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WHY MARINE RESERVES?

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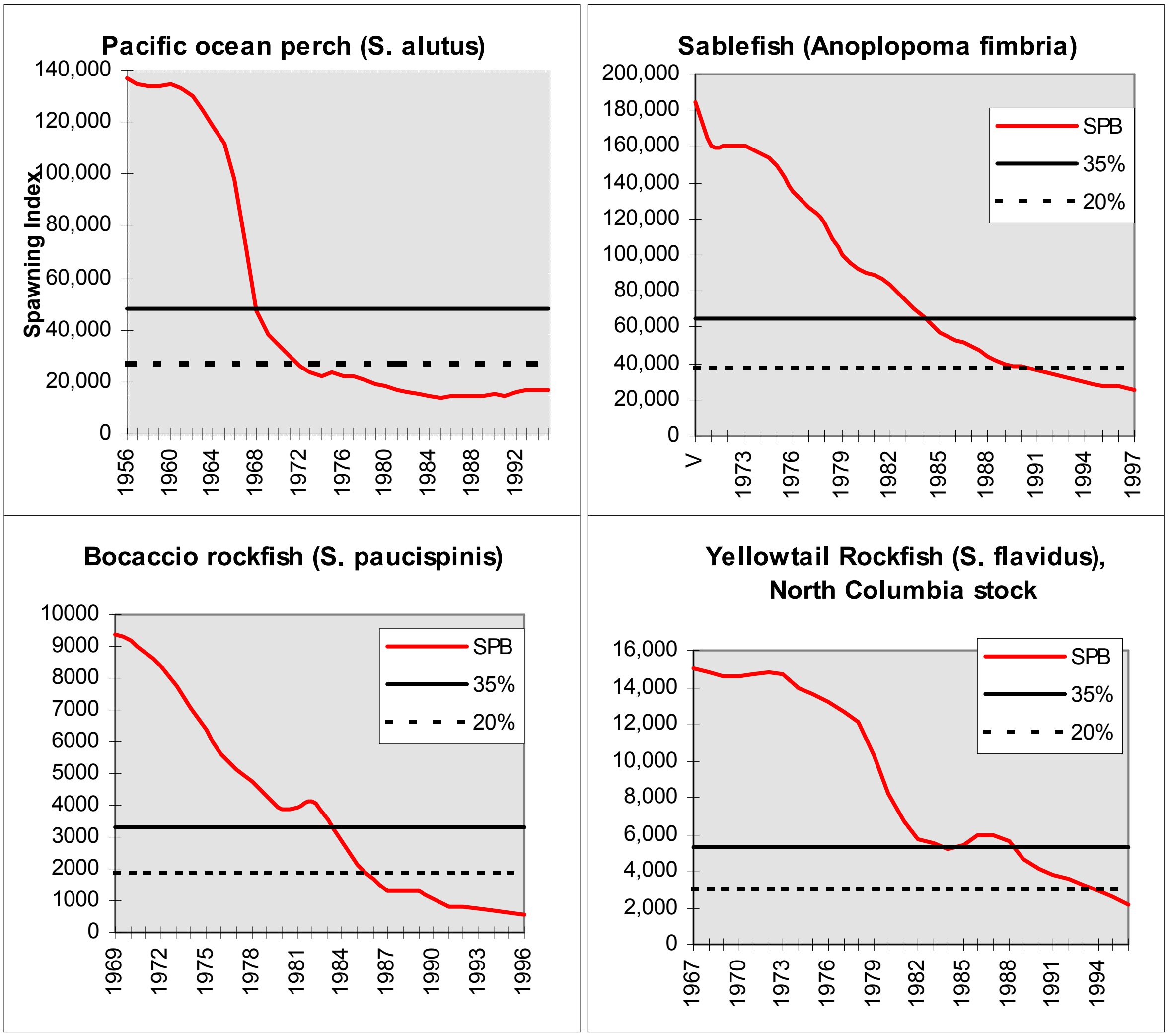
Introduction

There is a long and cherished tradition of setting aside wilderness and park areas for the long-term enjoyment and benefit of the public. The United States has set the standard. In 1872, President Ulysses S. Grant signed a bill to create the first National Park, Yellowstone. In 1894, Yellowstone became a no-take zone; all hunting was prohibited. The protection of habitat by Congress began as early as 1903 and continued throughout the early part of the twentieth century.

Today, about 4% of the land in the United States has been protected in National Parks. Our Nation's territory extends beyond the land, 200 miles out to sea. This is termed the Exclusive Economic Zone (EEZ). Yet, less than 0.5% of U.S. territorial waters are protected in National Marine Sanctuaries. Fishing is banned within only 36 square miles (0.2%) of all Sanctuary waters, amounting to about 0.001% (one-one thousands of a percent) of U.S. territorial waters.

On the U.S. Pacific coast, conventional fisheries management strategies have not prevented the decline of many groundfish species and the fisheries associated with them (Fig. 1). Fifteen species of groundfish appear to be overfished, including two species that have declined to less than 10% of their unfished levels: ling cod and bocaccio. Several species do not appear to be reaching the equilibrium expected as a result of management (bocaccio, widow, canary, yellowtail, and black rockfish); these stocks are not being harvested sustainably (Ralston, 1998). The future of natural marine ecosystems, and the fishing industry, is uncertain without innovative conservation strategies. New guidelines for preventing overfishing and rebuilding depleted stocks adopted by the Pacific Fishery Management Council are a step in the right direction, but may not be sufficiently conservative.

Figure 1. Estimated time-series of spawning biomass for five species of Pacific coast groundfish (metric tons).



Notes:
Solid line is 35% of virgin spawning biomass; dashed line is 20%.
POP from PFMC (1995).
Sablefish redrawn from 1997 Draft Sablefish Assessment (baseline model) (PFMC 1997).
Bocaccio and Yellowtail from PFMC (1996), Appendices.

Setting aside parts of the ocean that serve important roles during reproduction, pelagic dispersal, or juvenile settlement can safeguard against many threats facing marine organisms (Bohnsack, 1993). More marine reserves in which fishing is banned are needed to protect marine organisms and the fisheries that depend on them. Ocean environments without fishing disturbance are needed to fully realize the research, educational, and conservation benefits of marine protected areas. The biodiversity and ecosystems that would be protected within marine reserves provide many goods and services to society, such as insurance against fishery management failures, potentially enhanced fisheries, a way to reduce uncertainty about the effects of fishing and other factors on habitat, a way to separate the effects of fishing from the effects of environmental variation, enhanced educational opportunities, increased revenue from tourism and property sales, and potentially important medicines and other natural products.

This report examines the marine reserve concept and summarizes some of the voluminous literature on marine reserves, with an emphasis on studies of West Coast marine reserves.

Defining Marine Reserves

There have been many names given to marine protected areas, including parks, reserves, harvest refugia, and sanctuaries. The functions of these designations have included: enhanced tourism, habitat protection, refuge for intensively fished species, preservation of biodiversity, increased target species productivity, identification of a framework for sustainable use management; and illustration of human impacts on marine environments (Allison et al., 1998). The World Conservation Union defines a marine protected area (MPA) as:

> "Any area of intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical, and cultural features, which have been reserved by law or other affected means to protect part or all of the enclosed environment."

For the purposes of this report, marine reserves will simply be defined as areas protected from all fishing activity. The theory behind marine reserves is that fish populations can recover from the effects of intense fishing within reserve boundaries if fishing is banned. Once fish size, density, and fecundity increase, the reserve can act as source of larvae, juveniles, and adult fish for populations outside the reserve.

Importance of Marine Reserves

Protect Marine Habitat, Biodiversity, and the Continuity of Exploited Fish Populations

Marine reserves offer direct protection to all species within their borders. Moreover, they can protect the continuity, or connectivity, of marine populations. Connectivity is recognized as a key factor in maintaining viable populations on large geographic scales. As stocks begin to decline, once continuous populations can become isolated islands. As species populations become reduced and isolated, they become more vulnerable to environmental change. Networks of marine reserves present a way to maintain biodiversity, spawning locations and continuous fish populations. This provides protection against other human impacts, such as pollution, and unforeseen alterations in the marine environment.

Improve Marine Research

Marine reserves provide places in which to study marine ecosystems relatively free from the confounding influences of human activities. Using such reserves, we can begin to define what a truly "healthy" marine ecosystem really is, something that cannot be accomplished in a laboratory or in areas in which fishing occurs. Reserves can also illuminate the effects of fishing on habitat, and guide efforts to reduce those effects. Research in marine reserves would provide insights into life histories, population dynamics, ecological energetics, nutrient cycling, and other crucial information -- insights that could significantly improve fisheries management, separate the effects of natural environmental fluctuations (e.g., El Niño events and regime shifts) from the effects of fishing, help to establish standards and targets for protecting marine ecosystems, and provide other as yet unknown benefits to society.

Protect Against Uncertainties in Fisheries Management

Fisheries management is, and will continue to be, an uncertain business. About 60% of U.S. exploited fish stocks are not assessed. Similarly, only about 25 of the 83 species of groundfish exploited off the West Coast have been assessed. Estimates of abundance, productivity, and population sizes (and fishing mortality rates) that will produce maximum sustainable yield remain highly uncertain. Marine reserves provide a hedge against this uncertainty -- even if fishing mortality rates are grossly underestimated (or abundance is grossly overestimated), resulting in overfishing, the fish within reserves will persist (to potentially help rebuild the fishery). Marine reserves also provide a refuge for unassessed species, and those species that are taken in unknown quantities as bycatch. The ecological impacts of fishing are also uncertain, though there are indications that they can be serious: overfishing of grazing fish from coral reefs has lead to population explosions of urchins in some cases, and overgrowth by algae in other cases. Whole populations of puffins and other seabirds starved to death off the coast of Norway when fishing depleted their food supply. Marine reserves can help scientists and fishermen elucidate the ecological impacts of fishing, to help guide conservation policies.

Rebuild Depleted Fish Populations

Well planned and rigorously monitored marine reserves can rebuild depleted fish populations and potentially enhance fisheries. Fish and other organisms within marine reserves have been shown to increase in size, number, and density. In tropical areas such as the Philippines and Caribbean, fish populations have doubled to quadrupled within five to eight years within marine protected areas (e.g., Russ, 1985; Roberts, 1994). The few studies that have been conducted of the effects of marine reserves on fisheries indicate that fishery yields were significantly enhanced in places adjacent to marine reserves, and that reserves can protect recruits that settle inside, allow them to grow to larger size, and export them to local fisheries (e.g., Russ and Alcala, 1996; Klima et al., 1986; Gitschlag, 1986; Davis and Dodrill, 1989). In the temperate water marine reserves of New Zealand, California, and Washington, fish and shellfish (including lobsters) have increased in abundance by factors of 2 to 8, become larger, and greatly increased egg production relative to fished areas (Rowley, 1994).

Education

Marine reserves provide an excellent opportunity for public education. Both children and adults deserve places where they can observe healthy marine ecosystems. This can be accomplished through field trips, the transmission of video images from deepwater ecosystems, and the communication of research results by Aquariums, Natural History Museums, and educational curricula.

Enhance Tourism and Property Values

Marine reserves protect healthy natural resources, and it is expected that dependent economic activities, such as tourism and property sales, would increase, especially with respect to nearshore reserves. Many people are attracted to places of natural beauty to live, work, and play. The designation of marine protected areas creates a sense of place and special appeal. For example, both the Virgin Islands Marine Park and the Bonaire Marine Park in the Caribbean region generate economic benefits of about $20 million per year for modest investments in maintenance ($150,000 and $2.1 million per year, respectively) (Dixon, 1993).

Protect Species that May Provide New Medicines and Other Biomedical Advances

The biodiversity that is protected within marine reserves may yield important new medicines and other products. For example, many sessile (non-mobile) marine organisms such as corals and sponges produce antibiotic compounds. Novel antibiotics will become increasingly important as more and more bacterial strains become resistant to existing antibiotics. Certain sponges from the Red Sea produce substances that strongly inhibit the AIDS virus. A marine snail and a Caribbean sea whip produce compounds that may be used to treat inflammatory diseases such as arthritis that have proved resistant to treatment thus far. Certain species of sea squirts produce remarkably strong natural sun-blocking agents. Bioceramics made by marine animals show promise for use in artificial limbs and organs. Research on marine natural products has barely scratched the surface -- as more research is conducted, more and more useful substances will certainly be discovered. Marine reserves protect species that one day may provide important new medicines and other biomedical products.

Conservation Biology and Rockfish Ecology

Source and Sinks

Metapopulations are defined as systems of local populations connected by dispersal of individuals. The processes of colonization and extinction determine the structure of local populations. Source-sink populations are a type of metapopulation. One local population, termed the source, has high fecundity (total egg production), genetic diversity, and long persistence. This population exports offspring and mature adults to a second population, termed the sink. The sink is dependent on immigration for persistence (Erikson, 1997).

Island Biogeography Theory

Island Biogeography Theory is concerned with the pattern of species-area relationships. It states that large islands support more species than small islands. It holds for most everything from vascular plants, to reptiles, to mammals. The term island is not confined to the literal meaning, but includes fish that live in lakes, insects restricted to one plant species, and mammals that occupy patches of alpine forest. There is a limit to the number of species that can survive within the bounds of a finite amount of habitat. National Parks and nature preserves essentially operate as islands within an area of disturbed habitat. The size of an island and its distance from either other islands or the mainland affects extinction and immigration rates. For a population within a confined habitat to persist into the future it either needs to be large enough to maintain genetic diversity and a natural population structure, or it needs a source of new recruits from outside. Given two islands with equal colonization rates, the smaller island will have a reduced population size and an increased species extinction rate. Given two islands equal in size, the island further from the source pool will have a reduced immigration rate and lower species equilibrium (Gotelli, 1995; Diamond and May, 1981).

Reserve Networks

One important problem in designing marine reserves is to determine whether a network of smaller reserves or one large reserve will be more effective in retaining species. The answer to this question depends on the differential extinction probabilities between smaller and large reserves, the number of populations to be protected by the reserve or network of reserves, the correlation of year-to-year fluctuations in the environment and populations, and the probability of recolonization of an area emptied by a local extinction event (Caughley and Gunn, 1996; Soule and Simberloff, 1986). Theoretically, networks of marine reserves that protect source and sink populations would best serve marine biodiversity conservation. Releasing several subpopulations from fishing pressure may restore a more natural mortality and age structure. The reserve then can act as a source for other populations because larger, older individuals have a greater fecundity, thus enhancing fisheries.

A network of reserves, further, would maintain genetic diversity within the range of fish species populations and avert the isolation of metapopulations (Allison et al., 1998). However, Allison et al. (1998) point out that it is difficult to demonstrate that reserves serve as emigration sources and that there are many forces at work in fish recruitment. More reserves are needed to conclusively demonstrate that reserves can export fish or larvae. Marine systems differ greatly from their terrestrial counterparts in scale, variability and human impact. Furthermore, marine reserves must also contend with the forces of ocean currents that can distribute both offspring and pollutants. Hence, terrestrial reserve theories may not apply entirely to the marine environment.

Rockfish Management

Sustainable fishing of rockfish is difficult for several reasons, including low sustainable yield and the multispecies nature of fisheries. Rockfish are long lived, slow growing and have low natural mortality. The evidence suggests that such species cannot support a large sustained yield (Leaman and Stanley, 1993). Rockfish have a two-phase life cycle: an open water egg or larval stage and a demersal (bottom) juvenile and adult stage. Ocean currents passively transport eggs and larvae. Survival in this stage is very low. The open water stage can last from about a week to 18 months. Juveniles and adults are considered relatively sedentary because they generally associate with one reef for most of their adult lives. Juveniles allocate most of their surplus energy reserves to growth. Adults, however, tend to grow more slowly because more of their energy reserves are put into reproduction. Older adult fish may not be much 1arger but their fecundity increases exponentially. Estimation of maximum sustainable yield is very difficult because of extreme recruitment variability. Marine reserves offer a way to protect spawning biomass of relatively sedentary species like rockfish fairly reliably. In addition, marine reserves tend to increase average reproductive potential relative to fished areas, because they allow individuals to grow larger. Larger fish tend to produce many more eggs than smaller fish. Hence, fish protected by marine reserve management may be more valuable in terms of reproductive capacity than fish protected through quota management.

Evidence That Marine Reserves are an Effective Management Tool

There is very strong evidence that fish and invertebrate abundance and size increase in marine reserves, sometimes very dramatically.

A recent scholarly survey of 89 scientific papers on marine reserves revealed that: (1) 90% of the reserves studied had higher fish biomass than fished areas; (2) fish density was higher in 63% of the reserves; (3) 83% of the reserves had larger carnivorous fish and invertebrates; and (4) 59% of the reserves had higher biodiversity (Halpern, 2000). This survey showed that the average size of fish and shellfish within reserves are between 20 and 30% higher relative to fished areas; densities are roughly double in reserves; and biomass levels are nearly triple in reserves.

There is strong evidence from both temperate and tropical waters, including areas off California, Washington, and British Columbia (Canada) that fish populations increase in abundance (by factors of 2 to 13), size, and reproductive capacity (by factors of 20 to 55) in marine reserves, in which fishing is banned (Fujita et al., 1999).

Species that respond well to marine reserve management include lingcod and rockfish, both of which have suffered steep declines in abundance due to fishing (Fujita et al., 1999).

CASE STUDIES: FISH ABUNDANCE AND SIZE INCREASE IN MARINE RESERVES

Table 1. Marine reserves increase fish abundance and size within their borders.

Taxa / area	Reference	Reserve size	Effects
Coral reef fish			
Australia	Rigney (1990)	Not listed	Abundance of legal-size and juvenile coral trout 2x greater in reserve.
Florida	Clark *et al.* (1989)	Not listed	93% increase in snapper abundance and 439% increase in grunt abundance in reserve.
	Johnson et al. (1999)	40 km^2	Relative abundance greater by factors of 2.4 to 12.8 for gamefish, depending on species.
	Bohnsack (1982)		Densities higher in reserve.
New Caledonia	Wantiez *et al.* (1997)	Not listed	67% increase in species richness, 160% increase in density, and 246% increase in biomass in reserve.
Philippines	Russ and Alcala (1996b)	0.75 km (Sumilon) 0.45 km (Apo)	Sumilon: Density decreased significantly when reserve reopened to fishing. Density increased 300% in the 5 years after reclosure. Apo: Density increased 6 years after reserve created.
Temperate water fish			
California	Paddack (1996)	6.8 km^2 (Big Creek)	No difference in rockfish size in reserve (but reserve less than 4 years old).
	Paddack (1996)	1.4 km^2 (Hopkins Marine)	Larger and more abundant rockfish in reserve.
	Paddack (1996)	1.25 km^2 (Point Lobos)	Larger and more abundant rockfish in reserve.
New England	Murawski et al. (1998)	17,000 km^2	Scallop abundance increased 14-fold in 4 years; larger scallops inside closed areas.
Mediterranean	Francour (1997)	0.72 km^2	Number of spp nearly 2x higher in reserve; abundance and biomass 5x greater in reserve.

Bell (1983)	7 km^2	Overall density of 18 target spp 2x higher in reserve.

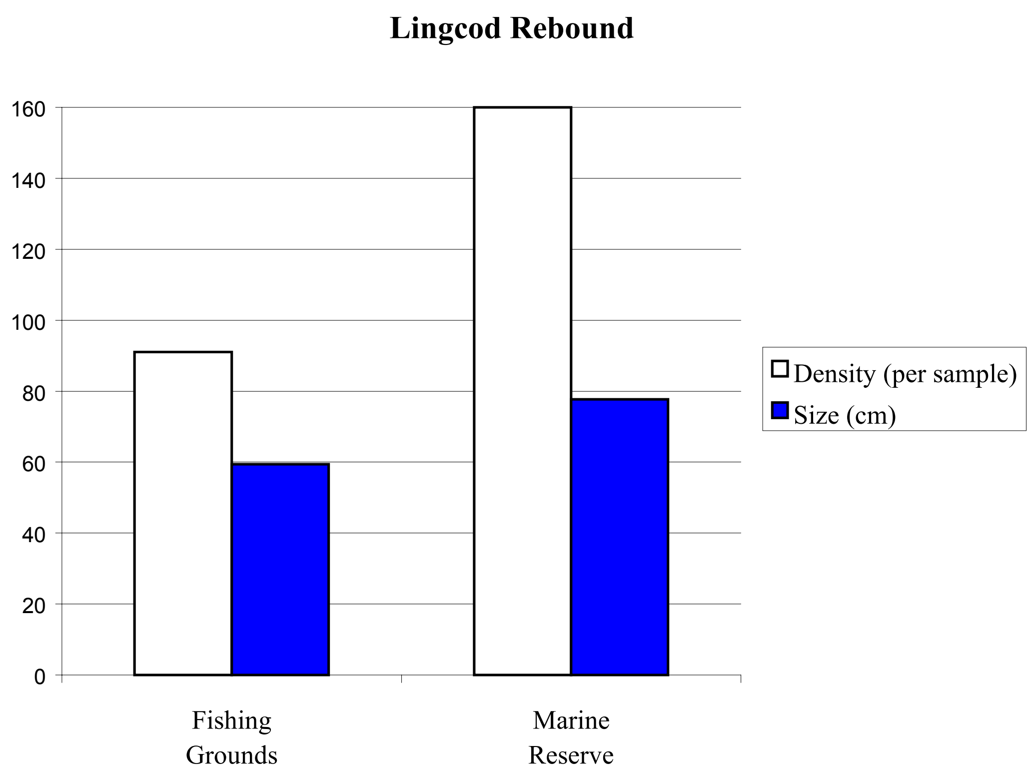
Table 1 **(cont). Marine reserves increase fish abundance and size within their borders.**

Taxa/area	Reference	Reserve size	Effects
Temperate reef fish			
New Zealand	Cole *et al.* (1990)	Not listed	Increase in abundance for some species (snapper, blue cod and red moki) in reserve; increased size of snapper in reserve.
	McCormick and Choat (1987)	5 km^2	62% of individuals larger than 300mm in reserve, compared to 38% in fished area.
South Africa	Buxton and Smale (1989)	300 km^2	Abundance of 2 of 3 spp studied 4x and 13x higher in reserve.
Vancouver	Martell, 1998	<1 km^2 (Porteau)	Greater lingcod spawning in reserve.
	Martell, 1998	<1 km^2 (Whytecliff)	Above average lingcod spawning in reserve.
Washington	Palsson and Pacunski (1995)	<2 km^2 (Edmunds)	Larger coppers, quillbacks, and lingcod in reserve.
	Palsson and Pacunski (1995)	<2 km^2 (Shady Cove)	Number of spp almost 2x higher in reserve; number of lingcod and lingcod nests nearly 3x higher in reserve.
Lobster			
Florida	Davis (1977)	95 km^2 (29 mos)	Abundance declined 60% upon reopening of reserve.
New Zealand	Cole *et al.* (1990)	Not listed	Increased abundance in reserve.
Conch			
Venezuela	Weil and Laughlin (1984)	4 km^2	Individuals 12% larger on average in reserve.
Red sea urchins			
Washington	Tuya *et al.* (2000)	Not listed	Abundance of medium and large urchins greater in reserves; no discernable impact on rockfish, lingcod, sea cucumbers, scallops, small urchins.
Abalone			
California	Tegner *et al.* (1992)	Not listed	Pink and green abalone did not respond after 10 years of protection, but green abalone juvenile abundance increased after managers placed adult transplants in reserves.

Marine reserves allow overfished species to recover. Almost all of the scientific studies published so far show increases in fish abundance, density, and/or size within marine reserves relative to fishing grounds. Less is known about reserves on the West Coast. Only about eight marine reserves on the West Coast between California and British Columbia have been studied, including: Shady Cove, Edmunds Underwater Park, Whytecliff Park, Porteau Provincial Park, Hopkins Marine Reserve, Point Lobos marine park, Big Creek Marine Reserve, and Anacapa Island within the Channel Islands National Park.

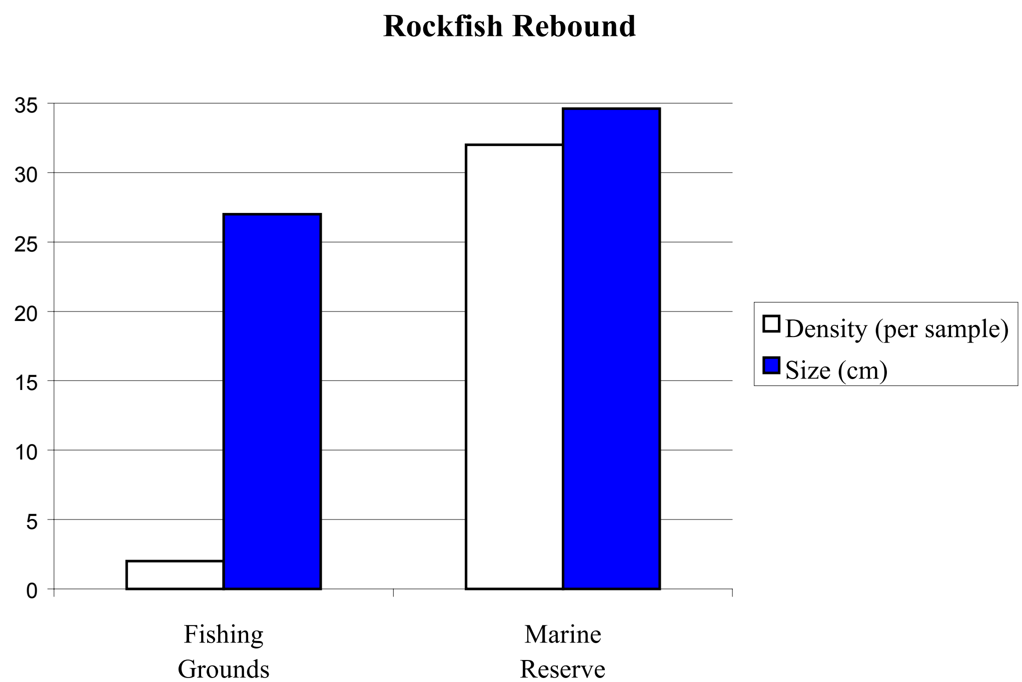
Shady Cove Marine Reserve, Washington

"Shady Cove Marine Reserve in the San Juan Islands (Friday Harbor), Washington has been in place for 7 years, and is less than 2 km in extent. Yet researchers found almost three times the number of large lingcod and lingcod nests in the reserve than in a nearby control site. Almost twice as many fish (all species) were found within the reserve, in comparison with the control site. Rockfish and lingcod showed particularly striking responses to protection within the reserve." Source: Palsson and Pacunski, 1995.



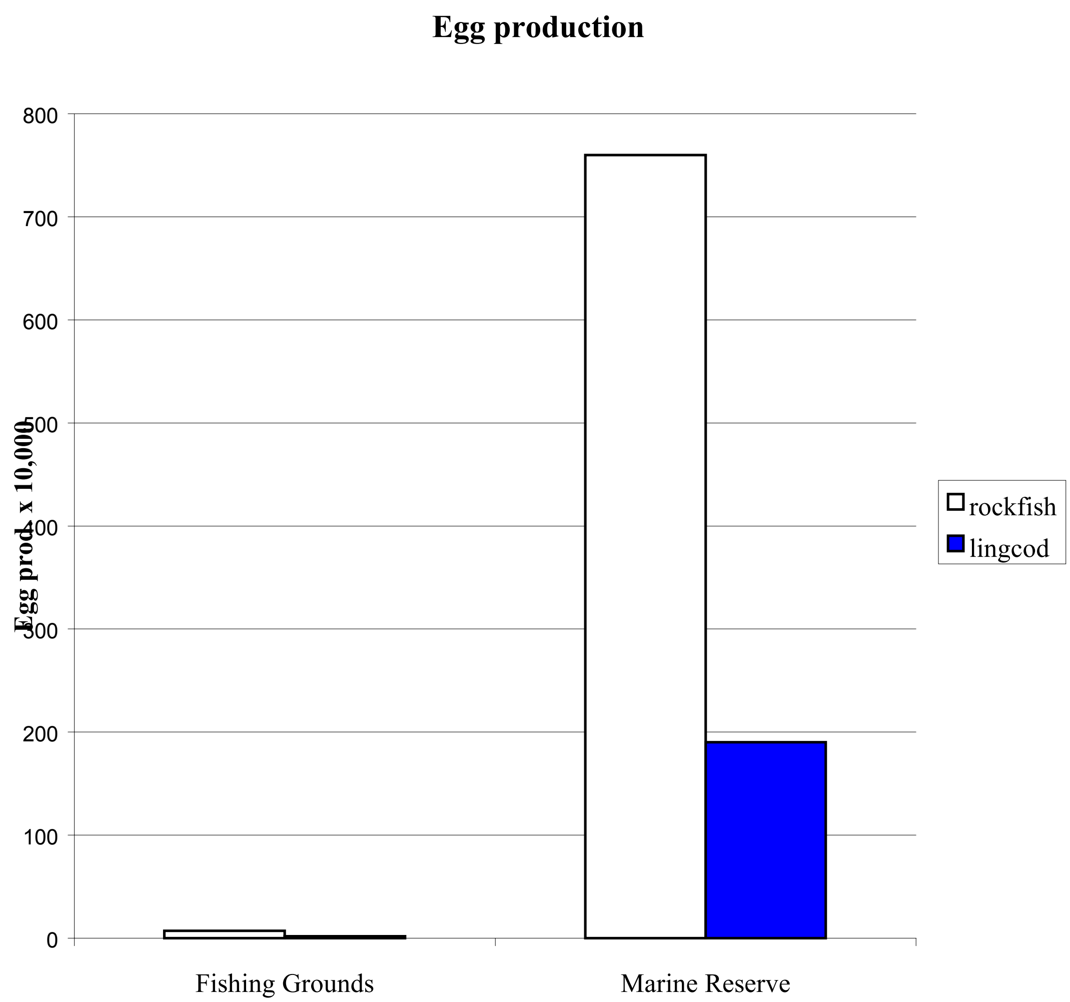
Edmunds Underwater Park, WA: Fish Abundance

"There were more copper rockfish at Edmunds Underwater Park (mean 32.0 fish/$90m^2$ transect) than at any of the four fished sites (mean 1.3-3.5/transect)." Source: Palsson and Pacunski, 1995).



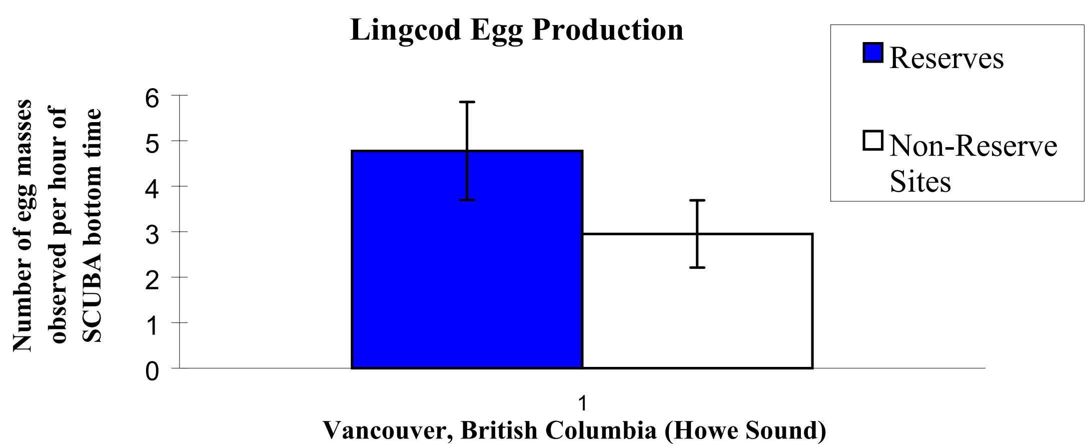
<u>Edmunds Underwater Park, Puget Sound, WA: Egg Production</u>

"Edmunds Underwater Park can produce an estimated 20 times as many lingcod and 55 times as many Rockfish eggs and larvae acre per acre than fished sites." Source: Palsson and Pacunski, 1995.



Whytecliff Park and Porteau Provincial Park, Vancouver, British Columbia

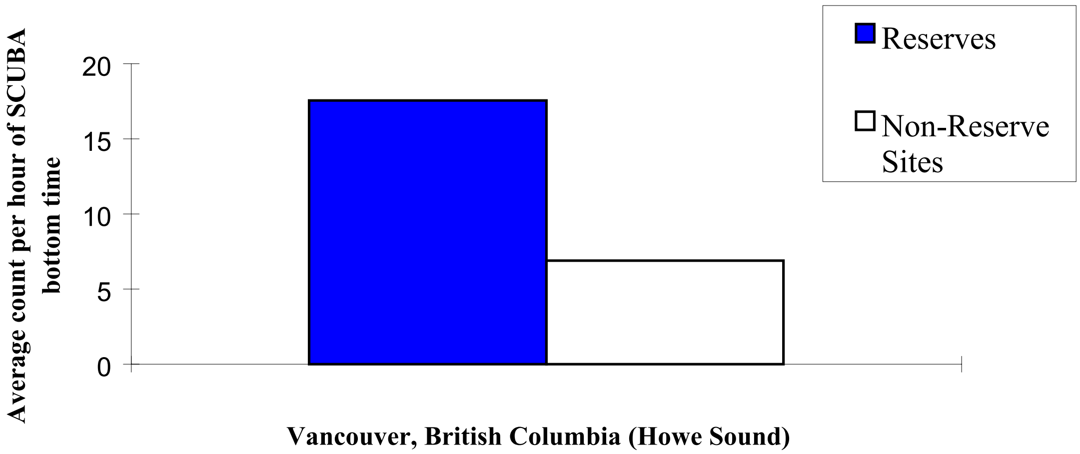
"Inside Howe Sound are two Marine Protected Areas (MPAs), Whytecliff Park and Porteau Provincial Park. Since 1993, fishing has been prohibited from these two sites, and it was expected that lingcod, that remain within the boundaries, would grow larger and lay larger sized egg masses inside of MPAs. There are larger sized lingcod spawning in the two MPAs in comparison to the two fished sites." Lingcod are also more abundant within the MPAs. Source: Martell, 1998 (Bachelor of Science Thesis).



Reserves = Whytecliff and Porteau Cove. Non-reserves = Ansell Pt. and Popham

Whytecliff Park and Porteau Provincial Park, Vancouver, British Columbia

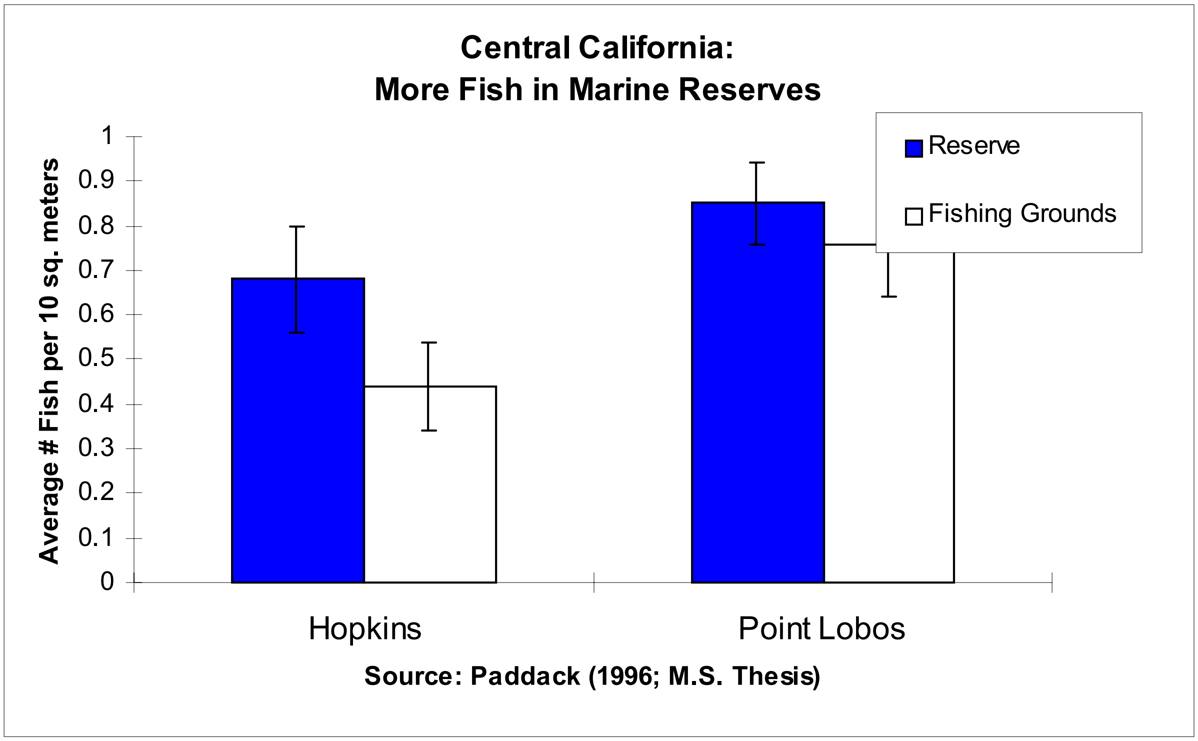
Ling cod Abundance



Reserves = Whytecliff and Porteau Cove. Non-reserves = Ansell Pt. and Popham Island. Source: Martell (1998, Bachelor of Science Thesis)

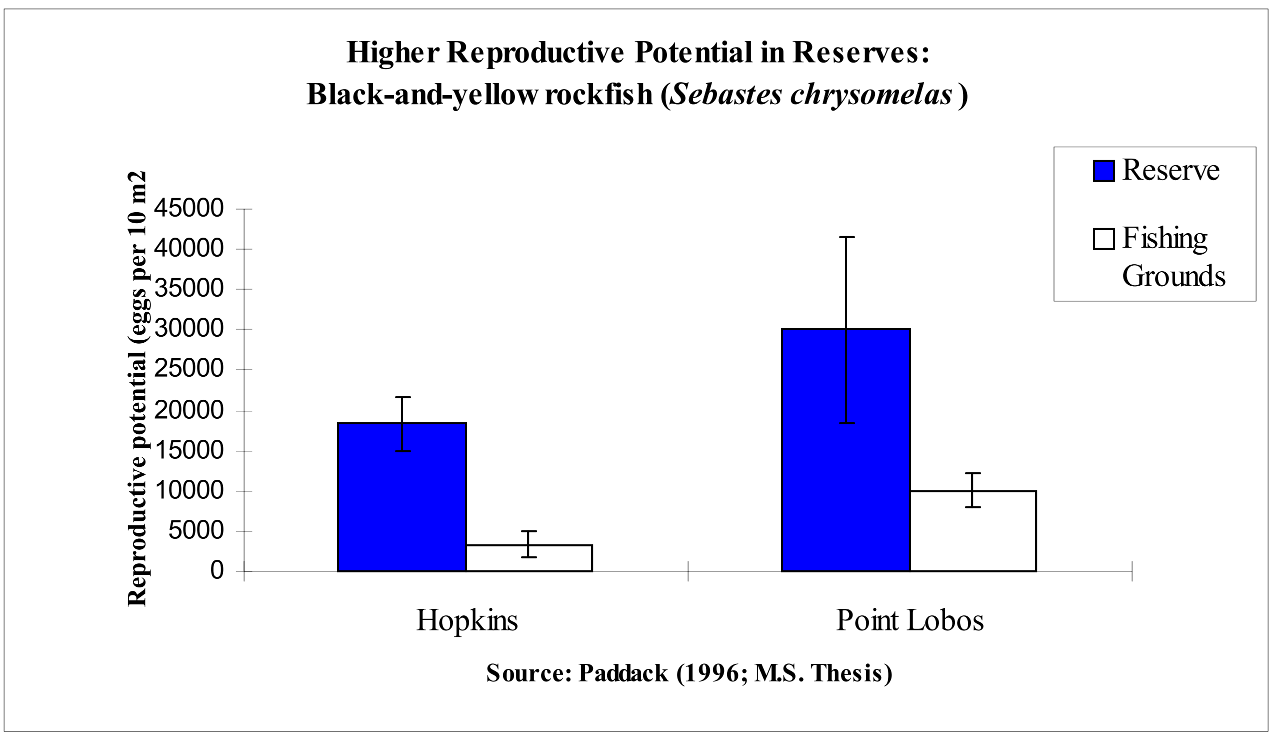
Hopkins Marine Reserve and Point Lobos Marine Park, CA

Hopkins Marine Reserve, located near Monterey, California, is only 1.4 square km in extent, and has been in place for about 13 years. The Point Lobos Marine Reserve, near Carmel, California is about 1.25 square km in extent, and has been in place for 37 years. Average fish density is greater within these marine reserves than in adjacent fishing grounds.



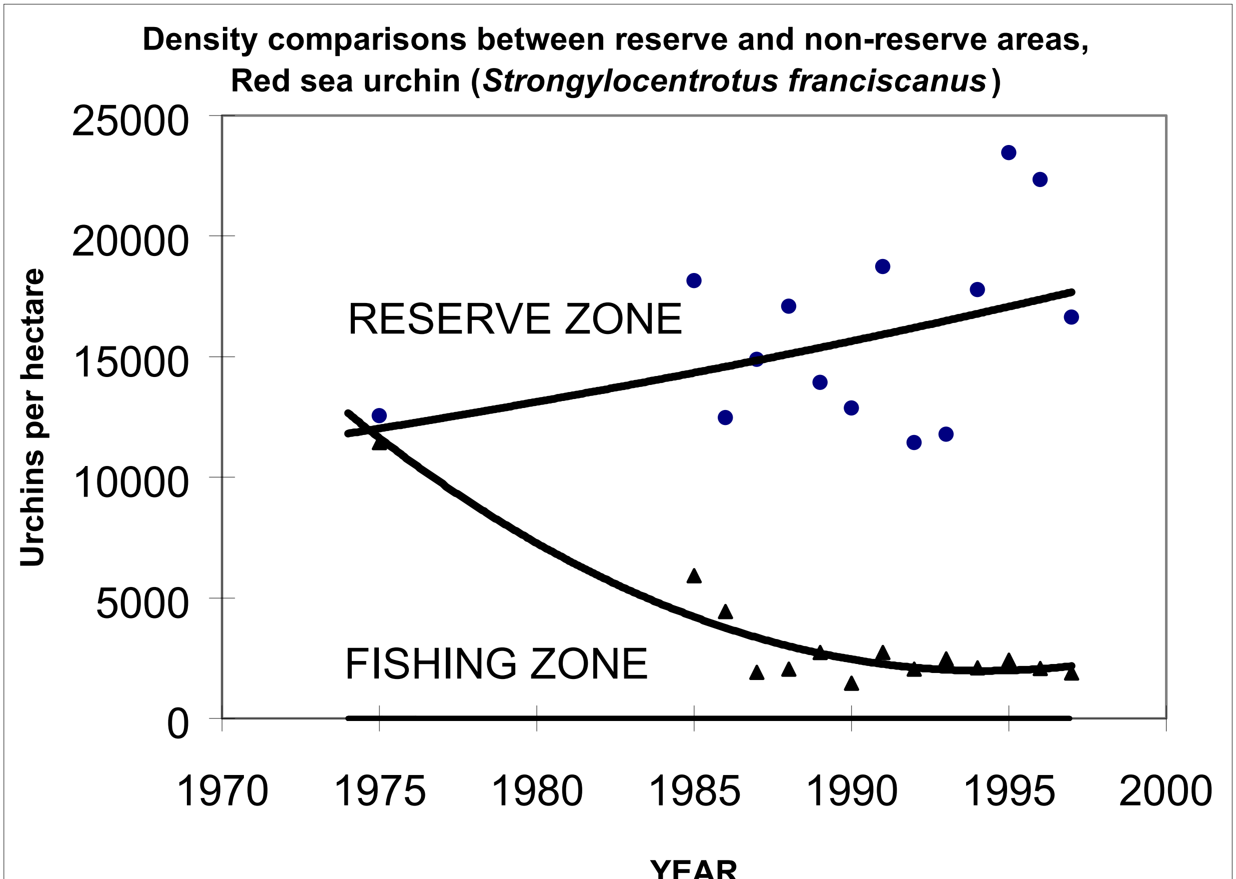
Hopkins Marine Reserve and Point Lobos Marine Park, CA

Reproductive potential is also enhanced within these reserves.



Anacapa Island, Channel Islands National Park, CA

"The red sea urchin is one of California's most valuable fisheries. Urchin density is higher within the Anacapa Island marine reserve than in fished areas. This trend has persisted through time." Source: G. Davis, Channel Islands National Park (personal communication).



Location: Anacapa Island, California. Source: G. Davis, Channel Islands National Park. The red sea urchin is one of California's most valuable commercial fisheries.

CASE STUDIES: MARINE RESERVES CAN HELP REBUILD DEPLETED POPULATIONS OUTSIDE THEIR BORDERS

While it is clear that fish and invertebrates increase in abundance, size, and reproductive capacity within marine reserves, the capacity of marine reserves to help rebuild depleted populations or enhance yields outside their borders has not been as well studied. Of the 10 field studies we reviewed, catches increased significantly near marine reserves in 7 of them. Compliance with reserve regulations was relatively poor in one marine reserve that did not enhance catches; another had degraded habitat. The third reserve that did not enhance catches did increase catch-per-unit effort outside the reserve after 2 years of protection; total catch may increase over baseline levels with time (Fujita et al., 1999).

More and larger fish inside marine reserves means much greater reproductive capacity. For example, one blue rockfish (*Sebastes mystinus*) that is 25 cm long produces 50,000 eggs, while one blue rockfish that is 32.5 cm long produces 300,00 eggs (6 times more). One female Pacific ocean perch (S*ebastes alutus*) that is 23 cm long generates 10,000 eggs, while one that is 45 cm long generates 300,000 eggs (30 times more) (Casillas, *et al*., 1998). Therefore, one would expect that a fish protected within a marine reserve would yield much greater "bang for the buck" than a fish protected with fishery management (e.g., lower catch rates).

Table 2. Marine reserves can enhance fisheries adjacent to them.

Taxa / area	Reference	Reserve size	Effects
Coral reef fish			
Florida	Johnson et al. (1999)	40 km^2	Tagged fish left reserves to enter fishing grounds; several world records set near reserve.
Caribbean	Polunin and Roberts (1993)	Not listed	Saba and Hol Chan Reserves: Greater abundance, size, or biomass
Kenya	McClanahan and Kaunda-Arara (1996)	10 km^2	110% increase in catch per unit effort after 2 years of protection, although 35% decrease in total fish landed.
Philippines	Russ and Alcala (1996a)	0.45 km (Apo)	Significant positive correlation for mean density with duration of protection, and for species richness with duration of protection. Fishers reported increased catches.
	Alcala and Russ (1990)	0.75 km (Sumilon)	Catches 54% higher while reserve intact, compared to 1 year after reserve reopened.

Temperate water fish			
South Africa	Bennett and Attwood (1991)		Within 2 years of protection, catch rates of 2 spp increased 4-5x, reaching unexploited levels. Catch rates of 4 other spp approached 30-60% of unexploited levels 2.5-4.5 years after protection.
Shrimp			
California	Schlining (1999)	Not listed	Median catch per unit effort close to reserve significantly greater than median catch per unit effort far from reserve ($p < 0.043$).
Gulf of Mexico	Klima et al. (1986)	Not listed	No increase in yield, but compliance by fishers only 65%.
Crab			
Japan	Yamasaki and Kuwahara (1989)	13.7 km^2	46% increase in catch per unit effort in areas adjacent to reserve after 5th year of protection.
Trochus			
Palau	Heslinga *et al.* (1984)	Not listed	No improvement after 20 yrs (perhaps due to degraded habitat within reserve).

Modeling Studies

In addition to the empirical results gained thus far from West Coast marine reserves, several modeling studies indicate that marine reserves should result in more total catch, despite the loss of catch from within the reserves. For example, a study by Polacheck (1990) focused on the movement of adult fish out of the reserve suggests that a marine reserve could augment catch by 8-20%. Other studies indicate that the movement of larvae out of reserves could greatly enhance catches, especially when stocks are overfished, for both coral reef fishes (Sladek Nowlis and Roberts, 1997) and for bocaccio off the West Coast (Sladek Nowlis and Yoklavich, 1998).

Summary

All but one of the 8 West Coast marine reserves that have been studied to date contain more fish, larger fish, and/or more fecund fish than comparable fished areas. The single exception (Big Creek reserve off Big Sur, California) had been closed to fishing for less than 4 years at the time of the study (Paddack, 1996). Furthermore, fishing intensity in this area is thought to be less than that off nearby Monterey, California, where two marine reserves contained more abundant (and larger) fish than did fished areas. Less fishing intensity and the fact that the Big Creek reserve is quite young would explain the lack of contrast between waters within the Big Creek reserve and adjacent waters.

Modeling studies support the empirical studies that have been done on marine reserves. They indicate that rockfish biomass and catches would be enhanced by marine reserves.

In addition to rebuilding fish populations depleted by overfishing, marine reserves can provide insurance against fishery management failures caused by lack of sufficient data, understanding, or political will. Marine reserves would protect *real* fish from too much fishing, rather than the paper fish that fishery managers *think* will be protected, based on data that are often woefully inadequate and analyses that are often quite uncertain.

The participants in a recent workshop on marine harvest refugia reached a general consensus that "marine harvest refugia exemplify a precautionary approach to the management and conservation of rockfish resources on the West Coast," and that "while there are limits to our scientific knowledge of rockfish ecology, **we have sufficient understanding of the problems associated with their management and conservation to proceed with the process of implementing refugia as a supplement to traditional management practices**" (Yoklavich, 1998; emphasis added). Workshop participants went on to say that "marine harvest refugia are one of the few constructive ways to address protection and conservation of essential fish habitat, and offer the opportunity for habitat to recover from disturbances including impacts from fishing gear. Refugia hold promise in allowing us to separate environmental variables from fishery effects, incorporate ecosystem principles into fisheries assemblage management, and collect the needed baseline data for more accurate stock assessments" (Yoklavich, 1998).

Recommendations

- The creation of marine reserves that represent important pieces of all major marine habitat types within coherent networks is the best way to protect the vast diversity of life in the sea at all levels: distinct populations, species, habitats, and entire biogeographic provinces. Marine reserves should be designed to protect or restore essential physical and ecological processes that create and maintain ecosystems.

- The U.S. should commit to establishing a marine reserve network in federal waters of every region of the U.S. These networks should include representative samples of all ecosystem and habitat types in the waters off New England, Southeast Atlantic, Gulf of Mexico, Pacific Coast, Alaska, and Hawaii. These networks should be coordinated with networks within state waters, to account for species and ecological processes that cross jurisdictional boundaries.

- The Pacific Fishery Management Council should establish a network of marine reserves within their area of jurisdiction in representative habitat types (within each biogeographic zone) by 2001. The reserves should be monitored, and directed research aimed at optimizing reserve/network design should be conducted. The design, location and size of the individual reserves and the network as a whole can be modified as research results indicate.

- Coastal states should establish networks of marine reserves throughout state waters. For example, 45% of California's 12,000 square miles of territorial coastal waters (5,400 square miles) is in protected areas. However, fishing is banned only within about 0.4% of the protected areas. Clearly, more no-take marine reserves are needed in state waters if reserves are to be evaluated and provide the many benefits they are capable of providing. Washington has in place a process for designating more reserves. Oregon currently lacks any no-take marine reserves, nor does a formal process for establishing reserves exist.

- Marine reserves are only effective when they can be effectively enforced. Using transponders, satellite tracking techniques, and video monitoring systems, enforcement officials can keep track of fishing vessels and differentiate vessels that are merely traversing marine reserves from vessels that may be fishing illegally. Some enforcement authorities believe that marine reserves, with a simple ban on fishing, will be far easier to enforce than the many complex regulations that are in place on fishing grounds.

- Creation of marine reserves is not a panacea for the many problems that fishery managers face. Marine reserves should be combined with other policies to meet multiple management objectives. The successful implementation of marine reserves is dependent on preventing the displacement of fishing effort into other areas, movement of target species in and out of the reserve, protection of a significant percentage of critical habitat, and a reasonable enforcement and management costs.

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