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9-1-2001

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## NSUWorks Citation

Robin L. Sherman, David S. Gilliam, and Richard E. Spieler. 2001. Site-Dependent Differences in Artificial Reef Function: Implications for Coral Reef Restoration .*Bulletin of Marine Science* , (2) : 1053 -1056. [http://nsuworks.nova.edu/occ\\_facarticles/141](http://nsuworks.nova.edu/occ_facarticles/141).

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## SITE-DEPENDENT DIFFERENCES IN ARTIFICIAL REEF FUNCTION: IMPLICATIONS FOR CORAL REEF RESTORATION

*Robin L. Sherman, David S. Gilliam and Richard E. Spieler*

There is an increasing use of artificial structure in coral reef restoration (for references, see Spieler et al., this volume). Often artificial reef structures are chosen for a restoration project simply because they were used elsewhere. However, it is questionable whether the results obtained at one restoration site can be extrapolated to another. In recent years, several studies have examined the effects of artificial reef site selection on formation of associated fish, algae, and/or invertebrate assemblages (Alevizon et al., 1985; Blinova et al., 1994; Bombace et al., 1994; Caley and St. John, 1996; Chang, 1985; Haughton and Aiken, 1989; Hixon and Beets, 1989; Jara and Cespedes, 1994; Kruer and Causey, 1992; Lozano-Alvarez et al., 1994; Moffitt et al., 1989; Relini et al., 1994; Sherman et al., 2000; Sherman et al., 1999; Sogard, 1989; Spieler, 1998; Tomascik, 1991). Although not designed specifically as coral reef restoration projects, the results of these studies lend insight into the problems of restoration. This paper is an overview of recent literature on site selection intended for resource managers interested in using artificial reefs in coral reef restoration. To that end, we re-examined the data from several studies comparing similar artificial reef structures at different sites.

### GENERAL METHODOLOGY

The studies re-examined used a variety of reef materials (i.e., tires, boats, bridge rubble, concrete block, asbestos plates, formed modules) in different geographical locations, and a variety of deployment sites. Site differences include depth, substrate type, turbidity/visibility, prevailing currents, salinity, and temperature. Linear distances between study sites varied from 0.75 k to >1000 k.

Reef modules were deployed at specific locations and censused periodically (daily to annually) for specific organisms (algae, invertebrates, fish). The reefs were censused using a variety of methods from mid-water trawls to divers on scuba performing a variety of visual census techniques. Generally, species richness and organism abundance was noted, and in many cases, biomass was calculated.

### DISCUSSION

Significant differences in biotic assemblages on replicate reefs were found with linear differences of as little as 0.75 km, changes in depth of only 10 m, differences in substrate from sand to seagrass or hard bottom. These differences may be related to variability in current, water temperature, or light penetration as well as substrate type. The effects may manifest themselves as differences in species richness and/or organism abundance. Comparable conclusions have been reached in the case of algae (Blinova et al., 1994; Relini et al., 1994), macro-invertebrates (Lozano-Alvarez et al., 1994; Pamintuan et al., 1994; Tomascik, 1991), fishes (Caley and St. John, 1996; Chang, 1985; Haughton and Aiken, 1989; Kruer and Causey, 1992; Sherman et al., 2000; Sherman et al., 1999; Spieler, 1998) and combinations of these (Bombace et al., 1994; Jara and Cespedes, 1994; Markevich, 1994; Sogard, 1989). Several of these studies are discussed below.

**FISH STUDIES.**—Fish recruitment and assemblage formation were examined off Ft. Lauderdale, Florida, on small (1 m<sup>3</sup>), replicate, concrete artificial reef modules designed to mimic ledge formations on local natural reefs (Spieler, 1998). Twenty reef modules were deployed on sandy substrate at each of two depths (7 m and 21 m), roughly 1 km apart, with 35 m between modules at each site. This study was designed to examine whether the presence of an existing fish assemblage affected juvenile fish recruitment (0–5 cm TL), species composition or overall fish assemblage formation. Data were collected monthly for 18 mo by visual census. Half the modules at each depth (10) were cleaned of all fishes, following monthly census, using a piscicide, while fish assemblages on the other 10 modules at each site were allowed to continue to develop. Significant differences were found between sites for juvenile fishes, total fishes, species richness, and biomass irrespective of the presence or absence of resident fishes.

In a separate study, Sherman et al. (2000) found significant differences between small (1 m<sup>3</sup>) replicate reef modules (Swiss Cheese reefs) at two different depths (7 m and 20 m) 1 km apart, off Fort Lauderdale, Florida. Thirty reef modules were deployed at each site, on sandy substrate, with 35 m between each reef module. This study tested the effects of refuge size and complexity on the formation of fish assemblages. Replicates (10 each) were constructed with three different tunnel configurations (six in each direction), 12 large (15 cm per side), 12 small (7.5 cm per side) or six large and six small. Significant differences were found between sites for recruits, total fishes, species, and biomass.

The previous study (Sherman et al., 2000) was designed, in part, to duplicate a study done by Hixon and Beets (1989) in St. Thomas, Virgin Islands, examining refuge size and fish assemblage formation. Hixon and Beets (1989) found a significant difference in species composition based on refuge size (i.e., large holes = large fishes, small holes = small fishes) with the majority of the large fishes on the reefs being piscivores (groupers). They found a negative relationship between resident piscivores and small fishes. In the Florida study, the correlation, between fish size and tunnel size was not so clear cut. The large tunnel reefs had both more large and more small fishes than the small tunnel reefs. The primary difference in results between these two studies appears to be a function of species composition. In St. Thomas, the fish assemblages were shaped by the presence of resident predators (groupers) while in Florida, the fish assemblages were made up of primarily large (>20 cm) herbivores (surgeonfishes).

These studies support the results of others examining fish assemblage formation on artificial structures (Sherman et al., 1999; Sogard, 1989; Caley and St. John, 1996; Walsh, 1985; Alevizon et al., 1985).

**INVERTEBRATES.**—Tomascik (1991) examined settlement of coral species on 120 terracotta tiles placed on three natural reefs in Barbados, West Indies, with experimental sites on the reef crest and between spur-and-groove formations. Tiles were oriented both vertically and horizontally at each site. His results indicate a significant difference in coral recruitment between the three reefs, between reef crest and the spur-and-groove zones, and between experimental tiles oriented vertically versus horizontally. Tomascik (1991) proposed that the differences were driven by a combination of turbidity differences and other environmental stresses (sedimentation rate, nutrient concentration, salinity) at the two southernmost reefs.

In an examination of concrete block structures as a habitat for spiny lobster (*Panulirus argus*) in Mexico, Lozano-Alvarez et al. (1994) found dramatic site differences. Of eight sites examined, using four reef types, one site contained 82% of all lobsters surveyed

while the other seven sites combined contained the remaining 18%. They concluded that in addition to physical characteristics of the shelters, local habitat features play a crucial role in determining the success of artificial shelters in attracting and concentrating lobsters.

Pamintuan et al. (1994) examined 32 concrete tent-like structures in clear and silty areas in the Philippines. The reefs at the silty site had greater mean percentage cover and total number of sessile species, greater number of mobile invertebrate species, and greater total number of individuals. The authors attributed the difference in initial colonization to negative phototactic behavior of some species of settling larvae and concluded that the divergent development of the two communities was based primarily on physical factors at the sites. Likewise, Sogard (1989), working with artificial seagrass mats in New Jersey, found site-dependent differences in decapod assemblages and attributed them to differences in initial epifaunal colonization of the mats.

### CONCLUSIONS AND RECOMMENDATIONS

Taken as a whole, these studies indicate that similar artificial reef structures placed at different locations will produce dissimilar results. In addition, several other studies have been done using either small sample sizes within or between sites, or different reef structures at different sites (Blinova et al., 1994; Bombace et al., 1994; Chang, 1985; Haughton and Aiken, 1989; Jara and Cespedes, 1994; Kruer and Causey, 1992; Markevich, 1994; Moffitt et al., 1989; Relini et al., 1994). Experimental design limitations in these studies prevent the performance of rigorous statistical comparisons of census data, or introduce confounding variables such as dissimilar reef design. Nonetheless, these studies also support the conclusion that site-dependent variables are critical determinants of artificial reef function.

This paper serves as a caution to resource managers planning to use artificial reefs in habitat restoration projects. Data acquired on a particular artificial reef design at one site may not be suitable for extrapolation to another. Also, monitoring a single design, at a single site, such as is seen in many artificial reef and coral reef restoration projects, has limited value. What is needed at this point is a better understanding of artificial reef design, key environmental determinants of artificial reef function, and interactions between artificial reef design and those environmental determinants of function. To this end, coral reef restoration projects using artificial reefs should incorporate multiple designs and include an ecological assessment along with an extended monitoring period.

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