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Benthic colonization and ecological successional patterns on a planned nearshore artificial reef system in Broward County, SE Florida

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Abstract. Nearshore marginal reefs are frequently impacted from beach restoration activities. Beach nourishment can impact nearshore hardbottom through burial and subsequent habitat degradation. In response to increased beach nourishment activities, reef restoration projects have increased immensely over the last decade. In Southeast Florida, the deployment of artificial reefs (ARs) as mitigation for nearshore habitat loss has become routine. To determine the success of ARs as appropriate nearshore habitat replacement, long-term AR colonization studies are essential to evaluate ecological processes and succession rates in shallow marine environments. This paper reports on the development, recruitment and ecological succession rates of macrobenthic communities on a mitigative AR system located in Broward County, Florida. Pioneering organisms and community composition were evaluated via the Coastal Planning & Engineering, Inc. Benthic Ecological Assessment for Marginal Reefs (BEAMR) method. Benthic communities were sampled at 9-, 12-, 18-, 24-, and 36-month post-deployment. Both spatial and temporal fluctuations of colonizing organisms were assessed, as well successional stages of contemporary organisms. Results indicated a typical colonization pattern where biotic cover and diversity increased on the AR system progressively from 9 to 36 months post-deployment; however, equilibrium was not attained at the functional group level due to frequent physical disturbances.

Key words: Artificial reef, community development, recruitment, macrobenthic communities, functional group.

Introduction

Beach nourishment can impact nearshore hardbottom through burial and subsequent habitat degradation. In response to increased beach nourishment activities, reef restoration projects have increased immensely over the last decade. In southeast Florida, the deployment of artificial reefs (ARs) as mitigation for nearshore habitat loss has become commonplace. To determine the success of ARs as appropriate nearshore habitat replacement, long-term AR colonization studies are essential to evaluate ecological processes and succession rates in shallow marine environments (Cummings 1994; Perkol-Finkel and Benayahu 2005; Thanner et al. 2006).

Understanding the spatial and temporal fluctuations of colonizing organisms is essential in forecasting benthic community development on ARs. Classic models of colonization suggest a directional successional sequence where pioneering species rapidly colonize the substrata in high numbers followed by a more diverse climax community (Bailey-Brock 1989; Cummings 1984; Palmer-Zwahlen and Aseltine 1994; Stanos and Simon 1980). Alternatively, Sutherland and Karlson (1977) suggest that classic succession cannot be evaluated with a new AR system as recruitment is determined by stochastic larval recruitment and the relative dominance of pioneer species. Additionally, biological habitat complexity is an important factor pertaining to larval settlement and species composition; thus, only after a temporal community shift will additional species have the opportunity to settle onto suitable habitat (Connell and Slather 1977).

In 2003, approximately 9 acres (3.6 ha) of limestone boulders were deployed in 5-m water depths between Florida Department of Environmental Protection (FEDP) R-monuments 101 and 125. The diameter of each boulder was 1.2-1.8 m. The limestone boulders, acquired from a Grand Bahamian quarry, were placed in a single layer on hardbottom areas covered with approximately 0.9 m of sand. The distance between individual boulders did not exceed 2.1 m. This study reports on the biotic community development and ecological succession patterns on this AR system located in Broward County, Florida (Fig. 1).

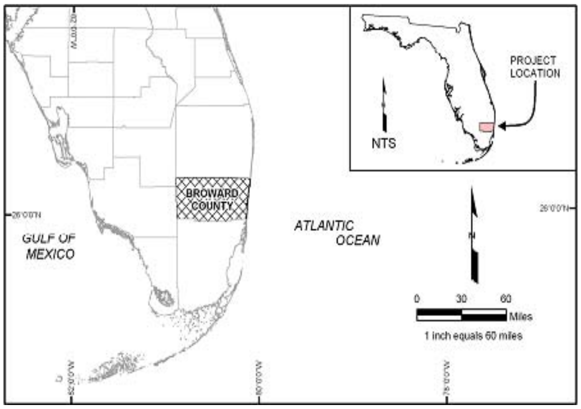
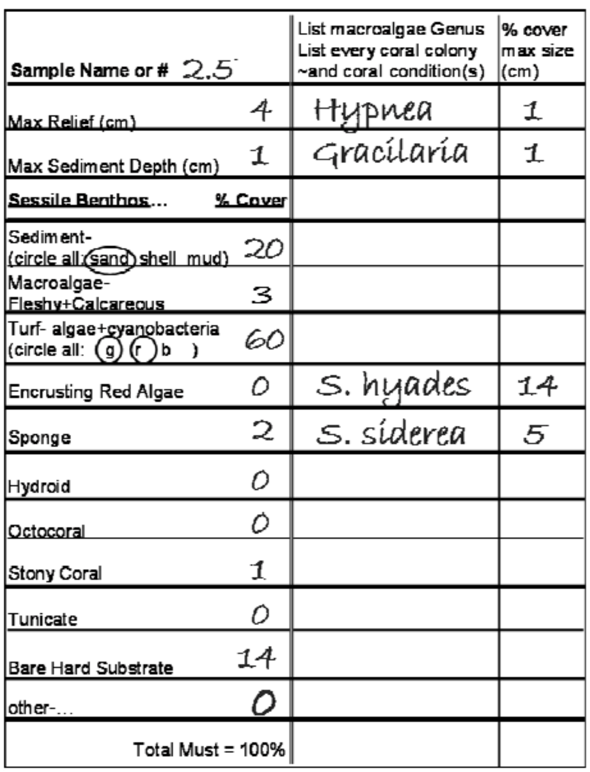


Figure 1: Study Location 25°58'50"N to 26°2'58"N.

Material and Methods

Benthic community composition was measured 9, 12, 18, 24 and 36 months after deployment using the Coastal Planning & Engineering, Inc. Benthic Ecological Assessment for Marginal Reefs (BEAMR) method (Lybolt and Baron 2006). A component of the BEAMR protocol includes a standardized BEAMR datasheet which prompts biologists to complete all fields *in situ* and strengthens quality assurance (Fig. 2).



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 2: Example of a completed BEAMR datasheet.

BEAMR samples three core characteristics in each quadrat: physical; abiotic and biotic percent cover; and coral density. Physical characteristics recorded are maximum relief in the quadrat (to nearest cm) and maximum sediment depth (to nearest cm). Visual estimates of planar percent cover of all sessile benthos are pooled to 19 major functional groups. Macroalgae percent cover data are reduced to genus-level percent cover (all genera with at least 1% cover). Each colony of octocoral and stony coral is identified and the maximum height or width is measured to the nearest cm. Octocoral individuals are identified to genus and stony coral individuals are identified to species whenever possible. The smallest size recorded is 1 cm, which includes individuals less than or equal to 1 cm. As with all non-consumptive surveys, BEAMR is necessarily constrained to visually conspicuous organisms with well defined discriminating characteristics for identification.

A total of 26 transects were sampled at each monitoring event. Prior to benthic data collection, stainless steel pins were installed on each transect at 0, 1, 5, 10, 15, 20, 25, 29, and 30 m to ensure permanent sampling sites. BEAMR was conducted on the north side of each 30-m transect using 12 replicate 1.0-m^2 quadrats (1 m x 1 m) every 2.5 m, starting at 0.0-m. The southwest corner of each BEAMR quadrat was aligned with the precise point of the sample location.

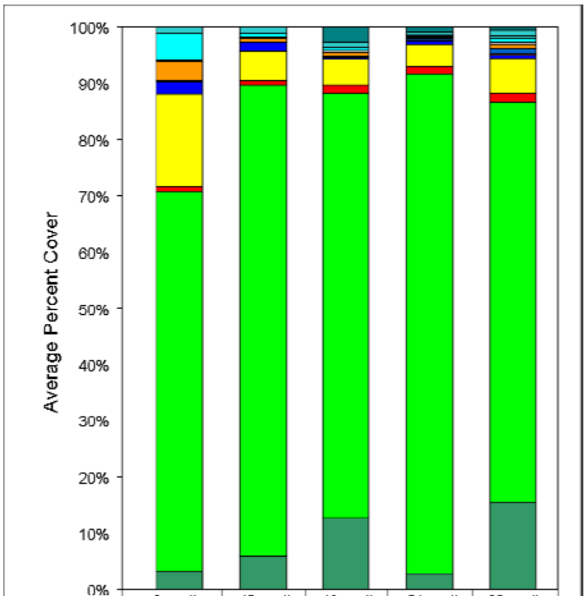
Non-parametric multivariate analyses were performed using PRIMER-E® (v6) (Clarke and Gorley 2006; Clarke and Warwick 2001). The biotic dataset was standardized by total and transformed by a log (X+1) transformation. A Bray-Curtis similarity matrix was also applied. Multi-dimensional scaling (MDS) ordinations and analysis of similarity (ANOSIM) routines were derived from the Bray-Curtis similarity matrix to determine if significant changes in the biotic assemblage occurred over time. Diversity indices were also comparatively analyzed.

Results

The biotic benthic community of the artificial reef was analyzed in order to determine recruitment patterns. Fig. 3 presents the biotic community on the artificial reef at the five discrete monitoring times. Turf algae was the dominant taxon over time. Of the faunal functional groups, sponges (16.4%), bryozoans (4.9%), tunicates (3.4%), and hydroids (2.2%) were highest during 9-month post-deployment but decreased sharply thereafter.

Sponge average percent cover decreased after 9 months and remained at approximately 5% for the remaining monitoring events. Scleractinian corals and *Millepora* spp. demonstrated the most consistent increase in abundance over time (Fig. 3).

A similarity percentages (SIMPER) analysis identified discriminating functional groups between each monitoring survey. Between 9-month and all subsequent monitoring surveys, bryozoans and macroalgae were the primary contributors to the dissimilarity (Fig. 4).



	9-month	12-month	18-month	24-month	36-month
Zoanthid	0.03	0.01	0.00	0.02	0.04
Wormrock	0.04	0.00	2.68	0.78	0.48
Sessile Worm	1.00	0.99	0.88	0.63	1.06
Millepora	0.02	0.03	0.04	0.15	0.25
Bryozoan	4.87	0.62	0.61	0.19	0.87
Bivalve	0.16	0.12	0.21	0.11	0.35
Barnacle	0.02	0.01	0.01	0.00	0.01
Anemone	0.01	0.05	0.05	0.00	0.03
Tunicate	3.44	0.87	0.68	0.25	0.80
Stony Coral	0.01	0.05	0.19	0.36	0.76
Octocoral	0.15	0.09	0.01	0.13	0.41
Hydroid	2.21	1.52	0.37	0.51	0.53
Sponge	16.44	5.10	4.56	3.89	6.16
Encr Red Algae	0.87	0.95	1.54	1.19	1.48
Turf	67.50	83.78	75.49	88.99	71.19
Macroalgae	3.25	5.80	12.68	2.80	15.59

Figure 3: Biotic community composition (n=26) at 9-, 12-, 18-, 24- and 36-month post-deployment.

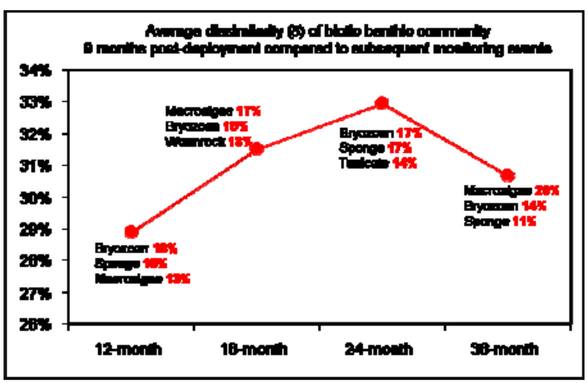


Figure 4: Average dissimilarity (δ) of the benthic community between the 9-month and subsequent monitoring events. Percentages of the major contributors to δ are listed at each event.

Initially bryozoan cover was relatively high at 4.9% but decreased rapidly 3 months later to less than 1% where it remained consistently thereafter. Macroalgae cover increased consistently until 24-month where percent cover decreased to less than 3% (refer to Fig. 3). However, macroalgae percent cover rebounded to almost 16% at the 36-month monitoring event. Stony coral became a dominant contributor (8.8%) to the community dissimilarity between 12 and 36 months.

Non-parametric multivariate analyses were applied to the functional group dataset to further examine changes in biotic composition over time. A MDS ordination with cluster overlay indicated a distinct difference between the biotic assemblage at 9-month post-deployment compared to subsequent monitoring intervals (Fig. 5). However, the functional group assemblages remained at least 75% similar throughout all monitoring surveys. Additionally, results of a 1-way ANOSIM revealed the 24-month post-deployment biotic community most closely resembled the 12-month community (R=0.273). This similarity correlates with the decrease in macroalgae cover from 12.7% at 18-month to 2.8% at 24-month (see Fig. 3). The 1-way ANOSIM also revealed the strongest biotic differences existed between 9- and 36-month assemblages (R=0.677), and between the 24- and 36-month assemblages (R=0.655).

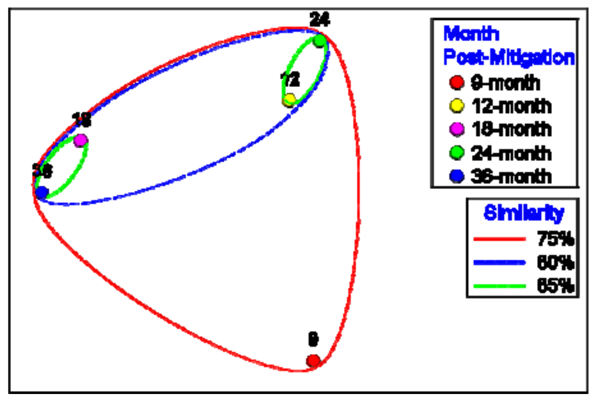


Figure 5: MDS ordination based on Bray-Curtis similarity of the biotic assemblages on the artificial reef at 9-, 12-, 18-, 24-, and 36-month post-deployment (stress = 0.1).

Diversity indices were calculated on the non-transformed data at each monitoring survey utilizing PRIMER (Table 1). The overall trend showed an increase in community diversity over time.

Table 1: Diversity indices of the biotic benthic community over time.

	No. of Functional Groups (S)	Margalef's (d)	Pielou's (J')	Shannon's H' (loge)	Simpson's (1-d)
9-month	16	5.93	0.69	1.92	0.86
12-month	15	5.87	0.68	1.85	0.85
18-month	16	6.03	0.72	1.99	0.86
24-month	14	5.62	0.71	1.87	0.84
36-month	16	5.72	0.77	2.12	0.90

The macroalgae community was analyzed to determine which genera were the initial colonizers and successive genera (Fig. 6). *Padina* spp. had the highest percent cover at 9-month (3.7%) while *Wrangelia* spp. dominated the substrate at 36-month (76.7%). *Dasya* spp. was most prevalent at 18-month (55.2%), which was the only winter survey.

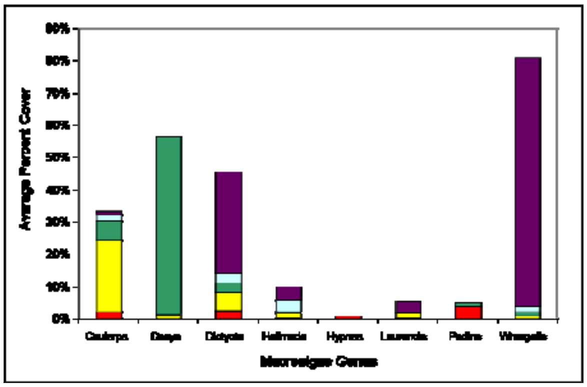


Figure 6: Average percent cover of dominant macroalgae genera over time.

The octocoral and stony coral community were also analyzed to determine the initial colonizers and successive genera (Fig. 7).

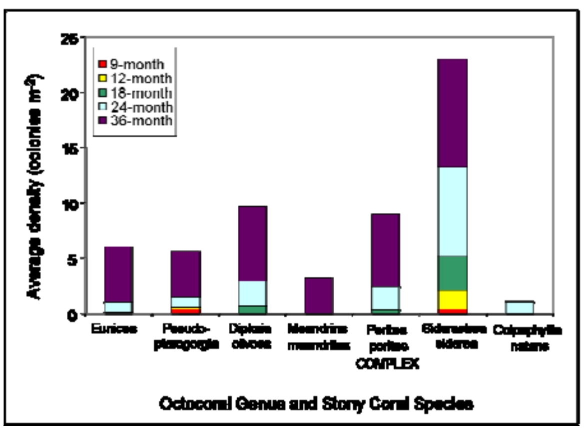


Figure 7: Density of dominant octocoral genera and coral species over time.

Overall two soft coral genera dominated with *Pseudopterogorgia* spp. initially recorded at the 9-month monitoring event while *Eunicea* spp. were recorded, at a very low density, during the 12-month monitoring event. Of the scleractinians, *Siderastrea siderea* was the only pioneer species recorded during the 9-month survey. *Siderastrea* spp. are considered one of the most stress tolerant species found in southeast Florida (Lirman et al. 2002). Four additional scleractinian species dominated during the subsequent monitoring events including *Diploria clivosa, Meandrina meandrites, Porites porites* complex, and *Colpophyllia natans*. *D. clivosa* and *P. porites* were initially recorded at the 18-month survey, while *C. natans* was first recorded at the 24-month event. *M. meandrites* was only documented during the 36-month post-deployment monitoring survey.

Discussion

The three year study of benthic community development showed a series of biotic changes over time. Initial colonizers on the Broward County AR system consisted of typical fouling organisms such as bryozoans, hydroids, sponges and tunicates. Bryozoans and hydroids are known fouling organisms which are often replaced over time in biotic succession (Abdel-Aleem 1957; Otsuka and Dauer 1982; Palmer-Zwahlen and Aseltine 1994). As the AR substratum was biologically altered and became more complex over time, the benthic community differentiated further. Results demonstrate that a large percentage of these pioneering organisms were replaced by more persistent and biologically complex organisms, *i.e.* scleractinians and octocorals, as the AR "soak" time increased. This ecological successional pattern is supported by overall increasing trends in diversity indices.

As of 36-month post-deployment, bryozoan percent cover decreased by 4%, tunicate percent cover decreased by 2.6%, sponge percent cover decreased by 10.4%, and hydroid percent cover decreased by 1.7%.

Fouling organisms are essential in elevating the habitat complexity of AR systems, thus making it suitable for coral settlement (Perkol-Finkel and Benayahu 2005; Schuhmacher 1988) and a large increase in octocoral and coral density over time was evident. However, while this increase may be attributed to scleractinians' preference to settle on a complex substratum rather than simple one (Carleton and Sammarco 1987; Guichard et al. 2001), coral larvae tend to remain inconspicuous upon settlement (Edmunds 2000). Hence, coral recruits present at the 9-month monitoring survey may not have been visually conspicuous and were, therefore, not accounted for until the 12-month post-deployment survey.

Results indicate a shift in community composition over time; however, a classic directional successional pattern was not evident. As the MDS ordination of the biotic community over time suggests, and the ANOSIM results confirm, a strong similarity between the 12- and 24-month assemblages occurred, while a strong difference was detected between the 24- and 36-month assemblages.

Considering that succession did not proceed in a classic directional pattern beyond 18 months post-deployment may be due to the frequent physical disturbances present in the area during 2005. Two hurricanes affected the Broward County coastline immediately preceding the 24-month monitoring survey. Both Hurricane Dennis and Katrina elevated wave frequency and heights resulting in extreme impacts to the nearshore coastline during July and August 2005. This included intense sand inundation and scouring. Eradication of the existing biota on the AR system may be correlated to these disturbances including the significant decrease in the total macroalgae percent cover. Macroalgae cover increased consistently until the 24-month monitoring event when it was then reduced by a total of 9.9%. Macroalgae cover rebounded post-hurricane by a total of 12.8%, as observed during the 36-month monitoring survey.

Unlike macroalgae, stony coral average percent cover increased consistently throughout this study suggesting that the high relief of the AR system may have provided protection from burial associated with storm activity.

In summary, community structure exceeded an initial developmental stage. Colonization of the AR system investigated in this study can be explained only partially in terms of classic directional succession as physical disturbances impeded progress to a possible climax community.

Acknowledgement
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