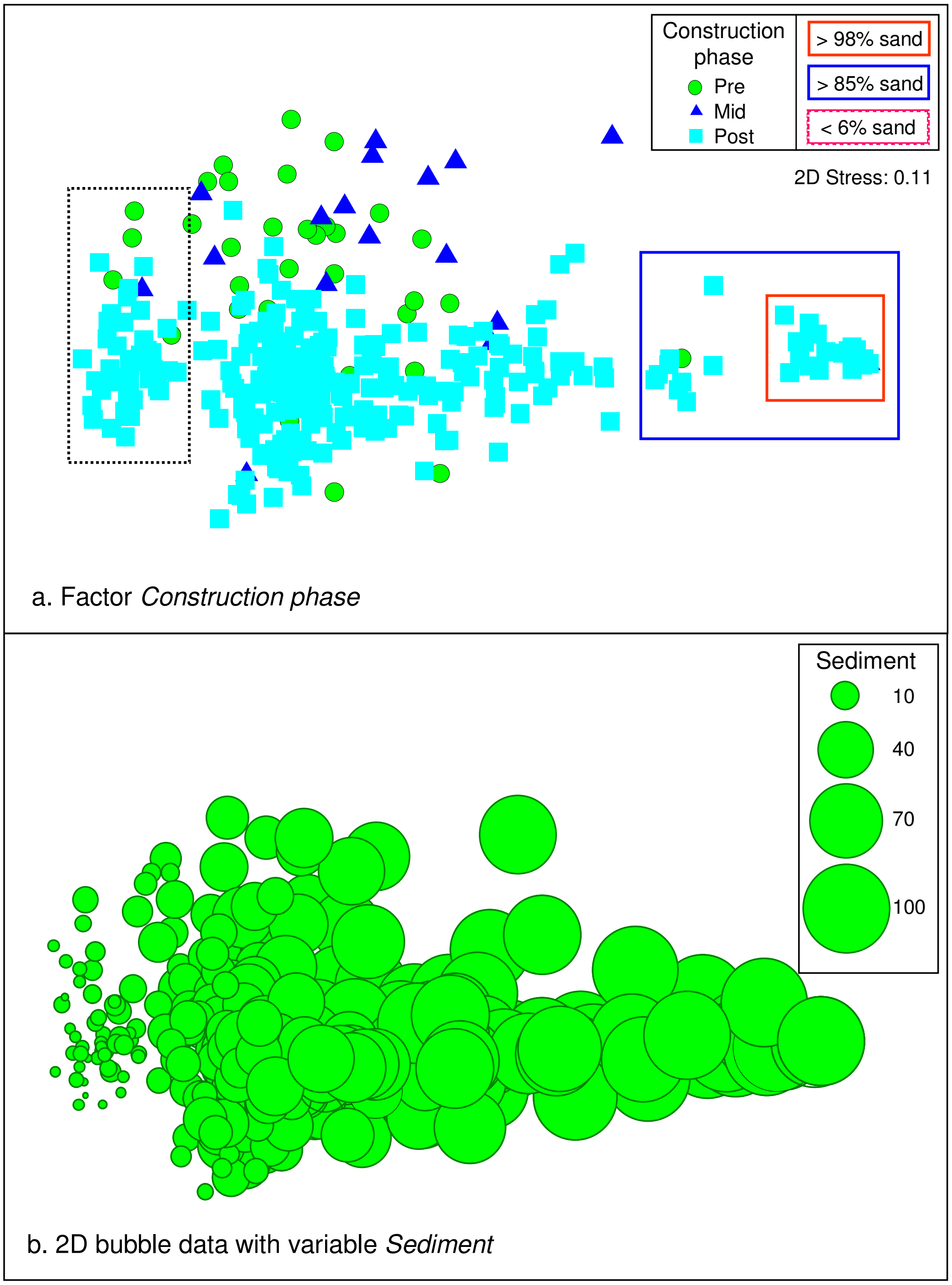


Figure 6. MDS ordination of all control and experimental transects monitored between 8-month pre-construction and 18-month post-construction monitoring events a. defined by beach *construction phase* and b. a 2-dimensional bubble plot defined by the variable *sediment cover*.

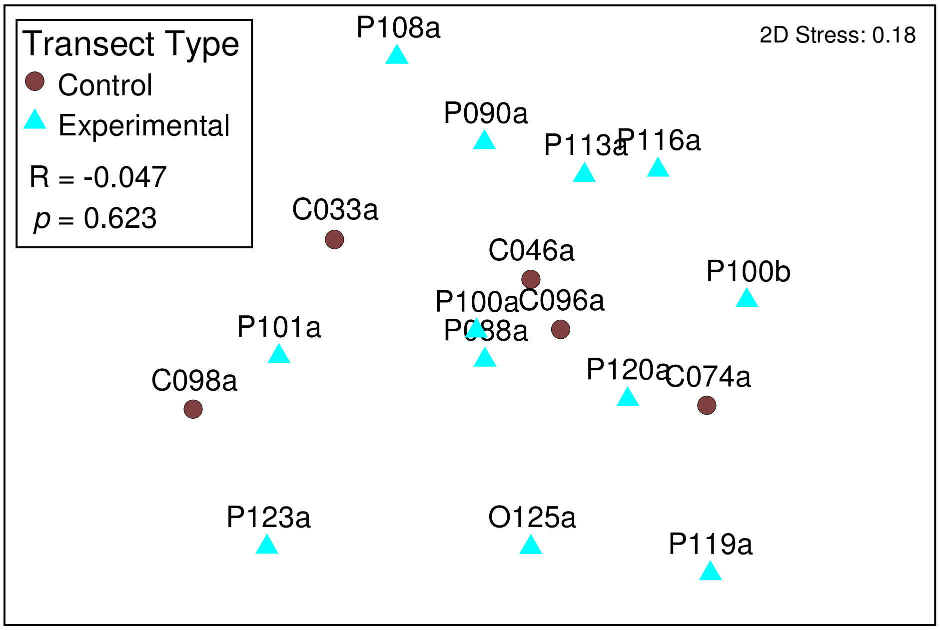


Figure 7. Second-stage MDS ordination and ANOSIM results (R and *p*-values) showing that significant differences in temporal pattern do not exist between control and experimental transect types based on functional group communities.

Transect	Similarity to Pre-Construction Community			
	0-Post	6-Post	12-Post	18-Post
P088a	**68%**	**68%**	**68%**	**68%**
P090a	**76%**	**76%**	**76%**	**76%**
P100a	**73%**	**73%**	**73%**	**76%**
P100b	**81%**	**81%**	**81%**	**81%**
P101a	**16%***	38%	67%	67%
P108a	73%	73%	73%	73%
P113a	**33%**	63%†	63%‡	63%
P116a	**71%**	**71%**	**71%**	**71%**
P119a	**74%**	83%	83%	83%
P120a	**80%**	88%	**85%**	**85%**
P123a	**32%**	**32%**	83%	83%
O125a	86%	86%	91%	86%

Table 1. Percent similarity between pre-construction and the 0-, 6-, 12-, and 18-month post-construction monitoring events of the benthic community for each experimental transect. *1-Post, †7-Post, and ‡15-Post substituted because no biotic data available at designated event. Significant differences are highlighted and bold.

DISCUSSION

Artificial Reef Discussion

Change in the biotic benthic community on the artificial reef has slowed as a function of time. The most change took place immediately following reef construction and the least change occurred between 36- and 48-month post-mitigation. This indicates that the artificial reef may be reaching equilibrium in carrying capacity and complexity.

As of 48 months post-mitigation, the artificial reef benthic community remained significantly different from the natural hardbottom; however, measurable progress was apparent in benthic community similarity. The structural difference between the artificial reef (high-relief boulders) and the natural hardbottom (low-relief pavement) may conserve the statistically distinct community through time (Perkol-Finkel *et al.*, 2005; Perkol-Finkel and Benayahu, 2007).

Beach Construction Discussion

Sediment cover was found to be the dominant influence in transect similarity over time and space at the functional group level. Increased sand cover created a distinct disturbance in community composition on the experimental transects which coincided with the commencement of beach construction. The community dissimilarity between the experimental and control transects increased between pre-construction and immediate post-construction, but decreased as sediment cover receded throughout post-construction monitoring. As of 18 months post-construction, the biotic benthic community on 6 of the 12 experimental transects was indistinguishable from pre-construction conditions. Overall, increased sediment cover adversely affected the functional group-level of the benthic community; however, the present state of the benthic community is that of progressive recovery.

CONCLUSION

The high-resolution dataset collected using the BEAMR methodology allowed for a comparison of the artificial reef versus the natural hardbottom, as well as for an analysis of beach renourishment effects on the nearshore natural hardbottom. The rigorous dataset assembled from the BEAMR methodology has proven its efficiency in the detection of changes in community composition on marginal reef habitats.

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