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A rationale for minimum 20-30% no-take protection

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ABSTRACT

In response to coral reef decline, the U.S. Coral Reef Task Force adopted a goal of protecting a minimum of 20% by area of all representative coral reefs and associated habitats as no-take reserves by 2010. Here we provide a rationale for using 20-30% minimum no-take protection to conserve coral reef ecosystems. Support comes from reproductive theory, knowledge about the vulnerability of reef species to exploitation, analysis of fishery failures, and empirical and modeling studies of reserves. Other support comes from applying principles of precautionary management and a need for having minimally disturbed reference sites. Reserves alone will not protect all species and must be used in addition to other fishery and resource management measures to obtain high sustainable fishery production. Ultimately, human activities must be within sustainable limits of coral reef ecosystems.

Keywords Coral reef, Fisheries, Management.

Introduction

Fishing and other forms of resource extraction can damage coral reefs by removing targeted species, altering habitat and food webs, and killing unwanted organisms as bycatch. The long-term impacts of resource extraction are mostly unknown. Traditional strategies seek to protect individual stocks by controlling fishing effort and mortality on a stock-wide basis. Management tools, such as landing and size limits, gear restrictions, and seasonal closures, are used to limit the size and number of individuals killed. Attempts to limit fishing mortality by controlling total fishing effort have frequently failed, however, for a variety of biological, economic, and social reasons (Ludwig et al. 1993). A less tried approach is to limit fishing and other activities to specific areas. Spatial protection in many cases may be more practical than other approaches because it requires fewer data, less analysis, and once established, may be easier and less expensive to enforce (Guénette et al. 1998, Crosby et al. 2000).

No-take reserves (NTRs) are areas protected from all fishing and other extractive use. As a habitat and ecosystem-based protection measure, NTRs potentially offer a high level of protection for coral reef structure, function and beauty, when they include coral reefs and reef associated habitats, such as seagrass beds, algal flats, and mangroves. Ideally, reserve networks should include permanent, representative, and replicated sites spread over a wide geographical range with a total coverage sufficient to be self-sustaining, despite what happens in surrounding areas (Ballantine 1997, Murray et al. 1999). Recognizing that truly sustainable yield requires the preservation of the long-term persistence of marine ecosystems in the face of growing resource demands, NTR use is based on the precautionary principle of withholding some resources from fishing until the impacts of extraction can be determined. NTRs can benefit fisheries; increase scientific knowledge; enhance non-extractive human activities; preserve future options; and increase public understanding and appreciation of marine ecosystems (Ballantine 1997).

To balance conservation and exploitation, the U.S. Coral Reef Task Force adopted a goal:
"Establish additional no-take ecological reserves to provide needed protection to a balanced suite of representative U.S. coral reefs and associated habitats, with a goal to protect at least 5% of all coral reefs and associated habitat types in each major island group and Florida by 2002; at least 10% by 2005, and at least 20% by 2010.Toward this end, immediately move forward to establish no-take reserves in the highest priority reef habitats." (USCRTF 2000).

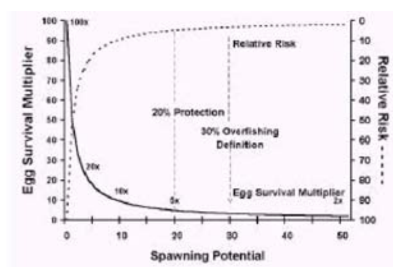

Fig. 1. Compensatory egg survival (solid line) needed to maintain adult populations and relative risk of stock collapse (dashed line) as a function of stock spawning potential. The egg survival multiplier is how many times egg survival must be increased to maintain the exploited population.

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Methods

Here we address common misunderstandings and outline a scientific rationale for minimum NTR protection based on reproductive theory, impacts of fishing on reef populations, analyses of fishery collapses, and empirical and modeling studies of no-take reserves. We focus on protecting exploited mobile species, particularly reef fishes, which are highly targeted, and because of their mobility are perhaps the least likely reef component to benefit from spatial protection. We argue that spatial protection provided to these species, by extension, will provide minimum protection sufficient to maintain associated communities of corals and other reef organisms.

Results

Reproductive theory

Fishing is sustainable in theory because more individuals are produced than are necessary to maintain populations. Classical surplus production models assume logistic population growth and predict that the maximum yield (MY) will be taken when population biomass is half the unexploited or virgin stock (Gulland 1972). At 50% biomass, spawning potential ratio (SPR), the ratio of total egg production under fishing to total production without fishing, also should be ~50% (Fig. 1). To maintain the adult population at 50% SPR, each egg produced must now double its average survival since only half the total number of eggs are now produced as in an unexploited population. Increased survival is possible because of biological compensation, where density dependent factors in smaller populations, such as reduced competition, lead to increased survival (Goodyear 1993). Presumably at 50% SPR most reef fisheries would be considered healthy with a low risk of collapse. As fishing mortality increases, however, stock biomass and SPR decline and the risk of stock collapse increases (Goodyear 1993, Mace and Sissenwine 1993, Katsukawa 1997) (Fig. 1, left). At some point, biological compensation cannot maintain the adult population and MY. At 20% SPR, for example, each egg produced now must have 5 times its natural survival to maintain the population; at 30% SPR, survival must be 3.3 times higher. As SPR levels drop below 20%, egg survival must increase exponentially to maintain the population (Goodyear 1993). Eventually, there is insufficient biological compensation to sustain the population. At 10% SPR, for example, each egg must have 10 times its natural survival and at 1% SPR survival must be 100 times the average unexploited level which is unlikely.

Reproductive theory summarized in Fig. 1 thus provides support for minimum 20-30% spatial protection because this range is well above the inflection point of the risk and compensation curves, where small changes in SPR have large impacts on risk of stock collapse and egg survival compensation (Fig. 1). The key assumption linking SPR to area is that the proportion of the fish population protected is proportional to area protected. In reality, it is the specific area inhabited by the fish that would require this level of protection. Without complete knowledge of stock density and spatial distribution, precautionary approaches suggest that at least 20-30% of the spatial habitat be protected as a minimum.

Known effects of fishing on SPR

Fishing can drive reef populations and spawning to extremely low levels for biological,social, and economic reasons (Ludwig et al. 1993). The number of over fished populations shows that management often has failed to achieve the goal of sustainability. Red snapper SPR in the Gulf of Mexico, for example, was between 1.5-4.8% when first assessed (Goodyear 1988). Many reef fish stocks in the southeastern U.S. had extremely low SPR levels, despite having enforced fishery management (Fig. 2). Out of 57 stocks with estimated SPRs, 19 (33%) were at or below 20% SPR and 30 (52%) were below 30% SPR,a level considered to be overfished for most reef species (Ault et al. 1998, NMFS 1999). Grouper (Serranidae) appear to be particulary vulnerable. This high number of species with low SPRs show that past management measures have not met fishery objectives. Additionally, SPRs are unknown for 77% of stocks listed in management plans and an unknown number of reef fishes were not listed. The fact that conventional fisheries management has failed to keep most reef fish stocks above the critical 30% SPR overfishing level lends credence to the rationale for at least 20-30% spatial protection to ensure viable stocks.

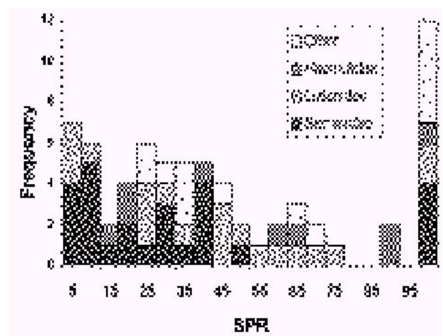

Fig. 2. Estimated SPRs for 57 reef fish stocks of 253 stocks listed in southeastern U.S reef fishery management plans. SPRs for 77% of listed stocks are unknown (Ault et al. 1998, NMFS 1999).

Fishery collapse and replacement % SPR

Recruitment overfishing occurs when a population is not able to replace itself. Because no existing empirical studies show the estimated percentage of SPR necessary to maintain specific coral reef populations, we examined available studies of temperate populations as surrogates under the assumption that the same reproductive principles would apply to coral reefs. Mace and Sissenwine (1993) examined 91 fished stocks of 27 species from the North Atlantic and found that SPR necessary to replace adult stocks at equilibrium levels (replacement % SPR) averaged around 19% but varied considerably among species (Fig. 3A). They noted that no single simple answer existed as to how much spawning per recruit was enough to maintain populations, but recommended maintaining at least 30% SPR as a conservative strategy when no other basis for estimating the replacement level was available. A cumulative plot (Fig. 3B) suggests that protecting 20% of the reproductive potential would be sufficient on average to sustain adult populations of about 57% of 91 fished stocks of 27 species. At a level of 30% SPR would be sufficient to protect about 77% of those stocks. Myers et al. (1994) examined stock and recruitment data for 72 finfish populations with at least 20 years of data and concluded that stock size corresponding to 50% of the maximum predicted average recruitment was a preferred reference level to prevent overfishing. Combined, these studies suggest that 20-30% spatial protection of such stocks (assuming they protect a similar percentage of fish) would be a bare minimum to help ensure replacement % SPR.

Modeling studies

Most modeling studies have focused on fishery benefits of NTRs, especially how well reserves can enhance stocks in nearby areas. Numerous models suggest that potential fishery benefits would occur depending on assumptions about adult movement, larval dispersal, and fishing mortality (e.g. Lauck et al. 1998, Roughgarden 1998, Bohnsack 2000, Mangel 2000. Hastings and Botsford (1999), for example, concluded that marine reserves could produce the same yield as with effort controls under a broad range of biological conditions, but could better sustain populations with sedentary adults.

Sladek-Nowlis and Roberts (1999) showed that fishery benefits most likely occur when overfishing is a problem and that the optimum total area for a NTR varied by species and the amount of fishing mortality in surrounding areas. They showed that 20% area provided significant benefits for a variety of species. Using an ECOPATH mass balance model, it was found the maximum increases in catch and overall biomass levels were reached when 20% of the system was protected. Many models, however, suggest that optimum fishery benefits may require closing much larger portions of habitat (Sladek-Nowlis and Roberts 1999, Lauck et al. 1998. Thus, modeling studies suggest that 20-30% higher in the 2.6 km^2 Ho Chan Reserve, Belize after only 4 years. At a larger scale, the 456 km^2 Exuma Sound

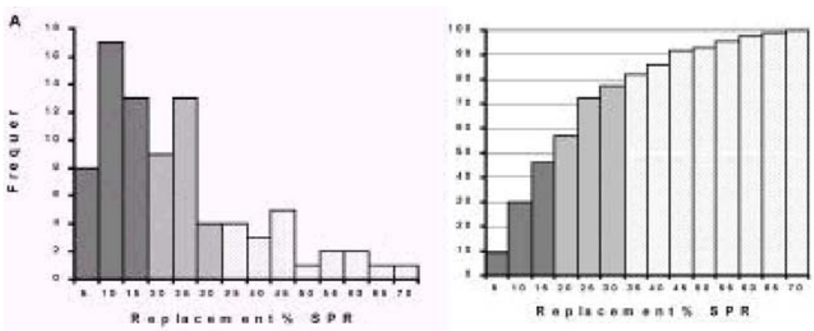

Fig. 3. Distribution of (A) replacement % SPR and (B) cumulative distribution of replacement % SPR necessary to replace adult stocks from 91 fished stocks of 27 species from Europe and North America (data from Mace and Sissenwine 1993).

spatial protection is a minimum and possibly insufficient to ensure sustainable stocks.

Empirical studies

The use of NTRs has remained limited and controversial, in part, because few empirical studies have been conducted at appropriate spatial and temporal scales. Most have focused on comparing differences inside and outside of reserves. Although most coral reef reserves are small or recently established, many have shown statistically significant responses (Fogarty et al. 2000). A 1.76 km^2 reserve in Barbados, for example, had larger mean fish size for 18 of 24 reef species and greater abundance for all species of exploited fishes than surrounding areas after 10 years of protection (Rakitin and Kramer 1996). The biomass for exploited fishes was also significantly Land and Sea Park, Bahamas had 15 times the density of adult queen conch (Stoner and Ray 1996) and significantly more and larger exploited grouper than nearby areas after 8 years of protection (Sluka et al. 1996).

Although empirical studies to date cannot tell us whether a minimum of 20-30% spatial protection is sufficient to ensure sustainable fish stocks, they do show that this size range can enhance local abundance and biomass of species that spillover to fished areas. The best studied reef reserves are in the Philippines and small: Apo Is. (~ 0.11 km^2 , 10% closed) and Sumilon Is. (~ 0.5 km^2, 25% closed; Russ and Alcala 1996a, 1996b, 1999). In both cases, biomass and abundance of exploited species increased over a decade in reserves and measurable fishery benefits were reported from surrounding areas. Fishery benefits of 20% area have not been examined at large scales for coral reefs, but have been for other habitats. Johnson et al. (1999) showed significantly higher fish diversity, larger size, and greater abundance in temperate estuarine reserves closed for 2 decades and covering ~ 22% of a wildlife refuge in Florida. Tagging showed that fish moved from reserves to fished areas. At a large scale, closure of 17,000 km^2 (~20%) of Georges Banks in 1994 resulted in a 14 fold increased scallop biomass and increased SPR for several collapsed finfish stocks after only 4 years (Murawski et al. 2000).

Conclusions

Studies reviewed here support a goal of fully protecting a minimum of 20-30% of coral reef habitat within no-take marine reserves until better estimates are obtained. Reproductive theory shows that the risk of population collapse and the amount of biological compensation necessary to maintain adult populations increase dramatically when SPR falls below 10%. Thus, protecting 20-30% of habitat offers a margin of safety. Much larger areas may be necessary for optimum benefits. Estimated fish SPRs in the southeastern US show the capability of fishing to drive populations to unacceptably low levels even under active fishery management. This situation, plus the high number of species in unknown condition provide additional support for applying at least 20-30% spatial protection as a precaution to protect coral reef biodiversity. Empirical analysis of replacement % SPR suggests that protecting 20-30% SPR could maintain adult populations and avoid fishery collapse for most species, but if used alone would not be sufficient for all species or provide high sustainable fishery yields. Protecting an SPR of only 20-30% may not allow a reliable margin for rebuilding stocks already depleted. Models and empirical studies of existing reserves also provide support for protecting a minimum of 20-30% of habitat by showing benefits within and outside of reserves.

NTRs will most likely benefit sessile and sedentary species and habitats easily damaged from fishing gear. They also are likely to benefit most reef fishes which are relatively site-attached as adults. They can support sustainable fisheries by supplying larvae and adults to fished areas. However, more mobile species will have less protection due to exposure to fishing while outside the reserve. In practice, target SPRs likely need to be higher than 30% to ensure optimum benefits to most regional stocks. For this reason and to prevent concentrating fishery impacts in open areas, it is essential that NTRs be complemented by other appropriate management practices, such as size limits, bag limits, quotas, limited entry, closed seasons, gear restrictions, and closed areas for specific fisheries. If these measures are not effective, other protective measures and possibly a much larger proportion of habitat may need to be closed. Relying solely on no-take area protection, however, reduces options and flexibility for optimizing social and economic benefits (Murray et al. 1999). It is important to understand that a goal of protecting 20-30% of representative habitats in a network of NTRs alone will not be sufficient to conserve coral reefs or solve all fishery problems. They will not protect reefs from pollution, climate change, or from local disasters (Allison et al. 1998). Since the definition of overfishing for most U.S. reef fish species is 30% SPR or greater, other management tools will be needed to provide the additional stock protection, prevent overfishing, and achieve optimum yield.

NTRs covering 20-30% of coral reefs will provide a high level of ecosystem protection from the impacts of fishing and reduce the chances of stocks declining to unacceptably low levels. They also can enhance a variety of non-extractive activities and public understanding and appreciation of coral reef ecosystems. Importantly, they provide a scientific basis to optimize protection through adaptive management since sequential trial and error is no longer acceptable (Walters and Hilborn 1976, Murray et al. 1999). NTRs also provide some insurance against stock collapse and can accelerate stock recovery in the case of management or recruitment failures, as well as providing genetic protection from adverse selective effects of fishing (Bohnsack 1999).

Despite theoretical and field data supporting the use of NTRs, many scientific questions remain involving the most effective size, number, distribution, and location of individual reserves, as well as, what total areas and habitats should be included. Despite numerous studies, much remains to be learned because most coral reef NTRs have been small, recently established, or not studied. Obviously, protecting only a small proportion of the total habitat will not provide significant or measurable ecosystem protection.

In summary, no-take reserves are an important ecosystem-based management tool for protecting coral reef ecosystems. Their use is based on the precautionary principle and complements other resource management measures. Protecting a minimum of 20-30% of coral reef area is a first approximation of a level of protection sufficient to help sustain coral reef ecosystems. As Leopold (1949) noted, "we cannot prevent human alteration, management, and use of resources, but we need to affirm their right to continued existence, and in spots, their continued existence in a natural state." Ultimately, human extractive activities must be within sustainable limits of the ecosystem if that ecosystem is to survive. Achieving 20-30% coral reef protection is likely to be a major challenge for much of the world given that poverty and short-term economics determines much of the success and failure of protected areas (McClanahan 1999, 2000).

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