Effects of Refuge Size and Complexity on Recruitment and Fish Assemblage Formation on Small Artificial Reefs

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ABSTRACT

There have been a number of natural and artificial reef studies examining possible correlation's between refuge size and complexity and the associated fish assemblages. Results of these studies have been contradictory indicating possible site dependent differences. We examined the role of refuge size and complexity in fish recruitment and the formation of associated fish assemblages, using artificial reef modules, at two different depths off Fort Lauderdale, Florida, USA. The 1 m^3 reef modules (Swiss Cheese reefs) were constructed of poured concrete with 12 tunnels running through the block, six tunnels in each direction perpendicular to each other. Twenty replicates were constructed of each of three different refuge configurations, 12 large tunnels (square opening, 15 cm per side), 12 small tunnels (7.5 cm per side) or six large and six small tunnels. Ten replicates of each reef design were deployed at each depth (7 m and 20 m) on sandy substrate. Significant differences were found for recruits (fishes 0 - 5 cm TL), total fish abundance, and species richness between refuge configurations as well as depths. Additionally, this study was designed, in part, to replicate work done previously by others, in the Caribbean examining the effects of refuge size on fish abundance and species richness. Differences were found between the studies. This may be due, in part, to differences in local fish species composition and population structure.

KEY WORDS: Refuge, site dependent differences, substrate

INTRODUCTION

Many aspects of artificial structure have been examined in efforts to identify ways to increase fish abundance and diversity, improve catch rates of targeted species, manipulate habitats, and restore damaged coral reefs (for references see: Bohnsack and Sutherland 1985, Bohnsack 1990, Bohnsack et al. 1991, Seaman 1997, Spieler et al. in press). A number of natural and artificial reef studies examined possible correlation's between refuge size and complexity and the associated fish assemblages (Molles 1978, Gascon and Miller 1982, Roberts and Ormond 1987, Brock and Norris 1989, Hixon and Beets 1989, Eklund 1996, Friedlander and Parrish 1998, Spieler 1998, Spieler in press, Authors unpublished). Results of these studies have been contradictory indicating possible site dependent differences. We examined the role of refuge size and complexity in fish recruitment and the formation of associated fish assemblages, using artificial reef modules, at two different depths off Fort Lauderdale, Florida.

MATERIALS AND METHODS

Experimental Design

This research focused on three central hypotheses:

i) the recruitment and aggregation of a diverse assemblage of fishes to artificial reefs can be effected by the size of the refuges available,
ii) diverse refuge sizes are superior to uniform refuge sizes for the recruitment and aggregation of a diverse assemblage of fishes to an artificial reef, and
iii) deployment site selection (i.e. depth) will effect the formation and maintenance of the fish assemblage on a small artificial reef.

Briefly, the experimental design consisted of comparing fish abundance, species richness, and species composition among three groups of reefs (10 Swiss Cheese reefs each) with either large holes only (Large refuge reefs), small holes only (Small refuge reefs), or large and small holes (Mixed refuge reefs), at two different depths. The hypotheses above allowed us to make three specific predictions that were statistically verifiable:

i) Artificial reefs with large refuges will have different fish abundance, species richness, and species composition than reefs with small refuges
ii) Reefs with mixed sized refuges will have greater fish abundance, and species richness than either large refuge reefs or small refuge reefs, and
iii) Reefs deployed at different depths will have different fish abundance, species richness, and species composition.

Construction and Deployment

The reefs (Swiss Cheese reefs) were constructed at the CSR Rinker Concrete Plant, Pembroke Pines, Florida using waste concrete (concrete remaining in trucks when returning from a job) poured into reusable molds made from pressure treated plywood. Tunnels were formed in the concrete using wooden dowels of either 3.5 cm square or 10 cm square wrapped in 2 cm thick Styrofoam. When assembled, this form contained approximately 1 m^3 of poured concrete with 12 tunnels (refuges) running through the block, six tunnels in each direction perpendicular to each other (Figure 1). Twenty replicates were constructed of each of three different refuge configurations, 12 large refuges (square opening, 15cm per side), 12 small refuges (7.5 cm per side) or six large and six small refuges. Ten replicates of each reef design were deployed at each of two depths (7 m and 20 m) on sandy substrate. The deep site was approximately one kilometer east of the shallow site. Thirty reefs were deployed at each site, in sandy substrate, with 35 meters between each reef.

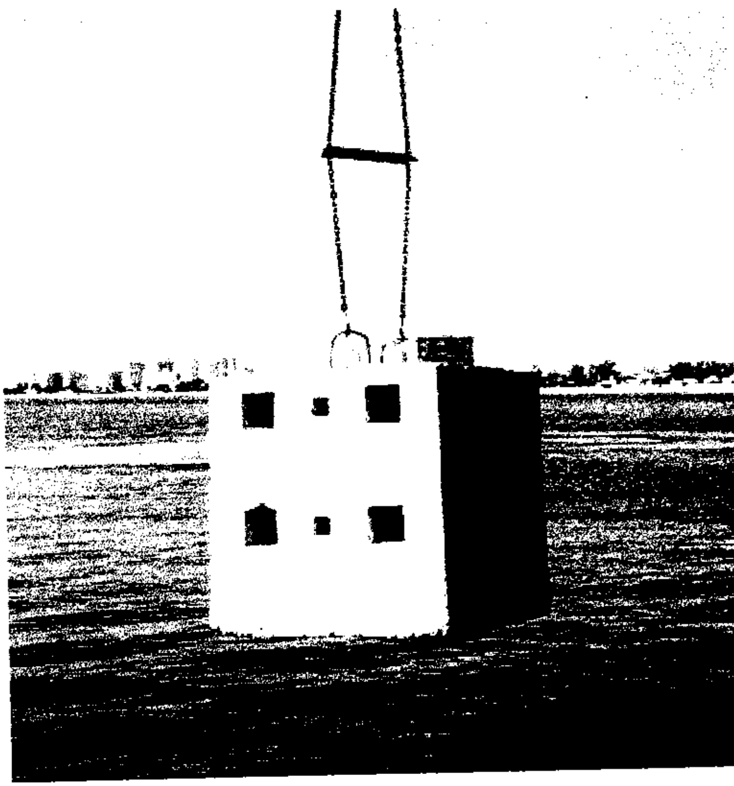

Figure 1. Mixed refuge size reef being deployed offshore Broward County, Florida, USA

Monitoring

In an effort to examine seasonal differences the reefs were monitored approximately quarterly (eight times) from October 1996 through January 1999. Divers, using SCUBA, counted, and recorded census data on slates marked on one edge with five size intervals: < 5, 5 - 10, 10 - 20, and 20+ cm to aid in length estimation. The reefs are small enough to allow for an accurate total count without sub-sampling. Species, numbers of fish per species, and estimated total length, by size class, of all fishes within 1 m of each reef (18 m^3, total volume including reef) were recorded. The size classes were also used to calculate fish biomass on the reefs. The mean total length (TL) for each size class was used in length-weight equations published by Bohnsack and Harper (1988). When a length-weight equation for an identified species was not available, the equation for a congeneric was used.

Data were analyzed with non-parametric analysis of variance techniques using Statistical Analysis Systems (SAS) software (SAS Institute Inc., Cary, NC, USA) (PROC GLM of ranked data Kruskal-Wallis k-sample test, and a Student-Newman-Keuls test between means).

RESULTS

Refuge Size

With the following exceptions, little difference was noted in the number of fishes (all species combined) among the three refuge sizes for any size class. At both the shallow and deep sites there were more 20+ cm fish and more total fish (all sizes combined) associated with large or mixed refuge reefs than small refuge reefs ($p < 0.05$, ANOVA/SNK) (Figure 2, 3). At the shallow site there were also more juvenile fishes (< 5 cm TL) on the large refuge reefs than those with small refuges ($p < 0.05$, ANOVA/SNK).

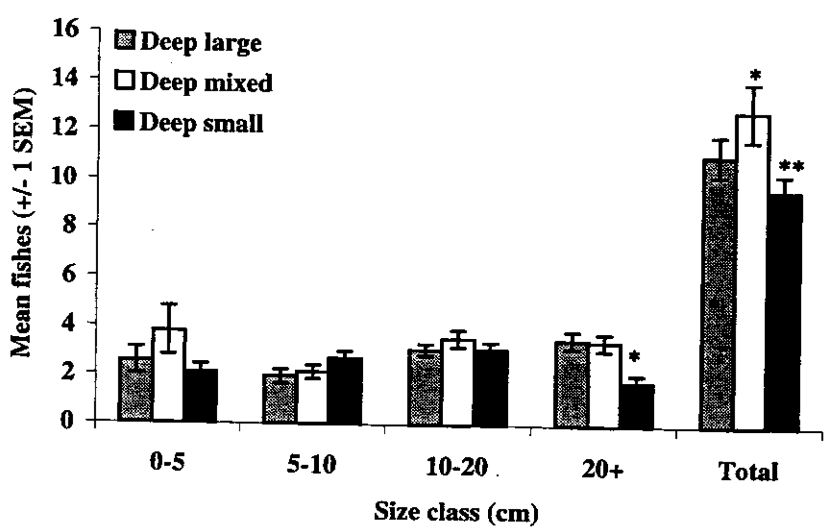

Figure 2. Mean number of total fishes (+/- 1 SEM) by size class on deep reefs with one of three treatments: large, small or mixed refuge sizes. Asterisked treatments are significantly different from other treatments within a size class ($p < 0.05$, SNK).

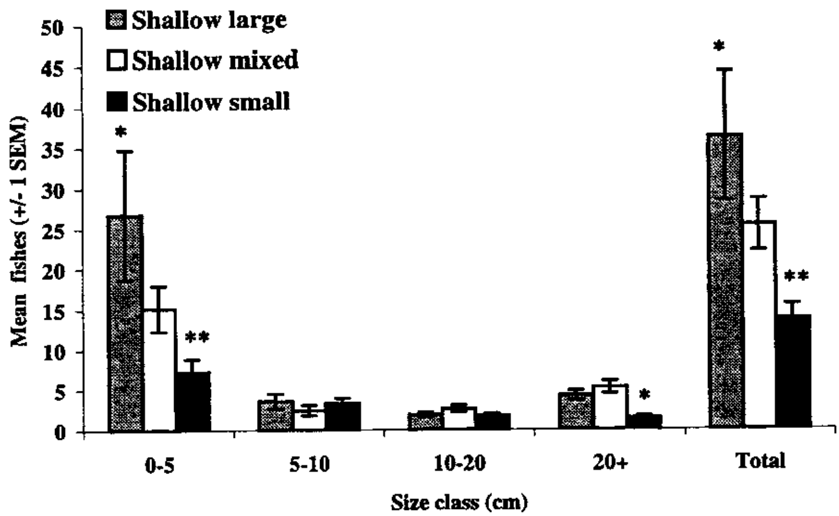

Figure 3. Mean number of total fishes (+/- 1 SEM) by size class on shallow reefs with one of three treatments: large, small or mixed refuge sizes. Asterisked treatments are significantly different from other treatments within a size class ($p < 0.05$, SNK).

Likewise, the number of species, by size class, did not differ much among the three treatments. Both shallow and deep reefs had more species in the 20+ cm size class on the large and mixed refuge reefs and at the shallow site, there were also more total species on the large and mixed refuge reefs ($p < 0.05$, ANOVA/SNK) (Figure 4, 5). There were more <5cm TL species on large and mixed refuge shallow reefs vs. deep. Large size class fishes (>10 cm), as well as total species (all sizes combined), were more abundant deep on large and mixed refuge reefs ($p < 0.05$, ANOVA/SNK). Throughout the year, total species (all size classes combined) were not significantly different on the deep reefs among months ($p > 0.05$) but were highest on the shallow reefs in July and November ($p < 0.05$, ANOVA/SNK).

Site Dependent Differences

Seventy-seven species were recorded at the deep site and 49 species at the shallow site. Of the 88 total species recorded, 40 were found exclusively deep (all refuge sizes combined) and 11 were only found shallow (Table 1).

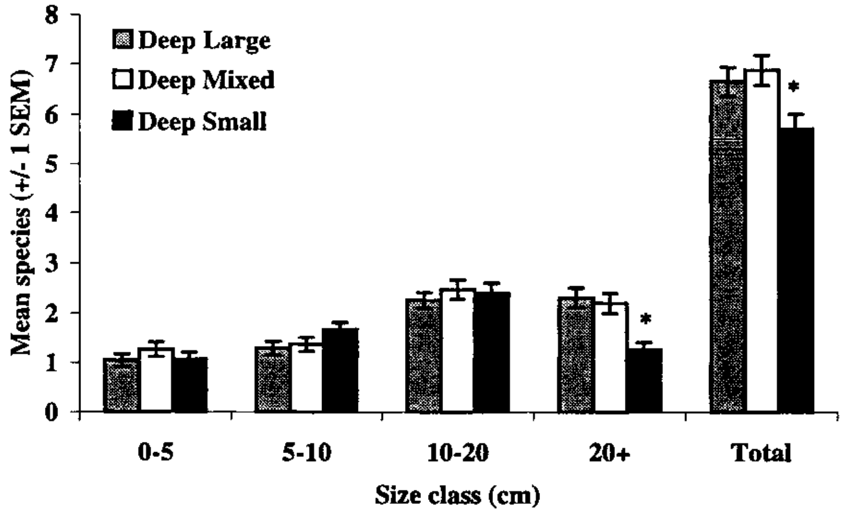

Figure 4. Mean number of total species (+/- 1 SEM) by size class on deep reefs with one of three treatments: large, small or mixed refuge sizes. Asterisked treatments are significantly different from other treatments within a size class ($p < 0.05$, SNK).

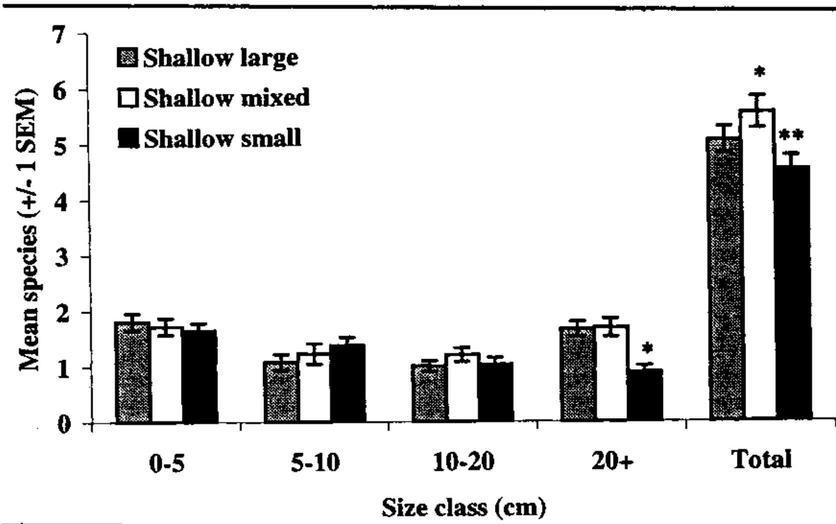

Figure 5. Mean number of total species (+/- 1 SEM) by size class on shallow reefs with one of three treatments: large, small or mixed refuge sizes. Asterisked treatments are significantly different from other treatments within a size class ($p < 0.05$, SNK).

Table 1. List of fishes

Common Name	Scientific Name	Deep	Shallow
STINGRAYS	DASYATIDAE		
Southern stingray	*Dasyatis americana*	X	
MORAY EELS	MURAENIDAE		
Purplemouth Moray	*Gymnothorax vicinus*	X	X
SEA BASSES	SERRANIDAE		
Black Grouper	*Mycteroperca bonaci*	X	
Scamp	*Mycteroperca phenax*	X	
Red Grouper	*Epinephelus morio*	X	
Graysby	*Epinephelus cruentatus*	X	
Coney	*Epinephelus fulvus*	X	
Sand Perch	*Diplectum formosum*	X	X
Butter Hamlet	*Hypoplectrus unicolor*	X	
Lantern Bass	*Serranus baldwini*	X	
Tobaccofish	*Serranus tabacarius*	X	
Harlequin Bass	*Serranus tigrinus*	X	
Tattler Bass	*Serranus phoebe*	X	
Belted Sandfish	*Serranus subligarius*	X	
CARDINALFISHES	APOGONIDAE		
Juvenile Apogonid	Apogon sp.	X	X
Flamefish	*Apogon maculatus*		
Twospot Cardinalfish	*Apogon pseudomaculatus*	X	X
JACKS	CARANGIDAE		
Juvenile Jacks	Carangid sp.		X
Blue Runner	*Caranx crysos*		X
Bar Jack	*Caranx ruber*		X
SNAPPERS	LUTJANIDAE		
Gray Snapper	*Lutjanus griseus*	X	X
Lane Snapper	*Lutjanus synagris*		X
Blackfin Snapper	*Lutjanus bucanella*	X	
Mutton Snapper	*Lutjanus analis*	X	X
GRUNTS	HAEMULIDAE		
Porkfish	*Anisotremus virginicus*	X	X
Juvenile Grunts	Haemulon sp.	X	X
Cottonwick	*Haemulon melanurum*	X	X
White Grunt	*Haemulon plumieri*		X
Tomtates	*Haemulon aurolineatum*	X	X
French Grunt	*Haemulon flavolineatum*	X	X
Bluestripe Grunt	*Haemulon sciurus*	X	X
Sailors Choice	*Haemulon parrai*	X	
Margate	*Haemulon album*	X	
PORGIES	SPARIDAE		
Saucereye Porgy	*Calamus calamus*	X	X

Table 1. Continued.

Common Name	Scientific Name	Deep	Shallow
Drums	SCIAENIDAE		
Highhat	*Equetus acuminatus*		X
Jacknifefish	*Equetus lanceolatus*	X	X
GOATFISHES	MULLIDAE		
Spotted Goatfish	*Pseudupeneus maculatus*	X	
BUTTERFLYFISHES	CHAETODONTIDAE		
Spotfin Butterflyfish	*Chaetodon ocellatus*	X	
Reef Butterflyfish	*Chaetodon sedentarius*	X	
ANGELFISHES	POMACANTHIDAE		
Queen Angelfish	*Holocanthus cilaris*	X	X
Blue Angelfish	*Holocanthus bermudensis*		X
Rock Beauty	*Holcanthus tricolor*	X	
French Angelfish	*Pomacanthus paru*	X	X
Gray Angelfish	*Pomacanthus arcuatus*	X	X
DAMSELFISHES	POMACENTRIDAE		
Dusky Damselfish	*Stegastes fuscus*	X	X
Bicolor Damselfish	*Stegastes partitus*	X	
Cocoa Damslefish	*Stegastes variabilis*	X	
Yellowtail Damselfish	*Microspathadon chrysurus*	X	
Sunshinefish	*Chromis insolatus*	X	
Yellowtail Reeffish	*Chromis enchrysurus*	X	
Purple Reeffish	*Chromis scotti*	X	
Blue Chromis	*Chromis cyanis*	X	
WRASSES	LABRIDAE		
Hogfish	*Lachnolaimus maximus*	X	X
Spotfin Hogfish	*Bodianus pulchellus*	X	
Spanish Hogfish	*Bodianus rufus*	X	
Clown wrasse	*Halichores maculipinna*	X	X
Slippery Dick	*Halichores bivittatus*	X	X
Puddingwife	*Halichores radiatus*	X	X
Yellowhead wrasse	*Halichores garnoti*	X	
Bluehead Wrasse	*Thalassoma bifasciatum*	X	X
PARROTFISHES	SCARIDAE		
Parrotfish	Scaridae spp.	X	X
Striped Parrot	*Scarus croicensis*	X	
Princess Parrot	*Scarus taeniopterus*	X	
Red tail Parrot	*Sparisoma chrospterum*	X	X
Redfin Parrot	*Sparisoma rubripinne*	X	
Redband Parrot	*Sparisoma aurofrenatum*	X	X
Stoplight Parrot	*Sparisoma virride*	X	
STARGAZER	DACTYLOSCOPIDAE		
Arrow Stargazer	*Gillellus greyae*	X	

Table 1. Continued.

Common Name	Scientific Name	Deep	Shallow
Combtooth Blennies	BLENNIDAE		
Redlip Blenny	*Ophioblennius atlanticus*		X
Barred Blenny	*Hypleurochilus bermudensis*		X
Seaweed Blenny	*Parablennius marmoreus*	X	X
GOBIES	GOBIIDAE		
Neon Goby	*Gobiosoma oceanops*	X	X
Bridled Goby	*Coryphopteru glaucofraenum*	X	X
Masked/Glass Goby	*Coryphopterus hyalinus/personatus*	X	
Goldspot Goby	*Gnatholepis thompsoni*	X	
SURGEONFISHES	ACANTHURIDAE		
Ocean Surgeon	*Acanthurus bahianus*	X	X
Doctorfish	*Acanthurus chirurgus*	X	X
Blue tang	*Acanthurus coeruleus*	X	X
LEATHERJACKETS	BALISTIDAE		
Orangespotted Filefish	*Cantherhines pullus*	X	X
Whitespotted Filefish	*Cantherhines macrocerus*		
Planehead Filefish	*Monocanthus hispidus*	X	X
Gray Trigger	*Balistes capriscus*	X	X
BOXFISHES	OSTRACIIDAE		
Scrawled cowfish	*Lactophrys quadricornis*	X	
Honeycomb cowfish	*Lactophrys polygonia*		X
Spotted trunkfish	*Lactrophrys trigonus*	X	X
Smooth trunkfish	*Lactrophrys triqueter*	X	X
PUFFERS	TETRAODONTIDAE		
Sharpnose Puffer	*Canthigaster rostrata*	X	X
Bandtail Puffer	*Sphoeroides spengleri*	X	
SPINY PUFFERS	DIODONTIDAE		
Balloonfish	*Diodon holocanthus*	X	
	Species per site	77	49
	Depth Exclusive Species	40	11
	Total species	88	

Some of the reefs positioned at the northern and western edges of the deep site (20 m) were placed near or on a destroyed tire reef. Thus, at the deep site, the immediate substrate varied based on the individual reefs proximity to a varying number of tires. This varying number of additional refuge spaces may have affected the study. However, statistical correlation of number of tires at distances of 5 m or less from the individual reefs against the total number of fishes (all species combined, $r^2 = -0.02$) or number of species ($r^2 = -0.04$) on the reefs was not significant ($p < 0 .05$, F-test). Therefore, treatment comparisons within the site were presumed to be equally affected by the presence of tires and data from the deep site were analyzed irrespective of tire data. However, the presence of the tire substrate at the deep site but not at the shallow site makes comparisons between reefs at the two sites questionable

.DISCUSSION

Refuge Size

Because the fishes associated with small refuge reefs did differ statistically in some size ranges from reefs with large refuges, in both total number of fishes and number of species, we accept the first prediction (Artificial reefs with large refuges will have different fish abundance, species richness, and biomass than reefs with small refuges). This supports the hypothesis that refuge size is an important aspect of artificial reef design for determining the associated assemblage of fishes. However, in this study small refuge reefs had lower numbers of total fishes and species, including juveniles, than large refuge reefs. These results contradict other studies where larger numbers of small fishes were associated with reefs with small refuges (Shulman 1984, Hixon and Beets 1989). Thus, although the results from this support the hypothesis that shelter size is important in artificial reef design, additional research is required to determine what those sizes should be relative to the local area and the species of interest.

Complexity

A basic premise of the experimental design in this study is: reefs with two different refuge sizes are more complex than identical reefs with a single refuge size. Mixed refuge reefs differed from small refuge reefs in numbers of fishes, species combined and numbers of species. However, the mixed refuge reefs never differed from large refuge reefs. In addition, there was no readily apparent differences in the species composition between large or mixed refuge reefs. These results, therefore, do not lend extensive support to our second prediction that mixed refuge reefs will have greater fish abundance, and species richness than either large refuge reefs or small refuge reefs.

Site Dependent Differences

There was a clear difference in species composition between the deep and shallow sites. It is not clear how much of this difference is due to differences in the substrate between the two sites (e.g. presence or absence of tires). However, similar site dependent differences in species composition were found in another study, using a different reef design, at similar depths (Sherman et al. 1999) where the results were not confounded by tire substrate.

This study was designed, in part, to replicate work done by Hixon and Beets (1984) in St. Thomas, VI, examining refuge size and fish assemblage formation. In their study, Hixon and Beets (1984) found a significant difference in species composition based on refuge size (i.e.: large holes – large fishes, small holes – small fishes). In that study, the majority of the large fishes on the reefs were piscivores (groupers). They found a negative relationship between resident piscivores and small fishes. In our study the correlation between fish size and refuge size, was not clear. The large refuge reefs had both more large fishes and more small fishes than the small refuge reefs. The primary difference in the results between these two studies appears to be driven by species composition. In St. Thomas, Hixon and Beets (1984) found the fish assemblages to be shaped by the presence of resident predators (groupers) while in South Florida, the fish assemblages were made up of primarily large (> 20 cm) herbivores (surgeonfishes), with few large resident piscivores.

CONCLUSION

The results of this study highlight again, the importance of site dependent factors (Sherman et al. 1999, Sherman et al. in press). Artificial reefs that exhibit specific results in one location may not necessarily yield the same results in another even within a limited geographical area. Additionally, an important recommendation to come out of this type of research, with regional comparisons in mind, is the importance of designing reefs with refuge sizes appropriate for the local species and life history stages being managed.

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