ASSESSEMENT OF BIOLOGICAL IMPACTS OF ARTIFICIAL REEFS AND FADS

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INTRODUCTION

A large volume of literature deals with the ecology at artificial reef sites--specifically with community composition, succession, biomass, and fishing success--whereas few studies address the broader biological impacts of artificial reefs and fish aggregating devices (FADs) on fish populations (Bohnsack and Sutherland 1985; Bohnsack 1989). The limited number of studies is certainly not due to a lack of interest but rather to the difficulty in collecting the appropriate date . To determine the possible biological impacts of artificial habitat in the presence of variations in the environment, fishing strategies, and gear, data must be collected from large-scale applications of artificial habitat on an appropriate spatiotemporal scale. 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 is speculative.

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 and increases the exploitable biomass. Thus, it can be useful to consider the three types of impacts on the exploitable biomass and total stock due to the artificial habitat. First, FADs and artificial reefs can simply redistribute the exploitable biomass without increasing it or total stock size. Second, FADs and artificial reefs can aggregate previously unexploited biomass and increase the exploitable biomass but not the total stock size. Third, when stocks are limited by high relief habitat, artificial reefs can increase it and hence total stock size. Thus, these three types of impacts distinguish not only between the two types of aggregation but also total stock size and exploitable biomass. Because some of their biological aspects will differ, the three impacts will be discussed separately in subsequent sections; however, all three may occur to varying degrees in any artificial habital application.

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. For example, some of the resources exploited on the natural habitat move to the artificial habitat, or a highly mobile resource that moves between natural habitat may add artificial habitat to its route. This type of impact appears to be illustrated by flatfishes (Pleuronectidae) in a study by Polovina and Sakai (1989). They considered the impact of 50,000 ^{3} of artificial reefs deployed in Shimamaki Bay off Hokkaido, Japan, and found that, although flatfishes were caught in substantial numbers at the artificial reefs, no increase in flatfish landings could be attributed to the artificial reefs when landings from the entire bay were considered. In sonic tagging studies, flatfishes readily moved from natural habitat to artificial reefs but were not long-term residents at either sites (Kakimoto 1984). It was concluded that the artificial reefs redistributed the flatfishes but did not change their exploitable biomass (Polovina and Sakai 1989).

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In another instance, an application of artificial reefs in the Gulf of Thailand did not appear to increase the exloitable biomass for one resource but did change its allocation among user groups (Sinanuwong 1988). Concrete cylinder artificial reefs were deployed over a 1 × 4 nmi area about 2 nmi offshore on fishing grounds for threadfin *(Eleuteronemus tetraductylum)*. The area was closed to trawlers and push-netters, and the resource was allocated to small-vessel, village fishermen using gill nets (Sinanuwong 1988). Earlier village fishermen had fished this resource (for about 15 days in November-December) until the schools were depleted by trawlers and push-netters; however, after the deployment of the artificial reefs, they were able to fish the schools for at least a 6−month interval. The threadfin catch by the village fishermen was 1,746 kg (mean catch rate, 4.7 kg/trip) prior to the deployment of artificial reefs and increased to 5,562 kg (mean catch rate, 8.3 kg/trip) after deployment (Sinanuwong 1988).

The Shimamaki study (Polovina and Sakai 1989) could not identify any biological impacts from the redistribution of exploitable biomass, but there were potential impacts: Because the density of the exploitable biomass per area of habitat had been reduced, growth and also natural mortality of the stock may have been affected. If the ecosystems at the natural and artificial habitats differed, some prey and predators may have been impacted as well. However, the greatest impact may be a reduction in exploitable biomass if fishing at the artificial habitat is not restricted. The siting of artificial habitat usually allows them to be more accessible to fishermen year-around and often to support a higher density of fishes than natural habitat. The higher density may increase the catchability of the fishing gear, whereas the greater accessibility increases fishing effort and can result in higher fishing mortality. An increase in fishing mortality will decrease the exploitable biomass in the area exploited. Whether the decrease in exploitable biomass results in lower future 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 there is a strong regional stock-recruitment relationship, then heavy local fishing mortality could reduce future recruitment.

The Thailand example (Sinanuwong 1988) 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. Further, 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.

IMPACTS DUE TO INCREASED EXPLOITABLE BIOMASS
BUT NOT TOTAL STOCK SIZE

Aggregation may not only cause a resource to be redistributed but also increase the resource exploited by the fishery. Artificial habitat might aggregate juveniles. Aggregation makes them more accessible to capture and hence increases the exploitable biomass by lowering the size at entry to the fishery. Conversely, aggregation might make available to fishing gear a portion of the resource that had been distributed at a low density and not previously exploited. An extreme case of this would be a resource that had not been fished because it was distributed widely at a low density at a natural habitat. An 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 which 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. The

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use of FADs (payaos) together with purse seines or ring nets in the Philippines was introduced in the tuna fishery in early 1970's. As a result, tuna catches rose from less than 10,000 metric tons (t) in 1970 to 266,211 t in 1986, representing 20% of the national marine catch (Aprieto 1988). Over 90% of the tunas caught at the FADs are less than 1−year-old and at about one-half the length at first maturity (Aprieto 1988). Some concern exists that the heavy fishing mortality with the small length at entry may result in growth and recruitment overfishing (Aprieto 1988). The question of whether FADs could cause growth overfishing has been examined by Floyd and Pauly (1984). Four factors are necessary for growth overfishing: i) presence of small fish on the fishing ground, ii) use of gear capable of catching small fish, iii) a market for small fish, and iv) high exploitation rates. All four of these factors are present in the Philippine tuna fishery. Using an exploitation rate of 0.7−0.8 for skipjack tuna *(Katsuwonus pelamis)* 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 due in part to growth overfishing (Floyd and Pauly 1984). Further, there is some evidence that the natural mortality of juvenile tunas is greater at FADs than for schools in the open ocean, suggesting that FADs have increased natural mortality as well (Aprieto 1988).

The biological impacts of this type of aggregation include all the impacts associated with aggregation that just redistributes exploitable biomass. However, when aggregation increases the exploitable biomass, other impacts occur and depend on the dynamics between fish aggregated and those not aggregated. Clark and Mangel (1979) developed a model for tuna purse seining in which tunas move from subsurface populations to surface schools which 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 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 in this case 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. The biological impact in this case is that increasing fishing effort on aggregations cannot increase the fishing mortality beyond a certain level. While the Clark and Mangel (1979) model was applied specifically to the tuna fishery at FADs, the results also apply to demersal resources aggregated at artificial reefs.

IMPACTS WHEN TOTAL STOCK SIZE INCREASES

In theory, providing additional habitat could increase the population size for some habitat-limited stocks. 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 stock (Bohnsack 1989).

Polovina and Sakai (1989), however, do provide some evidence that artificial reefs can increase the total stock. Fishery catches for octopus *(Octopus dofleini)* from two adjacent fishing grounds in a bay with a 27 km coastline near Shimamaki, Hokkaido, Japan, were examined before and after the deployment of about 50,000 m³ of artificial reefs. They found that octopus were caught at the artificial reefs, and when the total fishing ground catches were considered, the increase in octopus landings was explained by the increase in the volume of artificial reefs. The 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 impact 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 volume per year. It was concluded that the artificial reefs increased the exploitable biomass of octopus. This increase possibly came from either an aggregation of octopus from habitat not previously exploited or from new biomass due to the additional habitat. Unfortunately, no surverys of octopus abundance and size structure over the natural habitat and arificial 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, this issue was addressed by examining the change in catches in the two adjacent regions. It was 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 octopus 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 artifical 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).

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 pre-exploitation 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 the following: 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, or 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.

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 yields 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 less than 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 is generally seven times greater than on natural habitat (Stone et al. 1979). If 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 higher than those from a coral reef. This is equivalent to a yield of 0.05 kg/m^3. If as an upper bound this yield is assumed to come from only 1 m of vertical relief, then the yield per 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 reef 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 $0.5^* M^* B_O$, where M is the natural mortality and B_O is the unexploited exploitable biomass (Beddington and Cooke 1983). For example, the range of biomass estimates observed on tropical and subtropical artificial reefs is 26−698

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g/m^2 (Stone et al. 1979). More recently, a value of 1,266 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* M. For a tropical, fast-growing and short-lived species. M equaling 0.7 might be appropriate. Then a biomass of 650 g/m^2 at the artificial reef would support a miximum 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 an upper bound for the potential fishery yield from an artificial reef in this example is 0.2 kg/m^3.

Studies have documented total catches at artificial reefs of 8 kg/m^3 of artificial reef volume from the Philippines and 5–20 kg/m^3 from Japan (Sato 1985: Bojos and Vande Vusse 1988). Of course, these catches include fishes aggregrated by the reefs as well as any new production due to the reefs. Based on the examples previously considered, estimates of new production due to artivicial reefs is on the order 0.02–0.5 kg/m^3, indicating that these levels of catches from the artificial reefs are primarily from fishes aggregated by the reefs and greatly exceed the maximum catches that could be expected from new production.

CONCLUSIONS

1. Artificial habitat may function in three ways: it may redistriute exploitable biomass, increase exploitable biomass by aggregating previously unexploited biomass, or improve aspects of survival and growth and provide new production. In all three functions, artificial habitat has the potential to alter fishing effort, gear, size at entry to the fishery, species targeted, and hence fishing mortality. The impact of a 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.

2. 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. The data examined in this paper indicate that the potential new production due to artificial reefs is low relative to the catches at artificial reefs; hence, the primary role of artificial habitat is to aggregate resources.

3. More rigorous experimental designs are needed to document the biological impacts of artificial habitat. These designs need to use large numbers of artificial habitat to ensure sufficient statistical power exists to detect impacts in the presence of considerable natural variation which occurs in many marine systems. Also, they may need to have a control site without artificial habitat. A time series of data both before and after the deployment of the artificial habitat should be collected at the treatment and control sites. 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.

4. Since artificial habitat changes the spatial distribution and density of resources and the fishing effort, standard fishery models which do not treat this spatial dimension may not represent adequate models. Application of the Clark and Mangel (1979) model has proved useful for FADs. Further application of this model and habitat and diffusion models should result in more realistic models to evaluate potential impacts of artificial habitat (Mullen 1989; MacCall in preparation).

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