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inside:

This issue's focus: MARINE RESERVES

Marine Protected Area is a general term used to describe a variety of marine sites that have some type of management in place to protect the area from human activity. Frequently, the goal is to limit or prohibit the harvest of some fish species. Not all MPAs are established to prohibit harvest, however. Designations are sometimes made to promote recreational activities such as SCUBA diving, boating and shellfish harvest. These activities occur in areas called marine parks or underwater parks. Other designations include no-anchor zones that protect sensitive habitats from the scouring of boat anchors and no-access areas that may protect nesting or nursery areas from human disturbance. This type of area is often called a marine refuge.

In Puget Sound, a geographic harvest restriction authorized by the Washington State Department of Fish and Wildlife is either a marine conservation area or a marine preserve, depending on whether harvest is closed to all species or just selected species. Bottomfish Recovery Areas (no harvest of bottomfish requested) have also been designated by San Juan County. Other types of marine protected areas exist in Puget Sound and are managed by a variety of agencies.

Regardless of who makes the designation and what it is called, there are important questions being asked about the effectiveness of no-harvest restrictions. This issue of *Puget Sound Notes* is written by three Puget Sound scientists who are working to answer these questions. The term **marine reserves** will be used throughout this newsletter to refer to areas with specific harvest restrictions. There is much to be learned and there is little time to lose as several of our Puget Sound marine fish populations are in critical condition.

The *Puget Sound Management Plan* promotes the use of a variety of marine protected areas to achieve a net gain in marine species and long-term protection of critical habitats. The vision is for a network of MPAs that serve to protect migratory corridors, nursery areas and representative habitat. The sites should have long-term monitoring plans, provisions for periodic assessments and a strategy for evaluating effectiveness. Any MPA must continue to acknowledge and uphold tribal treaty rights and co-management roles of affected tribal governments.

*~ For additional information on MPAs and terminology, contact Ginny Broadhurst, marine protected area lead, at (360) 738-6122 or gbroadhurst@psat.wa.gov. You can also learn more by visiting the Puget Sound Water Quality Action Team's website at **www.wa.gov/puget_sound**.*

Scientific Approaches to Designing a Marine Reserve Network for Puget Sound

By Wayne Palsson, Washington Department of Fish and Wildlife

Introduction

The decline of marine fish resources in Puget Sound and throughout the world has prompted a host of initiatives focused on creating a system of marine reserves. Research in Puget Sound and elsewhere has shown that some marine species respond when protected from fishing in marine reserves. Species within reserves increase in numbers, grow to larger sizes, and increase their reproductive output in stark contrast to similar habitats that are open to fishing (Palsson and Pacunski 1995; Palsson 1998; Roberts and Polunin 1991). There is great enthusiasm for creating MPAs and reserve networks, but there is no consensus regarding the goals, objectives and design and selection criteria. So, how can science be used to create a system of marine reserves that affords protection to marine species, their habitats, and ecosystems?

Current Reserve Networks

To date, a number of reserves have been created in Puget Sound (Murray 1998), including those inspired by agency policies or directions, tribal agreements, voluntary initiatives by non-governmental organizations and local governments. San Juan County designed and implemented a system of marine reserves with planners asking local residents which sites in the county they believe have been overfished (Kaill 1999). A system of eight voluntary reserves was created based upon their responses. Skagit County is undertaking a similar approach based

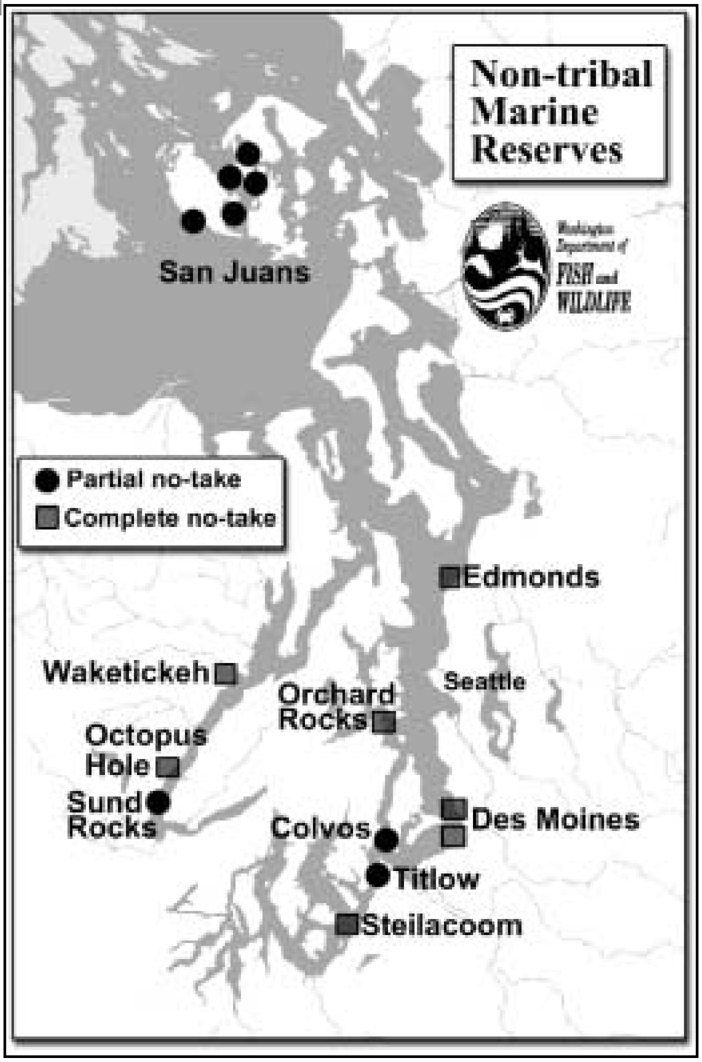

Figure 1. Marine and ecological reserves established by Washington Department of Fish and Wildlife for Puget Sound.

on known rocky habitats (McConnell and others 2001).

These efforts and others are building into a network of reserves. For example, Washington Department of Fish and Wildlife instituted 15 statutory marine reserves throughout Puget Sound (Figure 1) that protect bottomfish, shellfish, or intertidal invertebrates from non-tribal harvest. These reserves vary from 3 acres in size to 454 acres, and one has been in existence since 1970. The three Fish and Wildlife reserves in Hood Canal together constitute almost 15% of the nearshore rocky habitat in that region. As these and other agencies and groups consider creating marine reserves in Puget Sound, a cohesive process will be needed to set common goals, involve all concerned citizens, and use the best science to select sites and design a network that will complement the organizations' efforts. This article will review ongoing approaches to the design of marine reserve networks for Puget Sound and will identify important steps that should be considered in developing individual reserves and reserve networks.

Designing Reserves and Networks

Design of a reserve system will depend upon the goals and objectives established for the system, the nature of the species and habitats in the system, and the ability of science to predict and test the outcomes of marine reserve placement and networking (Gubbay 1995; Agardy 1997; National Research Council (NRC) 2001). Recently, Roberts and others (In review, *a*) presented a logical process for planning marine reserves. These steps include:

- Define the goals of the network.
- Define the area of interest.
- Divide it into possible reserve units.
- Select criteria for evaluation.
- Decide how to quantify the information needed to evaluate the criteria.
- Assemble the information on the potential reserve units.
- Evaluate and score the information in terms of biogeography, conservation targets for the criteria, site selection, and alternative approaches.
- Integrate information on site selection criteria, alternative approaches and final network design with respect to socioeconomic information.

Many authors identified important goals for MPAs including: conservation of biodiversity and habitat; protection of vulnerable species; improving fishery management by controlling exploitation rates, protecting critical life stages, reducing secondary fishery impacts, and conserving genetic diversity and life-history traits; providing scientific knowledge by providing control areas to compare areas impacted by human uses; providing societal benefits through educational and cultural heritage (NRC 2001). Many of these goals and objectives are appropriate for Puget Sound reserve networks and agencies such as the Puget Sound Water Quality Action Team, Fish and Wildlife, San Juan County, People for Puget Sound (PPS), The Nature Conservancy (TNC), and the Northwest Straits Commission have adopted some of them into their policies and goals. Many of these organizations seek to conserve all marine species and habitats by means of a network of representative marine reserves throughout their jurisdictions in Puget Sound.

Once goals and objectives are established for a Puget Sound reserve network, a variety of approaches exist to establish criteria for site selection and network (Gubbay 1995; Agardy 1997; Yoklavich 1998; Possingham and others 2000; NRC 2001). They include biological criteria such as biogeographic representation, habitat representation or heterogeneity, human threats, natural catastrophes, size, connectivity, vulnerable habitats, vulnerable life-history stages, exploitable species, species or populations of interest, ecosystem function and linkages, and provision of ecological services for people (Roberts and others, in review *b*). Other design elements include social, economic and pragmatic criteria among others (Salm and Price 1995). But one current thought is to consider biological criteria first in designing the system because if social or economic criteria override biological criteria, then areas of little biological importance will be selected (Roberts and others, in review *a,b*). This phenomenon can occur in Puget Sound where some of the best reserve candidates are often the most popular fishing sites and may be withdrawn from consideration.

TNC and PPS are undertaking formal and systematic approaches to marine reserve design. In identifying significant areas for protection, PPS has accessed species and geophysical inventories from a number of sources and associated probable marine habitats with measures of species richness (Bloch and others, in press). The Boundary Pass area separating the northern San Juan Archipelago from the Canadian Gulf Islands was identified as a species-rich area, resulting in an international effort to create the Orca Pass Marine Protected Area. TNC has used similar data sources to design a marine reserve network in the Puget Sound and Georgia Basin. The TNC approach is to use the Sites model, which, through computer simulation, minimizes the number of geographical units needed as reserves to protect the range of biological diversity in a region (Possingham and others 2000). The model, interfaced with a GIS, can also coalesce geographical units into clusters to avoid fragmentation. This eco-regional planning tool appears to be one of the most convenient tools to plan ecological reserves over broad areas.

In addition to creating broad-based representative systems, there are efforts underway to establish a network of marine reserves specifically to protect rockfish and their habitats. This effort is a result of the response to the petition for rockfishes in Puget Sound to be considered for endangered or threatened status under the Endangered Species Act and the observation that rockfishes appear to respond to protection offered by marine reserves (Palsson 1998). Sites or other broad-based models might be applied to the design of a rockfish network system, but modifications may be required to assure that specific habitat and behavioral features of rockfish are considered. Important ecological sub-regions may be overlooked in using broad-scale models that may ignore unique areas of biological productivity and species associations such as those that occur in the many sub-basins of Puget Sound. Large-scale models may also not account for the subtleties of species diversity and habitat function that are poorly defined in subtidal waters.

As scientists learn more about how marine species and communities relate to their habitats, they may need to modify approaches to design marine reserve networks for sensitive resources such as rockfishes. For example, much is known regarding how copper, quillback, and brown rockfishes relate to their habitats. They appear to prefer natural, high relief rocky habitats (Matthews 1990*a*), have small home ranges when in those habitats (Matthews 1990*b*), and, at least for copper rockfish, have specific life-history pathways that require nearshore kelp beds for nurseries (Buckley 1997). Copper rockfish occur in the highest densities upon rocky boulder fields and walls with high densities of crevices (Pacunski and Palsson, in press). Palsson (In press) related these habitat relationships and other aspects of rocky habitats in Puget Sound into a review of potential marine reserve criteria for rocky habitat species. Such specific criteria could be associated with charts of rocky habitat in Puget Sound (Pacunski and Palsson, in press) resulting in a list of potential reserve sites rated by their habitat features and functions. Models such as Sites may be adapted to these criteria and used to select a minimum representative system by basin or to achieve other conservation goals.

An alternative approach to reserve design could invoke the Criteria and Objectives for Marine Protected Area Evaluation (COMPARE) method proposed by Hockey and Branch (1997) for a marine reserve system in South Africa. Their approach was to rate individual marine reserve units for how identified criteria met conservation, fisheries management, and utilization goals set forth for reserves. By obtaining quantitative comparisons of reserve candidates from managers and experts, existing and candidate sites could be ranked and then selected or rejected in an objective manner.

Conclusion and Summary

Marine reserves have been created and are being designed in Puget Sound for a variety of reasons using a number of methods. The planning efforts underway have similarities and differences in goals and instruments of protection. This is the appropriate time for tribes, state and federal agencies, counties, non-governmental organizations, and citizens to come together to agree on a cohesive strategy for achieving a network of reserves in Puget Sound, firmly grounded on the best science available and focused on common goals. A variety of scientific approaches and tools now exist and can be focused on these waters to aid in the design and selection process. A growing body of experience locally and internationally can also aid in determining goals, measuring success, and involving constituents. Until entities can agree on unified or complementary approaches, the planning and implementation of a marine reserve network will suffer from a diffusion of focus, competition for funding, and a dilution of public recognition and affirmation.

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Inside and out of the San Juan Islands Marine Preserves:
Demographics of nearshore rocky reef fish

By Eric Eisenhardt,
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Introduction

Most research on marine reserves to date has taken place in tropical systems. Studies have shown temporal increases in abundance and size of fish in marine reserves on tropical reefs (Alcala and Russ 1990; Roberts and Polunin 1991), and export of adult biomass outside reserves (Russ and Alcala 1997). A handful of studies have tested the influence of marine reserves on nearshore rocky reef fish assemblages in temperate regions (McCormick and Choat 1987; Palsson 1998; Paddack and Estes 2000; Martel and others 2000). However, these temperate studies have relied on comparisons of **fished** and **reserve** sites (1) with little or no replication of treatments or (2) across limited time scales.

The San Juan Island Marine Preserves are fishery reserves created by the Washington Department of Fish and Wildlife in 1990. They restrict all forms of fishing except for salmon, herring and in certain areas, crab (Murray 1998) and offer an opportunity to study the effects of harvest restrictions on rocky reef species. Anglers targeting salmon have little interaction with rocky reef fish, with the exception of lingcod, *Ophiodon elongatus* (K. Koski, personal communication). There is little or no bycatch associated with herring fishing. Crabs are fished with pots and usually in soft-bottom habitats.

Bottomfish angler trips in North Puget Sound peaked during 1980 to 1983, and by 1994 the annual number of trips was down to early 1970's levels. A 10-fish bag limit for rockfish was enacted in 1983, and reduced to 5 fish in 1994. The current daily bag limit for rockfish is one fish. In 1992, the lingcod season was reduced from seven months to six weeks and minimum/maximum size limits were introduced. Directed commercial fisheries for rockfish using jig and troll gears were prohibited in the San Juans in 1984 (Palsson and others 1997). Trawling is allowed outside reserves, but rarely occurs in San Juan Channel, and has resulted in total annual rockfish landings of less than 100 pounds since 1994. No lingcod have been caught commercially during the last few years (W. Palsson, personal communication).

Data presented here were collected from six sites during July 27 to October 5, 2000. Historical data collected in San Juan Channel from 1974 to 1976 by Moulton (1977) are presented for comparison. The three San Juan Islands Marine Preserves in San Juan Channel that contain nearshore rocky reef were selected as study sites. These were paired with non-reserve sites to provide similar bathymetry, substrate complexity, algal communities, and exposure to oceanographic processes within each reserve/non-reserve pair.

The eight target species for which data were collected included five rockfish: copper *(Sebastes caurinus)*, quillback *(S. maliger)*, black *(S. melanops)*, yellowtail *(S. flavidus)* and Puget Sound *(S. emphaeus);* lingcod *(O. elongatus)*, kelp greenling *(Hexagrammos decagrammus)* and striped surfperch *(Embiotoca lateralis)*. These species are distributed over a gradient of susceptibility and desirability to local angler effort. They comprise the largest and most conspicuous members of the nearshore rocky reef fish assemblage in San Juan Channel. Due to space constraints, this paper will present data for three species: lingcod, copper rockfish and Puget Sound rockfish. See Eisenhardt (2001) for additional information.

It should be noted that this study surveyed 0 to 20m depths. The species studied are also known to inhabit deeper waters. In addition, the San Juan Islands Marine Preserves encompass depths greater than the depth range covered by this study. Therefore, these results should not be extrapolated to all depths.

Methods and materials

Data were collected via 25m x 2m visual band transects by two researchers using SCUBA. Data collected for each transect included species, length (TL to nearest cm), and depth for all target species sighted, as well as habitat information, including substrate complexity, slope, and percent cover of rock, algae, invertebrates and sediment. Forty-eight transects were completed at each site. See Eisenhardt (2001) for detailed methods. Fish densities were computed as fish per 100m^2 and statistics were computed using SYSTAT 10.

Results

Results are graphed as length-frequency distributions to compare demographics of fish populations inside and out of reserves in 2000 to the 1970s. Year 2000 data were grouped by reserve or non-reserve and graphed together. Historical data (Moulton 1977) were graphed below reserve/non-reserve data on the same horizontal axis. Total numbers of fish in reserves and non-reserves provide abundance estimates, as these data resulted from equal sized areas surveyed. Area surveyed for historical data was different. Therefore, 1970s abundance should not be compared to 2000 abundance using these figures. For results of population densities over time, see Eisenhardt (2001, in press). Vertical dashed lines in the figures indicate lengths at 50% maturity for males, females or both.

The data are species specific. Greater mean length (two-sample t-test: $p < 0.001$) and greater density (3 x 2 ANOVA: $F = 10.487$, $p = 0.001$) were found for copper rockfish in reserve sites compared to non-reserve sites. Large copper rockfish (>38cm), which have been reported to reach 35 years in age (Richards and Cass 1986), have virtually disappeared since the 1970s (Figure 1). Greater mean length (two-sample t test: $p < 0.001$) was found for lingcod in reserves compared to non-reserves, but no statistically significant difference in density of lingcod was found, due to the high variability in lingcod densities—despite 35% greater mean density of lingcod in reserves (Figure 2). In addition, 43% of lingcod sighted in reserves were greater in length than 50cm, compared to only 17% in non-reserves. Length at 50% maturity for male lingcod is 51.3cm (Jagielo 1994). Puget Sound rockfish showed an opposite trend with a greater mean length (two-sample t: test $p = 0.001$) in reserves, but greater density (3 x 2 ANOVA: $F = 10.487$, $p = 0.005$) in the non-reserve sites (Figure 3). Habitat variables were similar between each reserve/non-reserve pair. Further discussion of results for each of these species and possible mechanisms follows in the discussion section.

Discussion

Copper rockfish are a commonly targeted bottomfish and are often caught as bycatch by anglers targeting lingcod. The virtual disappearance of copper rockfish >38cm (a 45cm individual was sighted during the 2000 survey) is important to note, as fish this size were more common in the 1970s (Moulton 1977). This trend indicates increased

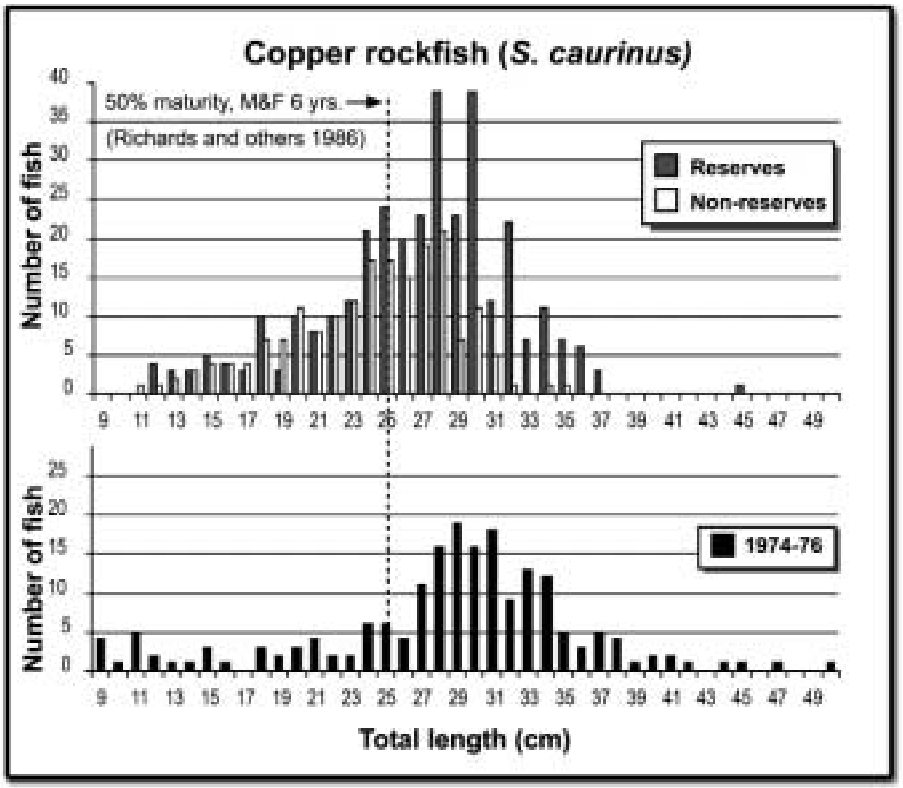

Figure 1. Copper rockfish length frequency distributions for reserves and non-reserves in 2000 (top) and the same regions in 1974-76 (bottom). Dashed bar indicates length at 50% maturity for both males and females.

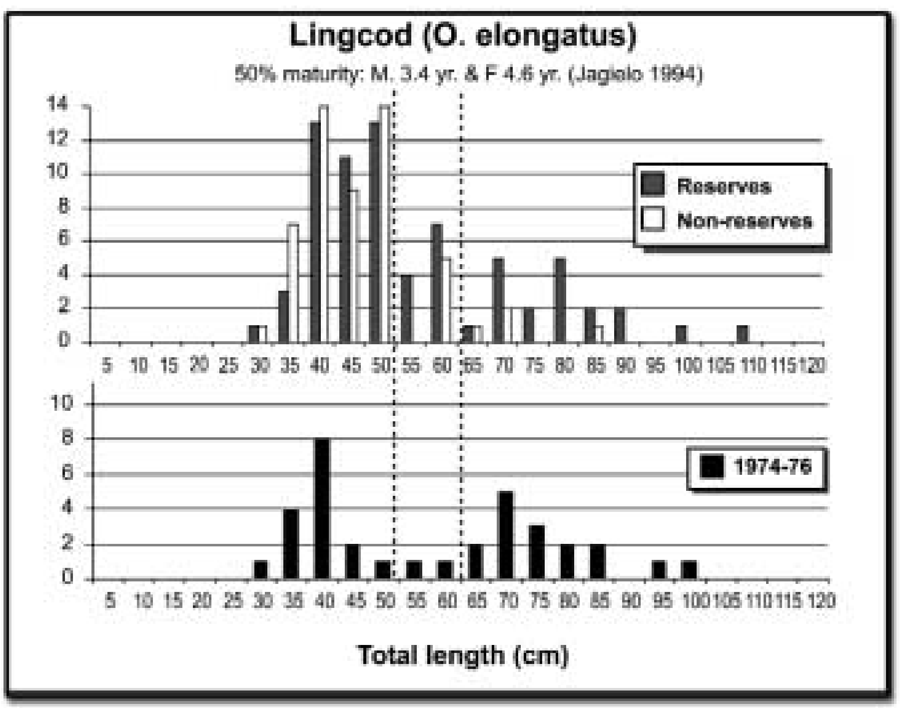

Figure 2. Lingcod length frequency distributions for reserves and non-reserves in 2000 (top) and the same regions in 1974-76 (bottom). Dashed bars indicate lengths at 50% maturity for males (left) and females (right). The lower legal size of the angler slot limit is 26 inches (66.04cm).

mortality of larger, more fecund individuals since the 1970s, almost certainly due to fishing pressure. This study shows that to regenerate an abundance of copper rockfish individuals >38cm, protection measures will need to be in place for at least 10 years. This is logical for a species that can live to be 35 years old. Given more time, copper rockfish >38cm will probably become more abundant in reserves.

While there were reproductive adult copper rockfish in both reserves and non-reserves, densities were greater in reserves—especially for larger length classes. Given the non-linear increase of copper rockfish fecundity as a function of length (DeLacy and others 1964; Washington and others 1978), reserves contain greater reproductive potential than non-reserves. The term “reproductive potential” is used to describe the number of eggs produced per area of habitat by a population (Paddack and Estes 2000).

During the spring of 2000, *Sebastes* larvae identified as copper/quillback rockfish complex were most abundant in the middle of San Juan Channel, and abundance increased with increasing distance from shore (Chasco and others 2000). This trend indicates that planktonic larvae of the copper/quillback rockfish complex in San Juan Channel are probably contained in a common larval pool. Therefore, larvae are probably dispersing from where they are released to this common pool, and then settling out as juveniles throughout San Juan Channel. If this is correct (and since fish in reserves seem to contribute a disproportionately greater share of larvae to the common pool than the area of rocky reef habitat encompassed by reserves indicates) reserves appear to supply a disproportionately large share of copper rockfish larvae to both reserve and non-reserve areas.

Lingcod are commonly targeted by anglers and are one of the most highly prized and sought after bottomfish in

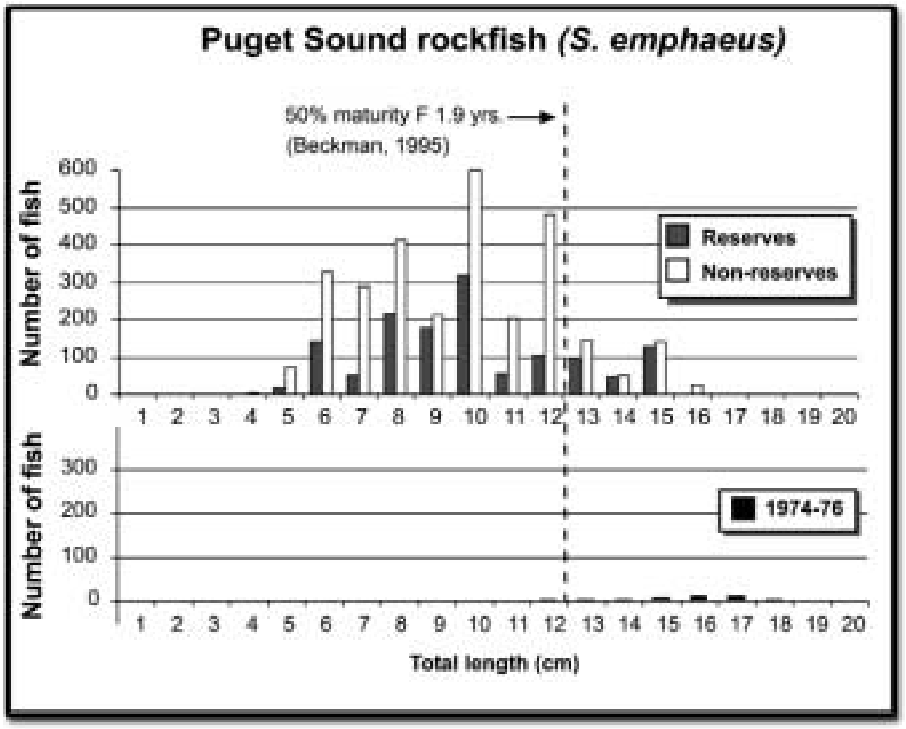

Figure 3. Puget Sound rockfish length frequency distributions for reserves and non-reserves in 2000 (top) and the same regions in 1974-76 (bottom). Dashed bar indicates length at 50% maturity for both males and females.

Despite possible disproportionate contribution to lingcod reproductive potential from reserves, both reserves and non-reserves have similar densities of subadult recruits, i.e. densities of individuals less than 50cm were similar in reserves compared to non-reserves (Figure 2).

Young-of-the-year lingcod have been found initially in soft-bottom areas, for example bays and coves, and then disappearing from this habitat and beginning to appear in nearshore rocky reef habitat sometime before the end of their first year. Due to the rocky nature of the San Juan Channel study area, shallow soft bottom habitat is scarce. Therefore, it is likely that lingcod found on different rocky reefs (including site pairs in this study) initially recruited to the same soft-bottom areas. If reserves are contributing disproportionately more reproductive potential than a per-area basis would indicate, it would follow that lingcod in reserves are augmenting recruitment outside reserves.

San Juan Channel. The low end of the legal size limit for lingcod is 26 inches (or 66.04 cm), the same size at which greater fish densities in reserves begin to appear. The distribution of lingcod in reserves is similar to that found in San Juan Channel during the mid-1970s, while the distribution in non-reserves is lacking larger individuals. This is strong evidence that removals by anglers fishing in non-reserve areas structure the demographic pattern of lingcod in San Juan Channel.

Lingcod inhabiting nearshore rocky reefs seem to be predominantly males, while females reside in deeper water most of the year and enter shallower nearshore waters only briefly to spawn (T. Jagielo, personal communication). Egg nests have been sighted via SCUBA in the reserves, however most or all of the broodstock may not typically be within working SCUBA depths and are possibly out of the reserve boundaries altogether (except during spawning). Still, assuming larger males guard larger egg masses during the nesting season (as seen by this author), larger males should have a disproportionately larger relation (on a per-fish basis) to the reproductive potential of the population. In this study, lingcod were significantly larger in reserves. Therefore, the reserve areas could be contributing disproportionately more to the reproductive potential of the population than the amount of area contained in reserves would indicate.

Puget Sound rockfish are seldom caught by anglers because they feed on plankton (Beckman 1995) and their mouths are too small for a typical bottomfishing hook (B. Miller, personal communication). They reach a maximum size of 18cm (Beckman 1995). Fishing is probably not structuring the demographics of this species. The greater abundance of Puget Sound rockfish in non-reserves versus reserves is probably due to increased predation of Puget Sound rockfish inside reserves by the more abundant and significantly larger lingcod inside reserves. Gut contents of lingcod revealed Puget Sound rockfish, and lingcod were often sighted in association with aggregations of Puget Sound rockfish (W. Palsson, personal communication).

The reserve network seems to play an indirect yet major role in regulating the density and mean size of Puget Sound rockfish at the various sites, since reserves appear to regulate the demographics of lingcod at different sites. Human influences appear to be structuring ecosystems directly (in the case of lingcod) and indirectly (in the case of Puget Sound rockfish). There could be other, unknown, indirect impacts on other species, for example killer whales *(Orcinus orca)* and harbor seals *(Phoca vitulina richardsii).*

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Ecological interactions and indirect effects in marine reserves: Expect the unexpected

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While a safe haven for some species, marine reserves may be a dangerous place for others. As top predators build in densities and grow in size within marine reserves, so do the number and size of predator mouths and stomachs. Consequently, predation risk may increase and prey species that we care about may decline.

Tropical and temperate empirical studies plus various mathematical models provide strong evidence that marine reserves, coupled with additional management tools, are an effective way to conserve marine resources and biodiversity (Allison and others 1998; Hastings and Botsford 1999; Mosquera and others 2000). Beyond releasing a target species from fishing mortality, marine reserves have been heralded as having multispecies benefits (Sobel 1996; NRC 2001). However, along with these benefits come interspecific interactions whose outcomes may befuddle managers, conservationists and resource users.

Fishing pressure can drastically alter marine ecosystems. Apart from impacting the targeted species, fishing pressure can alter food webs by modifying consumer interactions and thus the population abundance, size structure, and spatial distribution of non-target species. Consequently, fishing can lead to changes in community structure, diversity, and ecosystem processes. When fishing pressure is reduced or stopped with the use of marine reserves, an increase in previously fished consumers may also have community- and ecosystem-level effects.

As a management strategy, marine reserves account for the ecological complexity inherent in marine systems (Guénette and others 1998; Roberts 1997), and it is that very same complexity that may cause nontrivial departures from our simple expectations of how protected areas actually protect species. Along with examining the indirect benefits of marine reserves, this essay explores reasons underlying the failures of some species to increase in marine reserves and outright declines in others. Marine reserves remain an important tool for ensuring against fishery collapses and protecting biodiversity but they won't fix every conservation problem.

Indirect Benefits of Marine Reserves

Just as fishing pressure can have far reaching impacts well beyond a fishery itself (Dayton and others 1995; Botsford and others 1997; Jackson and others 2001), so can the reduction of fishing mortality through the use of marine reserves. Recently, Rogers-Bennett and Pearse (2001) described how marine reserves established to protect red sea urchins in California indirectly benefit abalone recruitment. Urchin spine canopies provide important microhabitat for juvenile abalone by enhancing the structural complexity of subtidal communities and offering protection from predators such as crab. Yet, while these reserves may be good for urchins and abalone, they must certainly be inhospitable for kelp-associated communities because urchins are voracious consumers of kelp. Here, the effects of protection may be directly and indirectly beneficial for several species and yet likely detrimental for others.

Community and Ecosystem Effects of Top Predators in Marine Systems

The removal of top predators from marine systems has been shown to alter marine communities and ecosystems by modifying food webs directly or indirectly via habitat degradation (Engel and Kvitek 1998) and/or by-catch (Armstrong and others 1993; Dayton and others 1995). The iconic work of Estes and Palmisano (1974) comparing two western Aleutian islands, one inhabited by sea otters, the other sea-otter free, illustrates a quintessential trophic cascade. Urchin barrens devoid of kelp surrounded islands where sea otters had been extirpated, while kelp beds dominated nearshore areas where otters had recolonized. Later, Duggins and others (1989) found higher growth rates of benthic suspension feeders (mussels and barnacles) on islands with sea otters than on islands without. The authors attributed this to the presence of organic detritus originating from kelp and substantiated their claim with stable carbon isotope analysis that confirmed that kelp-derived carbon was found throughout the

Photograph and cinematography by Brice Semmens.

Figure 1: LINGCOD LUNCH. Predator/prey interactions in Edmonds Underwater Park, Washington. In this underwater wild kingdom an adult male lingcod feasts on a starry flounder. To view this exhilarating footage visit http://www.reef.org/member/forum/sightings.htm.

nearshore food web. The higher levels of secondary production documented on islands with sea otters suggest far reaching ecosystem level effects of top predator presence. This is a classic example of a strong indirect effect with ecosystem level repercussions. Jackson and others (2001) describe several other historical examples of ecosystem functional change due to the depletion of major consumers from overfishing. So what kind of indirect community level effects, if any, might we expect when marine reserves are established, fishing is ceased and previously fished consumers return?

Trophic Cascades in Marine Reserves

Several ecosystem-based models have suggested that spatially organized trophic cascades may indeed occur in marine protected areas (Walters 2000; Salomon and others 2001). These model simulations indicate that marine reserves promote greater densities of large, high trophic level fish. Yet, as top predators become more abundant and larger within a simulated reserve, the local abundance of their prey species begins to decline, followed by a subsequent increase in abundance of even lower trophic groups. Declines in some species do not signify reserve ineffectiveness; on the contrary, they suggest that marine reserves may be helpful at restoring food web dynamics. Several comparative field studies have also shown that not all species increase in abundance with spatial protection (Bennett and Attwood 1991; Cole and Keuskamp 1998; see Eisenhardt this issue).

Research conducted in the Chilean rocky intertidal has provided considerable insight into the ecological interactions that may play out within a reserve once exploitation pressure is removed and top predators increase in density. Two years after the establishment of a 100m long rocky intertidal human exclusion zone in Las Cruces, Chile, there was a significant increase in the large, previously exploited, predatory gastropod *Concholepas concholepas* relative to surrounding exploited sites (Castilla and Durán 1985). The predatory snail began feeding on the dense intertidal mussel bed that had developed in the absence of *Concholepas.* The dramatic decline in the density of the competitive dominant mussel allowed increased species diversity by permitting the use of space by other sessile invertebrates and algal species. This study revealed that in the absence of human exploitation, the economically important *Concholepas* plays a key role in structuring intertidal communities and has dramatic impacts on the entire ecosystem.

Equivalent top-down effects have been documented in larger, more spatially complex subtidal systems with widely dispersing demersal fish. The Leigh and Tawharanui marine reserves, located in northeastern New Zealand, encompass greater abundances and larger size classes of spiny lobster and snapper than adjacent exploited waters (Babcock and others 1999). It has been postulated that pronounced indirect changes in community structure have occurred within these reserves due to an increase in these predators, both of which are known to feed on urchins. Urchins transplanted within the Leigh reserve suffered higher mortality than those transplanted outside the reserve (Cole and Keuskamp 1998). Babcock and others (1999) suggest that the proportional cover of urchin-grazed rock flats in the two reserves is significantly lower than in unprotected areas due to an indirect consequence of increased predator abundance and reduced grazer density. They further estimate that macroalgal primary productivity in the 26-year-old reserve is approximately 58% greater now than it was 20 years ago. Like the work of Castilla and Durán (1985), the results of Babcock and others (1999) indicate that these two marine reserves have indirect ecological impacts far beyond the protection of a target species.

Trophic Interactions in Puget Sound

Might similar top-down interactions be happening in our own back yard here in Puget Sound? Palsson and Pacunski (1995) compared the size, density, and reproductive output of lingcod and copper and quillback rockfish in five exploited sites and two reserve sites located in central and northern Puget Sound. At the Edmonds Underwater Park (EUP), lingcod and copper rockfish were found in higher abundance than at fished sites in central Puget Sound. Estimated egg production and fish biomass were also higher in the reserve. In contrast, young quillback rockfish were less dense at EUP than at some fished sites although larger quillback were found in the reserve. Low densities of small fish in the reserve could be due to predation; for instance, cannibalism by larger quillback, or consumption by other predatory species. Lingcod juveniles are likely to suffer a similar fate in EUP, as adult lingcod are notoriously cannibalistic (Rohwer 1978; Martell and others 2000).

Although lingcod may be safe at Edmonds, their prey certainly are not (Figure 1). This is an excellent example of how the ecological interactions that play out within a reserve can produce some unexpected results that challenge how we assess the biological effectiveness of reserves. These results do not suggest that the EUP is *not working* for young quillbacks. Rather, under some situations an increase in top predator density may cause a decrease in the density of lower trophic level species or juveniles of the same species. Field research is clearly required to test these speculations.

The Californian, Chilean, and New Zealand scenarios provide evidence that indirect effects take place within temperate marine reserves. Marine reserves have had beneficial ecosystem-level repercussions such as increased biodiversity and augmented production. Nevertheless, marine reserves may also create conflicts, particularly if protected consumers reduce commercially valuable prey. For example, despite the likelihood that sea otters promote kelp bed communities and secondary production, they feed on sea urchins, abalone, crab, and clams, all of which contribute to the economy of coastal communities and are part of native traditional subsistence harvest (Kvitek and others 1989). The expanding range of the sea otter and the potential resource conflicts that may ensue will present significant management challenges in Washington State and British Columbia in the future.

Failed Recovery in Marine Reserves

The scenarios described above illustrate indirect effects when fishing pressure is removed and top predators return. Another puzzle for management occurs when previously fished species fail to return in the first place. Although the effects of overfishing may be reversible in some cases, in others recovery may be hindered due to changes in community structure and food web dynamics (Hutchings 2000). For example, the slow recovery of Atlantic cod in the Southern Gulf of St. Lawrence following fisheries closures has recently been attributed to poor prerecruitment survival. Swain and Sinclair (2000) suggest that pelagic fishes such as herring and mackerel are potential predators or competitors of the early life history stages of cod and may be responsible for the poor prerecruitment survival. This predation is likely to be particularly important in preventing stock recovery when stock biomass is already low.

Ecological Interactions and Marine Reserve Assessment

The examples described above suggest that the ecological interactions that transpire within marine reserves may give rise to unforeseen outcomes, such as the extirpation of a certain prey species. By investigating the potential ecological interactions occurring within marine reserves, we can begin to predict the ecological effects of marine reserve establishment and the conditions under which spatial protection may be used to effectively conserve marine biodiversity.

This is an exciting time as scientists, government agencies and conservation organizations are all advocating spatial protection. The scientific community is responsible for informing marine conservation policy on such issues as marine reserve site selection criteria, design and assessment. As such, scientists and managers need to be accountable for providing realistic predictions regarding their ecological impacts. Advocating marine reserves as a panacea for all species could be misleading. Rather we need to acknowledge that simple expectations should be questioned and that departures from such expectations may exist.

Once established, will we always observe an increase in organism biomass and /or greater biodiversity within a marine reserve? Are these always valid criteria for evaluating the ecological effectiveness of marine reserves? Our limited knowledge about the processes governing ecosystem functioning presents a major constraint in understanding the effects of fishing on population dynamics and ecosystems (Hilborn and Walters 1992). Similarly, it may be difficult to predict the interactions and outcomes that may occur when fishing is restricted and marine protected areas are established. One thing is for sure, we should be prepared to expect the unexpected.

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