A GLOBAL PERSPECTIVE ON ARTIFICIAL REEFS AND FISH AGGREGATING DEVICES

BY

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PREFACE

In recent years, research on artificial reefs and fish aggregating devices (FADs) and their application to fishery enhancement has increased. For example, the Third International Conference on Artificial Reefs in 1983 had 43 presentations and 14 posters that covered work from 7 countries. At the Fourth Conference held in 1987, 350 participants from 26 nations attended and made 94 oral and 37 poster presentations on research and applications from 19 countries (Seaman et al. 1989).

Centers of activity for artificial habitats include Australia, Japan, Southeast Asia, the Caribbean, the Mediterranean, Pacific islands, and North America. This paper reviews four applications and worldwide impacts of artificial reefs and FADs. The applications are 1) enhancement of artisanal fishing, 2) small-scale commercial fishing, 3) recreational fishing and diving, and 4) mitigation of habitat loss due to shoreside development.

ARTISANAL FISHERIES

Artisanal fishermen have developed many artificial reefs and fish aggregating device (FAD) designs to create fishing grounds close to their villages. The structures have traditionally been constructed with sticks, poles, bamboo, or bundles of brush, but more frequently are being made from concrete and scrap tires.

In the Philippines, a widely used artificial reef module is made from bamboo poles that are arranged in a tripod, weighted with stones, and covered with coconut palm fronds. The units are usually placed in calm, shallow coastal waters; however, when these reefs are used in deeper water, a FAD may be attached to mark their location and to attract pelagic fishes. Large-scale deployments of reefs and FADs are used as part of regional development programs. Approximately 16,000 pyramid bamboo modules in clusters of 50 have been set along 40 km of coastline in the central Visayan Islands and over 8,000 bamboo modules have been deployed in the Samar Sea-Ticao Pass Project (Miclat 1988). These artificial reefs are planned, constructed, deployed, and maintained by the village fishermen (Miclat 1988). The reefs are conveniently located, and the value of the catches during the first year of deployment can exceed the installed cost of the reefs (Miclat 1988). For example, the bamboo pyramids used in the Central Visayan Project had an estimated installed cost of US\$4.00/m^3 while annual harvests are 8kg/m^3; therefore, if all the fish caught were sold, the installed cost of the reef would be repaid in 9 months (Bojos and Vande Vusse 1988). Recently, artificial reefs made from concrete reinforced with bamboo have been used instead of bamboo because the bamboo reefs only have a 4-year lifespan (Bojos and Vande Vusse 1988).

While FADs are used by artisanal fishermen in many countries, the situation in the Philippines is unique because artisanal fishermen fish FADs are deployed by commercial purse seiners. About 3,000

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FADs (payaos) are used for tuna fishing in the Philippines (Aprieto 1988). Although owned and deployed by purse seiners, the FADs are also proving very beneficial to the artisanal fishermen who are allowed to handline around the FADs for large tunas swimming at depths too deep to be caught in purse seine nets (Aprieto 1988).

In Cuba and Mexico, artisanal fishermen use artificial reefs to attract lobsters *(Panulirus argus)* and facilitate their capture. In Cuba, mangrove branches are used to form shelters, which consists of flat layers of branches, about 2 m in length and width, raised about 10–15 cm above the ocean bottom by cross branches. These shelters are set in depths of 4–6 m. Fishermen catch the lobsters by shaking the shelters and netting the lobsters as they leave. In the Gulf of Batabano, Cuba, cooperatives use 120,000 lobster shelters and harvest 7,000 tons (t) of lobsters from them (National Research Council 1988). In Mexico, similar shelters have been used since the late 1960's, but many are now made from ferroconcrete and corrugated roofing material.

Thailand's Department of Fisheries has used old tires and concrete cubes to construct artificial reefs for artisanal fishermen in the Gulf of Thailand. These reefs, placed on soft-bottom areas, provide hard substrata and vertical relief, which attract valuable snappers and groupers normally not found at soft-bottom sites. In one application, the reefs were seeded with green mussels (National Research Council 1988). In another case, artificial reefs were placed on fishing grounds in the Gulf of Thailand for threadfin *(Eleuteronemus tetradactylum)*. The area was closed to trawlers, thus allocating the resource to village fishermen using gill nets from small vessels (Sinanuwong 1988). Before deployment of the artificial reefs, village fishermen fished this resource for about 15 days in November-December, before the schools were depleted by trawlers and push-netters. However, after the deployment of the artificial reefs, trawlers and push-netters were unable to operate in the area, and village fishermen were able to fish the schools for at least 6 months. Prior to deployment of the artificial reefs, threadfin catch by village fishermen was 1,746 kg, with an average catch rate of 4.7kg/trip, but after the deployment of the artificial reefs, threadfin catch by the same fishermen increased to 5,562 kg, with an average catch rate of 8.3 kg/trip (Sinanuwong 1988). The Thailand Goverment is considering plans to expand its artificial reef program by using concrete cube modules (volumes of 1–and $2m^3$) to construct large artificial reefs with volumes of 25,000–50,000 m^3 and covering areas of 50–100 km^2 (Sungthong 1988). These large reefs would close large areas to trawling and create fishing sites for artisanal fishermen (Sungthong 1988).

The Malaysian Department of Fisheries has an artificial reef program, which, by 1988, deployed 65 artificial reefs made from over 505,000 scrap tires, 7 reefs made from sunken ships, and 4 reefs made from pyramids of concrete pipes (Hung 1988). The tire reefs consist of modules of tires tied into pyramids with polyethylene rope. The number of tires per artificial reef site varied: almost 40% of the reefs had less than 1,000 tires but 5% were composed of more than 30,000 tire (Hung 1988). The objective of the Malaysian artificial reef program is to enhance biological productivity and fishery resources in coastal waters. To prevent the overfishing of resources aggregated at the artificial reefs, the Department of Fisheries prohibits fishing within 0.5 mile of the artificial reefs (Hung 1988). The Malaysian artificial reef program is expanding, and by 1990, the artificial reefs are expected to contain a total of 2 million tires (Hung 1988).

In summary, artificial reefs and FADs can reduce travel and search time for artisanal fishermen and improve the catchability of their gear. As long as the total fishing effort on the resource is not sufficient to result in overfishing, the effects of these structures on the resource are not harmful. Competition between gears and fishermen at the artificial reefs and FADs is a potential problem if effort is not regulated, but these structures could also serve to redistribute fishing effort to resolve competition. Artificial reefs may be useful in closing areas to trawling to protect juveniles in shallow nursery grounds and to provide fishing sites for artisanal fishermen using gear that captures older fish. The application of artificial reefs and FADs should be a community project: fishermen should be involved in their planning construction, and maintenance. Artificial reefs have potential to serve as habitat for extensive mariculture. Artificial reefs and FADs built with local materials have appeal, but care should be taken to avoid depleting local forests and mangroves. Longer lasting reefs built from scrap tires and concrete may ultimately prove more economical.

SMALL-VESSEL COMMERCIAL FISHERIES

Small-vessel commercial fishermen typically sell all of their catch and use larger vessels with greater fishing power, hydraulics, depth finders, inboard engines, and so on. In many developed countries, these small-vessel commercial fishermen are operating at marginal economic levels, and governments see the use of artificial reefs and FADs as possibly being beneficial to the operations of these fishermen.

The Japanese have the most extensive system of artificial reefs to assist the small-vessel commercial fishermen. Since 1976, the Japanese have spent over US$1 billion to construct and deploy artificial reefs with an enclosed volume exceeding 17 million m^3 (Grove et al. 1989). As a result, 9.3% of the total nearshore habitat down to 200 m has been covered with artificial reefs (Yamane 1989). The artificial reefs reportedly are popular with fishermen, because they increase catches and decrease operating costs (Yamane 1989). Whether the artificial reefs actually increase fishery catches has been addressed in an analysis of fishery catches bofore and after the deployment of 50,000 m^3 of artificial reefs in a small bay in Hokkaido. Japan (Polovina and Sakai 1989). This study found that, while several resources were caught at the artificial reefs, an increase in landings for only one resource, octopus *(Octopus dofleini)*, was attributed to the artificial reefs (Polovina and Sakai 1989). It was estimated that the artificial reefs increased the octopus catches by 1.8 kg/m^3 of artificial reef. A survey of fishermen from this bay found that 53% used the artificial reefs regularly, 12% used them only when fishing elsewhere was poor, and 36% did not use them at all (Polovina and Sakai 1989). Further, 33% of the fishermen thought the reefs had expanded the amount of productive habitat, 38% thought the reefs did not increase the productive habitat, and 30% were unable to decide (Polovina and Sakai 1989).

In the Mediterranean Sea, Italy, France, and Spain have modest artificial reef and FAD projects. The coastal environment in many parts of the Mediterranean Sea has a soft bottom, water with a high nutrient level that is not fully recycled by the ecosystem, and many nearshore fisheries that are overfished, in part, because of illegal trawling. The objectives of these programs include 1) protection of nursery grounds from illegal trawling, 2) attraction of pelagic and benthic species that use hard substrata, and 3) provision of substrata for shellfish farming and nutrient recycling in eutrophic environments. Initially a variety of materials, including car bodies and ships, was used as artificial reefs, but most recent and planned artificial reefs consist of concrete cubes or blocks. A study of a 4,300 m^3 concrete block artificial reef in Italy found that the reef increased both mussel and fish catches (Bombace 1989). The net proceeds for a fisherman operating within the reef were 2.5 times greater than those operating outside the reef (Bombace 1989). In the eutrophic waters such as those of the Adriatic, the cost of the reefs is recovered about three times in 7 year (Bombace 1989). Initially, trawlers were opposed to the reefs since the area was closed to trawling, but they changed their attitude as they experienced good catches of large fish along the edges of the reef zone (Bombace 1989). Typically in Italy, when artificial reefs are deployed, the area covered by reefs is designated as a marine zone, and activities and users in the zone are regulated. Problems have been encountered in administering the usage of these zones, often because the marine resources in the zones are not sufficient for the demand (Bombace 1989). Commercial fishermen in Italy are promoting the development of more marine zones protected by artificial reefs, France has less interest in developing new zones, and Spain is just beginning to evaluate artifical reefs (Bombace 1989).

Other nations have deployed artificial reefs and FADs to assist commercial fishermen. For example, 19 areas around Taiwan have artificial reefs built from concrete blocks deployed in 20–40 m depths on flat, sand or pebble bottoms to improve fishing sites (Chang 1985).

In Jamaica, artificial reefs made from scrap tires weighted with rocks or concrete are used to create fishing grounds near fishing villages and to provide habitat in areas closed to fishing (Haughton and Aiken 1989). Most South Pacific island use FADs widely to enhance catches of offshore pelagic fishes. An evaluation of FADs in American Samoa showed that their use could significantly increase catch per unit effort (CPUE) of offshore pelagic fishes for a troll fishery (Buckley et al. 1989). However, replacing lost FADs is a permanent job for fishery departments since the lifespan of FADs anchored in unprotected ocean around Pacific islands is often only a few years. Further, FADs do not always increase catches significantly; a study in Puerto Rico found only a slight increase in catches with FADs (Feigenbaum et al. 1989).

Increased CPUE due to artificial reefs and FADs alone may not be justification for their use by commercial fishermen when they receive heavy and unregulated usage. Since artificial reefs and FADs are usually located in accessible sites, they produce an increase in fishing effort and possibly an increase in the catchability of the gear and, hence, an increase in fishing mortality. Concern has been expressed that increased fishing mortality may occur even with FADs (Floyd and Pauly 1984). However, even if artificial reefs and FADs do not have a detrimental impact on the exploited stocks, they still may not be beneficial economically. An economic study of commercial open-access fisheries around FADs in Hawaii found that, even if high levels of fishing at FADs do not result in recruitment overfishing and if fishing effort is unregulated, installation of FAD networks will not generally increase fishermen's aggregate profit (Samples and Sproul 1985). Further, deployment of FADs could result in decreases in employment, harvest levels, and sustained gross revenues. The limiting of commercial fishing effort at FADs is seen as a means of preventing these detrimental impacts (Samples and Sproul 1985).

RECREATIONAL FISHING AND DIVING

Artificial reefs and FADs are popular with recreational fishermen and divers because they provide convenient sites with concentrations of fishes; such usage is widespread throughout the United States. Reefs and FADs are constructed and deployed by sport fishing and diving organizations and State fishery departments. The most common materials used are ships, concrete, tires, and stone rubble. In the Gulf of Mexico, 4,000 oil and gas rigs function as artificial reefs (Mogurrin et al. 1989). Oil companies are required to remove these oil and gas structures once they are no longer producing. One use for them is to move them into shallower water to increase their effectiveness as artificial reefs. However, given the large open construction of these structures, there is some question as to the effectiveness of these structures as artificial reefs.

Local government agencies support artificial reefs for recreational fishing and diving in the United States and Australia. In the United States, over one-half of the State fishery agencies have artificial reef programs and spent an average of US$1.5 million annually on the construction and deployment of artificial reefs and FADs (McGurrin et al. 1989). A survey of fisherman and sport divers in southern Florida found that about 28% of the recreational fishermen and 14% of the sport divers regularly used artificial reef sites (Milon 1989). In Australia, artificial reefs from tires assembled in a tetrachedron create fishing and diving sites for recreational fishermen and divers. A total of 34,000 tires was used at one site in Western Australia, and the A$205,000 cost of the program was justified on the basis that the artificial reef would increase revenues in the local community through an increase in activity and hence consumer spending in sport fishing and diving (Young 1988).

The reefs and FADs concentrate both fish and fishermen and, as a result, some concerns over the resource and the conflicts between users have been raised (Samples 1989). Two forms of conflicts at artificial reefs and FADs have been observed: competition over a common stock, and conflicts from user congestion (Samples 1989). An example of the former occurs between commercial pole-and-line boats and recreational trollers around FADs in Hawaii. A pole-and-line vessel can capture all of the skipjack tuna *(Katsuwonus pelamis)* around a FAD, leaving nothing for recreational trollers in the short term. On the other hand, conflicts due to user congestion occur when many users are concentrated around a reef or FAD, often with various types of gear, such as purse seiners and trollers or handlining and diving gear. Various approaches that restrict access, limit effort, or segregate users in space and time may resolve these conflicts (Samples 1989). Of course, carefully planned artificial reefs and FADs also can serve to shift effort away from heavily used natural sites.

Artificial reefs for recreational uses are often constructed and deployed by fishing and diving clubs without the resources or inclination to properly research the siting, design, and materials. Experience in Florida and other states, where a large number of artificial reefs of various materials have been deployed by numerous user groups, indicates that if attention is not given to proper siting and materials, the artificial reefs may be ineffective and even damaging (Andree 1988). It has been recommended that a Florida artificial reef plan be developed to establish standards for siting, design, and materials and to establish a central artificial reef permitting maintenance system and a monitoring system (Andree 1988).

MITIGATION FOR HABITAT LOSS AND HABITAT ENHANCEMENT FOR RESERVES

Applications of artificial reefs for uses other than to specifically increase fishing success include providing habitat to mitigate the loss of habitat due to coastal development or pollution and to improve habitat in marine reserves. The loss of rocky habitat due to nearshore filling was successfully mitigated with a 2.83 ha quarry rock artificial reef in Puget Sound, Washington (Hueckel et al. 1989). On the Pacific coast of Costa Rica, 5,000 scrap tires were used to construct new habitat to protect marine fauna rather than for fishing (Campos and Gamboa 1989). The reef, used by juvenile and adult fishes, was not marked, apparently to prevent fishermen from finding it and fishing the area.

In the case of mitigation, it is important to be sure that the artificial reefs are an appropriate habitat, are properly sited to replace the lost habitat, and are not adversely impacting other species. For example, species that use flat, low habitat may be adversely impacted if artificial reefs are deployed. A study in Puget Sound, Washington, found that the composition of benthic organisms at potential artificial reef sites serves as a useful predictor of the fish species that will subsequently colonize the artificial reef (Hueckel and Buckley 1989). The use of artificial reefs just to increase habitat for reef-associated species is questionable when one considers that even large artificial reefs only represent a very small fraction of the available natural reef habitat in any area.

SUMMARY

Experience in many countries has shown that properly constructed and sited artificial reefs and FADs can create convenient fishing sites. These structures have proven particularly effective for artisanal applications in which fishing effort is relatively low. However, since these structures serve to change the distribution of fishing effort and fishes, they must be viewed within an overall fishery management plan. Their impacts need to be considered in a broad socioeconomic context, rather than just in terms of changes in CPUE. A number of countries are finding that, in the presence of heavy effort, artificial reefs and FADs alone may not be economically beneficial. Measures that regulate gear and effort at artificial reef and FAD sites may be required to avoid resource overfishing and user conflicts and to improve fishery economics.

While the literature is full of studies on the ecology at artificial structures, studies on the broader fishery management and socioeconomic impacts of these structures are lacking. For there to be progress in the applications of artificial reefs and FADs, scientists and managers must understand and apply these structures within an overall fishery management system.

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