The Impact of Artificial Reefs on Fish Diversity and Community Composition in Isla Ratones, Western Puerto Rico

ILSE M. SANDERS[1] and IDELFONSO RUIZ[2]

[1] *Interamerican University of Puerto Rico, Department of Biology, P.O. Box 5100, San Germán, Puerto Rico 00683*

[2] *Department of Marine Sciences, University of Puerto Rico at Mayagüez, Mayagüez, Puerto Rico 00681- 9013*

ABSTRACT

Artificial reefs have been used for purposes of habitat restoration, to provide structure in damaged areas or to enhance total reef area. Yet the ecological function that these reefs may fill is still not well defined. Of specific interest is how such reefs interact with adjacent habitats to affect overall fish community composition, and eventually production. During the first 10 months following deployment of small artificial reefs at Isla Ratones, Cabo Rojo, Puerto Rico, we compared fish diversity and community composition with fish on these reefs to those in the adjacent natural reef and sea grass beds. We conducted visual censuses by swimming transects over and around 10 artificial reefs, the shallow (<1.5m) and deep (>1.5m) natural reef and sea grass bed, of $15m^2$, $17m^2$ and $20m^2$, respectively. Species richness, evenness, density and mean size were compared. We observed 39 fish species in the artificial reefs, the most frequent being: *Acanthurus chirurgus*, *Chaetodon capistratus*, *Lutjanus apodus*, *Ocyurus chrysurus* and *Stegastes leucostictus*. Artificial reefs had a significantly greater number of species. Mean number of individuals/transect were significantly greater on artificial reefs, while natural reefs had higher densities than observed in sea grass. Size composition and abundance data indicate that artificial reefs were being used preferentially as nursery areas, relative to the natural reef, for 6 out of the 7 most abundant species found on the artificial reefs. Our results indicate that artificial reefs are being used principally as fish nursery habitat within the sea grass beds, providing the fish structure, rugosity, protection and food, and increasing the area where they can establish.

KEY WORDS: Artificial reefs, fish, nursery habitat

El Impacto de Arrecifes Artificiales sobre la Diversidad y la Composición de Comunidades de Peces en Isla Ratones, Puerto Rico

Arrecifes artificiales han sido usados para propósitos de restauración de habitáculo, para proveer estructura en áreas dañadas o para aumentar el área total del arrecife. Pero la función ecológica que estos arrecifes pudieran llenar todavía no está bien definida. De interés es cuánto estos arrecifes interactúan con los habitáculos adyacentes para afectar la composición general de la comunidad de peces, y eventualmente su producción. Durante los primeros 10 meses siguientes a la colocación de pequeños arrecifes artificiales en Isla Ratones, Cabo Rojo, Puerto Rico, nosotros comparamos diversidad de peces y composición de la comunidad de peces en estos arrecifes a aquellos en el arrecife natural adyacente y praderas de hierbas marinas. Llevamos a cabo censos visuales nadando transeptos por encima y alrededor de 10 arrecifes artificiales, parte llana (<1.5m) y parte profunda (>1.5m) del arrecife natural y pradera de hierba marina, de $15m^2$, $17m^2$ y $20m^2$, respectivamente. Riqueza de especies, uniformidad, densidad y tamaño promedio fue comparado. Observamos 39 especies de peces en los arrecifes artificiales, siendo los más frecuentes: *Acanthurus chirurgus*, *Chaetodon capistratus*, *Lutjanus apodus*, *Ocyurus chrysurus* y *Stegastes leucostictus*. Los arrecifes artificiales tenían significativamente mayor número de peces. El número promedio de individuos/transepto fue significativamente mayor en los arrecifes artificiales, mientras que los arrecifes naturales tenían densidades mayor que observadas en hierbas marinas. Datos de composición de tamaño y abundancia indican que arrecifes artificiales estaban siendo usados preferentemente como áreas de crianza, relativo al arrecife natural, para 6 de las 7 especies más abundantes encontradas en los arrecifes artificiales. Nuestros resultados indican que los arrecifes artificiales están siendo usados principalmente como habitáculo de criadero de peces proveyéndoles estructura, rugosidad, protección y alimento, y aumentando las áreas donde pueden establecerse.

PALABRAS CLAVES: Arrecifes artificiales, peces, criadero, habitáculo

INTRODUCTION

Isla Ratones is a small (0.43 ha) island located on the west coast of Puerto Rico, approximately 1 km offshore. The island is a protected area maintained by the Department of Natural and Environmental Resources and serves as a locally important tourist destination. However, aerial photos reveal that during the period 1936 - 1998 the island lost 45% of its land area due to the loss of a natural barrier. This prompted a community-based restoration project focused on the northwest side of the island. The second stage of the project was carried out during the summer of 2006 by planting 400 mangrove seedlings and placing 10 artificial reefs (Taino Reefs®). These reefs were deployed on the northwest side of the island along a channel between adjacent sea grass beds (Figure 1) primarily to detain erosion and sedimentation. On these structures small colonies of corals were implanted to create a habitat attractive to invertebrates and fish, and to eventually serve as an underwater interpretative trail. Deployment of these reefs, however, provided an opportunity to study the role of artificial reefs in an ecological context.

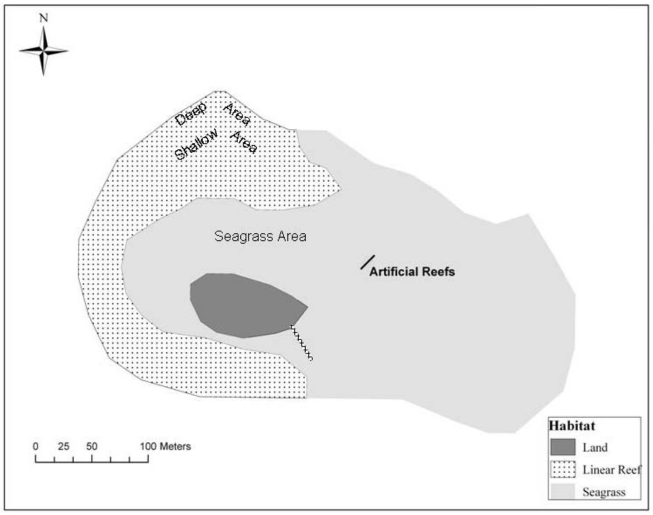

Figure 1. Isla Ratones showing the dock and the deep, shallow, seagrass, and artificial sampling areas.

Artificial reefs have been used for purposes of habitat restoration, to provide structure in damaged areas or to enhance total reef area. Yet the ecological function that these reefs may fill is still not well defined. Of specific interest is how such reefs interact with adjacent habitats, such as sea grass beds and natural reefs, to affect overall fish recruitment and community composition. Sea grass beds function as a nursery for juveniles of different reef fishes, many of them commercially important (Cocheret *et al.* 2002, Nagelkerken *et al.* 2002, Nagelkerken and van der Velde. 2003). This role is enhanced if additional structure is available within the sea grass matrix (Appeldoorn *et al.* 1997, Hill 2001). Artificial reefs within sea grass could provide fish additional structure, supporting a larger total area for settlement and shelter for enhanced survival. As the structures become colonized, they can also provide food and sustain fish production.

During the first 10 months following deployment of the artificial reefs, we compared the fish community composition and diversity on these reefs to those in the adjacent natural reef and sea grass beds. Our objectives were to study fish recruitment on the artificial reefs and to compare the kinds and frequency of species with areas on the sea grass beds and the adjacent natural reef. We wanted to know whether these artificial reefs could serve as a nursery and enhance fish recruitment.

METHODS

Fish Counts

The ten artificial reefs, 0.5 m in width and 1 - 1.5 m in length, were positioned east to west and spaced at one meter intervals, covering an area of approximately 15 m^2. Fish counts were made by two observers on the artificial reefs, the natural reef-shallow area (< 1 m), the natural reef-deep area (> 1.5 m) and sea grass (Figure 1). Fish in and around each artificial reef structure were observed for five minutes. Transects over the natural reef at both shallow and deep areas each covered approximately 17 m^2, those on the sea grass beds covered 20 m^2. We did 7 transects on the artificial reefs and natural reef-shallow area, and four transects on the natural reef- deep area and sea grass.

Fish were identified by species and assigned a size class (SCL) based on total length: SCL 1: 1 < 5 cm; SCL 2: 6 - 10 cm; SCL 3:11 - 16 cm and SCL 4: 16 - 20 cm. Number of individuals, site, habitat, and date was also recorded. The study was done during 10 months between August 2006 and May 2007 with the following number of transects: seven on the artificial reefs, seven on the natural reef-shallow area, four on the natural reef-deep area, and four on the sea grass beds.

Data Analysis

For species richness (number of species/m^2) data were tested for homogeneity of variance (Levene's test) and normality (Kolmogorov-Smirnov). ANOVA was performed on the four habitat types followed by a post-hoc Tukey test. For species diversity and evenness, data were used to calculate the Shannon-Weaver Diversity Index, using evenness as expressed by Pielou (1966). For density, the number of fish/m^2 was square-root transformed to normalize the data, and were then tested for homogeneity of variance (Levene's test). ANOVA was performed on the four habitats followed by a post-hoc Tukey test. Least-squares regression was used to analyze the relationship of total abundance to frequency of occurrence.

RESULTS

We found 39 species in the artificial reefs, 28 in the natural reef-deep area, 22 in the natural reef-shallow area, and 16 in the sea grass (Table 1). There was a significant difference in the mean number of species between habitat types ($F = 20.6$, $p < 0.000$); the artificial reefs had significantly greater number of species than the other three sites (Tukey, $p = 0.05$).

Diversity indices for fishes in the four habitats ranged from 0.97 to 1.36 (Table 2). Highest diversity was found at the deep area of the natural reef, followed by the artificial reefs. Evenness was highest in the deep area of the natural reef ($J = 0.94$) and was similar between the other three habitats ($J = 0.81 - 0.84$).

Fish density (number/m^2) was significantly different between the sites ($F = 9.05$, $p = 0.001$) (Table 3).

The artificial reefs had a significantly higher number of individuals than the other sites (Tukey, $p = 0.05$).

For the smallest size class (1<5cm), fish are more abundant in the artificial reefs than in the shallow and deep areas of the natural reef (Table 4). In fact, for 5 of 7 of the most abundant or frequently observed species, fish in the smallest size class were only observed on the artificial reefs. Within the artificial reefs, fish of Size Class 1 were equal to or more abundant than the other size class for six of the seven species. Only for *Ocyurus chrysurus* was the abundance greater in Sizes Classes 2 (6 - 10 cm) and 3 (11 - 16 cm).

Table 1. Mean number of species/m^2, standard deviation, and number of transects for four habitats: artificial reefs, natural reef-deep area, sea grass and natural reef-shallow area.

Habitats	Number of species/m^2	Standard Deviation	Number of Transects
Artificial Reefs	1.22	0.30	7
Natural Reef-deep	0.63	0.15	4
Sea grass	.46	0.13	4
Natural Reef-shallow	.41	0.12	7

Table 2. Shannon-Weaver diversity index (H), and evenness (J) for fish in sea grass, natural reef-shallow area, natural reef-deep area and artificial reefs.

Habitat	Diversity H	Evenness J
Sea grass	0.97	0.81
Natural Reef Shallow-area	1.13	0.84
Artificial Reef	1.29	0.81
Natural Reef Deep-area	1.36	0.94

Table 3. Fish density by transect for artificial reefs, natural reef-deep area, natural reef-shallow area and sea grass

Total number of individuals/ transect/ m^2			
Artificial Reefs	Natural Reef >1.5m	Natural Reef <1m	Sea Grass
6.27	1.29	3.00	2.25
8.20	1.53	1.53	1.45
1.27	2.12	1.53	1.45
5.93	2.00	1.18	0.55
3.33		0.47	
9.20		2.00	
5.20		2.00	
mean = 5.63	**mean = 1.73**	**mean = 1.67**	**mean = 1.42**

Table 4. Number of individuals/transect by size class for the most abundant/frequent species observed on artificial reefs, and shallow and deep areas of natural reef. Size classes: 1: 1<5 cm, SCL 2: 6-10 cm, SCL 3:11-16 cm, and SCL 4: 16-20 cm.

Species	Number of individuals/transect Size Class				Zone
	1	2	3	4	
Acanthurus chirurgus	6.3	6.0	1.1		Artificial
					Shallow
		11.0	1.0		Deep
Stegastes leucostictus	4.7	0.6			Artificial
					Shallow
					Deep
Ocyurus chrysurus	1.9	4.6	2.4	0.1	Artificial
		1.0			Shallow
		1.0			Deep
Chaetodon capistratus	4.1	0.9			Artificial
		1.0			Shallow
	4.0				Deep
Acanthurus coerulus	2.0	2.0			Artificial
					Shallow
		4.0	3.0		Deep
Stegastes variabilis	3.0				Artificial
	1.0	1.0			Shallow
					Deep
Lutjanus apodus	3.0	2.3	2.0		Artificial
			4.0		Shallow
		2.0			Deep

The frequency of observation of fishes on the artificial reefs is given in Table 5. Only five species were observed on all occasions: *Acanthurus chirurgus*, *Lutjanus apodus*, *Ocyurus chrysurus*, *Chaetodon capistratus*, and *Stegastes leucostictus*. These species, except *Stegastes leucostictus*, were also found in the natural reef at both shallow and deep areas. In total, 72% of the species found in the artificial reefs were also found in the shallow or deep natural reef. Other frequently observed species on artificial reefs were blue tangs, sergeant majors, redfin parrotfish, cocoa damselfish, and spotlight parrotfish. Of the total of 39 species, 13 (33%) were only observed once.

The 39 fish species observed on the artificial reefs totaled 592 individuals during the sampling period. The number of individuals observed over all sampling periods was generally related to frequency of occurrence (Figure 2; $R^2 = 0.77$, $p < .001$). *Haemulon aurolineatum* was atypical in that it was abundant but not frequent, occurring in two large schools (n = 47, in 2/7 transects).

Table 5. Number of times species were observed on artificial reefs out of a total of seven survey dates

Common Name	Species	Number of dates observed
Doctorfish	*Acanthurus chirurgus*	7
Foureye	*Chaetodon capistratus*	7
Schoolmaster	*Lutjanus apodus*	7
Yellowtail Snapper	*Ocyurus chrysurus*	7
Beaugregory	*Stegastes leucostictus*	7
Blue Tang	*Acanthurus coeruleus*	6
Sargeant Major	*Abudefduf saxatilis*	6
Redfin Parrotfish	*Sparisoma rubripinne*	6
Cocoa Damselfish	*Stegastes variabilis*	6
Spotlight Parrotfish	*Sparisoma viride*	6
Porcupinefish	*Diodon hystrix*	5
Dusky Damselfish	*Stegastes adustus*	5
Ocean Surgeon	*Acanthurus bahianus*	4
Banded Buterflyfish	*Chaetodon striatus*	4
Princess Parrotfish	*Scarus taeniopterus*	4
Red Hind	*Epinephelus guttatus*	3
Spotted Goatfish	*Pseudupeneus maculatus*	3
Greenblotch Parrotfish	*Sparisoma atomarium*	3
Redtail Parrotfish	*Sparisoma chrysopterum*	3
Yellowfin Mojarra	*Gerres cinereus*	2
Tomtate	*Haemulon aurolineatum*	2
Puddingwife	*Halichoeres radiatus*	2
Bluestriped Grunt	*Haemulon sciurus*	2
Longfin Damselfish	*Stegastes diencaeus*	2
Threespot Damselfish	*Stegastes planiforns*	2
Bucktooth Parrotfish	*Sparisoma radians*	2
Sea Bream	*Archosargus rhomboidalis*	1
Porkfish	*Aniostremus virginicus*	1
Bar Jack	*Caranx ruber*	1
Squirrelfish	*Holocentrus adscensionis*	1
French Grunt	*Haemulon flavolineatum*	1
Spanish Grunt	*Haemulon macrostomum*	1
Stripped Grunt	*Haemulon striatum*	1
Longspine Squirrelfish	*Holocentrus rufus*	1
Mutton Snapper	*Lutjanus analis*	1
Mahogany	*Lutjanus mahogoni*	1
French Angelfish	*Pomacanthus paru*	1
Bluestriped Lizardfish	*Synodus saurus*	1
Red Lizardfish	*Synodus synodus*	1

DISCUSSION

On an area basis, artificial reefs supported a greater number of species and much higher abundances than were found in the other habitats. Similarly, Prada (2002) found small patch reefs to contain more species, a proportionally greater abundance of smaller individuals, and fewer predators than on large patch reefs or continuous reefs. These results were thought to be due to a number of factors related to settlement dynamics, scale effects and seascape interactions (Prada 2002, Prada *et al*. In press). The same arguments may be applied to the case of the artificial reefs. Being placed within a surrounding matrix of sea grass, the artificial reefs may have attracted species that use either reef or sea grass habitat, as well as those that utilized both, e.g., grunts that shelter on the reef during the day, but feed in sea grass at night.

Of particular importance, most of the species observed on the artificial reefs were also observed on the natural reef, and for those species for which there were sufficient data, there was a clear indication that the artificial reefs supported smaller size individuals. This suggests that the artificial reefs may be serving as nursery areas that eventually may feed into the natural reef. For example, both the surgeonfishes *Acanthurus chirurgus* and *A. coerulus* displayed similar patterns in that individuals of the smallest size class were only found on artificial reefs. Individuals in the next two larger size classes were found in progressively decreasing densities on the artificial reefs while they began to appear on the natural reef. Additionally, data suggest that some species were resident upon the artificial reefs following colonization before eventually leaving with increasing size. We found *Acanthurus chirurgus* of size classes 1 and 2 (1 - 10 cm) in all sampling periods on the artificial reefs, but of size class 3 (11 - 16 cm) only in the more recent transects of January and March 2007. This shift to include larger sized fish could indicate that some of the small individuals found previously in the fall, stayed and grew around the artificial reefs. These patterns mirror similar patterns recorded on natural habitats. In La Parguera, Puerto Rico, small and large juveniles of *A. chirurgus* are commonly found in shallow inshore seagrass beds, especially associated with structure, before moving more offshore into fore and backreef areas of high and low relief coral (Aguilar 2004, Cerveney 2006).

In similar manner, the smallest size of *Lutjanus apodus* were only found during the first transect, 30 days after positioning the artificial reefs, with larger individuals being found in subsequent samplings, again suggesting residence and growth. In this species, the artificial reefs could substitute for preferred early juvenile habitat of red mangrove roots, which offer protection and shade, or they could mimic inshore backreef high relief corals that also serve as natural settlement sites (Cerveney 2006). Larger juveniles are known to shift their distribution to forereef habitats further offshore.

In contrast, *Ocyurus chrysurus* could be using the reefs as both nursery and permanent habitat since all size classes were found (1 - 20 cm). Juvenile yellowtails inhabit sea grass and the larger ones, upon reaching maturity may stay in sea grass, although typically they move to the shallow back reef and then fore reef with increasing size (Nagelkerken and van der Velde 2003, Aguilar 2004).

Although our study included only 10 artificial reefs that were not positioned according to a specific experimental design, their deployment gave us an opportunity to study fish recruitment on new structure. The data obtained over a 10 month period suggest that artificial reefs could augment important nursery habitat for some species. We found evidence for greater abundances, smaller sizes, and sustained residence but with a shift away from the artificial reefs as size increased. Artificial reefs could be used to increase nursery habitat for selected species if their deployment was designed to mimic the natural system, i.e., by matching the early juvenile habitat and shelf location as found for example by Lindeman *et al.* (1998), Nagelkerken and van der Velde (2003), Aguilar (2004) and Cerveney (2006).

ACKNOWLEDGEMENTS

We thank Rubén Flores and Freddyson Martínez for their help in field work, and Richard Appeldoorn for revising the manuscript. This work was funded by grant # 1002C of the program "Gulf of Mexico Community-based Restoration Partnership", Gulf of Mexico Foundation, in collaboration with "Comité Caborrojeños Pro Salud y Ambiente, Inc" and Interamerican University of Puerto Rico at San Germán.

LITERATURE CITED

Aguilar-Perera, J.A. 2004. *Coastal Habitat Connectivity of Reef Fishes from Southwestern Puerto Rico.* Ph.D. Dissertation, University of Puerto Rico -Mayagüez, Puerto Rico. 143 pp.

Appeldoorn, R.S., C.W. Recksiek, R.L. Hill, F.E. Pagan, G.D. Dennis. 1997. Marine protected areas and reef fish movements: the role of habitat in controlling ontogenetic migration. *Proceedings of the 8th International Coral Reef Symposium* **2**:1917-1922.

Cerveny, K. 2006. Distribution patterns of reef fishes in southwest Puerto Rico, relative to structural habitat, cross-shelf location, and ontogenetic stage. M.S. Thesis, University of Puerto Rico - Mayagüez, Puerto Rico. 162 pp.

Cocheret de la Morinière E, B.J.A. Pollux, I. Nagelkerken, G. van der Velde. 2002. Post-settlement life cycle migration patterns and habitat preference of coral reef fish that use seagrass and mangrove habitats as nurseries. *Estuarine and Coastal Shelf Science* **55**: 309–321.

Hill, R.L. 2001. *Post-settlement Processes and Recruitment Dynamics in the White Grunt, Haemulon plumieri Lacépède (Pices; Haemulidae).* Ph.D. Dissertation, University of Puerto Rico -Mayagüez, Puerto Rico. 152 pp.

Lindeman, K.C., G.A. Diaz, J.E. Serafy, and J.S. Ault. 1998. A spatial framework for assessing cross-shelf habitat use among newly settled grunts and snappers. *Proceedings of the Gulf and Caribbean Fisheries Institute* **50**:385-416.

Nagelkerken, I., C.M. Roberts, G. van der Velde, M. Dorenbosch, M.C. van Riel, E. Cocheret de la Morinière, P.H. Nienhuis. 2002. How important are mangroves and seagrass beds for coral-reef fish? The nursery hypothesis tested on an island scale. *Marine Ecology Progress Series* **244**:299–305.

Nagelkerken, I. and G. van der Velde. 2003. Connectivity between coastal habitats of two oceanic Caribbean islands as inferred from ontogenetic shifts by coral reef fishes. *Gulf and Caribbean Research* **14**:43–59.

Prada, M.C. 2002. *Mapping of Benthic Habitats off Southwest Puerto Rico Using Side-scan Sonar Technology.* Ph.D. Dissertation, University of Puerto Rico -Mayagüez, Puerto Rico.

Prada, M.C., R.S. Appeldoorn, and J.A. Rivera. [In press]. The effects of minimum map unit in coral reefs maps generated from high resolution side scan sonar mosaics. *Coral Reefs.*