Proceedings of the 11th International Coral Reef Symposium, Ft. Lauderdale, Florida, 7-11 July 2008
Session number 24

Coral recruitment and community development: the Broward County artificial reef compared to adjacent hardbottom areas, five years post-deployment

A.R. Hannes and L.S. Floyd

Coastal Planning & Engineering, Inc., 2481 NW Boca Raton Blvd., Boca Raton, FL 33431, USA

Abstract. Artificial reefs have been utilized as a tool for reef conservation, rehabilitation and mitigation. The success of artificial reefs is measured by their ability to mimic the natural hardbottom environments which they are intended to replace. Despite the numerous artificial reef studies, there are few comparative studies between artificial and natural reefs. This study examines recruitment and subsequent development of coral communities on an artificial reef, and compares them to adjacent natural hardbottom in Broward County, Florida, USA. We compare artificial to natural hardbottom coral communities by examining abundance, diversity and size class distribution over time. Scleractinian and octocoral abundance, diversity and average size on the artificial reef was nearly equal to those on the natural nearshore hardbottom five years post-deployment. This study presents the data from each of the seven monitoring events and discusses the variables contributing to coral recruitment and community composition on artificial reefs.

Key words: recruitment, artificial reefs, mitigation

Introduction

Coral reefs worldwide are in a state of decline and experiencing considerable degradation (Wilkinson 2000). Artificial reefs are frequently utilized as a means of rehabilitating and restoring degraded natural reefs (Bohnsack and Sutherland 1985; Seaman 2002), and in recent years artificial reefs have been deployed to prevent or mitigate for impacts resulting from anthropogenic damage (e.g., coastal development, ship groundings, pollution, etc.) (Spieler et al. 2001).

A majority of artificial reef studies have focused on the early colonization stages of benthic communities, while relatively few have included long-term monitoring to evaluate the development of artificial reef communities beyond the initial successional phases. In spite of the considerable attention paid to artificial reefs, there is also a scarcity of comparative studies between artificial and natural reef communities (Perkol-Finkel and Benayahu 2005). If we are to successfully utilize artificial reefs as tools for rehabilitation and restoration of degraded marine habitats, then more emphasis must be placed on evaluating the ability of benthic artificial reef communities to mimic those found on the natural reef (Perkol-Finkel and Benayahu 2007).

The current study presents results of five years of monitoring following the deployment of a limestone boulder artificial reef in Broward County, Florida, USA. In particular, the scleractinian and octocoral communities on the artificial reef are compared to those found on adjacent natural hardbottom substrate. Scleractinian and octocoral abundance, diversity and size class distribution are compared between the artificial and natural reef communities for each of seven monitoring events in order to evaluate the success of the artificial reef in resembling the natural community it was intended to replace.

Materials and Methods

Artificial and natural reef monitoring protocol

Construction of the Broward artificial reef was completed September 2003. The artificial reef was constructed as one layer of limestone boulders (1.2-1.8 m in maximum diameter) placed in the nearshore zone in approximately 4 to 6 meters mean water depths. Coral communities were evaluated using the Coastal Planning & Engineering, Inc. Benthic Environmental Assessment for Marginal Reefs (BEAMR) method (Lybolt and Baron 2006). A total of 54 30-meter long permanent transects were established on the artificial reef and the adjacent natural hardbottom (27 artificial transects, 27 natural transects). BEAMR was conducted along each transect using 12 replicate 1.0-m^2 quadrats (1.0 m x 1.0 m) spaced along the transect every 2.5 meters, starting at 0.0 m. Scleractinian coral colonies were identified to species level and octocoral colonies

were identified to genus level. Size was measured to the nearest cm. All natural and artificial transects were monitored 9-, 12-, 18-, 24-, and 36-months after artificial reef deployment. A subset of artificial reef transects was also sampled 48-months post-deployment. The artificial reef transects were all surveyed again at 60-months post-deployment.

Data analysis

Using PRIMER (v6) (Clarke and Gorley 2006), a Bray-Curtis similarity coefficient matrix was derived based on scleractinian and octocoral abundance per meter area of hardbottom for artificial and natural sites for each monitoring period. This similarity matrix was used to track the scleractinian and octocoral community changes at the artificial and natural habitats over time. Non-parametric multidimensional scaling (MDS) ordinations were created from the similarity matrices for both scleractinian and octocoral datasets. Simple agglomerative hierarchical clustering (Cluster) and similarity profiles (SIMPROF) were performed on both datasets to determine statistically significant differences in community structure over time.

Using PRIMER (v6) (Clarke and Gorley 2006), species richness (*S*), Shannon diversity index (*H'*), Simpson index (*1-λ'*), Pielou's evenness index (*J'*), and Margalef's index (*d*) were calculated for artificial and natural sites for scleractinian and octocoral communities over time.

Coral size class structures for artificial and natural sites were analyzed by calculating the scleractinian and octocoral size class abundance per meter area of hardbottom for each monitoring period. Size class profiles were compared to track changes in artificial and natural areas over time.

Results

Scleractinian community

Results from the MDS show that the scleractinian community at the natural hardbottom sites has remained stable over time, whereas, the scleractinian community on the artificial reef has gradually become more similar to the natural hardbottom community from 9-months to 60-months post-deployment (Fig. 1). Results of the SIMPROF suggest that the there have been three significant shifts in the scleractinian community on the artificial reef from 9-months to 60-months post-deployment, at which time the scleractinian community at the artificial reef has attained 70% similarity to the natural hardbottom community (Fig. 1).

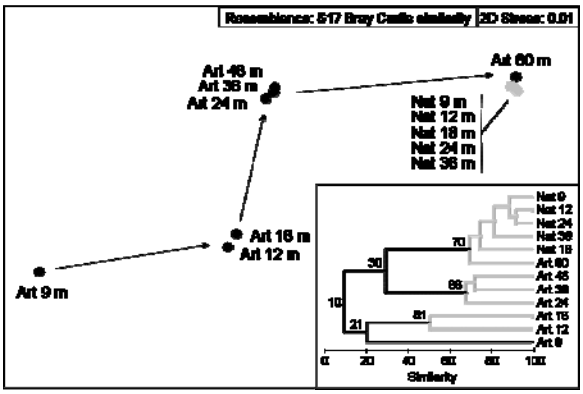

Figure 1: Two-dimensional MDS plot and corresponding SIMPROF dendrogram based on scleractinian abundance m^{-2} of hard substrate. Monitoring groups connected by grey lines cannot be significantly differentiated ($p \leq 0.05$).

Species richness at the natural sites remained between 11 and 14 species throughout monitoring (Table 1), whereas, species richness at the artificial reef climbed steadily throughout the duration of monitoring from 2 to 13. Diversity indices indicate that scleractinian diversity on the artificial reef increased steadily and by 60-months post-deployment, all four diversity indices surpass those of the natural reef (Table 1).

Table 1: Measures of scleractinian diversity on artificial reef and natural hardbottom.

	Scleractinians									
	Species Richness (S)		Shannon (H')		Simpson ($1-\lambda'$)		Pielou's (J')		Margalef's (d)	
Post-Deployment	Art	Nat	Art	Nat	Art	Nat	Art	Nat	Art	Nat
9-month	2	12	0.657	0.885	0.499	0.550	0.918	0.586	0.380	1.554
12-month	3	13	0.443	0.543	0.235	0.284	0.404	0.212	0.577	1.632
18-month	5	13	1.149	0.838	0.614	0.310	0.733	0.322	0.949	1.705
24-month	9	14	1.284	0.971	0.607	0.375	0.622	0.358	1.276	1.778
36-month	12	11	1.714	0.566	0.775	0.202	0.690	0.232	1.777	1.481
48-month	8	****	1.526	****	0.659	****	0.735	****	1.187	****
60-month	13	****	1.349	****	0.556	****	0.526	****	1.578	****

Scleractinian size class distribution at the natural hardbottom areas remained relatively unchanged from 9-months to 36-months post-deployment (Fig. 2). In general, the artificial reef scleractinian size class structure experienced steady increases in the three smallest size classes from 9-months to 48-months. Between 48-months and 60-months, the smallest size class (1-2 cm) experienced a five-fold increase and the 3-5 cm and 6-15 cm size classes experienced a three-fold increase, resulting in similar scleractinian size class structures at the artificial and natural habitats 60-months post deployment (Fig. 2).

Octocoral community

Results from the MDS show that the octocoral community at the natural hardbottom sites has remained stable overtime, whereas, the community on the artificial reef has gradually become more similar to the natural hardbottom community from 9-months to 48/60-months post-deployment (Fig. 3). Results from the SIMPROF indicate that by 48/60-

months post- deployment, the octocoral community on the artificial reef is 63% similar to that of the natural hardbottom sites (Fig. 3).

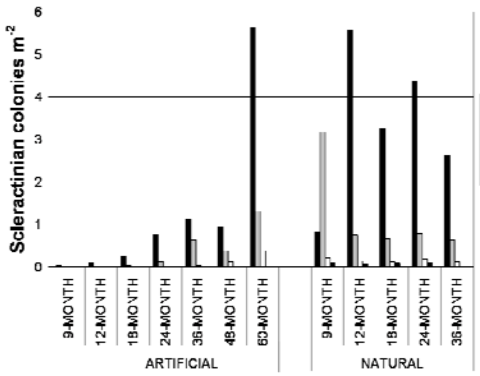

Figure 2: Scleractinian size class distribution on artificial reef and natural hardbottom for each monitoring period.

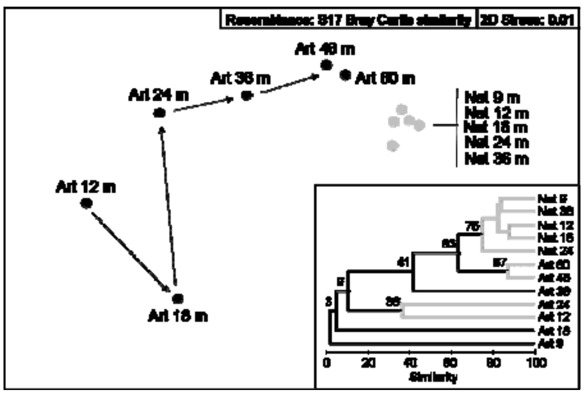

Figure 3: Two-dimensional MDS plot and corresponding SIMPROF dendrogram based on octocoral abundance m^{-2} of hard substrate. Monitoring groups connected by grey lines cannot be significantly differentiated (p≤ 0.05). Nine-month artificial reef monitoring event is not depicted in this figure, as the distance between it and all other subsequent events was too great to fit.

Species richness at the natural site remained stable throughout monitoring, between 8 and 11 (Table 2). Species richness at the artificial reef was 11 by the end of monitoring, equaling that of the natural sites. Diversity indices indicate that octocoral diversity on the artificial reef increased steadily, and by 60-months post-deployment resembled diversity observed on the natural reef (Table 2).

The artificial reef octocoral size class profile by 48/60-months post-deployment resembles that of the natural hardbottom, however, octocoral abundance was still greater at the natural sites than the artificial reef (Fig. 4). The abundance of octocoral recruits (1-5 cm) increased steadily throughout monitoring, while the level of recruitment on the natural hardbottom remained relatively constant.

Table 2: Measures of octocoral diversity on artificial reef and natural hardbottom.

	Octocorals									
	Species Richness (S)		Shannon (H')		Simpson's (1-λ)		Pielou's (J')		Margalef's (d')	
Post-Deployment	Art	Nat	Art	Nat	Art	Nat	Art	Nat	Art	Nat
9-month	****	8	****	[illegible]	****	0.757	****	[illegible]	****	[illegible]
12-month	3	10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.704	1.372
18-month	2	11	[illegible]	[illegible]	0.321	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
24-month	[illegible]	11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
36-month	[illegible]	8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
48-month	7	****	[illegible]	****	[illegible]	****	0.577	****	1.027	****
60-month	11	****	[illegible]	****	[illegible]	****	[illegible]	****	[illegible]	****

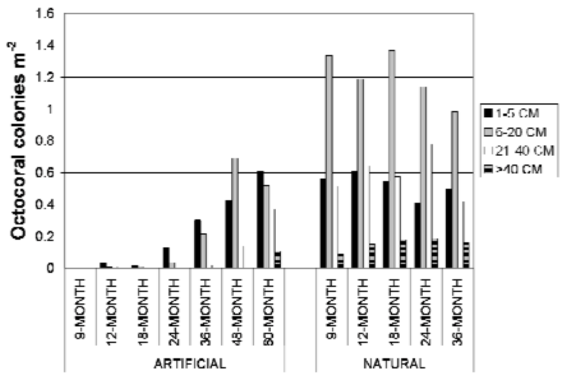

Figure 4: Octocoral size class distribution on artificial reef and natural hardbottom for each monitoring period.

Discussion

The Broward County artificial reef has succeeded in providing suitable habitat for recruitment and development of scleractinian and octocoral communities. These developing communities are becoming more similar in abundance, diversity and size class structure to the communities found on the adjacent natural hardbottom over time. As the MDS's suggest, by 60-months post-deployment, the scleractinian and octocoral communities on the artificial reef appear to be developing at slightly different rates, with the scleractinians and octocorals reaching 70% and 63% similarity, respectively, to the natural sites.

It is unclear why the scleractinian community appears to be more established, especially considering that only 5% of scleractinians on the natural hardbottom have reached reproductive size (>5 cm), while 30% of octocorals in the natural population are reproductive (>20 cm) (Bak and Engel 1979; Soong 1993; Gutiérrez-Rodríguez and Lasker 2004). It would be expected that this proportional difference in reproductive adults on the natural hardbottom would directly influence the level of recruitment onto the adjacent artificial reef. This reasoning seems to explain the observed trends until the last monitoring event: from 48-months to 60-months post-deployment, the scleractinian community at the artificial reef experienced a four-

fold increase in overall abundance and a five-fold increase in recruits (1-2 cm).

It is well understood that hurricanes or severe storms can reduce coral recruitment rates (Connell 1997); considering this in context of South Florida's active 2004 and 2005 hurricane seasons (corresponding to the 12-month and 24-month monitoring events) may explain the low recruitment levels leading up to 60-months post-deployment. A second explanation for the delay in high scleractinian recruitment levels could be related to time needed for organisms that produce chemical cues and substrate that enhance coral settlement to the artificial reef (e.g. crustose coralline algae) (Morse and Morse 1984; Vermeij and Sandin 2008).

Although this data shows that both the scleractinian and octocoral communities on the artificial reef are becoming increasingly similar to those on the natural hardbottom, structural differences between the low-relief natural nearshore habitat and the high-relief limestone boulders of the artificial reef are expected to lead to distinct climax communities (Baynes and Szmant 1989; Glasby and Connell 2001; Perkol-Finkel et al. 2006). The elevated surfaces of the limestone boulders will likely permit some species of corals to persist and grow that are unable to tolerate the ephemeral nature of the low-relief natural hardbottom. It is expected that the artificial reef will develop a climax community that will be more diverse than that on the natural hardbottom, and may include larger individuals and more colonies than found on natural hardbottom habitat. However, to date, the Broward artificial reef is succeeding as mitigation for natural hardbottom by harboring a coral community that continues to increase in resemblance to that of the adjacent natural hardbottom coral community.

Acknowledgements

We would like to thank Broward County Environmental Protection Department for their contribution to this work, as this data is part of the ongoing biological monitoring program for the Broward County Shore Protection Project—Segment III. We would also like to thank the Coastal Planning & Engineering, Inc. Marine Science and Biological Research Department for research and logistical support.

References

Bak RPM, Engel MS (1979) Distribution, abundance and survival of juvenile hermatypic corals (Scleractinia) and the importance of life history strategies in the parent community. Mar Biol 54:341-352

Baynes TW, Szmant AM (1989) Effect of current on the sessile benthic community structure of an artificial reef. Bull Mar Sci 44:545-566

Bohnsack JA, Sutherland DL (1985) Artificial reef research: a review with recommendations for future priorities. Bull Mar Sci 37:11-39

Clarke KR, Gorley RN (2006) PRIMER-E® (v6): User Manual/Tutorial. PRIMER-E Ltd, Plymouth, UK

Connell JH (1997) Disturbance and recovery of coral assemblages. Coral Reefs 16:S101–S113

Glasby TM, Connell SD (2001) Orientation and position of substrata have large effects on epibiotic assemblages. Mar Ecol Prog Ser 214:12-135

Gutiérrez-Rodríguez C, Lasker HR (2004) Reproductive biology, development, and planula behavior in the Caribbean gorgonian *Pseudopterogorgia elisabethae.* Invert Biol 123(1):54-67

Lybolt M, Baron R (2006) BEAMR (Benthic Ecological Assessment for Marginal Reefs): a preferred replacement for AGRRA and similar benthic assessment methods tailored for marginal reefs. Proc. 2006 ICRS European meeting, Bremen, Germany

Morse ANC, Morse DE (1984) Recruitment and metamorphosis of *Haliotis larvae* induced by molecules uniquely available at the surface of crustose red algae. J Exp Mar Biol Ecol 75**:**191–215

Perkol-Finkel S, Benayahu Y (2007) Differential recruitment of benthic communities on neighboring artificial and natural reefs. J Exp Mar Biol Ecol 340:25-39

Perkol-Finkel S, Shashar N, Benayahu Y (2006) Can artificial reefs mimic natural reef communities? The roles of structural features and age. Mar Environ Res 61:121-135

Perkol-Finkel S, Benayahu Y (2005) Recruitment of benthic organisms onto a planned artificial reef: shifts in community structure one decade post-deployment. Mar Env Res 59:79-99

Seaman W (2002) Unifying trends and opportunities in global artificial reef research, including evaluation. ICES J Mar Sci 59:S14-S16

Soong K (1993) Colony size as a species character in massive reef corals. Coral Reefs 12:77-83

Spieler R, Gilliam DS, Sherman R (2001) Artificial substrate and coral reef restoration: What do we need to know to know what we need. Bull Mar Sci 69(2):1013-1030

Vermeij MJA, Sandin SA (2008) Density-dependent settlement and mortality structure the earliest life phases of a coral population. Ecology 89(7):1994-2004

Wilkinson CR (2000) Executive summary. In: Wilkinson CR (ed) Status of coral reefs of the world: 2000. Australian Institute of Marine Science, Townsville, Australia pp 7-19