Incorporating No-Take Marine Reserves into Precautionary Management and Stock Assessment

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Abstract.- No-take marine reserves, areas protected from all fishing and other extractive activities, offer a conservative, ecologically and habitat based, tool for fishery management. They can support sustainable fisheries by providing significant protection of species composition, abundance, size and age structure, fecundity and spawning potential. They offer particular potential for protecting stock genetics from detrimental selective effects of fishing and are ideal for species with few available data or that have little economic importance. In many cases marine reserves may have less detrimental impacts on fisheries and provide better resource protection than more traditional measures, such as quotas, and size and bag limits. Marine reserves also provide essential reference areas to assess fishing effects, interspecies interactions, and environmental effects on stocks. Although few exist, they are being created at an accelerated rate worldwide. Increased use of no-take marine reserves poses some problems for stock assessment because portions of the stock will not be subject to traditional fishery-dependent data collection. This problem can be treated by greater use of spatially explicit models, fishery-independent length-frequency data, 'mean size in the exploitable phase', and stereo video technology.

Introduction

"The serious problems we have can't be solved at the same level of the thinking we were at when we created them. "

Albert Einstein.

Overfishing problems are receiving increased worldwide public and scientific attention, resulting in increased calls by scientists and conservationists to establish no-take marine reserves (Roberts, 1997a). The journal Science alone published at least eight relevant articles within the past year. Malakoff (1997) examined the possibility of extinction on the high seas from fishing, while Schmidt (1997), Williams (1998), Roberts (1997b) and Ogden (1997) examined no-take zones in fisheries management. Reznick et al. (1997) examined impacts of predation on the genetics of fish populations, a process quite analogous to fishing. The two most recent articles concerned fishing impacts on marine ecosystems. Dayton (1998) called for reversal of proof in fisheries management to show that fishing does not harm marine ecosystems and Pauley et al. (1998) measured fishing effects on top carnivores in marine food webs.

Fishery management must develop a social policy to protect resources in the face of increased demands for exploitation. Due to a variety of biological, economic, and social factors, traditional fishery management has often failed to maintain sustainable fisheries while protecting biodiversity and ecosystem function (Ludwig, et al., 1993; Dayton et al., 1995; Bohnsack and Ault, 1996; Pauly et al., 1998). Overexploitation, stock collapse, and loss of biodiversity are growing problems because of open access fisheries, increased fishing power, habitat damage from fishing, loss of natural refuges, and an inability of traditional methods to effectively control fishing effort and mortality (Boelert, 1996; Bohnsack and Ault 1996).

Since Beverton and Holt (1957), fisheries management has attempted to regulate fisheries by providing stocks a refuge in numbers, either by limiting the size of capture or reducing fishing mortality by controlling fishing effort. Unfortunately in many cases controlling harvest size and effort have not been effective or possible. Although largely overlooked (Pauly, 1997), Beverton and Holt (1957) noted that providing a refuge in space could also be used. In many cases, protecting areas from harvest potentially could be more effective than other management approaches. Despite this potential and support from hundreds of peer reviewed papers, fishery management is only beginning to seriously examine the use of marine reserves in fisheries management (Schmidt, 1997).

Here I discuss how marine reserves fit in a precautionary management strategy with emphasis on design principles and the potential of reserves to protect stock genetics from detrimental selective effects of fishing. Some obstacles to using reserves are examined and compared to use of size limits. Finally, I examine potential problems marine reserves pose for stock assessments. Approaches are suggested to solve these problems.

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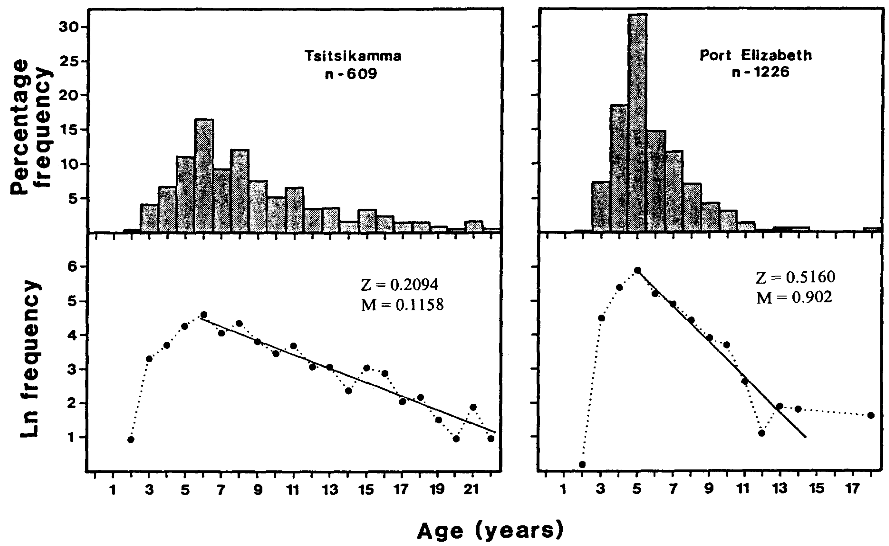

Figure 1. Distribution of age classes (top) and catch curves (bottom) of *Chrysoblephus cristiceps* sampled in areas protected from fishing for 25 yr, Tsitsikamma marine reserve (left), and fished, Port Elizabeth (right), South Africa. The slope of the descending limb of the catch curves is the estimate of total mortality. After: Buxton, 1993 (Fig. 9, pg 59), with kind permission from Kluwer Academic Publishers.

Marine Reserves: Attributes and Potential Benefits

Marine reserves are defined here as areas protected from all extractive activities. Many scientists have called for establishing networks of ‘no-take’ marine reserves to reduce fishing mortality, maintain sustainable fisheries, and protect biodiversity (Lauck et al, 1998). Spatial protection is a precautionary approach consistent with habitat and ecosystem management and is ideally suited to the ecology of most marine organisms that disperse as eggs and larvae but are relative sedentary or philopatric as adults. Besides providing fishery benefits, marine reserves can protect marine ecosystems, improve non-consumptive recreational opportunities, diversify the coastal economy, increase scientific understanding of resource dynamics, and facilitate public appreciation and protection of marine resources (Sobel, 1996).

Compared to having all areas open to exploitation, marine reserves offer major direct fishery benefits: (1) more fish from increased production and dispersal of eggs and larvae from larger size classes, greater abundances, and increased spawning potentials in unexploited reserves; (2) export of biomass from juvenile and adult fish moving across reserve boundaries to fishing grounds; (3) protection of genetic quality from detrimental effects of fisheries selection; (4) insurance against stock collapse from fishing or natural recruitment failure; (5) more rapid rebuilding in case stocks do collapse; (6) reduced annual variability in landings from fisheries by providing more consistent recruitment potential; and (7) sustained fisheries for vulnerable species that are rare, change sex (e.g. protogynous hermaphrodites), or that have strong Alee’ effects in which any reduced adult density has non-linear negative effects on fecundity (e.g. sea urchins and other broadcast spawners). Sobel (1996) and Bohnsack (1998) discuss additional fishery benefits. For example, with a sufficient network of protective marine reserves, overfishing is more difficult and recreational fisheries with reasonable bag or size limits could continue to operate year around with little fear of exceeding their quota and being closed. Reserves also could buffer detrimental effects of natural environmental variation by protecting a portion of older age classes from harvest until extreme environmental conditions change.

Marine reserves also offer important indirect fishery benefits by providing: (1) reference sites for determining fishery impacts on marine ecosystems; (2) monitoring sites for determining natural versus anthropogenic influences on stocks; (3) experimental sites with minimum human disturbance for fishery investigations on behavior, environmental factors, species interactions, and natural mortality; and (4) easier enforcement. Compared with traditional regulations, fishery violations are easier to detect because boardings are not required and only the act of fishing is the violation. Also, limited enforcement resources can be more effectively deployed over a limited area instead of the entire fishing grounds. The eventual ability to directly measure natural mortality in reserves is especially important because it is a key parameter in VPA and most stock assessment models.

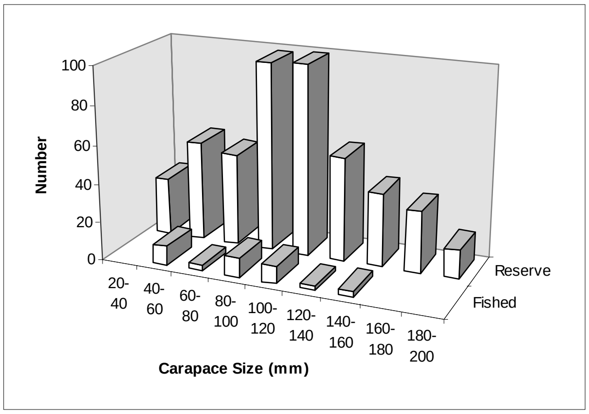

Figure 2. Population abundance and size structure of spiny crayfish, *Jasus*, from similar habitat inside and outside Leigh Marine Reserve, New Zealand. Data replotted from MacDiarmid and Breen (1992).

When all areas are exploited, natural mortality must be indirectly estimated. Given time, marine reserves could provide direct estimates of natural mortality (Fig. 1).

Scientific reviews, done almost annually this decade (e.g. PDT, 1990; Roberts and Polunin, 1991; Dugan and Davis, 1993; Rowley, 1994:, Roberts et al., 1995; Bohnsack, 1996; Ruckelshause, in press), support most predicted benefits of marine reserves. When protected from fishing, most stocks can recover in terms of increased abundance, density, biomass, size and age classes, and fecundity (Figs. 2 - 4). In some cases, observed abundance, density, and spawning potential can be orders of magnitude higher in reserves than surrounding fished areas with similar habitat. Although their primary contribution to fisheries is likely to be production of new recruits from export of larvae, they can also contribute significantly to direct export of adults and exploitable biomass to local fishing grounds (Fig. 3). Biomass export has been documented for tropical reef fishes (Russ and Alcala, 1996a), temperate reef fishes (Attwood and Bennet, 1994), estuarine fishes (Johnson et al., in press), and spiny lobster *Panulrus argus* (Davis and Dodrill, 1989). The importance of larval dispersal from marine reserves to surrounding fisheries is the most difficult hypothesis to test but has some support from studies of fishes (Tilney et al., 1996) and conch, *Strombus gigas* (Stoner and Ray, 1996). While closed areas were thought to benefit mostly sedentary species, some species considered highly mobile have been shown to benefit, including carangids, *Caranx melamphgus*, (Holland et al., 1996), spiny lobster, *P. argus* (Davis and Dodrill, 1980) and rock lobster, *Jasus* (MacDiarmid and Breen, 1992).

In essence, marine reserves offer a bet-hedging strategy in case of miscalculation or failure of more traditional management approaches. With marine reserves, all species receive some level of protection, including species for which there are little data. Data needed to do a full stock assessment are inadequate for most species under present funding and this situation is likely to continue based on projected level or declining NOAA funding through 2003 (Lawler 1998). Also virtually no data are collected on non-commercial species incidentally taken as bycatch or that are impacted by habitat alterations associated with fishing (Dayton, et al. 1995; Dayton 1998). Clearly, marine reserves offer precautionary protection in these situations.

Genetic Protection

Fishing can lead to changes in life-history (Buxton, 1993) and genetics of exploited species (PDT, 1990). Because fisheries harvest wild populations, they present unique genetic problems for management. An assumption that stocks can be intensively fished or over exploited with no long-term harm to stock genetics is questionable and should be a particular concern of fishery management (PDT, 1990). Size-selective fishing, in particular, can be a directional selective force on population life-history characters such as growth rates, age at maturity, maximum size, total fecundity, and behavior.

The theoretical basis for genetic effects of fishery selection is well established (Bergh and Getz, 1989). Natural populations are vulnerable to loss of genetic variability with severe reduction in population size (Da Cunha and Dobzhansky, 1954) or though directional selection effects. Loss of genetic variability can reduce stock persistence under high environmental variability. Directional selection from fishing can change population genetics and life history characters related to age at first reproduction, fecundity, age and size structure, and behavior. Goodyear (1996) modeled how large minimum sizes for red grouper cause the fishery to harvest the faster-growing members of each size class and this could induce strong genetic selection for slow growth that may significantly reduce future stock productivity.

Detrimental genetic changes from fishing are difficult to show (Nelson and Soule, 1987) but have been demonstrated for important fishery species including pink (*Oncorhynchus gorbuscha*) and chinook salmon (*O. tshawytscha*) (Ricker 1981), and orange roughy, *Hoplostethus atlanticus* (Smith et al., 1991). Empirical studies have demonstrated impacts of fishing on growth, size at maturity, maximum age (Drake et al., 1997) and behavorial characters, such as aggressiveness and shyness (Wilson and Clark, 1996). Fishing is a form of predation. Reznick et al. (1997) measured evolutionary rates based on genetic changes in artificial predation experiments on natural fish populations. They observed evolutionary rates ranging from 3,700 to 45,000 darwins,

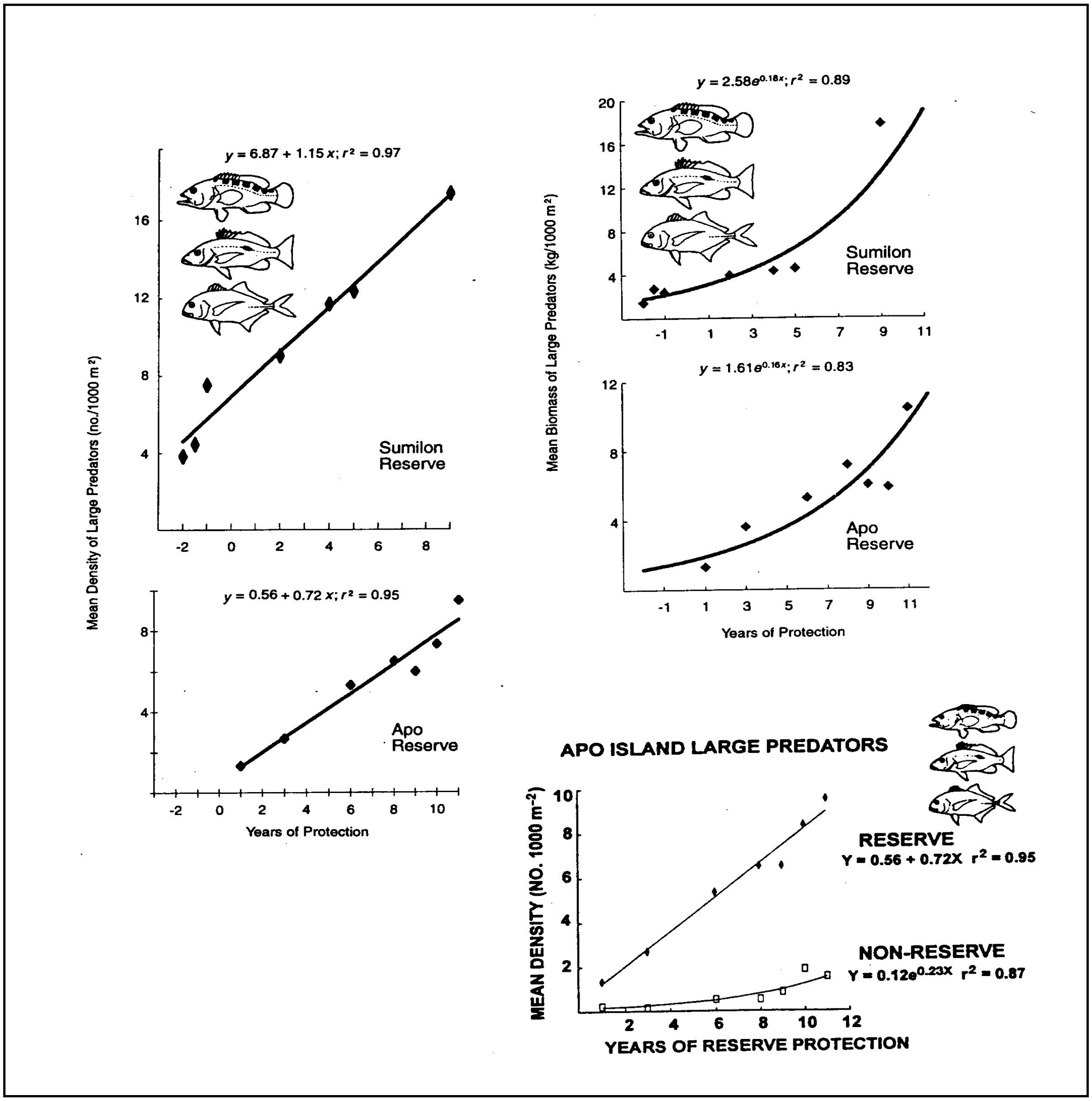

Figure 3. Changes in mean density (left) and biomass (right, top) of large predators (serranids, lutjanids, lethrinids, and carangids) inside Sumilon and Apo marine reserves, Philippines. Negative years were open to fishing. (Right, bottom) changes in density of large predators inside and outside Apo reserve. After: Russ and Alcala, 1996a, 1996b; with permission.

as compared to the evolutionary rates of 0.7 - 3.7 darwins typically observed in the fossil record and a geometric mean of 58,000 (range 12,000 to 200,000) darwins observed in animal and plant breeding efforts. These experiments suggest that the evolutionary effects of fishing could be closer to animal husbandry than natural selection (Svensson, 1997). By providing a refuge, marine reserves offer perhaps the only way to protect stock quality in terms of detrimental selective effects of fishing on genetics.

Design Criteria.

Ballantine (1997a,b) provided general design guidelines for designing marine reserves (Table 1). Most important, reserves should be no-take, permanent, and include representative replicates of all habitats. Public access is essential as a passive enforcement mechanism and for building continued support (i.e. the public must see benefits). Periodically opening reserves to fishing has been shown to be ineffective, especially for long-lived species, because the protected resources may take decades to build up and the benefits often can be dissipated quickly (Bohnsack, 1994).

The size of individual reserves and the total amount of habitat that should be protected in no-take zones is more controversial, although clearly substantial areas are required, especially to be self-sustaining. In his earlier papers, Ballantine (1991) argued for a minimum of

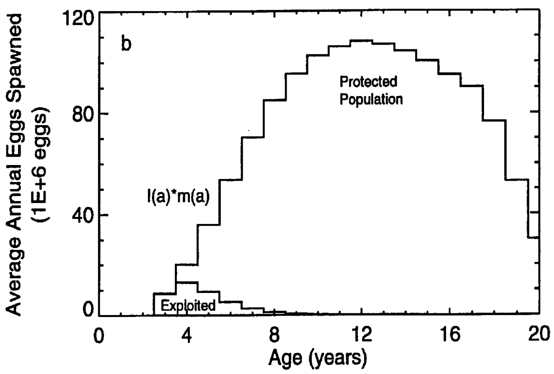

Figure 4. Reproductive potential (eggs spawned) by a typical scallop recruited at age two in an exploited and protected population as a function of age, mortality probability, and fecundity. Areas under each curve represent the lifetime eggs produced by an average individual in exploited and protected populations. After: McGarvey and Willison, 1995, with permission.

Table 1. Design Principles for Marine Reserves (After Ballantine 1997a,b).

- Include All Representative Habitats
- Permanent Reserves
- No-Take
- Network Design of Replicated Sites
- Geographically Dispersed
- Goal: Self-Sustaining
- Encourage Public Access
- Establish on Principle

10% coverage of all habitats, but more recently, he increased the recommended size to 20 to 30% (Ballantine, 1997b). Some scientists have suggested that 20% would be necessary based on minimum protection of spawning potential ratios (PDT, 1990) while some models have indicated that 30% or higher may be possible and still maintain maximum sustainable landings (Sladek-Nowlis, 1997). Some conservation groups are calling for protection of 20% of all marine habitats by the year 2020.

Ballantine (1997a,b) emphasized common sense and establishing marine reserves on principle in the same way that we build schools and educate children. His guiding principles are summarized in Table 2. The precautionary approach is particularly important for fisheries: without complete understanding of resources and processes, some resources should be withheld from exploitation. Even with good understanding, some areas should be left undisturbed from human impact. Also, if science is to have any importance in resource management, no-take reserves are absolutely essential as reference areas and controls to evaluate fishing impacts on natural systems.

Table 2. Principles used in establishing marine reserves (Ballantine 1997a, b).

- Precautionary Management (if you don't have complete understanding, withhold some resources from exploitation)
- Essential for Scientific Understanding as Control or Reference Areas
- Not Designed to Solve Species-Specific Problems (created independently of regulations required by exploitive activities)
- Some Areas should be Left in a Natural, Undisturbed State
- Protect all Species

Despite common sense and the fact that large areas are protected from exploitation on land, marine reserves remain controversial and only beginning to be incorporated into policy for most countries. In the Florida Keys National Marine Sanctuary, for example, the establishment of 19 no-take zones in 1997 included less than 1% of Sanctuary waters (U.S. Department of Commerce, 1996). Likewise, California, despite having 104 marine protected areas, currently has only a few hectares under no-take protection (McArdle, 1997).

Obstacles to Establishing Marine Reserves

The biggest obstacles preventing widespread use of marine reserves for fisheries purposes are concerns over: (1) short-term impacts to yield, (2) lack of direct experience, (3) lack of precise models predicting optimum locations and design features, and (4) crowding among anglers. Obviously marine reserves are subject to all other obstacles common to all fishery management actions, including apathy, ignorance, disproportionate political or economic influence, lack of enforcement, and general distrust of science and management among users. Phasing in closures over time helps avoid short-term detrimental impacts to fisheries by allowing accrued benefits to compensate decreased fishing area (Sladek-Nowlis and Roberts, 1997). The second two issues deal with specific local conditions and can only be effectively treated with an adaptive management approach of actually establishing reserves and modifying them accordingly as new information becomes available on local conditions. Marine reserve theory currently is general and real, but not precise.

Increased crowding is often used as the fatal argument to kill marine reserve proposals, but it is often more an issue of perception than substance, especially for small reserves. In fact, even large reserves may have less negative impacts on fishery landings than other conservation measures often used. Using gag grouper (*Myctoperca microlepis*) from the Gulf of Mexico as a model, I compared catch curves and crowding effects of a marine reserve that protects 20% of the total fishing

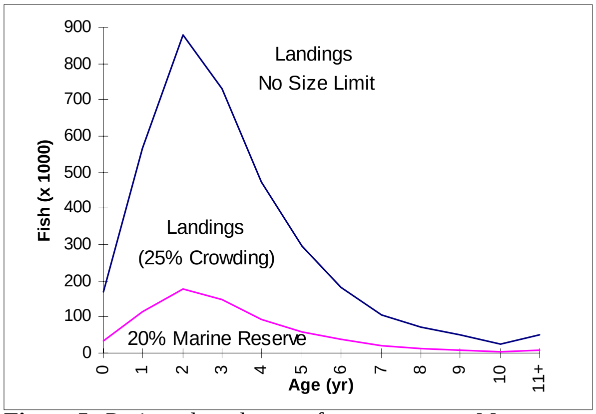

Figure 5. Projected catch curve for gag grouper, *Myctoperca microlepis*, in the Gulf of Mexico for 1992-1996 without size limits. A marine reserves covering 20% of fishing grounds would have protected 20% of the stock in all age classes and reduced the catch of all age classes by 20%. The resulting crowding, measured as the number of available fish per angler, for anglers displaced by reserves would have been 25%.

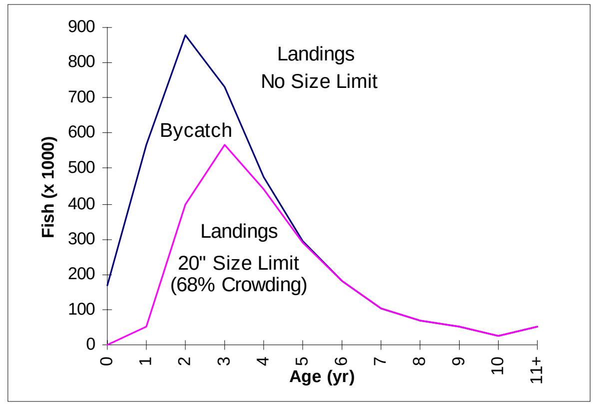

Figure 6. Catch curves for Gulf of Mexico gag grouper, *Myctoperca microlepis*, (1992-1996) with and without 20" minimum size limits. Ages at 20" vary around the 3 yr age class depending on individual growth rates. The minimum size limit results in 68% crowding in terms of available fish per angler. Undersized fishes caught must be discarded and are subject to bycatch mortality. Replotted from Schirripa and Legault (1997).

grounds with impacts of establishing a minimum 20" size restriction (Fig. 5). Closing 20% of fishing grounds as marine reserves results in 25% increased crowding in terms of angler density and available fish per angler, since 80% of the fishing grounds and fish must be shared by 100% of the anglers. With reasonable compliance and limited fish movements, nearly 20% of the stock and habitat is protected from fishing.

Figure 6 shows the same catch curve with and without a 20" minimum size limit. When measured in numbers of legally available fish per angler, the size limit leads to 68% crowding because of the large number of small individuals in the population that are now "protected". Although a popular management measure, minimum size limits may provide relative little stock protection unless there is a substantial change in how fishing is prosecuted. Since fish less than 20" will still be caught as bycatch, the conservation benefit of the size limit depends on the level of release mortality. Unless anglers can avoid catching legally undersized fish, Figure 6 underestimates the actual bycatch with a size limit. 'High grading' by recreational anglers under bag limits can become a problem which reduces conservation benefits. Although numbers of fish caught can be an important consideration for recreational anglers, commercial anglers rely on total weight and must now process more fish (or target other species) in order to obtain the same revenue. This increased fishing effort increases the bycatch of undersized fish while increasing the mortality of the larger legal-sized individuals with a disproportionate negative effect on spawning potential.

Thus, when "crowding" is compared on the basis of available fish per angler, the marine reserve is preferable in that it provides more secure protection of the stock and has less detrimental impacts on anglers. There is no bycatch for fish in the reserve. In addition, the conservation value of a 20" size limit is questionable since gag grouper change sex and are often caught in deep water where release survival is reduced. For any level of stock protection, marine reserves may be less obtrusive for anglers than other traditional management measures.

Challenges for Stock Assessment

As fishery regulations increase and no-take marine reserves become more widespread, new approaches to stock assessment will be required because traditional assessments that rely mainly on fishery-dependent (FD) data will be inadequate. Even without using reserves, fishery-dependent data are becoming less useful with increased regulation. For example, fewer data are available as size and bag limits are imposed, seasons are shortened, and fisheries are closed for rebuilding. With larger size limits, younger age classes are less represented or absent from the data. As fishing effort switches to larger individuals, older age classes become truncated. Also, as recreational fisheries expand and become more important, fishery sampling becomes more expensive, difficult, and less precise. Finally, with increased regulation, many anglers are less cooperative is supplying 'voluntary' data and may have increased incentive to deceive samplers.

Assessments based primarily on fishery-dependent data may be misleading when marine reserves are used because significant portions of the stock may be unavailable to fishing. Another problem is that present length-or age-based assessment methods rely on the assumption that a stock is homogeneous and reflects fishing pressure uniformly. With reserves, emigration from protected to fished areas potentially distorts the catch composition relative to the dynamics assumed in the standard models. Finally, increased fish abundance, density, and size in marine reserves can potentially contribute significantly to conservation targets such as SPR and prevention of over fishing. Fishery independent sampling that uses destructive fishing techniques are unlikely to offer much help because only on rare and exceptional cases, are reserve mangers likely to allow destructive sampling for fishery purposes (Fig. 1). Solutions to these problems will require development of spatially explicit stock assessment models and increased reliance on non-destructive, fishery-independent (FI) data collection and length-based assessment methods (Gallucci et al., 1996). Unfortunately, age for most fishes can not be directly determined from length data so that assessment methods will have to be appropriately adapted. Ault et al. (1998) provide an example of an assessment based on 'mean size in the exploitable phase' for 35 reef fish species in the Florida Keys using diver visual estimates of length frequency combined with headboat data.

New technology may facilitate length-frequency data collection in a cost effective manner. Development and application of underwater, stereo-video technology offers particular promise (Bohnsack, 1995). With modifidation of off-the-shelf technology, it is potentially possible to greatly increase the quantity, precision, and accuracy of FI data. Many more fishes could be observed than are landed in the fishery. Also, more size classes and greater depths could be sampled than is feasible using divers. Data collection can be controlled in terms of standardizing distances and sampling time. Accurate habitat information could be provided. including topography, benthic species composition, and presence of foraging resources. In waters with moderate turbidity, stereo images are superior to single images. However, electronic processing of images could potentially double the actual visibility by substituting pixels from unobstructed portions of each image. Video systems can be used directly by divers or remotely operated vehicles (ROVs), as well as independent passive gear (i.e. video traps). Not having to rely on divers would greatly expand the sampling potential in terms of depth, sea conditions, and lighting conditions. This could be especially useful where crepuscular or nocturnal sampling is desirable. Finally, by providing accurate distance estimates, the statistical basis for calculating density is greatly improved.

Conclusions

No-take marine reserves are an essential, but underutilized tool in precautionary fishery management. They are perhaps the only way to protect stock genetics from detrimental selective effects of fishing. General guidelines for establishing reserves exist but will have to be adapted to local conditions. Some of the concerns about using marine reserves compared to more traditional management measures appear to be based more on perception than substance. Use of marine reserves will require new approaches to stock assessments that use spatially-explicit models, fishery-independent length-frequency data, 'mean size in the exploitable phase', and stereo video technology for data collection.

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