HABITAT ALTERATIONS AS A BASIS FOR ENHANCING MARINE FISHERIES

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ABSTRACT

Artificial reefs and fish aggregating devices (FADs) can be used to alter marine habitats to increase fishery productivity. Artificial reefs enhance marine fisheries through both aggregation and production of marine resources. FADs can also enhance resource production. Most artificial reef designs do not completely replicate natural reef habitats. Considerable artificial reef construction has been in response to incentives for solid waste disposal. Recruitment and survival of juveniles is restricted because of the prevalent use of "materials of opportunity" for constructing artificial reefs. FADs are usually lost as a result of inadequate design and engineering. Funding has been haphazard and inadequate for developing artificial reef and FAD technologies. Most applications lack realistic, justified fishery enhancement objectives as the incentive for altering habitat. Solving these major constraints will make it possible to evaluate habitat-alteration technologies as a basis for enhancing marine fisheries.

RESUMEN

Los arrecifes artificiales y los aparatos para agregar peces (AAPs) pueden ser usados para modificar hábitats marinos, con el fin de aumentar la productividad en peces. Los arrecifes artificiales acrecientan las pesquerías marinas a través tanto de la agregación como de la producción de los recursos marinos. Los AAPs también pueden mejorar la producción del recurso. La mayoría de los arrecifes artificiales no duplican completamente el hábitat de los arrecifes naturales. Muchos arrecifes artificiales se construyeron como respuesta a incentivos formulados para disponer de los desperdicios sólidos. El reclutamiento y la supervivencia de juveniles se ha visto restringida por el uso generalizado de "materiales de oportunidad" en la construcción de arrecifes artificiales. Se pierden AAPs como resultado de diseño e ingeniería inadecuados. La financiación para el desarrollo de tecnologías de arrecifes artificiales y de AAPs ha sido impredecible e inadecuada. Muchos de los usos no tienen objetivos prácticos y justificados de acrecentamiento de las pesquerías como incentivo para alterar el hábitat. Si estas restricciones principales se solucionan será posible la evaluación de la tecnologia de alteración de hábitats como fundamento para acrecentar las pesquerias marinas.

INTRODUCTION

If we eliminate from consideration the obvious enhancement successes enjoyed in anadromous fishery resources, then it is a true statement that current technology provides few options for enhancing marine fisheries. The most historically viable technique is to use the spectrum of regulations to control harvests, but these restrictions are limited in power to increase the resources available for harvest, or to affect the temporal or spacial distribution of these resources.

The successful enhancement of anadromous fishes is linked to artificial production in hatcheries. This technique supplements natural levels of recruitment of juveniles, which can dramatically increase the resources available for harvest if the other factors necessary for survival are not restricted in the natural environment. Marine fish hatcheries may be a functional and productive enhancement technique for the few species that have accessible spawning aggregations, culturable embryonic and larval development, and adaptable juvenile rearing stages, if (and it is a big if) fishery demand for these species justifies continual large amounts of capital and operational funding. So far, all of these factors have been satisfied for only one species in the United States — red drum (*Sciaenops ocellatus*) (Rutledge 1989).

Preserving critical, productive natural marine habitats is rapidly being recognized as the key to preserving and enhancing marine resources and the dependent fisheries (the marine ecosystem is finally being realistically defined as critically finite). The National Marine Fisheries Service has requested that regional fisheries management councils consider adopting a marine habitat policy to "Conserve, restore and develop habitats upon which commercial and recreational fisheries depend, to increase their extent and to improve their productive capacity. . . ." (Anon. 1988). The third of the three objectives supporting this policy is to "create and develop productive habitats where increased fishery productivity will benefit society."

Altering marine habitats to increase fishery productivity is well within current technological capabilities. The two most prominent forms of marine habitat alterations—artificial reefs and fish aggregating devices (FADs)—can be used to enhance marine fisheries by increasing the amount of marine resources available for harvest, and by controlling the temporal and spacial distribution of these resources (Buckley and Hueckel 1985; Wilson and Krenn 1986; Alevizon 1988; Buckley et al. 1989; Polovina and Sakai 1989; and many others; see Buckley et al. 1985). Evidence is mounting that biological development on artificial reefs can also supplement natural production and recruitment of reef-related species. The capital costs for artificial reefs and FADs *can be* low relative to other enhancement options, and operational costs *can be* in the range of miniscule to moderate. However, to be completely objective and honest, it is necessary to point out that the validity of these statements is directly related to the "can be" provisos. Attempts to apply these habitat alterations have been both effective and ineffective in enhancing marine fisheries. Further, the level of effectiveness appears to be directly correlated with the amount of science included in applying and evaluating these technologies.

This may seem to be so obvious a correlation that it is trivial; however, it is disturbingly common to find artificial reef and FAD projects that do not have enhancement of marine fisheries as the real objective. These projects are conceived and implemented with methods ranging from absolutely no science to sloppy science at best. It is even more disturbing when these "nonscientific applications" are cited in the attempts to assess the values of these technologies as fishery enhancement and management tools. This error is compounded when poorly conceived projects and inappropriate evaluations are recycled in new evaluations; it seems that the learning curve has had insignificant slope.

ARTIFICIAL REEFS AND FISH AGGREGATING DEVICES

The real potential for using artificial reefs to enhance marine fisheries that target benthic and semipelagic resources has eluded most fishery managers, at least until recently. Little definitive research has been conducted on practical applications of artificial reefs since their rise to a certain level of prominence in the 1960s. As late as 1983 a comprehensive review of the research indicated that the potential of artificial reefs for improving fishery resources would only be realized when emphasis was shifted from construction and qualitative studies to quantitative analyses of governing biological and ecological factors (Bohnsack and Sutherland 1985).

There has been a recent evolution, on a multiregional scale, toward designing and evaluating artificial reef projects that target on specific questions about resource enhancement, particularly recruitment and survival of juveniles[1]. Recent research has shown that, when applied correctly, this technology creates long-term, if not permanent, alterations of benthic habitats, which develop biologically into replicates of productive natural reefs (Buckley and Hueckel 1985; Wilson and Krenn 1986; Alevizon 1988; and others). These alterations enhance the aggregation and production of important resources at locations that are atypical of the natural system. Artificial reef technology gives fishery managers some degree of power to direct the marine ecosystem and selected biota toward desired responses, which can be immediate and far-reaching in both time and area. These changes can increase the accessibility and fishability of traditional or new resources, and alleviate problems of fishery interaction by redistributing competing fisheries.

The potential for FADs to enhance marine fisheries for pelagic species has not eluded fishery managers as completely as the potential of artificial reefs. But there has been even less definitive research on this technology. The enthusiasm for using anchored buoys to enhance catches seems to be based on the successful use of *payaos* (bamboo rafts) in the Philippine purse seine fishery for tuna in the early 1970s (Matsumoto et al. 1981). The widespread use of FADs has received considerable funding from various states and nations, even though there was little, if any, scientific evidence that FADs met the fishery enhancement objective.

The first multiyear, quantitative assessment comparing FADs, offshore banks, and open-water areas was completed in 1987 in the tropical South Pacific (Buckley et al. 1989). This study verified the potential for correctly sited and engineered FADs to enhance marine fisheries to a level comparable to large, productive, offshore banks. When applied correctly, this technology provides the only practical method for increasing the accessibility of pelagic marine fish resources by affecting the movements

[1]Compilation of this research is presented in the Proceedings of The Fourth International Conference on Artificial Habitats for Fisheries, Bulletin of Marine Science, University of Miami, volume 44(2), March 1989.

of wandering schools of fish. This development of new, productive fishing locations is a powerful management tool for increasing catches while decreasing searching time, and for affecting the distribution of the fisheries.

WHAT IS THE PROBLEM?

An obvious question is, "Given the potential that artificial reefs and FADs have for meaningful enhancement of marine fisheries, why haven't these habitat alterations been integrated into comprehensive fishery management programs in the United States to a greater degree?" The answer seems to be centered on the perpetuation of our early decision that these technologies could be applied by amateurs, and at little cost! This resulted in a disregard for science and adequate funding, which created a preponderance of haphazard, unsuccessful applications to serve as the basis for evaluating the potential of these technologies. The facts are that until recently these habitat alterations have not been advanced as serious methods for enhancing marine fisheries.

The situation with artificial reefs has been superbly stated in the excellent editorial "The Rediscovery of the Free Lunch and Spontaneous Generation: Is Artificial Reef Construction Out of Control?" (Bohnsack 1987). Artificial reef programs in the United States are characterized as "poorly or haphazardly funded, and in the best of American traditions depend on voluntary community involvement with donated labor and surplus 'materials of opportunity.' Emphasis is on minimizing short-term expenses." The policy controlling artificial reef applications, as well as the need for evaluations, is established by individuals with little fisheries experience or training, and is "often based on meager anecdotal information or whim." The regulatory agencies involved give only incidental consideration to biological impact and fishery management issues, and there are no significant requirements for monitoring or evaluating artificial reefs.

The home base for the editorial, Florida, is probably the best example of the worst type of artificial reef program in the United States. Florida has almost 300 sites permitted for artificial reef construction, and claims to be the national leader based on the number of reefs. Unfortunately, Florida did not put forth concurrent effort to establish realistic fishery enhancement objectives for the projects, or to evaluate the resulting benefits or impacts. In fact, in Florida, "state funding of [artificial reef] projects is restricted to cleaning materials; use of funds for research, monitoring, or buying materials is prohibited!" (Bohnsack 1987).

It must be added that Florida does not deserve total responsibility for establishing this approach to artificial reef projects in the United States. Virtually all other coastal states have contributed by actively importing this flawed technology, or inventing their own mistakes, factors that have perpetuated past errors and discouraged improvement and refinement of the technology. As late as 1987, Oregon was considering a permit request to construct a large artificial reef in the ocean using materials of opportunity, with one of the objectives being to determine if the materials were "being buried or moved by waves or currents" (Buckley 1989).

It should not be surprising to learn that the home base for this paper, the Pacific Coast, has probably the two best examples of the best type of artificial reef program in the United States. Washington has virtually eliminated past policy errors that allowed artificial reef construction by diverse state agencies and the private sector, with no specific, testable fishery enhancement objectives. This habitat alteration is now controlled by the Department of Fisheries as a resource enhancement and management tool with potential impacts and benefits. An agency policy for artificial reef construction establishes criteria for fishery enhancement objectives, baseline surveys, biota-index-based siting, reef-to-natural-substrate ratios, and long-term monitoring (Buckley 1982). There are 11 active artificial reef sites in Washington, all intended to enhance specific urban recreational fisheries.

California, the site of some of the original applications of science to artificial reef projects, has recently reestablished its prominence in this field. Under the leadership of the Department of Fish and Game, a comprehensive Reef Plan, requiring specific objectives, has been promulgated to all state agencies involved in applying artificial reef technology. Current artificial reef projects are well funded for both construction and research, and they are based on the findings from several years of evaluations. The designs of a recent major series of artificial reefs, sited in three locations, incorporate many of the factors critical for accurately assessing the potential of this technology for resource enhancement.

Although most of the artificial reefs in the United States have ostensibly been to improve fisheries, many are "little more than disguised solid waste disposal programs, tax write-offs, or public relation gimmicks" (Bohnsack 1987). This fact is emphasized by the variety of junk, waste material, and garbage that has been used for construction, as well as the questionable objectives of maximizing the amount of material deposited or area covered. "Many of these reefs are of questionable value and in fact may have future detrimental impacts" (Bohnsack 1987). The best method for judging the fishery enhancement value of these artificial reefs is to determine which really came first, the excess solid waste, or the need for resource enhancement. It is clear that the solid waste disposal incentive has been and still is the reason that artificial reef projects fail to effectively enhance marine fisheries. For many, the terms *artificial reefs* and *solid waste disposal* are synonymous; visualize the 70-mile-long "artificial reef" being proposed in the Caribbean by Waste Central, Inc. of Philadelphia (Morrissey 1988). Is it any mystery why this technology lags so far behind its potential to enhance marine fisheries, and fails to receive adequate funding?

The history of how FADs got to where they are is less well documented; however, there are disturbing similarities with artificial reefs in the early use of "materials of opportunity," volunteer labor, and haphazard funding, all applied to projects with no testable objectives for enhancing fisheries. Perhaps the early applications of this technology followed the same pattern of thought. Clearly, the needed engineering and design, monitoring and research, and fishery management infrastructures are either not established or are not well funded in the majority of FAD programs in the United States. Hawaii has the most successful and largest FAD program, which seems to be correcting past errors in engineering and design to improve FAD durability; however, long-term, quantifiable assessment of the fishery enhancement objectives appears to be lacking (Matsumoto et al. 1981; Shomura and Matsumoto 1982; Brock 1985).

Comparisons of effective and ineffective FAD programs are not as easy, or as fair, as for artificial reefs; many of the "United States" FAD programs are in developing territories or possessions where technological capabilities vary, and usually cannot overcome the complexities of anchoring systems in hundreds of fathoms in the open ocean. Despite all of these problems, FAD programs are very popular with fishermen and fishery management agencies. They are exceedingly practical because they can dramatically increase catches, even over the short term, and they appear to serve as physical monuments to government responsiveness, monuments that fishermen can see in the void of the open ocean. However, it is the pressure of this popularity, combined with the lack of consideration for adequate engineering, that are major factors in the failure of FADs to achieve their potential to enhance marine fisheries.

In summation, the problem is that the lineage we have established for artificial reefs and FADs, combined with the paucity of long-term, quantifiable research to evaluate both forms of habitat alteration, impairs the acceptibility of these enhancement technologies. Unfortunately, this past record is firmly entrenched and is proving difficult to displace.

CRITERIA FOR APPROPRIATE APPLICATIONS

Appropriate applications of artifiical reef and FAD technologies can only occur if there is adequate funding for research, development, and evaluation of each project. This will enable the development of "good-quality" projects in a variety of regions, environments, and ecosystems, in response to a variety of fishery management situations. The subsequent evaluation of these projects over the long term will develop an accurate information base that can be used to correctly assess the fishery enhancement potential of these habitat alterations. Adequate funding is the key to advancing these technologies from their current, primarily amateur, status.

For responsible application of artificial reefs and FADs, the first criterion must be the careful evaluation of realistic and justified fishery enhancement objectives, which are the bases (incentives) for habitat alteration. These objectives have to be far beyond the overused, and self-serving, desire to "improve fishing"; they must address the species to be enhanced, the fisheries that will benefit, and the potential for adverse impact. This means that the technologies must be controlled by professional fishery managers and researchers. It is irresponsible to continue to allow marine habitat alterations that do not have high potential to produce the desired enhancement without causing offsetting impacts (Buckley 1989).

Appropriate siting and design criteria must be applied to both artificial reefs and FADs to ensure that there is high potential for each habitat alteration to produce the desired biological development. A biota index siting system, based on comparisons of biota at proposed artificial reef sites and on productive natural reefs, can be used to predict the occurrence of target species on artificial reefs (Hueckel and Buckley 1989). Areas of naturally occurring aggregations of target pelagic fishes can be analyzed to enhance the aggregating effectiveness of FADs. Physical and oceanographic parameters must also be given careful consideration in applying both of these technologies. (It has been common practice for the sites chosen for habitat alteration to be based on accessibility from harbors, and not on the potential for biological development.) The physical and spacial designs of artificial reefs must consider habitat configurations that allow replication of natural reef systems, especially for the recruitment, survival, and growth factors that control biological production.

As projects for artificial reefs and FADs proliferate, they must be incorporated into comprehensive fishery management and enhancement programs that cover ecologically relevant areas. These technologies are applied to create fishing locations, but the related removals can impact stocks over broad ranges, especially for migratory species. Stock level can also be affected by disruptions of normal recruitment patterns of planktonic juveniles, which can lead to increased survival or increased predation. In addition to the biological factors, management concepts such as "orderly fisheries" can benefit or suffer from something as basic as the juxtaposition of enhancement sites. The bottom line is that both artificial reefs and FADs create significant perturbations in the ecosystem, as well as significant redistributions of fisheries; these factors must be controlled and balanced so that they do not overpower the natural processes or disrupt the fisheries.

THE "PRODUCTION OR AGGREGATION" QUESTION

The "production or aggregation" question is an old issue that was raised about the biological processes occurring on artificial reefs. This was not an issue for FADs, because they were intended to take advantage of the tendency of pelagic fishes to gather around floating objects. The controversy over whether artificial reefs simply redistribute existing resources, or add to the total has been generated partly by the implied lack of fishery enhancement potential of the aggregation response when it occurred on reefs. This contradiction—FAD aggregation is good, artificial reef aggregation is not—seems a little absurd. Reviews of the literature show a distinct lack of research projects designed to test these alternate hypotheses. However, it is highly probable that the original lack of a scientific approach to applications of artificial reefs not only created the "production or aggregation" question, but also kept it from being answered.

Fortunately, there have been enough good artificial reef projects in recent years to provide ample evidence that this habitat alteration has both production and aggregation functions for the associated biota. The "either production or aggregation" constraint is not valid, and these two processes should be considered as two extremes on a continuum of biological development on artificial reefs (Bohnsack 1989). Production of new resources for fishery harvest is an easy management concept to understand, but the appreciation of benefits associated with aggregation of "new" resources for harvest seems to give some researchers and managers problems. The aggregation function of artificial reefs has fishery production benefits ranging from increased accessibility and harvestability of resources to increased deposition of feces-related nutrients on the reef habitat. The changing levels and interactions of both the production and aggregation functions, over species and over time, are important factors in determining the potential of this technology for fishery enhancement.

The fishery production benefits of FADs are obvious in the increased accessibility of pelagic fishes that exist naturally as wandering schools in a very large ocean. Aggregating these fishes in a particular area significantly reduces unproductive searching time, and increases catches. Although the "production or aggregation" question has not been applied to the biological processes occurring at FADs, there has been considerable speculation about how aggregation into situations for intense removal (and increased natural predation?) may affect the natural production of some species. There is concern about possible excessive harvests of juvenile yellowfin tuna (*Thunnus albacares*), which gather around FADs in nearshore areas that are accessible to intensive fisheries (Frusher 1986; Buckley et al. 1989; R. E. Brock, University of Hawaii, unpublished).

Recent research on yellowfin tuna feeding around FADs indicates that for some species the FAD may contribute to increased natural production by "causing resident fishes to change their feeding habits to take advantage of otherwise untapped resources" (Brock 1985). This has occurred when yellowfin tuna at FADs fed almost exclusively on deepwater oplophorid shrimp, whereas non-FAD yellowfin tuna did not eat this food (Brock 1985). Thus FADs may function as more than passive aggregators; they may create production, as well as aggregation, benefits to marine fisheries.

CONCLUSION

It is clear that altering marine habitats to increase their fishery productivity is technologically possible using artificial reefs and fish aggregating devices. Artificial reefs can enhance marine fisheries through both aggregation and production processes. The FADs' aggregation capabilities can also result in production through optimizing the use of alternate, atypical food resources.

The present designs of most artificial reefs do not provide the total habitat configurations that replicate natural reef systems, especially for recruitment and survival of juveniles. This is primarily due to the prevalent use of materials of opportunity to construct artificial reefs, a methodology that has been driven by incentives for solid waste disposal. Some modern artificial reefs using specific designs and construction techniques and selected materials meet many of the habitat requirements for resource production; however, the technology is still evolving toward complete replication of natural reefs. Critics of "artificial reefs in general" must realize that they are comparing natural reefs with incomplete, poorly conceived substitutes. The artificial reef idea is good; most current applications and designs are flawed.

Most of the FADs that have been deployed to date are severely underdesigned and underengineered. They often successfully aggregate target resources, but usually they are lost in a relatively short time. The failure to develop and apply adequate design and engineering criteria seems related to the "materials of opportunity" philosophy borrowed from artificial reefs, combined with pressures for rapid, popular solutions to oceanic fishery management problems.

Technologies for artificial reefs and FADs have suffered from inadequate, haphazard funding, and lack of realistic, justified fishery enhancement objectives as the incentives for altering habitats. Solving these two major constraints will allow refinement of these technologies and accurate evaluation of these habitat alterations as a basis for enhancing marine fisheries.

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