The Ecological Basis for Using Marine Fishery Reserves for Reef Resource Management

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ABSTRACT

Marine fishery reserves are specific marine areas protected from all consumptive exploitation, including fishing. Their primary purpose is to benefit fisheries by ensuring the persistence of fish stocks and associated fisheries by maintaining or enhancing spawning stock biomass. By protecting sedentary juvenile and adult organisms from exploitation, reserves increase the number of larger individuals and egg production. Natural dispersal processes spread eggs and larvae to surrounding harvested areas. Marine reserves provide insurance against stock collapse caused by management failure and interactions between fisheries and natural recruitment variability. Although marine reserves are primarily intended to protect or enhance fisheries, they also help protect biodiversity and reduce user conflicts by separating incompatible activities. Reserves can act as control areas in which natural systems and processes can be studied with limited human disturbance. Although obstacles will have to be overcome, the potential benefits of establishing marine fishery reserves are tremendous. With marine reserves we can protect our reef ecosystems and allow sustainable harvests for the present and for future generations.
INTRODUCTION: THE PROBLEM

Reefs are important complex ecosystems that support a high diversity of species and highly productive fisheries. Economically important tropical reef fisheries include snapper, grouper, spiny lobster, and conch. Temperate reefs include important species such as rockfish, lobster, and abalone. Problems arise because the human ability to catch fish often exceeds nature’s ability to produce fish. Many reef fish stocks are considered fully exploited or overfished in many areas of the U.S. and around the world (Munro and Williams, 1985; PDT, 1990; Goodyear and Phares, 1990).

To understand the problem, it is important to understand the typical life cycle and ecology of reef species. Reef species have a bipartite life cycle in which sedentary adults and juveniles live a demersal (bottom) existence in geographically restricted reef habitats while planktonic eggs or larvae disperse in the pelagic (midwater) environment. Eggs and larvae can spend anywhere from a week to several months floating around before settling into bottom habitats. Survival in these early stages is generally very poor but can vary by orders of magnitude between years due to uncertainties in currents, weather, food and predation (Richards and Lindeman, 1987; Doherty and Williams, 1988).

Reef organisms are vulnerable to overfishing in part because of their life history characteristics. These characteristics typically include slow growth, low natural mortality, long lives, delayed reproduction, large body size, and aggressive behavior. Such life history characteristics are adaptations for recruitment
uncertainty and low adult mortality (Doherty and Williams, 1988). Large, long-lived adults ensure the survival of the population despite recruitment uncertainty by providing a large supply of eggs over many years until a good recruitment event can replace the adult population. Excessive fishing can disrupt this replenishment process by increasing adult mortality in an environment where recruitment uncertainty persists.

Juvenile fishes tend to channel most of their food energy into growth and survival, often delaying reproduction for several years. Large body size is often an advantage in the natural environment because it helps in capturing prey and escaping predation. Large body size also allows greater mobility and provides a competitive advantage in protecting territory and securing mates. Adults allocate most of their surplus energy into reproduction and very little into growth; reproductive output generally increases exponentially with body size. Larger fishes, because they tend to be older, may also have increased reproductive success because of their experience and knowledge of where and when to find mates.

Excessive fishing can be disruptive. Fishing tends to be size-selective by harvesting larger species and individuals. Larger fish are more attractive targets for sport fishing, have more food value for subsistence fishing, and have more economic value for commercial fishing. Symptoms of overexploitation usually include declines in average fish size and disappearance of the larger species (Munro and Williams, 1985). The aggressive behavior, curiosity, and inexperience with humans make many reef
species vulnerable to a wide variety of fishing techniques. Species, such as grouper, which change sex by switching from female to male with age may be especially vulnerable to size selective fishing if fishing creates a shortage of males to fertilize eggs (Bannerot, et al., 1987). Reef fishes can also be depleted because their behavior is predictable in time and space. Also, the limited geographical coverage of reefs make them easy to locate.

Excessive loss of larger individuals can lead to recruitment failure because too few eggs are produced. Even if fishing pressure is acceptable for average conditions, several years of poor recruitment due to natural environmental events combined with reduced reproductive output due to fishing could cause a population to collapse. This would happen because not enough adults survive the poor recruitment years to adequately resupply the population when favorable recruitment conditions reoccur.

Sustained fishing mortality could result in a deleterious loss of genetic diversity through directional selection, especially when stock size is greatly reduced from natural levels. Essentially larger, faster growing, and more aggressive individuals are removed by fishing. This leaves smaller, slower growing, precocious individuals that will pass their genetically derived characteristics on to the next generation. Even though a species may persist, the change in genetic composition could result in characteristics which are undesirable from a human perspective. Individuals would tend to be smaller, more wary, and less valuable to the fishery because more food resources would be diverted into
egg production and less into growth. The population would tend to become diminutive and reproduce at smaller sizes. Because fishing changes the age structure of populations by removing older and larger individuals, the shorter generation time would accelerate the speed of the selective process. Favorable characteristics from a human perspective could be lost over time with continued fishing. Species that could not survive at smaller sizes for ecological reasons, such as not being able to catch prey, would tend to disappear.

Selective removal of certain species results in the loss of biotic diversity between species. Because most reef organisms exist in a highly integrated ecosystem, excessive removal of certain keystone species could cause unforeseen ecosystem disruptions or permanent alterations. Many species targeted by fishing are top predators, and top predators have been shown to be keystone species in many ecosystems. For example, the geographical distribution of kelp communities off the U.S. west coast has been greatly affected by the removal and later replenishment of sea otters that control herbivorous sea urchin populations (Estes and Palmisano, 1974; Palmisano and Estes, 1976; Simenstad, et al., 1978; Estes et al. 1982).

Population biomass is greatly reduced even in a healthy fishery. Having a fully exploited fishery may be incompatible with other uses and management goals, such as protecting biodiversity, genetic diversity, and maintaining some areas in a "natural"
balance for ecotourism, education, monitoring, and scientific research.

An important fishery management goal is to protect some older fishes from harvest to ensure adequate quantity and quality of reproductive output. Munro and Williams (1985) identified only about ten administrative management options applicable to reef fisheries. Unfortunately, many of the traditionally used fishery management actions are ineffective or impractical to use with most reef fish fisheries, especially when fishing pressure is high. For example, closed seasons and temporarily closed areas may not be effective because fishing effort can be increased at other times. Quotas and bag limits can be expensive to monitor and difficult to enforce. They also require timely and accurate data and precise knowledge about the various species and the fishery. The number of reef species involved, and the number of different users, gear types, and access ports make collecting adequate data for statistical treatment of individual species difficult or impractical. Selective fishing gears (e.g. mesh sizes, hook sizes) and limited entry, along with most other approaches, may reduce fishing effort but still tend to select against certain species and larger individuals within species. Finally, bag limits and size limits (for large or small fishes) can be ineffective due to unintentional release mortality, especially at high fishing pressure. Fishes often die when caught in deep water because of injuries associated with depth changes. Even when handled carefully, a certain percentage of fish will die because of the way
they are hooked. Hatchery programs and artificial reefs, although popular, have not been shown to be effective for marine species. Pulse fishing (closing an area and then reopening it) may be impractical because the areas must be closed for long periods of time because of the long lives of reef species. Also, the benefits of closure can quickly be lost when fishing resumes (Bohnsack, in press).

THE SOLUTION

"In wildness is the preservation of the world."

Henry David Thoreau, 1862

The concept of a marine reserve is simple: if left alone, natural systems will take care of themselves. A large body of scientific literature shows that harvested stocks will recover if fishing activities are removed.

Marine fishery reserves (areas with no consumptive usage) are designed to provide a population refuge in space and may be more effective than traditional management approaches when fishing pressure is high. Most traditional fishery management approaches are designed to provide a population refuge in numbers, and as noted above, may have limited effectiveness at high fishing pressures. Fishery reserves take into consideration the ecology of reef organisms and are ideally suited for reef fishes because of their relatively sedentary adult stages. Reserves can protect the age structure and spawning potential of adults while allowing eggs and larvae to disperse into surrounding areas to resupply those
populations. For many reef species, population models suggest that fishery reserves could increase the total fish production compared to present conditions.

Limited scientific information exists to precisely determine the optimum number, location and sizes of fishery reserves. Reserve areas must be large enough to have some biological integrity. Areas smaller than the home range of a species are unlikely to provide much protection. Protecting at least 10% of the habitat has been suggested as a minimum goal (see Ballantine, these proceedings). It is unlikely that protecting anything less than 10% of the habitat will provide any significant fishery benefits.

Fishing is based on the fact that most populations produce more offspring than are necessary to replace the adult population. Some empirical evidence and theoretical reasoning suggests that a minimum of 20% of the reef fish spawning stock biomass should be protected for fishery purposes (PDT, 1990). The empirical evidence consists of several populations (stocks) that collapsed when the spawning potential dropped below 20%. The spawning potential is the ratio of the reproductive output under fishing as compared to what would have existed if there were no fishing. The theoretical reasoning is based on the fact that eggs must have an exponential increase in survival when stocks are reduced by fishing (Goodyear, 1989). For example, when the spawning potential is at 20% due to fishing, eggs must achieve 5 times their natural survival rate (500%) to maintain the population. This increase is possible due
biological compensation, the fact that most populations are able to increase recruit survival somewhat when adult mortality increases. At a 10% spawning potential level, however, survival must be increased 10 times (1000%) which would be significantly more difficult to achieve. At a 1% spawning potential, a level that red snapper has existed at in the Gulf of Mexico in recent years, survival must be increased 100 times over normal levels. It is difficult to imagine a biological process that could increase survival this much. Based on these arguments, a mixed management strategy may be desirable where 20% of the habitat is held in protected fishery reserves while the other 80% is managed by traditional methods to optimize yield. Of course the 20% figure is only a guide and different species may need different levels of spawning potential.

Obstacles

Although terrestrial wildlife reserves are common and widely accepted, no similar areas exist in the U.S. marine environment. Clearly many obstacles exist for establishing marine fishery reserves. A primary problem is the lack of scientific and public understanding of the effects of fishing on marine systems. Until protected areas exist, it will be very difficult to scientifically distinguish the effects of fishing from natural processes and other human stresses such as habitat loss and pollution. Effort will be needed to promote public education and awareness about the function and importance of protected areas.
Institutional resistance to using new management approaches can be anticipated as well as opposition from local special interests near proposed reserves. As fish populations increase within reserves, the incentive for deliberate poaching will increase and at-sea surveillance and enforcement is likely to be necessary. Because some reserves may include artificial reefs, new artificial reefs may be needed to replace those lost to fishing access. Finally, establishing fishery reserves could have short-term impacts on certain users and on total harvest even though this loss would be compensated for by long-term fishery benefits. Clearly the establishment of marine fishery reserves will challenge the conservation commitment of many user groups.

Despite these obstacles, the growing world wide success and acceptance of marine reserves is promising. The experience in New Zealand is a good example of what can be accomplished (Ballantine, 1991; these proceedings). Clearly once fishermen recognize the benefits of having no fishing zones, the major hurdle has been achieved.

Benefits

The potential fishery benefits of marine reserves are considerable. Reserves offer great potential for improving reef fisheries by protecting critical spawning stock biomass, within-species genetic diversity, population age structure, recruitment supply, and ecosystem balance while maintaining reef fish fisheries. Trophy fisheries would be benefitted by large fishes
that occasionally would wander out of reserve areas. Such large individuals would be unlikely to exist under other management approaches. Problems of bycatch and hook and release mortality are eliminated within reserves because fish are not handled. Because fish are not handled at all the temptation for impulsive poaching is reduced. Economically important species that have become rare because of fishing gear selectivity will have an opportunity to rebuild their populations in reserves. Fishery reserves will allow also measurement of age, growth, and natural mortality which are critical for most fishery management models.

One of the most important functions of reserves is that they provide insurance against management and recruitment failures. All fishery management has some degree of uncertainty and risk. Fishery management can fail because of inadequate scientific models, errors in the data, inadequate compliance, or ineffective management actions. Chance events, such as environmental uncertainties in recruitment, could also lead to stock collapse even if fishery management was adequate for average conditions. If a stock collapses for whatever reason, fishery reserves can act as a reservoir for rebuilding a stock at a rate more rapid than otherwise would be possible. Reserves also may buffer against ecosystem disruption due to excessive fish removal.

A direct benefit to fishermen of having reserves is that regulations, such as quotas and size and bag limits, can be less restrictive. Reserves apply equitably to all fishery users and can simplify enforcement (i.e. either someone is fishing or they are
not). Data collection needs are reduced and management can occur without complete information and understanding about every species and ecosystem interaction.

A widely held assumption exists among fishermen that fishing activities do no significant harm to marine ecosystems (McClanahan, 1989). This assumption is not only untested, but is untestable without establishing areas protected from fishing. The benefits of having "control" areas in which to scientifically study unfished populations and to monitor the effects of fishing and natural variation alone may be worth the effort of establishing reserves.

Fishery reserves can be used for many other activities including sites for educational, economic, and scientific activities. Reserves can reduce user conflicts by separating incompatible activities. In many areas ecotourism and non-consumptive diving activities may benefit by having areas with abundant fish populations and large and "friendly" fish. Activities of underwater photographers, naturalists, and some scientists are incompatible with fishing. Reserves would certainly facilitate scientific studies of behavior, social organization, and dynamics of harvested species-- studies which are often not attempted at present because of the difficulty of locating and following targeted fishes.

In conclusion, the potential benefits of marine fishery reserves are tremendous although obstacles to establishing reserves will have to be overcome. Marine fishery reserves promise to provide a new and better way for managing our resources. By
protecting older and larger fishes, reserves will maintain critical spawning stock biomass, intra-specific genetic diversity, population age structure, recruitment supply, and ecosystem balance while maintaining and improving, reef fish fisheries. With reserves we can protect our reef ecosystems and allow sustainable harvests for the present and for future generations.

Acknowledgements
Much of the material for this presentation was extracted from a report on the potential use of marine reserves (Plan Development Team, 1990). I gratefully acknowledge the contributions of many colleagues to the development of the marine reserve concept, particularly Drs. Eugene Huntsman and William Ballantine. I thank B. Bohnsack for constructive comments.

Literature Cited


Reef Fish Dispersal

Settlement

(10's of Larvae)

Eggs & Larvae

Adults

(1,000,000's of Eggs)

Reproduction
Larval Dispersal

Non-Fishery Reserve

Fishery Reserve