

Artificial Reefs: The Importance of Comparisons with Natural Reefs

By Mark H. Carr and Mark A. Hixon

ABSTRACT

Methods used to evaluate the performance of an artificial reef will vary according to the purpose for which the reef was built. To determine how well artificial reefs mitigate losses due to human activities on natural reefs, the performance of artificial reefs should be evaluated using contemporaneous comparisons with relatively undisturbed natural reefs. Unfortunately, comparisons between artificial and natural reefs are typically confounded by differences in reef size, age, and isolation. We compared colonization and subsequent assemblage structure of reef fishes on coral and artificial (concrete block) reefs in which reef size, age, and isolation were standardized. Species richness and fish abundance (all species combined) were greater on reefs of natural rather than artificial structure, but substantial differences in species composition were not detected. Our results suggest that artificial reefs with structural complexity and other abiotic and biotic features similar to those of natural reefs will best mitigate in-kind losses of reef fish populations and assemblages from natural reefs. Because of the open nature of most reef fish populations, estimating the contribution of artificial reefs in attracting v producing reef fishes will require a regional assessment of rates of demographic processes on both artificial and nearby natural reefs.

The two primary goals of artificial reefs in coastal habitats have been, first, to enhance the production of reef-associated species (i.e., macroalgae, invertebrates, and fishes) and, second, to increase the convenience or efficiency of harvesting reef-associated species (Seaman et al. 1989; Seaman and Sprague 1991; Pratt 1994). Most often, the purpose of increasing production is to mitigate losses from overfishing or other human activities (e.g., pollution, habitat destruction, entrainment and impingement by cooling water systems of coastal power plants). The second goal has been to create reef habitat both attractive to reef species and easily accessible to harvesters, thereby increasing catch-per-unit effort (and per-unit cost), at least temporarily. However, with the ever-increasing concern for conservation and enhancement of reef-associated species, this second goal has received less priority and, in fact, has recently been perceived as a potential problem rather than a desired objective (Alevizon and Gorham 1989; Bohnsack 1989; Polovina and Sakai 1989).

During the past decade, artificial reef programs have received greater interest and scrutiny (Seaman et al. 1989; Seaman and Sprague 1991; Pratt 1994). Increased interest stems from growing fishing pressure

and the concern of fisheries managers about maintaining stocks of exploited species at harvestable levels, and the desire of conservation biologists to mitigate losses to reef-associated species caused by human activities. Greater scrutiny stems from the paucity of unequivocal evidence that artificial reefs fulfill their intended objectives, which has led to debate regarding their roles in producing versus simply attracting (i.e., redistributing) organisms, especially reef fishes.

Methods used to evaluate the performance of an artificial reef will vary according to the purpose for which the reef was built. If the primary objective of an artificial reef is to compensate for anthropogenic impacts on particular features of a natural fish population, community, or its habitat, the performance criteria must include information on those specific features (e.g., population abundance, size structure, species composition of fish and other reef biota; Ambrose 1994). If the objective is to mitigate a loss in fish production, then the performance criteria also should include information from which production can be estimated (e.g., larval recruitment, immigration, growth, reproduction, mortality and emigration). Alternatively, performance criteria required to mitigate in-kind losses in communitywide production

Mark H. Carr is an assistant research biologist at the Marine Science Institute, University of California, Santa Barbara, CA 93106; carr@lifesci.ucsb.edu. Mark A. Hixon is a professor at the Department of Zoology, Oregon State University, Corvallis, OR 97331-2914. Authorship decided by a coin toss.

include the structural (e.g., species composition and abundance) and functional (e.g., productivity) attributes of communities. In any case, the performance of artificial reefs should be evaluated using contemporaneous comparisons with relatively undisturbed natural reefs nearby. It also is important to know how quickly artificial reefs are colonized and what factors influence rates of colonization. For example, if long lag times exist between construction of the reef and establishment of the targeted assemblage, a different reef design or other methods that expedite the colonization of reef biota may be necessary to more quickly compensate for lost resources. It may be necessary to provide or enhance settlement habitat to increase the rate of recruitment of planktonically dispersed propagules (i.e., larvae and spores) or to transplant adults to provide a local spawning source of species with limited dispersal capabilities (e.g., some invertebrates or macroalgae). Obviously, knowledge of the dispersive potential of targeted species and the mechanisms of recruitment in natural habitats is critical to predicting rates of colonization of artificial structures, as is understanding the effects of reef isolation and the surrounding habitat on the rates and species composition of colonization. Reef size, age, and isolation have not been controlled in the few studies that have compared fish assemblages between natural and artificial reefs (e.g., Molles 1978; Ambrose and Swarbrick 1989; DeMartini et al. 1989). This is because artificial reefs are typically much smaller, younger, and far more isolated than their natural counterparts.

In this article, we suggest that evaluating the role of artificial reefs will benefit markedly from, first, more detailed comparisons of the populations and assemblages of reef species that use artificial reefs with those on natural reefs and, second, a determination of the spatial scales over which artificial reefs act to attract or produce reef species. Conceptually, many of the issues we raise are applicable to most reef-associated species, with some differences based on relative mobility. However, we focus specifically on reef fishes because of our greater familiarity with these species. We first address the importance of comparing artificial and natural reefs, using information gleaned from our recent experimental studies conducted in the Bahamas. We finish with a

more conceptual discussion of the effects of artificial reefs on regional fish production, the necessity of explicitly defining the region in question, and the importance of comparing local production on artificial and natural habitats at that scale.

An Experimental Comparison of Artificial and Natural Reefs

To determine the effectiveness of small artificial reefs in mimicking fish assemblages associated with natural coral patch reefs, we compared the rate of colonization and resultant fish assemblages on replicate natural and artificial reefs of roughly similar size, age, and isolation. Near the Caribbean Marine Research Center at Lee Stocking Island, in Exuma, Bahamas, we translocated 16 natural coral patch reefs (ca 6 m²) to an expansive, shallow (< 4 m depth) sand bank, where we also constructed 16 artificial patch reefs of nearly the same size (ca 4 m²) but of different structure (taller profile [0.8 m vs. 0.4 m] and less variable size of shelter holes) and initially without associated food organisms (Figure 1). Descriptions of the transplanted coral reefs and the artificial reefs are provided in Carr and Hixon (1995) and

M. H. Carr



This natural coral patch reef was translocated near similar artificial patch reefs in order to compare assemblage of reef fishes during an experiment in the Bahamas.

Hixon and Beets (1993, Figure 2; 24 large holes design), respectively. Our purpose for choosing concrete blocks was to use standard materials commonly employed in other studies of reef fish assemblages (e.g., Talbot et al. 1978; Bohnsack and Talbot 1980; Hixon and Beets 1989, 1993). Both reef types were isolated from their nearest neighbor by 200 m of

ARTIFICIAL REEF MANAGEMENT

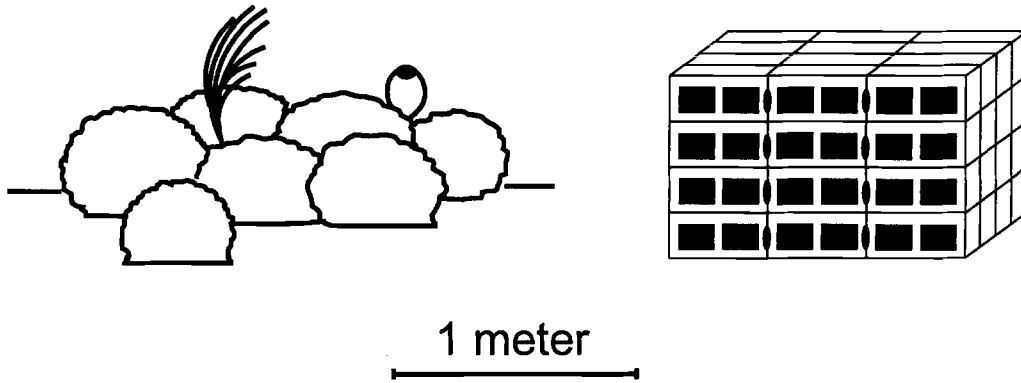


Figure 1 is a scale illustration of the artificial reefs and translocated natural coral reefs used in the experiment at Lee Stocking Island, Bahamas.

following two years. (The reefs are still being monitored at this writing.)

Comparison of the fish assemblages associated with our artificial and natural reefs showed that overall net rates of fish recruitment (all species combined) were nearly equal at approximately five new larval recruits per reef per census (Hixon and Carr, unpublished data).

Assuming our estimates

open sand and constructed from August 1991 to December 1992. However, eight of the artificial reefs were constructed at exactly the same time as eight of the natural reefs were translocated (14–19 December 1992), so we compare only these reefs in this article. We conducted complete visual censuses of the reef fishes colonizing each reef six times during the

of instantaneous rates of recruitment sampled on the six census dates are representative of relative recruitment rates throughout the two-year sampling period, net colonization rates of older fish were likely due to differential post-recruitment mortality, emigration, and/or immigration. During the first two years of the experiment, natural reefs accumulated fishes (both number of individuals and number of species) more rapidly than artificial reefs (Figure 2). Although species richness was higher on natural reefs throughout the sampling period, we found no strong difference in the species composition of fishes (Figure 3). Of 38 reef fish species observed on either reef type, only three occurred primarily on natural reefs and four occurred primarily on artificial reefs (Figure 3). All seven of these species were among the least abundant on the experimental reefs.

For the particular structural features of the natural and artificial reefs that we studied, these results suggest that, even when reef age was controlled, and the surrounding habitat and degree of isolation was standardized, the resulting number of individuals and species of fishes on natural reefs after two years was greater than on artificial structures. Thus, the greater vertical relief and shelter availability (number of holes) of artificial reefs did not compensate for the greater structural complexity (variety of hole sizes) and natural forage base provided by the corals and associated benthos of the natural reefs. These results suggest that artificial reefs intended to mitigate the degradation of natural reefs should be structurally as

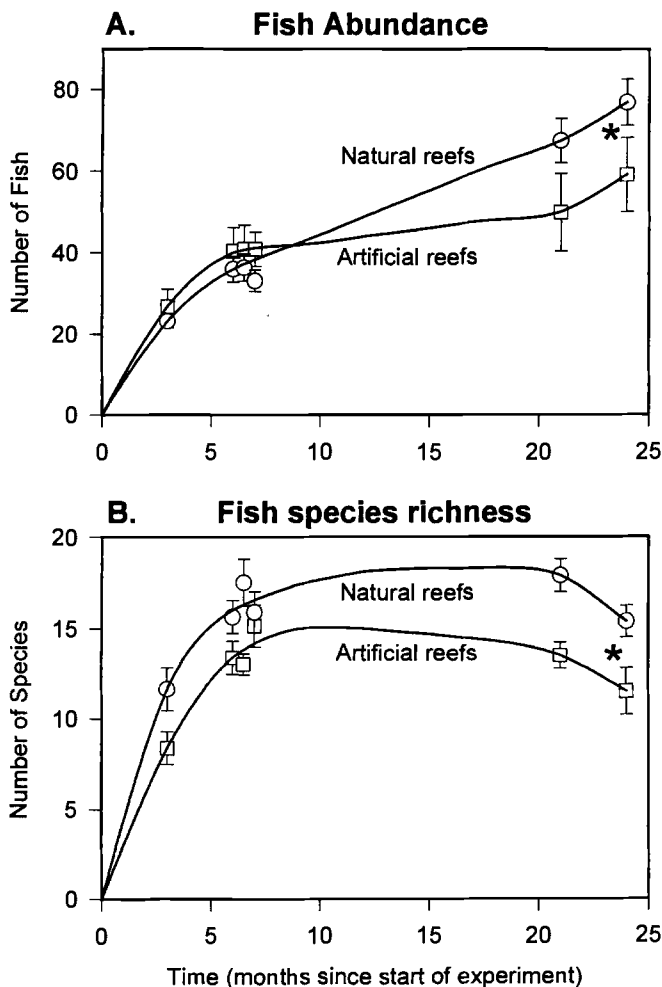


Figure 2 illustrates the mean (SEM) number of fish individuals and species colonizing 8 artificial and 8 natural patch reefs translocated to the same sand-bottom habitat off Lee Stocking Island, Bahamas, at the same time. In both plots, the final values are significantly different ($P < 0.05$, t-tests). Note that the final apparent decline in species richness was correlated with a winter census following a late summer census. After the summer settlement period, rare colonists disappear during the winter.

similar as possible to natural reefs, especially by promoting the development of naturally dominant benthos (such as corals or macroalgae).

Attraction v Production

Comparison of fish assemblages associated with natural and artificial reefs also is fundamentally pertinent to the "attraction-production" question. Although logistically difficult to quantify, attraction is a relatively straightforward concept, which we define as the net movement of individuals from natural to artificial habitats. Production is a more problematic concept. Best quantified as a change in biomass through time (integrating both the number and mass of individuals), it reflects births (typically via recruitment of planktonically dispersed larvae), immigration, growth, death, and emigration. Additionally, gamete production is critical to understanding the reproductive contribution of a local population to regional production. Without measurements of these demographic rates, estimates of production are difficult to interpret. Recent studies have begun to examine local production of fishes on artificial reefs (Polovina and Sakai 1989; DeMartini et al. 1994; Johnson et al. 1994). However, because of the dispersive potential of pelagic larvae of most reef fishes and the additional mobility of benthic juveniles and adults of many species, the relative fate and performance of fishes in natural v artificial habitats is critical to understanding the contribution of artificial reefs. The general question of interest is: Does an artificial reef provide a habitat for increased production that would otherwise not be possible? More specifically, could fishes that recruit to artificial reefs (by either larval settlement or immigration of older benthic stages) have recruited instead to natural reefs, and had they done so, what would be their relative rates of growth, mortality, and emigration, and how would their recruitment influence these demographic rates for resident conspecifics and other species? Importantly, these questions require assessing production on an artificial reef in the context of regional production on natural reefs.

By emphasizing production on an artificial reef in the context of regional production, it is essential to define explicitly the "region" in question. Two possible regions are of particular interest. First, there is the area enclosing a collection of local populations that influence one another's production, i.e., the metapopulation within which an artificial reef has been inserted. Second, and more tangible, is the area of interest to fisheries managers, regardless of how its boundaries are defined. Although the two kinds of regions are inextricably linked, we focus our discussion on the latter, in which the contribution of an artificial reef is to be assessed in a defined management area.

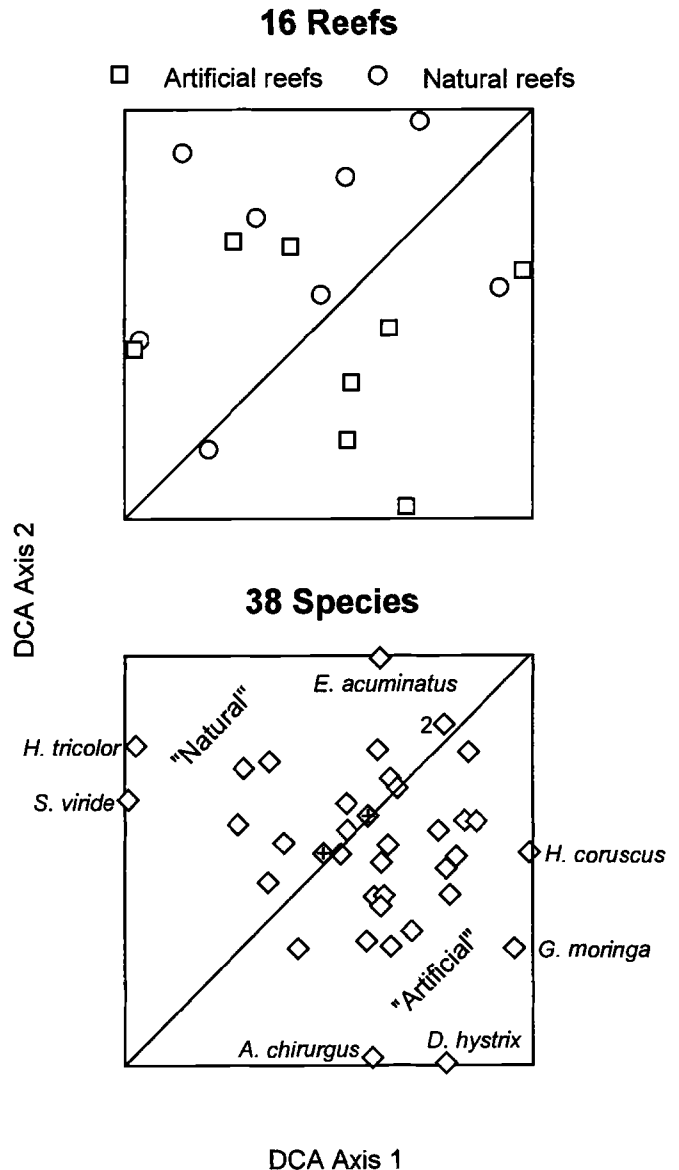


Figure 3 summarizes results of detrended correspondence analysis (DCA) of fish assemblages on 8 artificial and 8 natural patch reefs in the Bahamas in December 1994. In the upper plot (reefs in species "space"), reefs are plotted by their species composition "scores" along DCA axes 1 and 2, which represent linear combinations of species based on correlated patterns of abundance. The distance between reefs is proportional to the dissimilarity of fish species composition and relative abundances. Note that most of the natural reefs cluster above the diagonal, whereas most of the artificial reefs occur below the diagonal, with interspersed reef types in the center of the plot. There was no significant difference in the distribution of DCA scores between the two reef types (t-test, $P = 0.38$). In the lower plot (species in reef "space"), the position of each of 38 fish species corresponds with their abundance on reefs depicted in the upper plot, such that the 3 species named above the diagonal were mostly found on natural reefs and the 4 species named below the diagonal were mostly found on artificial reefs. The fact that most species cluster in the center of the plot indicates that most species were similarly abundant on both natural and artificial reefs, especially the two dominant grouper, *Epinephelus striatus* and *E. guttatus* (indicated by crossed symbols).

ARTIFICIAL REEF MANAGEMENT

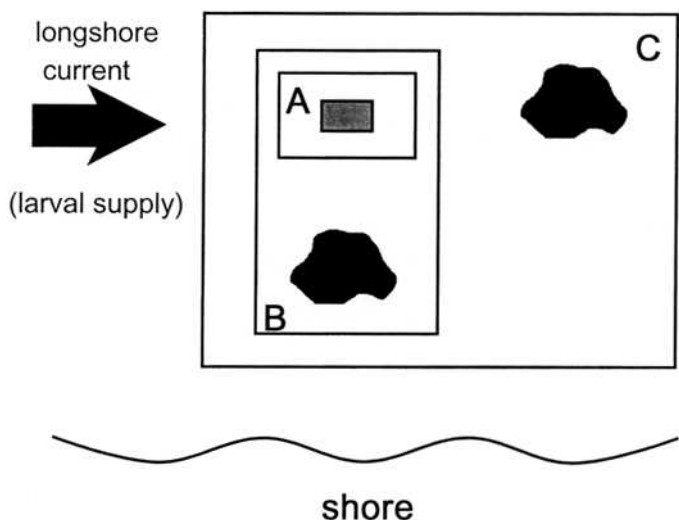


Figure 4 illustrates example scenarios depicting the importance of comparing natural and artificial reefs. In case A, where the management area includes only an artificial reef, the reef obviously increases regional production. In case B, a strong longshore current precludes any larval or migratory transport between an artificial reef and a natural reef within the management area. Here, larvae that settle on the artificial reef would be lost from the management area if the artificial reef did not exist. Thus, the artificial reef enhances local production even if its productivity is less than that of the natural reef. In case C, an artificial reef intercepts larvae destined for a natural reef down current. If the intercepted larvae grow less productively on the artificial reef than they otherwise would have on the natural reef, then only attraction has occurred, and the artificial reef has decreased regional production.

The size of the management area, and the spatial distribution of reefs within that area, can profoundly influence interpretation of an artificial reef's effects. For example, if no natural reefs occur in a management area containing an artificial reef, then any obligate reef organism on the artificial reef has necessarily enhanced production within that management area (Figure 4A). Clearly, the smaller the management area, the greater the contribution of the artificial reef to that area.

If natural reefs do occur in a management area containing an artificial reef, and if larvae that settle and survive on the artificial reef would have either (1) not settled on a natural reef in the management area if the artificial reef was not present or (2) settled but experienced either lower growth or lower survival on a natural reef than on the artificial reef, then the artificial reef again will have enhanced production. Failure to recruit to natural reefs in the absence of an artificial reef can be caused by sufficiently high mortality in the plankton or advection of larvae away from natural reefs. Relatively poor survival may reflect resource limitation on natural reefs or susceptibility to higher predation rates. For example, suppose that an artificial reef was built offshore of a natural reef and a strong longshore current isolated the reefs

from each other such that there was no larval or migratory connection (Figure 4B). If the management area included only these two reefs, then the artificial reef would necessarily enhance regional production even if the productivity of the artificial reef was less than that of the natural reef. In this scenario, larvae that settled on the artificial reef would be lost from the management area if that reef did not exist. On the other hand, if recruitment to an artificial reef reduces recruitment to natural habitats by intercepting larvae (Figure 4C), and if survival and growth are greater on natural reefs, the effect of an artificial reef will be to reduce the regional production of fishes, counter to its purpose. In both examples, knowledge of larval transport, settlement, and subsequent growth and mortality on both natural and artificial reefs would be required to answer the attraction-production question.

In summary, only if production of obligate reef organisms is greater on artificial reefs than on natural reefs within an explicitly defined management area can one conclude unequivocally that artificial reefs enhance production. If otherwise, then artificial reefs may enhance production, but testing this possibility

...if no natural reefs occur in a management area containing an artificial reef, then any obligate reef organism on the artificial reef has necessarily enhanced production within that management area.

involves distinguishing between cases B and C of Figure 4, which requires knowledge of the fates of settlement-stage larvae passing near artificial reefs. Currently, this task is extremely difficult, if not impossible, and emphasizes the importance of our understanding of mortality and transport of larvae. All studies of artificial reef communities, whether for mitigation purposes or examining the attraction-production question, would benefit by careful comparisons with natural reef systems. Such studies would necessarily include both local and regional spatial scales. 🐟

Acknowledgments

We thank J. Beets, R. Gomez, B. Head, T. Kaltenberg, S. Swearer, S. Thompson, and C. Tinus for help in translocating and constructing reefs in the Bahamas. Logistical support was provided by the administration and staff of the Caribbean Marine Research Center. J. Harding and D. Reed provided valuable comments on the manuscript. Support for this study was provided by the National Science Foundation grant OCE-92-17163 and the National

Underseas Research Program grants CMRC-92-46, 93-12, 94-15, and 95-3042. M. Carr also received support from Minerals Management Service grant 14-35-0001-30758.

References

- Alevizon, W. S.,** and **J. C. Gorham.** 1989. Effects of artificial reef deployment on nearby resident fishes. *Bull. Mar. Sci.* 44:646–661.
- Ambrose, R. F.** 1994. Mitigating the effects of a coastal power plant on a kelp forest community: rationale and requirements for an artificial reef. *Bull. Mar. Sci.* 55:694–708.
- Ambrose, R. F.,** and **S. L. Swarbrick.** 1989. Comparison of fish assemblages on artificial and natural reefs off the coast of southern California. *Bull. Mar. Sci.* 44:718–733.
- Bohnsack, J. A.** 1989. Are high densities of fishes at artificial reefs the result of habitat limitation or behavioral preference? *Bull. Mar. Sci.* 44:631–645.
- Bohnsack, J. A.,** and **F. H. Talbot.** 1980. Species packing by reef fishes on Australian and Caribbean reefs: an experimental approach. *Bull. Mar. Sci.* 30:710–723.
- Carr, M. H.,** and **M. A. Hixon.** 1995. Predation effects on early post-settlement survivorship of coral-reef fishes. *Mar. Ecol. Progr. Ser.* 124:31–42.
- DeMartini, E. E.,** **D. A. Roberts,** and **T. W. Anderson.** 1989. Contrasting patterns of fish density and abundance at an artificial rock reef and a cobble-bottom kelp forest. *Bull. Mar. Sci.* 44:881–892.
- Hixon, M. A.,** and **J. P. Beets.** 1989. Shelter characteristics and Caribbean fish assemblages: experiments with artificial reefs. *Bull. Mar. Sci.* 44:666–680.
- . 1993. Predation, prey refuges, and the structure of coral-reef fish assemblages. *Ecol. Monogr.* 63:77–101.
- Molles, M. C., Jr.** 1978. Fish species diversity on model and natural reef patches: experimental insular biogeography. *Ecol. Monogr.* 48:289–305.
- Polovina, J. J.,** and **I. Sakai.** 1989. Impacts of artificial reefs on fishery production in Shimamaki, Japan. *Bull. Mar. Sci.* 44:997–1,003.
- Pratt, J. R.** 1994. Artificial habitats and ecosystem restoration: managing for the future. *Bull. Mar. Sci.* 55:268–275.
- Seaman, W.,** **R. M. Buckley,** and **J. J. Polovina.** 1989. Advances in knowledge and priorities for research, technology and management related to artificial aquatic habitats. *Bull. Mar. Sci.* 44:527–532.
- Seaman, W.,** and **L. M. Sprague.** 1991. Artificial habitats for marine and freshwater fisheries. Academic Press, San Diego, CA.
- Talbot, F. H.,** **B. C. Russell,** and **G. R. V. Anderson.** 1978. Coral reef fish communities: unstable, high-diversity systems? *Ecol. Monogr.* 48:425–440.