REDUCING THE SPACE LIMITATIONS ON JUVENILE FISH IN REEF SYSTEMS

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Abstract: Spatial resources, especially three-dimensional structures, are generally considered the most limiting resources to fish abundance and diversity on coral reefs. Therefore, this space limitation should be considered in the design of artificial reefs. Despite extensive studies of the use of artificial reefs by adult fish, few studies have determined how juveniles use artificial reefs. To understand how artificial reefs may create new recruitment locations in space-limited fish communities, we need to also examine how juveniles use artificial reef structures. We monitored juvenile fish colonization of different types of artificial reef structures. We placed 18 structures, of three three-dimensional configurations, varying in complexity, around each of two coral heads on Little Cayman Island, one coral head on the north side and one on the south side. We installed the structures on 2 March 2007 and monitored juvenile fish colonization through 7 March 2007. We predicted that more fish would colonize the most three-dimensionally complex structures. Overall, we expected rapid colonization followed by a plateau, for all structure types. We recorded fish species composition and abundance on each structure during both day and night observation periods. Our data supported our prediction, with significantly more fish on more complex structures and fish abundance and species richness reaching a plateau after three days. Our results demonstrate that small-scale artificial reef structures may be important for reducing space limitations in diverse groups of juveniles and may form an integral part of artificial reef systems.

Key Words: artificial reef, microhabitat preference, spatial limitation

INTRODUCTION

Spatial limitation, especially of three-dimensional structure, is arguably the most important limitation on fish diversity and abundance in coral reefs (Sale 1977, Sale 1978, Gladfelter 1983, Holbrook 2000). There has been extensive research on the processes that lead to spatial limitations, including the limitations of structural habitat and the density-dependence of fish populations. Habitat availability is one of the best predictors of fish densities and abundance (Sale 1977; Holbrook et al. 2000). Where space is limiting, recruitment and survivorship of juveniles can be reduced, decreasing population carrying capacity and growth rate. Fish populations also show different degrees of vulnerability to density dependent mortality at varying levels of habitat availability, food resources, and predation risks (Anderson 2001; Holbrook and Schmitt 1988a, b, 2000; Schmitt and Holbrook 1999a, b). Because even taxonomically and functionally

similar fish can have different responses to prey and predator densities (Forrester and Steele 2000; Leis et al. 2002), understanding fish responses to different levels of these factors is complicated, but critical to understanding reef fish community dynamics.

Understanding the processes driving spatial limitation can help in designing the most effective artificial reefs. Artificial reefs increase fish abundance and species richness in areas that also have natural reefs by reducing spatial limitations on fish (Walker et al. 2002; U.S. Coral Reef Task Force 2005). Artificial reefs may help maintain species richness in reef fish communities where habitat degradation occurs (Rilav and Benayahu 1997; Golani and Diamant 1999; Strelcheck et al. 2005). In light of global climate changes and degradation of existing coral reefs, artificial reef research is increasingly important for the future of coral reef ecology (Bellwood et al. 2004; Hughes et al. 2003).

To create functional artificial reefs, many design factors must be considered, including structural complexity (Gratwickel and Speight 2005, Charbonnel et al. 2002), spatial orientation (Rivlov and Benayahu 1997), and location of the artificial reef with respect to surrounding structures and substrates (Strelcheck et al. 2005; Moreno 2002). Past studies highlight the importance of creating heterogeneous artificial reefs using different rugosities, orientations, and substrates. There is no single artificial reef structure equally suited for all fish or all age classes. Use of artificial reefs by coral and other reef species also needs to be considered (Eggleston and Lipcius 1992; Oren and Benayahu 1997).

The role of artificial reefs as habitat for juveniles has been examined in few published studies (e.g. Schmitt and Holbrook 1999a). The lack of research on use of artificial reefs by juvenile fish is surprising, given that juveniles have different habitat requirements from adults, including smaller-scale structural requirements. In addition, they may experience different degrees and types of space limitation, and display different territoriality behaviors than adult conspecifics (Holbrook et al. 2000). The lack of information on juvenile response to artificial reefs represents a substantial gap in our knowledge of artificial reef ecology (Bohnsack and Sutherland 1985).

Here we contribute to addressing this need by studying juvenile colonization of small-scale, three-dimensional structures at two patch reef locations on Little Cayman Island. We tested the potential for these structures to increase available space for juveniles, which might in turn reduce juvenile mortality in natural or artificial reef systems. We addressed three main

questions: (1) Do juvenile fish prefer certain artificial reef structure types?; (2) Does fish colonization in artificial reefs change over a period of several days; and (3) Do artificial structures support fish at night during periods of rest? Based on previous studies that found rapid adult fish colonization on large-scale artificial reefs (Golani and Diamant 1999; Gratwickel and Speight 2005; Santos et al. 2002), we also expected to see rapid colonization by juveniles, followed by a plateau in fish and species abundance. We also predicted that fish would prefer structures with more overhang (as found by Isbey and Gorbatkin 2007), and fewer fish would use the artificial reef structures at night than during the day.

METHODS

Study Site:

We monitored juvenile fish colonization of experimental reef structures on 2-7 March, 2007, at two locations on Little Cayman Island. Each study site contained 18 experimental structures, including six replicates of each of three structure types described below. One study site, on the north side of the island, was directly behind the Little Cayman Research Centre. The second, on the south side, was in Preston Bay, *c.* 300 m west of Pirate's Point. At both sites, we placed all 18 structures around a single coral head that was *c.* 4 m in diameter and separated by at least 5 m on all sides from other large coral structures (e.g., other coral heads and the back reef). This allowed 18 structures to be placed around the perimeter of the coral head, approximately 1.5 m from the head edge, with approximately 1 m between structures.

Experimental Methods:

At both sites, we created three-dimensional structures from dead coral heads found on the beach. Each structure consisted of five dead coral heads, arranged in one of three configurations that varied in the amount of space between heads (Fig.1). The first structure, henceforth referred to as "large overhang", had one large hole. The second structure ("double overhang"), had two holes (both smaller than the single hole in the large overhang structure). The third structure ('flat"), was a single line of five contiguous coral heads.

Each structure was placed in the water in the morning of 2 March, 2007. We collected data on fish colonization of each structure on 2 March (day 0) through 7 March (day 5). Due to rough weather, we could not collect data from the north site on 6-7 March. Each day, we observed each structure for two three-minute periods, recording the number and species of fish on the structure and noting interesting behaviors. All

structures were observed once before the second three-minute observation period began. Observation periods were summed for a daily total number of fish individuals and species per structure. For fish abundance, daily totals were averaged for each structure to calculate the mean number of fish individuals per structure over the 5 observation days. For fish species richness, we calculated the total number of species observed on a structure through the entire experimental period. To examine nocturnal structure use, we observed the structures at night, on 3 and 4 March (days 1 and 2).

Because the central coral heads chosen were at least 5 m from other corals, our coral heads were assumed to be the only source of juvenile fish. We censused the central coral heads once on 4 March to determine the species richness of the source populations of juvenile fish.

Statistical Methods:

We tested the effect of structure type on total number of fish species observed and mean fish per day with two one-way ANOVAs, and we used Tukey-Kramer multiple comparisons tests to compare fish abundance and species richness among structure types at alpha = 0.05. Since north and south sites (N = 6 replicates per structure type per site) had equal colonization, (Mean number of individual fishes per structure: north = 2.6 ± 0.3 (mean ± 1 SE) and south = 2.8 ± 0.3, t_{34}=0.48, P=0.63; Number of species per structure: north = 4.3 ± 0.5 and south = 5.1 ± 0.5, t_{34}=1.20, P=0.24), we combined the sites for analyses.

RESULTS

Both fish species richness and abundance increased rapidly from days 0-3 and then remained relatively constant through day 5 (Fig. 2). We saw no fish in the structure areas before placement and we saw fish entering the structure areas only from the central coral head, not from surrounding patch reef.

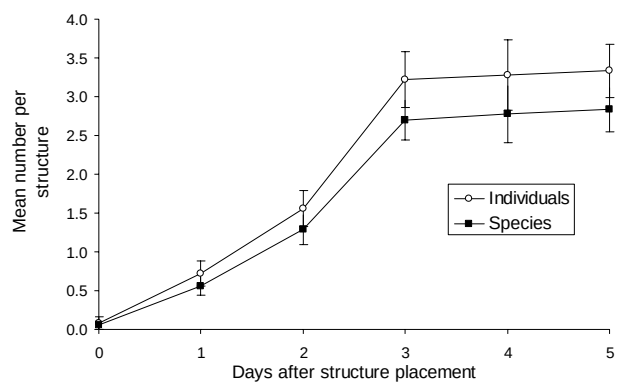

Figure 2: Mean number of individuals and species of fish (± 1 SE) colonizing 36 artificial reef structures over five days on Little Cayman Island. Data were collected 2-7 March 2007 at two locations on the island for three types of artificial reef structures (see Fig. 1 for details). Here we combine all data (overhang and no overhang, north and south locations) to show overall colonization patterns.

Structure type affected the average fish species richness and abundance ($F_{2,33}$=5.46, P=0.0089; $F_{2,33}$=9.44, P=0.0006, respectively). The average number of species per structure and mean fish abundance per day per structure for large overhang and double overhang structures were higher than flat structures, but there was no significant difference between large and double structure types (total species: Fig. 3). Fish abundance on large overhang structures (3.44 ± 0.25 individuals/day/structure) and double overhang structures (3.09 ± 0.47 individuals/day/structure) were 232% and 209% greater, respectively, than on flat structures (1.48 ± 0.24 individuals/day/structure). The mean total species observed per large overhang structure and per double overhang structure were 172% and 162% greater, respectively, than mean total species observed per flat structure (Fig. 3).

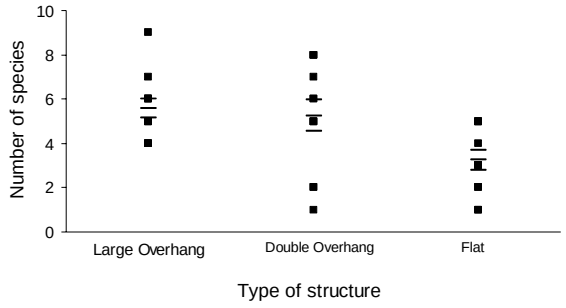

Figure 3: Numbers of fish (mean ± 1 SE) colonizing artificial reef structures with different amounts of overhang. See Fig. 1 for description of the three structure types (N=12 structures per type). Data were collected 2-7 March 2007 on Little Cayman Island.

Approximately 88% of the total juvenile species present in our census of the patch reefs were observed using the structures (22 of 25 species). Fish commonly observed using the structures diurnally included the ocean surgeonfish (*Acanthurus bahianus*), slippery dick (*Halichoeres bivittatus*), bluehead wrasse (*Thalassoma bifasciatum*), bridled goby (*Coryphopterus glaucofraenum*), dashed goby (*Ctenogobius saepepallens*), and rosy blenny (*Malacoctenus macropus*). Juvenile fish that colonized a single structure or two neighboring structures for the duration of the study included the ocean surgeonfish and beaugregory (*Stegastes leucostictus*). The beaugregory was the only individual fish that attempted to monopolize a structure.

An average of only 3.7% of the fish using the structures diurnally spent the night (days 1-2). This included one juvenile ocean surgeonfish, one post-larval ocean surgeonfish, one stoplight parrotfish (*Sparisoma viride*), and two bridled gobies. Post-larval stage fish of two nocturnally active species, the two-spot cardinalfish (*Apogon townsendi*) and the belted cardinalfish (*Apogon pseudomaculatus*), were observed using the structures at night. No nocturnally active fish were observed using the structures during the day.

DISCUSSION

Colonization over time:

The rapid colonization of the 36 artificial structures by juveniles of both common species (e.g. slippery dicks) and rarer species (e.g. the whitespotted filefish) supports the assumption that complex structures are valuable and often limiting resources in coral reef systems (Sale 1977; Holbrook et al. 2000; Anderson 2001). The structures were colonized by most (88%) of the juvenile species present on the two patch reefs and a single structure was rarely monopolized by a single individual, suggesting that these small-scale structural resources are accessible to most juveniles within the community.

After a period of rapid colonization, both the number of fish per structure and number of species per structure appeared to plateau after three days (Fig. 1). Golani and Diamant (1999) observed a similar saturation curve for large-scale artificial reefs, though over a much longer period. The saturation in our study may be attributed to two factors: (1) the structures have a fixed carrying capacity for fish; and (2) all individuals on the nearby patch reef able to colonize new structural resources had already done so after three days.

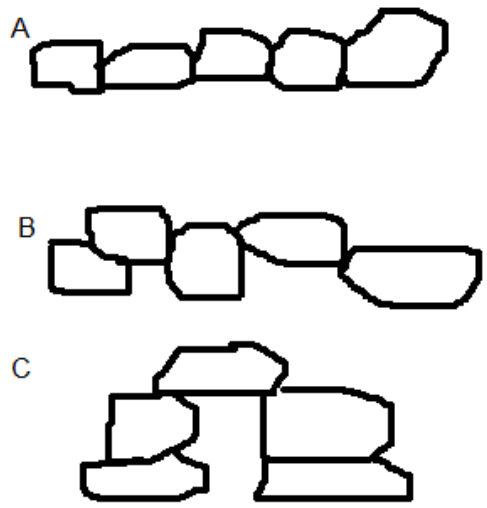

Figure 1: Three structure types used in artificial reef colonization experiment on Little Cayman Island. We refer to structure A as "large overhang," B as "double overhang," and C as "flat." Each structure contained five naturally occurring dead coral blocks of irregular shapes, c. 20-30 cm in mean linear dimensions. Structures were placed in the back reef at two sites: behind Little Cayman Research Centre on the north side, and in Preston Bay on the south side. After placement on 2 March they were observed for colonization until 7 March. . N=6 for each of the three structure types at each site.

Structure type preference:

Results supported our prediction that juveniles would prefer structures with overhangs more than they would prefer flat structures (Fig. 3). We observed no differences between large-overhang and double-overhang structures (for numbers of fish per structure per day, or for total number of species observed on a structure over five days). Overhang space in each of these structure types increases vertical habitat complexity and interstitial space, both of which increase biomass and diversity in fish communities on large-scale

artificial reefs (Rilav and Benayahu 1997; Gratwickel and Speight 2005). Presence or absence of overhang space may be more important than number or volume of overhangs. Structures with overhangs can support both fish who find refuge in overhang spaces (e.g. ocean surgeonfish) and fish that find refuge in crevices between the structure and the ocean floor (e.g. gobies).

Diel patterns:

Although many juvenile fish in the local community used the 36 structures, nearly 100% were diurnally active species, and only 4% of those used the structure to sleep (days 1-2). Our structures were positioned in foraging areas (e.g. sea grass and algae beds) and may have functioned mostly to provide shelter during foraging periods. The 4% that did sleep in the structures used crevices between the dead coral blocks or between the blocks and the ocean bottom. It is possible that a longer time period is necessary for diurnally active fish to begin using a structure at night. Increasing the number and size ranges of these crevices might increase the number of juvenile resting sites. Maximizing the suitable habitat for juveniles to use as resting space may be critical in increasing the overall carrying capacity for juveniles within a patch reef area (Sale 1977; Leis et al. 2002; Gratwickel and Speight 2005).

Significance for use in natural or artificial reefs:

Our results suggest that small-scale three-dimensional structures can be quickly colonized by a diverse group of juvenile fish. With further efforts to optimize sleeping space (e.g. crevices) within these small-scale structures, they could be useful for increasing juvenile survival rates, by reducing predation and increasing the carrying capacity of the habitat (Connell 1997; Forrester and Steele 2000; Anderson 2001). Small-scale structures may create habitat space that supports high fish abundance and diversity in both natural coral reef systems and artificial reef systems.

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