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Preface

The following is a collection of papers presented at a symposium held in conjunction with the Florida Sea Grant Extension Program at the annual meeting of the American Fisheries Society in Tampa, Florida in August, 1995. This collection does not include all papers submitted and/or presented at the symposium. This collection in no way is meant to preclude publication of these papers in any professional journal. Instead, this collection only adds to the gray literature and is intended for the use of symposium participants pending peer review and publication elsewhere. All materials remain the property of the individual authors. Citation of any of the collected papers is to be by permission of the respective author(s). Some of the papers have been edited by Mr. Bill Seaman, Florida Sea Grant College Program, Gainesville, Florida. Any questions on the contents of this report should be directed to Richard Christian, Sport Fish Restoration Coordinator, Atlantic States Marine Fisheries Commission, 1444 Eye Street, NW, Sixth Floor, Washington, DC 20036, (202) 289-6400.

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SPORT FISH RESTORATION

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SYMPOSIUM OVERVIEW

William Seaman, Jr.[1] and Gary Grossman[2]

Objective

Research on U.S. artificial marine habitats in the last 10–15 years has started to address and partially answer numerous questions about the ecology of these systems. However, a critical mass of quantitative information regarding enhancement of biological productivity remains elusive. The symposium objective was to determine whether and how artificial reefs specifically promote increased biomass production of marine organisms, especially species of fisheries interest.

The symposium was held under the auspices of the annual meeting of the American Fisheries Society (AFS). This actually fulfilled one of the recommendations made during the program, to bring artificial reef study and development more into the mainstream of Fishery Science. Indeed, artificial reef technology represents one of the most accessible fishery science practices for the U.S. angling public and allied conservation interests, and applications seem to be accelerating worldwide despite certain knowledge gaps.

Format

Results from selected studies of temperate and tropical systems in the U.S. Atlantic, Pacific, Gulf of Mexico and Caribbean Sea were analyzed for evidence concerning attraction and production of invertebrates and fishes. By design, symposium speakers all were invited so as to draw from long-term databases and experimental arrangements. By design, papers in this document are short, because extensive data analyses will appear in the technical literature. And by design, the symposium participants included a mix of managers and scientists to further an oft-neglected dialogue.

The evolution of studies of artificial reefs has been chronicled by international conferences in 1983, 1987 and 1991, all held in the U.S. The 1995 program, in Japan, predictably attracted fewer American workers. The symposium offered a timely U.S. focal

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point to continue technical momentum in this field. (See agenda in Appendix I.) Meeting in Florida — with one–half of all artificial reefs in U.S. coastal waters — was symbolic.

Highlights

The symposium targeted a question that nags scientists, resource managers and research funding agencies. As it turned out, at best the question may be answerable only in part. Please see accompanying articles in this document. Furthermore, participants urged that other issues should command more attention.

The biological enhancement question often is phrased as a simple dichotomy, wherein artificial reefs are perceived to either (1) aggregate fishes, so they are captured more easily, or (2) actually increase size and biomass of a population locally due to new biological production. Familiar examples include the appearance of adult fishes around sunken ships (attraction), and colonization of plants and bivalve molluscs on benthic structure (production). In reality, the response of species to artificial habitat can be characterized along a continuum, albeit one that generally is qualitative and unevenly described.

Fishery managers, harvesters, and scientists lack quantitative and long–term ecological evidence to describe exactly how abundance of marine organisms is affected at many of the world's marine artificial reefs. Such uncertainty hinders long–range planning for reef deployment and regulation of harvest, and raises questions for research. More broadly, artificial habitats offer fishery science a means of manipulating aquatic ecosystems to determine how processes such as reproduction and distribution respond to environmental variables.

A typical assumption of reef construction is that habitat is limited. For example, for fishes an increase in benthic marine habitat might increase foraging and spawning opportunities for adults or new recruits, or increase shelter from predators. If habitat is not limiting, redistribution of individuals (but no change in stock size) might occur. Whereas many fisheries managers and reef users assert that addition of artificial habitat will increase fisheries production, this view is in conflict with some reef fish ecologists who maintain that abundance of most species is limited by recruitment availability. In fact, review of relevant literature produced data and conclusions that support and refute the effect of recruitment on population size. In one setting, declines of fishes associated with coral reefs followed mortality of corals, but most non–corrallivores were not affected. Removal of reef residents has resulted in increased, no, or decreased recruitment depending on the study.

Much of the research on North American artificial reefs includes (1) an initial broad array of investigations characteristic of a young scientific field, including (2) descriptive studies of artificial reefs, mostly short–term (under five years), with no controls and no replication, (3) descriptive studies of natural reefs, with similar limitations as item 2 and focused on non–game species, and (4) experimental studies on reef isolates, and focused on non–game species, with uncertain extrapolation to large reefs. Meanwhile, the accompanying articles draw from the limited long–term database in this area, in line with the symposium objective of assessing whether and how artificial reefs specifically promote increased biomass production of marine organisms, especially species of fisheries interest.

Managers of artificial reefs continue to receive pressure to continue building them. They have diverse — and changing — information needs that can be addressed by science. The production vs. aggregation continuum can be an important factor for them. For instance, public officials will not support a habitat alteration that may be perceived as harmful (e.g., contributing to the decline of fishery resources) by some constituency. In the early years of modern U.S. reef program development (i.e., 1970s), principal information needs of managers concerned the materials and deployments to create effective reefs. In the 1990s reef managers are raising broader questions about population dynamics, community ecology, function of estuarine reefs, socio–economics, etc.

In addressing a focused question of mutual concern, managers and scientists have discovered a new common ground for exchange of information that meets mutual needs. This led immediately to scheduling future and consistent dialogue, and revisiting the U.S. national planning document for artificial reefs. One of the surprising consensus observations by symposium attendees is that artificial reefs still lack acceptance as bona fide tools of fishery management. There are few examples of their integration in overall management plans.

The "attraction–production question," indeed, may not be the most relevant issue for science to ponder, despite its popularity. In fact, resolving it may not be possible in all systems. A more productive approach may be for research to focus on individual species, their life history requirements, and how reefs can be designed to meet life cycle needs. Topics for emphasis include obligate reef organisms, larval transport, settlement, growth and mortality. What processes enhance productivity? Comparison with natural reef systems is essential. In doing so, scientists could enhance the evaluation of how reefs meet the goals sought by managers, and bring the information process full circle.

Follow–Up

We anticipate that a collection of abridged complementary papers will be published in a reviewed periodical, such as AFS's Fisheries, that is widely circulated in the aquatic science and resource management community. Research funding agencies will be availed of the results of this symposium. Findings will be presented to scientific audiences overseas and domestically.

Acknowledgements

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PRESENTED PAPERS

PRODUCTIVITY OF EXPERIMENTAL MODULAR ARTIFICIAL REEFS OFF SOUTHEASTERN FLORIDA

James A. Bohnsack[3], Anne–Marie Eklund,[4] and Alina M. Szmant[5]

Introduction

Artificial habitats are used for recreational diving, breakwaters, solid waste disposal, environmental mitigation, habitat restoration and scientific research. In fisheries, they are used to create new fishing sites, alter spatial and temporal distribution patterns of target species, improve harvesting efficiency, and increase fisheries production (Polovina 1991). The relative importance of whether artificial reefs create new fish biomass or primarily attract fishes (the attraction–production controversy) is considerable, particularly for species that have been depleted by fishing.

It is commonly assumed by many fisheries managers and reef users that reef habitat is limiting, and that the addition of artificial habitat will increase fisheries production. This common view conflicts with the current paradigm among reef fish ecologists that population abundances of most reef fish species are limited by recruitment variability, not habitat availability (Doherty and Williams 1988). For populations depleted by fishing, it is unlikely that adding additional habitat will increase the supply or biomass of fishes and may cause further depletion by concentrating remaining fishes and making them more vulnerable to fishing (Bohnsack 1989). Presumably if natural populations have been reduced, there would be plenty of surplus habitat and food resources available for recruits.

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Scientific Approach

With funding support by Florida Sea Grant, a series of experiments were conducted using modular concrete artificial reefs deployed on sand bottom in 9 to 12 meters of water, off Dade and Palm Beach Counties. Experiments were designed to test effects of nutrient enrichment on primary productivity, and the effects of reef size, habitat complexity, and predator exclusion on the reef fish assemblage of artificial reefs. The effects of nutrients on primary productivity were tested by comparing control reefs to a set of reefs treated with time released fertilizer. Replicates of one, two, four, and eight modules were used to compare reefs of different sizes. Habitat complexity was increased by filling hollow reef modules with concrete blocks, without changing reef size. Wire predator exclusion cages were used to prevent large piscivores from entering the reefs, again without changing reef size. In the reef size experiment, individual fishes were monitored to determine which settled directly on artificial reefs and which were attracted at later stages (i.e. immigrants).

Results

Nutrient enrichment had no significant effect on epibiota because strong currents and relatively high water column productivity favored filter feeders over algae on all reefs. Also heavy grazing pressure by fishes prevented algal growth. The results also suggested that at the scale of the reefs examined, most fishes depend on plankton or the surrounding benthos for food, not the reef itself.

Reef size had a major influence on fish assemblages. Small reefs had higher fish density per unit, while larger reefs had higher biomass density. Fish assemblages were very dynamic with strong seasonal variation in larval settlement and in numbers of resident species and individuals. Total biomass was less variable. The proportion of fishes immigrating to the reefs increased with reef size from 53% to 70% in numbers and from 94% to 99% in biomass. Fishes that settled as larvae accounted for 36% of the total resident abundance but only 2% of the total biomass. Relatively few individuals settled directly on the experimental artificial reefs except for grunts (Haemulidae). Most of the commercial and recreational species were either visitors or residents that utilized the reefs after first settling elsewhere.

Reefs with increased structural complexity had higher numbers and increased species richness over control or "empty" reefs (Eklund et al., in prep.). Predator exclusion cages showed significant and dramatic effects by greatly increasing fish abundance, particularly juvenile fish. When cages were removed at the end of the experiment, predatory jacks began attacking juveniles immediately and population levels declined to those of control reefs within one day after cage removal (Eklund, in prep.).

The Attraction–Production Question

In terms of the attraction and production question, most artificial reef managers assume that habitat is limiting and that artificial reefs will provide critical habitat to promote the production of new biomass through increased growth and survival of juveniles. Many artificial reefs, however, are primarily a fishing technique in which habitat is used to attract fishes in addition to bait. This attraction is not a problem as long as targeted species are not overfished. However, if overfishing is a problem then artificial reefs alone are unlikely to increase production or survival of fishes.

Present research has elucidated certain mechanisms of artificial reef function in the southeastern Florida environment. This research was a partial test of the attraction–production gradient proposed by Bohnsack (1989) in which attraction was predicted to be favored when natural hard bottom habitat was in good regional supply, while increased production would be favored when hard bottom habitat was scarce. Southeastern Florida has considerable hard bottom habitat. Most economically important species, including jacks, barracuda, and most snapper and grouper, are species that first settle inshore in sea grass, mangroves, or other habitats before using offshore artificial reefs as adults. If habitat is limiting, then other settlement habitats are probably more important for determining adult population size. Most individuals that settled on the experimental artificial reefs were species that had little direct economic importance (e.g. grunts, wrasses). These species, however, are important prey fishes for commercially and recreationally valuable fishes. The fact that reef size and structural complexity significantly impacted juvenile fish survival and assemblage structure has important implications for designing reefs for specific purposes: large empty reefs, such as wrecks, may be good for fishing but may not be as good as small complex reefs for enhancing recruitment or survival.

The attraction–production controversy persists despite numerous studies on artificial reefs for several reasons. First, long time series, over broad spatial scales (10's of km), are probably needed to provide a statistically detectable signal over natural variability. In what is perhaps the most definitive study, Polovina and Sakai (1989) used over 30 years of fisheries data in a very large, well–documented artificial reef program to show that artificial reefs increased production only for octopus while production for most fishes varied with recruitment in terms of year classes or were primarily attracted to artificial reefs from surrounding areas. No other study has matched this scale in time or space. Second, studies on large spatial scales are few. Even if reef habitat is limiting, all the artificial reefs deployed in most regions still account for a tiny amount of reef surface compared to natural reefs and thus their impact may be negligible. Third, many studies continue to incorrectly conclude that a higher density of organisms around artificial reefs is sufficient evidence of increased production. Such studies have design flaws or do not experimentally eliminate other mechanisms to account for the same observations. A final reason the debate still persists is that many of the answers coming in are not the ones desired by managers and users.

Future Research Directions

Future scientific contributions and future research possibilities are many. While our research tested the attraction–production gradient in an area with high levels of natural hard bottom, further research is needed to test the model proposed by Bohnsack (1989) in other areas with different species and with different levels of natural hard bottom. The importance of scale needs further research particularly at the large scales. The continuing studies by W. Lindberg and his colleagues in the eastern Gulf of Mexico are good examples of the type of needed research. Currently artificial reefs are only deployed on sand or other soft bottom. It is highly likely that many low–relief hard bottom areas could be enhanced by careful and selective deployment of artificial structures. No research has been done on this possibility, although it remains ripe with potential. The major importance of artificial reef research will likely be to further test ecological theories and models, many of which will have management applications.

Scientific advances will probably be in terms of designing specific artificial structures to meet the needs of specific species, either by reducing predation or increasing foraging efficiency. This approach will require research on the life history and feeding ecology of particular species with the goal of reducing mortality through critical life history stages in specific areas. Currently, the research by Herrnkind and colleagues on spiny lobster is an example of developing structures to meet a specific life history need. The idea of designing reefs to favor particular species remains elusive although certain studies have been encouraging (Patton et al. 1994). There is also a need to examine the possibility of using artificial reefs in marine reserves. The reefs could either be used to enhance "barren" bottoms closed to fishing or they could be built outside marine reserves to mitigate social impacts of closing areas to fishing.

To borrow from the medical profession, the bottom line of artificial reef usage should be to do no harm. Environmental impacts and engineering studies are needed to assess reef stability and degradation of artificial reef materials. Florida and most of the Gulf of Mexico and the southeastern U.S. are frequently threatened by hurricanes. Many reef materials used in the past have been moved, altered, destroyed or have disappeared. In many cases the fate of lost materials is unknown, and movement of large materials could be very damaging to natural reefs and other habitats. Research, monitoring and assessment studies need to continue in order to prevent such losses and damage.

A major emphasis of Florida Sea Grant should be to improve the incorporation of the best science into management actions. Much of the present research has not been utilized by managers and some unacceptable practices are still commonly used. Two examples are the use of large explosive detonations to sink vessels and the continued use of unstable or ineffective materials. In a time of limited funding and limited natural resources, it is particularly important not to waste precious resources on programs that are ineffective or that distract managers from more important actions that will conserve and promote fisheries production.

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ARTIFICIAL SHELTERS FOR EARLY JUVENILE SPINY LOBSTERS: UNDERLYING ECOLOGICAL PROCESSES AND POPULATION EFFECTS

William F. Herrnkind,[6] Mark J. Butler IV,[7] and John H. Hunt[8]

Introduction

We have been investigating the general question of how crucial the availability of crevice shelter is to survival of early juvenile spiny lobsters as they outgrow and leave vegetated settlement microhabitat. Specifically, we hypothesized that, because of their high vulnerability to predators at that size, survival is highest where numerous crevices are available in the immediate area. Therefore, comparatively more juveniles eventually achieve size refuge from most piscine predators (gray snappers, toadfish, etc.) than in shelter–poor areas, a trend that translates into correspondingly larger numbers recruiting into the lobster population.

Our artificial habitat research draws on a decade–long study of ecological processes regulating distribution, growth, recruitment, survival, and sheltering patterns of spiny lobster from postlarval entry into Florida Bay through the first year of benthic life. Several of our long–term field experiments, as well as other quantitative observations, have addressed the issue of whether shelter enhancement increases recruitment of juveniles at the local level. These studies incorporated artificial structures, mimicking size and performance of natural shelters (sponges, coral heads, seawhips, solution holes), to regulate shelter availability and quality experimentally. Results so far show a high consequence of shelter availability to both juvenile distribution and survival.

The ecological role of shelter during the initial juvenile period of crustaceans generally, and lobsters (spiny and clawed) in particular, has been a significant focus of research since the mid–1980's (Caddy 1986, Herrnkind and Butler 1986, Wahle and Steneck 1991). To show increased recruitment (productivity) at the population level in such organisms is extremely difficult because of their crypticity, mobility,

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extensive spatial distribution, variation in larval supply, and general inaccessibility. The Caribbean spiny lobster is one of few species with which one can perform long-term manipulations of both shelter and settlement numbers, permitting strong inference about the attraction-production issue and the nature of the ecological processes involved.

Scientific Approach

Our field experiments are designed to track individuals and local cohorts of newly settled juveniles in Florida Bay nursery habitats through most of their first benthic year. We monitor naturally occurring and introduced settlement-stage juveniles in replicated hard-bottom (sponge, seawhip, red alga) patches with natural and artificial shelter at biweekly or monthly intervals over periods exceeding six months. Techniques include microwire tagging of introduced, newly settled juveniles, marking and monitoring of natural shelters, and deployment of artificial structures (see Herrnkind and Butler 1994, Herrnkind *et al.* 1994, Butler *et al.* in press). Below we summarize findings from a series of such studies conducted over the past seven years.

Results

Our artificial lobster shelter unit consists of two stacked three-hole concrete partition blocks, 10 cm x 20 cm x 40 cm each. Within days or weeks of deployment in the field, the shelters become occupied by juveniles in the same size range as occupy natural crevices and provide an equivalent degree of protection from predators (Childress and Herrnkind 1994). The shelter block units (referred to hereafter as blocks) can remain effective for at least five to seven years, although some eventually become fully clogged by attached biota. These small units are about the size of large sponges and do not attract large predatory fishes, but, like natural crevices, some are used by crabs, small toadfish, and octopus. We have observed a single block to house up to 17 juveniles, although the typical range is 0–5 (mean for occupied blocks is 1.7). The hole size excludes lobsters over about 45 mm carapace length, the size at which juveniles usually become nomadic and leave the settlement habitat (Forcucci et al. 1994).

In an initial field experiment in Florida Bay, near Long Key, we found that adding blocks resulted in a manifold increase in numbers of small postalgal-stage juveniles growing up in three ~500-m^2 sites over a five–month period, as compared to the three similar unmanipulated natural sites (Butler and Herrnkind 1992). Elevated numbers of small juveniles apparently persisted through the following year on the block sites, and some blocks were still being occupied seven years later.

During the recurrent bouts of sponge die–off in central Florida Bay from 1991 to 1993, the percent of all lobsters that occupied blocks on 27 monitored research sites (150–850 m^2) rose from 24% (before the first die–off) to 49% following ~50% sponge loss to 70% following total sponge loss (Butler *et al.* in press). Simultaneously, occupancy of sponges declined from 51% to 17% to 0%. The number of juvenile lobsters on all sites actually increased form about 300 in 1991 and 1992 (mean of 307 in 1991, 337 in 1992) to over 400 in 1993 (mean of 427). Monthly size–frequency distributional patterns indicate that immigration of largely older juveniles (35–45 mm carapace length) accounted for part of the local increase in 1993. However, both the size–frequency data and the continued recapture of growing microwire–tagged individuals we introduced there at settlement stage showed that recruitment and growth were sustained. That is, the blocks effectively replaced the lost sponges as refuge and additionally served as housing for what we believe to be an influx of nomadic juveniles emigrating from the large sponge–less surrounding area.

The Attraction–Production Question

The results analyzed so far indicate that our artificial shelters attract juvenile lobsters in much the same way as natural structure, including crevices in or under large sponges, the most frequently occupied shelters in Florida Bay (Herrnkind 1994). Where natural shelters are present, they continue to be used in the presence of blocks; an individual block or particular sponge is rarely occupied all the time. In this situation, blocks seem to be used indiscriminately along with natural crevices.

If natural shelters are scarce, or become scarce as in the sponge die–off, blocks become the main shelter, favored over other pre–existing structures in the vicinity. Under these conditions, the blocks also sustain juvenile survival and growth following the alga–dwelling period. In one instance, described above, addition of blocks to an area of some pre–existing natural shelter was followed by a substantial increase of small juveniles, which grew up on those sites. We interpret this as a case of increased production stemming from increased survival of juveniles made possible by the additional, easily accessible refuge.

Several other workers have reported results supporting the dependency of early lobster stages on available crevices (e.g., Wahle and Steneck 1991, Polovina *et al.* 1995). As yet the evidence has not been sufficiently direct or unequivocal to prove a production effect due to increased shelter *per se* at the population level. To do so will require not only strongly inferential methodology but also accounting for the effects of other important coincidental factors, especially postlarval settlement magnitude, emigration–immigration, food resources, variation in predation, and variability of these conditions over the range of habitats.

We are presently analyzing data from two field experiments designed in part to test this idea, although, in both cases, disruptions to the ecosystem interrupted the projects. Because of the deleterious impact on juvenile lobsters from the recent sponge loss in Florida Bay, we were impelled to shift research to evaluating both the condition of the entire nursery and to fuller evaluation of artificial shelters as natural crevice replacements. To these ends, we have censused and quantitatively surveyed juvenile lobsters and their habitat from Biscayne Bay to Key West (Herrnkind 1994) and developed an individual–based model (Butler 1994; predicated on measured ecological and biological processes acting on juvenile lobsters) to estimate impacts at local and population scales. Also, we are conducting a large–spatial–scale, long–term field experiment using blocks in the region of total sponge loss. This study is not aimed at the production–attraction issue *per se* but may provide insight into the efficacy of artificial shelters specialized for particular life stages and ecological conditions. The information will allow assessment of such structures as a management tool as well.

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SITING AND DESIGN OF AN ARTIFICIAL REEF AS HABITAT FOR GIANT KELP: ROUTINE SCIENCE OR A RISKY VENTURE

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Abstract

An artificial reef is being planned to mitigate alleged losses of giant kelp and the invertebrate and fish communities associated with a kelp bed as part of an agreement between a State of California resource agency and a California electric utility. The agency required that the reef be built within a specific region, near San Clemente, California; and be constructed of 67% quarry rock (areal coverage) on a sand bottom. The project's first step was to initiate comprehensive siting and design studies. A 25-year time series of kelp surface canopy maps for a 100 km reach of coastline was entered into a GIS data base and analyzed in conjunction with geotechnical and human-use information to define ecologically favorable and acceptable sites in the general area. Design issues were addressed by: 1) comparing natural reefs with persistent and non-persistent stands of kelp, 2) examining the relationship of kelp distribution to various physical features such as bottom relief, and 3) examining the distribution of kelp on artificial reefs in the region. Results - site: a site was chosen near an area that appears most promising in the primary study area, but holds some ecological risk as it has little kelp despite considerable amounts of naturally occurring hard substrate. Results - design: moderate relief reefs (1m to 2.5m) had the most persistent stands of kelp; and reefs with intermediate exposure to sand scour or storm disturbance appeared to have successful kelp communities. By contrast, reefs that are high relief and have little sand disturbance, were dominated by sea fans (Muricea spp.). These long-lived invertebrates appear to preempt or replace establishment and persistence of giant kelp. Based on these design-related studies, we recommend that a low relief (0.5 to 1.5m) reef, with relatively high exposure to sand scour and occasional, partial burial, be constructed in order to promote the establishment of kelp. Scattered rock is proposed for places where there are thin veneers of sand over existing sub-bottom hard substrate. Piled rock is to be used for places where sand thickness is greater. These design recommendations results in less rock coverage than called for in the permit. Reflecting back to the permit, it is now apparent that it specified a design that was too similar to the artificial reefs in southern California that had already been built (over 35 presently exist in the region). This study has revealed that these existing artificial reefs have not typically sustained a persistent kelp bed. Disagreement still exists as to how to best proceed on this project: This conflict could lead to a kelp reef site and design with a high risk of failure.

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Introduction

Southern California kelp beds, dominated by giant kelp Macrocystis pyrifera, host hundreds of species of algae and provide habitat for hundreds of species of fish and macroinvertebrates (Limbaugh 1955, Foster and Schiel 1985, Ambrose et al. 1987, McPeak et al. 1988, DeMartini and Roberts 1990). In addition to the habitat structure the plants provide, kelp contributes substantially to the food chain both directly and through a detrital pathway. For instance, Duggins et al. (1989) showed that over half the carbon in certain predatory fish and birds in a kelp-dominated habitat can be traced to carbon ultimately fixed photosynthetically by kelps.

Off San Onofre, California, 33^{o} 23' N, 117^{o} 32' W (Figure 1), a moderate (1-m) rise in bottom contours over an along-shore distance of about 1 km is capped by a low-relief, cobble-boulder reef that has historically supported a kelp bed. There are several cobble-boulder areas in the San Onofre vicinity. Three areas of special relevance to this study lie adjacent to and southeast of the discharge structures of the San Onofre Nuclear Generating Station (SONGS). Sonar studies of this reef area define a hard-substrate area of 425 acres that on average supports a moderate-density kelp area (>4 plants per 100 m2) of 175 acres (Southern California Edison data - SCE 1993). The presence of kelp contributes to a much larger diversity and standing stock of fish than would otherwise occupy this low-relief reef (Quast 1968, DeMartini and Roberts 1990). It is not known to what extent most of the benthic invertebrates depend on kelp, but many of them probably benefit at least indirectly. Assuming a yearly net production of 500 g C m-2 (Jackson 1977), the San Onofre kelp bed should contribute some 350 metric tons of carbon per year to the coastal food web.

SONGS discharges cooling water to the nearshore ocean and is alleged to have been the cause of environmental perturbations, including the loss of nearby kelp habitat (Figure 1). Units 2 and 3 each have once-through cooling systems with 1100 MW generating capacity and 3137 m3 per min. pump capacity. The intakes are located 970 m offshore, temperature rise over the condensers is about 10.7_C, and discharge is through horizontal diffuser structures, each 750 m long with 63 ports set 2.2 m above the bottom. The Unit 2 diffuser spans from 1795 to 2545 m offshore, at depths of 11.9 to 14.9 m. The Unit 3 diffuser extends from about 1085 to 1835 m offshore, in depths of 9.8 to 11.6 m (SCE 1981, Schroeter et al. 1993). Based on a hydraulic model (Koh et al. 1974) and on actual field experiments (Reitzel et al. 1987), it is estimated that the diffusers secondarily entrain into a rising and spreading plume approximately 10 times the volume of water discharged. Some of this secondarily entrained water carries a naturally occurring suspended sediment load from near the bottom and forms a turbid plume near the surface. Studies performed by the Marine Review Committee (MRC) of the California Coastal Commission (CCC) concluded that this excess turbidity was the chief cause of kelp loss and changes in the hard-bottom benthic community (MRC 1989).

Because of the ecological significance of kelp beds, there have been efforts to protect, restore, and enhance them for over thirty years (KHIP 1963, Turner et al. 1969). Efforts have included some combination of attempts to control herbivorous fish and urchins, seeding of kelp embryos, transplantation of adult and juvenile plants, and the provision of artificial substrates. Upon reviewing these efforts for the MRC, Ambrose (1990) concluded that, while kelp bed establishment on artificial substrates has met with limited success, it ought to be feasible if the right combination of ecological factors can be understood and reproduced. To mitigate kelp loss due to SONGS, Ambrose recommended a low-relief reef, built of 2500 tons of quarry stone per hectare (1,000 tons per acre). Along with this recommendation, Ambrose expressed concerns relating to the physical and ecological performance of such a reef. These concerns became the basis for further recommendations by the MRC to the CCC and were eventually promulgated as conditions on the SONGS operating permit.

Reef Performance Criteria

Condition II.C of California Coastal Commission (CCC) permit number 183-73 (CCC 1989) requires the Southern California Edison Company (SCE) to build a 300-acre reef as mitigation for the effects of San Onofre Nuclear Generating Station (SONGS) Units 2&3 on the San Onofre Kelp bed (SOK).

Performance standards from the 1991 CCC Permit for the kelp mitigation artificial reef are:

1) The reef shall be constructed of rock determined to be suitable to sustain a kelp forest and a community of reef associated biota similar in composition, diversity, and abundance to San Onofre Kelp Bed (SOK);
2) The total area shall be no less than 300 acres;
3) The 300 acres reef shall be covered by at least 200 acres of exposed rock substrate;
4) The reef design shall take into account sediment deposition characteristics of the site so that 200 acres of exposed stable rock substrate will be permanently present, be sufficiently free of scouring to support a diverse and stable community of

attached biota, and allow kelp to become established and persist.

Additional performance criteria listed are (not verbatim):

1) The reef shall not be more than 10% covered by sediment;
2) At least 60% of the reef shall be populated by at least 4 adult kelp plants per 100 m2;
3) Within 10 years of construction, the standing stock of fish shall be at least 28 tons and be otherwise similar in biological character to the fish fauna of natural reefs;
4) Within 10 years of construction, the benthic community shall be similar in biological character to the invertebrate biota of natural reefs in the region.

SCE was instructed to select at least three potential reef sites, preferably in the reach from Dana Pt. to Camp Pendleton, on the basis of the following criteria:

1) Close to SOK but out of the influence of SONGS;
2) Minimal disruption of natural hard substrates and sensitive or rare biota;
3) Suitable substrate with low mud content "(e.g. hard- packed fine- to coarse-grain sand, exposed cobble or bedrock without an established biological community, or cobble or bedrock covered with a thin layer of sand)";
4) Depth locally suitable for kelp growth and recruitment;
5) Near a persistent natural kelp bed;
6) Away from sites of major sediment deposition;
7) Minimal interference with other human uses;
8) Away from discharges and disposal sites;
9) No adverse effects on cultural resources.

Other Relevant Studies

In a review of giant kelp and its environment, North et al. (1986) wrote, "There is a wealth of observation describing circumstances under which Macrocystis is found. Unfortunately we are not always able to explain the reasons for its occurrence or absence at a given location (a constant source of frustration for users and managers). In spite of considerable research on the genus, there remain more than a few factors that are understood poorly or not at all." Work on kelp bed stability continues to be published (e.g., Ebeling et al. 1985, Reed et al. 1988, Van Blaricom and Estes 1988), but a clear recipe for success of an artificial kelp reef cannot be readily culled from the literature. Four "gray-literature", or largely unpublished, bodies of work that were helpful guides to this siting and design study will be briefly mentioned here.

1) From 1967 through 1993 Dr. Wheeler North flew a small plane at low altitude over the kelp beds of Orange and San Diego counties, taking color and false color infra red photographs from which he produced maps of the surface canopies of the beds (North 1991). North's aerial surveys were accompanied by underwater observations of the health of the kelp as well as the general abundance of other kelp bed inhabitants. These surveys have been published by SCE annually (North 1994, and previous year's annual reports). This regional time series of kelp abundance, covering a period of several decades, is relevant to questions of kelp bed stability and siting.

2) Concurrent with the recommendations of Ambrose (1990), the California Department of Fish and Game (CDFG), the lead agency for artificial reef development in California, produced a set of generic recommendations for a kelp mitigation reef for possible application to SONGS mitigation. These recommendations were based to a large extent on a 9-year comparative study of the Pendleton Artificial reef (PAR) and other regional natural and man-made reefs (Wilson and Lewis 1990). The Wilson and Lewis recommendations were broadly similar to those of Ambrose. Both advocated quarry rock and construction aspects were similar. Recommended location was also the same - both advocated placing the reef near an existing kelp bed and on sand or low-relief hard substrate withou kelp, in the area from Dana Pt. to Camp Pendleton. Percentage of bottom covered by rock was also similar (63% vs 67%), but Wilson and Lewis investigated the use o various rock reef heights and assumed a hypothetical ultimate reef size of 375 acre (150 ha) vs the 300 acre (120 ha) reef that Ambrose envisioned for SONGS kel mitigation. Other principal differences were that Wilson and Lewis suggeste design details whereas Ambrose did not, and Wilson and Lewis discussed usin range of rock, ultimately discussing the use of about 4 times as much rock as di Ambrose. Further, both sets of recommendations stipulated that geological an biological surveys of candidate sites be part of any artificial kelp reef study plan.

3) In 1991-1992, SCE contractors performed geotechnical and benthic biologic surveys of seven predominantly sand-bottomed areas at locations deemed t represent viable sites for the SCE kelp reef (Zabloudil et al. 1991, and Eco-M 199 Data included seismic profiling of sub-bottom characteristics (with jet-probe grour truthing by divers), side-scan sonar mapping of substrate and kelp distribution, ar diver surveys of conspicuous epifauna. These results were very useful in the si selection process of the present study.

4) Finally, in a study that ran parallel to this one, Dr. Jake Patton investigated aspects of kelp and sea fan (Muricea spp.) ecology with special attention to the effects of substrate disturbance on the competitive dominance of sea fans over kelp on San Diego County reefs (Patton et al. 1995). To a large extent, Patton's work complements the observations of natural and artificial reefs recorded by this study's investigation. Though the studies are largely empirical, the kelp-sea fan-stability relationship has serious implications for the design of an artificial kelp reef.

Methods And Rationale of the Present Kelp Artificial Reef Siting and Design Study

The kelp reef siting and design study addressed the following questions: 1) where, within the constraints of permit criteria, could a large artificial reef be placed for best ecological advantage; 2) what would be the best design of a boulder-pile reef to support a kelp bed; and 3) what, from a practical engineering viewpoint, is a reasonable approach to this ecologically derived design? The project consisted of essentially four elements: a geographic information system (GIS) database, field ecology assessment, physical monitoring, and engineering studies.

The GIS database was used extensively to compile and analyze information relevant to the first two questions. It was the obvious tool of choice in overlaying all the various site selection criteria. Perhaps more importantly, GIS was used to address questions regarding the persistence of kelp beds that had never been quantitatively studied on the appropriate time scale. The approach was to digitize and compile the time series of maps of kelp canopies that had been produced by Dr. North, and then to "ground-truth" them to the extent possible by overlaying other, more precise but less extensive maps based on sonar surveys of kelp bed areas near San Onofre. While full development of this GIS database took nearly two years to complete, there was a need for preliminary information at earlier stages of the project. A preliminary version of this database was therefore used to design the field ecology study; final siting decisions were based on the fully developed product.

The first component of design was to develop criteria for a persistent kelp bed. The focus of the field ecology program was therefore to try to discern the structural (i.e. geological) differences between reefs that had supported persistent kelp beds and nearby reefs that had kelp canopies only occasionally during the period of record. Obtaining the unexpected result that these two categories of reef were structurally very similar, the study changed course somewhat. The possibility that reef location was at least as important as structure was therefore addressed. Additionally, the poor kelp performance on existing artificial reefs in San Diego County was considered with particular regard to structural features shared in common by these habitats that are not found on most natural reefs.

The final design proposed here in the summary takes into account ecological design recommendations, commonly available materials, achievable construction methods, and reasonable costs, in addition to CDFG, MRC and CCC guidelines. Further, this report summarizes only those results of direct importance to siting and design. Detailed methods, supporting data, and ancillary information are presented elsewhere (Final Report, SCE 1995).

Summary and Experimental Kelp Reef Recommendations

As partial mitigation for perceived ecological damage to a kelp bed attributed to the San Onofre Nuclear Generating Station (SONGS), the Southern California Edison Company is required by the California Coastal Commission (CCC) to build a 120-ha (300 acre) artificial reef as a condition for operating SONGS (CCC 1991). Kelp impact allegations, artificial reef mitigation feasibility, and reef design criteria were based on a previous study by the CCC's Marine Review Committee (MRC 1989). An experimental reef, to be monitored over several years to test the design, is to be built first. The reef is to be built of quarried rock at a site and in a configuration so as to foster the development of giant kelp (Macrocystis pyrifera) along with other normal kelp bed inhabitants. Herein is presented results of this project's initial work: the study to identify the most appropriate site and promising design for the kelp mitigation reef's Phase I experimental artificial reef.

It is recommended that the experimental reef be built at the San Clemente site just north of San Mateo Pt (Figure 2). The area further to the north of this site has had little kelp despite considerable amounts of naturally occurring hard substrate and it is therefore considered to present a high risk of failure for this project. Areas to the south of San Mateo Pt. have human use conflicts or are outside the reach of coastline (Dana Pt. to Camp Pendleton) preferred by the CCC. An area off Carlsbad even further to the south, may also be suitable but is far beyond the preferred reach and may be adversely influenced by a 1995-96 sand replenishment program recently begun as part of the near-by Batiquitos Lagoon restoration program and by a northern San Diego County beach sand replenishment program that is scheduled for 1996.

The San Clemente site consists of 100 acres (40 ha) of sand <1 m thick, 125 acres (50 ha) of interspersed sand and rock without kelp, and 125 acres (50 ha) of sand and rock with intermittent kelp historically present. In the immediate area offshore of this site is a relatively flat sandy bottom where the sand cover is greater than 1 m thick over either a cobble-rich layer or bed rock. This area could also be considered to test the scour/burial potential of various reef rock configurations. There appears to be no option that is clearly within all the CCC requirements and preferences stated in the SONGS permit.

Ecological investigations found that kelp beds in northern San Diego County occur on moderately low-relief reefs, and that the high-relief artificial reefs in this region tend to become densely populated by sea fans (Muricea spp.) to the exclusion of kelp. The success of sea fans on these structures is thought to be due to the low rate of disturbance by sand abrasion and burial afforded by the high rock piles. Therefore, the recommended design for a rock-pile kelp reef in this region is to allow for intermediate disturbance rates sufficient to deter sea fan development but allow kelp persistence.

Two artificial reef module designs, each also testing two rock densities are recommended for the Phase I or experimental reef. Both reef module designs are low relief, in the order of 0.5 to 1.5m:

1) One module application is for placement on areas that are naturally covered by very thin sand lenses, as in areas of mixed sand and rock: single boulders will be scattered. These will sink into the sand until they contact hard substrate such as bedrock or a sub-sand cobble layer, the plan being that the sand will be thin enough, and the boulders large enough, that emergent rock surfaces will be created. These scattered-rock modules will also be tested using two rock densities to assess the kelp attachment (kelp density and kelp persistence) aspects of the experimental reef. These scattered-rock modules will have a rock-to-sand bottom coverage of 25% to 50-60% (Figure 3).

2) On thicker naturally sandy bottoms, the second module design will be tested: small (25 m2), isolated piles or clumps of quarry run (mixed sizes) material. These small structures may be resistant to subsidence, and this is the primary aspects that will be tested. Also, for kelp attachment/persistence assessment, the rock piles will have different spacings (5 m apart and 2-3m apart) in the two variations of the modules, still representing a range of rock coverage - 25% and

60% over the existing sandy bottom (Figure 4).

Engineering solutions to the subsidence problem over deeper sand either use exotic (non-quarry rock) materials or exceed a budget based on the MRC design criteria, or both.

Conclusion

The design recommendations for the experimental kelp reef result in less rock coverage than called for in the 1991 CCC Permit. Reflecting back to the permit (CCC 1989), it is now apparent that it specified a design that was too similar to the artificial reefs in southern California that had already been built (over 35 presently exist in the region - Lewis and McKee 1989). This study has revealed that these existing artificial reefs have not typically sustained a persistent kelp bed. This fact, therefore, makes the Phase I experiment even more critical than originally thought.

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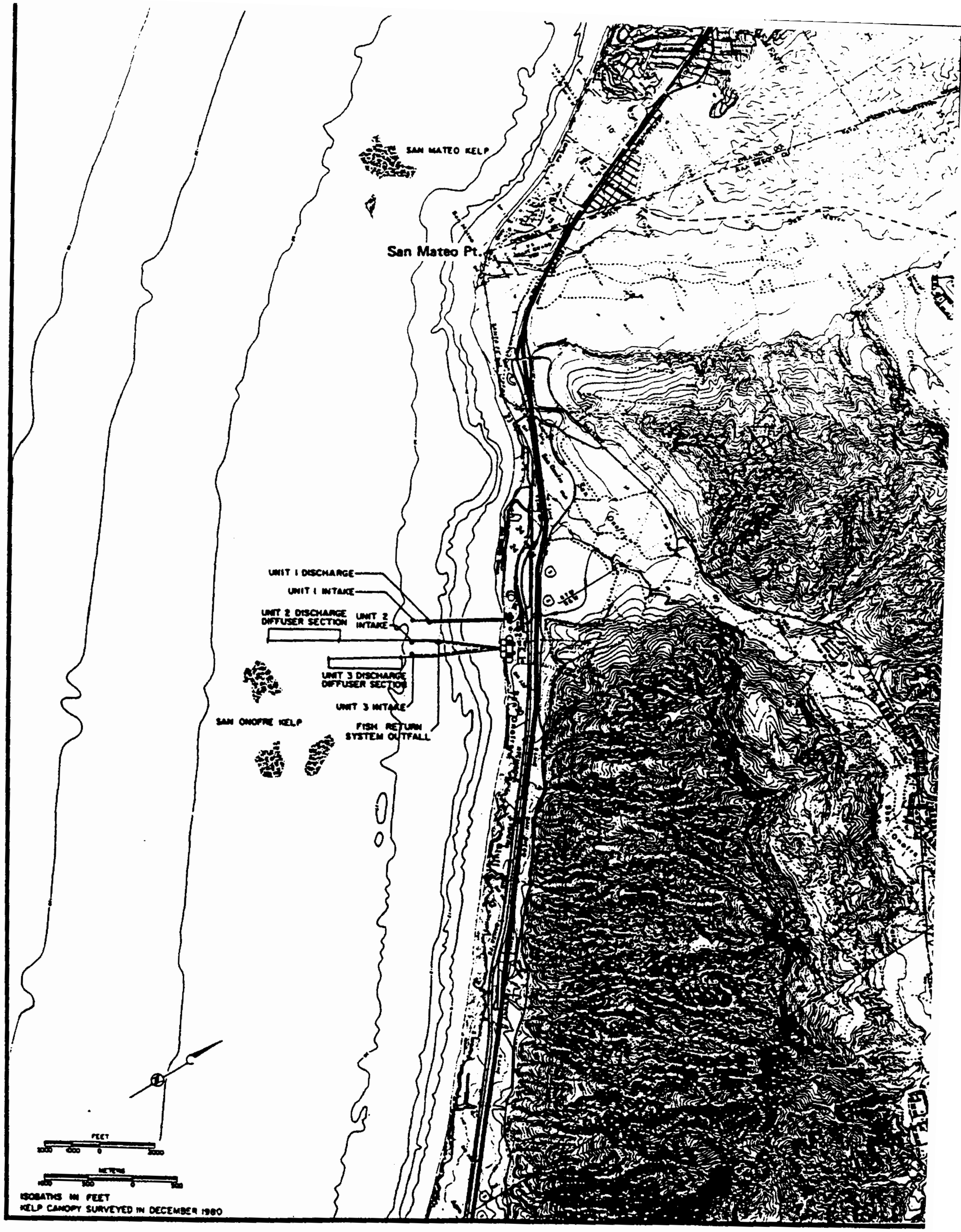

Figure 1:

Location of San Onofre Nuclear Generating Station along the Southern California coast showing positions of the Units 2 and 3 offshore cooling system diffuser discharge pipes with respect to the nearby San Onofre Kelp Bed. The San Mateo Kelp Bed, where the Kelp Mitigation Experimental Artificial Reef is being proposed, is further upcoast at the top of the map.

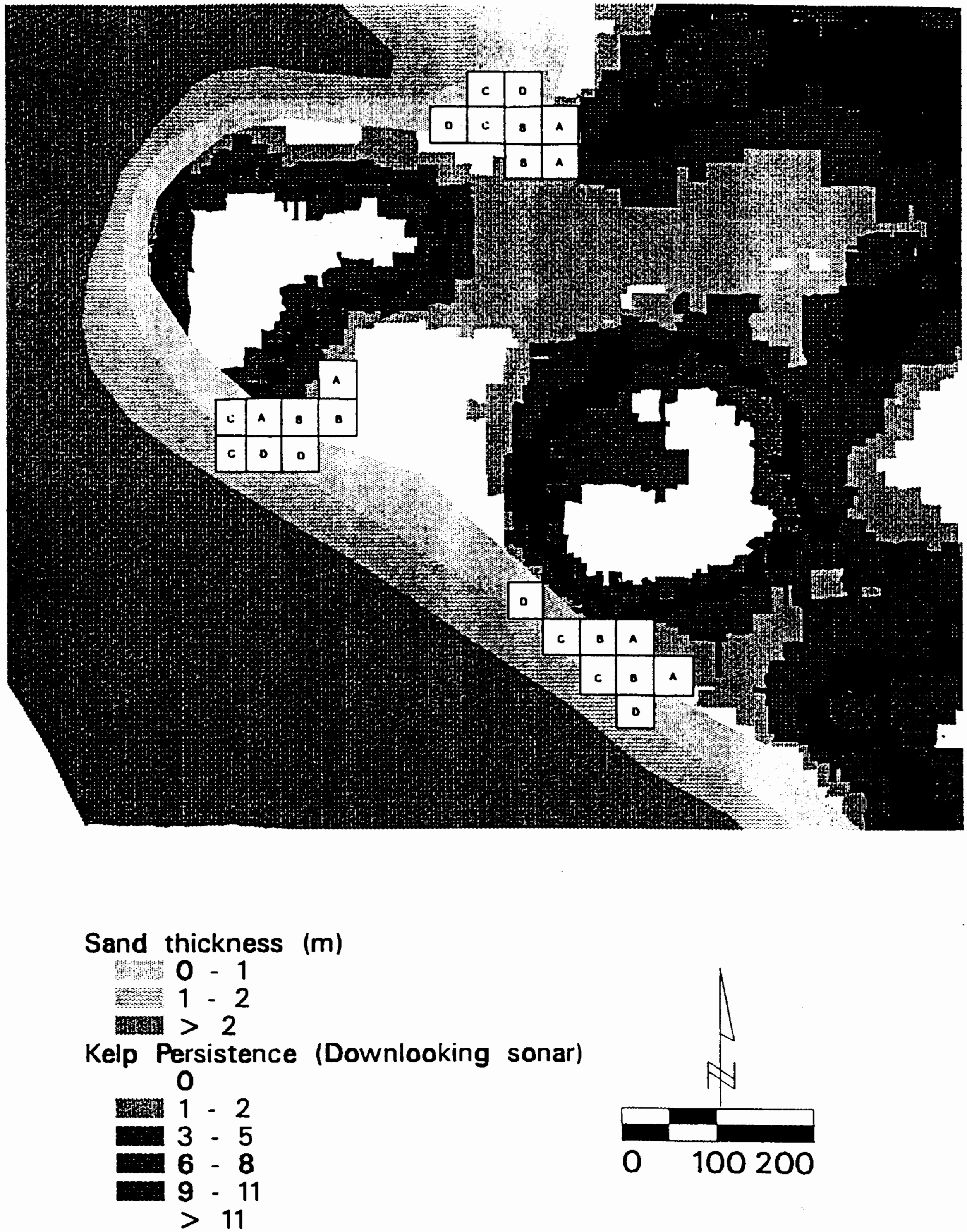

Figure 2:

Experimental reef site showing historically persistent kelp canopy, seabed features surveyed in 1991-92, and approximate locations of the three proposed clusters of experimental reef units. Kelp persistence is the number of downlooking sonar surveys (of 20 surveys taken over 10 years) in which kelp was present in a 50 x 50 m square.

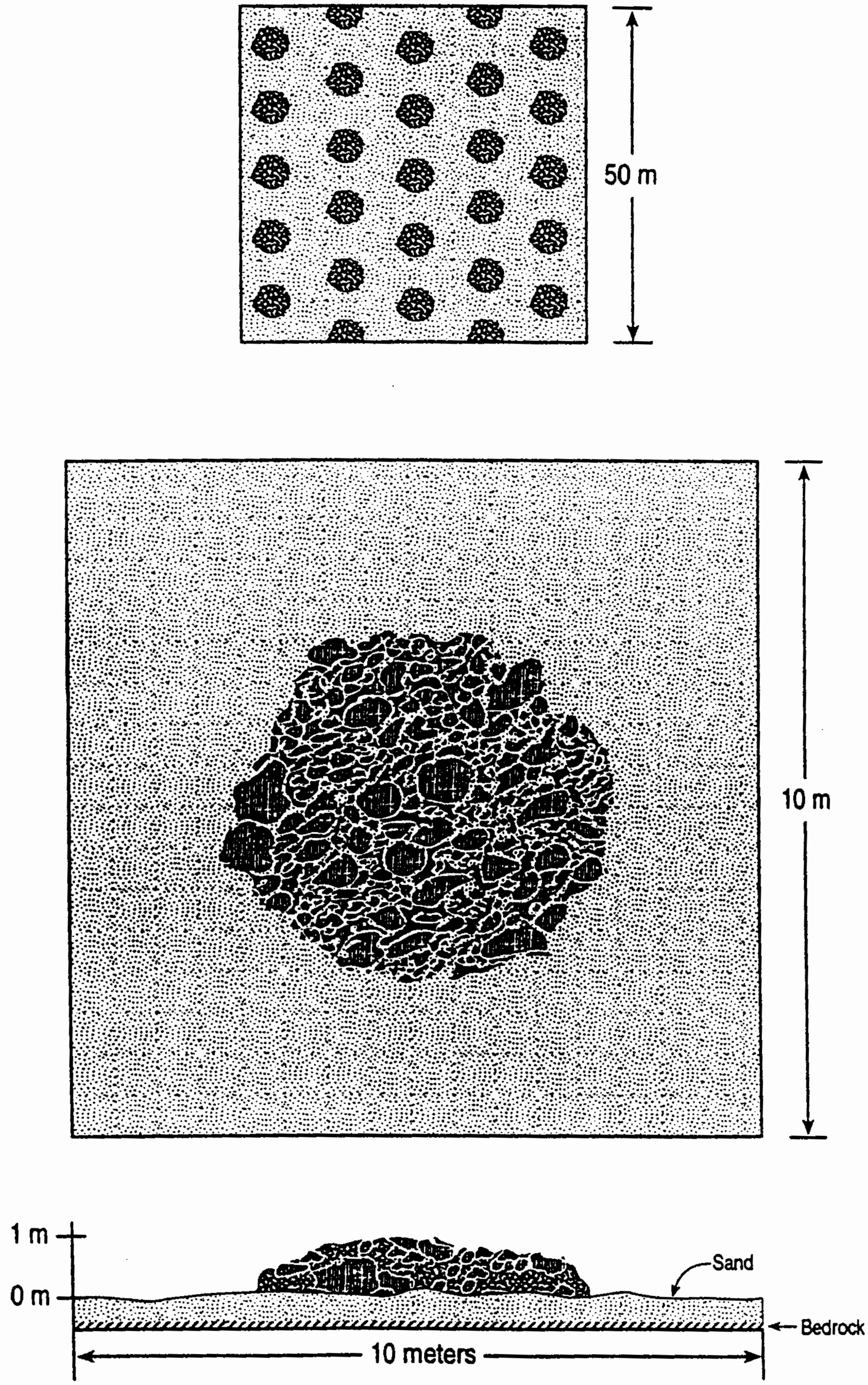

Figure 3:

Drawing depicting the distribution, size, and abundance of substrate in reef module designs for thin sand veneers or lenses over cobble or bed-rock bottoms. These scattered -rock artificial reef modules will be tested at two bottom coverages: 25% and 50%.

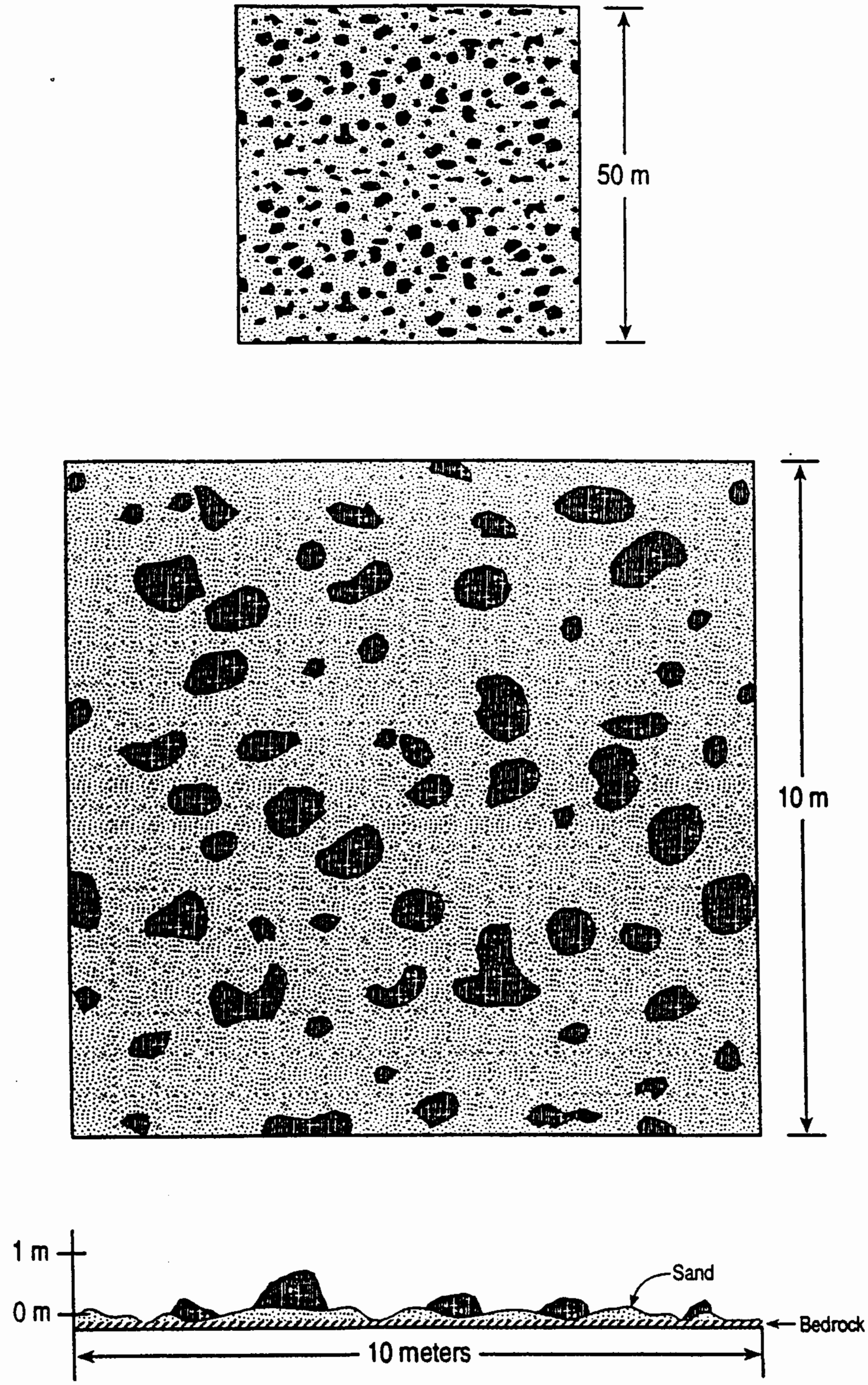

Figure 4:

Drawing depicting the distribution, size, and abundance of substrate in reef module designs for deep-sand bottoms. These clumped rock modules will be tested at two densities, such that the bottom will be covered at 25% and 50-60% rock.

MANAGEMENT PRIORITIES FOR RESEARCH ON ARTIFICIAL REEFS

Mike Meier[13] and Frank Steimle[14]

Introduction

Artificial reef managers can have multiple information needs that can be addressed partially by science. Their needs depend on the specific goals of their ree programs and can involve political, fishery management, and logistical issues. They also can vary with the local or regional situations within which they have to operate, such as tropical vs. temperate environments. The reef resource productio vs aggregation continuum can be an important factor for reef managers in most o their program goals. Politicians do not want to be found supporting a program tha may be deemed harmful (e.g., contributing to the decline of fishery resources) by some constituency. Even logistical-engineering issues involve making decision about processes or designs that best support management goals, such as cost-effectiv ways to achieve better or sustained fishing results, which involve the resource an economic benefits of various logistical or engineering options involved in plannin and developing artificial reefs.

To begin our discussion of research priorities, we review the evolution of th information needs of reef managers. In the early years of reef progra development, the major information needs of reef managers were primarily wha types of inexpensive material and deployments could be used to create effectiv reefs, i.e., long-lasting and supporting a fishery. There was also a general interest i understanding "how reefs worked" and what kinds and how many fishery resourc were found on these structures. As many reef fishery resources were obviousl declining by the 1970s and thereafter, and were heavily targeted by both commerci and recreational fisheries, resource managers and biologists became concerned abo the level of understanding on what the new reef habitats or programs real contribute to fishery resources. Reef managers, if they were not also the reef fishe resource managers, quickly became involved in this concern, and still are, evident from this symposium.

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Artificial reefs are generally considered to be a relatively "new" technological approach to fishery resource management, although the concept has been used for hundreds, if not thousands, of years in various parts of the world. As a perceived "new" technology, there has been a flourish of bio-mechanical research to develop cost-effective and apparently productive artificial reef unit designs. This is to be expected because a design that appears successful can be patented and sold. This search for the best reef designs, and general reef ecological studies, have dominated reef research in recent years. Because of the nature of the limited funding for this type of research, these studies tended to be relatively short (1-3 years) and restricted in scope.

Background

The National Artificial Reef Plan and provocative articles or viewpoints on artificial reefs by Jim Bohnsack and a few others in the mid-1980s, started many reef managers thinking beyond the logistical or political aspects of their programs, which usually engaged most of their time. Also at this time, the Atlantic States Marine Fisheries Commission (ASMFC) established an Artificial Reef Advisory Committee to bring together reef managers, and, collaterally, the former Sport Fishing Institute (SFI) established the Artificial Reef Development Center (ARDC) to promote the sharing of information and resolution of common problems. The production vs aggregation issue quickly became a focus for much discussion within these groups, and within several Fishery Management Councils.

Discussions within the ASMFC Reef Committee, in concert with SFI's ARDC, resulted in several summaries of what was being done with artificial reefs, at least along the Atlantic coast, and some guidelines or standards for use by reef programs. With these summaries there soon grew a concern that critical information was not readily available that could provide sufficient guidance for reef managers. In 1989, the ASMFC Artificial Reef Advisory Committee decided to survey 120 reef managers across the nation, with some international inquiries, about what they considered to be the major information deficiencies or gaps which inhibit better use of artificial reefs. The results of 28 responses were summarized in a report (Steimle and Figley 1990). The summarized reef information needs focused on ten topic areas, within each of which were several questions that responders thought needed to be addressed. We do not know how representative these responders were of the overall reef manager community but assume those who had strong information needs made the effort to respond; undoubtedly all reef managers have some information needs.

It is apparent from this list that reef managers have been aware of the need for additional information, even though these needs were frequently not stated very clearly or precisely (the report compilers used minimal editorial license in compiling the list). Many of the managers' information needs were practical, and reflected a need to be more effective and efficient in developing their reefs and documenting benefits. Many of the coarsely stated needs also reflect a concern for the effect that the reefs have on fishery resource populations and sustained use. Directly or indirectly, the production versus aggregation issue is part of many of their concerns and information needs.

Artificial Reef Research Needs

This section presents an updated version of the 10 general areas of concern summarized by Steimle and Figley. The original "Atlantic Coast" work has been augmented with input requested from Gulf and Pacific coast reef researchers and managers in order to present a more complete picture of perceived current artificial reef research needs.

Estuarine Applications

A primary interest expressed by reef program managers was the use o artificial reefs in estuarine environments. They were concerned as to whether or no artificial reefs would be productive in this highly variable environment and i artificial structure can be provided which will support the needs of various lif stages of estuarine dependent fishery resources. It may well be that man-mad structure may be more valuable to resources other than finfish.

If reef development is considered in estuarine waters, what designs might b most effective in providing supporting habitat for finfish and other resources upo which they depend; i.e., is it feasible to think that we can tailor reef structure t provide additional habitat suitable to the support of a particular life stage? Can th research community help reef managers identify stages at which artificial habitat might play a supportive role? If this type of design may be possible to conceiv under what conditions should these various types of habitat be provided an where? If we try to tailor reef modules to life stages, do we need to be concerne with the prospect of creating artificial feeding areas for higher predators during particularly vulnerable stage? Does any list of siting criteria that considers suc things as access, shipping lanes, other users, etc., need to be rethought and augmented? Reef program managers are concerned with the role that their activities might play in the estuary. This brief list only scratches the surface, and, as you will see, it is hard to separate many of these issues from other areas of concern, discussed below, as there is always some overlap in the areas covered by this and other topics.

Community Ecology

Understanding community ecology was expressed as the #2 concern in the "survey". Reef managers want to know if habitat is a limiting factor in reef fish abundance. Are there thresholds in terms of footprint (area of seabed covered by an artificial reef), "edge" habitat, aspect ratio, cubic volume, etc., which need to be exceeded to provide effective habitat? How much is enough? What is the relation between reef size and function?

We are also interested in the specific ways reefs are used by the various resource species. What are their temporal abundance patterns on reefs? What are the environmental factors that influence species composition on reefs? Are there interactions among species present on reefs that affect the "success" of reefs or their management? How does the surrounding habitat affect reef ecology and overall success in supporting fishery management objectives? Does the presence of a reef affect adjacent non-reef habitats and communities, and how? Along these lines, what is the effect of the presence of various sized and dispersed artificial reef structures on nearby natural reef communities or populations?

Reef Population Life Histories

In this third area of concern, reef managers want to know if artificial reefs support juvenile recruitment. If so, how? What is the mechanism involved? In general, do they recruit but become significant sources of food to other organisms? Do artificial reefs enhance the growth rates of resource populations? What species might use artificial reefs for spawning and where and when? Where and when do juvenile reef resources need reef-type or other sheltering habitat?

Concerning resource populations, what is the average residence time and what are the migration ranges and normal pathways, where applicable? While populations are utilizing artificial reef habitat, is there a difference in natural mortality as compared to other (natural) habitats?

Bioengineering and Designs

This area is more "nuts and bolts" in nature. Most reef programs hav developed structures on their own as part of a community wide attempt to crea the "holy grail" of reef modules and designs (most effective use of materials, etc.). some cases, stability was the major design criteria. In others, cost effectiveness, terms of processing and materials cost, availability, difficulty of fabricatio equipment involved, etc., were the overriding concerns. Whatever the paramete managers can always use outside input on improvements.

As previously referenced in 1) "Estuarine Applications", managers a interested in knowing if artificial reefs can be designed or used to specifica address the needs of specific resources' life stages, such as juvenile recruitme How important a factor is material surface in terms of composition, finish, etc., colonization? Are there differences among various types of reef materials; such steel vs plastic vs concrete? What might be the various cost factors among vario materials and designs as they might apply to specific program goals and regions; i desired life expectancy, stability requirements, quantities required, availability, etc.

In considering the use of "new" materials, managers are aware of the need address the potential of some of these materials and designs to have detrimen effects. How do we address this concern. Merely having materials of opportun available that are cheap and in large quantity is not enough. Also under the gene "engineering" heading, managers want to know the effect of reef designs on use a harvests. Can user conflict be reduced or resolved by appropriate reef designs? C management goals, such as development of not-to-be-fished "sanctuary" supported through appropriate design? As noted earlier, managers want to knov past siting criteria need to be rethought and developed past current standards address concerns about the effect on natural environments, currents and sedim transport, benthic communities, etc.; especially in different environments a socioeconomic conditions.

Harvest Analysis

Managers are interested in knowing what resources come off reefs and h they are taken , as well as the overall effect on what's left. This type of informat helps us to answer the "how well, do they work?" questions.

In general, managers are concerned about the long-term effects of "their" r on the overall fisheries they affect. We need data defining the sustained harvest fishing effort on reefs by user groups. This information will help assess the potential for artificial reefs to encourage or abet the overfishing of a resource. Along with providing CPUE data, this type of analysis will aid in deciding what regulations, if any , may be needed. Managers stated that they also need to know the long-term effects of reef design, size and location on sustained harvests. They are interested as to whether or not artificial reefs can be used as resource conservation tools without active enforcement. What are the long term effects of FADs, refuges, or SMZs to fishery populations?

Concerning the user part of the equation, managers want to know which types of gear are most effective harvesters of reefs and whether or not lost gear, commercial and recreational, is a problem.

Reef Population Dynamics

The most needed information in this category is reef resource recruitment rates and variability along with the source of the recruits. Managers feel that an overall definition of the structure and dynamics of reef populations "in general" is very much needed to develop an understanding of the "mechanics" involved.

Managers want to know if spacing of reefs and the materials thereon have an effect on juvenile recruitment and whether or not the condition (height, complexity, overall size, epi-faunal state, etc.) of a reef affects its use by resources. Is a difference in epifaunal colonization rates and biomass important in reef utilization by reef species?

A major concern is that of reef resource population structure; i.e., does the population structure of reef fish and shellfish differ from that on natural habitats? Does that structure and the temporal population dynamics differ from those of the rest of the population in a region and is this difference reduced or increased with time as artificial reefs mature?

Socio-Economic Evaluations

This is an area often overlooked by resource managers in general. Unfortunately, the artificial reef development community has, in some respects, fallen into the same category. Projects have been undertaken from time to time, on a variety of scales; however, follow-up is rare.

Reef managers perceive their socio-economic information needs to be rathe basic. They want the public benefit of their programs documented. They want t know who uses the reefs and to what extent. There is a need to know the fiscal cos benefit relationships among various reef types and materials, designs an deployment methods (fads vs benthic, estuarine vs inshore vs offshore, etc.), an whether or not these can be related to fishery productivity or other factors such a user accessibility. Managers need to know if artificial reef fisheries can really b regulated and, if so, at what cost in terms of dollars and effort. Also, they nee information on the existence of reef user conflicts and how to best manage ther We need to know the trade off between user benefit (harvest) and the resultan effects upon the resources i.e., are the reefs overfished? As managers of resourc belonging to the general public, we would like to know if "commercial reefs" a feasible.

Reef Resource or Community Production

In considering resource population and overall community productivity, v need to know the relationships between the size of a reef and its "productivity" terms of standing stocks, overall yield to fisheries and growth and survival rates. expressed earlier "how much is enough" and, also, what constitutes "enough Should enough be expressed in terms of substrate, cubic yardage, etc? Along the same lines, does the "Law of Diminishing Returns" apply to reef productivi especially fishery resources, relative to reef size? Studies based upon a single cul yard of "reef structure" may not apply to local, county and state programs w measure deployments by tonnage. What are the environmental parameters f productive reef? Food webs need to be quantified and trophodynamic mod (energy/carbon budget) need to be developed to understand how much and wh kinds of food must be available to support sustained reef resource populations.

Managers are interested in having quantitative data as to the "productivi (biomass production, yield, standing stock, etc.) of reef fish and invertebr communities to enable comparison with the habitat that is being "replaced" (also sections 2. Community Ecology, 10. Mitigation). Managers also expressed the need know the effect of a reef on the productivity of adjacent natural reef and non-r habitats as well as whether an artificial reef affects primary productivity direc (through the support of attached algae) or indirectly (through the increased sup of nutrients to the phytoplankton) and under what conditions.

Reef Data Acquisition and Distribution

Concerning the availability of data, reef managers are asking whether existing data bases are adequate for any type of predictive modeling of effectiveness of reef designs, or do we need to start in another direction. Also, should a national artificial reef database, such as that started by the former SFI-ARDC be re-implemented? Where data needs to be acquired, can effective but "cost" effective standard methods be formulated, especially to reduce high labor costs, such as in the use of divers? Accordingly, can standard assessment or monitoring procedures be developed and used to produce comparable data? Is there a problem with the timely distribution of reef information to reef developers and managers?

Artificial Reefs for Mitigation

The issue of using artificial reefs as mitigation for the loss of dissimilar habitat has been and will continue to be a controversial topic. Attempting to replace "like for like" is difficult enough. Developing wetlands comparable to those of nature has proven rather elusive. The difficulty is usually compounded when a situation arises (which is usually the case) in which artificial reefs are suggested as replacement for some other type of habitat loss. After all, how many artificial reefs have been built to replace other artificial reefs that have been lost due to development? In any event, reef program managers are usually the ones called upon for recommendations when these situations arise. Accordingly, reef managers are interested in the investigation of what habitats or resource communities can be "replaced" by artificial reefs (habitat). They are also asking if equivalent reef (mitigation) units can be determined and tested for replacement of various types of habitat being lost or degraded. We would also like to know if a reef ecosystem changes the flow of nutrients (carbon or others) into products deemed more important to man, than other products, i.e. would we rather have tautogs and sea bass, instead of herrings and hogchokers? Is what we "want" necessarily a good trade?

Conclusion

Reef managers want their reefs to have maximum sustained beneficial results at lowest costs and want to avoid situations where the reefs are found detrimental to reef resources or fisheries. Artificial reef program managers are aware of the fact that there is "no such thing as a free lunch". Accomplishing some of this goal depends on the reefs being able to provide for the needs of reef resources so they decrease natural mortality by providing shelter, increase survival and growth by providing food resources, i.e. support reef population productivity at a level equal or greater than harvest (fishing mortality) rates. To achieve these goals reef managers must have information on what types of reefs (material, design, size, location, etc.) are most and least productive in terms of balancing resource productivity to match harvests. In their efforts to accomplish these goals, reef programs address public user needs and use public resources, thus the application of resources that best addresses the public's need must be a prime focus of research.

Reef resource biologists who address the reef resource productivity issue must consider the habitat needs of all life stages of species that are reef-users at some point in their lives. Many "reef" fish use estuaries or other shallow water coastal habitats as juvenile nurseries or specific non-reef, offshore areas for spawning, and the recognition, conservation or enhancement of these habitats must be a prime research and management concern. The recruitment of juveniles to reefs to replace harvested adults may be entirely dependent on the condition and productivity of non-reef estuarine nurseries. The condition and availability of adequate suitable habitats between these nursery areas and offshore reefs also needs to be understood and considered in habitat management planning. In cooler temperate waters, where reef resources often leave estuaries and inshore reefs in coldest seasons, the wintering habitats of juvenile and adults need to be adequately known and these habitats and the resource use of them considered in planning research resource management.

There is a need to refine these managerial (reef and reef fishery) concerns for adequate information upon which to make decisions and develop public policy. Along with this, there is also need to review and summarize the extensive published literature base to see how well past and current research addresses their priority concerns. This is a bigger job then can be done here at this forum, although it is certainly doable and should be done. The review must go beyond the reef focus and include the life histories and habitat needs of all life stages of "reef" resources. Bill Seaman continued the process, started by Jim Bohnsack and others when he and selected writers summarized the state of research (Seaman and Sprague 1991); more is needed.

The process must continue with an improved dialogue among reef managers, those engaged or considering reef research, and the agencies capable or responsible for providing support for reducing information gaps. A good place to start this dialogue is through the respective coastal fishermen commissions, and state and local artificial reef programs. The SFI-ARDC artificial reef bibliography must also be finished, indexed, annually updated and electronically accessible in order to suppor its effective use by managers and researchers in finding artificial reef information and defining information deficiencies. There must be good reviews and summaries of the life histories and habitat requirements of all life stages of significant reef resources. Artificial habitats are too frequently used as fishery or habitat management tools and most reef resources are too heavily exploited to not have good state-of-the-art, information that is strongly relevant to management needs. Artificial reef programs will continue to function and the use of artificial habitats will expand, partially because of socio-political forces. At this writing, there are more than 325 permitted artificial reef sites along the Atlantic coast alone, approximately 40% of which have been developed within the last 10 years (Heins, 1995). Scientists, reef managers and funding agencies must work together to focus resources on assuring that the information base for making decisions on artificial reef use is at most up to date and comprehensive, and, at the very least, adequate.

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HOW REASONABLE IS IT TO ASSUME ENHANCED PRODUCTIVITY BY ARTIFICIAL REEFS, BASED ON EXPERIMENTS IN THE EASTERN GULF OF MEXICO?

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Introduction

If artificial reefs are to enhance populations of exploited species, they must somehow increase rates of growth, survivorship, and/or reproduction relative to the available natural habitat, and must do so sufficiently to offset any increase in fishing mortality they promote. We do not believe that a direct test of artificial reef effects on fish abundance can be accomplished at the level of fishery stocks or breeding populations. Neither stock-sized experiments nor fishery monitoring for empirical models are practical for the issue of attraction-production, given the great scale of most marine fish stocks relative to the limited scope of artificial reef development. Instead, we must rely on indirect tests of the broader issue by testing more directly the mechanisms or processes that *might* be enhanced by artificial reefs. In this respect, the research community represented at this AFS Symposium has been engaged in a process of elimination tantamount to Platt's (1964) testing of multiple working hypotheses.

Others have experimentally tested specific hypotheses pertaining to: larval fish settlement (Bohnsack et al. 1994), post-settlement demographic bottlenecks (Herrnkind and Butler herein), refuge from predation afforded by reef complexity (Hixon and Beets 1993), the behavioral attractiveness of artificial structure compared to natural structure (Hixon and Carr herein), and bottom-up processes of primary and secondary production within reef structure (Bohnsack et al. herein).

For our part, we have begun a program to test whether ecological processes involved in the trophic coupling between reef fishes and off-reef prey might be

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enhanced by artificial reefs. Earlier work (Lindberg et al. 1990, Frazer et al. 1991, Frazer and Lindberg 1994) led to our general three-step hypothesis: (1) We assume that reef structure provides motile species refuge from predation, and perhaps from currents. (2) Reef-dwelling species that forage off-reef on sand-dwelling benthic prey are expected to create a gradient of prey depletion around their refuge, resulting in a negative feedback to the reef-dweller's energy budget, residency, and local abundance. (3) The patchiness of reef habitat is expected to affect the degree of prey depletion and the intensity of negative feedback, such that smaller, more widely spaced patch reefs may be more favorable to such reef residents than are larger, more closely spaced patch reefs. Lindberg et al. (1990) termed this the "resources mosaic hypothesis". A theoretical foundation for this conjecture of how reefs might function can be found in mating system theory (e.g., Orians 1969, Emlen and Oring 1977), "ideal free distribution" theory (Fretwell 1972, Milinski and Parker 1991), and "density-dependent habitat selection" theory (MacCall 1990), all of which are variations on the same theme.

Scientific Approach

The Suwannee Regional Reef System (SRRS) was built to test the resource mosaic hypothesis experimentally on spatial scales deemed appropriate for reef fishery species of the region. The SRRS is located in the northeastern Gulf of Mexico, 24-29 km offshore from the mouth of the Suwannee River, with 22 reef sites approximately 2 km apart along the 13-m depth contour. Each reef site contains an hexagonal array of patch reefs spaced at either 25, 75 or 225 m. All patch reefs within an array are the same size, either 4 or 16 standardized cubes (i.e., 0.7 m^3, large central cavities, smaller corner holes). Our core experiment involves 16 of the 22 reef arrays in a 2 x 2 factorial design (i.e., 4 vs. 16 cubes/patch and 25 m vs. 225 m spacings). An entire reef array is one replicate.

Fish abundance and biomass estimates were obtained from total visual fish counts, which included modal size estimates for calculations of biomass (after Bohnsack and Bannerot 1986). Fish counts were done winter and summer for 5 years beginning in 1991. Densities of benthic infauna were estimated by standardized replicate core samples taken at distances of 1 m, 10 m, 25 m, 50 m, and 75 m from each of two patch reefs per reef array. Benthic coring was done winter and summer for the first 3 years.

A proper statistical analysis of these data requires that time also be considere in three ways: as repeated measures, as seasonal cycles, and as trends over time. A the time of this writing, we are collaborating with a statistician[18] to use gener linear mixed effects models in a stepwise component selection process. Here, w report selected *preliminary* analyses that (1) portray trends over time irrespective experimental treatments, (2) give one example of results from the mixed effec modelling approach, and (3) bypass statistical complications with time (i.e seasonality or trends) by using data from just one sampling season in an analysis covariance (% cover of surrounding hard-bottom habitat as the covariant).

The general research strategy has been to proceed in phases, to test first f treatment effects on fish abundance and biomass, and for effects on the patterns potential benthic prey. Then, if warranted by the results, the program wou proceed to more direct and intensive tests of reef effects on fish production ar trophic pathways. Here we present only the first 5-year phase.

Results

As a preliminary test for benthic prey density gradients, infaunal densiti were compared across the 5 distances from reef patches and non-reef control sit Species were pooled within functional groups defined by living position and feedi mode, because of high species richness (approximately 600 total species, includi 226 polychaetes) and high variability in species richness or composition amo replicate cores or between sampling seasons. Most species were rare. In 1992, the was evidence for effects of distance, with suspension feeders trending towards low abundances near reefs and burrowing forms exhibiting a mixed pattern (Fig. 1). I the suspension feeders, infaunal densities at 50 m and 75 m did not dif significantly from control sites, yet the densities at 1, 10 and 25 m did differ fr non-reef controls ($p<0.05$, ANOVA and Tukey's Studentized Range comparison).

Over 5 years, a total of 85 species of fish were censused, with the top 20 spec accounting for approximately 95% of total fish numbers and total estimated biom During this time period, the abundance of gag, *Mycteroperca microlepis*, increas substantially while other common species such as black sea bass (*Centropris*

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striata) declined (Fig. 2). Black sea bass were also more abundant in winter than in summer. Schooling baitfish such as herrings (family Clupeidae) occurred at the study reefs only during warmer months, and increased in abundance from one year to the next. A doubling in gag numbers coincided with a marked increase in clupeids during the summer of 1995 (Fig. 2).

For gag, the statistical model of best fit was derived from a general linear mixed effect model with covariance in time structured as a time-series rather than a split-plot or repeated measures model. The forward selection process for significant components identified an effect of season ($p<0.002$) and an interaction between patch reef size and the trend over time ($p<0.0002$). Gag were more abundant during summers than winters, and gag abundance increased at a greater rate on 16-cube patch reefs than on 4-cube patch reefs (Fig. 3).

Preliminary tests for reef treatment effects, using the summer of 1994 when n=4, suggested that some fish were affected by patch reef spacing (black sea bass, $p<0.10$, and tomtate, $p<0.05$) or patch size and spacing without significant interaction (pooled herring species) (Fig. 4). Clupeids were more abundant ($p<0.05$) at 16-cube patch reefs than at 4-cube patches, but effects of reef spacing remain unclear ($p<0.10$, Fig. 4). These and other species or groupings will be further analyzed by the statistical approach applied to gag above.

The Attraction-Production Issue

This first phase of research had the potential to disprove the resource mosaic hypothesis, and thereby eliminate from further consideration one mechanism by which artificial reefs might benefit fish. At this point, the hypothesis, and therefore the possibility of enhancement by reefs, remains viable. Yet, we must consider our first test to be weak relative to the attraction-production issue because, so far, we have tested only local fish abundances, standing stocks, and infaunal densities rather than direct measures of production or productivity. By contrast, alternative hypotheses about how artificial reefs might function have been tested and rejected by others (e.g. inherent attractiveness of artificial reefs over natural reefs, Hixon and Carr herein; bottom-up enhancement of primary and secondary production, Bohnsack et al. herein; limitation of larval fish settlement habitat, Bohnsack et al. 1994). So, in keeping with Platt's (1964) concept of strong inference, the ecological processes by which artificial reefs might enhance the coupling of reef fish to off-re prey production deserve serious consideration.

While claiming that our original hypothesis has survived its first test, v must also be clear that it requires some modification. The phenomenal increase gag abundance on the Suwannee Regional Reef System over the first 5 years of tl project was unanticipated. In part, we attribute that increasing abundance superior shelter characteristics of the reef cubes compared to most natural ha bottom habitat of the region. In this respect, our thinking about how reefs functi merges, in general, with Herrnkind and Butler's (herein) hypothesis regardi demographic bottlenecks. With respect to our hypothesis of benthic prey depleti negative feedback, and effects of habitat patchiness, some fish species responded reef treatments as expected, but gag did not.

It appears that our patch reefs fostered a localized abundance and persiste of schooling planktivorous fishes (e.g., herring) during the warmer months, a that resident gag could feed perhaps to satiation from such pelagic producti Treatment effects on the gag and baitfish indicate that reefs can manipulate su relationships. Although our general hypothesis must now be altered to inclu coupling to pelagic, as well as to benthic prey production, it is important to recogr that pelagic production ought to be less prone to prey depletion than the off-r benthic production. In the terms of ideal-free distribution theory, coupling to pelagic compartment should be closer to a continuous input model, while coupl to the benthic compartment may have qualities of a fixed input model.

Our results to date, and the logical framework in which these data interpreted, suggest that an enhancement of biological production (i.e., growth a survivorship) by artificial reefs might be possible. Whether such production wo be sufficient to offset fishing mortality remains to be seen. Furthermore, a very possibility exists that our findings may not apply to artificial reefs in general. instance, gag may be more amenable than the top reef-dwelling predators of ot systems to a switching between benthic and pelagic prey, triggered by p availability. The SRRS was also built to bracket a suspected influence of Suwan River outflow, whereas other reef systems may not have comparable pela production. Obviously, we must be careful not to extrapolate beyond the infere space of this study.

Future Research Directions

A second phase of research in the Suwannee Regional Reef Program is already underway. The primary goal is to quantify residency and movement patterns for juvenile-to-adult gag occupying the SRRS, and to determine if reef habitat patchiness and fishing pressure affects somatic growth rates and relative weights, as direct measures of production. The secondary goal is to test the effects of gag fishing mortality on reef fish community structure, as top-down community controls might affect off-reef coupling by other species.

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COMPARING ARTIFICIAL REEF AND NATURAL REEF COMMUNITIES

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Introduction

Comparing communities on artificial reefs with those on nearby natural reefs is essential to answer two important questions (see Bohansack and Sutherland 1985, Seaman et al. 1989, Seaman and Sprague 1991, Pratt 1994).

The *"mitigation" question*

Does the community inhabiting an artificial reef mitigate the degradation of or otherwise mimic a natural reef community?

The *"attraction-production" question*

Does an artificial reef merely attract organisms that would otherwise grow equally well (if not better) on nearby natural reefs if the artificial reef was absent? *or*

Does an artificial reef provide a habitat for increased production that would not otherwise be possible?

Our research examines both questions

The *"mitigation" question:* comparison of colonization rates and community structure of artificial and natural reefs without the confounding effect of the surrounding habitat: experimental data from Bahamas (Carr and Hixon 1996).

2. *"attraction-production" question:* comparison of production of artificial and natural reefs provides the *only* means of answering the question: observational data from Virgin Islands (Beets and Hixon 1994).

Mitigation Question

Rationale: Because natural reefs are in place long before artificial reefs are

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constructed, the surrounding habitats of the two reef types are invariably different This truism confounds comparisons between artificial and natural reefs, and usuall) cannot be avoided. In the Bahamas, we have been able to control both the age o reefs and the surrounding habitat in our comparisons of artificial and natural patcl reefs.

Methods Near the Caribbean Marine Research Center at Lee Stocking Island Exuma, Bahamas, we used a specially design vessel to translocate 16 natural cora patch reefs (ca $6m^2$) coral head by coral head to an isolated sand bank, where w simultaneously constructed 16 artificial patch reefs of nearly the same size (ca $4m^2$ but different structure (taller profile [0.8m vs. 0.4m], more but less variable shelte holes, and of course, no associated food organisms initially). Each reef was isolate from its nearest neighbor by 200m of open sand. Complete visual censuses of th reef fishes colonizing each reef over the next 2yr allowed comparisons c colonization rates and community structures.

Results Comparisons of artificial and natural reefs showed that:

1. Overall recruitment rates were nearly equal at approximately 5 new larv recruits per reef per census, so that net colonization rates were due to differenti postsettlement survival and/or emigration.

2. Natural reefs accumulated fishes (both number of individuals and number (species) more rapidly than artificial reefs (Fig. 1).

3. There were no strong differences in the species composition of fishes, especial considering important food fishes, such as grouper (Fig. 2).

Conclusions 1. Even when reef age is controlled and the surrounding habitat standardized, natural reefs are colonized more rapidly than artificial reefs.

2. Greater vertical relief and shelter availability (number of holes) of artificial ree do not compensate for the greater structural complexity (variety of hole sizes) ar natural forage base provided by natural reefs.

3. Artificial reefs intended to mitigate the degradation of natural reefs should structurally as similar as possible to natural reefs, especially by promoti development of naturally dominant benthos (such as corals).

Attraction-Production Question

Rationale We argue that answering the attraction-production question:

1. can only be addressed for an explicitly defined management area in terms of regional production.

2. is best addressed for obligate reef-dwelling organisms.

3. requires comparisons of natural and artificial reefs within the management area.

4. has not been accomplished for any system, except in the trivial case (but see Polovina and Sakai 1989).

5. is probably not possible in most systems.

Trivial Case If *no* natural reefs occur in a management area containing an artificial reef, then any obligate reef organisms on the artificial reef have necessarily enhanced production within that management area (Fig. 4A).

Nontrivial Case 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 and survived on a natural reef in the area, but grown *less* rapidly than on the artificial reef, then the artificial reef *has* enhanced production.

Semi-trivial Example Grouper "production" on a matrix of 52 artificial reefs off St. Thomas, U.S. Virgin Islands, was compared to that on 10 nearby natural patch reefs, all located within a single bay (Beets and Hixon 1994, see also Hixon and Beets 1989, 1993). Results were highly species specific (Fig. 3):

1. Postlarval Nassau grouper (*Epinephelus striatus*) settled differentially on the artificial reefs and grew to greater abundance there.

2. Mutton hamlet (*E. afer*) occurred exclusively on the artificial reefs.

3. Rarer species were either equally abundant on both reef types (*E. guttatus*) or

more abundant on natural reefs (*E. cruentatus* and *E. fulvus*).

Note, however, that our conclusions apply only to the bay in which the study occurred, and are possibly irrelevant outside our study area. Note also the conclusions depended upon the species being considered.

Conclusions 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 requires knowledge of the fates of settlement-stage larvae passing near artificial reefs, which is currently not possible. 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 (Fig. 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 settle on the artificial reef would be lost from the management area if that reef did not exist. For another example, suppose that a second natural reef occurred in the same management area down current of the artificial reef (Fig. 4C). If the artificial reef intercepted larvae destined to settle on the natural reef, and these organisms grew more slowly on the artificial reef than they would have on the natural reef, then only attraction has occurred. 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.

Future Research Directions

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. These comparisons should focus on the relative production of obligatory reef organisms, including an understanding of larval transport, settlement, and subsequent growth and mortality. Such studies would necessarily include both local and regional spatial scales.

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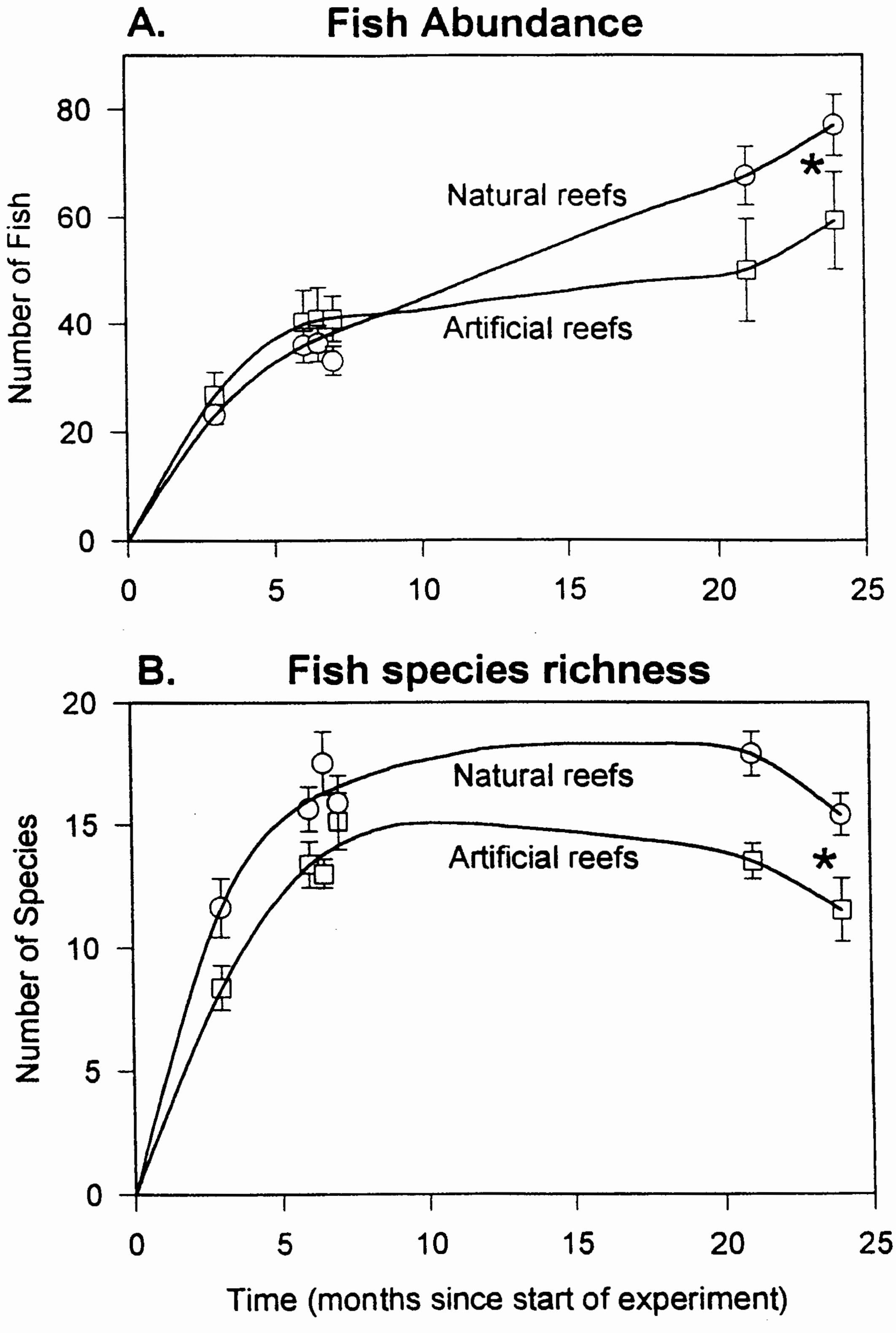

Fig. 1: Mean (± SE) number of fish individuals and species colonizing 8 artificial and 8 natural patch reefs translocated to the same habitat off Lee Stocking Island, Bahamas. In both plots, th final values are significantly different ($P < 0.05$, t-tests).

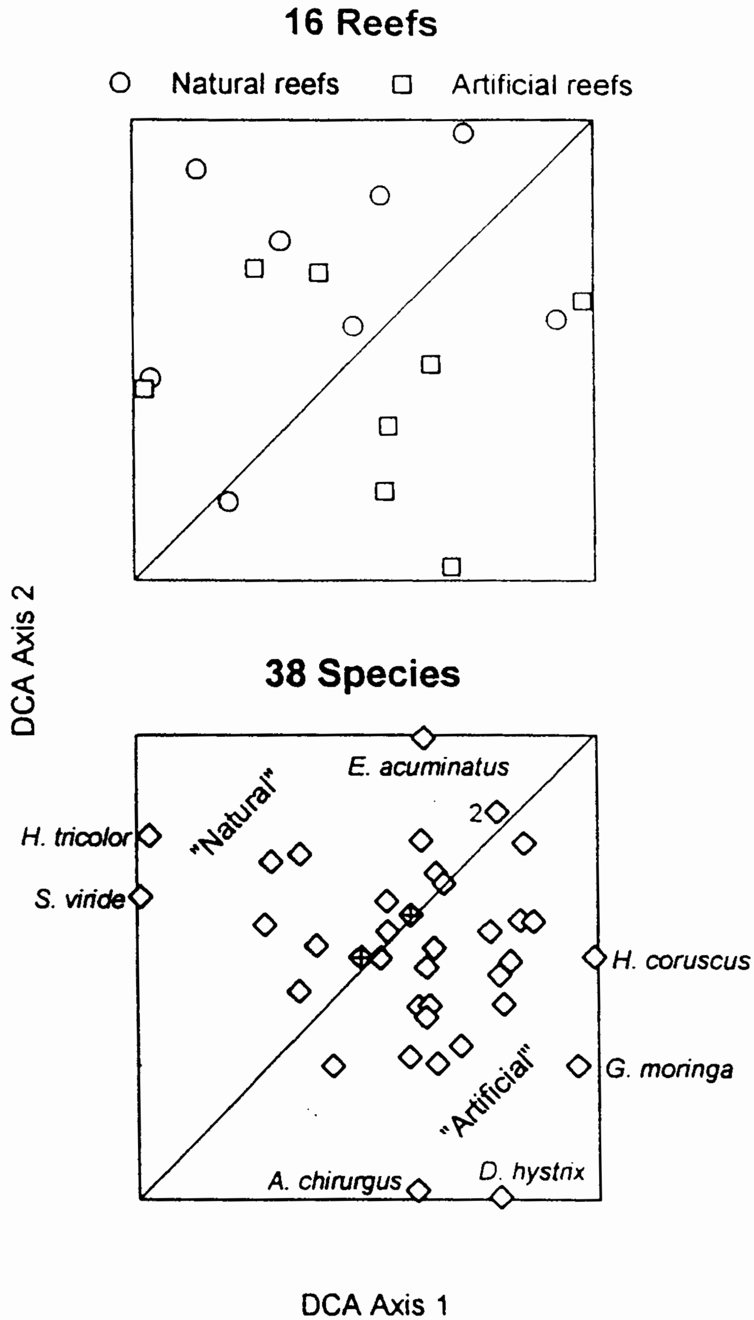

Fig. 2: Detrended correspondence analysis of fish assemblages on 8 artificial and 8 natural patch reefs in the Bahamas in December 1994. In the upper plot (reefs in species "space"), the distance between reefs is proportional to the dissimilarity of fish species composition and relative abundances. Note that most of the natural reefs cluster above the diagonal, whereas most of the artificial reefs occur below the diagonal. 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).

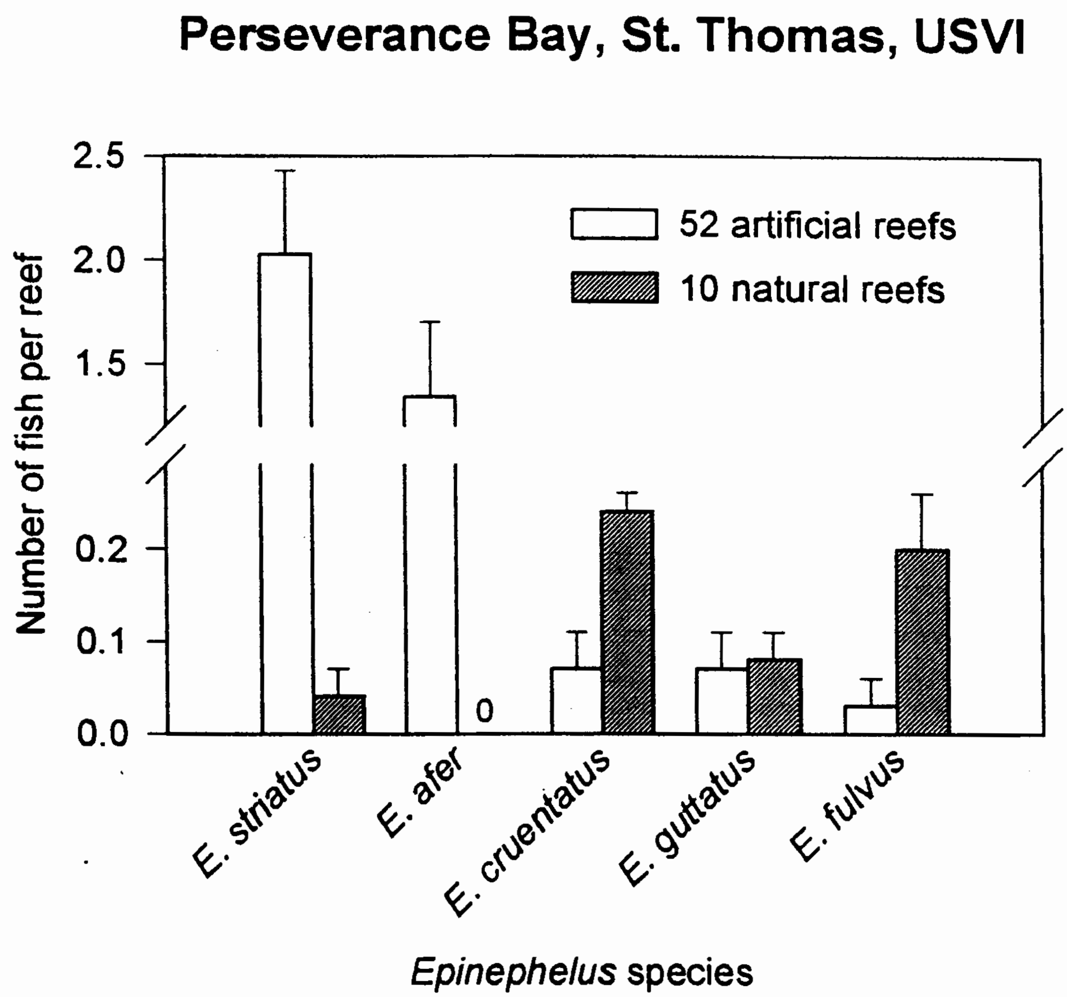

Fig. 3: Relative abundances (mean ± SE) of grouper on 52 artificial reefs and 10 natural patch reefs in Perseverance Bay, St. Thomas, U.S. Virgin Island, averaged over one year (modified from Beets and Hixon 1994).

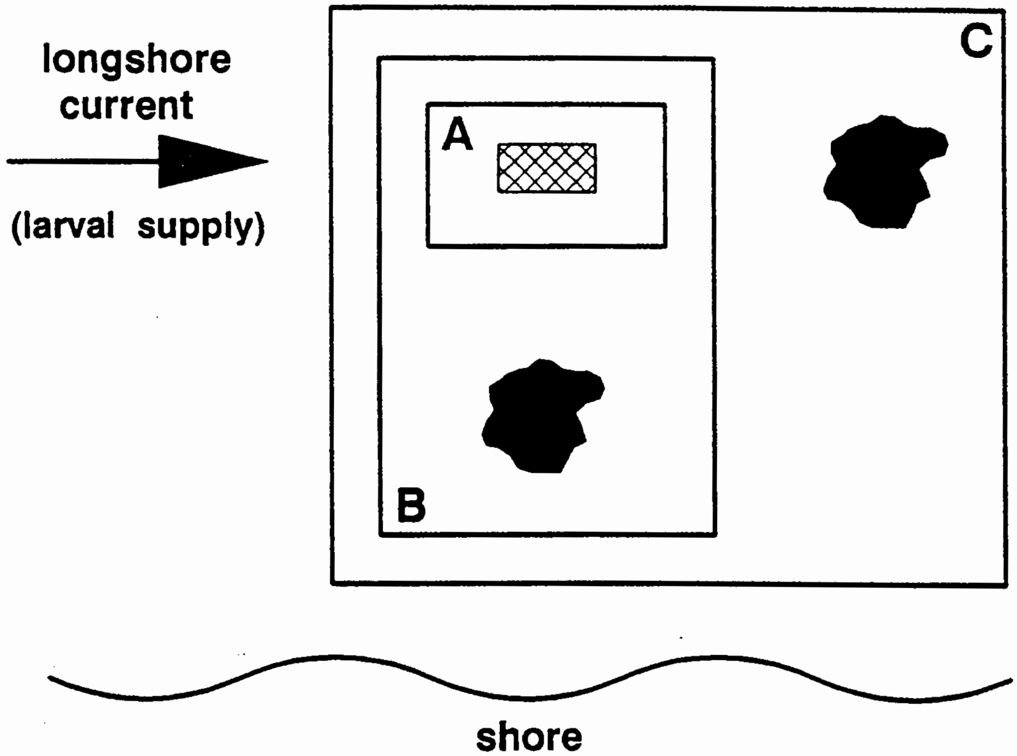

Fig. 4: Example scenarios depicting the importance of comparing natural and artificial reefs. A. Trivial case of a management area including only an artificial reef--the reef obviously increases regional production. B. Case where a strong longshore current precludes any larval or migratory transport 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 that reef did not exist. Thus, the artificial reef enhances local production even if its productivity is less than that of the natural reef. C. Case where 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.

MANAGEMENT DISCUSSION PANEL
ON
FUTURE ARTIFICIAL REEF RESEARCH AND MANAGEMENT

Panelists:
Mel Bell,[22] Jon Dodrill,[23] and Mike Meier[24]

Moderated by:
Ronald R. Lukens[25]

Introduction

As a part of the schedule of the American Fisheries Society Symposium on Artificial Reefs, a panel of individuals involved in artificial reef program management was convened to respond to the two keynote and six technical presentations provided by the invited speakers. One of the stated purposes of the Symposium was to draw artificial reef research and management functions closer together, and, in that regard, the Management Panel was charged with determining the degree to which researchers and managers are focusing on the same issues.

Management Panel Discussion

A guiding principal for artificial reef development and management, reputed to have originated with Dr. Jim Bohnsack, a research fishery biologist with the Miami Laboratory of the National Marine Fisheries Service, and borrowed from the medical profession, states "Do No Harm." The idea is that even if we can't prove that artificial reefs are having a positive impact on the environment and/or fishery populations, we should strive to assure that artificial reefs are not having a negative impact. This guiding principal is related to the overall topic of resolving the attraction versus production issue by assuring that even if fishery production is not

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taking place, no harm is coming to the environment or associated marine resources.

The Management Discussion Panel unanimously agreed that the presentations provided by the research panels were of high quality and addressed issues that are important to artificial reef managers. In a keynote presentation provided by Mike Meier, artificial reef program manager from Virginia, 65 research topics, organized under 10 categories, were identified as being important to overall understanding and management of artificial reefs. Of the six research projects presented, 18 of the 65 items identified by Meier were addressed, representing 28% of the total. This result led the Management Discussion Panel to conclude that, whether by design or divine intervention, communication between artificial reef researchers and managers is better than generally believed.

Need for Information Exchange

One of the most important conclusions of the Management Discussion Panel was that there is a need for better and more frequent opportunities for artificial reef program managers to interact with researchers in order to learn more about ongoing research and to convey to the researchers the kinds of research that are needed from the management perspective. In the past, such opportunities to meet with researchers have been limited to the international conferences, held about every four years, where many other activities are occurring. One of the problems associated with relying on the international conferences is that they occur in four year cycles, and it is usually several years before the proceedings are available. From a management perspective, such information needs to be available more frequently and on a more real–time basis.

A number of avenues to facilitate more frequent opportunities to bring artificial reef researchers and managers together were discussed, including continuing the activity through the annual meetings of the American Fisheries Society and using the existing committee structures established within the Atlantic and Gulf States Marine Fisheries Commissions to organize workshops and symposia. This topic will require further discussion; however, the need has been clearly established.

Understanding User Group Perceptions and Needs

Historically, there has been a gap between fishery managers and fishery researchers, born of a lack of understanding between both disciplines regarding the pressures facing each other. It is very easy, therefore, for artificial reef managers and researchers to fall into that same pattern. There was a call from the Management Discussion Panel to avoid the "us versus them" mentality, opting for a teamwork approach. The best way to foster such a teamwork approach is to provide for better and more frequent opportunities for the two disciplines to meet and develop an understanding of the pressures facing both. Some of the problems facing managers can be satisfied by research and some cannot; however, even if a problem cannot be solved by researchers, it is still important for researchers to have some understanding of management needs.

Artificial reef programs are often driven by fishermen or other external pressures. Even in the face of research or data that points to certain decisions, it is difficult to overcome the political forces that tend to influence those decisions. From the fisherman's perspective, if an artificial reef is built, he or she can fish on that site and usually be successful in catching fish. There is no perception of problems associated with an artificial reef, because he or she is catching fish. Even with the strides that have been made in bringing more professionalism to artificial reef development, individual citizens can still apply for and receive artificial reef permits, and there is little that the research or management community can do about influencing what those individuals do, short of regulatory controls that are typically broad and non-specific. State regulations must be crafted carefully in order to exert appropriate control over the actions of individuals.

User groups strongly believe that not only are we not doing harm by creating artificial reefs, but artificial reefs programs are doing great things. Their perspective is that they work, so more development is better. This perspective is encouraged by the fact that much of the funding for state programs and activities is provided by the Federal Aid in Sport Fish Restoration Program administered by the U.S. Fish and Wildlife Service. This fund is created by a tax on fishing supplies, and therefore is derived from the anglers themselves. In some states, substantial funding is provided by marine recreational fishing license revenue, and in some cases private sources. In that regard, it is important that the user groups be satisfied that the funding so derived is spent on activities that they support and think are beneficial. This then becomes a very important public relations tool to garner support from the recreational angling community for the agency's programs. These and other external pressures often interfere with the decision-making process, which leads researchers to believe that artificial reef managers largely ignore available research and data. A greater understanding of this process can dispel that belief, and encourage an enhanced teamwork approach.

Questions Other than Aggregation versus Production

There was general agreement that "aggregation versus production" is the wrong question to try to solve through research. The Management Discussion Panel concluded that the answer to that question is that both outcomes are occurring on a continuum, and the issue should be handled on a case by case basis, depending on a number of items including environmental factors that limit population size, location of artificial reefs, type of species targeted, among others. There was a concern that there are many other important questions that may go unanswered expecting a definitive solution to "aggregation versus production." One of the presenters provided an analogy that likens the use of artificial reefs to the use of nuclear power; the power can be used to produce safe energy to support society, or it can be used to annihilate society. Carrying that analogy a bit farther, the nuclear power plant is up and running (in excess of 400 legally permitted artificial reefs nation-wide, and active artificial reef programs in each coastal state of the Nation), and we don't have the luxury of building the nuclear reactor we want in order to supply safe energy to society. The question that faces us now is how do we harness and control the ongoing activities to achieve common goals?

Role of Reefs in Fishery Management

There was general agreement among the Management Discussion Panel that artificial reefs should be used as fishery management tools; however, there is little agreement about what that means. It was pointed out that current management plans use such tools as size and bag limits, quotas, and time and area closures. It is difficult to fit artificial reefs into such a scenario. It is very important for the management community to investigate the most effective ways to use artificial reefs in support of overall fisheries management activities, and thus integrate the artificial reef programs into fishery management programs. For example, in the northern Gulf of Mexico, red snapper is one of the most highly targeted species by the recreational fishing community. There are a great many research needs for red snapper and the habitat issues that impact the status of the stock. The important question is what impact has the development of artificial reefs in the northern Gulf of Mexico had on red snapper stocks. It is possible that we, collectively, have not only created a great deal of artificial habitat for red snapper, but we may have therefore altered the fishery for red snapper by enhancing its expansion. Recognizing the degree of conflict currently surrounding the directed commercial and recreational red snapper fishery, could this be viewed to a certain extent a conflict in which artificial reefs have played a role? By this example, it is suggested that there could be significant management implications from artificial reefs, even if we do not currently use artificial reefs as management tools.

Function of Reefs in Fisheries and the Environment

From the commercial fisherman's perspective (panel member Dodrill worked as a commercial fisherman in various fisheries for several years), an artificial reef is a fishing tool. It is designed to increase fishing efficiency, reduce travel time and costs, and makes certain fish species more accessible. As a result of these perceived benefits to fishing activities, it is important that their impact on artificial reefs and fish populations be evaluated. Fishing effort, catch, and what kind of fishing is taking place (commercial/recreational, trapping/hook-and-line, etc.), among other aspects of fishing on artificial reefs should be monitored. This is very basic to integrating artificial reefs into an overall program of fisheries management.

It was pointed out that offshore Alabama there are reportedly in excess of 6,000 individual artificial reef deployments within the large general permit areas. Offshore the Florida panhandle, in another large general permit area, a recent survey questionnaire indicated that 52 individuals were responsible for over 6,000 individual deployments. As a conservative estimate, these add up to over 12,000 individual sites concentrated in the offshore waters of northern Florida and Alabama, yet the spawning potential ratio of red snapper has only increased by one or two percent over the last ten years. The obvious question is what does that mean in terms of the relationship between artificial reefs and fishing pressure on highly desired fish species? In this example, it appears that an increase in available habitat may not have contributed to an overall increase in the red snapper stock due to fishing mortality.

A natural reef is an area of exposed rock, coral, or other hard bottom which is present because of the natural geology of the area. Artificial reef programs go into areas where the natural geology has not provided hard bottom, and supply hard substrate for the development of a reef community. In some cases, artificial reefs are deployed in the general vicinity of existing natural reefs. Other than the materials themselves (eg. rock versus steel) there should be no difference in the environmental dynamics that apply to a natural reef and an artificial reef. Basic reef fish ecology and population biology should be applied to artificial reefs as though they were natural reefs. The focus should be broader than just the question of what we are doing with artificial reefs. It should encompass how artificial reefs affect the status of the fish stocks that inhabit both artificial and natural reefs.

Expanding Reef Research

As an example of how complex an artificial reef program can be, Florida has a loosely organized artificial reef program that is centered at the coastal county and municipal level. The primary impetus is the placement of three-dimensional materials on the bottom within the limits of available funding. Over 30 counties and municipalities are involved at some level. Local reef coordinators decide where artificial reefs will be placed. These individuals include marine biologists, marine engineers, Sea Grant Extension Agents, solid waste managers, recreational planners, public relations staff, among a list of other disciplines. In 1963 there were 20 legally permitted artificial reefs in Florida. Between 1985 and 1995 300 artificial reefs sites were developed offshore Florida. A list of materials used includes concrete rubble, concrete junction boxes, concrete utility poles, prefabricated concrete modules, scrapped ships, barges, sail boats and other vessels, coke trucks, school buses, and other motorized vehicles, aircraft, military battle tanks, limestone boulders, a variety of steel materials, fiberglass culvert, and car bodies. It is believed that while the previous list adds up to a great deal of material, it is still a very small amount when compared to the natural hard bottom areas available in the offshore waters. Florida is the largest artificial reef builder in the Nation in terms of volume of material deployed, number of sites permitted and developed, and area covered, having spent $6.7 million of state and federal funds over the past ten years. This does not include the various county and municipal budgets that can at times be larger that the state's artificial reef budget.

It is estimated that less than ten percent of the funds expended on artificial reefs within the State of Florida have been spent on research. The Management Discussion Panel concluded that that trend needs to change with more funding from state, federal, and local sources being applied to formal research and data collection on both fishing activities and artificial reefs.

There was some discussion of the possibility that development should be reduced, in some areas and in some cases, while assessments of the impact of our collective efforts are conducted. Within the context of assessing our past and current efforts, there is a great need for social and economic data related to cost/benefit relationships and social impacts to local communities. Refinement of siting criteria should be conducted to determine the optimum locations for artificial reef development, given a reasonable mix of social, economic, and biological factors. Overall, there was strong support for increased funding for research and data collection.

Estuarine Reef Research and Development

Artificial reef development in estuarine areas was discussed as an area of research that has not received much attention. Fishermen have expectations that estuarine artificial reefs will function just like offshore marine artificial reefs. While in some ways that may be true, such that catch per unit of effort may be higher around estuarine artificial reefs that other estuarine habitats, the primary issue is obligate versus opportunistic species in terms of their relationship with reef or reef–like habitat. A good example is between red snapper and spotted seatrout. There is no question that fishing for red snapper over mud or sandflat or grassbed habitats will be unsuccessful, because of that species' requirement for reef or reef–like habitat. In contrast, spotted seatrout can be found associated with grassbed habitats, over mud bottoms around natural depth breaks, over oyster shell beds, and a variety of other habitat types. The presence of an artificial or natural reef is not a requirement for the presence of spotted seatrout. In this regard, artificial reefs in near–shore, estuarine areas may be functioning to make access to fish easier and enhance the potential for catch rates to increase. If we are faced with population concerns for selected estuarine species, current regulatory controls may not take into account potential increases in catch rates due to the development of a series of estuarine artificial reefs. The Management Discussion Panel encouraged researchers to begin looking into the function of near–shore, estuarine artificial reefs.

Conclusions

1. The American Fisheries Society Artificial Reef Symposium was successful in providing a productive forum for exchange of ideas and expectations between artificial reef managers and researchers.

2. Artificial reef programs should strive to conduct activities that are, at a minimum, environmentally compatible and do not negatively impact fish stocks (do no harm).

3. There is a need for better and more frequent opportunities for interaction between artificial reef managers and researchers.

4. Artificial reef managers and researchers must operate as a team to achieve mutual goals.

5. There is little public understanding or concern for environmental and fish stock issues related to artificial reefs. Their primary concern is for enhanced opportunities to catch fish.

6. The issue of aggregating fish versus contributing to increased production of fish biomass must be addressed on a case by case basis. There is no definitive answer to the dichotomy, but rather a continuum exists ranging from aggregation to production.

7. It is generally accepted that all artificial reefs attract marine organisms. The real issue is related to survivorship and ultimate recruitment into the spawning stock. In this regard, all sources of mortality, particularly fishing mortality, related to reef fish species must be better understood.

8. Artificial reef programs should be integrated into the respective state fishery management programs, using artificial reefs as fishery management tools. This should not be restricted to state management programs, but should be included in interstate and federal management activities, recognizing that a sizable portion of existing artificial reefs are located in the federal Exclusive Economic Zone.

9. Principals of basic reef ecology and fish population biology should apply equally to artificial and natural reefs.

10. Funding to support artificial reef research and data collection should be increased; however, not to the detriment of responsible artificial reef development.

11. High quality research of long-term duration, using good experimental design and sophisticated data analysis, should be supported.

12. Some artificial reef managers should consider slowing the pace of artificial reef development until studies are conducted to assess the current status and the impacts of existing artificial reefs.

13. There should be some emphasis on conducting studies to evaluate the function and impact of estuarine artificial reefs.

APPENDIX I - SYMPOSIUM AGENDA

8:15 – 8:35 a.m.
Moderator: William Seaman

Symposium Introduction: The Attraction– Production Continuum for Fishes on Artificial Reefs

8:35 – 8:55
Meier, M., and F. Steimle
What Information Do Artificial Reef Managers Really Want from Fishery Science?

8:55 – 9:15
Lindberg, W.J.
Can Science Resolve the Attraction–Production Issue?

9:15 – 9:45
Bohnsack, J.A., A.M. Eklund and A.M. Szmant
Productivity of Experimental Modular Artificial Reefs off Southeastern Florida

9:45 – 10:15
BREAK

Moderator: Richard Christian

10:15 – 10:45
Brock, R.E., and A.K.H. Kam
Long Term Stability in Fish Community Structure as It Relates to Habitat Development

10:45 – 11:15
Herrnkind, W., and M.J. Butler, IV
Artificial Dens for Early Juvenile Spiny Lobsters: Ecological Processes, Population Effects, and Modeling

11:15 – 11:45
Hixon, M.A., and M.H. Carr
Comparisons of Artificial and Natural Reefs: Controlling the Surrounding Environment.

11:45 – 1:15 p.m.
BREAK

Moderator: Alison Hatcher

1:15 – 1:45
Lindberg, W.J., and F.E. Vose

How Reasonable Is It to Assume Enhanced Productivity by Artificial Reefs, Based on Experiments in the Eastern Gulf of Mexico?

1:45 – 2:15
Grove, R.S., A. Jahn, T. Dean and L. Deysher
Siting and Design of an Artificial Reef as Habitat for Giant Kelp: Routine Scientific Application or Risky Research?

2:15 – 2:45
Discussion Panel I: M. Bell, J. Dodrill, R. Lukens (Moderator), M. Meier
Management Priorities for Resolving the Attraction–Production Issue

2:45 – 3:10
BREAK

Moderator: William Seaman

3:10 – 3:40
Discussion Panel II: J. Bohnsack, R. Brock, W. Herrnkind, M. Hixon, R. Grove, W. Lindberg
Research Priorities and Hypotheses for Resolving the Attraction–Production Issue

3:40 – 4:10
Grossman, G.
Summary: The Adequacy of Ecological Evidence for Increase of Production at Artificial Reefs

4:10 – 4:15
Seaman, W.
Symposium Closing and Follow–up