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Artificial reef design: void space, complexity, and attractants

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The potential for enhancing fish abundance, species richness, and biomass on artificial reefs was examined by attaching floating attractants and manipulating structural complexity of small concrete reefs each approximately 1.3 m in diameter, 1 m high. Experimental design consisted of a comparison of fish assemblages among three treatments (10 replicate, hemisphere-shaped reefs each): 10-m floating line attached (Streamer); concrete block in the central void space (Block); and no floating line or concrete block (Control). Reefs were deployed on sandy substrate at 20-m depth off Fort Lauderdale, Florida, USA. Divers recorded fish census data on slates 18 times over 24 months. Species composition, numbers of individuals per species, and estimated total length (TL; by size class: <5, 5–10, 10–20, and >20 cm) for all fishes within 1 m of each reef were recorded. Size classes were used to calculate fish biomass. There was a significant difference among treatments. Block reefs had higher numbers of individuals, species, and biomass than Streamer or Control reefs ($p<0.05$). With one exception, Streamer reefs did not differ from Controls for any of the parameters investigated ($p>0.05$). These results highlight the importance of structural complexity in artificial reefs designed to enhance fish recruitment, aggregation, and diversity.

Keywords: attractant, fish, Reef Ball™, structural complexity.

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Introduction

There has been an increasing frequency of use, worldwide, of artificial structures in efforts to increase fish abundance and diversity, improve catch rates of targeted species, manipulate habitats, and restore damaged coral reefs (Bohnsack and Sutherland, 1985; Bohnsack, 1990; Bohnsack *et al.*, 1991; Seaman, 1997; Spieler *et al.*, 2001). Many different types of structures have been used, including concrete block, formed concrete modules, polyvinyl chloride (PVC) pipe, fish aggregating devices (FADs), used tires, and other materials of opportunity (derelict ships, car bodies, bridge rubble, etc.). Although there have been some studies on functionality of artificial reef design (Grove *et al.*, 1991; Bohnsack, 1990; Mottet, 1985), few studies have looked specifically at the use of floating attractants or reef structure modification (more or less refuge or complexity) in an effort to affect juvenile fish recruitment or overall fish assemblage structure (Hixon and Beets, 1984; Sogard, 1989; Eklund, 1996).

One objective of this research was to determine if recruitment of juvenile fishes to artificial reefs can be enhanced through the use of a floating-line attractant. Several studies indicate that floating attractants can enhance fish recruitment. Beets (1989) in the Caribbean and Brock and Kam (1994) in the Pacific were able to increase juvenile recruitment to small artificial reefs by suspending midwater FADs above them, when compared with control reefs without FADs. Beets (1989) suggests that midwater FADs function as an effective type of structure for triggering settlement by competent reef fish larvae. Brock and Kam (1994) attribute increased juvenile recruitment to what they term the "stairway from heaven" effect, in which settling larvae can be focused over selected hard substrate by using midwater FADs. We questioned if a single line (without a FAD) suspended in the water column above the reefs would function as an attractant and enhance recruitment and aggregation of fishes to artificial reefs in southeast Florida, USA.

A second objective was to examine void space and complexity in reef design. Reef Balls™, popular artificial reef structures, contain a large central void space (Figure 1). There has been extensive engineering of artificial reefs in Japan and reviews of some of this work have promoted the idea that a large amount of void space is optimal for attracting fishes (Mottet, 1985). In contrast, recent work has indicated that decreasing void space and increasing the complexity of a reef may affect fish assemblage structure (Eklund, 1996). There have been numerous studies examining environmental complexity and associated fishes. In general, these studies find a positive correlation between structural complexity and fish abundance and species diversity (Spieler *et al*., 2001).

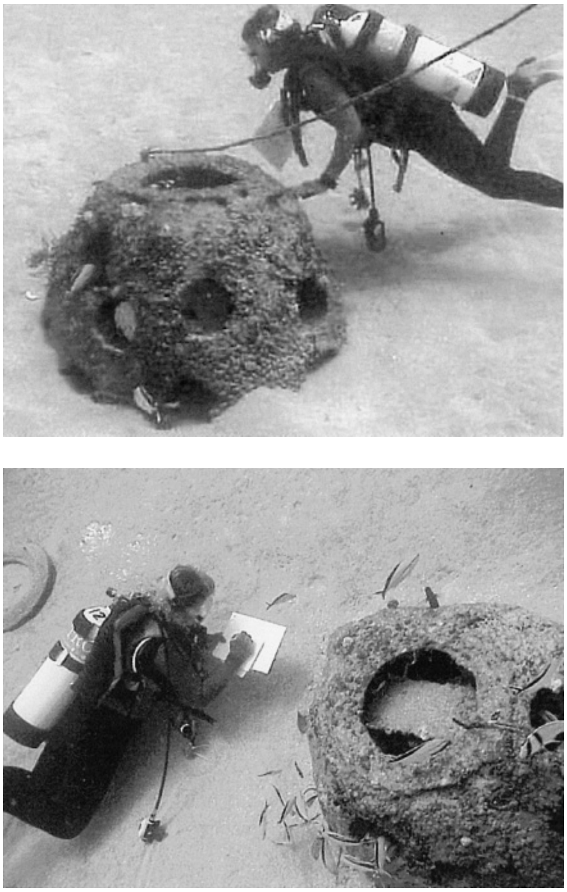

Figure 1. Reef Ball™ with (top) floating streamer and (bottom) with block filling central void space.

Materials and methods

Experimental design

We focused on two central hypotheses: (1) recruitment and aggregation of a diverse assemblage of fishes to artificial reefs can be increased by using a floating attractant, and (2) structural complexity is superior to extensive void space for the recruitment and aggregation of a diverse assemblage of fishes to an artificial reef. The two null hypotheses were: (1) Reef Balls™ with streamers will have equal numbers of individuals, species richness, and biomass as similar Reef Balls™ without streamers; and (2) Reef Balls™ with added structural elements will have equal numbers of individuals, species richness, and biomass as Reef Balls™ with standard internal void space.

The experimental design consisted of comparing fish assemblages among three treatments (10 Reef Balls™ each) with floating line (Streamer reefs), concrete block in the central void space (Block reefs), or no floating line or concrete block (Control reefs). This setup allowed us to make statistically verifiable predictions according to the hypotheses above.

Construction and deployment

Small, stand-alone artificial reefs designed by The Reef Ball™ Development Group Ltd. (Sarasota, Florida) were used (Figure 1). The elements were constructed using waste concrete (uncured concrete remaining in trucks returning from job sites) poured into fiberglass molds. Maximum dimensions of the individual reefs ("pallet balls") are 1.3×1 m with a weight of approximately 850 kg. The reefs are open at the top and have a large central void space created by a central bladder that is inflated for casting then deflated and removed after the concrete has hardened. Each reef was formed with 18 side holes in a consistent pattern.

Thirty Reef Balls™ were deployed by crane from a commercial research vessel at a depth of approximately 20 m in a site offshore Broward County (Florida, USA) permitted for the research. Individual reef sites were located by DGPS and marked by buoys. They were sited 30 m apart on sandy substrate, a minimum of 35 m from extensive hard bottom in a grid consisting of three north–south oriented rows of 10 reefs each. Wave action and technical difficulties during deployment caused some modification of the grid and six of the modules were less than 30 m from one another. After deployment, the reefs were tagged (cable ties and 6-cm plastic numbers) to facilitate underwater orientation and month-to-month comparisons.

The reefs were cleaned of all fishes using a piscicide. Treatment assignment (10 each) within the grid was randomized. One treatment had 10 m of floating polypropylene line attached to each reef (Streamer reefs; Figure 1a). To aid in buoyancy, Styrofoam floats, approximately 10 cm in diameter, were added to prevent the line from sinking due to bio fouling. The second treatment had four, standard 40 × 20–20 cm, concrete blocks placed in each central void space (Block reefs; Figure 1b). Two blocks were placed side-by-side as a base and the other two stacked on top, at right angles to the first two, forming a total of three levels. The remaining 10 reefs were not altered and served as controls for the preceding two treatments (Control reefs).

Monitoring

The reefs were monitored 18 times during a 2-year period. Divers, using SCUBA, counted and recorded census data on slates. The reefs are small enough to allow for an accurate total count without subsampling. The slates were marked on one edge with four size intervals (<5, 5–10, 10–20, and >20 cm) to aid in length estimation. Numbers of individuals per species present within 1 m of each reef (18 m^3, total volume including reef) and estimated total length by size class were recorded. The mean total length (TL) for each size class was used in length-weight equations (Bohnsack and Harper, 1988) to calculate fish biomass. When a species-specific length-weight equation 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 (SNK) test between means.

Results

There was a highly significant difference among treatments in the total number of fishes (all species and size groups combined; $p<0.001$ ANOVA; Figure 2a). Comparisons of means showed that, in each case where there was a significant difference among treatments, Block reefs had higher fish abundance than Streamer or Control reefs ($p<0.05$, SNK). Streamer reefs did not differ from Controls in number of fish, for any size class or all size classes combined ($p>0.05$, SNK). Block reefs had greater numbers of juvenile fishes (<5 cm TL) than either Streamer or Control reefs. With all treatments combined, seasonal differences in the number of fishes in each individual size class and total fishes (all size classes combined) were significant ($p<0.01$, ANOVA), with the exception of the 10–20 cm class. In general, April–June had the highest abundance ($p<0.05$, SNK).

Differences among treatments in the number of species were also significant, for individual size classes as well as for all size classes combined ($p<0.05$ ANOVA; Figure 2b). In each case, but one, Block reefs had higher

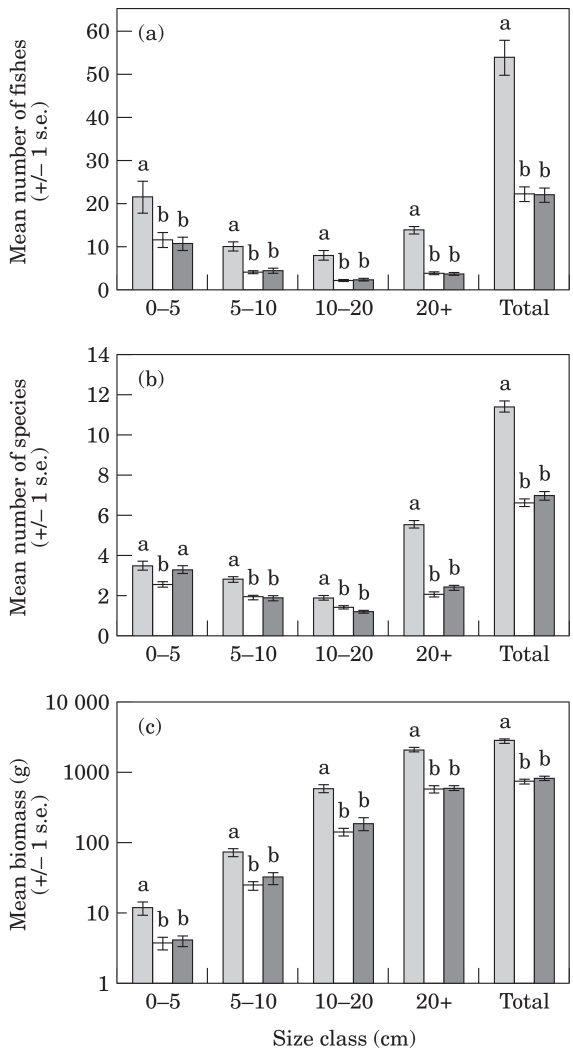

Figure 2. Mean (a) total number of individuals, (b) total number of species, and (c) total biomass (all ± 1 s.e.) on Block, Streamer, and Control reefs. Columns within each size class with the same letter above are not significantly different.

species richness than Streamer or Control reefs ($p<0.05$, SNK). Streamer reefs did not differ from Controls for any size class or for all size classes combined except <5 cm fish ($p>0.05$, SNK). With all treatments combined, seasonal differences in species richness were significant in all size classes as well as for all sizes combined ($p<0.01$, ANOVA). Although there were exceptions, the highest number of species were present in April–June ($p<0.05$, SNK).

Finally, differences among treatments in total biomass were also significant ($p<0.001$, ANOVA; Figure 2c). Comparisons of means show that Block reefs had higher biomass than Streamer or Control reefs in all cases ($p<0.05$, SNK). Streamer reefs did not differ from Controls ($p>0.05$, SNK). With all treatments combined, the same seasonal pattern of (significant; p<0.01, ANOVA) differences in total biomass emerges as for fish abundance.

Discussion

No differences were found between reefs with and without floating line, with the exception of 0–5 cm size class for species richness. Given the number of comparisons, this one exception could easily have been a chance event. Because null hypothesis (no 1) cannot be rejected, we must conclude that in this particular case recruitment and aggregation of a diverse assemblage to artificial reefs are not increased by using a floating attractant. Similarly, Munday and co-workers (1998), in work done in Australia, found no significant difference between reefs with a single floating streamer and control reefs, although they did find significant differences between patch reefs with and without lighted attracting devices. Gorham and Alevizon (1989) used polypropylene streamers on small model reefs in the Florida Keys, USA. Unlike our results, they found significantly higher numbers of juvenile fishes on reefs with streamers. However, they used ten 1-m streamers, with each three-strand polypropylene rope unraveled, per reef. Thus their reefs with streamers offered substantially more refuge than naked reefs and their results may reflect reduced post-settlement predation rather than increased settlement. Other studies have reported increased aggregations on artificial reefs with midwater FADs attached (Beets, 1989; Brock and Kam, 1994). Our lines did not have large floating structures attached, nor were fish schools noted in the vicinity of the lines. Whatever the cause for the differences among studies, floating a single line does not appear to be an effective attractant for recruiting fish or a stimulus for aggregation in the waters investigated here.

In contrast, we have to reject the second null hypothesis and conclude that in this case the reefs with less void space and more structural complexity had greater fish abundance, species richness, and biomass than similar reefs with more void space. These results support Eklund's (1996) observations that adding concrete block rubble to the void space of model reefs increased the numbers of fishes, species, and biomass over hollow reefs. Shulman (1984) found that the number and size of refuges significantly affected the number, size, and species richness of fishes associated with the reefs. Likewise, Hixon and Beets (1989) found a positive correlation between the number and size of refuges with the number and size of the associated fishes. However, the results obtained so far may not be extrapolated to other reef types, environments, and fish assemblages. Void space is simply another scale of shelter size, and optimum shelter size (including void space) appears to be highly species dependent (Bohnsack *et al.*, 1991; Spieler *et al.*, 2001).

At this point, our observations do not support the use of floating a single, FAD-less, line to enhance recruitment to and assemblage formation on small artificial reefs. Conversely, the results do support the importance of structural complexity in relation to void space in reef design. Of course, designers and managers will have to choose hole or shelter size in relation to the species and life history stages being managed.

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