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MARINE HARVEST REFUGIA FOR WEST COAST ROCKFISH: A WORKSHOP

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MARINE HARVEST REFUGIA FOR WEST COAST ROCKFISH
A Workshop

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Marine Harvest Refugia for West Coast Rockfish: An Introduction to the Workshop

Mary M. Yoklavich, NMFS, Southwest Fisheries Science Center, Pacific Fisheries Environmental Lab, Pacific Grove, CA

> *"The initial opportunity to take advantage of the unique life-history features of rockfishes has been missed. Many stocks of rockfishes have undergone severe depletion, and we have seen few, if any, results of management actions. A concerted effort is now required to reverse the process of depletion and generate management and monitoring programs more appropriate to the biology of these species."* B.M. Leaman (1991)

Our multi-species rockfish (*Sebastes* spp.) resources have been among the most economically valuable commercial and recreational fisheries along the west coast of North America for the last two decades. Historically they represent a mainstay of many coastal communities. For instance, many of the 59 species of rockfish in California waters have been commercially harvested from as early as 1875 (Phillips 1957, Lenarz 1987). Various types of gear have been used (e.g. hook and line, gill net, and trawl), but trawling with large mid-water and bottom nets has yielded the largest catches of rockfishes. Several stocks of rockfish have been the target of intense fishing pressure from both domestic and foreign trawl fleets since trawl gear was introduced in the 1950s.

After rockfish landings peaked dramatically in the mid-1970s to mid-1980s, exploitation rates have remained high and population biomass and size composition have decreased alarmingly for many individual species, and indeed for rockfish populations in general. Following overfishing in the 1960's, there is still little sign of recovery of Pacific ocean perch rockfish stocks in the northwest (Ianelli et al. 1995). New stock assessments indicate significant declines (i.e. at or below 20% of that estimated in 1970) in biomass for three other rockfish species as well (Ralston 1998). Bocaccio rockfishes recently have been considered a candidate for IUCN's (World Conservation Union) Red List of "critically endangered" species. While these declines likely are due to natural variability in the marine environment and resultant survival of young fish, as well as overexploitation, it is clear that traditional management efforts alone are not successfully protecting and sustaining coastal rockfish resources.

Rockfishes are tremendously diverse (about 102 species worldwide and at least 72 species in the northeastern Pacific [Kendall 1991]), and can dominate coastal benthic habitats from subtidal kelp forests to rock outcrops in submarine canyons at depths greater than 300 m. Many species of rockfishes are slow-growing, long-lived (50-140 yrs; Archibald et al. 1981), and mature at older ages (6-12 yrs; Wyllie Echeverria 1987). Survival and subsequent recruitment of young rockfishes vary widely from year to year

(Ralston and Howard 1995). Because of these life history characteristics, as well as the sedentary and aggregating life styles of many species, local stocks of rockfishes are particularly vulnerable to overexploitation.

As local nearshore stocks become depleted, fishing fleets expand their range to greater distances from port and into deeper waters (Karpov et al. 1995, Mason 1995). This trend is prevalent in many coastal fisheries, and creates difficulties in management based on catch statistics. Fishery managers have long thought the remote parts of the coast served as a buffer against overfishing, but are now concerned that fishing regulations alone may not prevent stock depletion. The most recent cause for concern is generated from the very effective (and as yet to be managed) commercial live-fish fishery being conducted in very shallow water (often < 10 m) from small skiffs launched from shore. From its inception in southern and central California, this fishery has grown exponentially in number of fishers and vessels over the last eight years; catch of live rockfishes has increased four-fold during this time (T. Barnes, CA Dept. Fish and Game, La Jolla, unpubl. data). This fishery continues to expand northward.

With increased fishing effort on stocks as yet experiencing little exploitation, it becomes all the more critical to evaluate the function and effectiveness of harvest refugia (aka marine protected areas; reserves; no-take zones) as viable management alternatives. Rowley (1992) suggested that harvest refugia can be most beneficial to species that have been overfished, reach great sizes or ages, and have limited movements or sedentary behavior, all of which apply to coastwide rockfish stocks.

Marine harvest refugia are being promoted worldwide as a viable option for resource managers to mitigate overfishing and the impacts of fishing activities to seafloor habitats. Refugia potentially can conserve and enhance fish populations by (1) increasing fish abundance, size and age composition; (2) protecting critical spawning stocks; (3) providing multi-species protection; and (4) providing undisturbed areas for research on fishery-related problems. Aside from protecting and enhancing fishery resources, harvest refugia also can contribute to preservation and maintenance of the natural diversity of individual species, genotypes, and habitats. Marine fisheries have been identified as one of the most critical environmental threats to biodiversity (Boehlert 1996). Although harvest refugia are now being considered as a supplement to traditional resource management, their effectiveness in fisheries management is poorly understood and refugia concepts, especially as they relate to temperate marine systems, largely are untested.

A workshop, sponsored by the National Marine Fisheries Service (NMFS) Office of Protected Resources, was convened at NOAA's Pacific Fisheries Environmental Laboratory in Pacific Grove, California on September 17-19, 1997 to evaluate marine harvest refugia to manage, protect, and conserve rockfish populations on the west coast of North America. The objectives of the workshop were to i) assess the current and future needs, benefits, and implementation of harvest refugia to protect and manage rockfish populations, and ii) develop recommendations for establishing and monitoring rockfish refugia on the west coast of North America.

The workshop brought together thirty-seven biologists, ecologists, social scientists, economists, and resource managers, representing federal and state agencies from Alaska to California, as well as academic interests from relevant institutes to address the following kinds of questions:

- What are key problems in managing rockfish populations?
- Can marine harvest refugia help to manage and conserve rockfish populations?
- What can we expect from marine harvest refugia?
- What are the costs, benefits, and risks involved in establishing harvest refugia?
- What are the design considerations for effective harvest refugia?
- Who are the stakeholders interested in the process of developing and implementing refugia?
- What are the requirements and considerations of these stakeholders?

The workshop agenda included fourteen plenary papers. Fisheries scientists presented information on the status of rockfish stocks and current management practices; ecologists and biologists described key elements of refugia design, both from conceptual models and practical experience; a marine policy analyst addressed the process of establishing refugia; and a representative from NMFS's division of law enforcement focused on compliance issues associated with closed areas. The plenary session also included several case histories of closed areas.

This information provided an ideal background for further discussions and generation of ideas and recommendations. Three concurrent working groups focused on issues related to:

- Benefits and Expectations of Refugia as a Fishery Management Tool
- Science-based Design Considerations
- Socio-economic Considerations and Implementation of Refugia.

There was general consensus that marine harvest refugia exemplify a precautionary approach to the management and conservation of rockfish resources on the west coast. It was recognized 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. 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.

This proceedings of the workshop, including papers on plenary presentations, related case histories of harvest refugia that have been established around the country, and the recommendations from the working groups, hopefully will serve to direct future research and managerial decisions regarding protection and conservation of rockfish resources, as well as to make specific recommendations on design attributes of refugia. It is clear that successful implementation of an effective system of refugia requires an ecosystem rather than single-species approach to protection. While this workshop was focused on west coast rockfish resources, the conclusions and recommendations will find broader application to developing harvest refugia, biodiversity, and habitat programs nationwide. This workshop has taken a proactive approach in addressing several critical elements of the NOAA Fisheries Strategic Plan (e.g. Build Sustainable Fisheries; Maintain Coastal Ecosystem Health; and Recover Protected Species [NOAA 1997]), is relevant to NOAA's responsibilities for coastal ecosystem and living marine resources, and offers ways to protect and conserve essential fish habitat and implement ecosystem principles in fisheries management.

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Otter trawl catch of bocaccio and chilipepper rockfish off central California, 1957. Photo by J.B. Phillips, CDF&G.

The Status of Federally Managed Rockfish on the U. S. West Coast

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Introduction

The harvest of rockfishes (genus *Sebastes)* represents a very important component of the United States west coast groundfish fishery. In 1995 reported landings from that sector of the fishery accounted for almost 22,000 mt and generated ex-vessel revenues of $20.5 million (Silverthorne 1996). Those totals represented 16% and 24% of combined groundfish landings and ex-vessel revenues, respectively. The rockfish harvest has, moreover, been of even greater significance historically, accounting for 30% and 32% of landings and revenues in 1990. Finally, it is important to recognize that the combined rockfish catch is composed of many different species. The groundfish Fishery Management Plan (FMP) lists 52 *Sebastes* species in the groundfish management unit (Table 1; Pacific Fishery Management Council 1993).

Due to the importance of *Sebastes* species in the groundfish fishery, the Pacific Fishery Management Council (PFMC) has actively managed the rockfish complex for many years (PFMC 1997). The purpose of this contribution is to briefly review the current management practices of the PFMC vis-à-vis the rockfish complex, and to describe trends in population biomass and spawning output for some of the better studied species.

The Current Management Regime

Management practices have evolved over time and regulations often vary with areas fished. In addition, in situations where sufficient information exists, regulations are likely to be promulgated for individual species. Conversely, where data are sparse or lacking altogether, the various species of *Sebastes* may be pooled into larger aggregates within the complex. Widow rockfish (*Sebastes entomelas*) provides a good example of PFMC management of a species for which data are plentiful. Primary harvest regulations for any particular species of rockfish are based upon the results of a stock assessment conducted for the PFMC by a fishery analyst (e.g. Ralston and Pearson 1997). Because rockfishes typically grow slowly and stocks are comprised of many age classes, stock biomass typically does not change rapidly (Gunderson 1997). Consequently, stock assessments of the principal rockfish species are usually conducted only once every three years. The main goal of a stock assessment is to estimate exploitable biomass of the stock in the year of the assessment and to project the population forward for the next three years under a specific harvest policy. For a number of years the Stock Synthesis model (Methot 1990) has been used in PFMC assessments to develop the best reconstruction of historical stock dynamics and to estimate population size in the near future. Stock Synthesis is a

Table 1. Species of rockfish in the groundfish FMP. Note that species in bold typeface have recently been assessed with the Stock Synthesis model and published estimates of population trajectory are available. Rockfishes evaluated in Rogers et al. (1996) were assessed through a static calculation that was based upon the $F_{msy} = M$ approximation, which was applied to adjusted swept-area trawl survey biomasses.

	Scientific Name	Common Name	Assessment Author(s)
1.	*Sebastes aleutianus*	rougheye rockfish	--
2.	***Sebastes alutus***	**Pacific ocean perch**	Ianelli et al. 1995
3.	*Sebastes atrovirens*	kelp rockfish	--
4.	*Sebastes auriculatus*	brown rockfish	--
5.	*Sebastes aurora*	aurora rockfish	--
6.	*Sebastes babcocki*	redbanded rockfish	--
7.	*Sebastes borealis*	shortraker rockfish	--
8.	*Sebastes brevispinis*	silvergray rockfish	Rogers et al. 1996
9.	*Sebastes carnatus*	gopher rockfish	--
10.	*Sebastes caurinus*	copper rockfish	--
11.	*Sebastes chlorostictus*	greenspotted rockfish	--
12.	*Sebastes chrysomelas*	black and yellow rockfish	--
13.	*Sebastes ciliatus*	dusky rockfish	--
14.	*Sebastes constellatus*	starry rockfish	--
15.	*Sebastes crameri*	darkblotched rockfish	Rogers et al. 1996
16.	*Sebastes dallii*	calico rockfish	--
17.	*Sebastes diploproa*	splitnose rockfish	Rogers et al. 1996
18.	*Sebastes elongatus*	greenstriped rockfish	--
19.	***Sebastes entomelas***	**widow rockfish**	Ralston & Pearson 1997
20.	*Sebastes eos*	pink rockfish	--
21.	***Sebastes flavidus***	**yellowtail rockfish**	Tagart et al. 1997
22.	***Sebastes goodei***	**chilipepper**	Rogers & Bence 1993
23.	*Sebastes gilli*	bronze spotted rockfish	--
24.	*Sebastes helvomaculatus*	rosethorn rockfish	--
25.	*Sebastes hopkinsi*	squarespot rockfish	--
26.	*Sebastes jordani*	shortbelly rockfish	Pearson et al. 1991
27.	*Sebastes levis*	cowcod	--
28.	*Sebastes maliger*	quillback rockfish	--
29.	***Sebastes melanops***	**black rockfish**	Wallace & Tagart 1994
30.	*Sebastes melanostomus*	blackgill rockfish	--
31.	*Sebastes macdonaldi*	mexican rockfish	--
32.	*Sebastes miniatus*	vermilion rockfish	--
33.	*Sebastes mystinus*	blue rockfish	--
34.	*Sebastes nebulosus*	china rockfish	--
35.	*Sebastes nigrocinctus*	tiger rockfish	--
36.	*Sebastes ovalis*	speckled rockfish	--
37.	***Sebastes paucispinis***	**bocaccio**	Ralston et al. 1996
38.	***Sebastes pinniger***	**canary rockfish**	Sampson 1996
39.	*Sebastes proriger*	redstripe rockfish	Rogers et al. 1996
40.	*Sebastes rastrelliger*	grass rockfish	--
41.	*Sebastes reedi*	yellowmouth rockfish	Rogers et al. 1996
42.	*Sebastes rosaceus*	rosy rockfish	--
43.	*Sebastes rosenblatti*	greenblotched rockfish	--
44.	*Sebastes ruberrimus*	yelloweye rockfish	Rogers et al. 1996
45.	*Sebastes rubrivinctus*	flag rockfish	--
46.	*Sebastes rufus*	bank rockfish	Rogers et al. 1996
47.	*Sebastes saxicola*	stripetail rockfish	--
48.	*Sebastes serranoides*	olive rockfish	--
49.	*Sebastes serriceps*	treefish	--
50.	*Sebastes umbrosus*	honeycomb rockfish	--
51.	*Sebastes variegatus*	harlequin rockfish	--
52.	*Sebastes zacentrus*	sharpchin rockfish	Rogers et al. 1996

model with separable time and age fishing mortality components that projects a simulated population forward in time. The separability aspect of the model means that, at least in its most basic configuration, the relative exploitation pattern of a fishery on the different age classes in a stock is modeled so that the pattern does not change from year to year. Even so, that simplification can be relaxed to allow for a changing exploitation pattern over time. Likewise, any particular stock assessment is based upon a maximum likelihood fit of the model to observed age and length frequency data, which are typically modeled with a realistic multinomial error structure. Auxiliary data are easily incorporated into the fitting procedure, and many other features of the model provide great flexibility to the analyst in creating a simulated population that possesses the most important characteristics and features of the actual stock.

Once a plausible trajectory of population biomass has been determined, based upon the joint and simultaneous analysis of all available data, the analyst projects the population forward under several harvest policies. The current policy favored by the PFMC for rockfish is a constant rate harvest at $F_{40\%}$. That policy is defined as the fishing mortality rate that reduces the spawning potential per recruit (SPR) to 40% of the unfished condition (Clark 1991, 1993). The Allowable Biological Catch (ABC) is then calculated by application of the $F_{40\%}$ fishing mortality rate to the model's estimate of exploitable biomass. The average yield over the three-year projection horizon is the estimated ABC.

Although the Stock Synthesis model provides a very powerful tool in assessing the status of rockfish stocks, for certain species it is not unusual for age and/or length frequency data to be sparse or missing altogether. Even determining the catch of the minor rockfish species can present huge problems in sampling the landings at commercial ports. In those situations a simpler approach has been taken, wherein the ABC is estimated using the $F_{msy} = M$ approach (Deriso 1982). That calculation assumes that the rate of natural mortality experienced by a stock (M) is a reasonable estimator of the fishing mortality rate that will produce maximum sustainable yield (F_{msy}). Triennial bottom trawl research surveys have been conducted by the Alaska Fisheries Science Center (AFSC) along the U.S. west coast since 1977 (Wilkins 1996). Stock biomass of the minor rockfish species has been estimated using those data and a swept-area calculation, with biomass adjusted for the catchability of the net and the completeness of survey coverage (Rogers et al. 1996). The ABC is then calculated as the product of adjusted swept-area biomass and an estimate of the natural mortality rate (M). Regardless of how it is estimated, once the ABC is determined the analyst's role in the management process is largely concluded.

The next step in the process is to convert the ABC to a Harvest Guideline (HG), which is equivalent to a Total Allowable Catch (TAC) or annual quota. The Groundfish Management Team (GMT) is a subsidiary body of the PFMC that receives the results of the stock assessment and prepares preliminary HG recommendations, which can be greater or less than the ABC. At this point in the process, estimated discards at sea are usually taken into consideration, as well as any other mitigating circumstances that would warrant altering the HG from the ABC. The Council receives the report of the GMT, with comments by its other advisory bodies (i.e. the Scientific and Statistical Committee, the Groundfish Advisory Panel, and the public), and sets the final ABC and HG by vote. The final HG is then apportioned between the limited entry and open access sectors of the fishery, which have fixed percentage allocations of the catch. To fish in the limited entry fishery, an operator needs a limited entry permit; these are "limited" in number and are bought and sold on the open market. However, with certain restrictions on gear, anyone can fish in the open access sector, although the percentage allocation of fish to that sector is quite small. These two fisheries are then managed using in-season actions to insure that (1) the annual HG is not exceeded and (2) there is a year-round opportunity to fish.

To accomplish the latter goal, the GMT examines overall fleet harvest rates and participation levels during the preceding three years and derives bimonthly cumulative catch limits that cannot be exceeded by limited entry fishermen. Open access fishermen have individual trip limits on catch applied to their landings to control the overall fleet harvest rate. As with the ABC and HG, the GMT's trip limit recommendations are reviewed by the Council and its advisory bodies before they are approved. Once established, the GMT then monitors cumulative landings as the year progresses and makes recommendations to adjust these bimonthly cumulative catch limits and trip limits up or down to suppress or accelerate the rate of landings. A major problem with this particular management procedure is the creation of management-induced discarding of species with low bimonthly cumulative limits.

Numerous other restrictions apply to commercial fishermen. These include, but are not limited to: (1) area management of species-specific in-season limits, (2) minimum mesh size requirements for trawl gear, (3) limitations on the transferral of limited entry permits, (4) linkage between fishing vessel size and permit class, (5) logbook reporting requirements, and (6) requirements to land only fish for which there was a specific market order.

In addition to widow rockfish, four other rockfishes are routinely managed in this manner, including Pacific ocean perch (*Sebastes alutus*), yellowtail rockfish (*Sebastes flavidus*), bocaccio (*Sebastes paucispinis*), and canary rockfish (*Sebastes pinniger*) (Table 1). Note that, while chilipepper (*Sebastes goodei*) and black rockfish (*Sebastes melanops*) have recently been assessed using the Stock Synthesis model, the ABCs of those species are currently consolidated within the overall *Sebastes* complex HG, which is the sum of the ABCs of the remaining rockfish. Clearly the management of rockfishes by the PFMC is quite complicated.

The Status of Rockfish Resources

In this section the status of seven of the major commercial rockfish species is briefly reviewed. Each was assessed for the PFMC within the last five years using the Stock Synthesis model or a similar approach (Table 1). Therefore, as a group, these species represent our best composite view of the overall status of federally managed rockfish on the U. S. west coast.

Widow Rockfish. In a recent stock assessment Ralston and Pearson (1997) described four distinct widow rockfish fisheries and modeled them over a time period that extended from 1970-97. Their approach emphasized an annual time varying component in the selectivity curve of each fishery (i.e. the strict separability assumption was relaxed), although the exploitation pattern among the three northern fisheries was linked. The purely age-based version of the Stock Synthesis model was used, and the incorporated auxiliary data sources included a logbook CPUE index, a bycatch index of widow rockfish in the Pacific hake fishery, and a survey index of pre-recruit abundance. The assessment indicated that widow rockfish total biomass (i.e. age 1+ fish) reached a maximum in 1973 due to the recruitment of a very strong 1970 year-class (Fig. 1). As expected, maximum spawning output lagged somewhat and peaked in 1978. Both population indicators have since declined, with total biomass currently believed to be 33% of its 1973 maximum and spawning output equal to 22% of its apex in 1978. Based on the assessment the HG of widow rockfish in 1998 was reduced from 6,500 to 4,300 mt (PFMC 1997).

Bocaccio. This species was last assessed by Ralston et al. (1996) and, like widow rockfish, four unique bocaccio fisheries were identified, including a significant recreational sector. For the assessment the length-based implementation of Stock Synthesis model was used, due to the availability of extensive and highly informative length-frequency data. Also, the selectivity curve was allowed to vary across years in two of the modeled fisheries. Auxiliary data sources included CPUE and length frequency data from the AFSC triennial shelf trawl survey, a Southwest Fisheries Science Center midwater trawl survey index of pre-recruit abundance, and a California Cooperative Oceanic Fisheries Investigation larval index used to track spawning output.

Results of the assessment showed that the bocaccio stock has undergone a severe decline in abundance (Fig. 1). The population, both in terms of total age 1+ biomass and spawning output, was at its maximum at the beginning of the modeled time period (1969-96). By 1996, however, total biomass and spawning output had fallen to 8% and 6% of their starting values, respectively, even though a strong 1977 year-class temporarily reversed the decline. No other federally managed species of rockfish is thought to be at such a relatively low level of abundance. In 1996 the PFMC reduced the bocaccio ABC from 1,700 to 265 mt, and it was further reduced to 230 mt in 1997 (PFMC 1997).

Pacific Ocean Perch. Pacific ocean perch (a.k.a. POP) is a rockfish species that was last assessed by Ianelli et al. (1995). They recognized two separate POP fisheries, i.e. the foreign fishery, which was responsible for large-scale removals during the mid-1960s but persisted until the mid-1970s, and a domestic fishery that has been relatively stable in comparison. Fishery-dependent data used in the stock assessment included age composition data based on surface and

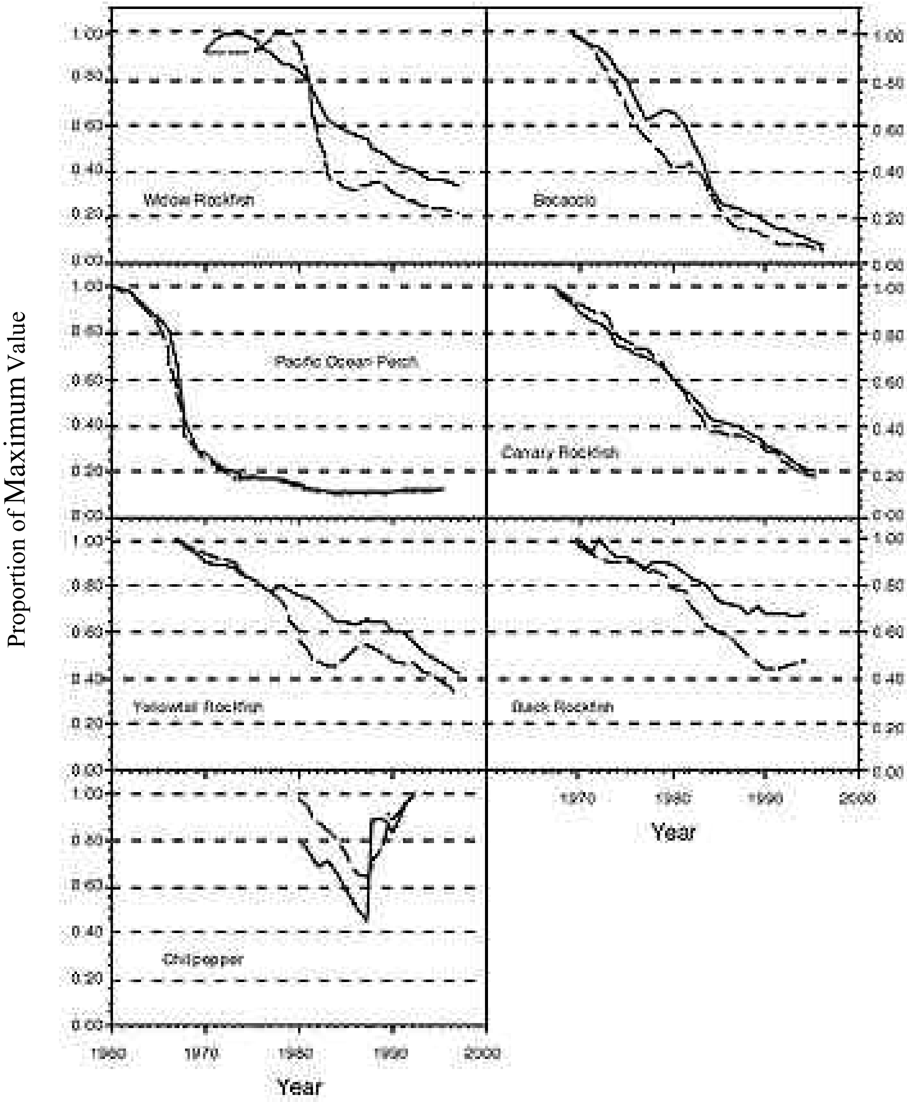

Figure 1. Trends in exploitable biomass (solid lines) and spawning output (dashed lines) for seven west coast rockfish stocks.

broken-and-burned otolith readings, size-frequency distributions, and a CPUE statistic developed from commercial catch rates. Fishery-independent data that were employed included estimates of biomass from the AFSC triennial shelf trawl survey and a dedicated POP survey, in addition to age and size composition information from both surveys.

Ianelli et al. (1995) showed that the POP stock experienced a precipitous decline during the 1960s due to massive foreign removals (e.g. 33,000 mt in 1967). Total age 5+ biomass and spawning output were at their maxima at the beginning of the modeled era (1960-95) and each population indicator declined to less than 20% by 1975 (Fig. 1).

The stock has remained depressed since that time, with biomass and reproduction currently estimated to be 13% of their all time highs. The PFMC has a zero ABC for POP, although the 1998 HG is 750 mt to allow for incidental landings of Pacific ocean perch bycatch from trawl fisheries for canary and other slope dwelling rockfish (PFMC 1997).

Canary Rockfish. Sampson (1996) conducted the last stock assessment of canary rockfish. He used a split-sex implementation of the age-based version of Stock Synthesis to model the two commercial trawl fisheries off Washington and Oregon. The only supplementary fishery-independent information that was incorporated in the assessment was the AFSC triennial shelf survey estimates of swept-area biomass and length-frequency data from the survey. Model specification issues resulted in a significant source of uncertainty in the assessment, particularly the assumption of constant natural mortality rate of recruited female fish. To adequately portray this uncertainty, Sampson (1996) provided model results under two different mortality scenarios.

Results of the assessment (Fig. 1) showed that, like other *Sebastes* species, canary rockfish have experienced a major long-term decline in abundance over the period 1967-95. The total biomass of age 3+ fish was greatest in the first year of the population simulation and had declined to 20% of its apex by 1995. Similarly, spawning output declined to 18% of its maximum value in the final year of the modeled period. Sampson (1996) concluded that canary rockfish had been overfished in recent years because removals exceeded projected catches at the $F_{20\%}$ rate. The current ABC of canary rockfish in the northern area (i.e. the Columbia and U. S. Vancouver International North Pacific Fisheries Commission statistical areas) is slightly more than 1,000 mt (PFMC 1997).

Yellowtail Rockfish. The stock(s) of yellowtail rockfish was very recently assessed by Tagart et al. (1997). Although those authors used the AD-Model Builder software to perform calculations (Fournier 1996), their population dynamics equations, error structures, and model building philosophy were identical to those used in the Stock Synthesis model. The assessment was rather sophisticated in its treatment of time-varying selectivity and in the way error estimates were produced. It was also tiered to determine the effect of stratifying the analysis to one, two, or three different stocks. Primary data in the simulation were landings and catch-at-age data, but three auxiliary data sources were incorporated in the model. These included the AFSC shelf trawl survey estimate of biomass, a CPUE statistic based on the analysis of commercial logbook data, and an index of abundance calculated from the incidence of yellowtail rockfish in the at-sea Pacific hake fishery.

The population was simulated over the period 1967-97 and results of the analysis showed a steady, long-term decline in abundance (Fig. 1). The total biomass of age 4+ fish is now thought to be 43% of the all-time high that occurred in 1967, while spawning output has fallen to 33% of its maximum. Although these specific results were forwarded to the GMT and PFMC for use in setting of the 1998 ABC and HG, the authors also developed other models that suggested even more serious declines in stock abundance have occurred. For 1998 the ABC of yellowtail rockfish in the northern area is 4,657 mt (PFMC 1997).

Black Rockfish. Relative to the species discussed thus far, black rockfish is less significant in terms of total landings, but it is a very important recreational species in Oregon and Washington and displays a more inshore distribution. With concerns about the stock expressed by sport fishing operators, the first assessment of this species was completed by Wallace and Tagart (1994). In their analysis they used the age-based version of Stock Synthesis and applied it to three distinct black rockfish fisheries, i.e. the trawl, jig, and recreational. Auxiliary data used in the analysis included a CPUE statistic from tagging survey results, tagging survey size composition data, and a measure of recreational fishing effort.

The stock assessment indicated that since 1970, black rockfish has been in a general state of decline (Fig. 1). Over the modeled time period (1970-94) the total biomass of age 4+ fish has currently declined to 68% of its apex; reproductive output has fallen even more, to 48% of the maximum. There is no specific HG for black rockfish and its ABC is aggregated in to the "remaining rockfish" total ABC (Rogers et al. 1996).

Chilipepper. Rogers and Bence (1993) conducted the last stock assessment of chilipepper. They used the length-based implementation of Stock Synthesis and applied it to four discrete fisheries, i.e. trawl, setnet, hook-and-line, and recreational. Auxiliary data sources used in the simulation modeling included AFSC triennial shelf trawl survey biomass estimates and length frequency data, as well as a time series of recreational fishing effort.

Results for chilipepper are quite unlike the preceding six species. The assessment indicated that over the relatively short time horizon of the model (1980-92), the total biomass of age 4+ chilipepper actually increased and was at its apex in the last year of the simulation; spawning output followed virtually the same temporal pattern (Fig. 1). Both of these population trends were due entirely to the recruitment of a very strong 1984 year-class that was estimated to be six times greater than the mean over the 1980-92 interval.

Conclusions

This brief review of the status of U. S. west coast rockfish stocks presents a fairly alarming picture. For example, the spawning output of bocaccio, Pacific ocean perch, canary, and widow rockfish are at or below 20% of their maximal levels (Fig. 1). Moreover, five of the seven species reviewed show no indication of coming to an equilibrium under the fishing mortality rates they have experienced (i.e. bocaccio, widow, canary, yellowtail, and black rockfish). It is apparent that, for these rockfish species, harvests have been largely based on the "fishing-up" of stocks that had accumulated their standing stock biomass over a considerable length of time (see Leaman and Beamish 1984). This mode of harvest is equivalent to mining a resource and is clearly not a sustainable practice in the long run.

It is important to note, however, that significant change is in store for the management of rockfish by the PFMC. With the implementation of the new national Sustainable Fisheries Act in 1997 (Public Law 104-297), there are now specific requirements to curtail fishing pressure and institute a rebuilding plan when biomass thresholds are exceeded. Prior PFMC management of rockfish was based simply on a constant rate SPR policy (either $F_{35\%}$ or $F_{40\%}$) that was applied to whatever exploitable biomass was believed to be available for harvest (Hightower and Lenarz 1989). The new guidelines require that if the biomass of a stock falls below B_{MSY} (i.e. the biomass that produces Maximum Sustainable Yield), then action must be taken to return the population to that level.

How those B_{MSY} levels will be defined for rockfish remains to be determined. Overfishing of rockfish stocks was previously defined by the PFMC as catches in excess of those obtained at an $F_{20\%}$ rate. The connection between SPR and spawning output is not direct, however, but depends critically on the compensatory response of the spawner-recruit curve. For example, spawning output below 20% of “virgin” may not be excessive if recruitment compensation is very high. The dilemma is that rockfish exhibit very erratic recruitment. That particular life history trait makes it quite difficult to determine the compensatory response without very long time series of data (Ianelli and Heifetz 1995).

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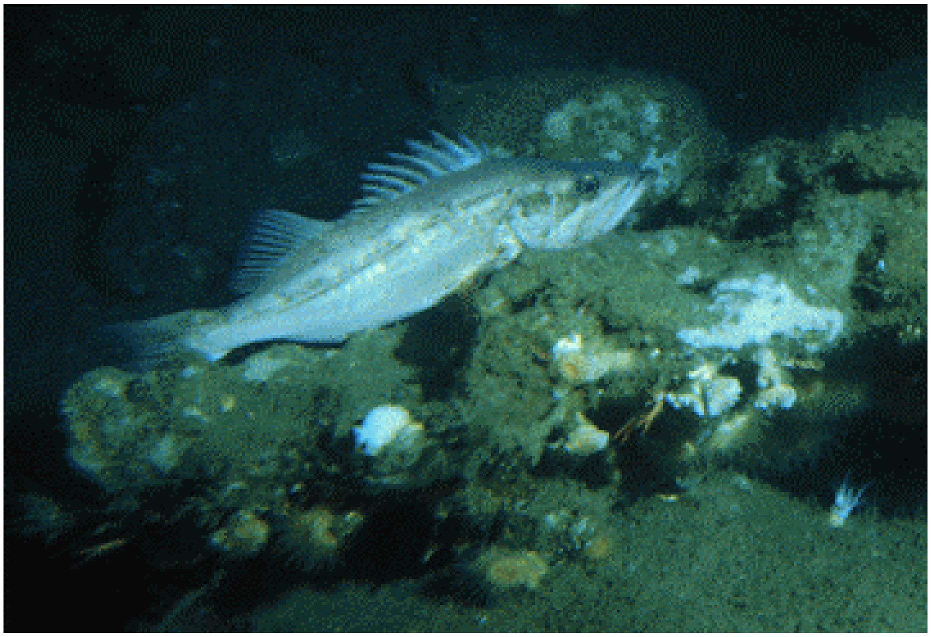

Bocaccio (*Sebastes paucispinis)* on rock outcrop viewed from the Delta submersible at 200 m in Ascension Canyon off the central California coast. Photo by M. Yoklavich

Experimental Rockfish Management and Implications for Rockfish Harvest Refugia

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Introduction

The precipitous declines of rockfish (genus *Sebastes*) fisheries off the west coast of North America during the 1960s and 1970s prompted remedial action by fishery management agencies in the United States and Canada (Lenarz 1987, Stocker and Leaman 1990). Despite stringent controls on harvests for some species, there was little indication of rehabilitation during the ensuing two decades. Recent stock assessments suggest that the situation for some stocks may have become even worse. Fishing mortality from solely domestic sources has been sufficient to both prevent rehabilitation and cause declines in previously abundant species. However, the commercial fishing industry and assessment biologists in management agencies often have vastly different views of the status of these stocks. This divergence is based in part on differences in indices used to monitor the status of the stocks by the two groups. Harvesters rely on their catch per unit of effort (CPUE) but CPUE is often hyperstable in the face of stock declines, due to rockfish aggregation. On the other hand, biologists may use complex population models that analyze many different data sets. To bridge this gap in perception of stock status, experimental harvesting programs involving industry and government were conducted off the west coast of Canada during the 1980s and 1990s. The results of these programs in terms of stock indices were reported in Leaman and Stanley (1993). I focus here on the lessons learned in the design and implementation of these programs and their implications concerning marine protected areas for rockfishes.

The two experiments were initiated on stocks of Pacific ocean perch (*Sebastes alutus*, POP; Fig. 1). Both stocks had been subjected to large foreign fisheries during the 1960s. One program (Vancouver Island) generated a specified overharvest over a limited period, while the other (Langara Spit) was to be an unlimited harvest over a specified period, followed by an equivalent period of no harvest.

Background

Analyses of the Vancouver Island stock by several investigators, using a variety of techniques, showed stock decreases ranging from 69-82% over the 1965-1977 period (Gunderson 1981, Kimura 1981, Kimura and Tagart 1982). Through a bilateral technical committee, Canada and the U.S. prohibited directed fishing on this stock in 1977, in an attempt to initiate rehabilitation. This regulation was in effect in both countries until 1980.

In 1979, British Columbia harvesters pressed for a re-opening of this area based on their acoustic observations of "large" aggregations of rockfishes. Canada Department of Fisheries and Oceans (DFO) biologists had no evidence from biological

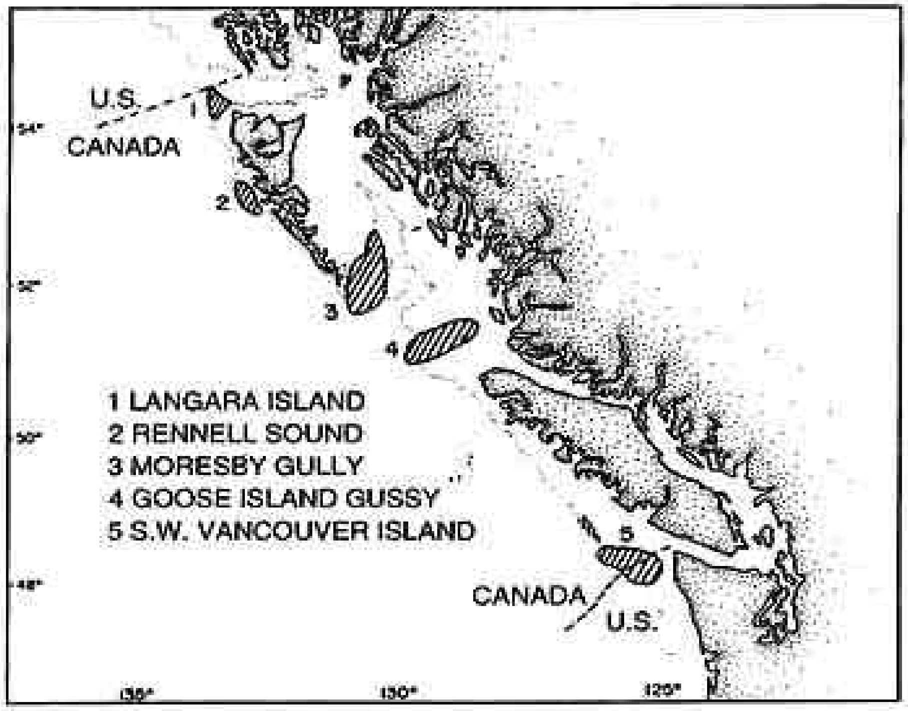

Figure 1. Locations of primary stocks of Pacific ocean perch off British Columbia.

sampling programs to suggest a major change in stock abundance since 1977 and suggested that, prior to 1977, the size of aggregations had been affected by fishing activity. Rockfishes aggregate naturally (Leaman et al. 1990), particularly when undisturbed by fishing. The lack of fishing activity on this stock during 1977-1979 may have contributed to the observations reported by the fleet.

The Langara Spit stock of POP was also the object of major foreign fisheries during the mid 1960s. Although these fisheries were documented poorly, analyses suggested approximately 85% of the foreign catches of rockfishes from the west coast of the Queen Charlotte Islands originated in the Langara Spit area. Unlike other POP stocks on the B.C. coast, this stock was not exploited by the domestic fleet during the major foreign fishery. Directed fishing by the domestic fleet began in 1979 and was restricted by quota until the fall of 1983. Catches of POP during this period averaged <250 mt/y.

Experimental Design

To address the impasse in perception of stock status, DFO proposed, after extensive internal discussions, an experimental overharvesting program in cooperation with industry. The experimental design for both areas called for comprehensive trawl surveys before and after the period of overharvesting. Swept-area surveys for aggregated species have several sources of potential bias (Byrne et al. 1981, Smith 1981, Smith 1990). Although the shortcomings of trawl surveys for aggregated species were acknowledged, the planning team for the experiment believed that some standardized measurement of relative abundance would be a valuable adjunct to fishery statistics and biological samples. For the Vancouver Island experiment, the period of overharvesting was proposed as three years, after which the quota would be returned to the sustainable level. The estimated sustainable yield for the Vancouver Island stock in 1980 was 300 mt (Stocker 1981). The proposed harvest of 500 mt was 67% greater than the estimated sustainable level.

For the Langara Spit experiment, the design called for unrestricted fishing bordered by periods of sustainable or conservative harvest, to obtain maximum contrast with the period of high fishing mortality. Therefore, the planning team agreed that the experiment would consist of two treatments: 3-5 y of unrestricted harvest, followed by an equivalent period of conservative harvest or closure.

The detailed objectives of both experiments were:

- to test the validity of trawl survey biomass estimates;
- to develop estimates of fishing mortality based on removals;
- to examine the stock-recruitment relationship relative to other stocks and to fishing mortality;
- to develop a detailed biological and fishery statistics database for use in analyses, e.g. fishing power estimation;
- to validate ageing techniques through the injection of a large negative anomaly in the age spectrum of the stock;
- to examine movements as they might be interpreted from micro-scale distribution of fishing effort; and
- to involve industry in both research and management programs.

A number of conditions, under which the experiments were to be conducted, were agreed upon and explicitly stated at the outset. These were:

- trawl surveys would precede and follow the experiment manipulations;
- industry would supply detailed logbook data (tow locations, durations and depths, species compositions, etc.) for their fishing in the areas; and
- in the case of the Langara experiment, the fishery would have to be closed for a period equivalent to the open period, after the unrestricted fishing portion of the experiment.

The arrangement between the DFO and industry as envisioned by the original experimental concept was to have ongoing contact between scientists, harvesters, and stock managers (Fig. 2). Harvesters would

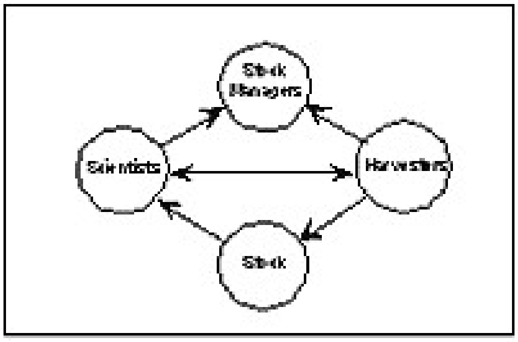

Figure 2. Relationship of participants in the experimental programs, as envisioned at the beginning of the programs.

impact the stock through fishing activities, scientists would communicate with harvesters and assess this impact, and both would communicate their views to and consult with stock managers.

Harvesting Interventions

The quota for the Vancouver Island stock was raised to 500 mt in 1980 and remained at that level until 1984. Although initially scheduled to last three years, the overharvesting experiment was extended an additional two years because both the 1980 and 1983 qualified catches were below the target quota (Table 1). All segments of the planning team agreed with this extension. Unstandardized catch rates for the Canadian fleet over the experimental period declined rapidly. CPUE was standardized by vessel tonnage class, which is linearly related to vessel horsepower, hence towing ability. The standard vessel class was the modal class for those vessels participating in the fishery. Estimates of this standardized CPUE also showed a general decline during the 1979-1985 period (Fig. 3a). Significantly, the variance of the CPUE also declined during the experiment,

Table 1. Canadian landing statistics for Pacific ocean perch (POP) in the Vancouver Island experimental fishing area, 1967-1990. Twenty-five percent Qualification Landing data are from those hauls where at least 25% of the catch was POP. This excludes hauls where POP was not the target.

YEAR	Total Landings	25% Qualification Landings (mt)	Effort (h)	CPUE (mt/h)
1967	7.02	6.83	14.50	0.471
1968	0.12	-	-	-
1969	2.49	1.26	12.50	0.101
1970	303.86	273.11	293.20	0.931
1971	218.38	200.82	400.70	0.501
1972	117.25	12.67	14.30	0.886
1973	-	-	-	-
1974	-	-	-	-
1975	5.46	1.46	7.00	0.209
1976	1.29	0.87	1.00	0.870
1977	16.17	8.81	46.30	0.190
1978	53.06	50.95	38.90	1.310
1979	124.86	121.03	85.70	1.412
1980	429.85	395.38	380.90	1.038
1981	547.32	504.96	709.80	0.711
1982	507.97	452.48	555.00	0.815
1983	751.52	325.23	411.10	0.791
1984	551.17	404.10	720.60	0.561
1985	243.11	195.86	692.70	0.283
1986	242.10	140.49	185.10	0.759
1987	542.27	394.80	460.60	0.857
1988	307.46	77.64	228.80	0.339
1989	279.16	146.47	426.00	0.345
1990	289.60	148.28	490.98	0.302

indicating that the infrequent large hauls of POP seen early in the experiment were largely absent by the end.

For the Langara Spit area, the quota was removed in 1983. Annual landings of total rockfishes increased steadily for the first three years of the experiment, to a peak of almost 5000 mt, before declining dramatically in 1987 (Leaman and Stanley 1993). Landings of POP followed suit with total rockfish landings (Table 2). Standardized CPUE for POP also declined dramatically for the fishery over the course of the experiment (Fig. 3b). However, the most striking aspect of the Langara Spit experiment was that the landings far exceeded even the most optimistic estimate of exploitable biomass derived from the previous trawl surveys.

Changes in the stock abundance indices for the Vancouver Island experiment were consistent with a significant decline in biomass. Relative biomass estimates from both Canadian and U.S. post-experiment surveys were lower by at least 50%. Catch rates in the Canadian commercial fishery were also substantially lower following experimental harvesting. In addition, the size frequency of POP in 1985 suggested a total mortality rate at least four times the optimum level. Standardized CPUE for Langara POP declined from 3.34 mt/h in 1984 to 0.89mt/h in 1990 (Fig. 3b). It accompanied a rise and fall in average total fishing effort per trip. Changes in the biological aspects of the population, including truncation of the age spectrum and high mortality rates on recruiting fish, were substantial and have been presented in greater detail in Leaman and Stanley (1993).

Table 2. Canadian landing statistics for Pacific ocean perch (POP) in the Langara Spit experimental fishing area, 1976-1990. Percent qualification is the percentage of POP in catch necessary for inclusion of data (see caption for Table 1).

YEAR	Total Landings	25% Qualification Landings (mt)	Effort (h)	CPUE (mt/h)
1976	-	-	-	-
1977	1.42	0.70	2.30	0.304
1978	22.22	6.65	16.80	0.396
1979	227.49	223.83	108.50	2.063
1980	84.56	64.80	39.50	1.641
1981	109.22	53.15	24.10	2.205
1982	342.23	194.18	109.30	1.777
1983	291.98	208.28	193.50	1.076
1984	2173.86	1779.38	980.00	1.816
1985	1921.21	1712.09	1514.50	1.130
1986	2725.37	2558.46	2319.30	1.103
1987	1129.70	1015.88	1119.60	0.907
1988	1088.79	1027.99	1373.60	0.748
1989	1532.50	1401.89	1574.40	0.890
1990	1162.00	1123.65	1336.09	0.841

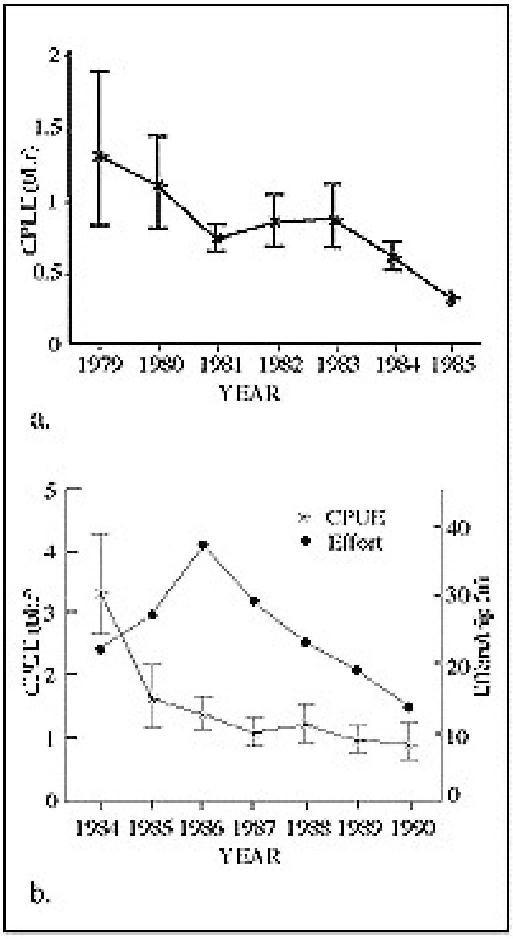

Figure 3. Standardized catch rates and 90% confidence intervals for Pacific ocean perch fisheries off southwest Vancouver Island (3a.) and Langara Spit (3b.), 1979-1985. The mean effort per fishing trip to the Langara Spit area is also presented in 3b.

Implementation Problems

The Vancouver Island experiment exhibited no serious implementation problems. Cooperation and data capture from harvesters were both acceptable. For the Langara Spit landings area, it was apparent even early in the experiment that the requirement for accurate reporting by vessels was not being met. There was strong evidence of mis-reporting of landings from elsewhere as originating from the experimental area. Indeed, industry has subsequently acknowledged that some data submitted prior to 1989-1990 were "unreliable".

Some vessel masters attempted to use a refusal to provide logbook information in 1984 as leverage to obtain concessions on rockfish quotas in other areas. Faced with this conflict, researchers recommended suspension of the experiment because one of the fundamental goals, data capture, was not being met (Leaman 1985). Managers also were concerned about these events but, rather than terminating the experiment, worked with industry to develop a compromise. A permit system was instituted which required detailed logbook data as a condition of the permit to fish in the area. However, the success of the compromise system required higher levels of surveillance than could be achieved with available resources.

The beginning of the second phase of the experimental design, closure, was scheduled for 1988. However, two factors made it difficult to implement this phase of the experiment. First, industry had come to depend on harvest levels achieved during the unrestricted fishing phase. Second, some harvesters were still able to obtain profitable trips from the area because of the aggregating behaviour of rockfishes and the lowered number of participants in the fishery. These individuals therefore argued for continuation of the experiment on the basis that little or no over-exploitation had been demonstrated. When other harvesters ceased fishing in the experimental area, they also ceased providing any data on the experiment. Lastly, the long lag in response of some stock indices to the effects of harvest, because of the late age at recruitment of rockfishes, meant that not all indices from the experiment presented a consistent picture of stock status.

The fishery was kept open for 1988-1989. The target level of desired effort was achieved in both years. Analyses of reliable data from the observer program implemented during these two years indicated noteworthy declines in some indices of stock status. Standardized CPUE for vessels previously suspected of non-compliance was only 76% of that for other vessels. These suspect vessels had reported CPUE well in excess of other vessels, during the period when observer verification was not required.

For 1991-1992 there was again debate about instituting the second phase of the experiment. Researchers, managers, and the primary industry advisory body to DFO recommended closure of the Langara Spit area. However, economic issues concerning fish plants and communities benefiting from the unrestricted harvest levels continued to play a role in the experiment. Harvesters who had been part of the original design team made direct entreaties to both politicians and senior DFO managers to keep the experimental area open. The researchers responsible for the design of the experiment were excluded from the discussions between these groups and a decision to extend the unrestricted harvest an additional two years was made. The original design now took on the appearance of Fig. 4. The area was finally closed in 1993.

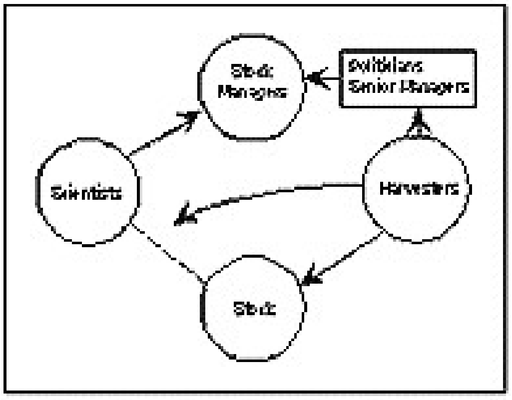

Figure 4. Relationship of participants in the experimental programs, as seen at the end of the Langara program. Actions by harvesters interfered with flow and interpretation of data for the stock. Industry also interacted with managers outside of the experimental framework

Discussion

A major result of these experiments is the finding that cooperative programs with industry can be frustrated or even destroyed by the actions of only a few individuals. When population responses to experimental manipulations are subtle, even small amounts of data contamination can significantly diminish the ability to interpret observations correctly. It was expected that industry would value the learning effects of the Langara Spit relationships of the participants from the experiment, since it directly addressed their concerns that researchers underestimated abundance and productivity. However, harvesters did not provide quality data consistently, and cooperating vessel masters did not appear to pressure non-cooperating masters to adhere to the experimental program.

Researchers failed to anticipate that the Langara Spit experiment would assume an economic life of its own. Once established, this experimental fishery came to be regarded as a necessary part of the groundfish industry. The landings also had a localized impact because the majority went to a single port.

Several strong lessons have emerged from these two programs:

1. There should be a clear statement of objectives at the outset. These objectives should be endorsed by all levels of participants.

2. Indices and criteria for evaluation of results also should be agreed on during the planning stages. For the experiments described herein, researchers did not detail how specific changes in indices would be interpreted, rather they assumed it would be 'assessment as usual'. The interpretation that will be placed on specific types of changes to indices must be agreed upon at the outset. There should also be agreement on what actions will be taken in response to the changes in indices, prior to the time when these actions are required.

3. Agreement on the forum in which the results of experiments will be interpreted, as well as when and by whom evaluation decisions will made, should be gained at the outset.

4. There should be frequent reviews with all participants during the course of the experiment. The reviews should not only examine experimental progress but should also be used to re-confirm objectives, as well as the design and evaluation criteria.

5. A commitment from all levels of industry and government to the process and the time frame of the experiments, and to how the results may affect the design of future management programs, should be acquired. Institutional or industry impatience should not compromise the proper conduct of experiments.

6. The ability to monitor stock changes requires complete and accurate data and, conversely, is very susceptible to contamination by incorrect data. Managers and researchers should understand the limited ability to perceive changes in a biological system with high variance, even when data are fully reliable. All participants should be aware of the large cost of even small amounts of illegal harvest. Therefore, planning for such experiments should anticipate the need for different data capture methodology (e.g. observers) or increased enforcement under conditions of non-compliance, together with mechanisms to fund these alternatives.

7. Participants should be made aware of potential results, both biological and economic, prior to undertaking the experiments. For one of the experiments we describe, the economic impacts of removing an unrestricted fishing program, once instituted, were greatly underestimated.

Implications for Rockfish Reserves

All of the lessons from our experiments have direct parallels to any programs for rockfish harvest reserves. Establishment of no-take reserves will remove present sources of information on status of stocks within the reserves. Researchers must have a means of monitoring these reserved stocks to demonstrate whether there are positive changes to them. More importantly, originators of the reserves (and their superiors) will be pressured to demonstrate that, whatever the positive changes in the reserves, there are distributed benefits to stocks outside the reserves. There will be rapid and continuous pressure on advocates of the reserves to provide such demonstration. Institutional impatience and the tenure of the individuals who make the original decisions on reserves can be critical components of commitment. For these reasons, formal and documented agreements among parties may be necessary to long term success. As was the case for the experiments described here, decision points should also generate responses upon which participants had agreed, prior to the inception of the reserves.

A further consideration is that the creation of harvest reserves will remove some proportion of the production basis for present fisheries. Depending on the size and location of the reserve, this proportion may be extremely difficult to estimate. For rockfishes, in particular, aggregating behaviour means that productivity may not be a simple analogue of bottom area. Reserve designers will need to anticipate potential increases in the exploitation of the remaining non-reserve production base, if overall yields are not adjusted for this removal. This increased exploitation may create an artificial disparity between the performance of stocks in the reserve and those outside. Reserve stocks may appear to be prospering but this may be simply an artefact of the increased fishing mortality outside the reserve.

The experiments described here involved limited numbers and categories of participants. The harvesters involved also had direct economic links to the performance of the fishery. In the case of reserves, much more effort needs to be directed at valuation of non-extractive use, to provide balance to the economic influence of harvesting. Incorporation of viewpoints from non-extractive users also will make the planning process more involved, the objectives more contentious, and the measures of success more diverse. This suggests that individual reserves may each require unique framework agreements among stakeholders.

The experience of these Canadian fishing experiments suggests that gaining prior agreement on decision points may be one of the key components of successful reserve implementation.

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Concepts Relevant to the Design and Evaluation of Fishery Reserves

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Recognizing the Costs of Improperly Designed or Evaluated Marine Fishery Reserves

It is generally assumed that any management plan intended to reduce exploitation of a biological resource will, at worst, do no harm and afford the potential for benefits. Consequently, proper design and evaluation methods are often considered supplementary, a non-vital task, that will only make a plan even more successful. In the context of marine fishery reserves, this attitude translates to the perspective that any reserve is a good reserve and that a design based on sound ecological and socio-economic criteria is of only secondary importance. However, poorly designed or implemented policies can actually hurt the resource they were intended to protect or enhance. Thus, like any other management plan, marine fishery reserves and their associated resources can suffer from poor design or improper evaluation.

In reality, there are costs associated with any management strategy that can be magnified by poor design and inadequate or inaccurate evaluation. The effort and finances invested in one plan can detract from alternative and concurrent strategies, some of which could be more effective. Examples of tradeoffs among alternative management plans are well documented for the salmon (Hunter 1991, Meehan 1991, Stouder et al. 1997) and krill (Nicol and de la Mare 1993) fisheries. Similarly, reserves may contribute to, but not be sufficient protection for some marine resources (Allison et al. 1998). Because reserves have been argued to most effectively augment rather than replace other management strategies (Carr and Reed 1993, Roberts 1997, Allison et al. 1998), the costs of implementing reserves may then detract from effort and finances required of other strategies (e.g. enforcement). Such costs can be ameliorated with supplemental resources, but the possible need for additional resources must be recognized. Thus, the cost of development of any management plan must be weighed against both those costs incurred in the absence of that policy (i.e. continued loss of resources) and the relative costs and benefits of alternative policies. A clear analogy exists from terrestrial reserves where the cost-benefit of movement corridors versus larger but isolated reserves has been debated (Simberloff et al. 1992).

More troublesome are the potentially insidious costs of those reserves that are ineffective by poor design or that are judged to be ineffective because of flawed evaluation. Poorly designed fishery reserves could provide minimal benefits while giving a false sense of security to managers and fishers (akin to a statistical Type II error; accepting a hypothesis when in fact it is false). In this case, the reserves could be used to justify relaxed restrictions in the remaining fishing grounds and exploited populations could be subjected to a combination of concentrated effort and less restrictive regulations. Also disconcerting is the possibility that properly designed fishery reserves are in fact highly effective at managing or protecting fisheries, but early attempts fail to demonstrate this because these initial reserves are poorly designed (akin to a Type I error; rejecting a hypothesis when in fact it is true). Like poor design, improper evaluation can jeopardize the future of a reserve program. Well designed reserves may be highly effective at sustaining and enhancing fisheries, but flawed methods of evaluation (e.g. improper response variables are measured, low statistical power) can fail to demonstrate their positive effects. Again, it may be difficult to justify the future of a reserve program because of a lack of demonstrable benefit. The worst case scenario involves the flawed evaluation of poorly designed reserves, which could lead to either positive evaluations of an ineffective reserve system or abandonment of a potentially valuable management strategy.

Based on these potential costs, design and evaluation of marine fishery reserves should be considered a necessary task, not simply icing on the cake. However, the concerns raised above and the need for effective design and evaluation apply equally well to any (including a competing) management policy. Furthermore, these potential costs must be weighed against the costs born by continuing any current ineffective management strategy.

Designing Sustainable Protected Populations and Communities

It is often argued that the greatest promise for fishery reserves to sustain or enhance exploited populations is by exporting larvae to them (Carr and Reed 1993, Quinn et al. 1993, Roberts 1997, Allison et al. 1998, Sladek Nowlis and Yoklavich 1998). Indeed, the highly dispersive larval stage and open population structure of many demersal fishes are key to the great potential of fishery reserves as instruments of fisheries management. But the importance of larval recruitment to the replenishment of local populations can be both the key to success and the Achilles heel of a sustainable marine reserve. Just as many exploited adult populations can be greatly influenced by, if not entirely reliant upon, larvae produced elsewhere by other local populations, so might populations protected within a reserve be strongly reliant on recruitment of larvae produced outside that reserve. As such, continued or increasing over-exploitation of unprotected populations can jeopardize the replenishment of protected populations within a reserve. Only if a single reserve is sufficiently large to encompass the range of dispersal of many larvae produced by its local populations will it be self-replenishing and therefore potentially self-sustaining. Although there is growing suggestion for some local replenishment of reef fish populations (especially on oceanic islands), given the long planktonic duration and tremendous dispersal potential of many exploited species (especially many species of rockfishes, genus *Sebastes*, with planktonic durations of 1-3 months) it seems unlikely that any single reserve will be of sufficient spatial extent to be largely self-sustaining. Moreover, a single completely self-replenishing reserve will likely have lower potential to contribute to exploited populations because most larvae would have to be retained in the reserve, assuming no compensatory reduction in larval and juvenile mortality. Therefore, a collection or network of reserves seems necessary in order to ensure that reserve populations are both self-replenishing and self-sustaining. The spatial design (distribution and number) of a network should aim for a high likelihood of connectivity (via larval dispersal) among reserves, while replenishing exploited populations outside reserves. Critical goals of future research should include a better understanding of, and capacity to predict, dispersal potential of targeted species, and understanding the balance between self replenishment and reliance on recruitment from exploited populations necessary to sustain protected populations.

Sources and Sinks: Not All Habitats and Local Populations Are Created Equal

The concept of source and sink areas (sensu Pulliam 1988) has valuable implications for fishery reserves. First, the concept raises the important notion that local populations of reef fishes are likely to differ in their relative contribution to the replenishment of themselves and other populations within an exploited stock. Such differences arise from variation in habitat quality, rates of natural (and fishing) mortality and, therefore, local productivity (i.e. larval production) among populations, and from differences in the planktonic fate of larvae dispersed from a population. Second, when applied to the open local populations of most marine organisms, the concept should focus attention on the fate of larvae dispersed from a population. However, the importance of larval fate is only recognized when it is realized that Pulliam's original definition of source and sink areas does not apply directly to the more open populations typical of most marine organisms. Pulliam's model, originally developed for more closed populations of terrestrial species, defines sink populations as those in which *within-habitat* reproduction is insufficient to balance *local* mortality, and instead are maintained locally by continued immigration from more-productive "source" areas or populations nearby. However, because pelagically dispersed larvae are transported away from parental populations, local open populations of many, if not most, marine organisms are generally thought to rarely if ever replenish themselves. Of course this is influenced by the spatial scale at which one arbitrarily defines a local population and the extent to which larvae disperse from that population. For such species, offspring primarily replenish other locations (i.e. populations) and the extent to which they do so relative to recruitment to the parental location determines that location's relative role as a source or sink among a collection of local locations. Obviously, and fundamentally, reserves should be located to protect those populations that contribute greatly to the replenishment of other populations, both exploited and protected. Protection of species in a location that produces larvae with a low likelihood of recruitment to other locations, with or without protection, is a serious design flaw.

Recognizing this revised definition of source and sink populations for open marine populations raises several critical questions:

(1) how is the relative contribution of a local population best predicted and evaluated? (2) given that this contribution is largely based upon the fate (i.e. likelihood of successful recruitment) of larvae produced by a candidate population, how is larval fate best estimated? and (3) what is the year-to-year variation in habitat quality and patterns of larval dispersal (i.e. changes in the relative role of a population as a source or sink) and how can such variation be incorporated into the design (particularly reserve location and distribution) and evaluation of protected populations? Evaluating a local population's contribution to the replenishment of other populations is conceptually straightforward. This is determined by measuring the extent to which catch-per-unit-effort (as an estimate of population size) of the fished population increases or decreases when a candidate local population increases (from protection), or decreases (by exploitation). If a reserve is to function as a management tool, that population's contribution should be reflected in the size or dynamics of the fished population as that local population's size is altered by the level of exploitation. The value of protecting a potential source population should be manifested ultimately as a reduced rate of decline or increase of the fished population (and increased replenishment of other protected populations to ensure sustainability of a reserve network). However, for long-lived species like rockfish, this ultimate influence of a reserve is likely to lag many (at least 5-10) years after protecting a population. More proximate effects (i.e. changes in size structure, density and larval production) could be used to evaluate the potential contribution of a protected population, but importantly, these are not sufficient to evaluate the actual contribution of a reserve population.

Predicting the potential contribution of a local population requires some estimate of the fate of larvae produced by that population. Knowledge of larval duration, oceanographic features that influence larval transport and survival, and regional patterns of current regimes can and should be used to shed some light on the potential fate of larvae released from a local population (Yoklavich et al. 1997). For many reasons, one being year-to-year variation in current regimes, such estimates are likely to be imprecise. Our lack of knowledge of several potentially important factors that influence larval transport identifies research directions for fisheries ecologists and the need for integrated research programs involving (larval) fish ecologists and nearshore oceanographers. For example, are the oceanographic features that influence patterns of larval dispersal of deep water species the same as those that influence shallow water species? If not, species complexes may differ markedly in those factors that determine source and sink populations.

Given the difficulties in predicting the fate of larvae produced by a potential reserve population, and because the contribution (or success) of a reserve is ultimately evaluated by the response of the exploited population, an adaptive management approach to marine reserves seems imperative. Only by establishing reserves based upon available ecological information and measuring the response of other populations (both fished and protected), can the contribution of a protected population be evaluated. Thus, by varying certain criteria (e.g. high vs. low upwelling regimes) when establishing reserves (akin to varying levels of an experimental treatment) and measuring the response of other populations (fished and protected), we can both identify valuable reserve sites and learn how to identify such sites for future reserves.

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Design Criteria for Rockfish Harvest Refugia from Models Of Fish Transport

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Abstract

We used an existing model in our initial examination of the effects of marine harvest refugia, i.e. protected areas where fishing is prohibited, on the bocaccio rockfish (*Sebastes paucispinis*) population off central and northern California. We incorporated size-specific life history information into the model, including growth, survival, and fecundity, and examined the long-term fisheries consequences of refugia. The key assumptions of the model were that larvae dispersed widely from their areas of origin and adults remained in the areas where they settled. Using the model based on these assumptions, we predict moderate-to-great potential for enhancement of bocaccio catch if refugia are established, depending on the magnitude of fishing mortality outside the protected area. From this model, we also suggest that refugia could decrease variability in annual catches. In the future, we will expand this study to include rockfish species with different life history characteristics and to examine in greater detail the effects of adult movements on the model output.

Introduction

Growing theoretical and empirical evidence supports the use of marine harvest refugia, i.e. protected areas that are closed to fishing, as a supplemental management technique for both fisheries and conservation. Potential fisheries benefits arise from the export of adult and larval fishes from the refuge to surrounding fishing areas, which theoretically can increase catches if the augmentation exceeds lost catches from reduced fishing area. Potential conservation benefits occur on population and ecosystem levels. If designed properly, a refuge can protect self-sustaining populations of harvested species (Russ 1985, Plan Development Team 1990, Roberts and Polunin 1991, 1993, Dugan and Davis 1993, Rowley 1994, Roberts et al. 1995, Bohnsack 1996, Sladek Nowlis and Roberts, unpubl. MS). Additionally, the lack of fishing in an area can prevent physical damage to the ecosystem from fishing gear (e.g. McAllister 1988) and can minimize ecosystem shifts due to selective fishing (e.g. Hay 1984, Castilla and Durán 1985, McClanahan and Shafir 1990, Roberts 1995, McClanahan et al. 1996, Pauly et al. 1998).

Most studies of marine harvest refugia have focused on tropical systems, where the majority of these protected areas exist. There is strong empirical evidence that some tropical reef fish species increase in abundance within refugia (Roberts and Polunin 1991, Dugan and Davis 1993, Rowley 1994, Bohnsack 1996, among others). Weaker empirical evidence suggests that refugia can enhance the populations in surrounding unprotected waters (McClanahan and Kaunda-Arara 1996, Russ and Alcala 1996). Two mechanisms have been proposed for this augmentation: spillover, where adults move from the refuge to fishing areas (Polacheck 1990), and larval transport, where adults within the refuge sustain outside populations through the dispersal of their offspring (Sladek Nowlis and Roberts, unpubl. MS).

Modeling the contributions of these two mechanisms -- adult spillover and larval transport -- to the enhancement of unprotected populations offers some useful insight. Polacheck (1990) modified a model by Beverton and Holt (1957) to examine fisheries enhancements via adult spillover from refugia. This cohort model included explicit parameters for fishing effort and for the propensity of the species to move across the refuge boundary. Because of the cohort approach, the supply of new recruits was not affected by the size of the adult population. Thus, Polacheck could only examine the effect of larval transport indirectly, through the spawning stock biomass -- a measure of the reproductive potential of the population. This model predicted fisheries enhancements from the refuge (i.e. greater fishery yields despite a smaller fishing area) only under limited circumstances. Enhancements were more likely at high fishing pressures outside the refuge and with intermediate rates of movement by adult fishes. Even under these conditions, the catch augmentation was always modest (maximum 8-20%, depending on the amount of fish movement). From these analyses, we can conclude that adult spillover from refugia results in, at best, only moderate fisheries enhancements.

Sladek Nowlis and Roberts (1997) used cyclical population models to examine fisheries augmentation by larval transport from harvest refugia. In these models, recruitment in the entire management area was affected by the population densities in both the protected and unprotected areas. The models assumed no adult spillover so as to focus on the effects of larval transport. This assumption also seems to fit well with the growing evidence regarding the limited movements of coral reef fish (Holland et al. 1993, Holland et al. 1996). In contrast to models of adult spillover, Sladek Nowlis and Roberts predicted fisheries enhancements from harvest refugia under a wide range of conditions, but specifically any time the resources are overfished (i.e. fished beyond the maximum sustainable yield). Moreover, their models predicted that refugia provide enormous catch enhancements via larval transport, particularly when fishing mortality is high. Polacheck's (1990) findings complement the result that larval transport is a more effective mechanism for providing fisheries enhancements from refugia. Spawning stock biomass, and thus potential reproductive output, was greatest in his models at the lowest rates of adult movement.

Sladek Nowlis and Roberts' (1997 unpubl. MS) study of larval transport focused specifically on coral reef fishes, whose mobility is limited and whose populations receive minimal management. Here we present preliminary results for the temperate bocaccio rockfish (*Sebastes paucispinis*) using the same model structure. This species has been economically valuable in both the commercial and recreational fisheries off central and northern California for at least the past two decades. The latest assessment of the bocaccio rockfish population in this area indicates a significant decline in biomass, and current abundance now is less than 10% of that estimated in 1970 (Ralston et al. 1996). Like most rockfish species, bocaccio have highly variable annual recruitment, and the last strong year class occurred in 1977. Initial fisheries in the early 1970's took advantage of accumulated biomass of this moderately long-lived species (e.g. maximum age is at least 50 yr [Ralston et al. 1996]), and subsequently on the survivors of the 1977 year class. Bocaccio are now at the lowest level of abundance of all federally managed rockfish species, relative to initial surveys in 1969. Consequently, the Pacific Fisheries Management Council has reduced the Acceptable Biological Catch of bocaccio in 1996 and 1997 (Ralston 1998).

For this species, we predict optimal refuge proportions, the proportion of the total managed area closed to fishing, and corresponding sustainable yields as functions of fishing mortality. We also investigate how refugia might impact yearly catch variations. Finally, we compare our results to historical records of fishing pressure on bocaccio to determine the likelihood that refugia might provide benefits to this fishery. This study is part of an ongoing investigation with several goals: (1) to determine the potential effectiveness of harvest refugia for rockfish; (2) to assess the effect of adult mobility on potential refuge benefits; and (3) to examine the influence of minimum size limits, particularly above or below the size at first reproduction, on potential refuge benefits.

Methods

We applied a model developed by Sladek Nowlis and Roberts (unpubl. MS) to a size-structured bocaccio rockfish population in central and northern California. This model examines long-term fishery yields based on various values for fishing mortality and refuge size. We represented fishing mortality by the parameter *u* (the rate of exploitation), which is the proportion of the fish population caught per year and is related to instantaneous rate of fishing mortality (F) as $u = 1\text{-}e^{-F}$. Only fish in the fishing areas were subjected to this mortality. We represented refuge size by the parameter s, the proportion of the management area closed to fishing. We also used species-specific life history information, including larval and juvenile survival rate, adult natural survival rates, von Bertalanffy growth parameters, and size-specific fecundities (see Table 1 for all estimated parameters and their references). Fish had to reach threshold sizes before they became reproductive and before they were vulnerable to the fishery.

The key assumption of the model involves transport of fishes from the closed area to nearby fishing areas. We assumed that adults did not enter or leave the refuge, whereas the larvae were dispersed widely across the refuge boundaries, resulting in an even distribution of newly settled juveniles. From previous studies (Sladek Nowlis and Roberts 1997, unpubl. MS), we know that the quantitative results of these models depend on the accuracy of all parameter values, as well as the functional relationship between stock and recruitment. In contrast, the qualitative results largely depend on the movement assumptions and the existence of some form of a density-dependent relationship between stock and recruitment.

Results

Results of the model using parameters from the bocaccio population off central and

Table 1. Model parameter values, and their sources, for the bocaccio rockfish (*Sebastes paucispinis*) population in central and northern California. [1]Modified from Yoklavich et al. (1996) and Ralston and Howard (1995); [2] best guess; [3] Rogers and Pikitch (1989); [4] Wyllie Echeverria (1987); [5] Ralston, et al. (1996); [6] Annual survival probability = e^{-M}; [7] Thomas and Bence (1992); [8] Wilkins (1980); [9] Phillips (1964).

[1]Larval Survival			**Fecundity**	**Adult Survival**	**von Bertalanffy for Females**
Period	Instantaneous Mortality	Survival Through Period	No. annual spawns = 1	[5]M = 0.2	[8]L_∞= 87.76 cm
0-20 d	0.14	0.06081	[3]Fecundity = 0.001878 x (Fork length)$^{4.878193}$	[6]Annual survival probability = 0.8187	[8]k = 0.11
21-60 d	0.08	0.04076			[8]t_0 = -1.73 yr
61-180 d	0.04	0.00823	[4]Fork length at 1st maturity = 26 cm	[7]Total length at recruitment to fishery = 40 cm	[9]c = 0.0079 kg/cm^3
180-365 d	0.01124	[2]0.125			[9]x = 3.1067

northern California qualitatively match those from coral reef fishery species (Sladek Nowlis and Roberts unpubl. MS). In a deterministic environment where the conditions remained constant, sustainable yields without a harvest refuge increased with annual fishing mortality until they peaked at the maximum sustainable yield (Fig. 1). They then fell as rapidly as they rose. In this latter region of the curve, where catches fell with increasing fishing mortality, the fishery can be classified as overfished. The optimal refuge proportion was non-zero, indicating that a reduction in fishing area resulted in higher catches than if the entire management area had been fished, whenever the fishery was overfished. Additionally, the optimal refuge proportion increased with fishing mortality. Yields with an optimally-sized refuge remained similar across a wide range of conditions, from u = 0.10 and no refuge to a heavy fishing mortality of u = 0.6 or more and a refuge encompassing approximately 25% of the managed area. In sum, refugia enhanced catches whenever the fishery was overfished, and the optimal refuge size increased with fishing pressure while the yields remained similar to the maximum sustainable yields.

In a stochastic environment, where larval survival varied from year to year, we found that catch variability generally decreased with refuge size (Fig. 2). This pattern was particularly common when fishing mortality was high and with initial increments in refuge size. We used the ratio of the standard deviation to the average annual catch as our measure of variability. This ratio represents the catch variability in terms of the mean. Thus, a ratio of 1 indicated that the standard deviation in annual catches is equal to the mean -- an extremely high degree of variation. Variability in annual catch increased at the highest refuge proportions for all levels of fishing because, as the population declines

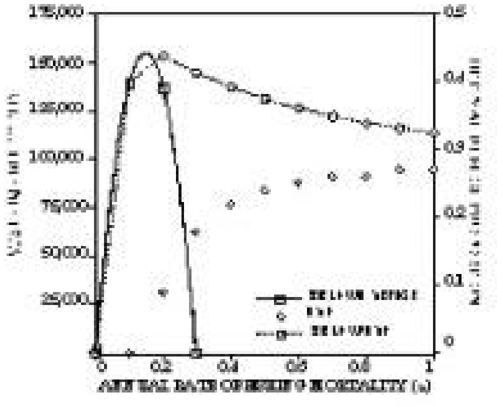

Figure 1. Central and northern California bocaccio rockfishes yield enhancements from refugia over a range of annual fishing mortalities. Long-term sustainable yields (in kg per year) without harvest refugia (solid lines and square points), optimal refuge proportions (ORP) that maximize long-term sustainable yields (dotted line and diamonds), and yields with optimally-sized refugia (dashed line and circles) are graphed against annual fishing mortality (*u*).

toward extinction, the catches approach zero more quickly than the variation in catch. This is not a trivial result because, if this phenomenon is realistic, we would expect to see wildly variable fisheries when they are on the verge of disaster. Specifically, there might be a few moderately productive years in an otherwise collapsing fishery.

Finally, we compared our estimate of the fishing mortality at which the bocaccio population would begin to benefit from a harvest refuge to the history of fishing mortality for this species, as determined in the most recent stock assessment (Ralston et al. 1996). Any fishing mortality above $u = 0.15$ suggests that a refuge would have been useful for augmenting catches (Fig. 3). That is, refugia might have enhanced catches consistently in the central and northern California population since the late 1970s.

Discussion

The general conclusions of this study regarding the benefits produced by harvest refugia to a fishery, and the magnitude of those benefits, are consistent with those from coral reef species (Sladek Nowlis and Roberts unpubl. MS). Specific predictions, such as how much area to close, are more species-specific. According to the best available parameters, the bocaccio has a higher population growth rate (i.e. $\lambda = 1.21$) than most coral reef fishery species previously

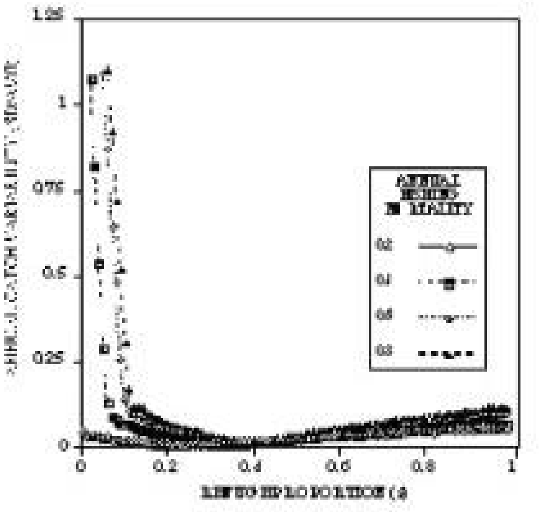

Figure 2. Effect of increasing refuge proportion (the size of the area closed to fishing, relative to the entire management area) on catch variability for the bocaccio rockfish population off central and northern California. Each line represents a different annual fishing mortality, varying from 0.2 (solid line, open circles) to 0.8 (dashed line, filled triangles). For each possible combination of fishing mortality and refuge proportion, the model was run ten times. The mean and standard deviation of the catches were for the next 100 years.

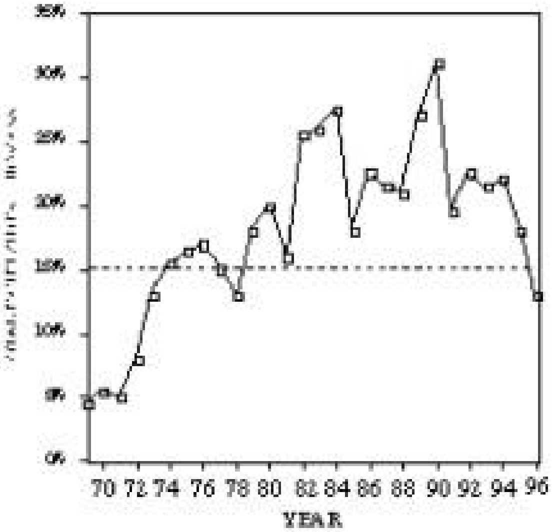

Figure 3. Potential for bocaccio rockfish off central and northern California to benefit from refugia. The solid line is the proportion of the bocaccio population's biomass caught each year from 1969 to 1996 (from Ralston, et al. 1996), a quantity approximately equivalent to fishing mortality (u) as used in the model. The dotted line is the threshold fishing mortality above which the population is overfished and would yield higher catches with refugia.

examined (mostly $\lambda < 1.16$). As a result, the model predicts that bocaccio populations can maintain a more productive fishery in the absence of refugia than those coral reef fishery species. The population growth potential is affected by virtually every parameter included in the model. Consequently, when making these comparisons across species, particularly tropical species whose life history is poorly studied, it is critical to be aware of the model's sensitivity to small errors in parameter values.

There clearly is room to improve our parameter estimates for bocaccio rockfish. In particular, we assumed that stochastic larval survivorship is normally distributed, when in reality it is characterized by a few good years interspersed among many bad ones. Future modeling efforts will more accurately incorporate variability in recruitment.

More generally, we can improve the model by including a transfer rate to represent the probability that adults move across the refuge boundary. This transfer rate was not necessary in earlier models for several reasons, including analytical simplicity, direct comparison to Polacheck's (1990) model of adult transport, and the relatively high site fidelity of many coral reef fish species and some rockfish species.

For bocaccio rockfish, however, it is unrealistic to consider only refugia that have been designed to minimize adult spillover. Because bocaccio potentially can move 150 km or more (Hartmann 1987), our current model's results will only apply to large management areas (e.g. a significant portion of the central California coast and Monterey Bay National Marine Sanctuary). Interestingly, older bocaccio rockfish seem to be relatively sedentary and inactive (M. Yoklavich pers. observation). A model with stage-specific transfer rates will allow us to design refugia for managing this species on a more accurate spatial scale.

At this point in the development of our model, we also do not account for the influence of regional oceanography and associated physical transport on the dispersal and retention of larval rockfishes and subsequent distribution of newly settled juveniles. Patterns in ocean circulation likely have significant consequences to the survival of young stages of rockfishes (Ralston and Howard 1995, Yoklavich et al. 1996), and therefore to the placement of effective harvest refugia along the coast. Additionally, because the distribution of adult bocaccio can be habitat-specific (Yoklavich unpubl. MS), the amount and quality of benthic habitat need to be accounted for in updated versions of the model in order to determine the value of the refuge.

With a revised model, we also plan to compare our results and conclusions using parameters from bocaccio with those from other rockfish species. We will examine an inshore species having relatively high site fidelity, such as the grass rockfish *(Sebastes rastrelliger*), as well as an offshore, deepwater species with relatively high site fidelity, such as the yelloweye rockfish (*S. ruber*) or greenspotted rockfish (*S. chlorostictus*). These comparisons should give us additional insight into the relative effects of movement propensities, population growth potential, and other life history traits on refuge benefits.

From our initial findings, we suggest that harvest refugia can enhance total catches of bocaccio while dampening annual fluctuations in catches. The benefits are more likely and of greater magnitude when refugia are designed to facilitate larval transport rather than adult spillover. Thus, a harvest refugia system might best comprise individual units large enough to contain a sufficient spawning population of the target species.

Harvest refugia may provide other benefits as well, including multi-species assemblage management, enhanced persistence of heavily targeted species, reduced ecosystem damage from fishing, the maintenance of fishery-favorable genetic complexes, and increased economic potential from tourism. This formidable combination of possible benefits make refugia a management option that cannot be overlooked.

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The Influence of Larval Transport and Retention on Recruitment Patterns and the Design of Harvest Refugia for Rockfish

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Abstract

Harvest refugia have been proposed as a supplemental strategy to traditional fisheries management. Meroplanktonic metapopulations, such as rockfish, sea urchins and crabs, may benefit from harvest refugia, which protect sedentary adults while allowing for linkage between refugia and replenishment of harvested areas via larval dispersal. However, design and implementation of refugia are hampered by a paucity of knowledge of spatial patterns in settlement and recruitment. Theoretical studies suggest that connectivity between multiple refugia and harvested areas depends critically upon larval dispersal. Recent work has identified a potential physical oceanographic basis for larval transport of crabs and sea urchins in the upwelling system of northern California, which may be applicable to other meroplanktonic species in this system. Here we characterize aspects of the biological and physical structure of northern California mesoscale circulation that influence the transport of meroplankton, and discuss their relevance to harvest refugia. These circulation features suggest that harvest refugia for nearshore rockfish species should be replicated at a scale comparable to the distance between discrete larval retention zones during the upwelling season.

Introduction

Harvest refugia (areas of no fishing) have been proposed as a strategy to maintain or recover fish stocks worldwide (Davis 1989, Bohnsack 1990, Polunin 1990, Roberts and Polunin 1991, Carr and Reed 1992, Rowley 1994, Ballantine 1996, Holland and Brazee 1996). Two benefits of no take refugia are often suggested: 1) they provide an area of high density, large sized, highly fecund individuals that serves as a natural hatchery, and 2) they provide a source of adults to fished areas through "spillover" by immigrating out of the refugia. Thus spatial management offers a buffer against uncertainty in present management techniques by maintaining sufficient numbers of individuals and spawning stock to repopulate areas subjected to intensive harvest pressure. Here we focus on the first of these advantages, the role of larval dispersal in linking adult populations.

Researchers continue to study the difficult problems of understanding the influence of coastal circulation on the dispersal pathways of marine organisms (Possingham and Roughgarden 1990, Wing et al. 1995a, b, 1998, Botsford 1998, Botsford et al. 1994, 1998). The spatial extent of the adult populations and the rate at which they receive larvae from other areas influence the long-term population dynamics (Botsford et al. 1994). Through studying the temporal and spatial patterns of dispersal, retention, transport and settlement of larvae we can gain insight into the local population dynamics. The importance of larval transport is not just the influence on the number of recruits entering the population, but also on the pathways larvae travel between release and settlement. Keough and Black (1996) outline data required for predicting the pattern and scale of larval dispersal including, 1) knowledge of the relationship between local factors and the number of larvae exported from the local population, 2) an understanding of the hydrodynamic processes that transport propagules, 3) knowledge of the relative contribution of larval biology to dispersal, and 4) an understanding of the relationship between fertilization, larval density, settlement and recruitment/ population dynamics. Mapping the patterns of connectivity between adult sources of propagules and sites of larval settlement is critical to the design of management strategies (Roberts 1997). Identification of larval sources and the linkages between local populations is fundamental to designing harvest refugia aimed at maintaining and restoring depleted stocks.

The intensive harvesting of several species in California (i.e. red sea urchin, abalone and Dungeness crab) has led to proposals for spatial management or harvest refugia to recover these stocks and sustain fisheries (Botsford et al. 1993, Quinn et al. 1993, Tegner 1993). Following depletion of offshore groundfish fisheries there has been a recent surge in growth of the nearshore live-fish fishery, which targets several species of rockfish (*Sebastes* spp.). Many species of rockfish are long-lived, shallow-dwelling reef fish that are highly vulnerable to the live-fish fishery.

Here we briefly describe ongoing work to identify the spatial pattern of recruitment in meroplanktonic species in northern California and their relationship to physical circulation patterns. We use this work as a basis to discuss some general themes related to the design of harvest refugia in upwelling systems.

Larval Transport in the California Current

For the past two decades, increased awareness and understanding of mesoscale variability in coastal circulation off northern California have drawn attention to its implications for meroplanktonic larvae. During the upwelling season in April through July (Largier et al. 1993), the presence of strong offshore flows and an equatorward jet led to the question of how species with a planktonic stage during these months could persist (Parrish et al. 1981). The probable answer to this question lies in the potential for retention of larvae in alongshore frontal zones (Richardson and Pearcy 1977, Shenker 1988) and areas to the south of promontories, termed "upwelling shadows" (Fig. 1; Graham et al. 1992, Graham and Largier 1997), and in subsequent transport of these larvae by flow reversals, both cross-shelf and alongshore, during periods of relaxation from upwelling winds (Farrell et al. 1991, Roughgarden et al. 1991, Wing et al. 1995a, b).

The pattern of upwelling varies along the coast due to the combined effects of coastal bathymetry and the shoreline on wind velocities. For example, the prevailing winds are usually stronger on the windward side of Point Reyes than on the leeward side. This results in the equatorward jet of cold, nutrient rich water, separating from the coast and flowing offshore, while a warm gyre develops behind the Point entraining outflow from San Francisco bay. Meroplanktonic larvae are concentrated in this cyclonic eddy, which

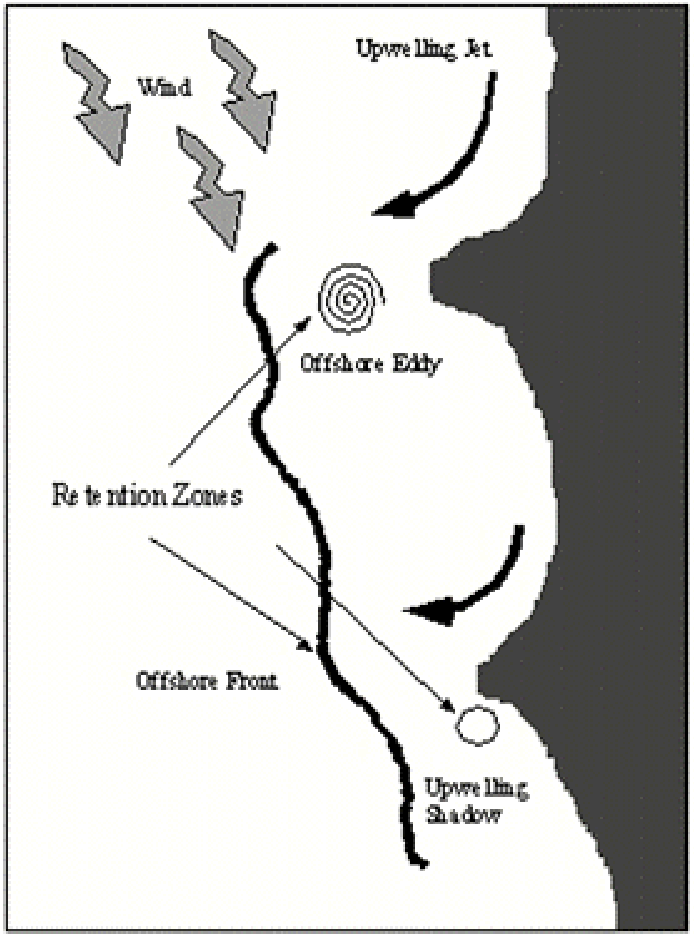

Figure 1. Schematic view of coastal circulation that could retain larvae during active upwelling. Larvae would be transported from these zones to nearshore juvenile habitat during upwelling relaxation.

serves as a retention zone (Wing et al. in press). Only when the winds that drive upwelling occasionally relax, does the warm water within this retention zone flow poleward (Send et al. 1987). During these relaxation periods larvae are transported northward, past Point Reyes. Temperature time series and AVHRR satellite images provide evidence for a warm current flowing northward during these wind relaxations (Wing et al. 1995 a, b).

The work of Wing et al. (1995 a, b) has focused on the alongshore variation in transport and settlement of several species of meroplankton, especially crabs. Settlement of crab species along the coast north of Point Reyes occurs primarily during relaxation from upwelling conditions, when warm water flows poleward from the retention zone in the Gulf of the Farallones (Wing et al. 1995 a, b). Planktonic larval distributions and hydrography near Point Reyes during upwelling suggest concentrations of crab and rockfish larvae are retained in the source of the relaxation flow to the south of Point Reyes (Wing et al. in press). However, a direct link has not yet been made between this transport mechanism and adult abundance.

Different meroplanktonic species were associated with the different features in this region (Wing et al. in press). Concentrations of crab larvae were higher south of Point Reyes while concentrations of rockfish larvae were greatest along the outer edge of the upwelling shadow. An upwelling plume off Point Reyes and an "upwelling shadow", indicated by warmer water in the northern Gulf of the Farallones, were evident in 1994 and 1995, as were frontal regions marked by boundaries between four water masses; 1) newly upwelled, 2) coastal Gulf, 3) oceanic and 4) San Francisco Bay outflow.

The spatial distribution of recruitment for purple sea urchins, *Strongylocentrotus purpuratus* (Ebert and Russell 1988) and red sea urchins, *S. franciscanus*, (Morgan 1997) is also influenced by local circulation patterns. Miller and Emlet (1997) found that sea urchin settlement in Oregon coincided with periods of increased sea surface temperature. Morgan (1997) developed a recruitment index from size distribution data, and found that regions predicted to be subjected to more frequent upwelling relaxation flow had relatively more small individuals in the population. Sites that were in regions that only rarely came into contact with these flows had little recent recruitment. This work suggests that there are at least two spatial and temporal scales important to regional recruitment in this upwelling system: 1) relatively large, episodic interannual recruitment events, which may occur at long intervals but maintain the species over the entire range, and 2) intra-annual spatial patterns that relate to local metapopulation dynamics. Large, episodic inter-annual recruitment has been reported for sea urchins in northern California by several authors (Ebert 1983, Ebert et al. 1994, Wing et al. 1995a,b, Miller and Emlet 1997).

The development of an upwelling shadow in the northern part of Monterey Bay has been identified as a dynamic response to active upwelling. This feature persists during periods of upwelling, but slowly degrades and breaks up after prolonged relaxations in upwelling (on the order of a week). Graham et al. (1992) characterized this region of Monterey Bay and identified the upwelling shadow by warmer water and a distinct zooplankton community, different from the zooplankton found in the colder upwelled water. They suggested that the recirculation of this warm water feature is very important to the dispersal and recruitment of larvae (Graham and Largier 1997).

Similar patterns of flow reversal during breaks in upwelling winds have been described in Monterey Bay (Farrell et al. 1991, Roughgarden et al. 1991). Roughgarden et al. (1991) found that barnacle larvae were retained in offshore fronts associated with active upwelling. During periods of wind relaxation, they observed a cessation of upwelling and movement of this front towards shore. Prolonged onshore and cross shelf transport during relaxation coincided with the observation of settlement pulses in the intertidal region of Monterey Bay (Farrell et al. 1991).

Larvae may also be entrained into anti-cyclonic eddies, found offshore of upwelling jets such as Pt. Arena (Largier et al. 1993, Washburn et al. 1993). At this location a warm core anti-cyclonic eddy develops offshore behind the cold upwelling jet and persists for several months during the upwelling season (Washburn et al. 1993). It is likely that this feature can passively aggregate larvae during periods of upwelling. Observations of AVHRR satellite images during relaxations in the upwelling winds show this warm eddy feature expanding across the shelf moving onshore north of Point Arena, flowing poleward (see for example Fig. 1, p. 88 in Morgan 1997).

Applicability to Rockfish

Rockfish of the genus *Sebastes* are also meroplanktonic species, thus physical transport via coastal circulation is a significant factor in the life history of these species. Rockfish parturition occurs in the late fall to early spring in this region so that at the time of the spring transition rockfish larvae and juveniles are subjected to transport by these upwelling jets and relaxations prior to returning to their adult habitats (Wyllie-Echeverria 1987). Peak settlement of rockfish occurs from May to June, 3 to 6 months after being released into the plankton (Kendall and Lenarz 1987, Moser and Boehlert 1991). Multiple years of sampling have identified a link between the abundance of pelagic juveniles and later cohort strength (Ralston and Howard 1995). Temporal coherence of strong recruitment events at two sites separated by over 350 km for two species of rockfish suggests that large scale oceanographic events are important to recruitment (Ralston and Howard 1995). Interannual variation in juvenile rockfish abundance related to upwelling strength has been identified (Ainley et al. 1993, Yoklavich et al. 1996). Larson et al. (1994) note that, " . . . spatial and temporal variation in upwelling could have important effects on both year class strength and the geographical structure of rockfish populations (p. 176)."

The association between pelagic larval and juvenile rockfish and hydrography has been explored (Lenarz et al. 1991, Larson et al. 1994, Yoklavich et al. 1996, Wing et al. in press). In central California, larval rockfish have been distributed well offshore, near an upwelling front, suggesting offshore advection during upwelling (Larson et al. 1994). Pelagic juveniles were usually found inshore of this region, and Larson et al. (1994) suggested that transport during upwelling relaxation was one mechanism that might influence their distribution, although they stressed that this mechanism was not necessarily the primary means responsible for successful settlement of juveniles. Yoklavich et al. (1996) also proposed that the region of active upwelling near Pt. Año Nuevo might serve as a source of larval rockfish for other areas through onshore transport during periods of wind relaxation. Wing et al. (in press) found pelagic juveniles offshore at the edge of the upwelling front in northern California, but also found larger individuals nearer to shore. It is likely that onshore transport of larval and juvenile rockfish occurs in a similar manner to other meroplankton species in this system, but further work is needed to explore the spatial patterns in juvenile settlement.

Adult populations with dispersing larvae in northern California are maintained by transport of propagules from upwelling shadows or similar retention features (Wing et al. 1995a, Graham and Largier 1997). The high concentrations of rockfish in the Gulf of the Farallones (Wing et al. 1998), or offshore of Pt. Año Nuevo (Larson et al. 1994, Yoklavich et al. 1996) make these areas important sources for larvae that will eventually settle into coastal populations. Whether these larvae move northward (Wing et al. 1995a), or onshore (Larson et al. 1994, Yoklavich et al. 1996), via transport during upwelling relaxation is a characteristic of local circulation. These retention zones may serve as important conduits for larval transport from their offshore planktonic habitat to nearshore nursery habitats (Wing et al. 1998). Retention sites have considerable ecological importance because they supply propagules to coastal populations (e.g. the member-vagrant hypothesis of Sinclair 1988).

To summarize, there is now a partial mechanistic understanding of nearshore circulation during the upwelling season, which may lead to spatial patterns of larval settlement for meroplanktonic species. The spatial variability in settlement of crabs, as well as the relative strength of red sea urchin cohorts, is predictable at the scale of individual upwelling jets and retention zones. The redistribution of larvae depends on individual species behavioral abilities to orient themselves with different mesoscale features. Periodic relaxations from upwelling winds provide windows during which larvae and juveniles of meroplanktonic species are able to successfully recruit to adult populations.

Relevance to Harvest Refugia Design

Carr and Reed (1992) suggest that the pattern of larval replenishment will influence the number, size and distance between refugia. We have suggested that the combined process of concentrating larvae in retention features during active upwelling, and the subsequent return and redistribution to adult populations during upwelling relaxation is a consistent pattern in central and northern California upwelling systems (represented schematically in Fig. 1). This suggestion is a variation on the more general models of Carr and Reed (1992), which detail several alternative means by which larvae may link metapopulations. Our model supports the idea that one or more source populations contribute to a regional larval pool (retention zone), which then redistributes larvae in a specific manner according to the nature of the upwelling relaxation flow.

This pattern of larval retention and redistribution can provide information on whether potential marine refuge sites will replenish fisheries (Wing et al. in press). Rowley (1994) points out that larval replenishment is likely to enhance or rebuild fisheries only under certain conditions, specifically when: (1) larvae produced in the refugia are a significant addition to regional production; (2) larvae are transported to appropriate habitats; (3) increases in larval production result in increased settlement, and (4) larval settlement is limiting. Under these criteria, refugia should be evaluated such that they provide for large production of larvae of target species, and contribute to the regional population at a level sufficient to sustain a targeted harvest rate.

Future attempts to design harvest refugia will need to map specific current regimes and adult habitat in order to have an understanding of how local factors may influence larval dispersal (e.g. Yoklavich et al. 1997). Our general review of larval transport in northern California suggests that the unique features associated with individual upwelling centers, (i.e. headland regions with an offshore jet and retention zone), are an appropriate spatial scale at which to address larval dispersal. The mesoscale circulation features associated with these centers likely constitute semi-closed metapopulations that produce, retain and re-distribute larvae. The question of which populations would be most important as a source (e.g. Pulliam 1988) is not addressed by this review and will require further study.

Our recommendation for a conservative harvest refugia strategy would be to replicate a series of refugia in each upwelling region corresponding to a discrete upwelling jet and retention zone so as to make no assumption regarding locations of source populations. These general concepts will need to incorporate specific regional variations on the theme of retention and re-distribution of larvae, and the inter-annual persistence of retention zones.

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Design Principles for Rockfish Reserves on the U.S. West Coast

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Abstract

The decline in rockfish populations on the U.S. West Coast has created an increased interest in the use of marine reserves for augmenting the management of marine fisheries. Marine reserves theoretically have many intrinsic values, but their projected benefits are directly related to the size, shape, and location of the reserves. Although many uncertainties exist, information is available with which to design reserves for rockfishes. In this paper, I discuss an approach to development of reserves that uses existing information, acknowledges regional biotic differences and environmental uncertainty, and facilitates the development of goal oriented reserves. A precautionary approach to the placement of reserves suggests that a system of marine protected areas with reserves of different sizes and distributed across bioregions and upwelling cells will increase the chances of accomplishing reserve goals and objectives. Given the level of uncertainty in the timing, distribution, and magnitude of important biological and physical processes, however, a reserve system should be designed to incorporate principles of adaptive management. One efficient way to locate a reserve is to include as many species groups as possible by encompassing a diversity of rockfish habitats and depth ranges. The number of factors that influence the success of a reserve system and our ability to differentiate benefits caused by a reserve from interannual variation suggests, however, that future reserves will be greatly larger than almost all existing ones.

Introduction

Recent stock assessments indicate there has been a consistent decline in the size of many eastern Pacific rockfish populations since the late 1970’s (e.g. Pacific Fishery Management Council 1995, Ralston 1998). These reduced populations have been reflected in diminished catches of rockfishes; a situation similar to that of declining harvests from many of the world’s most productive fishing grounds (FAO 1992). Many of the west coast rockfish populations have experienced not only diminished abundance, but also decreased average lengths and weights (Pearson and Ralston 1990). The decline in population abundance is related both to poor recruitment and extensive fishing effort, but the decline of other biological parameters is indicative of a negative response of fish populations to high harvest rates.

The dramatic reduction in rockfish populations has resulted in an increased interest in fishery issues, not only by fishery management agencies, but by the general public as well. Currently, many conservation organizations, ecologists, and public officials are suggesting marine protected areas (MPAs) as a means to augment traditional fishery management techniques (Rowley 1994, McArdle 1997, Allison et al. 1998). Increasingly, fishery managers are also considering MPAs as tools that may be used to help sustain the ocean's resources (e.g. Bohnsack 1993, Dugan and Davis 1993, Auster and Malatesta 1994, Lauck et al. 1998).

MPAs theoretically can benefit many marine species and habitats, and have the potential to benefit commercial fisheries as well. Properly designed MPAs can increase the diversity and abundance of species in an area, protect critical habitats, and protect species at critical stages in their life history (Agardy 1994, Rowley 1994, Allison et al. 1998). The expected benefits to marine environments and human communities can only be realized, however, if goals and objectives of proposed MPAs are clearly defined (Starr and Johnson 1997). Improperly designed MPAs potentially can result in decreased protection for many rockfish populations (Carr and Reed 1993, Carr and Raimondi 1998). In this paper, I describe a way in which existing information that describes coastal oceanographic processes and rockfish life histories, distributions, densities, and habitats can be used to design and locate MPAs for the purpose of improving fishery management of rockfishes.

MPA Design:

Species Groups, Bioregions, Coastal Circulation. For a system of reserves that is designed to protect large segments of an ecosystem, it is sufficient to protect a broad array of representative species. An important step in designing a system of MPAs for rockfish management, however, is to define the species targeted for protection. For the design of harvest refugia exclusively to improve fishery management of rockfishes, the selection of species or species groups to be protected is a primary consideration, because more than 60 species of rockfishes inhabit coastal waters of the U.S. West Coast (Love 1991). Species selection is complicated by the fact that rockfishes occupy many different habitats and are targeted in both commercial and recreational fisheries (Leet et al. 1992, Starr et al. 1998, Lea et al. in press). Given the large number of rockfish species, one approach to selecting species for protection is to lump rockfishes into groups based on spatial distribution or ecological guilds. Once species are grouped, marine reserves that protect those groups of species can be distributed among biogeographic regions, along latitudinal and depth clines, and across habitat types.

The California Department of Fish and Game developed one method for grouping rockfishes. For management purposes, they divide rockfishes into three groups for analysis of recreational fisheries: nearshore (<100 m), mixed depth, and deep (>100 m) rockfishes (Sullivan 1995). Sufficient information is also available to lump many rockfishes into ecological groups that incorporate several life history traits or habitat preferences, such as those described in Table 1. These groups were based on the preferred depth range of adult rockfishes, habitat associations, life histories, and preferred location in the water column (Pearcy et al. 1989, Love et al. 1990, Stein et al. 1992, Lea et al. in press).

An important design principle for marine reserves is that a system of reserves should contain representative habitats (Carr et al. 1998). Terrestrial scientists and managers have been using a zoogeographic approach to protect representative habitats for several decades (Wheeler 1996). The first element of this approach is to define bioregions. Five bioregions are believed to exist off the western coast of the U.S. The boundaries of these bioregions are not explicit, but may be broadly defined by Cape Flattery, WA to Cape Blanco, OR; Cape Blanco to Cape Mendocino, CA; Cape Mendocino to

Table 1. Groupings of selected rockfish species for the purpose of designing harvest refugia (information from Pearcy et al. 1989, Love et al. 1990, Stein et al. 1992, Lea et al. in press).

	Species	**Common Name**	**Habitat**
Deep Benthic (>100 m) Hard Bottom			
	S. chlorostictus	greenspotted	int. depth, hard or mixed bottom
	S. constellatus	starry	int. depth, rock
	S. helvomaculatus	rosethorn	deep mixed, varied habitats
	S. levis	cowcod	deep rock
	S. nigrocinctus	tiger	deep rock
	S. ruberrimus	yelloweye	deep rock
Deep Benthic-Soft or Mixed Bottom			
	S. crameri	darkblotched	deep, mud/rock interface
	S. diploproa	splitnose	deep soft bottom
	S. elongatus	greenstriped	int. to deep mud/rock interface
	S. saxicola	stripetail	int. to deep soft bottom
	S. semicinctus	halfbanded	int. to deep soft/mixed bottom
	S. wilsoni	pygmy	int. to deep mixed/rock bottoms
	S. zacentrus	sharpchin	deep mud/cobble bottoms
Shallow Benthic (<100 m)			
	S. atrovirens	kelp	shallow rock
	S. auriculatus	brown	shallow rock
	S. carnatus	gopher	shallow rock
	S. caurinus	copper	shallow rock
	S. chrysomelas	black-and-yellow	shallow rock
	S. miniatus	vermilion	shallow to deep rock
	S. nebulosus	china	shallow rock
	S. rastrelliger	grass	shallow, low relief rock
	S. rosaceus	rosy	shallow to int. mixed rock
	S. serriceps	tree	shallow rock
Deep semipelagic			
	S. entomelas	widow	pelagic over deep rock
	S. flavidus	yellowtail	pelagic over deep rock
	S. goodei	chilipepper	deep rock, mud or sand
	S. hopkinsi	squarespot	int. to deep mixed bottoms
	S. jordani	shortbelly	pelagic, range of habitats
	S. paucispinis	bocaccio	solitary or schooling
	S. pinniger	canary	solitary or schooling
	S. rufus	bank	solitary or schooling
Shallow semipelagic			
	S. melanops	black	schooling fish near kelp
	S. mystinus	blue	schooling fish near kelp
	S. serranoides	olive	schooling fish near kelp

Monterey Canyon, CA; Monterey Canyon to Point Conception, CA; and Point Conception to Punta Eugenia, Mexico (Barry and Foster 1997). A comprehensive system of MPAs for rockfishes would include harvest refugia in each of these bioregions. A comprehensive system of MPAs could also include a continuum of reserve management practices in these bioregions ranging from limited harvest (e.g. of highly migratory species) to a complete ban on harvest and non-consumptive recreational use.

After bioregions are defined, terrestrial resource managers define and map representative and key habitats in each bioregion, identify species-habitat associations within each habitat and bioregion, define linkages between reserves (e.g. corridors), and then work to preserve representative habitats and associated corridors in each bioregion (Dethier 1992). This concept is sound, but the "open" nature of most marine populations and their reliance upon variable ocean conditions requires a slightly modified approach to selecting reserve locations. In addition to species distribution, home range, and habitat data used in the selection of terrestrial reserves, appropriate selection of marine reserve sites requires additional information about distributions and densities of large fishes, major currents, and spatial and temporal patterns of larval movement and juvenile settlement (see also Morgan and Botsford 1998).

Major physical processes need to be identified that will link MPAs into a network of representative habitats and species. For example, current regimes need to be described and mapped throughout each bioregion to assess the value of a reserve in providing larvae for recruitment in and outside of the reserve. This understanding of large scale physical processes will allow managers to locate reserves in areas that provide the best chance to protect representative habitats, key species, and recruitment processes in each bioregion. It will also be helpful in estimating expected benefits from each type of MPA. Some references that describe broad scale circulation patterns on the U.S. West Coast include Hickey (1989), Largier et al. (1993), and GLOBEC (1994).

MPAs should be located in all major upwelling cells as well as in all bioregions because upwelling greatly influences the distribution of species on the western coast of the United States. There are about five major upwelling centers off California and Oregon (Fig. 1), and upwelling plumes transport water offshore at almost all headlands, which are spaced approximately every 100 km along the California coast. Although there is some exchange between adjacent plumes, most of the upwelled water exists in quasi-enclosed cells with eddies that transport water back towards shore (Largier et al. 1993, Washburn et al. 1993, Yoklavich et al. 1997). Water circulation associated with these upwelling cells is a key feature in the survival and dispersal of many marine larvae (e.g. Parrish et al. 1981, Ainley et al. 1993, Botsford et al. 1994, Wing et al. 1995, and Morgan and Botsford 1998).

Reserve Location. Rockfishes occupy a variety of habitats, but are most typically found in areas with a diversity of rocky habitats (Table 1; Pearcy et al. 1989,

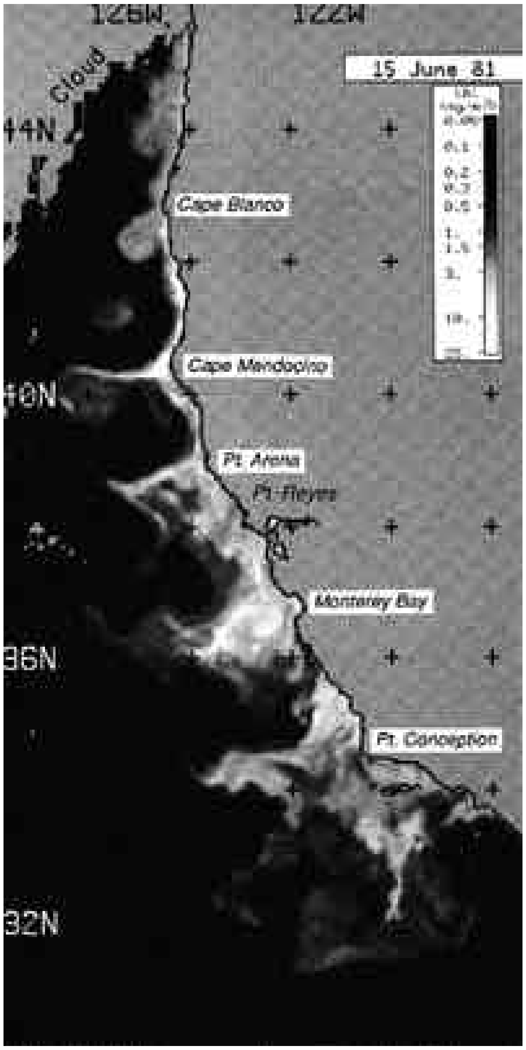

Figure 1. Major upwelling locations on the U.S. west coast as indicated by surface chlorophyll content (GLOBEC 1994).

O'Connell and Carlile 1993, Stein et al. 1992, Starr et al. 1996, Yoklavich et al. 1997). Thus, maps of complex bottom types that highlight rocky areas will help define appropriate locations for reserves. Some broad scale information about water depths and bottom types from the U.S. National Ocean Service is available and can be used as a first cut at defining habitat types. Additional information about bottom types is available from site-specific research cruises that collected swath bathymetry to study the ocean floor. More detailed maps of selected parts of the ocean bottom, such as those provided by sidescan sonar, can also provide preliminary definition of rockfish habitats (e.g. Yoklavich et al. 1997). In the absence of complete maps of coastal subtidal habitats, one way of proposing locations of MPAs is to examine the distribution of rocky shorelines and predict that subtidal rocky habitats occur nearby. Data from specific research projects, and anecdotal data provided by fishers can be also used as a basis for locating nearshore rockfish habitats that would be suitable reserves.

An important design principle for a system of MPAs is that the system should be self-sustaining (Ballantine 1997a,b). Two clear objectives for establishing self-sustaining marine reserves are to protect areas that are important sources of spawning biomass and to protect areas that will receive recruits and thus be future sources of spawning potential. In the first objective of protecting areas that serve as source populations (Pulliam 1988), protection should occur both for areas that historically contained high fish abundance and for areas that currently contain high fish abundance (Carr et al. 1998). Historically productive fishing areas, which are now over-exploited are likely to show a positive, but slow response to protective measures. Areas that currently contain high fish abundance may show a more immediate response to protection by increasing spawning biomass.

Discussions with fishers and fishery managers will help in the identification of areas that historically contained high fish abundance, but are currently depleted due to fishing. Protecting historically abundant areas alone is insufficient for rockfish management, however, because the relatively long life span and sporadic recruitment of many rockfishes indicate that it will take a long time after harvest ceases for large spawning animals to repopulate those areas. The biological characteristics of longevity and sporadic recruitment of rockfishes also suggest that the concept of a rotation of open and closed areas will probably not work for rockfishes as it has for faster growing, more sedentary animals in other parts of the world.

In the short term (e.g. next 25-50 yr), selecting an area with currently high rockfish densities to serve as a source population will thus be more effective than selecting areas that historically contained high densities. With respect to the identification of current source locations, information is available with which to identify concentrations of important fish species. Fox and Starr (1996) described methods of plotting isopleths of catch rates to map locations of high fish density (Fig. 2). Isopleths of fish size can be similarly plotted using length and weight data obtained on research cruises, an important consideration given the disproportional increase in fecundity with increase in size of rockfishes (Love et al. 1990).

One complicating factor in determining an appropriate location for protection of a source population is that we cannot be certain that all areas with high fish abundance actually serve as source populations. Most juvenile rockfishes are planktonic for lengthy periods of time (Moser and Boehlert 1991), making it difficult to determine which adults produced a successful year-class. Julian et al. (Western Groundfish Conference, Feb. 1998, unpubl. abstract) recently suggested that the majority of individuals in a cohort of larval fish may have similar genetic structures, suggesting that year-class strength may be greatly influenced by only a few sources. If this concept proves to be true, it will be even more difficult to identify specific metapopulations to protect, especially given the interannual variation in environmental factors that influence larval survival.

Research on larval distributions of rockfishes suggests that recruitment processes are both spatially and temporally variable. Ralston and Howard (1995) described the strong interannual relationship between upwelling and larval survival of rockfishes. They showed that larval survival is low when sea surface temperatures are unusually warm or cold and that year-class strength is high when sea surface temperatures are intermediate. Yoklavich et al. (1996) also described spatial variability of larvae and identified a possible mechanism for survival by suggesting that juvenile rockfishes are carried offshore in upwelling jets, thus avoiding predation. Several researchers have postulated the existence of larval retention zones that replenish nearshore areas during periods of upwelling relaxation (e.g. Quinn et al. 1993, Wing et al. 1995, Morgan and Botsford 1998). The circulation caused by periods of upwelling relaxation provides a possible mechanism for juveniles to return to nearshore habitats as they grow.

A moderate level of upwelling is good for survival of rockfish larvae, but too much upwelling is detrimental (Ralston and Howard

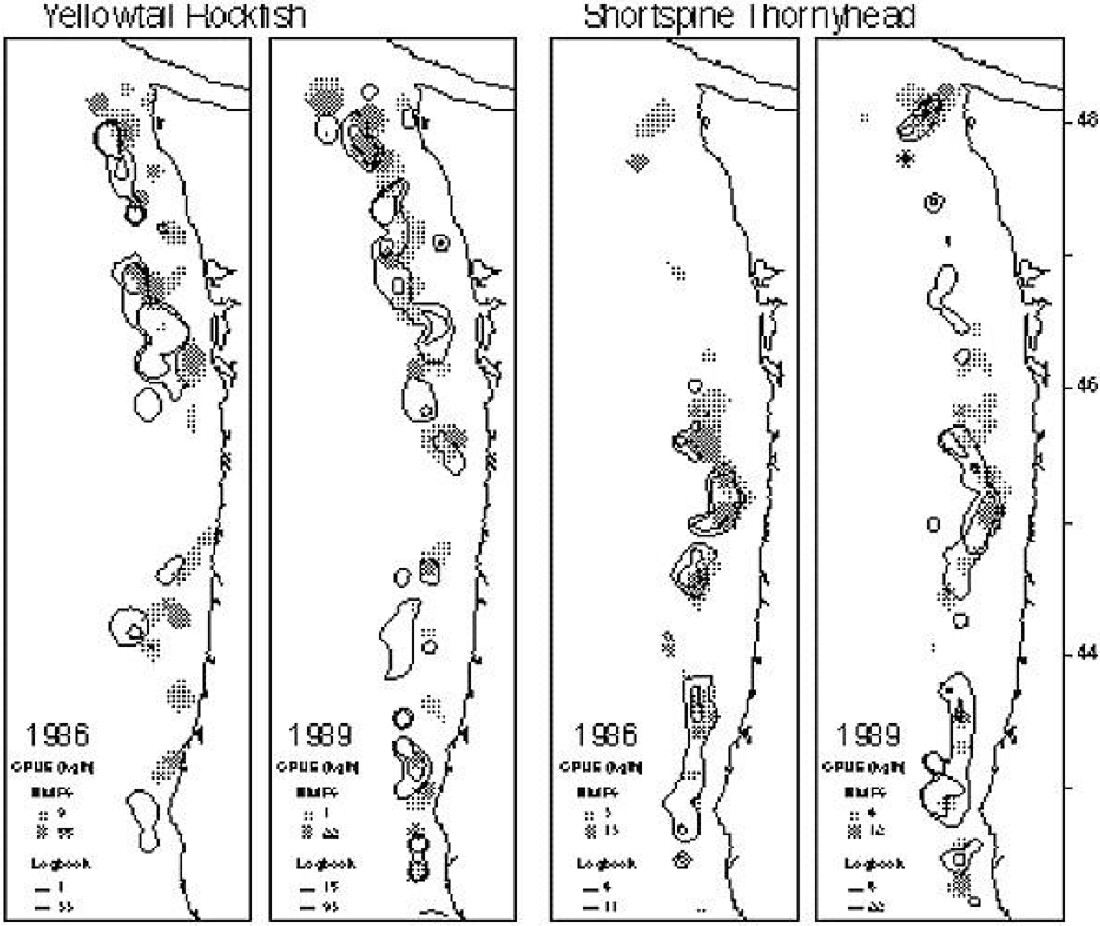

Figure 2. Example of how NMFS research cruise data and commercial fishery logbook data can be used to identify locations of high fish density, as defined by isopleths of CPUE (from Fox and Starr 1996).

1995). It follows then, that during intense upwelling episodes, when there is strong alongshore and offshore flow, larvae produced by adults living near headlands are likely to be swept too far offshore to survive. Conversely, in years with weaker upwelling, larvae produced too early or too late to become entrained in upwelling jets, or by adults living far from headlands, are likely to remain in the nearshore zone and experience high predation. Thus, each year there may be an optimum time of parturition and distance of spawning adults from an upwelling jet to maximize the likelihood of survival of larvae and juveniles. The optimum location for spawning adults and time of parturition will vary annually as the strength and timing of upwelling events vary. This temporal and spatial variation in upwelling events provides a difficulty in locating a single reserve to enhance rockfish recruitment processes, because there is currently insufficient information to predict where and when an optimum time or location of parturition may be. Given this uncertainty, a precautionary approach to protect viable source populations would be to distribute a series of reserves along the coast that are located at various distances from headlands.

Similarly, there is currently little information that would enable us to determine if a reserve is a potential future source of larvae, or if it will be a sink. Also, given the longevity of most rockfishes, a single reserve may serve either as a source or a sink for a few short time periods (e.g. 1-5 yr) in any longer time period (e.g. 50 yr). Thus, to maximize the opportunities of locating reserves in an appropriate location, a system of MPAs should contain several reserves that are located and designed with consideration for oceanographic currents to maximize chances of larvae and juveniles moving offshore and inshore, respectively (Fig. 3).

In all cases, the design and setting of MPAs should account for the habitat type and quality both inside and outside the reserve. It makes little sense to protect an area from fishing, for example, if the water quality inside and adjacent to the reserve is poor. Similarly, if an objective of the MPA is to improve fishing outside the reserve, it is important that suitable habitat is available within and adjacent to the reserve for emigration of juvenile and adult fishes as densities increase.

Reserve Size. The size and shape of a reserve will directly influence the effectiveness of a MPA (DeMartini 1993). As a corollary, the goals and objectives of the MPA will influence the appropriate size of the reserve. A productive MPA system may include large reserves that protect a substantial portion (e.g. 20-50%) of the spawning stock biomass of a species, reserves that supplement fishery management by protecting representative habitats (e.g. 10-20% of typical habitats), and reserves that protect critical or unique habitats, areas, or species (Carr et al. 1998).

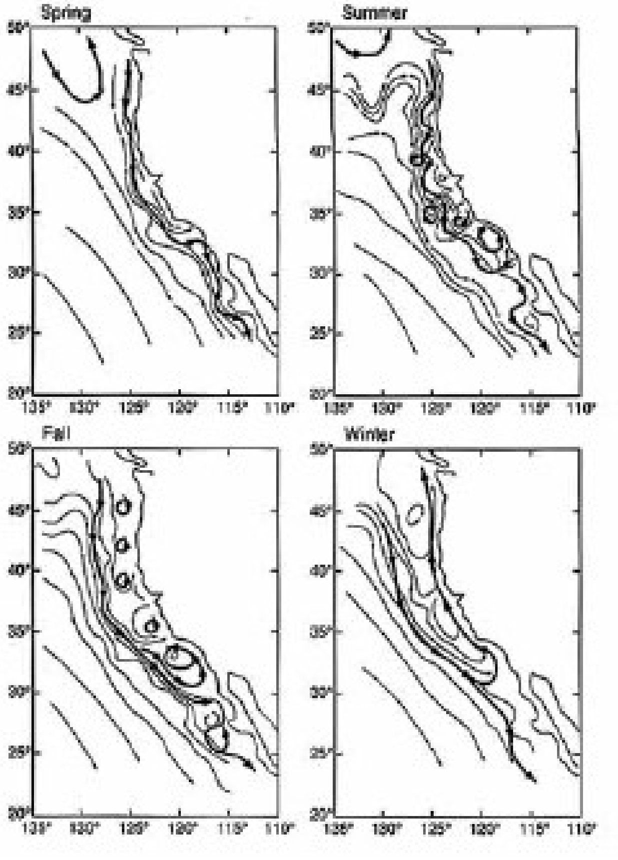

Figure 3. Seasonal circulation patterns of the California current system (GLOBEC 1994).

For conservation of rockfishes, a system of reserves will be less effective if fish consistently move outside the reserve boundaries. Tag returns indicate that many of the nearshore rockfish species typically found in kelp beds move less than 2 km, although a few of the nearshore species have been shown to move hundreds of kilometers (Lea et al. in press). Little is known about the movements of most of the deeper water rockfishes, but some species have shown movements on the order of tens of kilometers (Hartmann 1987, Pearcy 1992), and a few species have exhibited movements on the order of hundreds of kilometers (Mathews and Barker 1983, Stanley et al. 1994). Based on morphology and ecology, the semi-pelagic species are thought to be more mobile.

The home range and movement patterns of rockfishes, the complexity, size, and patchy distribution of rockfish habitats, the uncertainty of optimum larval source locations, and social factors all influence the sizes of reserves needed to accomplish MPA objectives. Also, the size of any reserve should be large enough to facilitate enforcement and to limit deleterious edge effects caused by fishing adjacent to the reserve. Although optimum size is dependent upon many factors, clearly the size of effective MPAs will be greatly larger than virtually all existing harvest refugia. In addition to the biological reasons for having larger reserves, the practical considerations of enforcing regulations and managing a marine reserve indicate that the single-large or several-small debate should be decided in favor of fewer, larger reserves.

Given the current uncertainties in our understanding of reserve processes, one strategy for the development of a system of marine reserves would be to create a series of reserves that contained 20-50 km of coastline, and extended to the westward edge of the continental shelf across a mosaic of habitats. In central California, rocky shorelines average about 0.3 km long and comprise about 45% of the shoreline habitat types (Research Planning Inc. 1994). Thus, a reserve spanning 20-50 km of coastline would be large enough to incorporate the typical movements of most rockfishes, encompass a variety of habitats, and probably be large enough to limit edge effects. A series of reserves this size spaced at intervals away from headlands would also maximize chances of having one of the reserves in the system contain a metapopulation that produces recruits to the MPA system.

Shape. Shape is extremely important when evaluating the differences between reserves designed for recreational and commercial fisheries. Most recreationally harvested species live in nearshore habitats, primarily shallow water kelp beds or rocky habitats. For these species, a long narrow MPA encompassing nearshore habitats may be appropriate for the objective of increasing species composition or relative abundance in the reserve. It would certainly be appropriate to protect key habitats such as nearshore kelp beds when considering a Heritage Reserve (e.g. Reserve A, Fig. 4). A long narrow MPA would not, however, effectively protect deep water rockfishes typically caught in commercial fisheries. A reserve that spanned a smaller portion of the coast, but extended well offshore would provide more protection for both recreational species and the commercially harvested species in deep water, and provide greater opportunity for the spillover effect to occur (e.g. Reserve B, Fig. 4). A reserve designed as a swath extending from the shoreline to the edge of the continental slope would have a greater chance of capturing and retaining larval or juvenile rockfishes. Such a design would also ensure that the reserve has an opportunity to accommodate the ontogenetic shift of some rockfishes to deeper habitats as they mature, an event that may not occur in the case of Reserve C (Fig. 4).

In some locations, habitat complexity as a function of area could decrease with distance from shore. In these areas, a reserve shape that covers an increasing area with distance offshore (Reserve D, Fig. 4) may be a more appropriate design than Reserve B (Fig. 4). MPAs that augment fishery management should thus be individually designed and be based largely on the distribution of habitats and species that are selected for protection. Reserve shape should ultimately be determined on a case by case basis using a combination of information about bathymetry, habitat complexity, and species distribution and relative abundance.

Summary

The identification of appropriate goals and objectives for various species groups and reserves is key to developing a comprehensive system of networked MPAs. Although many

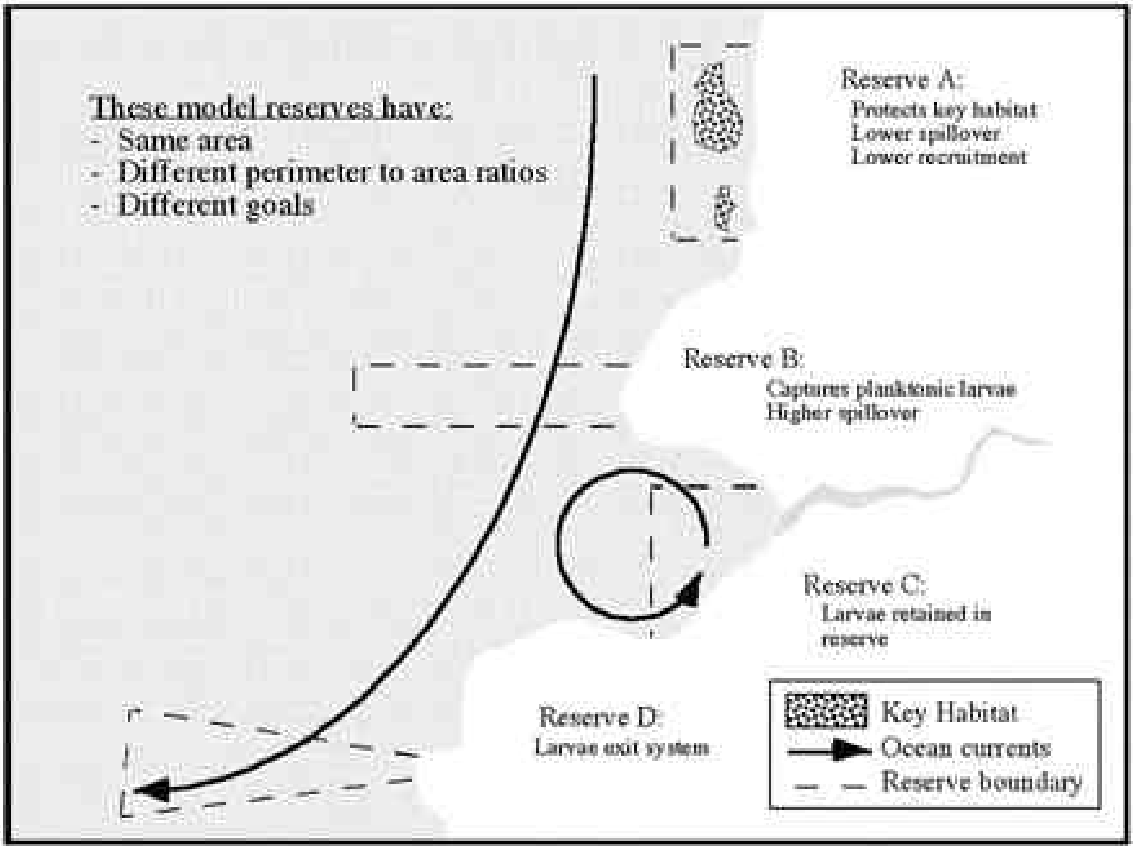

Figure 4. Schematic depicting some design considerations for marine reserves. Reserve A protects key habitat but is not in path of major currents; Reserve B is placed in the path of a major current and includes habitats in several depth zones; Reserve C is in a partially closed system and thus immigration and emigration will be limited; and Reserve D is at a boundary between upwelling zones and the fate of larvae and juveniles is unknown.

uncertainties exist, information is available with which to design MPAs to augment fishery management practices for rockfishes. Given the level of uncertainty in the timing, distribution, and magnitude of important biological and physical processes, a reserve system should be designed to incorporate principles of adaptive management. The number of factors that influence the success of a MPA and our ability to differentiate benefits caused by a reserve from interannual variation suggests, however, that future reserves will be greatly larger than almost all existing MPAs.

The complexity of issues related to the creation of effective MPAs indicates that reserves will need to be individually designed, but should fit into a connected network. A precautionary approach to the placement of MPAs suggests that a system of MPAs with reserves of different sizes and distributed throughout the U.S. west coast bioregions and upwelling cells will increase the chances of accomplishing MPA objectives. Specific locations of marine reserves can be established after species distribution, fish density, habitats and currents are broadly mapped. One efficient way to locate a reserve is to include as many species groups as possible by encompassing a diversity of rockfish habitats and depth ranges. An example of an appropriate shape of a reserve would be one that occurs as a swath from a rocky shore out to the edge of the continental slope and across complex habitats such as at the head of a submarine canyon or a seamount.

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Monitoring the Response of Rockfishes to Protected Areas

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Introduction

No-take refuges have been suggested as a potential tool for fisheries and ecosystem management, especially for populations of fishes prone to overexploitation. Their efficacy primarily has been demonstrated in tropical and southern temperate systems where fish size, density, reproduction and fishery yield have increased with duration of protection or in comparison to nearby fished areas (Roberts and Polunin 1991, Dugan and Davis 1993). For rockfishes (genus *Sebastes*) and other fish resources living in association with rocky outcrops in northern latitudes, few no-take refuges exist and few studies have been conducted to monitor population or ecosystem responses to the absence of fishing. In addition, rockfish present a challenge to refuge monitoring because they are long-lived, outcrop-dwelling, and often inhabit areas difficult to sample. Regardless, in implementing any system of no-take refuges for fishery management purposes, monitoring must be conducted to measure the population and fishery responses to protection and assure that the goals and objectives of the no-take refuges are achieved.

Historic patterns of stock indicators have indicated that rockfish populations in Washington State's Puget Sound have experienced long-term declines in abundance (Palsson et al. 1997), and recent information suggests that some species of rockfish are at less than 10% of their historic reproductive output. Declining stock trends have continued despite enacting traditional restrictions on commercial and recreational fisheries. Because of this, alternative management strategies have been sought to rebuild rockfish populations and have led to an investigation of no-take refuges as a fisheries management tool. Monitoring activities within two existing no-take refuges began in 1992 and were first summarized and reported in 1995 (Palsson and Pacunski 1995). Comparisons of these no-fished areas to comparable fished areas strongly indicate that overfishing is the primary cause of the declines in abundance, decreases in average size, and size truncation of larger rockfish in Puget Sound.

Four permanent no-take refuges containing subtidal waters have been created within Puget Sound (defined here as the inland marine waters of Washington including Puget Sound, the Straits of Juan de Fuca and Georgia, the San Juan Archipelago, and Hood Canal). These refuges were established for the general purpose of conservation without specific goals and objectives. Although regulations for most of these refuges do not prevent the harvest of salmon and invertebrates and non-game fishes, bottomfishing for sport or commercial purposes is not allowed. These refuges are small, ranging from 0.002 km^2 (0.2 ha) to 5.49 km^2 (549 ha). The Edmonds Underwater Park (EUP) was created in 1970, San Juan Marine Preserves in 1990, Sund Rocks in Hood Canal in 1994, and Titlow Beach near Tacoma, Washington in 1994.

This paper will describe the methods used to monitor the response of rockfishes to no-take refuges in Puget Sound. These methods were used to test density, size, and reproductive output differences between fished rock areas and no-take refuges. The methods and results will be compared to other refuge and monitoring studies for rockfish and a comprehensive monitoring system for rockfish populations in marine refuges will be presented.

Methods

In order to monitor some of the Puget Sound refuges and fished sites, a visual census technique developed by Matthews (1990a) using scuba diving was adapted to examine the relative site usage of rockfish. A more detailed description of the strip transect method can be found in Palsson and Pacunski (1995) but is summarized here.

Seven sites were selected where permanent transects were established. Five of these sites were located in central Puget Sound near Seattle. Of these five sites, four were fished (Port Blakely, Blake Island, Boeing Creek, and Orchard Rocks) and also censused by Matthews (1990a). The other site was the no-take refuge at EUP, which was established 27 years ago. Two additional sites were monitored in the San Juan Archipelago: one at a fished site on the east side of Turn Island, and one at Shady Cove located within the six-year old no-take refuges of the San Juan Marine Preserves. Three individual transect lines, each 30 m in length, were located at each site. Every attempt was made to locate each line in a high relief microhabitat with comparable complexity and substrate among all sites. All transect lines except at EUP were made of lead line and were permanently embedded along the bottom. Buoys or other permanent features were used at EUP and temporary tape measures were set out at each time of sampling.

Sampling at the San Juan sites was conducted during the spring and fall of 1992 and continued during subsequent springs until 1997. Refuge and fished sites were sampled as paired treatments usually within a 24 h period and during similar daytime and tidal periods. Many paired observations were made during the first two years of study, but only a few were conducted during subsequent years. During sampling, two divers swam on either side of each transect line and identified, counted, and measured each rockfish within 1.5 m of the transect line. All crevices were examined with the aid of an underwater light. Data were recorded on waterproof paper at the time of observation. Individual fish were measured to the nearest 10 cm interval with the aid of a plastic staff graduated with 10 cm marks. The accuracy of this measurement system was verified on a number of occasions by measuring fish underwater, spearing them, and confirming the measurement on the surface. Observations in Central Puget Sound were initiated during the fall of 1993 and during the following fall of 1994, but only one observation was made at each site. Sampling was increased at these sites during 1995 and 1996 when one observation was made at each site per month for the months of April, May, June, October, November, and December.

Primary data analysis was patterned after the analysis of variance conducted by

Matthews (1990a). Fish density for each transect was treated as an independent observation and subjected to a square root transformation (Zar 1984) to normalize variances. These data were then subjected to a one-way analysis of variance to test for differences among sites. Data were pooled among all years. Analyses were conducted separately for central Puget Sound sites and the San Juan Islands. If a difference was detected, a Tukey multiple range comparison was conducted to determine which comparisons differed. To evaluate the effect of fishing on each species, each species was categorized by the relative occurrence in the recreational catch.

Reproductive potential was determined by estimating the number of eggs that would be produced given densities and length frequency distributions from central Puget Sound fished and no-take refuge sites. Length frequencies were multiplied by egg production at length estimates from DeLacy et al. (1964). Total reproductive potential was estimated by multiplying the length effect by the rockfish densities averaged for each fished and reserve treatment group.

Results

The densities for five species of rockfish differed among sites in every central Puget Sound comparison (ANOVA, $P<0.0001$). Multiple range comparisons found that the highest densities of heavily fished copper rockfish (*Sebastes caurinus*) and black rockfish (*S. melanops*) were found at EUP, and the lowest densities were found at the fished sites (Table 1). The highest densities of the heavily fished quillback rockfish (*S. maliger*) were at the Boeing Creek site, and EUP had intermediate densities. Lightly fished brown rockfish (*S. auriculatus*) and Puget Sound rockfish (*S. emphaeus*), which are rarely caught by fishers, were in highest densities at some of the fished sites. For the heavily fished species and black rockfish in central Puget Sound, EUP always had the

Table 1. Mean densities (fish/transect) of rockfish from Puget Sound fished and no-take refuge sites.

		Central Puget Sound					San Juan Islands	
		Port Blakely	Blake Island	Boeing Creek	Orchard Rocks	Edmonds Park	Turn Island	Shady Cove
Species	Fishing Intensity	fished	fished	fished	fished	no-take	fished	no-take
Copper	Heavy	4.2	1.8	2.4	0.6	30.7	7.2	13.6
Quillback	Heavy	1.1	2.1	35.8	0	17.3	0	1.0
Brown	Light	0.9	5.7	4.2	7.3	0.1	0	0
Black	Medium	0.3	0.04	0.6	0.2	1.9	0.9	0
Puget Sound	None	0.1	0.2	86.7	0	0.1	141	154
Large (>=40cm)								
Copper	Heavy	1.1	0.5	0.1	0.2	26.1	1.1	1.4
Quillback	Heavy	0	0.1	0	0	6.8	0	0
Brown	Light	0	0.1	0	0.7	0	0	0
Black	Medium	0.1	0	0	0.2	1.9	0.2	0

* Shaded cells indicate greatest Tukey contrast at 0.05 level of significance.

greatest densities of large individuals (greater than or equal to 40 cm).

Comparison between the San Juan Island sites revealed that copper rockfish densities were greater at the Shady Cove refuge compared to the Turn Island fished site; however, densities of large rockfish did not differ between the fished and unfished sites. Quillback and brown rockfish were too infrequent to evaluate, but more and larger black rockfish were found at the fished Turn Island site. Puget Sound rockfish densities were essentially equal between the sites.

For central Puget Sound, the average size of quillback rockfish was 29.5 cm in the long-term EUP refuge, which differed from the fished areas where they averaged 20.4 cm (Fig. 1, t-test, P<0.0001). Fifty centimeter individuals were observed in the refuge but this size category was absent at the fished sites. Copper rockfish averaged 42.9 cm at EUP, which differed from the mean size of 29.1 cm observed at fished sites (Fig. 2, t-test, P<0.0001). At EUP, copper rockfish measuring 40 cm and 50 cm were the most common sizes observed at EUP compared to 20 cm and 30 cm at the central Puget Sound fished sites (Fig. 2).

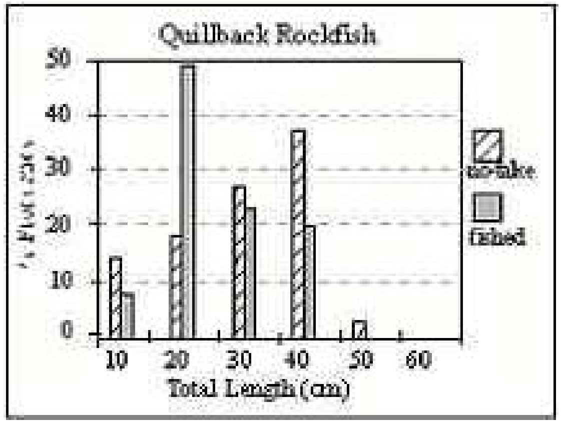

Figure 1. Length frequency distributions of quillback rockfish from central Puget Sound fished and no-take refuge sites.

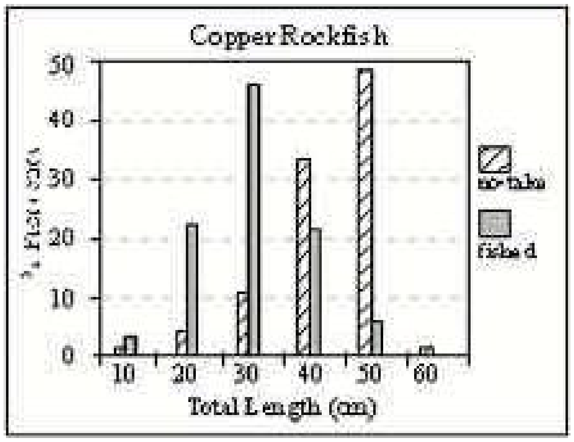

Figure 2. Length frequency distributions of copper rockfish from central Puget Sound fished and no-take refuge sites.

The reproductive potential at EUP exceeded the potential at the average fished site in Puget Sound by a ratio of fifty-five to one (Fig. 3). The difference due to the length frequency distributions between no-take and fished sites accounted for a four fold increase in egg production, while the difference due to densities accounted for almost a fifteen fold increase in egg production.

Discussion

The results from monitoring seven sites in Puget Sound demonstrate clear density and size responses by heavily fished rockfishes to no-take refuges. These contrasts have proven useful in assessing the impact that fishing has had on rockfish populations. Compared with other fishery data, these monitoring results confirm size truncation, decreased population abundance, and a reproductive potential that is less than 10% that of historical levels. High site fidelity and small home ranges (Matthews

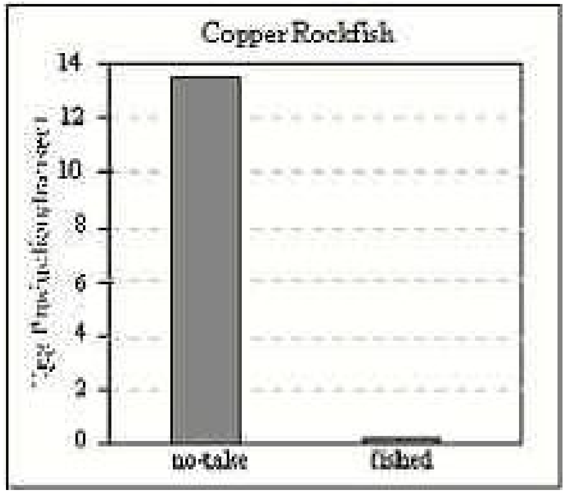

Figure 3. Reproductive potential of copper rockfish from central Puget Sound fished and no-take refuge sites.

1990 b,c) make copper, quillback, and brown rockfishes suitable candidates for a management regime that includes the use of no-take refuges to assure population stability and prevent overfishing. An extensive system of no-take reserves currently is being considered in Puget Sound as a viable management tool to reverse declines in rockfish and other fish populations on rocky outcrops.

The results from Puget Sound are similar to the few studies of rockfish responses to no-take or natural refuges. Paddack (1996) found that larger rockfish occurred in several no-take refuges in central California and that increased sizes corresponded to duration of protection. The older EUP in Puget Sound had both extreme size differences as well as drastic density differences compared to the younger refuge at Shady Cove. Instead of a fifteen-fold difference in copper rockfish abundance as observed in central Puget Sound, the San Juan refuge only had a two-fold increase in density compared to the fished site and after seven years of protection did not show a size response. The differences in density and sizes contributed to a vast difference in the reproductive output in the older refuge compared to the fished sites. Paddack (1996) observed a two- to three-fold increase in the reproductive potential of rockfish at older refuges in central California compared to their fished sites. This result is similar to the four-fold increase we observed by just considering size effects alone.

Other refuge studies have shown long-term effects of protection and the effects of fishing on rockfish. Gunderson's (1997) study of offshore rockfish populations found that relative densities were unchanged in natural refuges after 24 years compared to declines in nearby fished areas and in overall populations. Greater densities of rockfish also appear in natural, deepwater refuges in Monterey Bay that are not observed in shallower habitats more subject to fishing pressure (Yoklavich 1997).

There are a number of possible biological responses that may occur in marine refuges as a result of protection afforded by harvest restrictions. Puget Sound monitoring efforts tested for changes in size distributions and abundance, which are the most common investigated responses in refuges (summarized by Roberts and Polunin 1991 and Dugan and Davis 1993). The reproductive response also was estimated for copper rockfish and similar studies have documented increased reproductive effort from refuges (Roberts and Polunin 1991, Palsson and Pacunski 1995, Paddack 1996). Other responses that have been measured include the fishery response. The catch rates of fishers were surveyed near refuge borders and Alcala and Russ (1990) found increased fishery yields as a result of the refuge. Other monitoring activities may not relate to abundance changes or fishery responses but may include determining the response of community parameters (species richness and diversity), behavior (e.g. migration and movement), genetic diversity, or other variables depending upon the design and purpose of the refuge.

A variety of techniques and methods might be used to monitor rockfish and other fish populations in no-take refuges. Two studies specifically on rockfishes have used visual census techniques with scuba diving (Palsson and Pacunski 1995, Paddack 1996). This sampling mode also has been employed by a number of studies evaluating the refuge impacts on species other than rockfish (Bell 1983, McCormick and Choat 1987, Buxton and Smale 1989, Alcala and Russ 1990, Cole et al. 1990, McClanahan and Shafir 1990, Rakitin and Kramer 1996). Other monitoring techniques have included pot surveys (Ratikin and Kramer 1996) and catch rates as relative population indicators (Bennett and Attwood 1991, Gunderson 1997). Studies have measured size responses by directly measuring fish in water with rulers (Palsson and Pacunski 1995, Paddack 1996), by measuring lengths from catches (Bennett and Attwood 1991, Ratikin and Kramer 1996, Gunderson 1997), or by visual estimation (McCormick and Choat 1987, Buxton and Smale 1989). Age responses have been measured by Gunderson (1997). There are many other responses that could be monitored including home ranges and site fidelity, genetic diversity, predator-prey interactions, and system productivity.

Size and abundance responses continue to be the most direct refuge variables to monitor, but the ability to monitor these and other responses for rockfishes depends upon the available survey and sampling techniques. Fishery-independent or direct surveys of rockfishes have been difficult to develop because rockfish often inhabit rocky outcrops that are difficult to sample with nets and other conventional techniques. Trawl surveys have been used along the west coast to estimate the density and abundance of rockfish (Lauth et al. 1997), but trawl survey results for rockfish are often questioned because of poor net performance over rocky bottoms. Pelagic rockfishes have been surveyed with scientific echosounders (Matthews et al. 1989, Boettner and Burton 1990, Starr et al. 1996), but broad scale surveys have not been regularly conducted in part because of a problem in identifying species composition. Scuba surveys have been conducted in the nearshore environment where densities and sizes have been estimated (Larson 1980, Matthews 1990a, Palsson and Pacunski 1995, Paddack 1996); however, many rockfish inhabit deep habitats that are beyond the reach of conventional scuba techniques.

The development of *in situ* technology has increased the variety and applications of direct survey methods. An underwater television camera mounted on a remote operated vehicle (ROV) has been used to estimate rockfish abundance (Adams et al. 1995) and has promise for some species. Submersibles have been used in a number of successful applications to estimate rockfish densities in relation to their habitat (Richards 1986, Richards and Schnute 1986, Pearcy et al. 1989, Krieger 1993, O'Connell and Carlile

1993, Starr et al. 1996, Yoklavich 1997). Other undersea methods have been used to study rockfish and may be relevant to monitoring their response in no-take refuges. These include tagging studies using conventional and sonic tags (Mathews and Barker 1983, Matthews 1990b,c, Pearcy 1992). Many of these tools are limited by the time and money needed for their use and the untested effects on fish behavior during their use.

On a broader scale, rockfish stocks have been assessed with fishery dependent techniques such as catch-at-age and dynamic pool models (Tagart 1991, Ralston 1998). In particular, these assessments estimate spawning stock biomass, which may be used as an overall measure of the success of no-take refuges to regional productivity. Catch rates also can be used as relative indicators of population abundance (Gunderson 1997, Palsson et al. 1997).

The selection of a monitoring method and study design will influence the ability to infer population changes. Visual assessment techniques can underestimate numbers of cryptic species in kelp forests (Davis and Anderson 1989) and some rockfish were likely overlooked during the Puget Sound surveys. Unpublished data from our other scuba studies in Puget Sound indicate that approximately one third of all individual rockfish are hiding in crevices, and this observation may limit using other direct survey equipment such as video cameras, submersibles, and echosounders.

The monitoring of rockfish populations in Puget Sound was conducted by scuba strip transects placed at permanent locations. The selection of permanent transects may have improved the precision of density estimates especially in before/after or duration studies but may have complicated the comparative analysis among sites. Sedentary rockfishes are highly site specific (Matthews 1990b,c) and likely prefer certain microhabitats. If permanent or random transects do not reflect the same mix of microhabitats among treatment groups, differences in densities may confound survey results. Paddack (1996) surveyed randomly-selected and permanent transects to test for density differences among refuge and fished sites, but the variability was too great to discern density differences. Had permanent transects been exclusively selected and controlled for microhabitat differences among sites, density differences may have been detected. In selecting Puget Sound transect locations, every attempt was made to achieve a similar composition of microhabitats. Currently we are evaluating the relationship between rockfish abundance and microhabitat selection, and these results will be used to evaluate the influence of microhabitats on the results.

An ideal study design to monitor the response of rockfishes in no-take refuges was described by Carr and Reed (1993). They identified that refuge responses should be measured before and after refuge establishment and at the same time compared among refuge and non-refuge treatments. The results from monitoring the response of rockfish populations in Puget Sound refuges suggest the following additional sampling strategies. After implementing a no-take refuge, monitoring abundance, size, and other responses might best be accomplished with fixed transects that would minimize the variability due to microhabitat differences.

Sampling events in this scenario would be randomly selected over time and independent from each other. In contrast, to test for among site differences between fished and refuge treatments, transects should be randomly selected within each microhabitat at the time of each sampling event. In addition, the survey results should be frequently evaluated to determine the statistical power to detect differences and to optimize sampling strategies.

Monitoring programs are critical to the successful implementation of no-take refuges in a fishery or ecosystem management scheme. Without outlining clear and measurable goals followed by a monitoring program to test that those goals are being fulfilled, managers cannot be assured the no-take refuges are serving as fishery buffers, maintaining biodiversity or achieving other intended benefits. For the Puget Sound comparisons, some species such as brown rockfish had higher densities of large and small fish at fished sites and densities of Puget Sound rockfish were equal among treatments or greater at fished sites. Negative responses to no-take refuges could include competitive interactions precluding one species or another, increased and density-dependent predation, higher disease rates, and poor siting or habitat quality resulting in population sinks (Matthews 1990a). Without a comprehensive monitoring program, the attraction versus production debate plaguing artificial reef programs (Grossman et al. 1997) could certainly plague the implementation of no-take reserves for fishery management. The results of monitoring efforts in Puget Sound to date have provided a baseline of existing conditions and insight for an improved and comprehensive monitoring program to be implemented with an expanded system of no-take reserves being planned for Puget Sound.

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The Role of Law Enforcement in the Creation and Management of Marine Reserves

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All users of the marine environment are effected by the creation of a marine reserve. The establishment of a reserve changes the activities of all persons who would come into contact with that reserve. In truth, a marine reserve is an effort to effect a cross-cutting change in human behavior with respect to a very small piece of the environment. It is very impressive to look upon a new addition to a NOAA nautical chart and to see depicted with dotted blue lines a particular geographic area designated for special behavioral modifications on the part of its human users. For example, "Note D" of chart 11400 describes the Florida Middle Ground. This note explains "*the following restrictions apply: fishing the coral is prohibited except as authorized by a permit issued under 50CFR-638.4. Bottom longlines, traps, pots and bottom trawls may not be fished within the area*". After reading this explanation, the casual reviewer would assume that this prohibition has succeeded in its goal in restricting those listed fishing activities. Actually, nothing could be further from the truth. The historical record of compliance in the Florida Middle Ground, an area roughly equal in size to Monterey Bay, California, is abysmal. Bottom trawling vessels routinely are detected fishing unlawfully in the area and, despite severe penalties and loss of catch, compliance has never been achieved in the 15 years that the area has been protected.

The effort to protect the Florida Middle Ground, however, is not completely without success. The level of activity within the area would be intense if it were not for the existing regulations. The resources identified within the Florida Middle Ground would be nonexistent without the protection afforded by the prohibitions. The degree of success that is attained is attributable directly to the level of enforcement commitment placed on keeping the area closed. Aerial patrols and surface patrols to keep a police presence is the classic methodology for enforcing regulations associated with any form of marine reserve. Achieving a physical presence within any closed area is always difficult. Enforcement seeks to be present in the closed area often enough to deter violations. When violations are detected, enforcement then looks toward severe penalties and sanctions to further decrease incentive to conduct unlawful fishing activities. This classic formula for maintaining a closed area has never succeeded. Eventually enforcement resources are taxed beyond their ability to keep a physical presence within the closed area and complaints of little or no law enforcement begin to surface in front of managers responsible for maintaining such closed areas.

Enforcement resources are expensive and assumptions of the level of resources needed to achieve compliance within any marine protected area are almost always incorrect. When it comes to knowing how much enforcement is necessary, managers wishing to achieve a closed area are often willing to accept anything in order to place the concept firmly within the existing Code of Federal Regulations. There are false assumptions that the lawful users will provide sufficient policing to keep poachers from accessing the designated area. There are false assumptions that "other agencies" will contribute to the success of enforcement efforts. There are false assumptions about the frequency with which aerial and surface patrols will transit the area. There is almost always shock and amazement when existing enforcement resources request significant increases in the numbers of employees, vessels and aircraft.

A detailed and peer-reviewed threat analysis is necessary before the consideration and creation of a marine reserve.

- The threat analysis should identify all potential incursions into the marine reserve by persons seeking to circumvent, disobey or ignore the proposed regulations.
- The threat analysis needs to reflect that there are determined, willful violators who do not “buy into” the concept of the closed area.
- The threat analysis needs to identify cultural variations in perceptions of the use of the marine environment.
- The threat analysis needs to consider all the possible sources of catastrophic incursion and seek to eliminate the motivation for these incursions.

The results of the threat analysis need to be circulated among potential user groups, who will provide the reaction to the proposed regulations. Most of all, the completed threat analysis must be used to allow enforcement to realistically predict what the likelihood of compliance will be for the regulations enacting the marine reserve.

In the United States, various forms of marine reserves, closed areas, or Habitat Areas of Particular Concerns (HAPCs) have been enacted with regularity since the Magnuson Fishery Conservation and Management Act came into effect March 1977. In practice, the reaction to the regulations enacting a closed area is always different and more clever than what was expected or predicted by managers and enforcers. A long and needlessly inefficient game is played by poachers, enforcers, and managers in order to achieve the goals of the closed area. Creation of a marine reserve allowing little or no harvest will likely precipitate an even stronger reaction than those experienced in the creation of closed areas. The level of enforcement resources, particularly traditional enforcement resources such as officers, boats and planes, is usually recalculated in an emergency setting by enforcement managers desperate to curtail frequent and blatant violations within the closed areas. Almost entirely absent from these considerations is any effort to apply nontraditional enforcement mechanisms. For example, if managers truly wish to establish an area where bottom trawling is completely prohibited, the means to compliance could propose a nontraditional solution such as the placement of cement tetrahedrons as an effective barrier around the marine reserve. My suggestion is that if the opposition to the placement of such permanent barriers is strong, then the prohibition to trawling should be reconsidered because it is not likely that sufficient enforcement resources will ever exist to completely close any area to this activity.

Creation of rockfish refugia along the Pacific coast will require nontraditional enforcement approaches combined with an appropriate background level of traditional enforcement to have a realistic probability of successful implementation. Even matters as simple as routine patrol must be closely examined with regard to the likelihood of implementation under the usual budgetary restraints. Most people are very familiar with the success of river-keeper and bay-keeper programs on the Hudson River and portions of Chesapeake Bay. Routine presence by marked non-enforcement units can have a positive effect in deterring incursions as long as fully equipped and accredited law enforcement officers are in sufficient number to respond to the scene when actual violations are detected. In the documentation for a recent conference on the creation of the Oculina Bank marine reserve off the east coast of Florida, enforcement agencies were asked, “if we create a marine fishery reserve, how best can it be enforced with the resources we have?" The only recommendation being considered in the initial document was the traditional deterrents of increasing penalties for violators within the proposed marine reserve. I submit that this option can be portrayed most commonly as the “head hunting syndrome.” Violations will occur at an increasing rate, complaints will increase to a point where sufficient enforcement resources are focused on the problem, and after a certain amount of time, a violator will be caught while poaching within the marine reserve. The premise becomes that if this one person is severely punished it will deter all of the violations. My experience is that this has never worked. Determined poachers view heavy fines and penalties as an occasional cost of doing business and only rarely do the enforcement action and subsequent criminal or administrative penalty succeed in entirely removing the poacher from the fishery. The high level of recidivism among determined poachers is a well-known and established behavioral pattern. Each and every natural resource enforcement organization along the coastal United States knows who the top poachers are within their areas of jurisdiction. Indeed, each natural resource officer frequently knows all the significant poachers within his or her individual districts. Successful enforcement programs that will achieve the goals of a marine reserve must acknowledge that dedicated, hard-to-deter poachers will continue to operate unlawfully within the marine reserve at every opportunity.

Enforcement programs dedicated to the protection of a marine reserve cannot survive or accomplish their goal with overwhelming public opposition. Generally, in natural resource law enforcement, when there is overwhelming opposition to any regulation, the court system reacts to those cases that are brought under that regulation by supporting the public and dismissing the cases. The court systems provide balance between regulation and over-regulation. Enforcement programs focused on the effective implementation of regulations enacting marine reserves of the future must be innovative and must have strong public support.

Those populations of users closest to the closed area are most heavily impacted by the creation of a marine reserve. “Not in my backyard" is a very common cry from the local citizenry. Creation and management of the marine reserve cannot assume that the correct response to local opposition is strong enforcement. Strong enforcement of a strongly opposed regulatory regime usually results in letters from congressmen and senators and lawsuits from opposing non-governmental organizations. Successful enforcement programs related to marine reserves must emphasize community oriented policing techniques and strongly emphasize educational aspects of marine reserve regulations. Enforcement has a role in teaching all user groups exactly what the benefits of the marine reserve will be. If a ten-year-old grade-schooler learns from his or her father that the marine reserve is taking food from his plate, this child quickly will begin his or her own campaign of lifelong poaching activities. If the educational program integrates a large enforcement component into the outreach efforts, young minds can often be brought to support the concept of the marine reserve and help to influence their parents' opinions.

Lastly, managers must not be afraid to postpone enacting regulations for a marine reserve when there is clearly no possibility of attaining the minimal funding necessary for enforcement. In the charge given to the conference on Oculina Bank as referenced above, the correct conclusion might be that it is not possible to provide enforcement with existing resources. Enforcement of marine reserves must not be either overwhelmed or under-funded.

Evaluating Marine Harvest Refugia: An Economic Perspective

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I. Introduction

Evaluating the economic effects of a harvest refuge will be complicated by uncertainties regarding 1) the biological effects of the refuge; 2) difficulties in predicting how potentially affected parties are likely to respond to the refuge; 3) shortcomings of models used to estimate economic effects; 4) lack of appropriate data; and 5) lack of experience with this novel approach to fishery management. This paper discusses some of the complexities involved in such economic evaluation in order to better anticipate the types of analyses and information needed. Section II provides a general introduction to methodologies and concepts relevant to the evaluation. Section III discusses some of the economic issues specific to refuges. Section IV provides brief concluding remarks.

II. Conceptual Overview of Economic Evaluation Techniques

Cost-benefit Analysis: One tool for evaluating the economic effects of a harvest refuge is cost-benefit analysis. Because this type of analysis typically takes the perspective of society (i.e. the nation) as a whole, the scope of costs and benefits and the approach to measuring them will differ somewhat from the manner in which these terms are understood and employed by private firms. An important concept in cost-benefit analysis is the notion that society, by choosing one particular use of its scarce resources, incurs an "opportunity cost" in terms of the foregone benefits that those resources would have generated in some alternative use. Thus, for instance, in terms of evaluating a refuge, the opportunity cost of the refuge would be measured by the net economic benefits (benefits minus costs) associated with the status quo management regime that the refuge is intended to replace.

Two separate and additive sources of social benefit commonly considered in cost-benefit analysis are consumer surplus and economic rent:

> (1) Consumer surplus--the net economic benefit provided by a good or service to the public-at-large--is the difference between the maximum dollar amount each person is willing to pay for a good and the amount actually spent on the market to acquire it, summed across all consumers. For any particular good, willingness-to-pay (WTP) varies among individual consumers, due to differences in preferences, incomes and the amount of the good already consumed.[1] Because society attaches value to non-market as

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[1] WTP declines as the amount consumed increases, with consumption ceasing altogether once an individual has become sufficiently satiated that his WTP falls below the market price.

well as market goods, non-market activities such as sport fishing[2] also are legitimate sources of consumer surplus. Consumer surplus also applies to non-consumptive environmental goods. For instance, it is referred to as "non-consumptive use value" for activities such as wildlife viewing and as "non-use value" for goods and services (such as healthy ecosystems) that are valued regardless of whether a person expects to ever benefit from using or seeing them.

(2) Economic rent pertains to benefits generated by "factors of production," that is, labor, land, capital and businesses that contribute to the production of goods and services provided to consumers. Economic rent is measured by the difference between what a factor earns in its current use and the minimum amount of compensation necessary to motivate the owner of that factor to keep it in that use. Because a factor is likely to leave its current use only if earnings fall below what it would earn in its next best alternative use, this minimum compensation would be the factor's "opportunity cost," i.e. the economic opportunity foregone by remaining in the current use.

The use of cost-benefit analysis to evaluate a refuge would involve predicting immediate and long term responses of potentially affected parties to the refuge, relative to the status quo. These responses would then be translated into estimates of costs--costs directly attributable to the refuge (e.g. monitoring, enforcement) as well as opportunity costs (i.e. net benefits foregone by giving up the status quo)--and benefits (consumer surplus and economic rent generated by the refuge). A cost-benefit ratio describing aggregate costs relative to aggregate benefits would be used to summarize the results, with a ratio value less than one indicating a net economic gain to society associated with the refuge, and a value greater than one indicating otherwise. While a cost-benefit ratio is useful for summarizing the overall outcome once individual gains and losses associated with the refuge are weighed against each other, it masks the specific effects of the refuge on individual segments of society. To address such distributional concerns, a breakdown of aggregate costs and benefits over time and among various segments of society would likely also be included in the analysis.

Economic Impact Analysis: Economic impact analysis focuses on the distribution of economic activity--as measured by market output, employment and household and business income--within a particular geographic area (e.g. city, state) designated by the analyst. Impact analysis could be used to evaluate changes in economic activity associated with a harvest refuge, both in terms of direct effects on the economy within the

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[2] Unlike market goods, which are purchased via a single market transaction at a given price, a sport fishing trip is created by combining non-market resources (e.g. time spent travelling to the fishing site) with one or more market goods (e.g. gasoline, bait).

designated area and so-called "multiplier" effects, which occur as direct effects ripple through other economic sectors within the same area. The nature and magnitude of multiplier effects vary according to characteristics of the economy and tend to dissipate more rapidly in smaller, less diverse economies that rely heavily on goods and services imported from outside their boundaries.

The use of impact analysis for evaluating a harvest refuge would involve predicting the direct effects of the refuge within the boundaries of the economy, then estimating the multiplier effects resulting therefrom. The required predictions would address not only the extent of direct reductions or expansions in output, income and employment associated with the refuge, but also whether reductions in one sector of the economy might be offset by expansions in other sectors, and vice versa. The extent of such substitutions would depend, for instance, on whether commercial fishermen displaced by the refuge take up alternative fishing or non-fishing activities within or outside of the local economy, or whether increases in ecotourism associated with the refuge represent an addition to or displacement from other leisure activities already occurring within the economy.

Because of its focus on market transactions, impact analysis disregards goods and services that may be desired by society but do not generate output, income or employment (e.g. environmental amenities that provide non-use value). Furthermore, while impact analysis provides information regarding the volume of money that changes hands in the economy, it says nothing about how efficiently that money is used in providing goods and services to consumers. Because goods are subject to multiple transactions as they move through the economy and are counted in each transaction according to the full market price rather than the value added at each level of the market, the output effects estimated by impact analysis typically reflect a significant amount of monetary double-counting. Despite these limitations, impact analysis likely will have considerable appeal to persons concerned about the effects of a refuge on local economic activity.

III. Application to Harvest Refugia

In order to systematically evaluate the economic effects of a harvest refuge, it is important to know: (1) the specific objectives intended to be met by the refuge, (2) the specific management alternatives to be evaluated, (3) the dynamics and current status of resources likely to be affected by the proposed refuge, and (4) current human uses of the proposed refuge area (e.g. commercial and sport fishing, nonfishing recreation such as boating and diving). Management options should include, at minimum, a "status quo" alternative and a refuge alternative. If various types of refuges (differing significantly in terms of size, shape, location, etc.) are to be considered, more than one refuge alternative may be specified. The alternative(s) to be considered may include refuges in combination with traditional management rather than mutually exclusive practices.

Because the economic analysis is intertemporal, the status quo is defined to include not only the current status of resources and their use but also how these likely would change over time, based on the customary types of management measures (e.g. quotas, trip limits) that would continue to be used in the absence of the refuge. While these projections may take the form of linear extrapolations from past trends, this approach may or may not suffice, depending on the particular fish stocks being considered for refuge protection.[3]

The scope of the economic analysis will be significantly affected by the types of uses to be restricted within the refuge and the effect of such restrictions not only within but also outside the refuge. Thus, for instance, economic effects on sport and commercial fisheries would be evaluated in the context of the likely response of fishermen and fishery managers to such closure. While curtailment of fishing within the refuge may be accompanied by a loosening of customary harvest restrictions outside the refuge, this will not necessarily occur immediately or even over the long-term--depending on what fishery managers expect in terms of biological and fishery benefits from the refuge and how they respond to the opinions expressed by the fishing industry and other interest groups. Moreover, new management issues may arise in areas outside the refuge if, for instance, outside stocks experience undue fishing pressure or significant social conflict develops as a result of the influx of vessels from the refuge. Also, depending on the extent to which current stock assessments are based on fishery-dependent data and how much of such data would be lost by closure of the refuge to fishing, the effects of such data loss on the reliability of stock assessments also may need to be considered.

Economic effects on fishing activities outside the harvest refuge may take a variety of forms. For instance, vessels that customarily fished in the refuge may incur additional costs to travel to more distant fishing grounds or to relocate to a port outside the refuge. Processing plants in the vicinity of the refuge may experience reduced revenues, relocate or shut down altogether. Spillover effects may also occur if increased congestion on fishing grounds outside the refuge causes operating costs to increase for all vessels on those grounds, not just those displaced from the refuge.

Issues of equity and fairness may arise, because a harvest refuge may affect fishermen differently, depending on the extent of their prior reliance on the fishery within the refuge and their ability to divert their activities to areas outside the refuge. For instance, a refuge in nearshore waters may have a disproportionate effect on smaller fishing vessels, because larger boats may be better able to divert fishing effort to more distant areas. A refuge over one type of ocean bottom may have a disproportionate effect on vessels that employ gear typically used on that type of seafloor, particularly if access to other areas with the same type of bottom is limited. A single refuge may have a greater effect on fishermen who customarily operate

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[3] Given the declining trends in a number of West coast fish stocks, growing awareness of the limitations of current stock assessment techniques and the "precautionary" approach to management prescribed by the new Magnuson-Stevens Fishery Conservation and Management Act (Sustainable Fisheries Act of 1996), fishery managers may be inclined to take a more conservative approach to resource use than would be indicated by a linear extrapolation. Perhaps one indication of this is the Pacific Fishery Management Council's imposition of unusually conservative harvest restrictions on the groundfish fishery in 1998.

in that vicinity than a system of refuges with a broader geographic distribution.

While a harvest refuge may cause short- and long-term economic disruptions in a fishery, it may also provide long-term gains to the fishery, for example higher yields, reduced variability of yields, and reduced probability of fishery closure due to overfishing. If the refuge is designed to protect some subset of resident fish species but fishing activity for all species is prohibited in the refuge, the refuge may provide some incidental protection for these other species as well. On the other hand, a prohibition on fishing for all species within the refuge (not just species the refuge is designed to protect) will result in economic dislocation for all fishermen who customarily operate within the refuge and exacerbate spillover effects on fisheries outside the refuge, because all fishing effort would be diverted to outside areas. Non-fishing activities such as recreational boating or diving may also be excluded from the refuge if, for instance, they are thought to adversely affect resources or habitat within the refuge or perhaps even for non-biological reasons (e.g. simplifying enforcement, ensuring "equitable" exclusion from the refuge). To the extent that such non-fishing exclusions occur, economic consequences for those activities would have to be investigated as well.

In addition to any fishery benefits associated with a harvest refuge, the public-at-large may reap benefits in the form of non-use value--the value attached by the public to marine resource enhancement within the refuge that is independent of their present or future use of those resources. Non-consumptive use value may also be enhanced if, for instance, increased resource abundance or biodiversity in the area of the refuge causes the value of ecotourism-related activities to increase.

While a harvest refuge may result in cost savings in terms of lesser reliance on traditional management measures within the refuge, some form of traditional regulation, monitoring and enforcement likely will continue to be needed on fishing grounds outside the refuge. Additionally, costs associated with establishing the refuge may be significant, depending on the technical complexities associated with refuge design, the regulatory requirements associated with refuge implementation and the extent of public controversy. Resources will also be needed for long-term monitoring and validation of refuge benefits and for enforcement of restrictions on access to the refuge.

Informal public surveillance may mitigate some of the enforcement costs associated with a harvest refuge. However, the probability of this occurring and the risks associated with wrongly assuming that such surveillance will in fact occur should be carefully evaluated. The extent of enforcement costs also will be affected by the nature of the refuge regulations. If the regulations prohibit access to the refuge by all vessels, a vessel's mere presence in the refuge will be sufficient grounds for citation. If only fishing vessels are denied access, an enforceable means of distinguishing fishing vessels from other vessels (e.g. presence of fishing gear on board) must be devised. If the prohibition is on harvesting fish within the refuge, a vessel will likely have to be caught in the act of harvesting, because fish already on board may have been harvested outside the refuge. While prohibiting access to the refuge may be more effective from an enforcement perspective than prohibiting fishing, it may also be more burdensome for fishing vessels (and perhaps also non-fishing vessels) if they must spend extra travel time detouring around the refuge while engaged in activities outside the refuge. Refuge size and location will have a bearing on this issue as well, because a large refuge in a heavily used area will likely impose greater inconvenience on vessels than a smaller refuge in a remote location. The incremental enforcement cost of the refuge relative to the status quo also will depend on whether at-sea surveillance is expected to be conducted in the vicinity of the refuge for reasons independent of the refuge, or whether such surveillance would have to be initiated specifically because of the refuge.

IV. Conclusions

The economic effects of a harvest refuge will be affected by the policy objectives it is intended to meet, the size and location of the refuge, and the types of uses to be prohibited within its boundaries. Thus, consideration of the potential range of economic effects is best initiated during early development stages of the refuge rather than after the fact. Such forethought will better enable policy makers to anticipate potential sources of support and opposition to the refuge and increase the likelihood of an economically as well as biologically positive outcome.

The information requirements for conducting an economic evaluation of a refuge are extensive. Given the uncertainties involved, the analysis may end up providing very approximate and incomplete estimates of economic effects. However, even an approximate evaluation likely is better than none at all, because it provides a framework for conceptualizing the issues involved and a systematic way of informing policy makers regarding the range of potential economic effects and the extent to which they can be documented and quantified.

Marine Harvest Refugia: An International Policy Perspective

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Interest in fishery reserves, marine harvest refugia, and marine protected areas as fishery management tools has grown quickly over the last decade. This is an international phenomenon, and one in which developing countries have played a leading role. The largest number of marine harvest refugia have been set up on coral reefs. These have generally been promoted from two different perspectives: (1) as marine protected areas for tourism (e.g. in Belize); and (2) as part of development projects devolving management responsibilities to local communities (e.g. in the Philippines and Sri Lanka).

Most of these early experiments have been characterized by:

- Initial resistance by fishers that are excluded from traditional fishing areas;
- Significant, and often dramatic increases in numbers and size of fish or other harvested resources *within* refugia;
- Often anecdotal increases in harvests *outside* refugia;
- Poor documentation of baselines and changes in biological assemblages and fishery catches.

Despite this lack of documentation, results have been perceived as positive enough to result in:

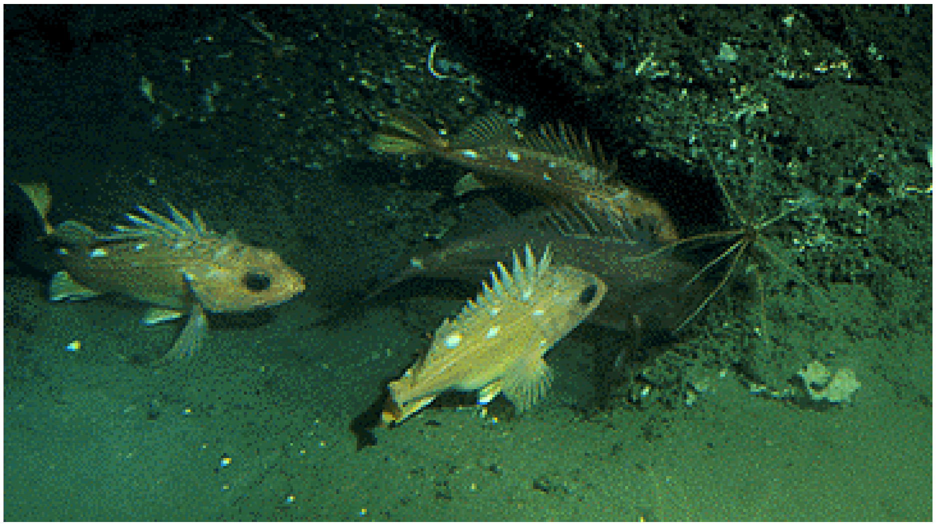
- Local community support for refugia (e.g. the Philippines);
- International donor agency (e.g. U.S. Agency for International Development, Global Environment Facility) support shifting from small-scale experiments of the late ‘80s to much larger-scale national initiatives (although still with a reluctance to support needed monitoring activities);
- Inclusion of refuges in fishery “best practices” (e.g. FAOs Code of Conduct for Responsible Fisheries) especially for new or still-developing fisheries and artisanal fisheries; and
- The beginning of a much more ambitious dialogue about the next generation of marine protected areas.

The global biodiversity conservation movement has accelerated interest in marine protected areas and harvest refugia. This stems from the view that such areas are the fishery management tool most likely to conserve biological communities and their processes in addition to target fishery species. This approach has been championed by both environmental and community-based nongovernmental organizations, as well as, more recently by the scientific community. This is reflected in several World Conservation Union (IUCN) resolutions and the conclusions of the International Group of Experts on Marine and Coastal Protected Areas (1995). At the First Symposium on Marine Conservation Biology, over 400 marine scientist and conservation biologists – including most of the top names in the field – endorsed a “Call for Action” on marine biodiversity conservation. Included in this call was:

> *“Increase the number and*
> *effectiveness of marine protected*
> *areas so that 20% of*
> *Exclusive Economic Zones*

> *and High Seas are protected from threats by the year 2020."*

The Parties to the Convention on Biological Diversity (currently 173 countries and the European Community) have also responded to the interest in marine harvest refugia. The three objectives of the Convention are: (1) the conservation of biological diversity; (2) the sustainable use of its components; and (3) the fair and equitable sharing of the benefits arising out of the utilization of genetic resources. The Conference of Parties to the Convention specifically identified the need for Parties to establish marine protected areas, and in May, 1998, directed both Parties and the Secretariat of the Convention to facilitate research and monitoring activities related to the value and the effects of marine and coastal protected areas or similarly restricted management areas -- such as no-take harvest refugia -- on sustainable use of marine and coastal living resources. These issues will form part of the Convention's program of work on marine and coastal biodiversity.



Group of greenspotted rockfish (*Sebastes chlorostictus*) viewed from the Delta submersible at 150 m in Soquel Canyon, Monterey Bay, CA. Photo by M. Yoklavich

Marine Reserves – An Environmentalist's Perspective

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Marine Reserves Serve Many Purposes

Marine reserves, defined as areas in which fishing is banned and all other extractive human activities are minimized, serve many purposes. First and foremost, areas of the sea should be set aside and protected from as many anthropogenic threats as possible, simply because such areas have an inherent value (existence value), and because future generations deserve to inherit some portion of the natural ecosystems that exists today.

If what has been learned in aquatic ecosystems is any guide, then the protection of representative pieces of all major habitat types within coherent networks of protected areas will be the best way to protect biodiversity at all levels (from populations to ecosystems) in the sea. Coherent networks protect both a number of individual protected areas and the essential physical and ecological processes that create and maintain ecosystems, such as sediment transport characteristics, migrations of organisms, and fluxes of nutrients and energy. Effective protection of biodiversity can also have the practical benefit of preventing or reducing constraints placed on fishing to protect depleted populations. In some extreme cases, such as Pacific salmon listed under state and federal endangered species acts, such constraints can close fisheries entirely.

Marine reserves also provide places in which to study marine ecosystems without the confounding effects of human activities, and to begin to apply the definition of a "healthy" marine ecosystem. An operational definition of ecosystem health (for example, the identification of the most important attributes of ecosystem structure and function, and quantitative thresholds for each of these attributes) will be essential for establishing standards and targets for protecting marine ecosystems. Research on relatively undisturbed marine ecosystems would also be expected to yield insights into life history, population dynamics, ecological energetics, nutrient cycling, and other structural and functional attributes – insights that could significantly improve fisheries management.

Education is another important function of marine reserves. Both school children and adults deserve to have places in which they can observe how relatively unimpaired marine ecosystems look and function. 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 curricula.

Marine reserves in accessible, nearshore areas would be expected to protect and increase tourism-based economic activities, since many people are attracted to places of natural beauty that are designated as parks or reserves.

While the emphasis of the Workshop on Marine Harvest Refugia for Rockfishes is on the potential of marine reserves as a fisheries management tool, it is important to bear in mind the other purposes of marine reserves.

The stated purposes of a marine reserve largely will define whether or not the reserve is judged successful. The need for scientific work, and the ultimate design of a marine reserve or a network of marine reserves, will also depend to a large extent on the purposes.

Defining Success

Much of the debate over whether society should proceed rapidly with the establishment of marine reserves (without much ecological analysis), versus a go-slow approach based on research and design, seems to be fueled by a lack of clarity about purposes.

A marine reserve that includes a spectacular stretch of coast, kelp forests, and rocky outcrops accessible to divers could be "successful" in achieving many of the purposes listed above, even if no fishery benefits accrue. Likewise, a deepwater reserve in which scientists can study community and population structure, and ecosystem processes without the confounding effects of fishing could be successful in terms of defining ecological baselines and fostering research, even if fishery yields are not enhanced. The placement and design of such reserves require careful thought and analysis, but perhaps not as much as a marine reserve aimed at increasing fishery yield.

Marine reserves with the express purpose of enhancing fisheries yield are probably more likely to fail in the absence of careful design than are other types of marine reserves. For example, placement of reserves may also be crucial to ensure fishery enhancement, because some areas may serve as sources of larvae or young fish, while others may serve as sinks. If a fishery is limited by the number of spawning adults, and if the marine reserve network does not protect enough spawners, the network would fail to restore the fishery. If a fishery is limited by pre-recruit survival, a marine reserve might be established to protect nursery areas from damage by fishing gear and fishing mortality; but fishery yields would not be enhanced unless the reserve was carefully designed to protect *only* the nursery areas, not areas to which recruits would be expected to migrate. Similarly, fishery yields would be enhanced if adults migrated outside the boundaries of the reserve network. The extent of such migration would likely be influenced by the size of individual marine reserves and by the ratio of reserve area to perimeter, as well as by the extent to which particular species move.

Perhaps the most robust purpose of a marine reserve designed primarily as a fisheries management tool is to provide insurance against fishery management failures. Fishery management is very often based on uncertain estimates of fish abundance that are derived from infrequently conducted surveys, and on uncertain estimates of fishing mortality and effort (subject to the vagaries of weather, the market, and fishermen's reports). These data are fed into models using many uncertain parameters. Scientists then compare projected abundance and fishing mortality with estimates of the mortality rates and abundance levels that would support maximum sustainable yield. However, these estimates are in themselves based on uncertain relationships between spawning potential and recruitment or on uncertain estimates of natural mortality, compounding the uncertainty. Thus, fishery management protects fish projected to exist, based on uncertain data and models. Well designed and managed marine reserves would protect real fish and real ecosystems even if fishery management completely fails, or results in fishing mortality that is greater than projected.

Recommendations

- Whenever discussing marine reserves, clearly articulate the purposes to avoid confusion and unproductive arguments.

- Marine reserves chosen on the basis of natural beauty, proximity to research and educational facilities, or inclusion of recognizable habitat-types or communities (e.g. kelp forests, rocky outcrops, etc.) can be successful in providing research and educational opportunities, establishing baselines for ecosystem health to guide policy, providing a sense of marine "wilderness" that many people value, and directly protecting biodiversity, even if they do not enhance fishery yields.

- Marine reserves intended as fishery management tools need to be carefully designed to address specific factors germane to enhancing fishery yields, or to protecting spawning potential.

- Establish more marine reserves in the short term, to serve as the basis for research that will guide the establishment of marine reserves in the future. There are limits to how well a marine reserve or a network of marine reserves can be designed in the near-absence of practical experience, which is the situation now.

Marine Reserves: Lessons from Florida

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Abstract

The successes and failures of three Florida marine reserves are examined relative to design criteria proposed by Ballantine (1997a, b). The oldest no-take reserves in the United States are estuarine reserves created in 1962 in the Merritt Island National Wildlife Refuge. In 1994 the South Atlantic Fishery Management Council established a reserve to protect fish and coral ecosystems in the *Oculina* Banks on the East Coast. In 1997 the Florida Keys National Marine Sanctuary established the first planned network of no-take marine reserves in North America. Results show that success and public support are more likely if key design principles are followed. Lessons from these case histories should be useful in California and elsewhere.

Introduction

Florida is typical of many coastal areas facing a crisis in fisheries management due to expanding fishery demands and declining resources. Due to a variety of biological and social factors, traditional fishery management practices have often failed to maintain sustainable fisheries and protect biodiversity (Bohnsack and Ault 1996, Roberts 1997). Because of these failures, networks of `no-take' marine reserves, areas protected from all extractive activities, have been recommended to protect biodiversity, maintain sustainable fisheries, and restore depleted aquatic ecosystems (Plan Development Team 1990, Bohnsack 1996). Spatial protection using no-take marine reserves is a habitat and ecosystem based management approach ideally suited to the ecology of most marine organisms (Bohnsack 1993, 1994, Roberts 1997). Reserves can potentially treat problems of serial depletion of more vulnerable species and detrimental genetic selection, as well as growth and recruitment overfishing (PDT 1990). Besides providing fishery benefits, marine reserves protect marine ecosystems, improve non-consumptive recreational opportunities, diversify the coastal economy, increase scientific understanding of resource dynamics, and facilitate social appreciation and protection of marine resources (Ballantine 1997a).

Because marine reserves are a relatively new management approach, standard design criteria are still being developed and evaluated. Ballantine (1997a,b) proposed several design criteria (Table 1). Permanent marine reserves should include all representative habitats and have a no-take rule except for limited collecting for research and education purposes. Individual sites should be replicated and in a network design with the goal of being self sustaining. Public access involving non-consumptive activities should be encouraged. Ballantine also suggested protecting a minimum of 10% of each habitat. This paper discusses the successes and failures of three Florida marine reserves in relation to these criteria.

Table 1. Essential design criteria for marine reserves. Modified from Ballantine (1997a, 1997b).

1. **Biogeographic representation.** Include representation of all marine habitats in every biological region. The general pattern of 'no-take' areas is determined by marine topography.
2. **No-take.** Acceptability and practicality are highly dependent on the `no-take' rule.
3. **Permanent protection.**
4. **Replication.** Replication is essential.
5. **Network Design.** Networks are necessary to provide emergent properties and to provide connectiveness between reserves. System efficiency and stability depend on supportive interactions between reserves.
6. **Self-sustaining.** The minimum level of protection is that which is self-sustainable.
7. **Size and Total Area.** The area required to provide direct benefits needs to be at least 10% of the total areas and 20-30% for optimum benefits to be realized. Reserves should be larger and further apart when moving from inshore to offshore.
8. **Provide public access.** Public support depends on access for greater understanding and appreciation.
9. **Create independently of regulations required to treat problems created by exploitive activities**. Reserves should be created to protect the ecosystem and not solve specific problems. No-take reserves are additional measures to fisheries management.
10. **The regional arrangement is partly deterministic and partly an optimization.** The precise location of 'no-take' areas is not deterministic and must be based on general guiding principles. A basic reason for establishing reserves is because of our ignorance, not because of our knowledge.

Background

Florida has many marine protected areas. In 1934, the first marine protected area in the Southeastern United States was established in the Dry Tortugas, Florida (Davis 1981). Since then, numerous levels of resource protection have been applied to specific areas. Some areas protect single species from harvest for fishery purposes such as pink shrimp (*Penaeus duorarum*) in the Tortugas sanctuary off southwestern Florida (Klima et al. 1986) and spiny lobster (*Panulirus argus*) in Dry Tortugas National Park, Everglades National Park, and Biscayne Bay Lobster Sanctuary (Davis and Dodrill 1980, 1989). Some areas limit types of fishing, such as commercial fishing in Everglades and Dry Tortugas National Parks. Others have banned certain fishing gears (e.g. spear fishing, fish traps, or trawling). Very few areas have limited recreational fishing. Only three attempts have been made to protect all species or particular habitats with fishing bans.

Results

Merritt Island National Wildlife Refuge. Beginning in 1962, approximately 40 km^2, 22% of aquatic areas, in the Merritt Island

National Wildlife Refuge (MINWR) were closed to fishing and public access for security needs of the Kennedy Space Center at Cape Canaveral (Fig. 1). This action unintentionally created two no-take estuarine reserves. After two decades, the effects of closure on larger fish species was examined by Funicelli et al. (1988) and Johnson et al. (unpubl. data, National Marine Fisheries Service, 75 Virginia Beach Dr., Miami, FL 33149). Catch-per-unit-effort (CPUE), diversity, and fish sizes of economically important commercial and recreational species were significantly greater in two unfished areas (Banana Creek and North Banana River) than in nearby fished areas of Mosquito Lagoon, Indian River and South Banana Creek. Compared to fished areas, CPUE (standardized to remove habitat and environmental influences) was 2.5 times higher for total gamefish and for individual species: spotted seatrout (2.4x), red drum

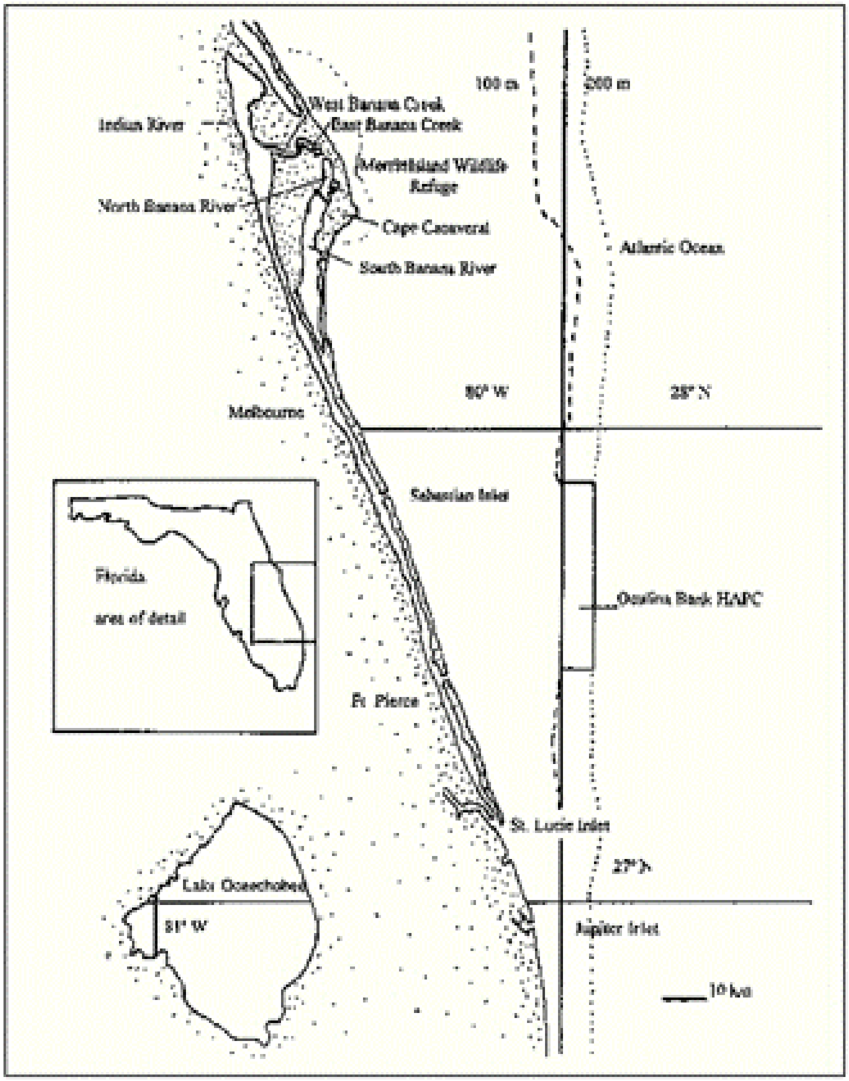


Figure 1. Location of marine reserves at Merritt Island Wildlife Refuge and *Oculina* Banks.

(6.3x), black drum (12.8x), snook (5.3x), and striped mullet (2.6x) (Johnson et al., unpubl. data). Tagging studies documented the export of individuals from reserves to surrounding fished areas. Also, the condition and large size of fishes suggested that breeding populations existed in protected areas for some species.

***Oculina* Bank Reserve**. The first recommendation to establish no-take marine reserves to deal with fishery problems occurred in 1990 when the South Atlantic Fishery Management Council's (SAFMC) Snapper-Grouper Plan Development Team recommended closing up to 20-30% of the shelf in order to protect at least 20% of the spawning potential of the reef fish complex (PDT 1990). Their report was later endorsed by an independent peer-review panel (Roberts et al. 1995). In response, the SAFMC experimentally closed for 10 yr the *Oculina* Banks off the east coast of Florida in 1995 to all trawling, bottom fishing, and anchoring, although drift surface fishing and trolling for pelagic species were allowed. The *Oculina* Banks had been documented as an important grouper spawning site (Gilmore and Jones 1992) and was designated a Habitat of Particular Concern (HPAC) in 1984 because of extensive growth of *Oculina* coral. The closed area was 6.4 km x 45 km (4 x 28 mi) at approximately 87 m (270 ft) depth, 29 km (18 mi) off the Florida east coast (Fig. 1).

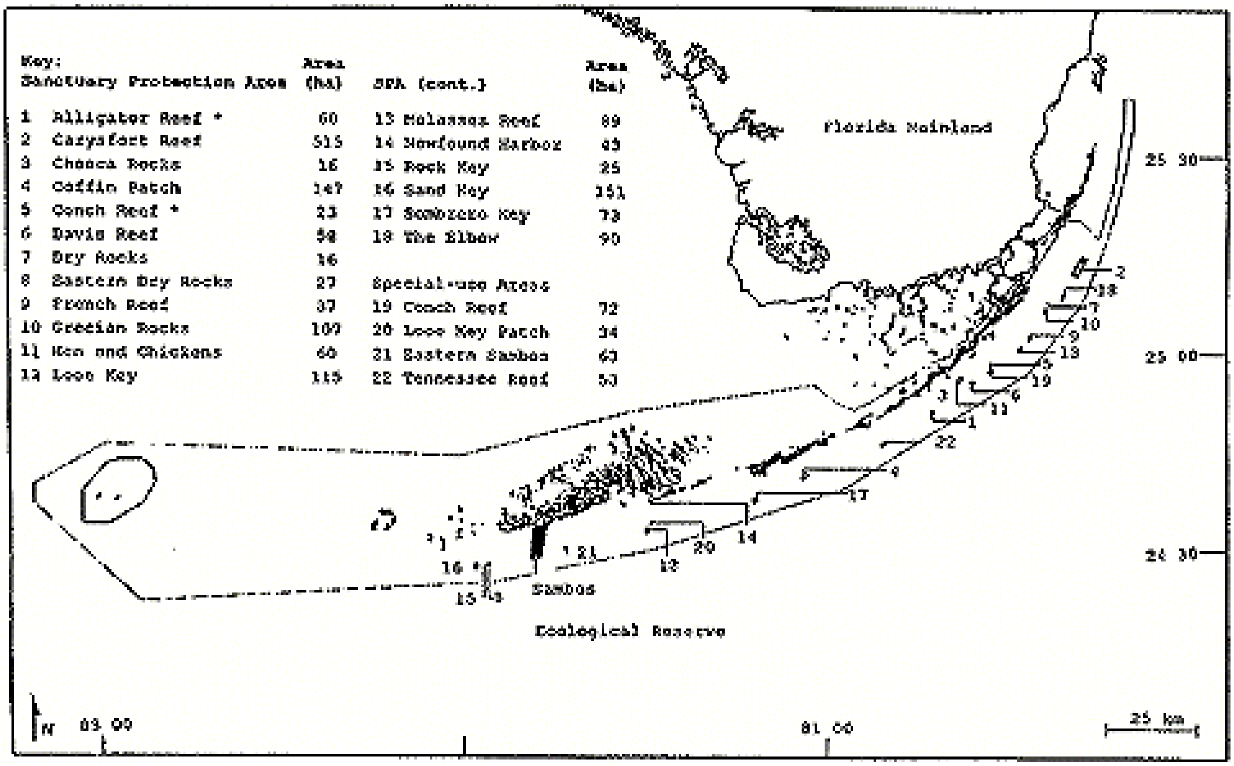
Although still early in the experimental period, the *Oculina* reserve has had several documented problems that may minimize its effectiveness. First, much of the coral habitat had been destroyed, apparently from shrimp or scallop trawls (C. Koenig and C. Grimes, NMFS/SEFSC Panama City, FL, unpublished data) and may no longer be attractive to fishes. Second, there were numerous complaints about lack of awareness, compliance and enforcement of regulations. In 1996, experimental concrete structures were placed in the reserve with attached living *Oculina* to determine if habitat recovery could be enhanced by seeding (C. Koenig and C. Grimes, NMFS/SEFSC, Panama City, FL, unpublished data). When re-examined a year later by remote video, the transplants were living and had grown, suggesting that seeding could be used to recover damaged habitat. However, the structures were fouled with fishing line and gear, indicating a lack of compliance with the bottom fishing prohibition. Based partly on these observations, the SAFMC in 1997 expanded protection to prohibit all fishing in the reserve.

Florida Keys National Marine Sanctuary. In 1990 the U.S. Congress designated the 9,515 km^2 Florida Keys National Marine Sanctuary (FKNMS; Fig. 2). The NOAA sanctuary specifically excluded areas under jurisdiction of the National Park Service (Everglades, Biscayne, and Dry Tortugas National Parks). A draft management plan was developed based on scientific advice, public involvement, and cooperative Florida and federal efforts (Bohnsack 1997). An important, but contentious element of the plan was the proposed creation of 26 ‘no-take’ zones. The National Marine Fisheries Service's (NMFS) Southeast Fisheries Science Center had recommended closing at least 10-15% of the Sanctuary to be able to provide and detect significant fishery benefits. Based on compromises and public input, the resulting draft plan reduced the total no-take area to approximately 6% of the Sanctuary (Department of Commerce 1994).

No-take zones in the draft management plan included three large "Replenishment Reserves" (later renamed Ecological Reserves), 19 small (mean 0.82 km^2, range 0.16 – 3.27) "Sanctuary Preservation Areas" (SPAs), and four small "special use" research zones (mean 1.15 km^2, range 0.68-1.77). The research zones had limited access and were intended, in part, for research to assess the effects of diving activities. The SPAs protected one habitat from extractive activities, the intensively used, high relief coral reef at many popular diving locations. The three large ecological reserves included representative areas with multiple habitats in the Upper Keys, Lower Keys, and the Tortugas. Each extended as a band, several km wide, from shore to offshore areas. Each was intended to be large enough to have some potential ecological integrity. The largest reserve (377 km^2) was placed most upcurrent in the Tortugas because this was considered a potentially important source area for larvae dispersed by the Florida and loop currents. The second largest (79 km^2) was proposed at Carysfort Reef, Key Largo, an area of high biodiversity in the John Pennekamp Coral Reef State Park and the Key Largo National Marine Sanctuary. The smallest ecological reserve (31 km^2) included rich inshore and offshore reef habitats at Western Sambos Reef in the Lower Keys.

After public comment, the no-take areas in the final plan were reduced to less than 1% of the Sanctuary, mainly by the elimination of the two largest ecological reserves (Department of Commerce 1996). Reasons for dropping these two reserves are enlightening. The largest was rejected, in part, because of a perceived lack of habitat information and opposition to its large size. More important, however, was opposition because of the lack of coordination between NOAA who manages the FKNMS and the National Park Service who manages Dry Tortugas National Park. The Sanctuary Advisory Council recognized that for a reserve to be effective, the two agencies must coordinate their efforts and include habitats in both areas. Despite the initial rejection, the final plan calls for creating a new ecological reserve in the Tortugas region within two years after implementing the management plan and after additional planning and coordination (Department of Commerce, 1996). This effort was initiated in 1998 by FKNMS.

The Key Largo Ecological Reserve was rejected partly because of influential local political opposition and the perception that there was sufficient protection already under regulations of Everglades National Park, Biscayne National Park, John Pennekamp Coral Reef State Park, and the Key Largo National Marine Sanctuary. A major focal point for opposition was that this was the only proposed "ecological reserve" that made exemptions of the 'no-take' rule: commercialspiny lobster fishing would be continued and catch and release fishing would be allowed in shallow nearshore areas. Many recognized that these exemptions for an "ecological reserve" were contradictory to the intendedpurpose of providing areas in natural balance. Allowing fishing for spiny



Key:

Sanctuary Protection Area	Area (ha)	SPA (cont.)	Area (ha)
1 Alligator Reef *	60	13 Molasses Reef	89
2 Carysfort Reef	515	14 Newfound Harbor	43
3 Cheeca Rocks	16	15 Rock Key	25
4 Coffin Patch	147	16 Sand Key	151
5 Conch Reef *	23	17 Sombrero Key	73
6 Davis Reef	58	18 The Elbow	90
7 Dry Rocks	16		
8 Eastern Dry Rocks	27	Special-use Areas	
9 French Reef	37	19 Conch Reef	72
10 Grecian Rocks	107	20 Looe Key Patch	34
11 Hen and Chickens	60	21 Eastern Sambos	63
12 Looe Key	115	22 Tennessee Reef	53

Figure 2. Location of sanctuary protected areas (SPAs) and the Sambos ecological reserve in Florida Keys National Marine Sanctuary.

lobster was especially troublesome because spiny lobster was potentially an important benthic keystone species.

On July 1, 1997, the Western Sambos Reef Ecological Reserve, together with 18 SPAs and the four special-use research zones, became effective. These provide a total of 46 km^2 as no-take marine reserves. An additional four SPAs (3.07 km^2) were modified to allow catch and release trolling. Direct observations so far indicate excellent compliance with the closures due to the presence of buoys marking zone boundaries and an intensive public awareness campaign. Frequently, experienced users provide self-enforcement by alerting novice users to the rules on the water. Although it is too soon to determine biological impacts, one obvious change occurred even during the first summer. Spiny lobster were frequently seen in SPAs and the ecological reserve in August and September after the fishing season opened in early August. In prior years, spiny lobster were rarely seen after the first week of the season.

Discussion

Successes. The two unique 'no-take' estuarine reserves at MINWR were extremely successful in protecting biodiversity and benefiting populations of exploited species inside protected areas. Research demonstrated that the reserves benefited fisheries by exporting juvenile and adult fishes to surrounding fishing grounds. Much of this success can be attributed to excellent compliance and strict enforcement.

The *Oculina* Bank reserve represents an important first step by a fishery management agency to attempt to seriously evaluate the value of permanent closed areas to fisheries management. Also, preliminary experiments suggest that although the *Oculina* habitat has been heavily damaged from fishing, coral transplants may accelerate habitat restoration.

The FKNMS now has the first planned network of no-take marine reserves established in continental North America. This represents a major step forward in our philosophy for protecting and managing marine resources. Acceptance of the no-take concept in FKNMS was facilitated by widespread public education and involvement, and the fact that the 'no-take' provision applied to all consumptive users (Bohnsack 1997). Replicated reserves were publicly supported for goals of ecosystem protection and when consistent with the no-take principle. Agreement to establish reserves was facilitated by involving broader community interests besides fishing interests (Bohnsack 1997).

The Sambos ecological reserve is the first marine reserve in the U.S. designed to include multiple habitats. Although the two largest ecological reserves were dropped from the final plan, provisions were made to add one in the Tortugas within two years. This provision is a success in that it shows public support and recognition of the importance of having a well-designed reserve in the region.

Failures. Although it is too soon to determine the eventual biological impacts of the *Oculina* Bank, the early problems arose from allowing some types of fishing. This reserve so far represents a scientifically confounded experiment because the habitat is severely damaged, there is evidence of widespread poaching, and there is only one non-replicated reserve for comparative purposes. The remoteness of the site, lack of public awareness and enforcement, and the failure to make the site completely 'no-take' has facilitated poaching and confusion for the public. In addition, the depth and current conditions make monitoring and research extremely difficult and expensive. Although important, the *Oculina* habitat is only a small part of the reef ecosystem in the southeastern U.S. The provision of waiting 10 yr before implementing other such zones could be considered a failure in taking a precautionary approach to management. In late 1997, the SAFMC voted to prohibit all fishing in the *Oculina* reserve and to add a surrounding 2 mi (3 km) no-trawl buffer zone to ease the difficulty of enforcement. These actions should increase ecosystem protection, enforcement capability, and public compliance.

Despite success in establishing marine reserves in FKNMS, considerable skepticism and opposition was mounted by fishing interests who wanted complete proof of effectiveness before giving support. This opposition resulted in considerably less protected area than was recommended by scientific advice. Some objectors demanded proof that fishing caused damage before they would accept ‘no-take’ areas, conveniently ignoring the fact that undisturbed areas are necessary to demonstrate such damage.

One failure in the FKNMS was that the no-take protection tended to be applied only to the most charismatic habitat: high-relief coral reefs. Except for the one ecological reserve, similar protection was not applied to other habitats. Clearly there is a need for further research and public education about the importance of protecting other habitats. The lack of protection for reef habitats below the 18 m contour was also a notable shortcoming of the present plan.

The rejection of the two largest proposed ecological reserves will prevent sufficient protection to measure and demonstrate any significant fishery benefits. Although the remaining protected areas are anticipated to provide many ecological, scientific, and educational benefits, they are unlikely to provide significant fishery benefits because too little habitat was included. In rejecting the Tortugas ecological reserve, the Sanctuary Advisory Council recognized that any successful reserve would require inclusion of areas inside the Dry Tortugas National Park and participation by the National Park Service. Rejection of the Key Largo reserve was especially unfortunate because that region had the highest biodiversity, received the most intense use, and probably needed increased protection, despite the number of surrounding parks.

The decision to include some fishing in the proposed Key Largo reserve was done in the spirit of compromise assuming that some increased protection would be better than none. Some of us mistakenly thought that it would eventually be corrected in future revisions to the Sanctuary Management Plan. Instead, the logical inconsistency of allowing some fishing was a basis for rejecting the zone entirely. Violation of the key no-take design rule made rejection easier.

Design Criteria. The conformity of marine reserves to Ballantine's design criteria varied considerably between sites and may help explain some of the successes and failures (Table 2). Ballantine considered the no-take rule particularly important, which may help explain the better results at MINWR and FKNMS than at the *Oculina* Banks. Only MINWR and FKNMS have replicated sites and only the FKNMS reserves are geographically dispersed. The ecological reserves in FKNMS and the closed areas in MINWR protect a variety of habitats. Size of protected areas varies considerably between sites. The total protected area is still a small fraction of the region although possibly significant in size for *Oculina* and high relief coral habitats.

Ballantine (1997a,b) considered public access essential for developing public appreciation and understanding of marine reserves and conservation efforts. The experience at MINWR supports this claim. Although the MINWR reserves are a biological success, lack of public access, largely due to security issues, has prevented any significant public appreciation or awareness of protection benefits. Also, the scientific community has been largely unaware of effects because the scientific research is only now in the process of being published.

Ballantine noted that placing no-take zones within easy public access facilitates compliance and enforcement. In support of this premise, easy public access to FKNMS protected zones appears to enhance compliance while the remote location of the *Oculina* reserve has led to problems with

Table 2. Comparison of Florida reserves with regard to Ballantine's design criteria.

Design Criteria	Merritt Island Wildlife Refuge	*Oculina* Banks	FKNMS Sanctuary Protected Area	FKNMS Ecological Reserve
Geographically Dispersed	No	No	Yes	No
Representative Habitat	Estuarine	*Oculina*	Coral Reefs	Coral Reef Seascape
No-Take Rules	Yes	No	Yes	Yes
Permanent Protection	Yes (since 1962)	Yes (10 yr review)	Yes (5 yr review)	Yes (5 yr review)
Replication	Yes	No	Yes	No
Self-Sustaining	Yes	Unknown	Unknown	Unknown
Public Access	No (security)	No (depth)	Yes	Yes

compliance. I suggest that this problem of compliance at the *Oculina* reserve is short-term and, in particular, the result of a lack of public experience, understanding and acceptance of no-take zones. Hopefully, compliance will improve as the public gains experience, sees benefits, and begins to understand and appreciate the value of marine reserves.

Conclusions

The Florida experience supports Ballantine's design criteria. Success was more likely when key criteria were followed and failure often resulted when not followed. Exempting some users from the no-take provision clearly reduced public support and jeopardized attaining goals.

The establishment of a marine reserve network in the Florida Keys represents a significant philosophical improvement in protecting marine resources in the U.S. despite the fact that the total area fell short of scientific recommendations. Marine reserves were included in the final FKNMS management plan despite some intense opposition because most of the public agreed that establishing no-take reserves was a reasonable and necessary action. There was less agreement about the level of protection necessary, the total area to protect, and the specific location of marine reserves. An obvious lesson is that coordination between governmental agencies is essential. Success resulted from coordination and cooperation between state and federal agencies. In contrast, failure of coordination and cooperation between two federal agencies resulted in the rejection of the Tortugas ecological reserve.

The Merritt Island National Wildlife Refuge provides a unique case history of effects of estuarine reserves and another example in a growing list of successful no-take reserves protecting biodiversity. Compared to surrounding areas, it clearly shows the impacts of fishing on species composition and abundance, and is also one of the few reserves in which export of fishes to surrounding fishing grounds has been well documented.

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Stakeholder Group Perceptions of Marine Reserves in the Florida Keys National Marine Sanctuary

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Introduction

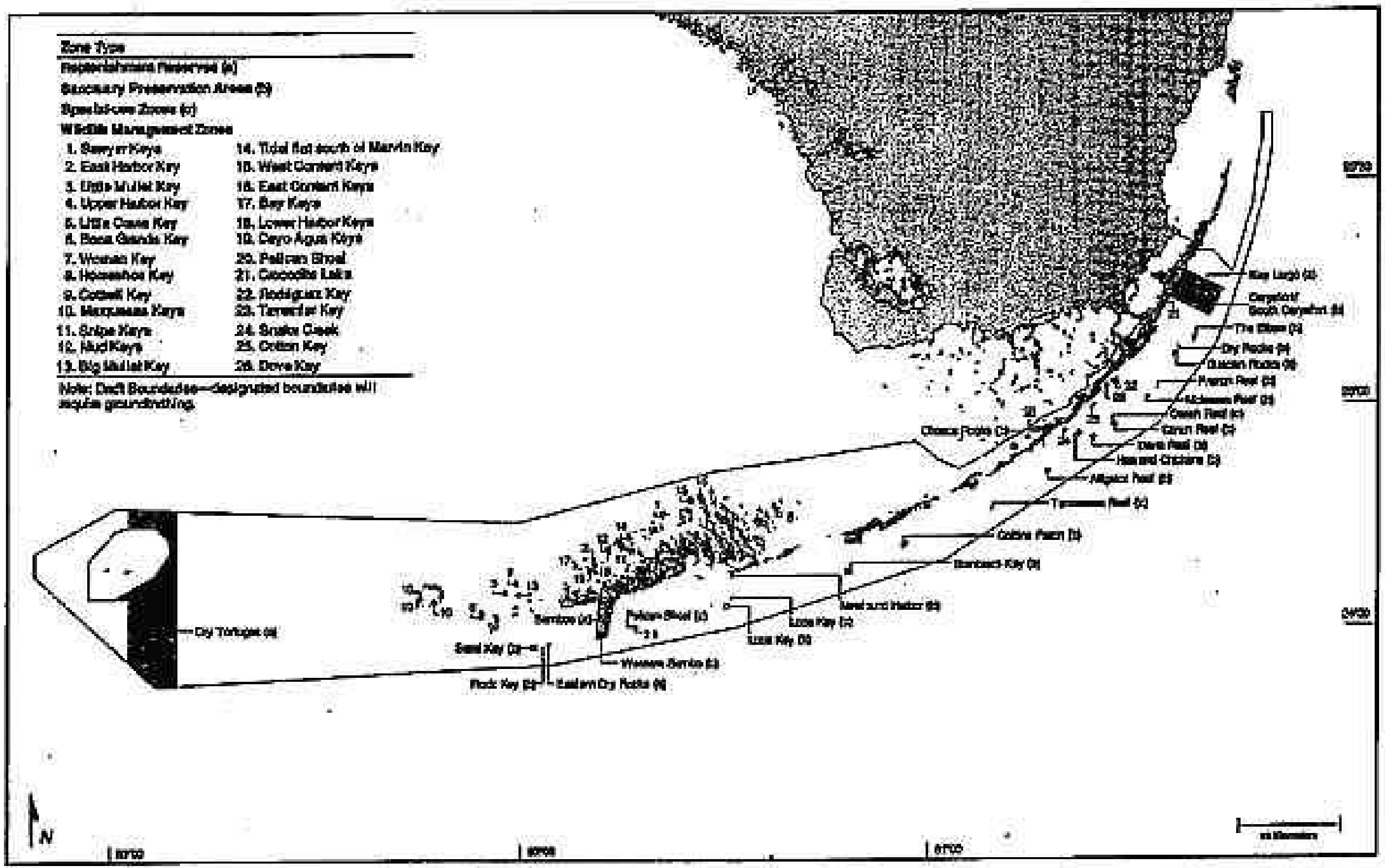
Marine protected areas and their subset of marine reserves ("no take" zones) are enjoying increasing use as fisheries management tools (Ballantine 1995). Designation of a marine reserve involves ecological issues and uncertainties (location, size, shape, duration, placement in series). Marine reserve designation also raises a number of social science questions (Wolfenden et al. 1994, Farrow 1996). These issues include the political acceptability of the marine reserve concept, the social/economic groups that will stand to gain and lose as a result of reserve creation, and the perceptions and opinions that group members possess about the marine reserve.

We have conducted comprehensive surveys of different users of newly designated marine reserves in the Florida Keys in order to 1) understand the social and economic interests and characteristics of the groups, 2) assess the groups' opinions and perceptions of the marine reserves and their formation, 3) elucidate the obstacles faced by marine reserve managers during the designation process, and 4) recommend strategies that managers might consider when working with the public on reserve formation. The results of this research have applicability to the formation of marine reserves wherever they might be.

Introduction to the Florida Keys National Marine Sanctuary

Congress created the 9,515 km^2 Florida Keys National Marine Sanctuary (FKNMS) in 1990 as part of the National Oceanic and Atmospheric Administration's (NOAA) National Marine Sanctuary Program. The purpose of the designation was to protect the coral reefs, sea grasses, mangroves, and other marine resources of the Florida Keys. The enabling legislation mandated that NOAA develop a zoning strategy as part of the Sanctuary Management Plan to ensure resource protection (Suman 1997).

NOAA coordinated the lengthy development of the Draft Management Plan that was released in March 1995. The Zoning Action Plan proposed five distinct types of zones: Replenishment Reserves, Sanctuary Preservation Areas (SPAs), Wildlife Management Areas, Special-use Areas, and Existing Management Areas (Bohnsack 1997; refer to Map 1.) The three proposed Replenishment Reserves (Key Largo, Sambos, Dry Tortugas) would have accounted for about five percent of the Sanctuary's area (487 km^2), while the 19 small SPAs, protecting heavily used shallow reefs, totaled 15.55 km^2. Generally, the Replenishment Reserves and SPAs were to be "no-take" areas where consumptive uses would be prohibited. Replenishment Reserves were large areas with contiguous, diverse habitats intended "to minimize human influences, to provide natural



MAP 1. Preferred Zoning Strategy proposed in the 1995 Draft Management Plan for the Florida Keys National Marine Sanctuary.

spawning, nursery, and permanent residence areas for the replenishment and genetic protection of marine life" (NOAA, 1995, p. 264). The Draft Management Plan also proposed four "Special-use Areas" designated for research only that would account for an area of 1.86 km^2. Designation of Wildlife Management Areas would restrict human access to bird nesting and feeding areas, as well as turtle nesting sites, while Existing Management Areas were sites within the FKNMS borders that were managed by state or federal regulations prior to FKNMS designation.

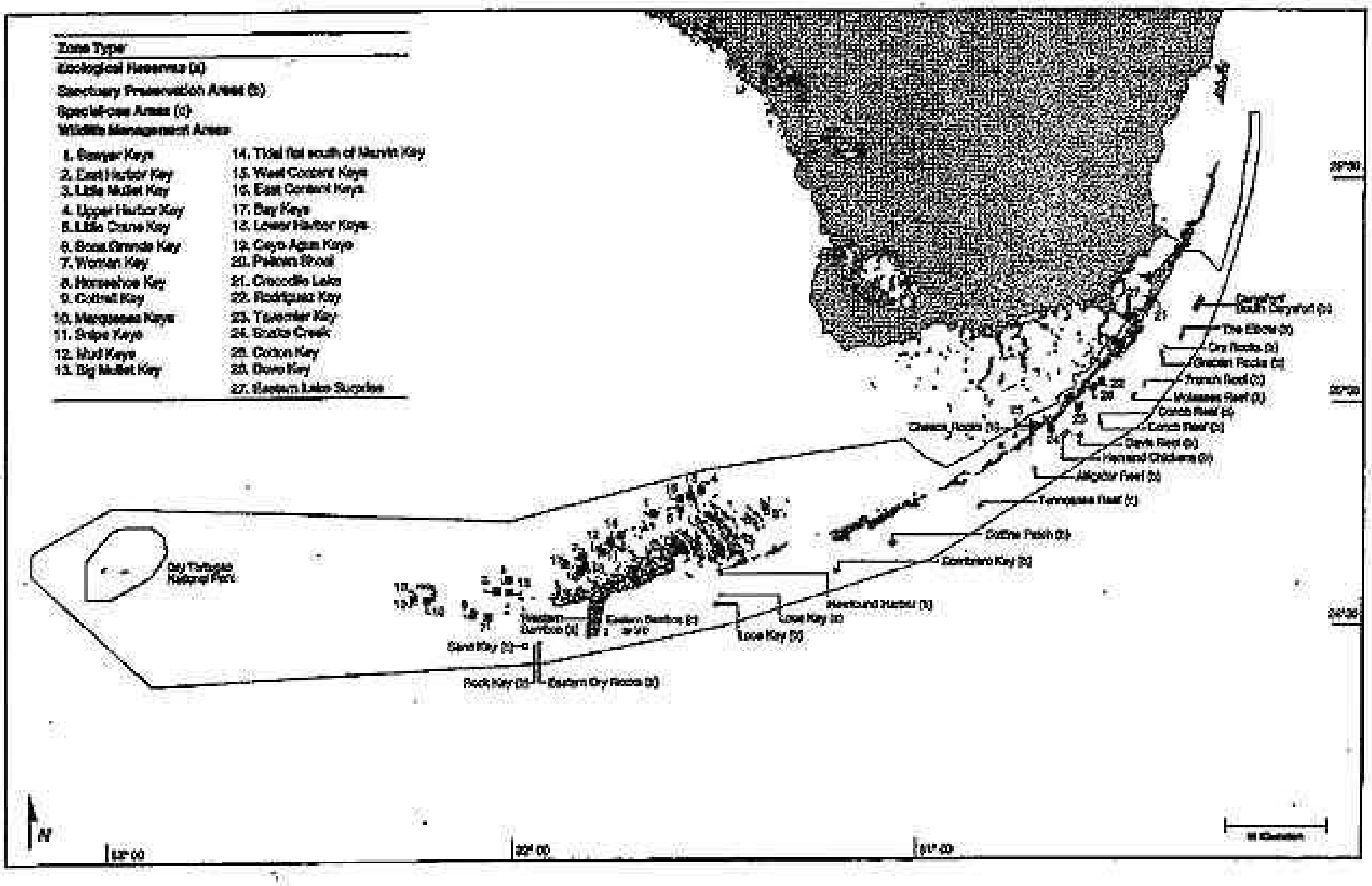
The public hearing process exposed the extremely contentious nature of the FKNMS, especially the Zoning Action Plan (National Research Council 1997, Suman 1997). Many public comments focused on the allegedly unproven hypothesis that the Replenishment Reserves would export adult fish and larvae to the surrounding waters (Florida Sportsman Magazine 1995). Opposition to the FKNMS was led by the Conch Coalition, a loosely organized grassroots group comprised of treasure salvors, commercial fishermen, real estate interests, and other Monroe County (Florida Keys) residents waving an anti-regulation banner. Concern centered on a perceived excess of regulation, intervention by the federal government, and displacement of traditional users and uses.

The acrimonious and polarized debate on these issues delayed the release of the FKNMS Final Management Plan until September 1996 (Suman 1997). NOAA significantly altered some aspects of the Zoning Action Plan with only one small "no take" reserve (Western Sambos) remaining out of the three proposed (NOAA 1996; refer to Map 2.) NOAA also postponed establishment of the large Dry Tortugas Replenishment Reserve pending further studies on the final boundary. Finally, NOAA changed the name "Replenishment Reserve" to "Ecological Reserve" to "reflect public concerns over the purpose of these areas" (NOAA 1996, p. 255).

As a result of the modifications, NOAA zoned only about 0.3 percent of the FKNMS or 30 km^2 as an "Ecological Reserve". Eighteen small SPAs (16.51 km^2) continued to protect shallow reef areas that experience heavy diving pressure (NOAA 1966, p. 262 & 271, Bohnsack 1997). Ecological politics had taken their toll on marine reserve implementation.

Stakeholder Groups

Numerous stakeholder groups play a role in marine ecological politics of the Florida Keys. These represent the permanent population of 80,000 Monroe County residents and, in addition, approximately 2.5 million tourists who visit the county each year (Leeworthy 1996). This research focuses on three stakeholder groups: commercial fishers, commercial dive operators, and members of environmental groups. All have a special interest in the marine reserves of the FKNMS that they voiced during the public hearing process. Commercial fishers were concerned about creeping fishing regulations and exclusion from marine space. Dive operators carry scuba and snorkeling enthusiasts to the shallow coral reefs, many of which are now designated as SPAs, and wished to guarantee their continued access to these areas. National and local



MAP 2. Zoning Strategy of the 1996 Final Management Plan for the Florida Keys National Marine Sanctuary.

environmental groups have long lobbied for increased protection of the marine resources of the Florida Keys and increased restrictions on consumptive use of the marine resources.

Approximately 2,300 persons in the Florida Keys hold a Florida Saltwater Products License and are classified as commercial fishers. Of these individuals, greater than half are fulltime fishers. The Florida Keys' fisheries are multispecies-based, and the target species depend on the season and applicability of restrictive regulations. Important fishery resources include stone crab, lobster, shrimp, snappers and groupers, mackerel, tropical fish and sponges, and offshore species (dolphin and tuna). In 1995, Monroe County's shellfish and finfish landings had a dockside value of $68.9 million, the largest of any county in Florida (FDEP 1996). Monroe County commercial fishers harvest a major portion of their total catch inside the boundaries of the FKNMS (Milon et al. 1997).

Approximately 20 to 30 percent of visitors to Monroe County dive or snorkel during their visit (Leeworthy and Wiley 1996). Visitors to the Florida Keys spend about $31 million per year on scuba diving and snorkeling activities. (English et al. 1996) While some visitors have their own boat, many divers pay a commercial dive operator to transport them to a dive site. We identified approximately 75 commercial dive operators in Monroe County, about 80 percent of whom have a dive destination that is a FKNMS SPA (Shivlani and Suman in press).

National environmental groups, such as The Nature Conservancy, the Center for Marine Conservation, and The Wilderness Society have supported NOAA's efforts to implement the FKNMS. Local environmental groups, such as Reef Relief, Last Stand, and the Sanctuary Friends of the Florida Keys, claiming a membership of over 3,600 persons and focusing on local issues, were active participants in the FKNMS planning process. Over half of the members of these local groups engage in each of the following non-consumptive activities: swimming, snorkeling, boating, and bird watching. These individuals are also Sanctuary users, although their uses are largely not commercial or extractive.

Survey Methodologies

During 1995, we developed three surveys to characterize the demographic, social, and economic status of members of the three target stakeholder groups. Additional questions probed informational sources on the FKNMS and Zoning Action Plan, participation in various types of public fora, perceptions and acceptance of the Sanctuary zoning strategy, and expected outcomes of the zoning strategy (Alreck and Settle 1985). The three groups of surveys were essentially identical with the exception of a few questions. We developed questionnaires in consultation with organizations of commercial fishers, dive operators, and environmental groups and revised the surveys as a result of pilot field tests.

We conducted personal interview surveys with commercial fishers and dive operators and mail surveys with members of environmental groups from June 1995 until March 1996. In total, the research team sampled 337 commercial fishers or 15 percent of the total pool of the 2,430 Saltwater Products License holders who resided in

Monroe County. Our sample pool does not include about 30 individuals who refused to participate in our survey. Interviewees were identified through the major fish houses in the Florida Keys, the commercial fishing organizations, the Florida Sea Grant extension agent, and phone calls. Based on the total pool of commercial fishers, we determined that a randomized sample size of 332 interviewees would achieve a sample error of plus or minus 5 percent of the total sample. The ratios of full-time/part-time fishers in our sample paralleled that in the total population.

"Dive operators" conduct businesses that specialize in diving/snorkeling, transport divers to specific field sites, operate throughout the year, and utilize vessels equipped especially for diving. We identified 75 "dive operators" in Monroe County and conducted personal interviews with 62 of these individuals or 83 percent of that pool. Thirteen dive operators refused to participate in our research efforts. The number of interviewees was more than sufficient to guarantee a 95 percent confidence interval.

We obtained the mailing lists of the membership of the three local environmental groups and sent questionnaires to the pool of 3,680 individuals. We received mail responses from 401 environmental group members or 11 percent of the total sample. This response rate was sufficient to guarantee a 95 percent confidence interval.

Attitude and perception questions elicited responses ranging from 1 to 5 that indicated degrees of support for or opposition to statements, i.e. Likert scale survey techniques (Alreck and Settle 1985). When we report support for a statement, we sum Responses 1 (Strongly Agree) and 2 (Moderately Agree). Similarly, opposition to a statement sums Responses 5 (Strongly Disagree) and 4 (Moderately Disagree). Response 3 represents neutral reactions to the statements.

The surveys began with general questions to probe the social and economic status of the interviewees: age, ethnicity, income and economic activities, group memberships, and uses of the marine environmental resources. Questionnaires then elicited responses regarding the sources of information used to obtain information regarding the FKNMS zoning strategy, the relative value and usefulness of these information sources, and the types of public participation activities in which the interviewees engaged.

We then tested interviewees' attitudes and perceptions regarding the fairness of the FKNMS planning process, the purpose of the zones, potential beneficiaries of the zoning strategy, and overall support for the zoning strategy of the FKNMS. Table 1 lists some of the survey questions that we adopted: Questions 1, 2, 3, and 4 (FKNMS planning process); Questions 5, 6, 7, and 9 (purpose of the zones); Questions 8 and 10 (beneficiaries of the zones); Questions 11, 12, 13 (support for the zoning strategy).

Survey Results and Their Significance

Using the surveys, we obtained information on the three groups' sources of information regarding the FKNMS zoning strategy, participation in public fora, and their perceptions regarding the planning process,

TABLE I. Comparative Survey Responses of Commercial Fishers, Dive Operators, and Members of Local Environmental Groups

STATEMENT	COMMERCIAL FISHERS N=337		DIVE OPERATORS N=62		ENVIRONMENTAL GROUP MEMBERS N=401	
	Support	Oppose	Support	Oppose	Support	Oppose
1. Information that NOAA provided you on the zones helped you understand the overall effects of the zones.	11%	38%	46%	28%	37%	12%
2. NOAA's process to develop boundaries and regulations for the zones has been open and fair to all groups.	9%	60%	38%	30%	40%	15%
3. Participation in the Sanctuary process does not matter because the average person cannot influence the decisions.	67%	18%	45%	45%	21%	57%
4. Once Sanctuary regulations are enacted, there will be no way the average person can voice his/her opinion about the usefulness of the regulations.	75%	10%	60%	29%	24%	44%
5. The main purpose of the zones is to increase overall stocks inside the zones.	44%	44%	83%	10%	68%	13%
6. The main purpose of the zones is to increase overall stocks outside the zones.	23%	63%	59%	13%	53%	20%
7. The main purpose of the zones is to conserve and protect marine biodiversity inside the zones.	61%	29%	83%	10%	82%	8%
8. The primary group to benefit from the zones will be commercial fishermen.	5%	90%	24%	62%	23%	43%
9. Zones are the most effective way to reduce user conflict in the Florida Keys.	12%	74%	32%	49%	51%	19%

10. The economic effects of the zones on the economy of the Florida Keys will be positive.	17%	68%	51%	24%	68%	11%
11. I support establishment of zones somewhere in the Florida Keys.	27%	64%	75%	19%	76%	7%
12. I support establishment of zones in the exact locations as proposed in the Sanctuary Plan.	6%	86%	40%	43%	39%	17%
13. I generally support the establishment of the Florida Keys National Marine Sanctuary.	13%	77%	64%	19%	83%	9%

purpose of the zones, beneficiaries of zones, and support for the zoning strategy. We asked all survey participants to indicate whether they had used any of 14 different information sources in learning about the FKNMS and its zoning strategy. These sources included several from NOAA, the commercial media, and anti- and pro-Sanctuary groups.

The commercial fishers' four most common sources of information were newspapers (75%), TV/radio (46%), NOAA public meetings (38%), and sources from commercial fishing organizations (36%). Fishermen who used the different information sources considered that the commercial fishing organizations supplied the most useful and reliable sources of information.

Sources of information most referred to by dive operators were publications of dive organizations (76%), NOAA's Draft Management Plan (69%), newspapers (66%), and NOAA public meetings (57%). Respondents reported that they considered the most useful and reliable source to be the FKNMS Management Plan.

For environmental group members, the four most popular sources of information were publications from their own environmental group (81%), newspapers (78%), TV/radio (47%), and NOAA's Draft Management Plan (42%). Environmental group members ranked the FKNMS Management Plan as the most useful source of information.

Participation in public fora varied among the three interest groups. Participation in one or more NOAA workshops, hearings, or meetings ranged between 65% (dive operators), 44% (commercial fishers), to 34% (environmental group members). Attendance at Sanctuary Advisory Council meetings followed a similar trend: 34% (dive operators), 25% (commercial fishers), and 13% (environmental group members). Likewise, 79% of dive operators, 50% of commercial fishers, and only 40% of environmental group members read parts of the Draft Management Plan. Dive operators appeared to be the most engaged in public participation opportunities, while environmental group members were the least engaged.

We report some of the results from the user group surveys in Table I. These results provide insight into the different positions of the three groups and the perspectives of group members to public processes. The questions that we have selected illustrate the perceptions of respondents to concepts, such as the usefulness of NOAA information on marine reserves, the fairness of NOAA's process in developing zoning regulations, engagement in the public participation process, the purpose of the "no take" zones, beneficiaries of the zones, positive economic benefits of the zones, support for the siting of the zones, and support for the establishment of the FKNMS.

NOAA-generated information on the "no take" zones was generally not well-received by the commercial fishers, and only 11% of that group considered NOAA materials to give satisfactory consideration to reserves' positive and negative effects (Question 1). Dive operators and environmental group members had a much more positive opinion of NOAA information (46% and 37%, respectively).

The perception of NOAA's "fairness" in the development of zone regulations and boundaries varied among the three stakeholder groups (Question 2). Only 9% of the commercial fishers agreed with this concept while agreement among the other two groups was approximately 40%. Fishers felt that they would be harmed the most by the creation of "no take" zones. They perceived themselves not to be part of the process that developed zone location, size, and governing regulations.

Commercial fishers displayed a high degree of alienation from the public process (Question 3 & 4). Two thirds of fishers believed that public participation was futile because it could not influence the outcome, and three fourths of fishers believed that they would be unable to state their opinions about zones once they were established.

The groups varied considerably in their perception of the ecological purposes of zones (Questions 5, 6, 7). All groups considered enhancement of biological diversity inside the zones to be the primary purpose of marine zones. The concept that replenishment reserves might export fish larvae and adults and increase the fish stocks in adjacent waters was met with skepticism by all groups. Only about a quarter of fishers agreed that replenishment was a purpose of zones, while just over half of dive operators and environmental group members expressed support for the concept.

Few individuals from any group considered that commercial fishers would be the primary beneficiaries of the zoning strategy (Question 8), and a mere 5% of fishers considered themselves to be beneficiaries. Half of the environmental group members and a third of the dive operators believed that zones would be the most effective way to reduce user group conflicts (Question 9). Similarly, 51% of dive operators considered the economic effects of zones to be positive. SPAs will most likely attract larger numbers of divers to the Florida Keys and, therefore, benefit this stakeholder group. About 68% of environmental group members believed that zones would have a positive economic benefit from improved marine conservation and increased ecotourism.

Support for the establishment of zones somewhere in the Florida Keys was especially high (75%) for dive operators and environmental group members as they considered that their interests would advance as a result (Question 11). Support dropped, however, when they responded to a question about the exact zone locations that the Draft Management Plan proposed (Question 12). A large number of stakeholders recognized the benefits of marine reserves but preferred not to have one in their vicinity ("Not-In-My-Back-Yard" or NIMBY). For example, residents of the affluent Ocean Reef Club development in Key Largo generally support marine conservation efforts, but they also enjoy fishing and argued that the Key Largo Replenishment Reserve be moved south so as not to abut their properties. Even 27% of fishers supported establishment of reserves somewhere in the Florida Keys, but only 6% could embrace the exact locations that NOAA recommended.

More generally, support for the FKNMS varied significantly by stakeholder group (Question 13). About 83% and 64% of environmental group members and dive operators, respectively, supported the establishment of the FKNMS. However, only 13% of commercial fishers were FKNMS proponents.

Discussion

Commercial fishermen demonstrated high degrees of alienation to the FKNMS planning process and overwhelming opposition to the designation of the FKNMS and its zoning strategy. Even when they believed that they could actually participate in the modification of regulations, fishers tended to conclude that their opinions would be incapable of altering the current scenario. Perhaps fishers' independent nature and occupation, their lower levels of formal education, and repeated negative experiences with numerous government fisheries regulations explain this attitude. Commercial fishermen in Monroe County must deal with complex, and often contradictory, regulations of the Florida Marine Fisheries Commission, the South Atlantic Fisheries Management Council, and the Gulf of Mexico Fisheries Management Council. By 1986, the National Park Service had prohibited commercial fishing in nearby Everglades National Park (Florida Marine Fisheries Commission 1993). In 1994, Florida voters adopted a constitutional amendment to ban nets from state waters, a measure that largely affected commercial fishermen (Barnes 1995). Commercial fishers repeatedly mentioned that, through its zoning strategy, NOAA "was trying to force them out of business". Many commercial fishers stated that they would suffer a negative economic impact from the "no take" zones. Considering the $97,000 average cost of a Monroe County commercial fisher's vessel, one can understand their concern.

Despite their alienation and general opposition to marine reserves, fishers' responses suggest some possible bridges to cooperation with marine managers. Almost half of the sampled fishers participated in some public fora regarding the FKNMS designation; the participation rate was higher than that of environmental group members, who generally seem to believe that the "natural resource administrative system" works for them. It is rather ironic that the vocal participation of fishers, who appear to be so alienated from resource management, actually succeeded in reducing the size and number of the "no take" areas of the FKNMS. On the other hand, the fact that a quarter of commercial fishers could embrace the marine reserve concept someplace in the Florida Keys, as long as the location did not impact their present fishing activities, suggests that a core group of fishers does adopt a conservation ethic.

While dive operators generally are not consumptive users of the marine zones, their businesses are clearly dependent on their access to healthy coral reefs. This group displayed the highest indices of participation in public fora, perhaps related to an average capital investment of $225,000 per dive operator that we surveyed. Although dive operators show some skepticism regarding the public participation process, their group displayed the highest levels of participation. Of the three groups, dive operators held the highest opinion of NOAA-produced information. Generally, dive operators' belief that their businesses will directly benefit from the creation of SPAs affects their perception of the zoning plan. Restrictions on consumptive uses will improve the health of marine resources and, therefore, increase the quality of the diving experience. SPAs will most likely attract larger numbers of divers to the Florida Keys and, therefore, benefit this stakeholder group. Some divers expressed concern that in the future the Sanctuary might limit the number of divers at a dive site or charge user fees (which dive operators could subsequently pass on to divers). However, these potential fears did not greatly reduce dive operators' support for the FKNMS and the establishment of zones.

Members of environmental groups were most supportive of the FKNMS and the zoning strategies. In fact, many of them felt that NOAA should have gone further than it did. For example, the average percentage of the FKNMS area that environmental group respondents would reserve as "no take" zones was 33 percent. Most of these individuals engaged in some type of nonconsumptive use of Florida Keys marine resources and would receive no direct economic gain or loss from the zoning plan. Nevertheless, they believed that restriction on consumptive uses would elevate the public's enjoyment of nonconsumptive uses. Ironically, while they displayed the least evidence of alienation from the public process, environmental group members had the lowest participation in public fora. Perhaps, the absence of a direct economic link to the marine reserves explains this lower level of participation.

NOAA's original attempts to convince the public of the replenishment reserve concept did not meet with great success among any of the three stakeholder groups, although dive operators and environmental group members accepted this concept much more than commercial fishers. Changing the name of these areas from "Replenishment Reserves" to "Ecological Reserves" before releasing the Final Management Plan suggests that NOAA may have realized this. The agency wisely eliminated a name that confused the public and was a lightning rod for the opposition.

Despite NOAA's monumental efforts to develop a zoning strategy for the FKNMS that was ecologically supportable and politically fair, the agency found political waters in the Florida Keys to be turbulent.

Although NOAA distributed thousands of copies of the three volume FKNMS Draft Management Plan, many individuals (especially commercial fishers) considered the document to be too voluminous and complex to be of much benefit to resource users. Despite NOAA's provisions for multiple opportunities for public participation (significantly more than mandated by statutes and regulations), large numbers of persons from all three user groups felt alienated from the participatory process.

In the future, a marine resource agency, such as NOAA, might consider development of abbreviated planning documents that would be more "user friendly" and tailored to the interests of different user groups. The documents should also be understandable by major user groups that do not speak English, like Cuban fishermen who account for 20-25% of the fishing population in the Florida Keys. Perhaps NOAA could employ Sanctuary "extension" agents to work directly with small focus groups of resource users at convenient locations and times. For example, NOAA might develop a joint extension process through commercial fishing organizations and meet commercial fishers at fish houses during non-fishing hours to discuss the zoning strategy and other aspects of the FKNMS. Participatory mechanisms must evolve from rigid forms of one-way communication (resource manager to resource user) to flexible fora with open discussion. In the future, NOAA should enter into planning for marine reserves without preconceived notions about details of these areas. Details should emanate from focus groups between resource managers and consumptive and non-consumptive users. The ultimate goal for resource managers must be to convince stakeholder groups to embrace marine reserves as their own and comprehend the relevance of the reserves to their group's interests (Kelly 1992).

Had NOAA revised its public participation strategy and improved its working relationships with all user groups in the Florida Keys, the agency might have been able to develop a zoning strategy that protected a more extensive area of the FKNMS and engaged the enthusiastic support of larger percentages of all consumptive and non-consumptive stakeholder groups. Instead, the replenishment reserve strategy became a political football that evolved into a sacrificial lamb.

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Trials and Tribulations of Attempting to Establish an Experimental Deep-Water No-Fishing Zone in a National Marine Sanctuary

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The National Marine Sanctuary Program has designated sites in federal and state waters that are of national significance based on natural resource and archeological value. Most sites are not truly sanctuaries from all human activities but are managed for multiple use, including natural resource harvesting (e.g. Barr 1995). Restriction of human activities within sanctuaries is initially determined during the designation process. Generally, activities which took place within each site prior to designation are grandfathered into the site designation, including commercial and recreational fishing activities.

Stellwagen Bank National Marine Sanctuary (SBNMS) is 682 nm^2, located off the north coast of Massachusetts. The site was designated due to an abundance of natural resources including fishes and marine mammals. All historic commercial fishing activities (e.g. using trawl, scallop dredge, gillnet) are allowed and regulation of these activities rests with the New England Fisheries Management Council (NEFMC) and the National Marine Fisheries Service (NMFS). The site is the focus of a wide range of research including understanding the role of landscape processes that structure the abundance and distribution of fishes (e.g. Auster et al., in press). The U.S. Geological Survey is presently using multibeam bathymetry and sidescan sonar to produce high resolution seafloor maps of the site and these provide the basis for sampling for other studies.

An ad hoc group of scientists proposed an experimental management area (EMA) within the sanctuary to act as a reference site to study the impacts of fishing gear (e.g. bottom trawl, scallop dredge) on seafloor habitats. Initial studies have shown that these types of gears can have significant impacts on a range of seafloor habitats (e.g. Auster et al. 1996). However, a systematic study assessing the effects of chronic impacts to a range of habitat types has not been conducted. This type of knowledge is required by managers to begin to manage fishing activities for conservation of habitat integrity. The sanctuary was deemed to be the best site for such work off the northeast U.S. as the entire range of sediment types (i.e. mud to boulder) is found in a relatively small area, recruitment processes of benthic species are influenced by a restricted range of oceanographic processes, high resolution base maps would greatly improve sampling by reducing variability of the within-treatment station characteristics, and the proximity to major ports allows use of smaller vessels and day trips to conduct field work (rather than larger vessels and multi-day support needs for offshore sites).

A proposal was prepared that outlined the conceptual basis for the project (Auster et al. 1995). Studies in the closed area were designed to address the following questions:

1. Are there differences in habitat composition between bottom dragged and protected areas?
2. Is the composition and productivity potential of the benthic community different between dragged and protected areas?
3. Are there differences in benthic microalgal and demersal zooplankton production, biomass, and composition between dragged and protected areas?

The project has a five year time frame, annual reporting requirements (to SBNMS, NEFMC, and NMFS), and a built in evaluation procedure that would open the closed area if no significant differences are found after three years.

Draft proposals were distributed to NEFMC staff, council members, and NMFS. Guidance was provided suggesting that a series of public information meetings should be conducted to bring this unique proposal to the public. Three public meetings were held and constructive input suggested that the initial site selection be adjusted to account for the fishing patterns of small trawlers from the ports of Provincetown and Gloucester, Massachusetts, such that each fleet would be giving up a small portion of traditional grounds rather than the Provincetown fleet bearing the effect of the initial closed area proposal for the southern end of Stellwagen Bank. New stations in a middle bank location ultimately were selected and remotely operated vehicle reconnaissance showed that patterns of habitats were similar to the southern site and would be acceptable for the proposed study (Fig. 1). Also, the size of the proposed closed area was greatly reduced as the new boundaries encompassed the same range of habitats in a smaller area.

Discourse about the proposal from the fishing community (at the public meetings, in the press, and on the radio) largely focused on the perceived inconsistency between the "promise" that the sanctuary would not manage fisheries and the proposal to close an area within the sanctuary. Despite the explanation that any subsequent actions based on the proposal would be taken by the NEFMC and NMFS, not the sanctuary program, the perception of broken promises persisted. While there was support from some segments of the fishing community, non-governmental organizations, and various interested parties, complaints from segments of the local fishing community to their congressman resulted in his public rejection of the project. Clearly, such a reaction should have been anticipated and congressional staff should have been briefed about the project to allow them to form an opinion prior to input from constituents.

These initial actions occurred during the proposal and review of Amendment 7 to the Northeast Multispecies (Groundfish) Fishery Management Plan. This plan put further restrictions on fishing days-at-sea, reduced targets for particular groundfish species (i.e. Atlantic cod, haddock, yellowtail flounder), and threatened even further closures beyond the existing closed sites from Amendment 5. Given the great angst of the fishing community to an "experimental site" when further reductions loomed on the horizon, we decided to table the proposal until the Amendment 7 review

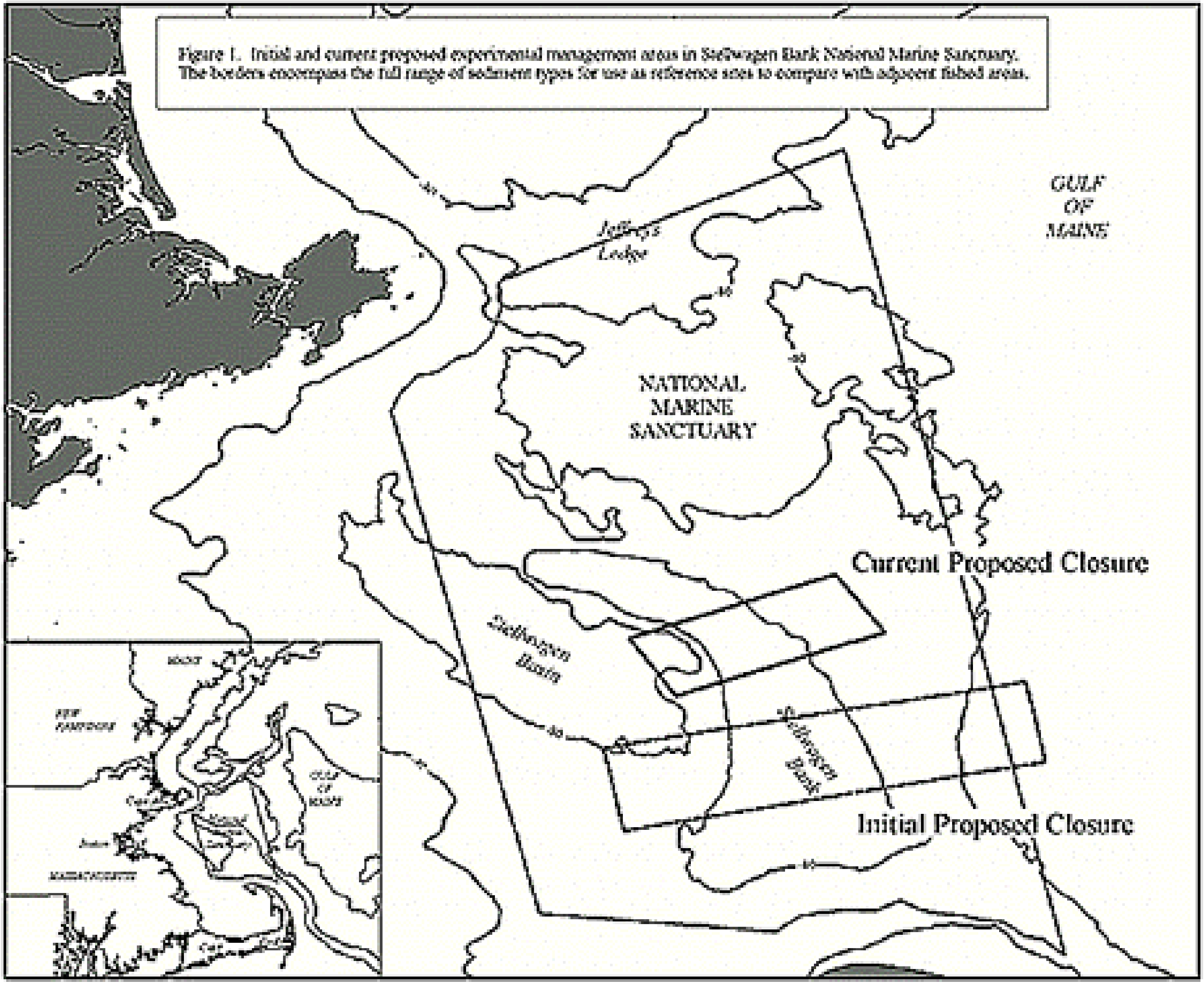

Figure 1. Initial and current proposed experimental management areas in Stellwagen Bank National Marine Sanctuary. The borders encompass the full range of sediment types for use as reference sites to compare with adjacent fished areas.

process was complete.

A meeting with the Regional Director further elucidated a pathway by which the project could be acceptable to NMFS and the Council. Based on this meeting, a new project element was included to develop a series of management recommendations and options based on the results of the study. A revised draft was subsequently given further review at NMFS. Comments were received that suggested the proposal be re-cast as a full science proposal, describing sampling schedules and analytical techniques. However, the NEFMC and NMFS were never considered a source of funding (nor did they suggest they may be) and elements of the project could change based on comments that would come out of the peer review process.

At the outset of the initial proposal, there were commitments (i.e. funds and ships) for the start-up year of the project, but additional funds and expansion of the studies would depend upon fully reviewed proposals to appropriate agencies (e.g. NOAA's National Undersea Research Program, Sea Grant, Sanctuaries Division). Two of the investigators had a Sea Grant project already funded that addressed some of the operant questions and the location of the work was to be changed to this site if the proposal was implemented. Unfortunately, after the Amendment 7 process was completed and regulations implemented, further reductions in fishing mortality would be required. This may necessitate additional closures and further delay the consideration of the proposal in a more favorable environment.

The proposal currently is in revision and will be submitted to the NEFMC for action (see Postscript). Rather than attempting to garner support as was done previously, the proposal will be submitted directly to the NEFMC and any subsequent requests for revision, public meetings, etc. will be part of the official record and be more fully considered within the formal Council process.

The process to date has produced several generalities to consider in future actions regarding the proposals for protected areas at SBNMS and other national marine sanctuaries. First, the time frame for any such proposal to make its way through the Council review process must be considered within a management field that is constantly shifting based on continued management considerations apart from research needs. Moreover, questions persist regarding the efficacy of the closure in the face of unsure funding to conduct the work. Finally, the issue of displacement of fishing effort by such closures must be addressed. Movement rates of most fish exceed the size of the proposed area of closure so the research program would not necessarily be "locking up fish". However, the closure would certainly disrupt the length of tows of mobile gear users and exclude setting fixed gear. This issue has been alluded to during initial meetings and will inevitably arise during the Council hearing process. The ultimate objective of this project is to provide information for strategic management decisions. How can this process be streamlined to develop the knowledge required for attaining sustainable fisheries?

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Postscript

The NEFMC designated a 884 nm^2 year-round closed area in the western Gulf of Maine, under Framework Adjustment 25 to the Northeast Multispecies Fishery Management Plan (Federal Register, Vol. 63, No. 61, p. 15326-15333). The closure takes effect on 1 May 1998. This action was undertaken as part of a suite of measures to reduce fishing mortality on the Gulf of Maine stock of Atlantic cod (*Gadus morhua*). The closure area encompasses the eastern side of Stellwagen Bank and a large section of Jeffreys Ledge. This closure provides the essential elements for the study that I have outlined above. Currently, there are plans to conduct an initial research cruise from 27 April-10 May 1998 to address all of the issues outlined in the initial proposal. This initial cruise will form the baseline to compare changes in subsequent sampling efforts.

Closed Areas to Manage Rockfishes in the Gulf of Alaska

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Introduction

Current Management. Since 1988, rockfish (*Sebastes* spp.) in the Gulf of Alaska have been divided into three management assemblages based on their perceived habitats and spatial distribution (Table 1). Shortraker and rougheye rockfish (*Sebastes borealis* and *S. aleutianus*) became one of the three management subgroups within the slope rockfish assemblage in 1991. Managed by the North Pacific Fisheries Management Council (NPFMC), a constant exploitation rate strategy is the preferred management scheme for this assemblage. The rockfish fishery in the Gulf of Alaska has been managed primarily by season limits and gear restrictions. A directed fishery for shortraker/rougheye rockfish occurred only in 1991 and 1992 and has been designated as a bycatch fishery thereafter. During a bycatch only fishery, a vessel can retain no more than a certain percentage of the bycatch species haul by haul. Once the allowable biological catch (ABC) is reached, these species attain prohibited species status, and have to be returned to the sea when caught.

Current management allows vessels to "top-off" their catch during the bycatch season. The intended purpose of setting the "bycatch" season is to protect the population from a directed fishery but to allow for "natural" bycatch in other directed fisheries. Such bycatch management measures have failed in instances where some fishermen deliberately target bycatch species (Fig. 1). Thus, the "topping-off" fishery can be thought of as a directed fishery on a bycatch species. Our concern is that these stocks are very slow growing, long-lived, and patchy in their distribution, and therefore could be severely depleted by continual topping-off.

Commercial Fisheries. Most commercial fisheries for shortraker and rougheye rockfish occur on the continental slope, a narrow band along with the coastline of the Gulf of Alaska. This assemblage is usually caught by trawl

Table 1. Gulf of Alaska management assemblages and assemblage subgroups.

Management Assemblage	Subgroups of Assemblage
Slope rockfish	Pacific ocean perch (POP) Shortraker/rougheye rockfish Northern rockfish Other slope rockfish (17 species)
Pelagic shelf rockfish	Five species
Demersal shelf rockfish	Seven species

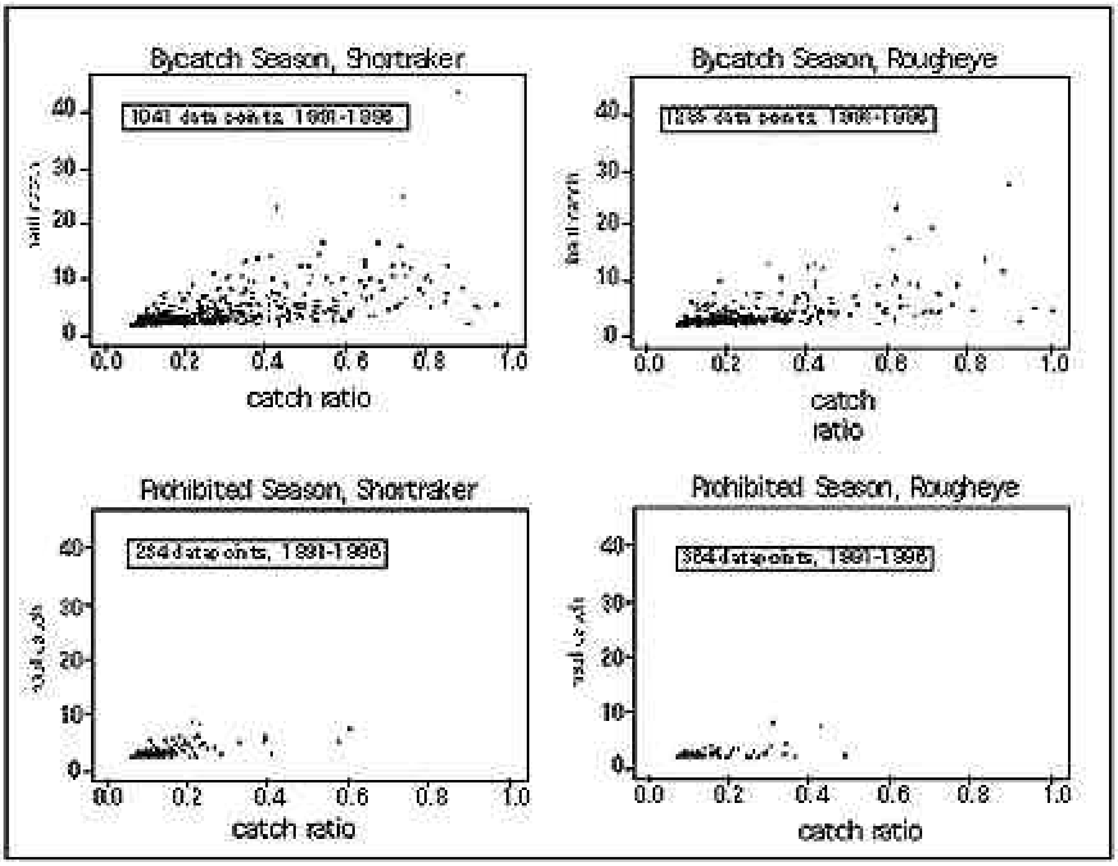

Figure 1. Total catch per haul (mt) versus proportion of shortraker and rougheye rockfish in that haul. The upper panels show hauls made during the bycatch season, when these species could be legally retained, while the lower panels show hauls made during periods when their retention was prohibited.

and longline gear. Most of the shortraker and rougheye taken on longline gear is considered an incidental catch in the directed sablefish and halibut longline fisheries. Major species that co-occur with this assemblage include: Pacific ocean perch (*Sebastes alutus*), sablefish (*Anoplopoma fimbria*), northern rockfish (*Sebastes polyspinis*), rex sole (*Errex zachirus*), and thornyhead (*Sebastolobus alascanus*).

Observer Program. An observer program was established by the National Marine Fisheries Service (NMFS) in 1973 to aid in the management of fisheries within the 200-mile fishery conservation zone (now called the Exclusive Economic Zone) established by the Magnuson Fishery Conservation and Management Act of 1976. The domestic groundfish observer program requires that vessels 125 feet or longer carry a NMFS-certified observer while fishing for groundfish. Vessels 60-124 feet in length must carry a NMFS-certified observer during about 30% of their fishing days in each calendar quarter of the year in which they fish more than 10 days. Observers collect a wide variety of data including total catch (including discards) and effort, catch composition, biological samples, gear design and operation information.

Shortraker/rougheye rockfish. Stock assessment of slope rockfish is hampered by limited information and considerable uncertainty as to current stock abundance and long-term productivity. The adequacy of current trawl survey methodology to assess rockfish biomass is questionable. These concerns have prompted the Alaska Fisheries Science Center to develop a comprehensive working plan to improve stock assessments and management for rockfish.

Both shortraker and rougheye rockfish inhabit the deeper waters of the outer continental shelf and upper continental slope regions throughout their range. Shortraker and rougheye rockfish are among the largest *Sebastes* species in body size present in the Gulf of Alaska (L_∞ =72.36 cm and 54.74 cm, respectively). Both species are slow-growing, very long-lived (maximum age ≈ 140 years) and mature at an age of around 20 years (McDermott 1994). The age of recruitment into the fishery is thought to be about 30 years (Nelson 1986). The early life histories of both species are not well known. However, geographic movements of these species appear to be very restricted during exploitable ages (Gunderson 1997).

Although both species are among the most economically important species within the assemblage, very little work on their population dynamics has been accomplished to date. Reconstruction of the historical removals were attempted based on all the auxiliary survey and observer data because no independent catch data were available prior to 1991. Stock Reduction Analysis (SRA; Kimura et al. 1984, Kimura 1985, 1988) provided useful stock assessment information, including estimates of instantaneous rates of fishing mortality and historical biomass (Soh unpubl. MS).

Discard Rates. Preventing stock depletion and discards at sea are among the problems to be resolved for better management of *Sebastes* populations. Percentage discarded of the four slope rockfish management subgroups in the Gulf of Alaska were estimated by observers (Table 2). In 1994, over 40% of the shortraker/rougheye rockfish catches were discarded and amounted to 820.7 mt (= annual catch of 1832 mt * 0.448). This was worth about $2.71 million (= 820.7 mt * 2.2 lb/kg * $3/lb at sea * 0.5 for headed and gutted rockfish) and represents a significant waste. As an alternative, incorporating harvest refugia into the current management scheme

Table 2. Observer estimates of percentage of total catch discarded for the four slope rockfish management subgroups in the Gulf of Alaska.

	1991	1992	1993	1994	1995	1996
Pacific ocean perch	15.7	21.5	79.2	60.3	19.8	17.6
Shortraker/rougheye rockfish	42.0	10.4	26.8	44.8	30.7	20.5
Northern rockfish	-	-	26.5	17.7	12.7	16.3
Other slope rockfish	20.0	29.7	48.9	65.6	72.5	75.7

may offer a way to reduce wastage due to discards. As an illustration, we compare the outcomes of status quo management and one alternative refugia scheme using a 20-year simulation, and attempt to show how discard problems can be resolved. Also, this alternative management scheme may avoid depletion of valuable stocks.

Approach

Population Dynamics Model. Reconstructing the historical removals of rougheye and shortraker rockfish (R/S) from the Gulf of Alaska is not a trivial matter. Accurately estimating these removals is hampered by the fact that both species were never officially reported in the commercial landings until 1991. However, both species were undoubtedly caught in significant quantities prior to 1991 because shortraker and rougheye rockfish are frequently caught with Pacific ocean perch and other *Sebastes* species. Furthermore, it is clear that the amount of geographical overlap among the demersal *Sebastes* species is considerable based on historical catch and survey data. It is this overlap that forms the basis of our catch reconstruction. To estimate the historical R/S catches, we multiply the distributional ratios of R/S by certain known reference catches (Soh unpubl. MS).

By employing SRA, we examined trends in biomass and potential long-term production. This assessment technique, which incorporates Schnute's (1985) version of the delay-difference equation, is a biomass-based method of stock assessment that links the exponential form of the catch equations when age data are insufficient or unavailable. Input requirements for the SRA model included: catch data (in biomass), natural mortality, the delay-difference growth coefficients, the age at recruitment, the Beverton-Holt recruitment shape parameter, and one or more estimates of stock biomass.

GIS. Spatial distribution of shortraker and rougheye catches were created using the geographic information system (GIS) software Arc/Info. Technical procedures in GIS include the spatial generalization of point data for refugia work. Relying on historical catches from the observer and NMFS survey databases, “hotspots” and localized concentrations of adults were easily detected. We evaluated different geographic areas of refugia using different cutoff criteria for the cumulative (1987 to 1996) catch.

Modeling of Refugia Management. Two separate zones, refuge and harvestable area, were defined to discuss the outcomes of various refugia systems based on a simulation approach. The outcomes depend on the size of the refuge area. This size was determined arbitrarily according to the cutoff points that were determined by commercial catch quantile analysis. Separation of the biomass and recruits between refugia and harvestable area is based on the simple assumption that cumulative historical catches (1987 to 1996) reflect the spatial distribution of the adult biomass within the Gulf of Alaska.

We are not assuming that closed areas are self-contained production systems, because we know very little about habitat requirements for juveniles and larval transport patterns. However, it seems clear that adult habitat requirements are quite specific, and we assume that all prime habitat is reflected in the distribution of "hotspots". Independent population dynamics models are run for the refugia and harvestable areas, with an exploitation rate (and F) = 0 in refuge areas. We also predict reduction in the yield of other groundfish such as POP, thornyhead, sablefish, and rex sole inside the refugia.

Discards can be greatly reduced by retaining all catches in the harvestable areas until the ABC is attained. This scenario is based on the supposition that harvestable areas are expected to have less dense stocks because all hotspots in the Gulf are designated as refuge areas. Ending biomass, the range of expected yields, and fishing mortality in harvestable areas will differ with refuge size. We will pick only one size of refuge area as an example: those areas that accounted for 40% of the catch for shortraker and 29% of rougheye during 1987 to 1996, but represent only 5.4% of the trawlable area within the Gulf of Alaska (Fig. 2).

Example: Simulation Results. The SRA model was applied to the Gulf rockfish stocks, and 20-year projections were simulated under two scenarios, comparing the ending biomass with identical catch amounts retained by fishermen (Table 3). Under the refugia system, annual harvests are set equal to about 70% of those caught under the current system, because the average discard

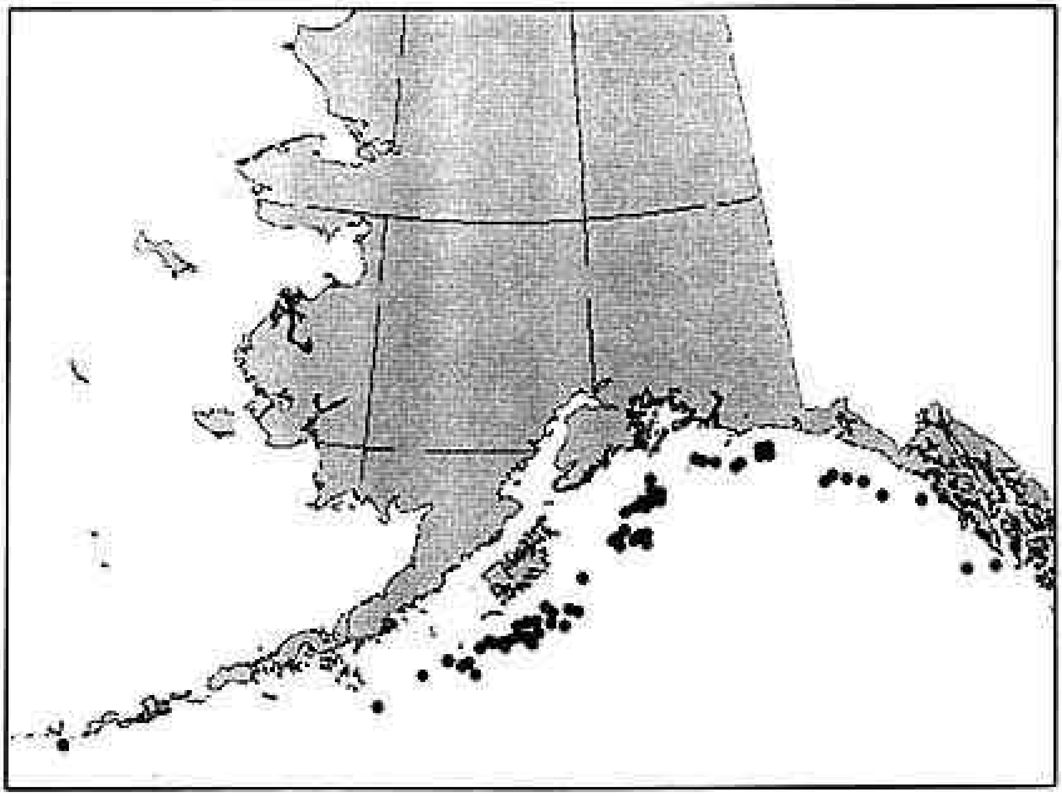

Figure 2. Example of the use of GIS to delineate "hot spots" and refugia. The dark circled areas delineate those 314 km^2 "pixels" containing the upper 0.5% of the 1987-1996 commercial catch of rougheye and shortraker rockfish.

Table 3. Results of shortraker and rougheye rockfish Stock Reduction Analysis simulation.

Shortraker	**Current management**	**Refugia management**
Biological Yield	7,259 mt/20 yrs (with discards of 2,120 mt)	5,140 mt/20 yrs
Ending Biomass	16,459 mt	18,337 mt
Average F	0.023	0.028
Rougheye	**Current Management**	**Refugia Management**
Biological Yield	19,146 mt/20 yrs (with discards of 5,591 mt)	13,556 mt/20 yrs
Ending Biomass	35,809 mt	40,541 mt
Average F	0.025	0.025

rate was about 30%. Instantaneous fishing mortality (F) for shortraker was set to 0.023 and for rougheye 0.025. In the case of shortraker rockfish, the procedure was as follows:

1) Apportion population biomass between refugia and harvestable areas, using commercial fishery data and GIS (Fig. 2).

2) Set constant F = 0.023 for the open ocean system, and calculate accumulated yield and ending biomass for 20 year simulation.

3) Set biological yield under refugia system = 7,259 * (1 - 0.292) = 5,140 mt, where 0.292 is an average discard rate (1991 to 1996) under the current system, and determine the fishing mortality (F) required to obtain this in the harvestable areas.

The outcomes of this simulation depend on the size of the refuge area. The results above are based on a refuge area representing 5.4% of the trawlable area within the Gulf of Alaska.

Impact On Other Fisheries. Establishing no-take zones obviously affects other fisheries in the zone. To minimize these impacts, depth effects need to be considered for practical application of refugia boundaries. For example, the proportion of catches within the refuge area (5.4% of the Gulf), as compared with those from the whole Gulf, for major species on the continental slope changes significantly among depth strata (Table 4).

Outlook

Refuge areas can be defined in such a manner that several benefits can be derived with minor impacts to other fisheries. Major improvements resulting from refugia management are as follows:

- Maintain current catch levels with reduced discard waste,

Table 4. Percent of Gulf-wide catches (1987 to 1996) at three depth strata within refugia area.

Depth (m)	shortraker	rougheye	POP	thornyhead	northern	dusky	sablefish	rex sole
100-713	28	29	15	12	12	17	6	12
200-713	27	28	12	12	1	1	5	6
300-713	23	25	2	9	0	0	3	1

- Maintain geographic structure of shortraker and rougheye populations,
- Insure the protection of spawner biomass,
- Avoid "shutdowns" of the fishery due to depleted stocks.

Though we simulated results for only one size of refugia, further analyses also resulted in higher ending biomass for a wide variety of refugia size with a minor increase in fishing effort outside refugia. Because of the difficulties in enforcing refugia management, it appears that industry support will be required if refugia are to be effective. This is particularly true if refugia are delimited using depth criteria.

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Shortraker rockfish (*Sebastes borealis*) near isolated boulder, as viewed from the Delta submersible in the Gulf of Alaska in 300 m of water. This species can reach 120 years of age. Photo by K. Krieger

The Use of a No-Take Marine Reserve in the Eastern Gulf of Alaska to Protect Essential Fish Habitat

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Introduction

The Alaska Department of Fish and Game (ADF&G) has management authority for demersal shelf rockfishes and lingcod in state and federal waters of the Gulf of Alaska. Management of these species has included annual catch quotas, season and gear allocations, trip limits, and area closures. ADF&G has used an occupied submersible to obtain habitat-specific density estimates of demersal shelf rockfishes in the Eastern Gulf of Alaska since 1990 (O'Connell and Carlile 1993, O'Connell et al. 1997). During these surveys we have made over 300 dives in depths between 40 m and 200 m between Dixon Entrance (54°30' N) and Fairweather Ground (58°30' N). Direct observation using in-situ technology has greatly increased our understanding of the linkage in the marine system between species diversity, abundance, and habitat complexity. It also has allowed us to identify areas that appear to be of critical importance to a variety of fish species.

A specific habitat that appears to be particularly important is an area off Cape Edgecumbe that is dominated by two large volcanic cones (Fig. 1). These pinnacles rise abruptly from the seafloor at the entrance to Sitka Sound where ocean and tidal currents create massive water flows over this habitat (Fig. 2). The most southerly and shallowest cone (Nineteen-Fathom Pinnacle) is topped by a volcanic plug that extends to within 40 m of the ocean's surface. The plug has shear vertical walls on one side that drop down to a rubble apron composed of large angular blocks of considerable size (up to 10 m). A fairly linear lobate feature extends northeastward to the base of the northern cone. The northern pinnacle is more gentle in morphology and is deeper, with its crest lying at a depth of 70 m. The crest of this pinnacle comprises exposed volcanic rock (plug) that sits atop an almost smooth cone and large angular boulders surround the base. The steeper of the two pinnacles (Nineteen-Fathom Pinnacle) has extremely complex rock habitats and supports a diversity and density of fishes not seen in surrounding areas.

The boulder field at the base of this pinnacle provides important refuge for adult fishes including large numbers of yelloweye rockfish (*Sebastes ruberrimus*; Fig. 3), tiger rockfish (*S. nigrocinctus*), prowfish (*Zaprora silenus*), and lingcod (*Ophiodon elongatus*). Aggregations of small deep-water rockfishes occur here as well, including sharpchin (*S. zacentrus*), pygmy (*S. wilsoni*), and redstripe (*S. proriger*). Besides harboring adult fishes, this boulder field also is used as spawning habitat by lingcod. While it had been previously reported that lingcod spawn and nest-guard in shallow water, in-situ observations at the pinnacle have identified

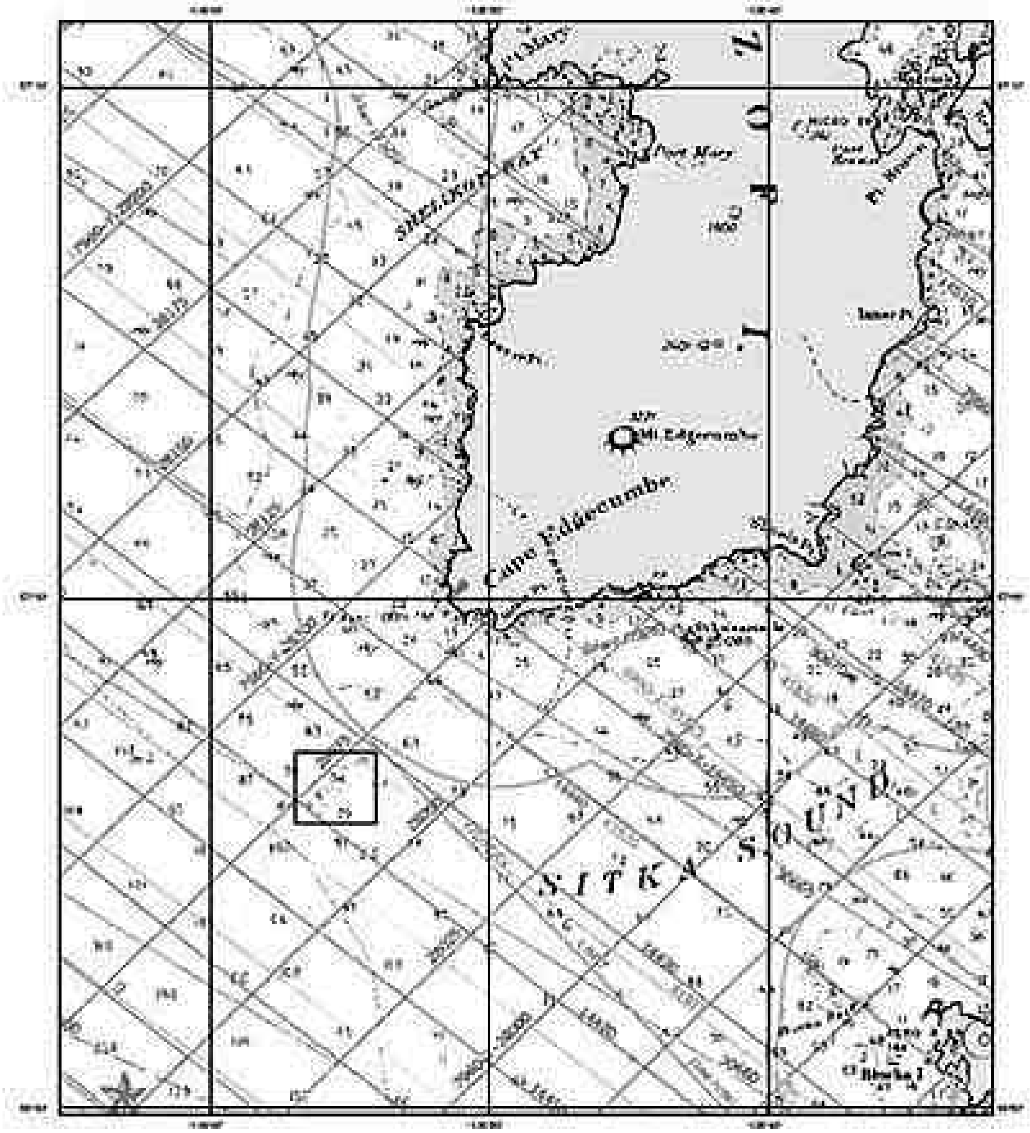

Figure 1. Boxed area is proposed no-take marine reserve, southeast Alaska.

lingcod nest-guarding in the boulder field at depths to 140 m (O'Connell 1993). The female lays a large egg mass in caves and crevices between boulders and the male fertilizes the eggs and guards the "nest" until hatching.

The sides of the pinnacle are comprised of columnar basalts and *Primnoa gorgonians* provide biogenic habitat for fishes on the steep walls of the pinnacles (Fig. 4). Juvenile rockfishes occur in great abundance at the top of the pinnacle and utilize the dense assemblages of sessile invertebrates, including *Metridium* and hydrocorals for cover. Adult lingcod utilize the top of the pinnacle as a seasonal feeding platform after spawning. These fishes occur in extremely dense aggregations during the late spring and early summer (Fig. 5). In addition to fish living and feeding directly on the habitat or using the pinnacle and associated infauna for cover, large schools of pelagic fishes congregate in the water column above the pinnacle. These include black (*S. melanops*), yellowtail (*S. flavidus*), dusky (*S. ciliatus*) and widow (*S. entomelas*) rockfishes that feed on the plankton in the water column.

History of Fishing

The area surrounding the pinnacles has been an important fishing ground for halibut (*Hippoglossus stenolepis*), salmon (*Oncorhynchus* sp.), and rockfishes. In the late 1980s several fishermen began to target the pinnacles for yelloweye rockfish using bottom longline gear. In 1987 a directed fishery for lingcod began (Gordon 1994). The directed fishery used modified troll gear called dinglebar gear. This gear is very effective at catching lingcod and operates by bouncing a lead bar along the bottom and trailing leaders and jigs to attract fish. By early 1991 some lingcod fishermen discovered that lingcod congregate on the tops of the pinnacle during early summer and began aggressively targeting this area. The small size of the area, large density and feeding behavior of the fishes make them extremely susceptible to fishing pressure. Hourly catch rates of lingcod at this site exceeded catch rates in the surrounding area by three-fold (ADF&G confidential logbook data).

Several management actions have

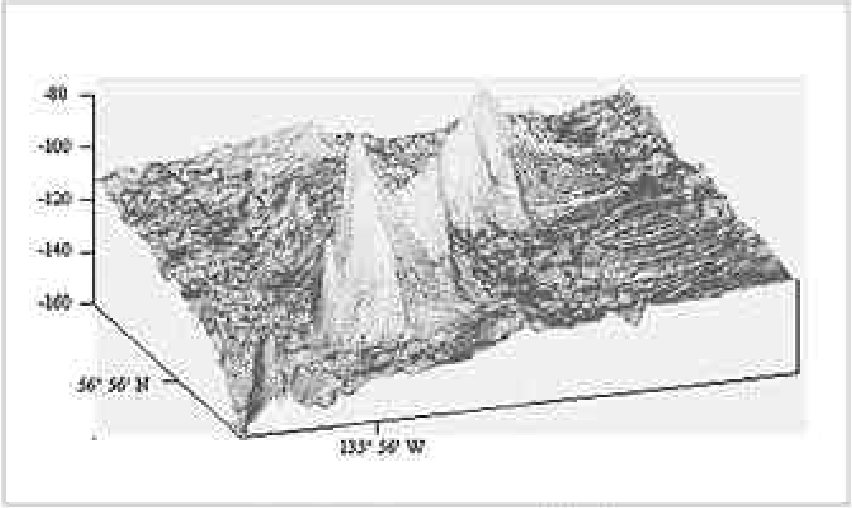

Figure 2. Bathymetry of pinnacles area, 10 X vertical exaggeration.

Figure 3. Yelloweye rockfish in boulder field at base of pinnacle.

occurred regarding the commercial fishery in this area. The pinnacles are in federal waters. The State of Alaska has management authority over lingcod and demersal shelf rockfish in both state and federal waters. In 1991, as part of a larger winter closure to protect nest-guarding male lingcod, the Alaska Board of Fisheries closed all harvest of lingcod from December 1 - April 30 in the waters from Cape Edgecumbe to Biorka Island, which includes the pinnacle area. There have been several conservation closures in the area beginning in 1992. In 1997 an emergency order (EO) was issued that prohibited all retention of groundfish by commercial fisheries in a four square mile area that included the pinnacles. This emergency order was reissued for 1998.

Prior to 1997 there had been no significant sport fish or charter boat harvest of bottomfish in the pinnacle area. However with the expansion of the charter boat fleet out of Sitka and their increased interest in bottomfish, the pinnacles area became the target of an intensive charter boat fishery. The commercial fishery emergency orders have no authority over the charter boat and sport fishery. In effect, the commercial fishery EO had simply reallocated the harvest of groundfish on the pinnacle to a different user group.

The Alaska Department of Fish & Game (ADF&G) has petitioned the Alaska Board of Fisheries (BOF) and the North Pacific Fishery Management Council (NPFMC) to enact a bottomfish reserve for the pinnacle areas. The petition is to permanently close a 3.1 mi^2 (8.1 km^2) area to all bottomfish and halibut fishing (including commercial, sport, charter, bycatch and subsistence) and anchoring to prevent localized over fishing, protect nursery habitat provided by rock outcrop and invertebrate epifauna, and to create a bottomfish refuge. This closure would protect the fragile nature of this rare habitat, and prevent the harvest (including bycatch) of lingcod and rockfish during critical portions of their life history.

Approach to Implementation

The authority to establish a marine reserve in southeast Alaska is complicated by the various jurisdictions of state and federal agencies. The pinnacles occur in federal waters but some of the species inhabiting the area are managed by the state of Alaska.

Once we had determined that we were interested in creating a marine reserve for groundfish, we began garnering support for the reserve. We contacted various scientists

Figure 4. Yelloweye rockfish resting on *Primnoa* growing on wall of pinnacle.

Figure 5. Lingcods on top of pinnacle.

and biologists involved in research and management of groundfish in the area and requested a review of our proposal. We also held public meetings to discuss the idea with local users of the area and other interested public. We were able to take a small group of scientists, managers, and fishermen on submersible dives of the pinnacle as part of the education process. Videotapes of these dives were shown at a variety of public meetings. Once we had agency and public support for the reserve, we moved ahead with official proposals for action.

In Alaska, lingcod and black rockfish are not listed as groundfish species in the Federal Fisheries Management Plan. Consequently, the state of Alaska has management authority over these species even in federal waters. Because the BOF would not be meeting to discuss southeast groundfish regulations for three years, ADF&G submitted an agenda change request (ACR) that would allow the proposal to be addressed at an earlier BOF meeting. The ACR was submitted in October of 1997 and was proposed jointly by the Commercial Fisheries Division and the Sport Fish Division. BOF booklets were circulated for public review to allow for written public comments. Local advisory committees to the BOF reviewed the proposal. The Sitka Fish and Game Advisory Committee (which is comprised of representatives from the commercial fisheries, charter fisheries, subsistence fisheries, sport fisheries, conservation groups, hunters, and general public) unanimously supported the proposal. Several special-interest groups (both conservation and resource-user) submitted letters of support. In February 1998, after a public hearing to discuss this and other regulations, the BOF voted unanimously to establish the pinnacle reserve as a no-take area for all bottomfish species over which they have authority (currently lingcod, black rockfish, blue rockfish, and demersal shelf rockfish).

Concurrent with the effort to get the State to implement the closure, was the effort to have the NPFMC implement a companion closure for other species including halibut. ADF&G submitted a proposal for the pinnacles reserve to the NPFMC's Gulf of Alaska Plan Team at their August 1997 meeting. The Plan Team endorsed the proposal and it was forwarded to the NPFMC. In September 1997 the NPFMC agreed to further consider the pinnacle reserve and requested a staff analysis be conducted.

The draft Environmental Assessment and Regulatory Impact Review was released at the April 1998 NPFMC Council meeting. The preferred alternative listed in this document was to prohibit all fishing activities in the closure area, including trolling for salmon. The NPFMC is scheduled to take final action on the proposal at their June 1998 meeting (see Postscript).

If approved by the NPFMC this will be the first no-take reserve in the Gulf of Alaska. Although the area is relatively small in total area (3.1 mi^2; 8.1 km^2), it encompasses a wide range of depths and a variety of rock habitats. The margins of the closed area occur in water depths between 180 and 150 m; bottom habitat types include cobble, gravel, and lava flow. One pinnacle rises to 70 m and the other to 40 m.

Research

ADF&G has conducted in-situ assessments of bottomfish in this area since 1989 using an occupied submersible and has mapped the area using sidescan sonar and swath bathymetry. In 1997, several permanent transects were established using on-bottom flags, which will facilitate long-term monitoring (Fig. 6). Using a combination of technology, including a submersible equipped with an array of imaging systems, sidescan sonars, GIS and 3D-data visualizations, ADF&G has been able to characterize this habitat. Habitat-specific fish densities and complete detailed quantification of habitat may now be determined. Future submersible observation along with the use of a drop-video camera system will allow seasonal monitoring of the distributions, diversity, and abundance of fauna in this area.

Enforcement Issues

One difficulty in establishing marine reserves is the ability to enforce closures. This is a particular concern in remote areas where people other than the resource users are unable to monitor the area. The pinnacles occur at the corner of Cape Edgecumbe off the mouth of Sitka Sound. There is significant boat traffic in the area and the salmon troll-drag turnaround is adjacent to this spot. There are regular Coast Guard over-flights and the State Fish and Wildlife Protection officers monitor this area by boat. Fishing in closed waters is a serious violation under both state and federal statutes and always results in at least a fine and forfeiture of fish. More importantly there is strong local support for the closure in the Sitka area. The local Sitka advisory committee to the Alaska BOF unanimously supported the closure, as did the Alaska Longline Fishermen's Association. Given the strong support for the closure and the opportunity for fishermen and boaters to observe the area, it seems likely that the boundaries of the area will be respected.

Conclusion

The recently reauthorized Magnuson - Stevens Fishery Conservation and Management Act (Sustainable Fisheries Act of 1996) has a mandate to identify, conserve, and enhance essential fish habitat (EFH). The Act identifies EFH as, in part, the substrate necessary to fish for spawning, breeding, growth, and maturity. The pinnacle area provides habitat for all these purposes for a variety of species and is extremely productive, in part due to its physical

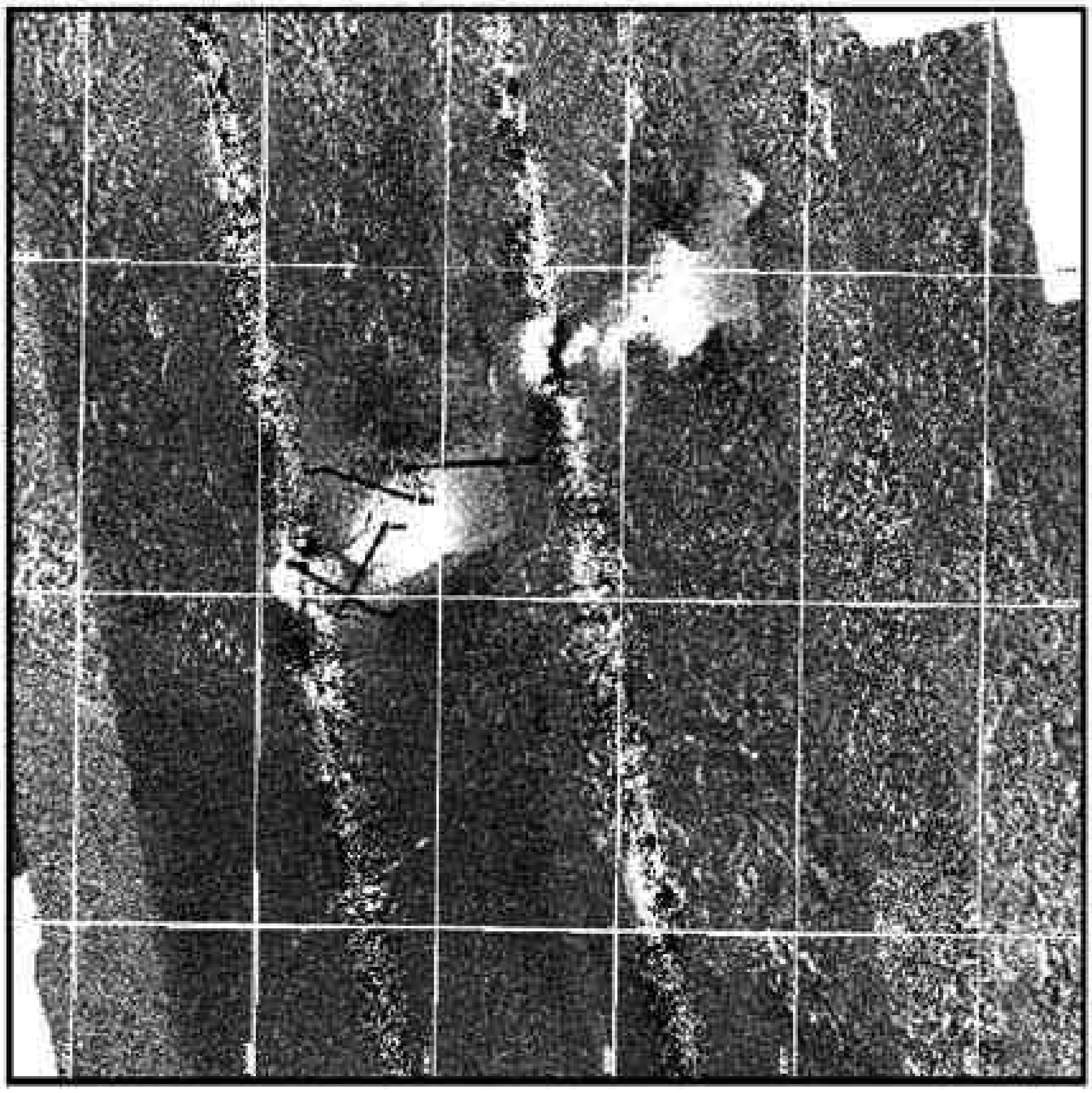

Figure 6. Digital sidescan mosaic of pinnacle areas with transect.

oceanography. Closure of the area will allow a vital habitat to maintain populations at natural levels in an area surrounded by heavy fishing pressure. Because baseline information has already been collected on the habitat and the associated fish populations, it will be possible to monitor the changes in diversity, distribution, and abundance of organisms and it may be possible to determine if the closure provides benefits to the area surrounding the reserve.

Acknowledgements

This work was funded in part through grants from NOAA's National Marine Fisheries Service Alaska Region and the West Coast National Undersea Research Center. We thank the following people for their contributions towards this effort: Cleo Brylinsky, Dave Gordon, Bev Richardson, Deidra Holum, and Jim

McRea for help in the field; Rich Slater, David Slater, Chris Ijames and the crew of Delta Oceanographics and the R/V Cavalier; Greg Beam and the crew of the F/V Ida June; Jim McRea, Andrea Fildani, and Cleo Brylinsky for mapping and GIS support.

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Postscript

During their June 1998 meeting in Dutch Harbor, Alaska, the NPFMC adopted a plan amendment to prohibit boat anchoring and all fishing for groundfish, halibut, and scallops in the pinnacle area. This amendment originally was proposed by the ADF&G as a means to protect important habitat for rockfish and lingcod, and was later incorporated into the EFH amendment package. After reviewing the material, the Council decided to separate the pinnacle closure from EFH provisions, and to adopt it as a separate amendment (tentatively assigned Amendment 59 to the Gulf of Alaska Groundfish Fishery Management Plan). In the future, the pinnacle area will be re-evaluated for consideration as a "habitat area of particular concern" under the EFH guidelines. An option for prohibiting recreational and commercial salmon fishing in the pinnacle area was considered, but not adopted. The Council will discuss the salmon issue with the Alaska BOF at its committee meeting in July. NPFMC staff contact is Dave Witherell (Anchorage, Alaska).

Restrictions on Rockfish Fishing in Existing California Marine Protected Areas

Deborah A. McArdle, University of California Sea Grant Extension, Santa Barbara, CA

A total of 101 areas of special biological significance, city underwater parks, ecological reserves, Marine Resource Protection Act (MRPA) ecological reserves, state parks, refuges, reserves, University of California natural reserves, national marine sanctuaries, national parks and biosphere reserves comprised 18.2% of the total California state waters on 31 December 1998. Due to overlapping boundaries, and to the omission of two marine protected areas (MPAs) that were completely within federal waters, there were actually only 65 MPAs with unique geographical boundaries (the MPAs in federal waters had no restrictions on the take of rockfish.) I analyzed the extent to which rockfish fishing was restricted in these 65 MPAs.

Of the 65 MPAs, ten prohibited rockfish fishing and totaled 8676.3 acres (35 km^2) (Table 1). However, the ten MPAs that did prohibit the take of rockfish were not designated, designed or located with the goal of rockfish protection. The ten areas covered 0.2% of the 3,591,000 acres (14,532 km^2) of California state waters (from the coastline to 3 nautical miles offshore, including island coastlines). In addition to the ten MPAs that

Table 1. Marine Protected Areas that completely prohibit the take of rockfish in the four marine ecological regions of California.

Region		Area	
		Acres	(km^2)
I. Northern Region		0	(0)
II. North Central Region			
1. King Range MRPA Ecological Reserve		1511.1	(6.1)
III. Central Region			
2. Hopkins Marine Life Refuge		80.2	(0.3)
3. Point Lobos Ecological Reserve		682.3	(2.8)
4. Big Creek MRPA Ecological Reserve		935.6	(3.8)
IV. Southern Region			
5. Vandenberg MRPA Ecological Reserve		1524.8	(6.2)
6. Big Sycamore Canyon MRPA Ecological Reserve		1279.2	(5.2)
7. Catalina Marine Science Center Marine Life Refuge		2087.8	(8.4)
8. Heisler Park Ecological Reserve		31.6	(0.1)
9. Scripps Coastal Reserve		87.0	(0.4)
10. San-Diego-La Jolla Ecological Reserve		458.7	(1.9)
	TOTAL:	8676.3	(35; 0.2% of state waters)

Table 2. Marine Protected Areas that prohibit the take of rockfish, either commercially or recreationally, in the four marine ecological regions of California.

	Area	
	Acres	(km^2)
A. No Rockfish May Be Taken Recreationally		
I. Northern Region	0	(0)
II. North Central Region		
1. Point Cabrillo Reserve	55.8	(0.2)
2. Gerstle Cove Reserve	6.4	(0.03)
3. Point Reyes Headlands Reserve	501.3	(2.0)
III. Central Region	0	(0)
IV. Southern-Baja Region		
4. Lovers Cove Reserve, Santa Catalina Island	13.1	(0.05)
TOTAL:	576.6	(2.3; 0.02% of state waters)
B. No Rockfish May Be Taken Commercially		
I. North Region	0	(0)
II. North Central Region		
1. Del Mar Landing Ecological Reserve	52.0	(0.2)
III. Central Region		
2. Carmel Bay Ecological Reserve	1564.9	(6.3)
IV. Southern Region		
3. Abalone Cove Ecological Reserve	66.0	(0.3)
TOTAL:	1682.9	(6.8; 0.04% of state waters)

completely prohibited rockfish fishing, four additional small MPAs prohibited recreational fishing for rockfish (Table 2). These four areas totaled 576.6 (2.3km^2) acres and comprised 0.02% of the state waters. Another three small MPAs restricted commercial fishing of rockfish (Table 2). These three areas totaled 1682.9 acres (6.8 km^2) and comprised 0.04% of the state waters.

Although all were relatively small, the proportion of area that protects rockfish varies geographically (Fig. 1). For this analysis I divided the state into four general regions including a northern, north central, central and southern region. These regional divisions were adapted from those used by the California Department of Parks and Recreation. The northern region extends from the Oregon border to Cape Mendocino. The north central region extends from Cape Mendocino to Elkhorn Slough. The central region extends from Elkhorn Slough to Point Conception and the southern region extends from Point Conception to the border of Mexico.

On a statewide level, the major coverage (63.0%) of the MPAs that prohibited the take of rockfish occurred in the southern region totaling 5469.1 acres (22.1 km^2; n=6 MPAs). However, the MPAs that prohibited the take of rockfish in the southern region only comprised 0.2% of the region's waters. The MPAs that prohibited the take of rockfish in both the north central (n=1) and the central (n=3) region comprised only 0.04% of their regional state waters. The northern region

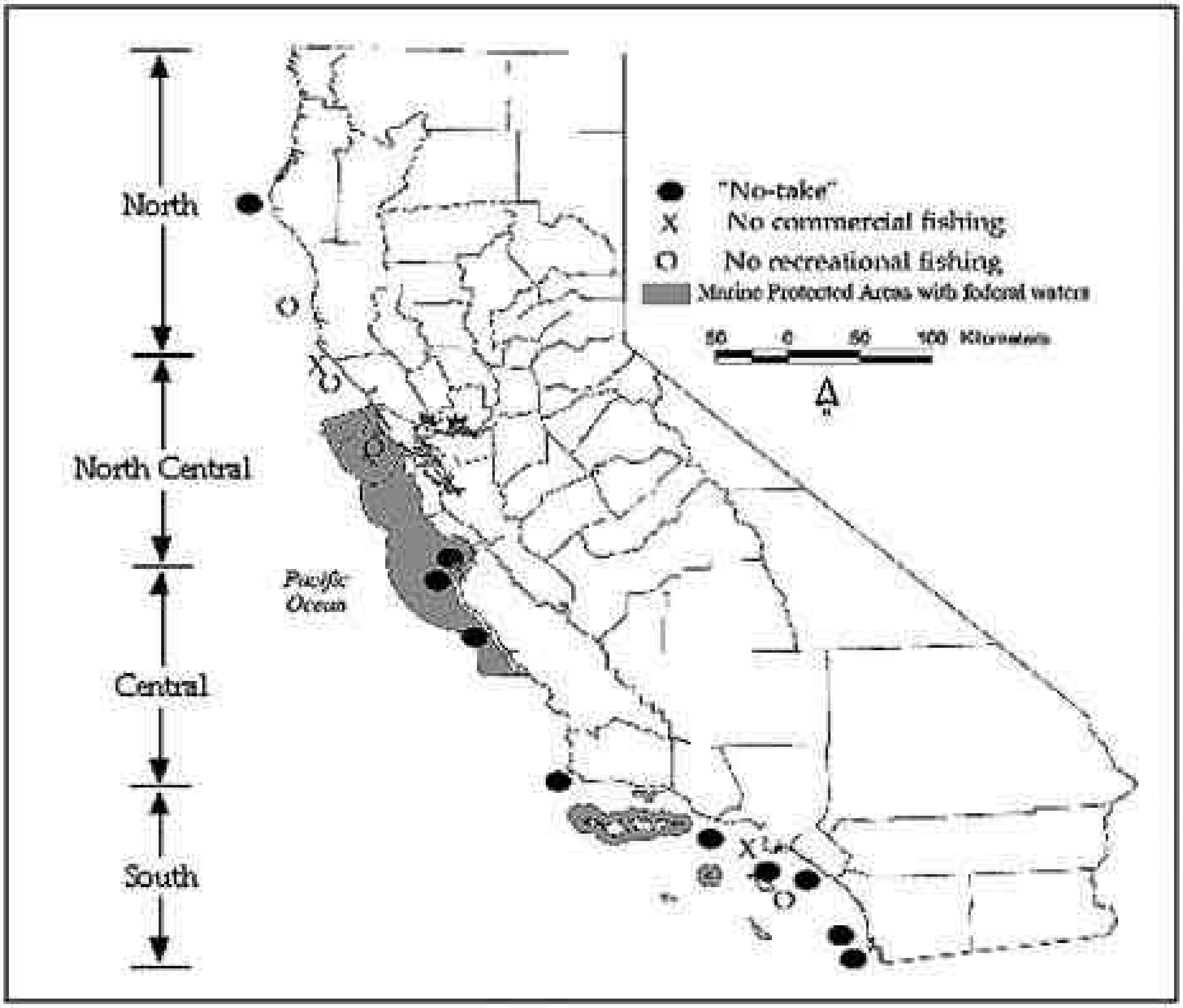


Figure 1. Marine Protected Areas of California that restrict the take of rockfish. The "No-Take" areas comprise 0.2% of the state waters. (The point dots are not drawn to scale.) The MPAs in federal waters do not restrict the take of rockfish.

had no MPAs that prohibited the take of rockfish.

The ten MPAs that prohibited the take of rockfish were not designated, designed or located with the goal of rockfish protection. They were established on other criteria such as the protection of invertebrates or of finfish in general. The first "No-take" area that contained rockfish was the Scripps Coastal Reserve, in 1965. The University of California Regents designated the natural reserve to provide undisturbed environment that could be used as an experimental and educational research station for Scripps Institution of Oceanography. In the seventies, three MPAs were established as ecological reserves (i.e. Heisler Park, Point Lobos and San Diego-La Jolla). The Fish and Game Commission designated these ecological reserves to protect aquatic resources for the future of mankind. Two marine life refuges (i.e. Catalina Marine Science Center

Marine Life Refuge and Hopkins Marine Life Refuge) were established in the eighties. The State Legislature designated the refuges with the initial goal of protecting only marine invertebrates (as is the goal of all the other twelve marine life refuges). However, because of their unique relationship with academic institutions and marine laboratories, the refuges were designated as complete "No-take" areas. Finally, four MRPA ecological reserves were established in 1994 (i.e. King Range, Big Creek, Vandenberg, and Big Sycamore Canyon). Their goal was to provide undisturbed areas for scientific research.

The MPAs that prohibited the recreational fishing of rockfish were all established by the Fish and Game Commission as reserves. These were all designated in the 1970's and only prohibit recreational fishing because the Commission's authority does not expand to commercial fishing except when specifically provided by the State Legislature. All of the three MPAs that prohibited commercial rockfish fishing were established by the Fish and Game Commission as ecological reserves. These were also all designated in the 1970's (Table 2).

Although the existing MPAs were not designed to protect rockfish, most if not all, do contain rockfish populations. In the north central region, for example, King Range MRPA Ecological Reserve has a substantial rockfish population. It should also be noted that both Point Cabrillo Reserve and Gerstle Cove Reserve, in the north central region, have served as *de facto* "No-take" areas for the past ~20 years. The regulations that are mandated by the reserve designation only restrict recreational finfish and invertebrate fishing. However, confusion over the interpretation of these regulations has resulted in commercial fishing also being prohibited in both MPAs. Both of these MPAs contain rockfish within their boundaries. In addition, the commercial take of rockfish in the Del Mar Landing Ecological Reserve is prohibited and the recreational take of rockfish in Point Reyes Headlands Reserve is prohibited.

In the central region, Hopkins Marine Life Refuge, Point Lobos Ecological Reserve and Big Creek MRPA Ecological Reserve all contain rockfish populations. In addition, although not a "No-take" area, the commercial harvest of finfish and invertebrates in the Carmel Bay Ecological Reserve is prohibited. Of the six MPAs that prohibit the take of rockfish in the southern region, five have rockfish populations within their boundaries (i.e. Big Sycamore Canyon MRPA Ecological Reserve does not). In addition, the commercial take of rockfish in the Abalone Cove Ecological Reserve is prohibited.

Although the existing MPAs that protect rockfish represent only a small proportion of state waters (0.2%), they could be further evaluated to determine what positive role they play in conserving this valuable species complex.

WORKING GROUPS

Introduction

The three working groups were important components of this workshop. Group chairs and rapporteurs were identified prior to the workshop, and their input on the structure and topics of discussion were incorporated into the instructions given to each working group. Participants were assigned to each group to achieve a balance in expertise and assure representation of all interests. Each chair presented a summary of their group's findings to the plenary session for feedback. Members were exchanged among the working groups to facilitate cross-fertilization of ideas and recommendations. The Chairs and Rapporteurs drafted summary reports of their group's deliberations, including recommendations for needed actions and research.

Each working group was asked to discuss specific topics that pertained to the overriding goal of evaluating the function and effectiveness of harvest refugia to manage rockfish populations and maintain species and habitat diversity along the west coast. Many of the topics were considered by all three working groups.

Working Group I: Fishery Management Considerations

Given the current status of west coast groundfish populations and our methods and abilities to manage these resources, this group was asked to consider the following issues and questions in their discussions of refugia for rockfish management:

1. Status and prospects for the current management framework
    - A. Are rockfish stocks being depleted?
    - B. What are the shortcomings of existing management for rockfishes?
    - C. Is sustainable management of rockfish resources possible?
2. What are our options for improved management of these resources?
    - A. How can current management measures be revised to increase conservation of groundfish assemblages and to rebuild stocks?
    - B. Over what time span must we act? Which options are the most effective while easiest to implement?
3. Is there a need for marine harvest refugia to manage and conserve rockfish populations?
    - A. What are the benefits?
    - B. What can we expect from marine harvest refugia?

Participants:

Alec MacCall, Chair (NMFS, Tiburon Laboratory, Groundfish Analysis Branch)
Tory O'Connell, Rapporteur (State of Alaska, Groundfish Management)
George Boehlert (NMFS, Pacific Fisheries Environmental Laboratory)
Don Gunderson (University of Washington, Fisheries Research Institute)
Bob Lea (California Department of Fish and Game)
Dave Mackett (NMFS, Southwest Fishery Science Center)
Marc Mangel (University of California, Santa Cruz)
Rod McInnis (NMFS, Southwest Region)
Sung Kwon Soh (University of Washington, School of Fisheries)
Larry Six (Pacific Fisheries Management Council)
Jim Thomas (NMFS, Office of Habitat Protection)
Cindy Thomson (NMFS, Southwest Fishery Science Center)

The management working group limited their discussion to the implications of marine refugia to fisheries management of rockfishes, while acknowledging that there are other justifications for no-take areas unrelated to commercial and recreational fisheries.

Rockfishes are vulnerable to overharvest, particularly because of the following life history characteristics:

-low mobility of adults
-extreme longevity (up to 140 years in age)
-low natural mortality

- -infrequent recruitment success
- -low productivity/biomass
- -habitat specificity
- -limited knowledge for many species

There is a dearth of scientific knowledge of stocks and life histories for many of the 72 species of rockfishes that occur in the Northeast Pacific. The mechanisms associated with recruitment and year-class-strength, in particular, are not well understood. This lack of knowledge is a persistent and unavoidable characteristic of these resources and is unlikely to be resolved even with greatly increased research efforts.

Traditional fishery analyses and management have performed poorly in protecting the sustainability of these resources. There are at least two unsolved management problems. First, currently we have no effective management practices to deal with the interdecadal variability in recruitment of most rockfish populations. Second, assemblage management may be required for numerous co-occurring species of rockfishes, but this can result both in the weakest (i.e. lowest productivity rate) species in the assemblage being seriously depleted and in serial overfishing.

Benefits. Considering these life history characteristics and limitations in management that are symptomatic of rockfish populations, several benefits of harvest refugia were identified. The biological benefits of refugia that are expected by scientists and managers include:

- -maintenance of longevity and genetic diversity by reducing the effects of fishery selection
- -complete protection for a portion of the population
- -increased habitat and biological diversity
- -de facto protection of other groundfish species
- -a control area for monitoring demographic and ecological trends
- -decreased uncertainty in stock assessments, and
- -insurance or a hedge against uncertainty in management

Considering the fishermen's expectations, harvest refugia might offer a way to reduce bycatch problems, as well as improve fishery yields. Improved fishery yields does not necessarily mean increased yields, but rather could be indicated by reduced variability of harvests, larger average size of fishes, etc. Refugia also provide insurance or a hedge against uncertainty in management, and could improve the public image of the fishing industry.

Costs and Risks. There are a number of costs and risks involved in establishing harvest refugia or no-take areas, and there are few opportunities to learn from other's experience as this is a new management technique. Refugia may confound fishery stock assessments, given the current assessment techniques. For example, “leakage” of older fish from the protected area into the non-protected areas may distort catch-age composition, causing errors in standard age-based fisheries analyses. Rockfish refugia may increase fishing effort in open areas, which could negatively affect other open-area fisheries. Fishermen likely will expect a reduction in traditional regulations in trade for no-take areas. While refugia could actually reduce maximum yields under many scenarios, this outcome could be compensated to an even greater extent by reduction in the risk of overfishing.

There is always the risk of making hollow promises when offering harvest refugia as a management tool. A realistic payoff scenario should be established, including how soon to expect benefits and at what level of benefit. Evaluating the success and benefits of the refugia will be difficult. Optimal locations may change over time. Appropriate sizes of refugia need to be determined. A schedule to evaluate the effectiveness of the refuge should be established.

Identifying specific sites for rockfish refugia focuses attention on locations of prime habitat. This could result in increased harvest in these locations if the refugia are not implemented. A related concern is that the no-take areas, once established, will attract illegal fishing. This type of risk possibly can be reduced by assignment of property rights, which would encourage fishermen to take a personal interest in the protection of the refuge. Natural predators, such as sea lions, may also be attracted to increased resources, resulting in increased natural mortality rate of fishes inside the refuge.

Evaluating the effectiveness of refugia may require expensive monitoring programs. Enforcement of no-take areas will be difficult and will require additional costs; a feasible plan of enforcement should be developed early in the process. Vessel-tracking-systems (VTS) are an attractive aid to enforcement, but their establishment and cost of output monitoring need to be determined. Establishing and monitoring refugia for management purposes requires large upfront and ongoing costs, potentially with little measure of payoff.

Management Problems and Refugia As A Solution. This working group identified key management problems and the likelihood that harvest refugia would be an effective management tool to solve them, recognizing that there are both strategic and tactical solutions to some problems. The following scores were used:

0 = refugia are not effective
1 = refugia have potential, but solutions depend on other management actions as well
2 = refugia are promising
3 = refugia are "The Answer"

Problem	**Score**
• Bycatch and discard	
Tactical: reduce bycatch in specific areas	2
Strategic: protect enough of the stock so bycatch outside refuge doesn't matter	1

• Rare successful recruitment events and low natural mortality	2
• Assemblage management and lack of information	2-3
• Habitat degradation and gear effects	
Tactical: offers an opportunity to recover	3
Strategic: may cause overfishing in open areas	1-2
• Recruitment Overfishing	2
• Localized depletion and spatial distribution of harvest	
Tactical:	2
Strategic:	0-1
• No baseline data for stock assessments	2-3
• Need to separate environmental variables from fishery effects	2-3

Recommendations

Management. There was considerable discussion about new provisions in the Magnuson-Stevens Fishery Conservation and Management Act (M-SFCMA), as amended by the Sustainable Fisheries Act of 1996. Language under Section 303 in the M-SFCMA gives the Fishery Management Councils the authority to implement marine harvest refugia as part of a fisheries management plan. Marine harvest refugia are one of the few constructive ways to address protection and conservation of essential fish habitat and the implementation of ecosystem principles in fisheries management.

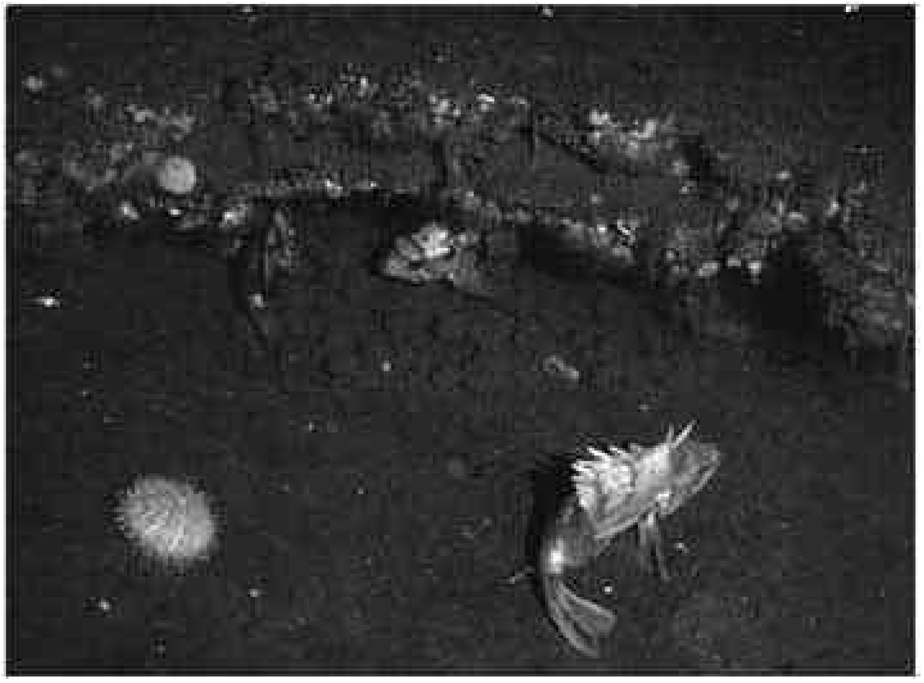
The working group made the following recommendation regarding the establishment of strategic harvest refugia as a tool for rockfish management:

> *A marine harvest refugia is a permanent no-take area. For rockfishes in particular, and groundfishes in general, there are limits to our scientific knowledge. Further, there are currently no effective management practices to deal with infrequent recruitment and its interdecadal variability, which are exhibited by rockfishes. Current rockfish assemblage management can result in serial overfishing and overfishing on the weakest stocks.*
>
> *We recommend the development of marine harvest refugia for rockfish management. Expected benefits of rockfish marine refugia include:*
>
> 1. *protection insurance (demographic, ecological and habitat, and genetic)*
> 2. *establishment of control areas that will provide information on effects of fishing and baseline data for stock assessment*
> 3. *reduction of catch variability and increased possibility of sustainability*

> *The expected level of success and benefits of the refugia need to be identified and defined; how success or effectiveness will be evaluated should be established prior to refugia implementation.*
>
> *Marine reserves provide one of the few management tools for implementation of multiple provisions of the M-SFCMA that traditional management tools cannot address, including protection of essential fish habitats, incorporating ecosystem principles in fisheries management, and taking a precautionary approach to management.*

Research. The working group discussed needs for further information relating to expectations of harvest refugia for rockfishes, and recommended the following areas of research:

- Tactical use of refugia for managing local bycatch and discard problems.
- Effects of refugia on fisheries yields and effort.
- Means to protect refugia from anthropogenic impacts, including illegal fishing.
- Determine which species will benefit most from management by refugia and develop criteria for candidate species and sites.
- How much and what type of science is needed for refugia implementation and evaluation?
- Quantify economic and social costs of implementing refugia.
- Develop criteria for evaluation of harvest refugia (performance vs expectations).



Darkblotched (under ledge; *Sebastes crameri*) and cowcod (foreground; *S. levis*) rockfish viewed from Delta submersible at 250 m in Año Nuevo Canyon off the central California coast. Photo by Mary Yoklavich

Working Group II: Science-based Design Considerations

While considering the unique life history characteristics and the current status of west coast rockfish populations, the following questions and topics are relevant to the identification of those critical design elements that influence the extent and success of harvest refugia:

1. What is the motivation for designing the harvest refugia?

2. What are the design considerations for the most effective marine harvest refugia?

3. Do we currently have sufficient understanding of the dynamics of the natural system to identify specific characteristics for rockfish refugia?

4. What information do we need to implement effective refugia for rockfishes?

Participants:

Mark Carr, Chair (University of California, Santa Cruz)
Lisa Ziobro, Rapporteur (Monterey Bay National Marine Sanctuary)
Tom Hourigan (NMFS, Office of Protected Resources)
Dan Ito (NMFS, Alaska Fisheries Science Center)
Deborah McArdle (UC Sea Grant Marine Extension Program)
Lance Morgan (University of California, Davis and Bodega Laboratory)
Wayne Palsson (Washington Department of Fisheries)
Richard Parrish (NMFS, Pacific Fisheries Environmental Laboratory)
Steve Ralston (NMFS, Tiburon Laboratory)
Paul Reilly (California Department of Fish and Game)
Josh Sladek Nowlis (NMFS, Northeast Fisheries Science Center)
Rick Starr (UC Sea Grant Marine Extension Program)

The design working group recommended three different scenarios in which marine harvest refugia could be developed for rockfish populations, based largely on the goals and objectives for establishing the refugia. The three scenarios range from small no-take areas used for research and to protect key habitats and species to large harvest refugia used to enhance fisheries. Each scenario includes different design characteristics and subsequent levels of protection. It is important to understand that the three distinct scenarios provide greatly different benefits, and that a system of marine refugia could include all three levels of resource protection.

Scenario I. Harvest Refugia as an Alternative Strategy For Sustainable Fishery Management

Goal

In this scenario, marine harvest refugia collectively comprise an area that is sufficient to sustain fisheries in adjacent fished areas. Refugia at this level of protection are designed from an ecosystem approach, whereby specific requirements for targeted species are considered along with more general objectives.

Objectives

1. Protect and maintain spawning biomass
2. Select for larval dispersal over adult spillover
3. Establish and maintain natural size and age structure of a population
4. Preserve essential fish habitats and increase habitat diversity
5. Enhance and protect biological diversity (i.e. species, community and genetic diversity)
6. Provide control communities, that is "pristine" communities that can be used as benchmarks for comparison with unprotected areas to estimate the effects of exploitation

Design Considerations

Size. Refugia are established on the largest scale, protecting from 20 to 50% of (1) the total area of habitat for multi-species, or (2) the spawning potential for targeted species. Size of individual refugia should be based on the extent of rockfish movements and on the pristine size structure of the population.

Number. The number of refugia will be based on the size of individual refugia and on the collective or total area of protection.

Shape. The shape of each refuge is region-specific, encompassing an onshore-offshore swath for increased protection of both shallow and deepwater rockfishes and of the whole ecosystem. Additionally, a contiguous swath of protected area, rather than patches, offers logistical advantages in terms of effective enforcement.

Location. Refugia would be established within a minimum of three bioregions along the west coast, considering the following criteria:

1. Sites should be located with consideration to ocean current regimes (i.e. as a bet-hedging tactic, select multiple sites in regions of both high and low upwelling).
2. Sites should include both heavily and less exploited populations. Heavily exploited populations are more likely to exhibit a greater, although lagged, response to protection. Areas of heavy exploitation most likely indicate sites of historically large populations.

Less exploited populations may provide immediate response to protection by maintaining existing spawning biomass.

3. Sites should meet habitat diversity and depth requirements for multi-species assemblages.
4. Sites should have sufficient resources to support spawning biomass.
5. Sites should be distributed in a network that guarantees replenishment of one another and increases the likelihood of sustainability.

Restrictions. These refugia would prohibit directed fisheries for rockfish species of concern. They also would prohibit those gear types that adversely affect these species and that adversely disturb or destroy essential habitats. One consequence of such restrictions would be to allow exploitation of non-demersal transient species (e.g. salmon, tuna). Within this scenario, there may be a range of restrictions in different areas, including a core zone that would prohibit all fishing.

Primary Information Needs For Effective Design

1. Current regimes
2. Spatial structure of populations
3. Demographics of exploited and unexploited populations, especially size and age structure
4. Regional-scale habitat maps
5. Habitat associations, depths, movements
6. Stock assessments for targeted species
7. Distribution of fishing effort

Research Goals

1. Explore methods to quantitatively or qualitatively describe larval dispersal
2. Describe mechanisms that influence larval dispersal and recruitment
3. Conduct adaptive management, using the information gleaned from established refugia (e.g. the effects of various design criteria) to improve the design and management of existing and future refugia

Scenario II. Harvest Refugia as a Buffer or Insurance Against Overfishing

Goal

In this scenario, marine harvest refugia supplement fishery management practices, thereby providing a buffer against fishery collapse caused by environmental change, failed fishery management plans, or unexpected natural or anthropogenic events. Refugia created under this scenario also serve as a benchmark for management trials or experiments.

Objectives

1. Provide a buffer against uncertainty associated with environmental change and deficiencies in fishery management strategies
2. Preserve essential fish habitats and increase habitat diversity
3. Enhance and protect biological diversity (i.e., species, community and genetic diversity)
4. Provide control communities, that is "pristine" communities that can be used as benchmarks for comparison with unprotected areas to estimate the effects of exploitation

Design Considerations

Size. Refugia are established on an intermediate scale, protecting from 5 to 20% of a species' essential habitat. The smallest possible size (e. g. 5%) should encompass the typical movements of individuals of a targeted species.

Number. The number of refugia will be based on the size of individual refugia and on the collective or total area of protection. A suggested minimum number of refugia would be one per upwelling region.

Shape. The shape of each refuge is region-specific, encompassing an onshore-offshore wedge for increased protection of the whole ecosystem and to accommodate the larger home ranges of deeper dwelling species. Additionally, a contiguous swath of protected area, rather than patches, offers logistical advantages in terms of effective enforcement. The exact shape of the swath would be dependent on the distribution of species and habitats to be protected, and be designed to maximize the diversity of species and habitats.

Location. The refugia need to encompass the essential fish habitats of the species and/or species complex. The criteria listed for large scale refugia need even more emphasis and consideration here. Refugia in this scenario would be established within a minimum of three bioregions along the west coast, and placed in upwelling cells with careful consideration of the following criteria:

1. Sites should be located with consideration to ocean current regimes (i.e. areas of high and low upwelling as a bet-hedging tactic).
2. Sites should include both heavily and less exploited populations. Heavily exploited populations are more likely to exhibit a greater, although lagged, response to protection. Areas of heavy exploitation most likely indicate sites of historically large populations. Less exploited populations may provide immediate response to protection by maintaining existing spawning biomass.
3. Sites should meet habitat diversity and depth requirements for multi-species assemblages.
4. Sites should have sufficient resources to support spawning biomass.
5. Sites should be distributed in a network that guarantees replenishment of one another and increases the likelihood of sustainability.

Restrictions. These refugia would prohibit directed fisheries for rockfish species of concern. They also would prohibit those gear types that adversely affect these species and that adversely disturb or destroy essential habitats. One consequence of such restrictions would be to allow exploitation of non-demersal transient species (e.g. salmon, tuna).

Primary Information Needs For Effective Design

1. Demographics of exploited and unexploited populations, especially size and age structure
2. Regional-scale habitat maps
3. Habitat associations, depths, movements
4. Stock assessments for targeted species
5. Distribution of fishing effort
6. Current regimes

Note: Although comprehensive information for the above listed items generally is unavailable, effective refugia implementation can occur using existing data.

Research Goals

1. Evaluate response of populations to protection (BACI [Before After Control Impact] monitoring designs)
2. Explore response of stock in terms of 1) spawning potential, 2) change in size and age distribution, 3) yield and catch per unit effort at different spatial scales
3. Experiment with management strategies on exploited population
4. Monitor the response of the fishery to harvest refugia
5. Improve the design and management of existing and future refugia using the information gleaned from established refugia

Scenario III. Harvest Refugia as Heritage Sites And Areas For Fisheries Research

Goal

In this scenario, marine harvest refugia protect representative essential fish habitats and key associated species. Refugia at this smallest level of protection are not intended as an alternative or supplement to traditional fisheries management. These areas may be quite small, but focus critical protection on ecologically valuable areas and highly sedentary species. Refugia created under this scenario also may serve as important control sites for research.

Objectives

1. Preserve essential fish habitats and increase habitat diversity
2. Enhance and protect biological diversity (i.e. species, community and genetic diversity)
3. Provide control communities, that is "pristine" communities that can be used as benchmarks for comparison with unprotected areas to estimate the effects of exploitation

Design Considerations

Size. Refugia are established on the smallest acceptable scale, protecting less than 5% of the population.

Number. The number of refugia will be based on the size of individual refugia, the collective or total area of protection, and on the distribution of essential fish habitats.

Shape. The shape of each refuge is region-specific. Shape is a function of the distribution of key habitats and species, and of the need for habitat and ecosystem protection. Where possible, an onshore-offshore wedge should be considered to protect all portions of the local ecosystem. This shape also has logistical advantages, in terms of effective enforcement, as compared to patches of protection.

Location. Refugia would be established by bioregion, considering the following criteria:

1. Large enough to incorporate home ranges of species and to minimize edge effects
2. Include representative essential fish habitats (not just unique habitats) of both exploited and unexploited populations
3. Areas that maximize habitat diversity
4. Provide coupling with natural refugia to increase overall protection
5. Complementary to and integrated with protected areas under other management jurisdictions
6. Located in deep water near existing nearshore refugia
7. Contiguous across depths allowing onshore-offshore movement

Restrictions. These refugia are no-take areas, allowing fisheries research by permit.

Primary Information Needs For Effective Design

1. Regional-scale habitat maps identifying essential fish habitats
2. Detailed fish habitat maps and descriptions of proposed refugia
3. Descriptions of fish-habitat associations, depth distributions, movements of key species
4. Identify levels of exploitation in and around selected areas of protection

Note: Although available information is sufficient to proceed with establishment of harvest refugia at this level of protection, a thorough review and identification of information gaps is needed.

Research Goals

1. Evaluate the response of the communities to protection (BACI monitoring designs)
2. Quantify fish home ranges and movements
3. Conduct experiments to separate fisheries effects from environmental variables
4. Compare health (e.g. quality and quantity) of fish habitats inside and outside refuge

Working Group III: Socio-economic Considerations and Implementation

In considering the principles for the conservation of wild living resources, Mangel et al. (1996)[1] summarized that “Resources have scientific, ecological, aesthetic, and functional values that are not expressed in the market place. Adequately identifying and effectively measuring all relevant consumptive and non-consumptive values of varying stakeholders is a non-trivial and complex matter, but it must be undertaken.” In evaluating harvest refugia for rockfishes, the following social and economic topics and questions might be considered:

1. Do we currently have sufficient understanding of the social and economic considerations associated with implementing harvest refugia for management purposes?

2. Who are the stakeholders involved in managing these resources?
    1. What do they require?
    2. What are their motivations?
    3. What are their expectations?

3. Can we establish valuation of our rockfish resources from the ecological as well as economic perspective?

4. What are the risks involved in establishing harvest refugia?

5. What would be the most effective approach to implementing refugia?

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[1] Mangel, M., L.M. Talbot, G.K. Meffe, M.T. Agardy, D.L. Alverson, J. Barlow, D.B. Botkin, G. Budowski, T. Clark, J. Cooke, R.H. Crozier, P.K. Dayton, D.L. Elder, C.W. Fowler, S.Funtowicz, J. Giske, R.J. Hofman, S.J. Holt, S.R. Kellert, L.A. Kimball, D. Ludwig, K. Magnusson, B.S. Malayang III, C. Mann,E.A. Norse, S.P. Northridge, W.F. Perrin, C.Perrings, R.M. Peterman, G.B. Rabb, H.A. Regier, J.E. Reynolds III, K. Sherman, M.P. Sissenwine, T.D. Smith, A. Starfield, R.J. Taylor, M.F. Tillman, C. Toft, J.R. Twiss, Jr., J. Wilen, and T.P Young. Principles for the Conservation of Wild Living Resources. Ecol. Appl. 6(2): 338-362.

The establishment of harvest refugia for rockfish (i.e., no-take areas; HRR) necessitates three broad sets of policy decisions: 1) those concerning whether or not to establish them, 2) those assessing sizes and locations of refugia to be established and 3) those addressing the management of refugia, once they are established (see Tisdell, C. and J. M. Broadus. 1989. Policy issues related to the establishment and management of marine reserves. Coastal Management 17:37-53). These decisions are not only about resource management per se. They also are about the management of people, and therefore require consideration of the social, cultural, economic and political environment in which these decisions are made. In particular, it is important to understand the range of individuals and groups who value these resources, the nature and extent of those values, in what way the establishment of harvest refugia likely will affect these people, and how they might respond. Differences in values, perceptions, and beliefs among groups are likely to lead to fundamentally different responses to the establishment of harvest refugia. By understanding these differences, proponents of refugia can: 1) capitalize on the support and initiative of a group; 2) provide appropriate and more effective communication about the concept of no-take areas; and 3) predict and mitigate opposition to refugia. The direct involvement of these diverse stakeholders throughout the process can bode even better for the outcome of a refugia effort because this provides for ongoing feedback that can contribute to appropriate design and implementation, and invests these groups in the process and the outcome.

Among the questions that should be asked when exploring the social and economic aspects of marine refugia are: 1) What individuals and groups have interest in, or would be affected by, harvest refugia for rockfish; 2) What are the social and economic characteristics of these groups; 3) What are their values, perceptions, beliefs and attitudes regarding rockfish, marine resources, and refugia; 4) What is the nature and extent of their 'use' of the resources; 5) What are the costs and benefits of HRR, in psychological, social and economic terms, to these individuals and groups, as well as to society as a whole; and 6) How do these costs and benefits change, given different harvest refugia alternatives versus the status quo? Answers to these questions can, and should, inform decision-making at all stages -- from conceptualization through evaluation -- in the establishment of rockfish harvest refugia.

Our working group began by asking a general question: Is enough known about rockfish life history and the status of and vulnerability to their fisheries to establish HRRs? The conclusion was that yes, we have sufficient understanding to proceed, and that refugia exemplify a precautionary approach to resource management. However, there was some disagreement as to how refugia should be conceived -- as an experiment in resource management or as a mechanism for protecting and enhancing rockfish resources? Because the efficacy of harvest refugia for rockfish has yet to be ascertained, we concluded that an experimental approach should be taken, rather than proposing refugia as a panacea for declining resources or as a substitute for traditional resource management. Participants cited a lack of marine wilderness areas, which are analogous to terrestrial wilderness areas as established by the Wilderness Act of 1964, through which rockfish might be protected more effectively. Such areas, proposed as experiments in resource management, would provide a reference point to better understand: 1) natural processes in undisturbed systems; and 2) fishery management measures in other areas. The group concluded that it is important ecologically to enhance population health (e.g. genetic, habitat and species diversity) and that refugia can have positive socio-economic benefits for diverse groups of people.

A more focused discussion of socio-economic considerations and implementation of HRR included generating support for refugia, gaining a better understanding of risks associated with their establishment and evaluation, and obtaining compliance with and enforcing them.

There was general agreement that if HRR are to be used, the problems they are meant to address (e.g. growing fishing pressure, declining residential rockfish populations, diminishing productivity) must be recognized and the objectives of the proposed HRR clearly defined. Participants differed in their views on the appropriate mechanism and process for establishing HRR. Some said 'just do it,' echoing Ballantine's approach to establishing marine refugia in New Zealand. Others argued for proceeding with caution, citing social, economic and political complexities that, if not recognized and addressed, would lead to failure with efforts to establish and realize the potential benefits of an HRR network.

The ensuing discussion addressed a number of these issues in pursuing an HRR strategy. First, there is a diversity of stakeholders, variously identified as consumptive and non-consumptive users, non-users (i.e. those who value the resource for its existence), and more specifically as commercial and recreational fishermen, scientists, resource managers, and individuals and groups from among the local, regional and national public. Each of these groups has particular values, perceptions and beliefs about the existence and nature of the problem, its importance, whether and how it can be solved, and what might be expected of HRR. Some of the socio-economic considerations that are likely to influence their views on both the problem of conserving rockfish populations and HRR as a solution include: ethnic and cultural views of natural resources in general and fishes in particular, socio-economic status, physical proximity to the resource, and economic dependence on it. It is important to understand the diversity and complexity of stakeholders because their support for (or opposition to) HRR will be a function of these characteristics.

It was agreed that stakeholders clearly need to be involved in identifying the reasons for establishing HRR, and in conceptualizing, designing, implementing and evaluating them. Opinion of the working group diverged as to which stakeholders should be involved, when, and how. Discussion of examples of successes and failures in the establishment of marine protected areas along the California coast recognized the many options and arenas for pursuing HRR. Among these options and arenas are federal legislation and the fishery management councils, state legislation and resource management commission action, and citizen (grassroots) action initiatives.

Our group also considered the risks associated with establishing rockfish refugia. There was concern about overselling the refugia concept, thereby creating inappropriate and unreasonable expectations that could lead to erosion of the credibility of the refugia concept and of its proponents. Given the long life cycle of most rockfish species, the results of refugia might not be reasonably evaluated for several years following HRR establishment. At present, the public is likely to expect clear results in the short term. This discrepancy between ecological and socio-economic time horizons could lead to withdrawal of public support and increased opposition to HRR. However, this concern could be addressed (partially if not completely) through concerted efforts to understand and work with the perspectives and expectations of diverse stakeholders. Another concern was that the evaluation of refugia could render inconclusive results. Such an outcome could be due to the actual inefficacy of refugia, or to mitigating circumstances (e.g. unforeseen design flaws, illegal fishing within the closed area, and disturbances from either natural or anthropogenic impacts within the HRR).

The socio-economic considerations related to locating HRR prompted a discussion on design (e.g. distribution and size of HRR, as well as location). Recent experience with the establishment of four marine ecological reserves pursuant to California's Marine Resources Protection Act of 1990 was cited as a cautionary tale. All four reserves, which were established to provide for scientific research on the management and enhancement of marine resources, are very small, averaging 2 mi^2. Two of the reserves comprise inappropriate benthic habitats that provide no benefit to rockfishes, and two are in relatively remote areas where they are less likely to have a noticeable impact than if they were located in more accessible and used areas. In terms of spatial distribution, it was suggested that rockfish harvest refugia be established in multiple areas along the coast. Broad distribution would more likely cover a range of rockfish species and habitats, and would more equitably distribute the costs and benefits among coastal communities. This could help make refugia more appealing to, and supportable by, diverse stakeholders.

Some argued that the process of establishing a network of HRR, including conceptualization, design, implementation and evaluation, should begin as soon as possible, using a plan that can be phased in and expanded over several years. As part of this process, it is critical that the refugia, individually and as a network, be evaluated periodically to determine their effectiveness relative to the objectives articulated clearly from the start.

When discussing compliance with and enforcement of HRR, it was noted that a large proportion of stakeholders would likely comply with rules associated with harvest refugia, and would exert social pressure on others to do the same. Public education about harvest refugia should reinforce compliance and help lessen the need for enforcement. Nonetheless, enforcement will still be necessary and should be considered in the design and implementation process. Planning should carefully consider the range of needs and concerns, resources available, and opportunities for cooperation among local, state, and federal entities in promoting compliance and carrying out enforcement. In connection with this, it was noted that enforcement also pertains to the active involvement of relevant agencies; agency inaction can jeopardize the effectiveness of harvest refugia. Thus, in addition to insuring compliance and facilitating enforcement vis a vis citizens (the public), an HRR strategy must include mechanisms for insuring agency involvement.

Finally, the group also agreed there should be a network among all those involved in the HRR process that considers inter-state and international issues of rockfish resource management and protection through traditional resource management (e.g. gear restrictions, catch limits) as well as refugia. A primary concern was the need to coordinate the development of rockfish harvest refugia efforts among all interested groups to avert conflict with other initiatives (and thus potential loss of resources or support for HRR) and, more positively, to leverage resources to more effectively pursue and achieve the goals related to the establishment of harvest refugia for rockfishes.

Typical jig boat with 3000 lb of rockfish caught off the central California coast in 1938. Photograph from J. B. Phillips (1939)[1].

Preparing set lines coiled in baskets for early morning fishing for rockfish off the central California coast in 1938. Photograph from J.B. Phillips (1939)[1].

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[1] Phillips, J.B. 1939. The rockfish of the Monterey wholesale fish markets. CDFG Bull. 25: 214-225.

Consolidated Recommendations of the Working Groups

The recommendations and conclusions of the three working groups are synthesized as follows:

Need for Rockfish Refugia. There was general consensus that marine harvest refugia exemplify a precautionary approach to the management and conservation of rockfish resources on the west coast. It was recognized 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. The goals and objectives of establishing harvest refugia and the problems being addressed by this process must be clearly defined at the onset of planning. The expected level of success and how it will be evaluated should be established prior to refugia implementation.

Key Problems in Managing Rockfish Populations and Associated Expectations of Refugia. 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. Secondly, there are currently no effective management practices to deal with infrequent recruitment and its interdecadal variability, which are exhibited by rockfishes. Refugia hold promise in addressing this problem by allowing researchers to separate environmental variables from fishery effects. Further, current rockfish assemblage management can result in serial overfishing and overfishing on the weakest stocks. Refugia will allow us to incorporate ecosystem principles into fisheries assemblage management. Refugia also provide the needed baseline data for more accurate stock assessments.

Design Considerations For Rockfish Refugia. Three different scenarios for developing rockfish harvest refugia were recommended, based on the goals and objectives for establishing the refugia. These scenarios range from small no-take heritage sites used for research and to protect key habitats and species to large harvest refugia used for sustainable fisheries management. Each scenario includes different design characteristics and subsequent levels of protection. These distinct scenarios provide greatly different benefits. A coastwide network of marine refugia could include all three levels of resource protection.

Considerations of Stakeholders. It was agreed that stakeholders need to be identified early in the process of implementing rockfish refugia. Stakeholders clearly need to be involved in identifying the reasons for establishing the refugia, and in conceptualizing, designing, implementing and evaluating them. A network among all those involved in the refugia process should consider interstate and international issues of rockfish resource management.

Compliance and Enforcement. Public education should reinforce compliance and lessen the need for enforcement, but enforcement will be necessary and should be considered in the design and implementation process. Assignment of property rights, which would encourage fishermen to take a personal interest in the protection of the refuge, would foster compliance. Vessel-tracking-systems, an attractive aid to enforcement, need to be considered. Planning should carefully consider the range of needs and concerns, resources available, and opportunities for cooperation among local, state, and federal entities in promoting compliance and carrying out enforcement.

Suggested Research

A synopsis of research needs and direction, as suggested by the working groups, includes:

1. Quantify economic and social costs and benefits of implementing harvest refugia.
2. Develop criteria for candidate species and sites of harvest refugia.
3. Develop criteria for evaluation and monitoring of harvest refugia (performance vs expectations).
4. Quantify fish movements and home ranges, to be applied to design of harvest refugia.
5. Describe larval dispersal and ocean transport as related to design of harvest refugia.
6. Develop means to protect harvest refugia from anthropogenic impacts, including illegal fishing.
7. Evaluate effects of harvest refugia of varying spatial scales on fishery yields and effort (empirical and theoretical).
8. Assess recovery of fish habitats inside vs outside of harvest refugia.
9. Conduct adaptive management experiments to improve design of harvest refugia.
10. Assess tactical use of harvest refugia for managing local bycatch and discard problems.

Epilog

A Call for Change in Managing Our Rockfish Resources

Donald Gunderson
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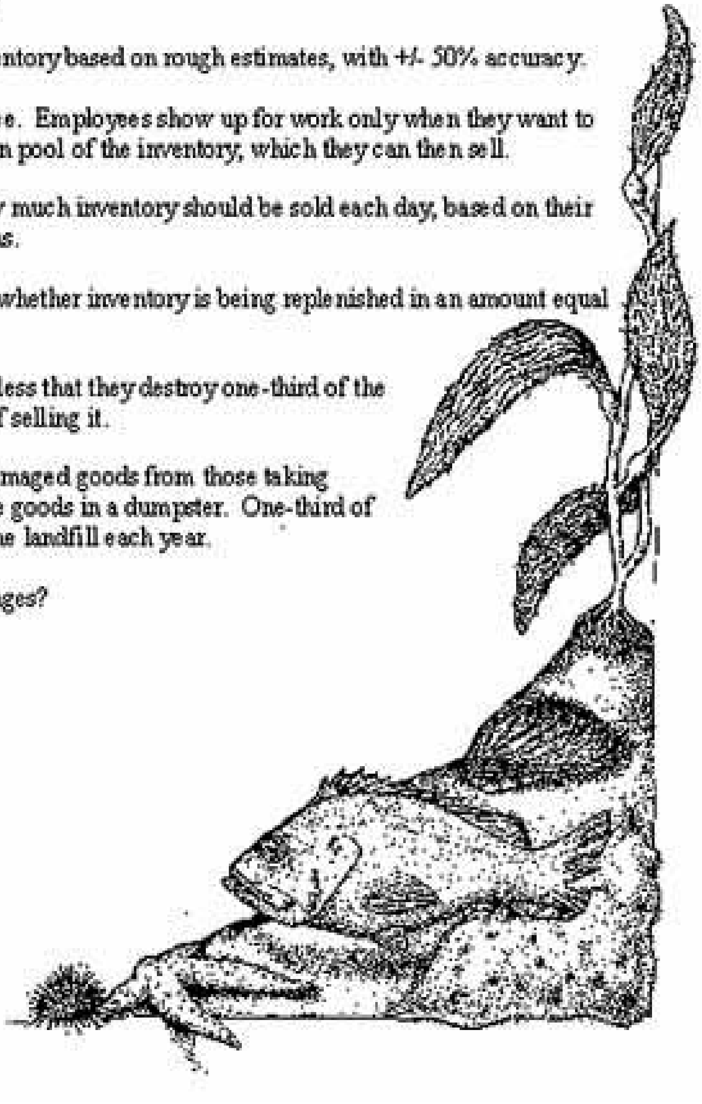
Imagine a corporation where:

1. The government takes inventory based on rough estimates, with +/- 50% accuracy.
2. Anyone can be an employee. Employees show up for work only when they want to and compete for a common pool of the inventory, which they can then sell.
3. The employees decide how much inventory should be sold each day, based on their economic needs and dreams.
4. The employees don't care whether inventory is being replenished in an amount equal to sales.
5. The employees are so careless that they destroy one-third of the inventory in the process of selling it.
6. The employees hide the damaged goods from those taking inventory, and throw these goods in a dumpster. One-third of the inventory ends up in the landfill each year.

Isn't it time for major changes?



Rockfish Refugia

Ed Ueber
Gulf of the Farallones
National Marine Sanctuary

We met together
So we could say
It is a good
To let rockfish play

Where they can be safe to roam
And not have someone destroy their home;
Where gun or net or hook or club
Would not cut short some rockfish's love.

Then some day - a long time from now -
The future will have rockfish named cow.
Striped and China and Vermillion will be free
To allow our children rockfish to sea.

Rosy rockfish (*Sebastes rosaceus*) viewed from Delta submersible at 100 m off Point Sur off the central California coast. Photo by M. Yoklavich.

Appendix 1

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