DESIGNATED HARVEST REFUGIA: THE NEXT STAGE OF MARINE FISHERY MANAGEMENT IN CALIFORNIA

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ABSTRACT

Marine fishery management has traditionally been based on the biology and population dynamics of individual target species. Management controls are generally exercised through limits on individual fish sizes, seasons of harvest, catch limits, and restrictions on gear efficiency designed to protect reproductive stocks. Distance from port and depth provided de facto refugia from harvest during the first century of modern exploitation, but recently few California nearshore demersal fisheries have been able to sustain high yields using traditional species-specific management strategies.

Designated harvest refugia, or fisheries reserves, should now be evaluated as management tools to enhance or sustain these coastal fisheries. In other parts of the world, designated harvest refugia provide recruits to adjacent harvest zones, protect the genetic diversity of wild stocks, and serve as experimental controls for determinations of potential yield. This concept could be adapted to California's coastal ecosystems by applying accepted theories from ecology and conservation biology. Hypotheses regarding the optimum number, size, and distribution of fishery reserves in relation to harvested zones should be empirically tested in existing marine parks and reserves and in additional protected areas set aside especially for this purpose.

RESUMEN

La explotación racional de los recursos pesqueros se basó tradicionalmente en el conocimiento de la biología y la dinámica poblacional de ciertas especies. En general, el control de la explotación se realiza imponiendo limitaciones en el tamaño de los individuos, restringiendo la pesca a ciertas estaciones del año, limitando el tamaño de la captura, y limitando la eficiencia del equipo de pesca con el objeto de proteger el stock reproductor.

Durante el primer siglo de la explotación pesquera moderna, la distancia desde el puerto y la profundidad ofrecían refugios seguros, pero recientemente una pequeña parte de la pesquería demersal costera en California ha podido mantener un alto rendimiento usando estrategias de explotación tradicionales.

Actualmente, se debe evaluar el uso de refugios de pesca o reservaciones perqueras como herraminetas de trabajo alternativas si queremos aumentar o mantener estas pequerías costeras. En otras partes del mundo, los refugios de pesca proveen reclutas a las zonas de pesca adyacentes, protegen la diversidad genética de la población salvaje y sirven como control experimental para determinar el rendimiento potencial. Este concepto podría ser adaptado al ecosistema costero de California, empleando teorías ecológicas y de conservación biológica. Las hipótesis que consideren el número óptimo, el tamaño y la distribución de las reservaciones portegidas de la pesca en relación a las areas de pesca deberán probarse empíricamente en los parques marinos y reservaciones existentes y en areas de protección adicionales especialmente diseñadas para este propósito.

INTRODUCTION

For more than a century, California's nearshore demersal fisheries were sustained by de facto harvest refugia. Zones beyond the economic reach of vessels and gear went largely unharvested and served as sources of replenishment for harvested areas closer to port or in shallower waters. These refugia have been lost to technological advances in the last 30 to 40 years. Conservation of fishery resources in the future may require designation of management zones to recreate these harvest refugia. This paper describes large-scale, long-term ecological research to test hypotheses regarding the optimum sizes and distributions of harvest refugia required to maximize sustained yields from California's nearshore fisheries.

For more than two decades, fatal flaws in single-species and population-based maximum sustainable yield (MSY) approaches to fisheries management have been seriously discussed in the scientific literature (Roedel 1975; Larkin 1977; Barber 1988).

Despite this discussion, little has changed in management approaches to coastal marine fisheries during the past 40 years or so. In California, fisheries are still managed by species-specific limits on seasons, individual fish sizes, types and sizes of gear, and daily take (bag limits) designed to achieve some approximation of MSY, or a socioeconomic derivative of it called optimum sustainable yield (OSY). I do not wish to enter the debate on the efficacy of traditional single-species, population-based management, but rather to acknowledge that its persistence identifies a significant doubt regarding this approach to fisheries management. I will discuss possible alternatives whose efficacy can be scientifically tested and evaluated.

Larkin (1977) identified two extreme alternatives to single-species MSY, and a wide spectrum of middle-of-the-road management philosophies between them. One extreme may be described as technocentric, resource-information-dependent and -driven, providing rigid control and order, and sociologically simple. A good example of this approach is the Western Australian rock lobster fishery, where harvest rates are based on extensive biological knowledge of the target species, *Panulirus cygnus*, and the number of fishermen and their fishing power are closely regulated (Bowen 1980). The alternative extreme path is to intervene as little as possible in relation to social and economic market forces, imposing only enough regulation to prevent complete stock collapse. Most nearshore California fisheries seem to be managed somewhere between these extremes, but clearly nearer the latter philosophy. Commercial and recreational landings of sea urchin, rockfish, abalone, rock crab, angel shark, California halibut, and spiny lobster have shown greatly reduced yields in recent years in southern California (CDFG unpub.), which not only suggests reduced stocks, but, more important, also indicates a potential for increased production with a different management regimen.

The management strategy I will discuss here may be nontraditional for California marine fisheries, but it is neither unique nor a new idea. It is, nonetheless, an approach that I believe represents the next logical step in the management of California's coastal marine fisheries. It is time to investigate the possibility of setting aside and protecting ecologically discrete zones that are naturally buffered from environmental perturbations and that can produce larval and juvenile recruits for sustainable harvests in adjacent zones. Implementation of such a strategy will require significant social and economic change, and no small amount of courage. It will also suffer from all of the inherent uncertainty and distrust new endeavors always face.

In *The Prince*, a classic treatise on exercising political power, Machiavelli warned 400 years ago:

> It must be considered that there is nothing more difficult to carry out, nor more doubtful of success, nor more dangerous to handle, than to initiate a new order of things. For the reformer has enemies in all those who profit by the old order, and only lukewarm defenders in all those who would profit by the new order, this lukewarmness arising partly from fear of their adversaries, who have the laws in their favor; and partly from the incredulity of mankind, who do not truly believe in anything new until they have had actual experience of it. Thus it arises that on every opportunity for attacking the reformer, his opponents do so with the zeal of partisans, the others only defend him half-heartedly, so that between them he runs great danger.

If a new order of fisheries management is to succeed, it must be based on sound research to reduce the inherent uncertainty of environmental systems and to develop confidence from actual experience in the new approach. This research will take years to conduct and should begin now. As coastal ecosystems become more and more stressed by coastal development, pollution, and fishery harvests, and as landings continue to decline, the case for a new order of fishery management will become easier and easier to make. But at some point it may be too late, as the plight of the Mediterranean Sea reminds us today. We need bold decisions now to apply what is known of ecosystems and ecological processes to fishery management in order to develop a new order of things for the future.

After a century of European investigations and experience, limnologists and oceanographers long ago adopted holistic approaches to aquatic ecosystems that led to the development of several bodies of modern ecological theory on system structure and function and on the roles of predation and competition in ecosystem dynamics. Conservation biologists are currently debating issues of genetic diversity, minimum viable populations, and island biogeographical theory in order to determine optimum reserve boundaries (Lewin 1983; Schonewald-Cox et al. 1983; Quinn and Harrison 1988). This body of theory and knowledge should now be applied to coastal marine fisheries in order to provide a testable ecological basis for management that could increase fishery productivity and stability. What is required is nothing less than a long-term, large-scale experimental ecological study in which socially managed fishery harvest is the major experimental variable.

THE SOUTHERN CALIFORNIA ABALONE FISHERY

The California abalone fishery serves as an example of a mature coastal fishery that could benefit from a new approach to management. The modern fishery was developed intertidally for black abalone, *Haliotis cracherodii*, in the 1850s by Chinese immigrants, and grew to an annual harvest of nearly 2,000 MT by 1879 (Cicin-Sain et al. 1977). Regulations prohibiting sale of abalone collected in the littoral zone shifted the fishery to Japanese hardhat divers and four subtidal species—red abalone (*H. rufescens*), pink abalone (*H. corrugata*), green abalone (*H. fulgens*), and white abalone (*H. sorenseni*)—until World War II. For 20 years following the war, approximately 2,000 MT were harvested commercially each year until those stocks were depleted and black abalone replaced them as the major harvested species in 1973 (Burge et al. 1975). By the early 1980s, total annual harvest was down to about 500 MT (Ault 1985) and had fallen to 276 MT by 1986 (CDFG unpub.). In the late 1950s, development of scuba diving provided access to subtidal resources for a new segment of the burgeoning human population of southern California. No reliable data on total recreational harvest are available for the abalone fishery, but for two years (1982–83) in Channel Islands National Park the reported recreational harvest from commercial passenger fishing vessels alone was 8% of the reported commercial harvest in the park, which was 273 MT in 1982 and 150 MT in 1983 (Forcucci and Davis 1989).

In apparent response to economic pressure, California fishing statutes were changed in 1984 to permit commercial harvest of previously protected black abalone stocks in the ecological reserves around San Miguel, Anacapa, and Santa Barbara islands. Populations of intertidal black abalone around the northern Channel Islands, particularly Anacapa, Santa Cruz, and Santa Rosa, suffered 90% mortality between 1984 and 1988 (Davis 1988). The apparent source of mortality was not harvest, but some natural agent, such as protozoan parasites in environmentally stressed segments of the population. Fur hunting and fishery harvest have reduced predator populations, thereby reducing the influence of natural predation as an ecological process buffering southern California coastal ecosystems against extreme changes (Paine 1974; Tegner 1980; Tegner and Levin 1983). Competition for food and space among the prey species, such as sea urchins and abalone, correspondingly increased, and losses of some species under extreme conditions would be expected (Paine 1974). Perturbations in algal production, such as those due to the recent (1982–83) El Niño, would thus be expected to precipitate dramatic, competitively driven population fluctuations in abalone and also urchin populations, exactly like the fluctuations observed at the Channel Islands. Recovery from these losses by such long-lived, slow-growing animals will be slow and economically disruptive. We are thus seeing signs that California coastal ecosystems are losing their "buffering capacity," and we may expect to witness more frequent and extreme fluctuations in these resources in the future.

The abalone fishery has evolved from a laissez-faire management approach in the mid-nineteenth century to a highly regulated, limited-entry fishery in the late twentieth century, and yet stocks and landings are still falling precipitously. Because it is further along in its socioeconomic evolution, the California abalone fishery provides a useful early warning for more recently developed fisheries, such as the sea urchin fishery. The abalone fishery also provides a useful model for developing new management approaches, such as that suggested above, because it is not unique; many other long-lived, slow-growing, late-maturing, resident species such as rockfish and spiny lobster could also benefit from this geographic and ecologic approach to management.

ECOLOGICALLY BASED MANAGEMENT UNITS

The concept of ecologically based management units is not new, but it has not yet been broadly applied to coastal marine fisheries. Most ecological units can be described as geographical zones, and zoning human use on such a geographic basis is broadly applied in natural resource management, especially in terrestrial environments. Wildlife and waterfowl refuges are essentially zones where harvest is restricted or prohibited for the purpose of producing and perpetuating stocks for human use elsewhere. Montane national parks regularly produce "overflows" of ungulates and predators, such as elk, deer, wolves, and grizzly bears, which are harvested in neighboring areas. In Australia, the Great Barrier Reef Marine Park Authority uses six kinds of zones within this 348,700-km^2 marine park to regulate human uses and conserve natural resources (GBRMPA 1981). Zoning is also a cornerstone of marine park management in Canada (Parks Canada 1986) and in the policies of the International Union for the Conservation of Nature and Natural Resources (Kelleher and Kenchington 1987).

In marine fisheries, single-species sanctuaries for spiny lobster have proven to be effective and popular ecologically based management tools. In both New Zealand and Florida, closing moderately large areas (100 to 1,000 km^2) of juvenile lobster habitat to harvest increased adjacent adult populations, and thereby overall yields to the fisheries (Booth 1979; Davis and Dodrill 1980). A 190-km^2 marine park at Dry Tortugas, Florida, also serves as an adult lobster (*Panulirus argus*) harvest refugium as part of the Gulf of Mexico Fishery Management Council's and State of Florida's lobster fishery management plans. In this regard it provides larval and juvenile recruitment to adjacent and distant zones, protects genetic diversity of stocks, and serves as a site for research on natural mortality rates and environmental carrying capacity (Davis 1977).

The effectiveness of multispecies harvest refugia in marine fisheries has not yet been well tested (Johannes 1978), but evidence from coral reefs in the Philippines (Alcala 1981, 1988) and from a temperate ecosystem off the North Island of New Zealand (Jeff 1988) provides encouragement that such refugia may be extremely effective fishery enhancement tools. In the Philippines, eight small areas, ranging in size from 8 ha to 10,000 ha, were excluded from fishery harvest for varying periods of time (3 to 10 years). The area with the longest period of protective management, a 750-m-long segment of reef on the west side of Sumilon Island, was closed to all forms of fishing in 1974. Mean harvest rate for local fishermen was 0.8 kg man-day^{-1} before the closure. Within two years, the mean harvest rate from areas adjacent to the closed zone had tripled, and over a 5-year period the sustained yield of fish per unit area from the adjacent zones was one of the highest reported for any coral reef in the world, 16.5–24 MT $km^{-2}yr^{-1}$ (Alcala 1981; Russ 1987). After 10 years without harvest in this reserve area, fishermen began violating the reserve boundaries; within 2 years, fishery yields in entire area had declined more than 50% (Alcala 1988).

Harvest has been prohibited in the 547-ha Leigh Marine Reserve in New Zealand for 11 years. Not only have lobster and fish populations in the reserve increased to 2.5 to 20 times the densities in similar adjacent habitat, but both recreational and commercial fishers believe the reserve has increased their catches in adjacent areas. The reserve is also immensely popular with tourists (Jeff 1988). In spite of these successes, the small size of the closed area at Sumilon Island, the short duration of protective management at the other Philippine reefs, and the lack of conclusive fishery yield data from areas adjacent to the Leigh Marine Reserve require caution in interpreting these results as a definitive test of the efficacy of multispecies harvest refugia.

Of the more than one hundred national, state, and city marine parks and reserves in California, only four prohibit all fishery harvest and may thus have the potential to increase fishery production in adjacent areas. They are the Point Lobos Ecological Reserve in Monterey County, the landing cove portion of the Anacapa Ecological Reserve in Ventura County, Heisler Park Ecological Reserve in Orange County, and the San Diego-La Jolla Ecological Reserve in San Diego County. Most of these are so small that any positive effect on adjacent fisheries would be virtually undetectable, even if harvest or population data were available for evaluation (Davis and Pillsbury 1983). The largest of these harvest-free areas at Point Lobos is the subject of a preliminary study focusing on a management strategy for rockfish, *Sebastes* spp., and appears promising as a fish-producing and fish-exporting zone (VenTresca and Lea 1987; J. Hardwick, pers. comm.). With appropriate harvest constraints, existing marine parks and ecological reserves in California could provide established management units suitable for evaluating optimum size and distribution of harvest refugia to maximize long-term sustained yields of nearshore fisheries. Additional areas could also be especially set aside for this purpose.

DESIGN CONSIDERATIONS FOR HARVEST REFUGIA

Enough is known to design experiments to test the efficacy of harvest refugia. These experiments must incorporate both ecological and sociopolitical factors in their design. Perhaps the most critical factors affecting the efficacy and social acceptance of harvest refugia are size and location. The refugia must be large enough to be productive, assure perpetuation of target species populations, and be easily patrolled. They must be small enough to optimize the boundary-to-volume ratio and assure maximum export of harvestable products (eggs, larvae, juveniles, and maybe also adults). They must be located at sites that contain suitable juvenile and adult habitat, while taking advantage of natural processes that will promote dispersal and recruitment to convenient harvest areas.

Initial experiments should focus on a few species, say 10–12, whose life histories and environmental requirements are relatively well known. Good candidates would be giant kelp, *Macrocystis pyrifera*; abalone, *Haliotis* spp.; California spiny lobster, *Panulirus interruptus*; sea urchin, *Stongylocentrotus franciscanus*; kelp bass, *Paralabrax clathratus*; California sheephead, *Semicossyphus pulcher*; Pacific angel shark, *Squatina californica*; California halibut, *Paralichthys californicus*; and several rockfish such as copper, *Sebastes caurinus*, gopher, *S. carnatus*, vermilion, *S. miniatus*, blue, *S. mystinus*, and olive, *S. serranoides*. These species also have high potential for recreational and commercial fisheries.

Experimental design should deal with factors such as daily and seasonal migration patterns, the lengths and mobilities of larval stages, and the effects of natural processes such as currents, upwelling, storms, and El Niño events. Optimum refuge design will probably require compromises among the ecological requirements of several species, and empirical evidence should be gathered and applied to assure that the most valuable resources are not threatened by such compromises. Experimental controls for such large-scale social and ecological research units are difficult to design in space, and are best evaluated over time, but not simply as before-and-after studies (Green 1979). Definitive answers to the design questions will probably require many years of observation, but the actual time will depend on the various life-history characteristics of the target species, including annual variations in reproduction, recruitment, and mortality, and natural environmental cycles like El Niño events.

It is clear that, to be successful, this research must be transdisciplinary and socially acceptable to a broad constituency, including conservationists and recreational fishermen as well as fisheries scientists and commercial fishermen. The fishing community must be involved in the experimental design from the beginning to allow for selection of acceptable harvest zones and adjacent refugia. The boundaries between zones must be recognizable and enforceable. Existing marine parks and reserves represent most regions of the coast, and they already have established boundaries and law enforcement staffs to augment patrol activities. Zoning use, as opposed to seasons and size restrictions, would require a new approach to law enforcement (remember Machiavelli's warning). The prevailing philosophy is thus to "put all your eggs in one basket, and *watch* the basket." Watching the basket becomes even more important than it was under the traditional approach.

Zoning of uses is a viable approach to marine fisheries management that deserves serious evaluation in California in the late twentieth century. It has the potential of increasing consistent sustained harvests. It may allow reduced regulations and thus simplify enforcement and compliance. It may also allow dynamic market forces to optimize harvest sizes and seasons, and may permit those same forces to drive development of more efficient nondestructive fishing gear.

CONCLUSIONS

Historical records and the present condition of many nearshore California fisheries suggest that many of these stocks could sustain higher yields. Harvest refugia offer a promising new management strategy for many of these fisheries. Large-scale, long-term ecological research is needed to determine the optimum design of a harvest refugia system that will assure long-term maximum resource productivity. Existing marine parks and reserves meet many of the design criteria for conducting this research, and could be used effectively in initially developing a productive new approach to managing California's coastal fisheries.

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