5

Fisheries Applications and Biological Impacts of Artificial Habitats

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This chapter examines many of the applications of artificial habitats in various aquatic environments. The particular focus is on their biological impacts with reference to fisheries and their actual or possible role in fishery management.

Grouping artificial habitats by their primary users is a useful way to categorize the applications of these structures for analysis. Four principal categories recognized here include artisanal fisheries; small-scale commercial fisheries; recreational fisheries and diving; the replacement of habitat lost from shoreside development (mitigation); and enhancement of habitat in marine reserves. Examples of the uses and impacts of artificial habitats for these categories are discussed in the first section of this chapter.

The second section focuses on the biological impacts of artificial habitats. Their much debated role in aggregating production and creating new production is presented in a broader context. It is proposed that artificial habitats may (1) redistribute exploitable biomass without increasing it or total stock size; (2) aggregate previously unexploited biomass and increase exploitable biomass; or (3) increase total biomass. The discussion of each provides examples. Throughout the text, attention is given to identifying the effective uses of artificial habitats in fishery management.

Artificial Habitats for Marine and Freshwater Fisheries

I. Applications

Some of the better documented fishery and environmental applications of artificial habitats are presented in this section. The intent is not to provide an exhaustive global review, but rather to provide illustrative data for representative situations. This augments the description and synopsis provided in Chapters 1 and 2.

A. Artisanal Fisheries

Artisanal fishermen have developed many artificial reef and fish-aggregating device (FAD) designs to create fishing grounds close to their villages. Such structures traditionally have been constructed with materials of opportunity, for example, sticks, poles, bamboo, or bundles of brush, but are also frequently made from concrete and scrap tires.

In the Philippines, a widely used artificial reef module is made from bamboo poles arranged in a tripod, weighted with stones, and covered with coconut palm fronds (Fig. 5.1). The units are usually placed in calm, shallow coastal water. When such artificial habitats 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 in regional development programs (Fig. 5.2).

Approximately 16,000 pyramid bamboo modules in clusters of 50 have been set along 40 km of Philippines coastline in the central Visayan Islands, and over 8000 bamboo modules have been deployed in the Samar Sea-Ticao Pass Project (Miclat, 1988). These artificial habitats 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 cost of the reefs and their installation (Miclat, 1988). Catches include caesionids, mullids, lutjanids, serranids, siganids, lethrinids, haemulids, acanthurids, and apogonids (Miclat, 1988). The bamboo pyramids used in the Central Visayan Project had an estimated installed cost of U.S. \$4.00/m^3 and annual harvests of 8 kg/m^3; therefore, if all of the fish caught were sold, the installed cost of the reef would be recouped in nine months (Bojos and Vande Vusse, 1988). Recently, artificial reefs made from concrete reinforced with bamboo have been used instead of bamboo, which only has a 4-yr life span (Bojos and Vande Vusse, 1988).

Although FADs are used by artisanal fishermen in many countries, the situation in the Philippines is unique. The approximately 3000 FADs owned and deployed by commercial tuna purse seiners are also used by artisanal fishermen who handline around the FADs for large tunas (yellowfin, *Thunnus albacares*) swimming too deep to be caught in purse seine nets (Aprieto,

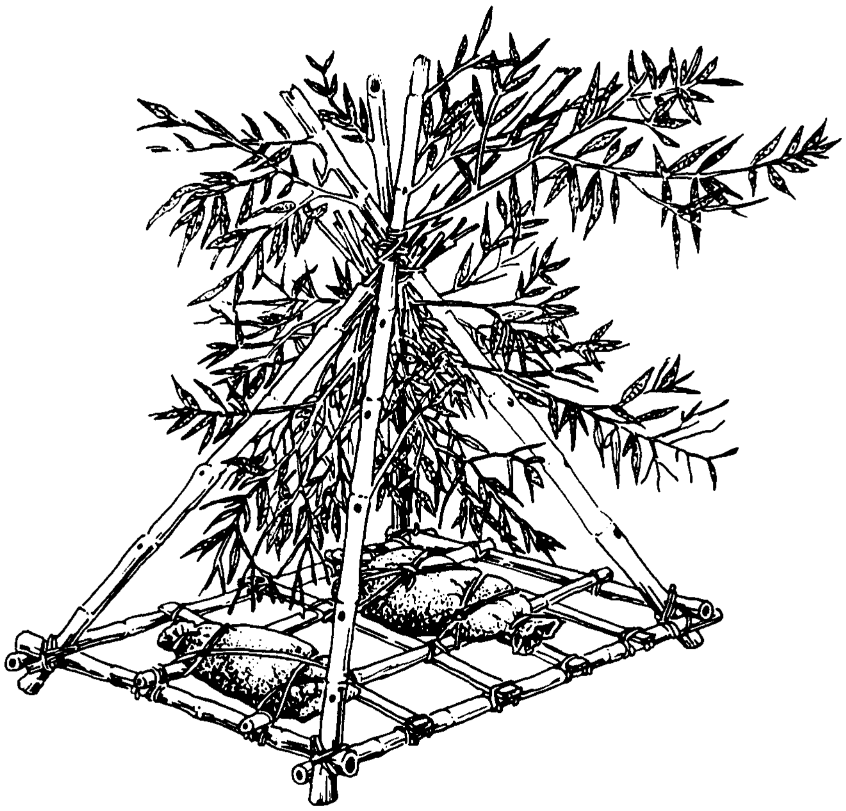


Figure 5.1 A benthic artificial reef used in the Philippines (redrawn from Aprieto, 1988).

1988). Because they exploit different resources and appropriate accommodations exist between commercial and artisanal fishermen, fisheries conflicts between these two user groups are rare.

In Cuba and Mexico artisanal fishermen use artificial reefs to attract lobster (*Panulirus argus*) and to facilitate their capture. In Cuba, flat layers of mangrove branches are used to form shelters (about 2 m in length and 2 m in width) that are set in depths of 4–6 m and raised about 10–15 cm above the ocean bottom by cross branches (Fig. 5.3). Fishermen shake the shelters and net the escaping lobsters. In the Gulf of Batabano, Cuba, cooperatives use 120,000 lobster shelters and harvest about 7000 metric tons (t) of lobster (U.S. National Research Council, 1988). In Mexico, similar shelters have been used since the late 1960s; many are now made from ferroconcrete and corrugated roofing material.

Thailand's Department of Fisheries has used old tires and concrete cubes

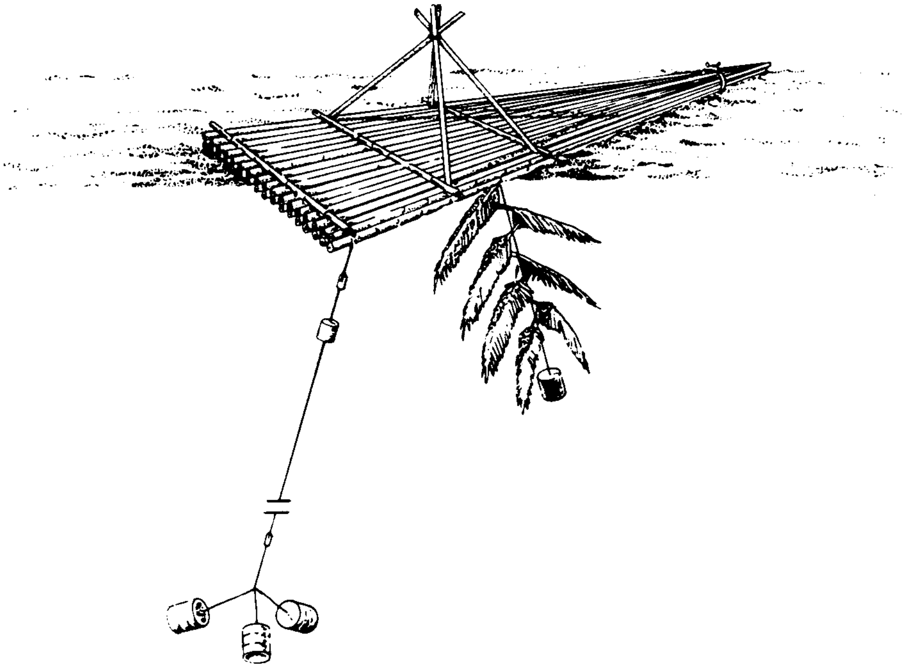


Figure 5.2 A bamboo raft or payao is a FAD used for tuna in the Philippines (redrawn from Aprieto, 1988).

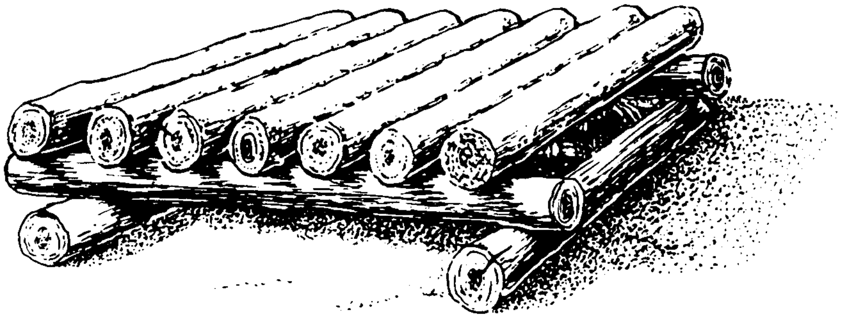


Figure 5.3 A traditional Cuban lobster shelter (after U.S. National Research Council, 1988).

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 that attract valuable snappers (Lutjanidae) and groupers (Serranidae) normally not found at soft-bottom sites. In one application, the reefs were seeded with green mussels (U.S. National Research Council, 1988).

In another application, 2805 concrete cylinders were deployed in the Gulf of Thailand over a 41 km^2 area previously used by trawlers and village fishermen as a fishing ground for threadfin (*Eleuteronemus tetradactylum*, family Polynemidae). This artificial reef had the effect of closing the area to trawlers, thus allocating the resource to village fishermen using gill nets from small vessels (Sinanuwong, 1988). Before the deployment of this artificial habitat, village fishermen fished this resource for about 15 days in late November and early December, before the schools were depleted by trawlers and push-netters. However, after deployment, 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. The threadfin catch by village fishermen was 1746 kg (average catch rate, 4.7 kg/trip) before deployment and 5562 kg (average catch rate, 8.3 kg/trip) after deployment (Sinanuwong, 1988). Unfortunately, the substrata where the reefs were deployed were soft, and most of the reefs sank into the bottom sediment after about a year.

The Thai government is considering plans to increase its artificial reefs by using concrete cube modules (volumes of 1 and 2 m^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.

By 1988, the Malaysian Department of Fisheries artificial habitat program had deployed 65 artificial reefs made from over 505,000 scrap tires, seven reefs made from sunken ships, and four 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: most of the reefs (40%) had fewer than 1000 tires, but a few (5%) were composed of more than 30,000 tires (Hung, 1988). The objective is to enhance biological productivity and fishery resources in coastal waters. To prevent overfishing of resources aggregated at the artificial reefs, the Department of Fisheries prohibits fishing within 1.7 km of the artificial reefs (Hung, 1988). By 1990 the artificial reefs are expected to contain a total of two million tires.

B. Small-Vessel Commercial Fisheries

Small-vessel commercial fishermen typically use larger vessels with greater fishing power, hydraulics, depth finders, and inboard engines, than do artisanal fishermen. In many developed countries, they operate at marginal economic levels, and governments perceive programs of construction and deployment of artificial habitats as being beneficial to the financial operations of these fisheries.

Japan has the most extensive system of artificial reefs to assist the small-vessel commercial fishermen of any nation, as described in detail in Chapter 2. Since 1976, the Japanese government has spent over U.S. $1 billion for reefs with an enclosed volume exceeding 17 million m^3 (Grove *et al.*, 1989), so that 9.3% of total nearshore seafloor to a depth of 200 m is covered with artificial reefs (Yamane, 1989). (See numerous illustrations in Chapter 4.)

The Japanese artificial reefs reportedly are popular with fishermen because they increase catches for a wide range of both demersal and pelagic fishes and decrease operating costs (Yamane, 1989). Whether the reefs actually increase fishery catches has been addressed by Polovina and Sakai (1989), who analyzed the 1945 to 1985 catch at a small bay in Hokkaido, Japan, where 50,000 m^3 of artificial reefs were deployed from 1960 to 1985. They found that although several resources were caught, an increase in landings for only one resource could be attributed to the artificial reefs: catches of octopus (*Octopus dofleini*) increased by an estimated 1.8 kg/m^3 of artificial reef. Fifty-three percent of the fishermen surveyed from this bay 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 these 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 about this question.

In the Mediterranean Sea, Italy, France, and Spain have modest artificial reef and FAD development 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 the projects 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, various materials including car bodies and ships were used as artificial reefs, but most recent and planned artificial reefs consist of concrete cubes or blocks (see Figs. 2.2 and 2.3).

In Italy, Bombace (1989) found that a concrete reef of 4300 m^3 increased both mussel and fish catches including striped mullet (*Mullus barbatus*), meagre (*Arnyrosoma regius*), sea bass (*Dicentrarchus labrax*), and mussels (*Mytilus galloprovincialis*). The net proceeds for a fisherman operating within the reef were 2.5 times greater than those operating outside the reef. In eutrophic waters such as those of the Adriatic, the cost of the reefs was recovered about three times in seven years (Bombace, 1989). Initially, trawlers were opposed to the reefs because the area was closed to trawling, but their attitude changed as their catches increased along the edges of the reef zone (Bombace, 1989).

When artificial reefs are deployed in Italy, the area covered by reefs typically is designated as a marine zone, and activities and users in it are regulated. However, the demands to harvest resources in these zones often exceed their productivity, and administrators are faced with the challenge of allocating resources among users (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 artificial reefs (Bombace, 1989).

Insular nations also 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, sandy, 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 to protect spawning stock from overfishing (Haughton and Aiken, 1989).

Most South Pacific island governments use FADs widely to enhance catches of offshore pelagic fishes (Fig. 5.4). 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 task for fishery departments since the life span 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 justify 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 increases in fishing effort, possibly increase the catchability of the gear, and hence increase fishing mortality. Concern has been expressed that even for pelagics, overfishing may occur as a result of the increase in fishing mortality (catch) arising from the use of 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

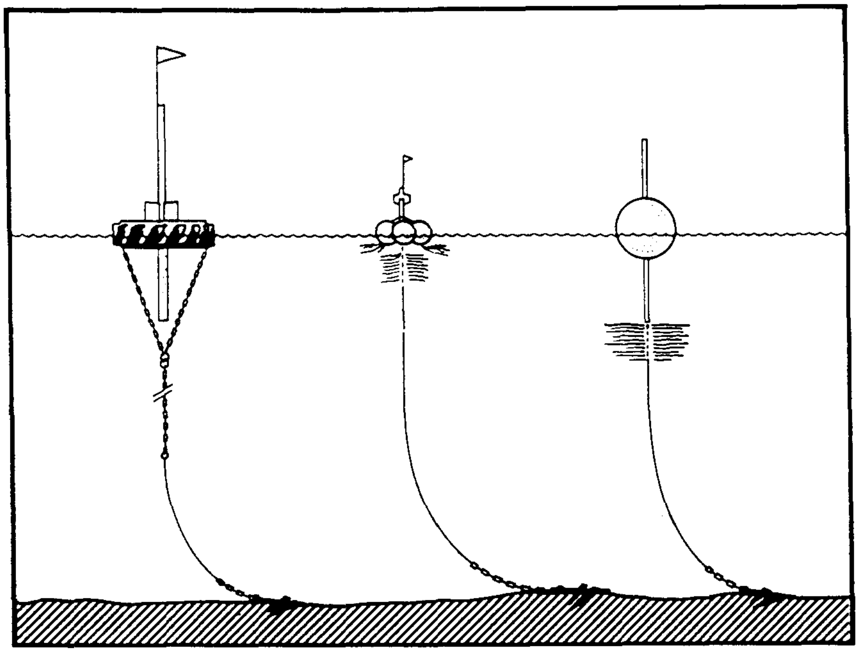


Figure 5.4 Representative FADs used in the Pacific Ocean (redrawn from U.S. National Research Council, 1988).

profit (Samples and Sproul, 1985). Further, deployment of FADs could result in decreases in employment, harvest levels, and sustained gross revenues. Limiting the commercial fishing effort at FADs is seen as a means of preventing these detrimental impacts (Samples and Sproul, 1985).

C. Recreational Fishing and Diving

Artificial reefs and FADs also are popular with recreational fishermen and divers because they provide convenient sites with a concentration of fishes and other organisms. Although globally they are not as widespread as artisanal and commercial fishing applications, where artificial habitats are employed recreationally, use can be extremely intensive. They often are constructed and deployed by sport fishing and diving organizations and state fishery departments in freshwater and marine settings. The most common materials used are ships, concrete, tires, and stone rubble (McGurrin *et al.*, 1989).

The most widespread recreational usage is in the United States. In the Gulf of Mexico, for example, 4000 petroleum structures function as artificial reefs (McGurrin *et al.*, 1989). Even while these structures are producing gas and oil, they are heavily used by recreational fishermen and SCUBA divers (Reggio, 1989). Louisiana has 3100 petroleum structures, which are the destinations of about 37% of all saltwater recreational trips, and over 70% of all recreational trips more than three miles offshore (Stanley and Wilson, 1989). A survey in southern Florida found that about 28% of the recreational fishermen and 14% of the sport divers regularly used artificial reef sites (Milon, 1989). Brush, timbers, tires, rocks, and concrete materials are used in lakes and reservoirs to enhance fishing (D'Itri, 1985). A large artificial reef covering 9500 m^2 was constructed in Smith Mountain Lake, Virginia, with 7000 scrap tires and 400 Christmas trees (Prince *et al.*, 1985). Sunfishes (*Lepomis* spp.) and white catfish (*Ictalurus catus*) were more abundant at this artificial reef site after deployment of reef materials. Furthermore, fishes foraged on the artificial reefs and catfishes deposited eggs inside the artificial reef (Prince *et al.*, 1985). A more detailed review of U.S. sport fishing habitats is provided in Chapter 2.

State government agencies in Australia also support artificial reefs for recreational fishing and diving. One structure is made of tires assembled in a tetrahedron to create fishing and diving sites, which are closed to professional fishermen (Young, 1988). In one instance, 34,000 tires, at a cost of A $205,000, were deployed on the premise that the artificial habitat would increase revenues in the local community through increased spending by sport fishing and diving interests (Young, 1988).

The reefs and FADs concentrate both fish and fishermen. Some concerns over the resource and the conflicts between users have been raised by Samples (1989) and others. Two forms of conflicts, i.e., competition over a common stock and conflicts from user congestion, have been observed (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.

Also, 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. A number of 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. Broader aspects of fishery management are discussed more fully in Chapter 7.

Artificial reefs for recreational uses have been constructed and deployed by fishing and diving clubs, which, unfortunately, may lack the resources or inclination to properly research the siting, design, and materials. Experience in Florida and other states indicates that the structures may be ineffective and even damaging (Andree, 1988). Andree (1988) has recommended that a Florida artificial reef plan be developed to establish standards for siting, design, and materials, and to establish central artificial reef permitting, maintenance, and monitoring systems. As other areas of the world initiate such programs, the experiences in active artificial habitat sites need to be consulted to avoid mistakes and negative environmental impacts.

D. Environmental Mitigation and Enhancement

Applications of artificial reefs (for uses other than increasing fishing success) include providing habitat to mitigate its loss due to coastal development or pollution and to improve habitat in marine reserves. This is a relatively recent application of this field, and much of the experience is limited to the Pacific mainland coast of the United States. In southern California, for example, the San Onofre nuclear station has affected organisms in two ways: by killing larval, juvenile, and adult fishes that are taken into the plant with the cooling water, and by producing a turbid plume that affects kelp, fishes, and invertebrates in the San Onofre kelp bed. A 120 ha artificial reef has been proposed as in-kind mitigation for impacts to the kelp-forest community from the plume, and a 60 ha structure proposed as out-of-kind mitigation for egg, larvae, and juvenile fish mortality from entrainment (Ambrose, 1990).

Loss of rocky habitat due to near shore filling was successfully mitigated with a 2.83 ha quarry rock artificial reef in Puget Sound, Washington (Hueckel *et al.*, 1989). An important feature of this mitigation was that before a site for the habitat was selected, a set of benthic species was identified to predict colonization of the site by economically important fish species.

On the Pacific coast of Costa Rica, 5000 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 and fishing the area. Artificial reefs may have potential to protect or improve aquatic ecosystems. For example, in Maryland's Chesapeake Bay artificial reefs have been proposed to provide habitat for the American oyster (*Crassostrea virginica*) to restore oyster population levels, not for fishery harvest, but to filter excessive nutrient and particulate levels from the water (Myatt and Myatt, 1990).

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, or low-relief habitat may be adversely impacted if high-profile materials are deployed.

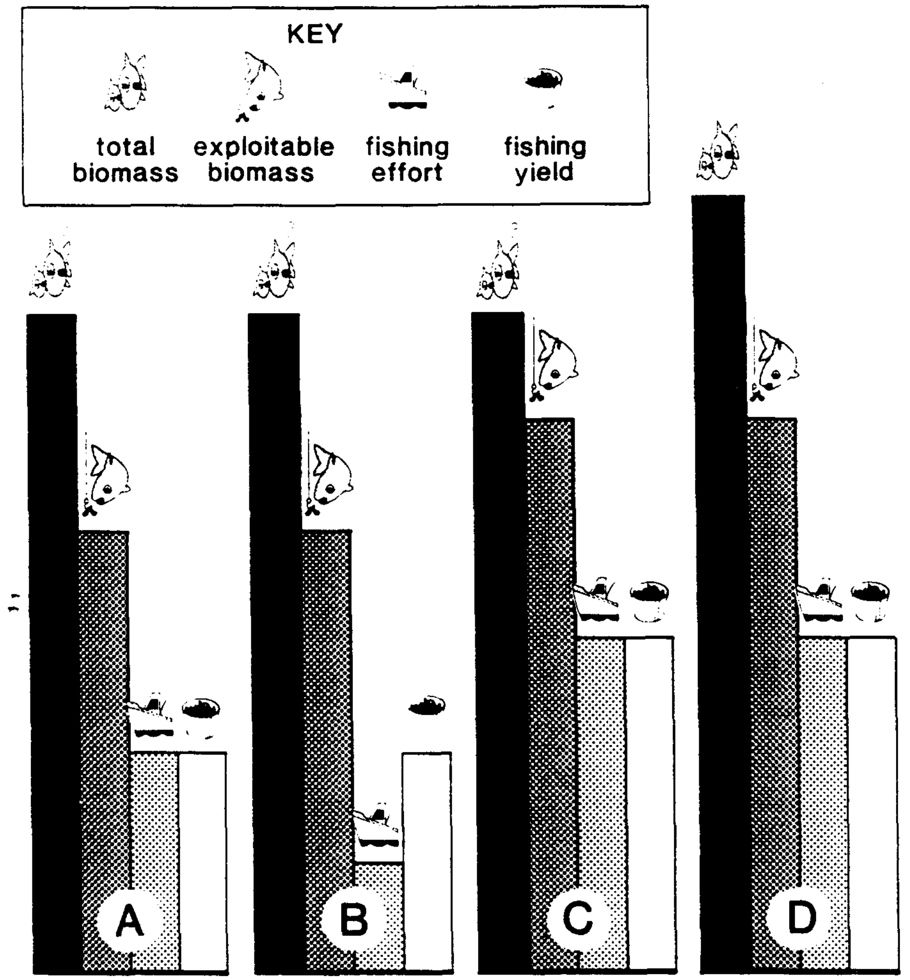
II. Biological Impacts

A considerable body of literature deals with the ecology at artificial habitat sites (see Chapter 3), whereas few studies address the biological impacts of artificial reefs and FADs on fish populations (Bohnsack and Sutherland, 1985; Bohnsack, 1989). The limited number of studies of this latter aspect is certainly not due to a lack of interest but rather to the difficulty in collecting the appropriate data. Data must be collected from large-scale applications of artificial habitat on an appropriate spatio-temporal scale to determine the possible biological impacts of artificial habitat in the presence of variations in the environment, fishing strategies, and gear. The scale of most research or pilot applications of artificial habitat is too small to detect biological impacts on stocks, even at a local level. Thus, much of the current thinking on the biological impacts of artificial habitat tends to be speculative. (The reader may consult Chapter 6 for a review of ecological assessment methods.)

Often discussions on the impacts of artificial reefs and FADs distinguish between impacts due to aggregation and those due to "new production" (Bohnsack, 1989). However, from both a management and biological perspective, it is important to make the distinction between aggregation that simply redistributes exploitable biomass and aggregation that attracts biomass not previously exploited, while increasing the exploitable biomass. It is useful to consider the three types of impacts on the exploitable biomass and the total stock due to the artificial habitat:

- Artificial reefs and FADs can simply redistribute the exploitable biomass without increasing it or total stock size;
- They can aggregate previously unexploited biomass and increase the exploitable biomass but not the total stock size;
- When stocks are limited by high-relief habitat, artificial reefs can increase stock and hence, total stock size.

These three types of impacts, therefore, distinguish between not only the two types of aggregation but also total stock size and exploitable biomass. Because some of their biological aspects will differ, the three impacts are discussed separately in subsequent sections. However, all three may occur in varying degrees in any artificial habitat application. They are illustrated in Fig. 5.5.



Prior to deployment of artificial habitats

When artificial habitats redistribute biomass

When artificial habitats increase exploitable biomass through aggregation

When artificial habitats increase total biomass

Figure 5.5 Three possible impacts of artificial habitat. (A) Total biomass, exploitable biomass, fishing effort, and yield for a resource prior to deployment of artificial habitats. Note the catch rate (yield:effort) is 1.0, and the yield is about one third of the total biomass. (B) When artificial habitats just redistribute the exploitable biomass to make it easier to catch, the same catch can be obtained with lower effort. (C) When artificial habitats increase the exploitable biomass but not the total biomass, an increase in catch can be achieved with greater effort without a reduction in catch rate, assuming that recruitment overfishing does not occur. (D) When artificial habitats increase the total biomass, the levels of all the variables in part (A) increase. Note that the only difference between (C) and (D) is the increase in total biomass.

A. Impacts Due to a Redistribution of Exploitable Biomass

For some resources, artificial habitat may primarily change the distribution of the exploitable biomass without increasing it or the total stock (Fig. 5.5 part B). For example, some of the resources exploited in the natural habitat move to the artificial habitat, or a highly mobile resource that moves between natural habitats may visit artificial habitats as well.

This type of impact appears to be illustrated by flatfishes (Pleuronectidae) in the study by Polovina and Sakai (1989) on the impacts of 50,000 m^3 of artificial reefs deployed in Shimamaki Bay off Hokkaido, Japan. Despite the flatfishes representing an estimated 30% of the gill-net catches at the artificial reefs, no increase in flatfish landings could be attributed to the reefs when landings from the entire bay were considered (Polovina and Sakai, 1989). In sonic tagging experiments, flatfishes readily moved from natural habitat to artificial reefs, but they were not long-term residents at either site (Kakimoto, 1984). Polovina and Sakai (1989) concluded that the artificial reefs redistributed the flatfishes but did not change their exploitable biomass.

Although the Shimamaki study did not identify any biological impacts from the redistribution of exploitable biomass, there are potential impacts caused by artificial reefs that redistribute exploitable biomass. The greatest potential impact may be a reduction in exploitable biomass if fishing at the artificial habitat is not restricted. Siting of artificial habitats usually allows them to be more accessible to fishermen all year and often works to support a higher density of fishes than a natural habitat. The higher density may increase catchability of the fishing gear, and the greater accessibility increases fishing efforts, which can result in higher fishing mortality. An increase in fishing mortality will decrease exploitable biomass in the area. Whether this decrease results in lower catches or recruitment to the fishery, either locally or in an adjacent region, depends on the stock dynamics. If the stock is migratory, then heavy fishing mortality in one region will result in lower levels of exploitable biomass in adjacent regions. If a strong regional stock–recruitment relationship exists, then heavy local fishing mortality could reduce future recruitment.

Similar to the situation in Shimamaki Bay, application of artificial reefs in the Gulf of Thailand also did not appear to increase the exploitable biomass for one resource. However, the allocation of the resource among user groups was altered (Sinanuwong, 1988). The reef site in the Gulf of Thailand was closed to trawlers and push-netters, and the threadfin resource was allocated to small-vessel, village fishermen using gill nets (Sinanuwong, 1988). Village fishermen had previously fished this resource for a short time until the schools were depleted by trawlers and push-netters. After the reef deployment, they were able to fish the schools much longer and catch, as well as catch rate, increased.

The Thailand example illustrates an application of artificial habitat that likely resulted in a reduction in fishing mortality, because the increase in catches by the village fishermen was probably less than the catches previously taken by the more efficient trawlers and push-netters. This example also shows that artificial habitat can result in a change in the types of fishing gear used. Such a change may impact the species caught, catchability, and fishing mortality. Since the species composition of the catches at the artificial habitat may differ from that at the natural habitat, fishing mortality may increase for some species but decrease for others as effort shifts from natural to artificial habitat.

B. Impacts Due to Increased Exploitable Biomass but Not to Total Stock Size

Aggregation may not only cause a resource to be redistributed but may also increase the biomass of a resource exploited by a fishery. (See Fig. 5.5 part C.) If artificial habitat aggregates juveniles, thereby making them more accessible to capture, the exploitable biomass may increase as the size of the fish at entry to the fishery decreases. Conversely, aggregation may make available to fishing gear a portion of the resource that has been distributed at a low density and has not been previously exploited. An extreme case would be a resource that has not been fished because it is widely distributed at a low density at a natural habitat. Artificial habitat will aggregate the resource at a density sufficient to support a fishery, and the resource can then be exploited. From a fisherman's perspective, if a resource is not overexploited, it does not matter whether exploitable biomass is increased by aggregating unexploited biomass to artificial habitat or from new production that increases stock size. In both cases, increased catches will be achieved without increased effort.

The impact of FADs on tuna in the Philippines appears to represent this type of aggregation. There, devices known as payaos (Fig. 5.2), together with purse seines or ring nets, were introduced to the tuna fishery in the early 1970s. As a result, skipjack tuna (*Katsuwonus pelamis*) catches rose from less than 10,000 t in 1970 to 266,211 t in 1986, representing 20% of the national marine catch (Aprieto, 1988). Over 90% of the tuna caught at the FADs were less than one year old, and they were about one-half the length of a mature tuna (Aprieto, 1988). There was some concern that the heavy fishing mortality with small length at entry may result in growth overfishing (i.e., lower catches than could be achieved with larger length at entry or lower fish mortality) and recruitment overfishing (i.e., a decline in recruitment to the fishery) (Aprieto, 1988).

The question of whether FADs can cause growth overfishing has been examined by Floyd and Pauly (1984). Four factors are necessary for growth overfishing: (1) presence of small fish on the fishing ground; (2) use of gear capable of catching small fish; (3) a market for small fish; and (4) high exploitation rates. All four of these factors are present in the tuna fishery in the Philippines. Using an exploitation rate of 0.7–0.8 for skipjack tuna and yellowfin tuna (*Thunnus albacares*) with the Beverton and Holt (1966) yield equation, the yield per recruit declines by an estimated 50% when the size at entry drops from one-half to one-fourth the asymptotic length (Floyd and Pauly, 1984). The recent decline in landings from this fishery may be partly due to growth overfishing (Floyd and Pauly, 1984). Further, analysis of stomach contents suggests that the predation on juvenile tunas by adult tunas is greater at FADs than in schools in the open ocean, suggesting that FADs can increase natural mortality as well (Aprieto, 1988).

The biological impacts of this type of aggregation include all of the impacts associated with aggregation that simply redistributes exploitable biomass. However, when aggregation increases the exploitable biomass, other impacts depend on the dynamics between aggregated and unaggregated fish. Clark and Mangel (1979) developed a model for tuna purse seining in which tunas move from subsurface populations to surface schools that are fished. Applying this model to the tuna fishery with FADs shows that the potential impact of FADs on the stock depends primarily on whether the rate of movement from the unaggregated population to the FADs, as well as the mortality of the unaggregated population, exceeds the intrinsic rate of population increase (Samples and Sproul, 1985). If the rate that tunas aggregate at FADs plus non-FAD mortality exceeds the population growth rate, then high fishing mortality at the FADs alone can drive the fishable population to zero. The relationship between catches at a FAD and effort follows the typical dome-shaped production curve. The biological impact is that excessive fishing effort at FADs can result in recruitment overfishing. However, when the growth of the population exceeds the non-FAD mortality and the rate of aggregation to the FADs, no amount of fishing at the FADs can exhaust the total population (Samples and Sproul, 1985). In this case, catch increases with effort to an asymptotic value, and the biological impact is that increasing fishing effort on aggregations cannot increase the fishing mortality beyond a certain level. While the Clark and Mangel (1979) model has been applied specifically to the tuna fishery at FADs, the results also apply to demersal resources aggregated at artificial reefs.

C. Impacts Due to Increased Total Stock Size

In theory, providing additional habitat could increase the population size for some habitat-limited stocks (Fig. 5.5 part D). For example, the habitat provided by artificial reefs might result in substrata for additional food, shelter from predation, settlement habitat, and lower densities at natural reefs (Bohnsack, 1989). However, despite the large number of studies on artificial reefs, very little direct evidence indicates that artificial reefs can increase the population size of a fish stock (Bohnsack, 1989).

One unplanned experiment in the United States that may merit further study is the biological impact from the oceanic petroleum platforms off Louisiana. A single petroleum platform in a depth of 40–60 m can provide about 1 ha of hard substrate, and platforms are estimated to represent over 90% of all hard-bottom substrate off Louisiana (Scarborough-Bull, 1989). The ecosystems at these structures differ from the naturally occurring soft-bottom ecosystem and demonstrate that artificial reefs can result in the establishment of hard-substrate ecosystems, even when isolated from similar ecosystems (Scarborough-Bull, 1989). Since these platforms represent large-scale habitat alteration with apparent impacts on species composition and abundance, plus fishing areas and species targeted, a quantification of these impacts would greatly add to our understanding of the impacts of artificial habitats.

In Japan, a relatively large-scale application of artificial reefs provides some evidence that artificial reefs can increase the total stock. A significant increase in landings and catch rates of *Octopus dofleini* was observed in a small bay near Shimamaki, Hokkaido, Japan after almost 50,000 m^3 of artificial reefs were deployed (Polovina and Sakai, 1989). Additionally, availability of data from two adjacent regions in the same bay made it possible to compare relative changes in catches and catch rates as a function of artificial reef volume in each bay. While changes in environment or fishery economics could alter catches and catch rates in each region, the relative catches and catch rates should be unaltered by these factors and reflect only the impacts due to the artificial reefs.

The magnitude of the increase in octopus catches attributed to the artificial reefs was about 90 t or about 1.8 kg/m^3 of artificial reef per year. Polovina and Sakai (1989) concluded that the artificial reefs increased the exploitable biomass of octopus. This increase may have come from either an aggregation of octopus from habitat not previously exploited or from new biomass due to the additional habitat.

Unfortunately, no surveys of octopus abundance and their size structure (over the natural habitat and artificial reefs before and after the deployment) were conducted to complement the fishery data and determine whether the reefs were aggregating the octopus or actually increasing the population size. However, Polovina and Sakai (1989) addressed this issue by examining the change in catches in the two adjacent regions. They hypothesized that, if artificial reefs aggregated octopus from the entire bay, then as the octopus moved to the region with the large reef volume, an increase in catches in the region with the large volume of artificial reefs would be accompanied by a corresponding decline in catches in the adjacent region with the low volume of artificial reefs. But if the artificial reefs increased the population of octopus, changes in catches in each region would be independent of the artificial reef volume in the adjacent region and depend only on the volume within each region. The catch and effort data indicated that the catches in each region were independent of the artificial reef volume in the adjacent regions, consistent with the hypothesis that the artificial reefs did indeed increase the population of octopus (Polovina and Sakai, 1989).

Studies on the ecology of *O. dofleini* have found that the animals are almost always associated with dens, with one animal per den. So in areas without a sufficient number of dens, habitat could be limited (Hartwick *et al.*, 1978).

When the exploitable biomass in a region is heavily fished, the density of the resource above the size at entry to the fishery is very low relative to the preexploitation density. Thus, habitat is not likely to limit the population above the size at entry to the fishery, and artificial reefs that provide more habitat for this portion of the population are not likely to increase new production.

If artificial reefs are to increase new production of this resource, they might provide habitat to improve larval settlement, juvenile growth, and a reduction in juvenile natural mortality. Thus, biological impacts of artificial reefs that increase total stock size are likely to include one or more of the following: an increase in postlarval settlement, juvenile growth, and juvenile survival. However, just as with the impacts from aggregation, an increase in fishing effort, and hence, fishing mortality may also occur as the fishery responds to more accessible habitat and higher catches.

1. Estimation of Biomass Increase

In the absence of studies that quantify an increase in stock size due to artificial reefs, two simple approaches—one based on yield from natural habitat and the other based on the standing stock estimates at artificial reefs, together with an estimate of yield to biomass—can provide useful estimates of the maximum potential enhancement due to artificial reefs.

For the first approach, yield per area of artificial reefs is simply estimated from fishery yield per area of corresponding natural habitat; the resulting figure is adjusted upwards for the observed higher catches between artificial reefs and natural habitat. For example, to estimate potential fishery catches from artificial reefs in the tropics, the range of fishery production from coral reefs must first be considered. Annual fishery production per area of coral reef habitat ranges from <1 t/km^2 to 18 t/km^2, with values clustering around 5 t/km^2 (Marten and Polovina, 1982). Biomass on artificial reefs in several tropical and subtropical studies is, on average, seven times greater than on natural habitat (Stone *et al.*, 1979). If, for example, artificial reefs can support 10 times the exploitable biomass of natural coral reefs, then an average annual value for the fishery catches from an artificial reef in the tropics is 50 t/km^2 or 10 times those from a coral reef. This value is equivalent to a yield of 0.05 kg/m^2. If, as an upper bound, this yield is assumed to come from only 1 m of vertical relief, then the yield per artificial reef volume is 0.05 kg/m^3.

The second approach to estimating the new production of an artificial habitat uses the biomass estimated from local artificial reefs and then estimates the potential fishery yield as a fraction of that biomass. The Beverton and Holt (1966) yield equation can be used to determine the fraction of the biomass at the reefs that can be harvested on a sustainable basis, if estimates of a number of population parameters are available (Beddington and Cooke, 1983). However, in the absence of estimates of population parameters, an upper bound for sustainable catch can be taken as one-half the product of natural mortality and unexploited exploitable biomass ($0.5 \cdot M \cdot B_0$), where M is the natural mortality and B_0 is the unexploited exploitable biomass (Beddington and Cooke, 1983).

For example, the range of biomass estimates observed for tropical and subtropical artificial reefs is 26–698 g/m^2 (Stone *et al.*, 1979). More recently, a value of 1266 g/m^2 was documented (Brock and Norris, 1989). Taking an average value for this range of 650 g/m^2 as an average estimate of the unexploited exploitable biomass, the fishery catches can be estimated by multiplying this value by an estimate of $0.5 \cdot M$. For a tropical, fast-growing, short-lived species, M equaling 0.7 might be appropriate. A biomass of 650 g/m^2 at the artificial reefs would then support a maximum annual fishery production of about 35% of the unexploited exploitable biomass, or 228 g/m^2. Again, if yield per square meter is assumed to be due to just 1 m of vertical relief, then in this example, 0.2 kg/m^3 is the upper bound for the potential fishery yield from artificial reefs.

Once an estimate of the fishery production due to new production from the artificial reefs is available for a specific application, this estimate can be compared with the actual catches from the reefs to determine to what extent they are functioning as fish aggregators. Total catches at artificial reefs have been documented at 8 kg/m^3 of artificial reef from the Philippines and 5–20 kg/m^3 from Japan (Sato, 1985; Bojos and Van de Vusse, 1988). Of course these catches include fishes aggregrated by the reefs as well as any new production due to the reefs. If the range of catches of 5–20 kg/m^3 of artificial reef represents a range for tropical applications, then based on the example previously considered, estimates of new production due to artificial reefs are on the order 0.05–0.2 kg/m^3, indicating that the catches are primarily fishes aggregated by the reefs and greatly exceed the maximum that could be expected from new production.

This discussion is primarily meant to illustrate two approaches that can be used to estimate the relative magnitude of new and aggregated production attributable to artificial habitats, in order to determine how the structures are functioning and their role in fishery management. Each application needs to be evaluated based on the biological and fishery information specific to that application. For example, the growth of oysters and mussels on reefs in eutrophic waters may result in substantial new shellfish production (Fabi *et al.*, 1989). Chapter 3 presents a discussion on the potential of artificial habitats to provide new production as a function of the ecological characteristics of species at the habitat. Also see Chapter 3 for more comparisons of catches and biomasses between natural and artificial reefs.

III. Discussion

Artificial habitats clearly play a role in fishing systems worldwide, and are increasingly employed by fishery and environmental managers in natural resources conservation and planning. Aspects of that role for artisanal fisheries, and fisheries in general, are presented in the following section.

A. Artisanal Fishing

Artificial habitats have proven particularly effective for artisanal applications where fishing effort is relatively low. However, since such structures serve to change the distribution of fishing effort and fishes, they must be viewed within an overall fishery management plan. Their impacts should be considered in a broad socioeconomic context, rather than just in biological terms or changes in CPUE.

Artificial habitats can substantially reduce travel and search time for artisanal fishermen and improve the catchability of their gear. As long as the total fishing effort in the resource is not great enough to result in overfishing, the effects of these structures on the resource are beneficial. Gear competition between 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 habitats 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 mature fish. The deployment of artificial reefs and FADs ideally should be a community project and fishermen should be involved in their planning, construction, and maintenance.

Artificial reefs and FADs built with local materials of opportunity have a certain appeal, but care should be taken to avoid depleting local forests and mangroves, or polluting the environment with inappropriate materials. Longer lasting structures built from properly ballasted scrap tires and concrete may ultimately prove more economical.

B. Fisheries Management and Other Applications

In the presence of heavy fishing effort, artificial reefs and FADs alone may not be economically beneficial. Measures that regulate gear and the fishing effort at artificial reefs and FADs may be required to avoid resource overfishing, user conflicts, and to improve fishery economics. While the literature documents many studies on the ecology at artificial structures, studies on the broader fishery management and socioeconomic impacts of these structures are lacking (see Chapter 7). For progress to be made in understanding the applications of artificial reefs and FADs, scientists and managers must deploy these structures within an overall fishery management plan consistent with the limitations of the particular artificial habitat. Finally, it is useful to view the application of artificial habitats as a decision to allocate space (the site of the habitat) and marine resources to certain user groups. This allocation and the impacts on all user groups should be understood and consistent with the objective of the artificial habitat.

The following list gives some examples of potential applications of artificial habitats that address specific management needs and that take advantage of the way artificial habitats can change the distribution of resources and fishermen, alter gear, and influence size and species harvested.

- When fishery managers wish to reduce fishing effort, artificial habitats may serve as a "bargaining chip" in negotiation. Artificial habitats can create fishing grounds close to port. Such proximity can improve the economics of fishermen by reducing expenses and increasing catchability, perhaps making it easier for fishermen to accept reductions in overall catch.
- When heavy trawling of near-shore nursery areas results in high mortality of juveniles, artificial reefs can be used to close an area to trawlers by creating unsuitable conditions for trawling.

- When one resource is overexploited, artificial habitats can serve to shift fishing effort to another resource. If soft-bottom resources are heavily fished, artificial habitats may be used to shift some fishing effort to coastal pelagic or hard-bottom resources.
- When competition between resource users is a problem, artificial habitats can be used to separate them. In cases of competition between artisanal fishermen and trawlers, artificial reefs can be used to create areas unsuitable for trawling, but suitable for artisanal usage. Sport divers might avoid competition with other types of fishermen for sites by identifying an area unused for fishing, regulating a prohibition of fishing at the site, and then deploying artificial reefs there to create a desirable dive site.

From a biological perspective, artificial habitat may function in one or all of the following ways: (1) to redistribute exploitable biomass, (2) increase exploitable biomass by aggregating previously unexploited biomass, and (3) improve aspects of survival and growth, thereby providing new production. In all three functions, artificial habitats have the potential to alter fishing effort, gear, size of fish at entry to the fishery, species targeted, and catch. The impact of change in fishing mortality on the stock depends on the relative level of exploitation and the rate of movement of the resource to the artificial habitat.

In artificial reef applications, it is possible to estimate the maximum catches from new exploitable biomass due to the artificial reef, and compare this with the actual catches to determine the extent to which the artificial reef is serving as a benthic aggregating device.

More rigorous experimental designs are needed to document the biological impacts of artificial habitat. These designs need to use large numbers of habitat structures to ensure that sufficient statistical power exists to detect impacts in the presence of considerable natural variation typical of many ecosystems. Also, they may require a control site without artificial habitat. Data of a time series should be collected at the treatment and control sites before and after the deployment of the artificial habitat. Fishery-dependent and fishery-independent data should be collected on an appropriate spatial scale and resolution to detect impacts at the artificial and natural habitats. (See Chapter 6.)

Since artificial habitat changes the spatial distribution and density of resources and the fishing effort, standard fishery models, which do not explicitly treat this spatial dimension adequately, may not represent the data fairly. For example, application of the Clark and Mangel (1979) model has proven highly useful for understanding processes at FADs. Further application of this model, along with habitat and diffusion models, should result in more realistic models to evaluate potential impacts of artificial habitat (Mullen, 1989; MacCall, 1990).

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