# MARINE PROTECTED AREAS IN THE PUGET SOUND:

# CAN A NETWORK DESIGN OF MPA'S OFFER GREATER PROTECTION THAN ISOLATED RESERVES FOR CRITICAL ROCKFISH POPULATIONS?

by

Stephanie L. Sparks

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This Thesis for the Master of Environmental Study Degree

by

Stephanie Sparks

has been approved for

The Evergreen State College
by

______________________________

Peter Dorman
Member of the Faculty

______________________________

Date

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# ABSTRACT

In the Puget Sound, some rockfish species have been reduced to 10% of their historic reproductive potential (Palsson 1998). Because of the drastic decline, there has been a major push for the use of marine protected areas (MPAs) as a management tool for this complex species. Previous literature has looked at the benefits that MPAs may have on threatened rockfish populations. Current gaps in MPA knowledge surround the question of whether individual or networked MPAs offer greater protection for fisheries populations. Several models have been developed to try to assess the potential benefits of these various designs of reserves. In addition, long-term MPAs have been established at Edmonds Marine Park and a network of MPAs has been established in the San Juan Islands. Review of these two ventures and other MPAs in the Puget Sound show that marine reserves have shown benefits, but are conflicted over design. Models that reflect MPA potential benefits lean towards the use of a networked design to promote rockfish species. Real world case studies and biological surveys at Edmonds Marine Park and the network of San Juan reserves have not necessarily mimicked models successes. Because of this, determining whether individual or networked reserves will show more benefit for rockfish species may be more situational than a definitive answer based on several environmental and social factors. Outside of modeling, current research has not clearly shown how MPAs interact with surrounding fished areas and is an essential component to the individual or networked reserves debate. Continued science needs to determine the effects of source and sinks, larval and adult spillover and compliance of MPAs before a clear distinction between individual and networked MPAs can be made.

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I would like to thank my parents and amazing grandparents for their love and support through this effort. To my parents for continuing to make sacrifices so that their children could have all the opportunities that they could ask for. I want to also give a special thanks to Peter Dorman who encouraged me and stuck by research explorations and dead ends. Thank you for your time, encouragement and support. Thanks to my sisters, Tyler, and friends who continually offered advice and love through this endeavor.

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# INTRODUCTION

In recent years considerable emphasis has been placed on the establishment of marine reserves, marine protected areas and no-take zones as fishery management tools for exploited rockfish populations. Marine closures can have multiple objectives, including protection of habitat, but the primary goal is the augmentation and protection of exploited fish stocks (Boersma and Parrish 1999; Bohnsack 1993). The efficacy of marine closures as fishery management tools remains hotly debated with some arguing that protected areas should form a core element of future fisheries management (Allison et al. 1998; Lauck et al. 1998), while others argue protected areas are simply one element of fisheries management (Hilborn et al. 2004). Despite the debate, the use of marine protected areas has been shown a productive way to protect ecosystem structures and function, while also benefiting fish populations (Agardy 1994; Lauck et al. 1998). Evaluations of the effects of marine protected areas have shown promise for long-lived and slow reproducing species such as rockfish. Several small reserves have been developed in California and Washington, which protect species from commercial fishing (McArdle 1998, Palsson 1998) and have shown benefit. For Washington, a network system protecting 20% of marine habitat is likely needed to protect 40% of the un-fished biomass, which is currently a management goal for rockfish in Puget Sound (Palsson 2001). Despite this, very few existing MPAs offer protection to rockfish species.

Previous literature has focused heavily on the scientific aspects of MPAs as a reserve for threatened species. Research has evaluated the use of MPAs as a tool for fisheries management (Agardy 1994; Allison et al. 1998). Research has focused on MPA scale and design requirements (Adron and Haggarty 2001; Bloch 2003; Don 2002; Eisenhardt 2001; Klinger and Ebbesmeyer 2001; Nowlis and Roberts 1998), larval spillover and recruitment (Botsford et al. 2001; Chasco et al. 2000), and assessment of current MPA sites (Roberts and Polunin 1991; Soh et al. 1998; Tuya et al. 2000). This current base of knowledge has inferred and led into the presumption that a network design of MPAs may offer greater benefit than isolated MPAs. Similar arguments have been made in the terrestrial world as well. Over the past twenty years, discussions have evolved regarding the benefits of wildlife corridors and green spaces to minimize habitat fragmentation. This debate continues as resource managers attempt to determine whether maximum benefit will come from protecting single large reserves or several pocket reserve areas. These questions now arise in the marine world. McNeil and Fairweather (1993) described an experimental evaluation of the single large or several small (SLOSS) debate by comparing the diversity and abundance of fish and macroinvertebrates associated with small and large seagrass beds. While results of this study were inconclusive, research did emphasize that processes affecting species' recruitment need specific consideration throughout the reserve design and analysis. The paper also highlighted the challenges of studying reserves in the marine environment, which is a continued theme with research involving aquatic resources.

Despite the current efforts in research on marine protected areas, the current body of literature has largely ignored the current piecemeal collection of MPAs nationally and around the world. Research has not investigated the varying benefits or potential detriments that are associated with isolated and networked MPA designs. This information signifies a major gap in the current base of knowledge on this topic and needs to be explored in order to understand the significance of MPAs and to determine whether they will be an effective management tool in the northwest and in other management areas around the world. This thesis will investigate whether a networked design of marine protected areas can offer greater protection than individual reserve areas for the protection of threatened and endangered rockfish species by examining case studies of various management strategies at Edmonds Underwater Marine Park and the San Juan Marine Reserves in Puget Sound.

## Where the Problem Begins - Critical State

Rockfish in the Puget Sound are one of the many species that have become victims of overfishing. Today many stocks of rockfish are either below average, depressed, or at critical stock conditions (Palsson 1998). These stock assessments refer to the determination of the abundance of a fish population, whether the abundance is stable over time with the estimation of natural and fishing-related mortality. Several studies have identified significant problems for Puget Sound's groundfish resources. Schmitt et al. (1994) reported the lowest groundfish catches in Puget Sound in fifty years and that there were five fishery collapses due to low fish abundance.  The 1995 Status of Stocks Document (Palsson 1996) found the majority of groundfish stocks are at ‘below average’ abundance.  Studies of rockfish and lingcod populations show these species are overfished in many areas of Puget Sound (Palsson and Pacunski 1995).  These reports supported the federal listing of three Puget Sound rockfish species under the Endangered Species Act (ESA).  April 2010, the National Oceanic and Atmospheric Administration (NOAA) announced the designation of canary and yelloweye rockfishes as “threatened” and bocaccio rockfish as “endangered” under the ESA.  In addition to this, Washington Department of Fish and Wildlife (WDFW) has listed 13 different rockfish as Candidate Species under their lists of Species of Concern.

Because of the critical state at which rockfish populations remain in the Puget Sound, many groups and agencies have taken an active role in attempting to revitalize groundfish resources to historically average or above historic levels. Fishery managers want to ensure that harvests are at levels that do not risk overfishing or that cannot fulfill natural ecosystem functions.  Typical fishery management strategies have not worked for Puget Sound rockfish populations. Management tools such as limiting the season, size limits, as well as the catch and release methods have simply not worked because of rockfish’s unique biology.  In general, rockfish have long life spans, often exceeding 50 years, are slow to mature and have a very low first year survival, which all results in long generation times.  In addition, rockfish are relatively easy to locate and catch, and they have a swim bladder that does not adjust to the rapid pressure changes when reeled up from deep water. As a result, the mortality of hooked rockfish is close to one hundred percent (Parker et al. 2000).

## Rockfish Biology

Puget Sound is home to approximately 30 different species of rockfish (Love et al. 2002). The geomorphology of Puget Sound, including rocky high-relief areas, crevices for hiding, and numerous eelgrass and kelp beds for larvae development, provides the ideal environment for rockfish populations. Rockfish are a very successful species of fish, however, their reproduction strategy and long lifespan makes them vulnerable to overfishing and other anthropogenic pressures. For the scope of this paper, three rockfish species were researched; quillback rockfish (*Sebastes maliger*), yelloweye rockfish (*Sebastes ruberrimus*), and canary rockfish (*Sebastes pinniger*). These species were chosen because they are all classified as "depleted" in the Puget Sound (WDFW 2009), but were once so plentiful that they were a significant part of Washington's local commercial fishery (Williams et al. 2010). In addition, all three species can be found in the north and south Puget Sound, which makes them comparable as we review MPAs in various parts and habitats of the Georgia Basin. Understanding the biological and life cycle requirements is the foundation of understanding the importance of establishing marine reserves to recover populations and protect rockfish habitat.

### Reproduction Strategies

Quillback, canary, and yelloweye rockfish species are all long-lived species. Canary is the youngest lived species, despite it living up to 84 years, quillback lives to 95 years, and yelloweye rockfish live up to 118 years (Williams et al. 2010). In general, rockfish become sexually mature much later than other bony fish in the Puget Sound. The species of focus typically mature between the ages of seven to eleven years, but it can be up to 20 years for longer-lived species. Maturity usually occurs when they reach approximately 30-40 centimeters. Rockfish have a viviparous reproduction strategy, which means that fertilization and embryo development is internal and young are born free swimming (Love et al. 2002). A mature rockfish can give birth to over a half a million young, which float on and feed in tidal currents, settling in sheltered bays and inlets (Love et al. 2002; Palsson 1996).

Marine protected areas have been recommended as a way to preserve older female fish, which have higher fecundity. Past studies have found that larger female rockfish produce the largest and highest number of eggs compared to smaller females. For example, a female copper rockfish that are 8 inch (20 cm) in length produce 5,000 larvae, while a female 20 inches (50 cm) in length may produce 700,000 larvae (Palsson et al. 2009). New studies are also showing the age of the female that relates to increased larval growth and survival rates. Steven Berkeley (2004) conducted an experiment between larvae from older and younger black rockfish females, which are similar in size and have similar life histories of quillback rockfish. During this fed treatment, the larvae of the older females grew in length and mass three times faster than the younger female's larvae. The oldest female larvae were able to survive starvation two times longer in the unfed treatments. The results found older females produced the highest quality larvae.

The larvae performance was highly correlated to the volume of oil globule present within the rockfish (Berkeley et al. 2004a). This research supports the goals of marine protected areas in retaining older fish populations within reserves as a recruitment source of rockfish outside of reserve areas. By removing larger, older fish the reproduction potential is impacted significantly. Therefore, MPAs have a critical effect on rockfish populations by protecting larger, older female rockfish and encourages reproduction ability. Protecting older fish may benefit fisheries in the long term as fecundity increases in a greater population of fish. The spillover of protected adults, juveniles, eggs, and larvae offers the potential to also maintain or improve fishery yields in areas adjacent to marine protected areas. Currently, rockfish are commonly caught before they reach sexual maturity, eliminating their entire reproductive potential (Palsson et al. 2009).

**Problems with Typical Fisheries Management**

Currently, commercial fishing of rockfish is not allowed and recreational fishing has a one fish bag limit per day. Despite these restrictive fishing regulations, fishery management techniques have not been sufficient in protecting rockfish populations in the Puget Sound. Bycatch of rockfish has continued to be a problem because of the biology of the fish. Rockfish have swim bladders that contain gas that is slowly regulated to allow the fish to maintain buoyancy at various depths, primary in deep waters with high pressure. Rockfish, unlike other species such as salmon, do not have a mechanism to rapidly expel gas from their swim bladder. When the rockfish are brought to the surface, from deep water (high pressure) to the surface (low pressure), the gas within the bladder expands, causing internal injuries to the fish which almost always leads to death. Because of this, typical fisheries management techniques, such as “catch and release” cannot be used as a management tool for rockfish.

Despite fishery restrictions, rockfish stock trends have continued to decline over the years. Comparisons of no-take areas to fished areas strongly indicate that overfishing is the primary cause of the declines in abundance within the rockfish community (Palsson 1998). Fishery management is based on uncertain estimates of fish abundance that are derived from infrequently conducted surveys, and on uncertain estimates of fishing mortality and effort all of which are subject to weather, the market, and fisherman’s reports. An essential purpose for MPAs designed for use as a fisheries management tool is to provide insurance against these many different uncertainties (Fujita 1998). A study conducted by Wayne Palsson (1995) evaluated seven MPA sites within Puget Sound to monitor the response of rockfish to no-take refuges. These sites included: Edmonds Underwater Park (established in 1970), four sites around the San Juan Marine Preserves (established in 1990), Sund Rocks in Hood Canal (established in 1994), and Titlow Beach in Tacoma, WA (established in 1994). Higher densities of rockfish were recorded within all study sites in comparison to nearby fished areas. A temporal pattern also began to evolve in relation to rockfish lengths and their reproduction potential, and the duration of time the reserve has been in existence. The reproduction potential of rockfish within Edmonds Underwater Park, which has been established for over 40 years, exceeded the average fished sites by a ratio of fifty-five to one. The younger reserves length distribution of rockfish was not significant enough to have a reproduction potential greater than the fished areas. These studies reiterate the fact that rockfish populations increase slowly, so sufficient time is needed before judging a MPAs success. The relationship between the biology of rockfish and MPAs are important for the recovery of the species. Preserving natural habitats helps ensures that following generations will benefit from their existence. Because of these many biological limitations, many consider marine protected areas the most productive way to protect rockfish populations in the Puget Sound.

## What is a MPA?

MPAs are areas specially managed to protect species, habitats and ecosystems. The official federal definition of an MPA is derived from Executive Order 13158: "any area of the marine environment that has been reserved for Federal, State, tribal, territorial, or local laws or regulations to provide lasting protection for part or all of the natural and cultural resources therein." MPAs have become a popular means for management because of the many potential advantages that they provide including: protection of spawning stock biomass, providing a recruitment source for surrounding areas, supplemental restocking of fished areas through emigration, maintenance of natural population age structure, maintenance of areas of undisturbed habitat, protection of genetic diversity, insurance against management failures in fished areas, reduced data-collection needs, simplified enforcement, and ease of public understanding and acceptance of areas of management, as well as much more other incidental benefits (Roberts and Polunin 1991).

Marine protected areas can offer varying amounts of protection. MPAs can be established as marine reserves which are no-take areas to multi-use reserves that could include fishing. Management designations of the MPA would be determined based on local goals and objectives. Marine protected areas can be an effective mechanism for increasing fish catches and maximizing conservation of heavily harvested and highly vulnerable fish populations that are threatened by unselective multi-species fisheries (Roberts 1998). In the last few decades there has been a number of field studies done that show the benefits of MPAs. In Kenya, the establishment of a reserve covering sixty percent of the former fishing grounds showed a 110% increase in catch per unit effort after just two years (McClanahan and Kaunda-Arara 1996). Similar benefits were observed on Apo Island, Philippines, where total fish density and species richness had increased by over 400% in both the reserve and the fishing grounds after 11 years of reserve protection (Russ and Alcala, 1996). These same authors also show that overall harvests dropped more than 50% two years after the re-opening of the reserve in the Philippines (Alcala and Russ 1990), suggesting that the reserve had provided enhancements to surrounding fishing grounds.

Case studies of MPAs in the northwest also have shown benefit to targeted rockfish species. A number of voluntary reserves have been established in the San Juan archipelago in 1990. In addition, the establishment of Edmonds

Underwater Park in 1970 has served as an effective reserve area for rockfish and other bottomfish species (Palsson 1995). These reserve areas have been shown to enhance both the abundance and size of individual fish in the reserves. For example, it was shown that outside the reserve areas rockfish rarely reaches a size greater than forty centimeters. Conversely, inside the reserves the majority of individuals were greater than forty centimeters in length (Palsson 1995). Other fish populations, such as lingcod, were also shown to benefit from the reserves, showing greater numbers and sizes of individuals within the reserves (Palsson 2001). These findings strongly support the idea that an MPA system can provide effective management for declining rockfish populations in Puget Sound.

## Categories of MPAs

Marine protected areas offer varying protections to rockfish based on the goals and objectives of the reserve when it is established. Marine protected areas can be established as No-take areas, Feature Specific MPAs, and Multiple Use MPAs. Each has different goals for implementation and management. The various management goals of various MPAs can be used as a way to work with various stakeholders and work around issues that may not be able to be solved simply through joint discussions.

### No-Take Areas

No-take areas are places where the extraction of all marine life is prohibited. No-take areas are designed to counter the exploitation of marine resources and related impacts. They are established for a number of reasons including biodiversity protection, protection of endangered species, protection of critical fisheries habitats or stocks, and protection of representative ecosystems. These restrictions apply to commercial fishing, as well as recreational and traditional fishing. Activities such as research, education and other non-consumptive uses are often also limited. No-take areas are not as restrictive as "no-intrusion" areas set up to protect sensitive areas such as breeding areas. Currently, Edmonds Underwater Park is the only no-take area in the Puget Sound.

**Feature-Specific MPAs**

Feature-specific MPAs are designed for a multitude of specific resource or activity management purposes. These purposes can include recreational features or attractions; protection of historic, archaeological or cultural features; specific fishery management objectives, such as harvest refugia for a single species or group of species; and scientific research use.

The San Juan Bottomfish Recovery Program's eight Bottomfish Recovery Zones are examples of MPAs that have been designed and implemented for the protection of an isolated species (such as rockfish). The San Juan sites are all fairly small, individually ranging from 27 to 136 acres. Collectively they cover about 527 acres of rockfish habitat. These feature specific marine protected areas are good in the fact that they are designed to be used as a sanctuary and a protection area for rockfish. Nevertheless, fishing of salmon and other fish is allowed. Although greatly reduced, this policy does not protect rockfish from bycatch mortality that can still occur at these reserve areas.

## Multiple Use MPAs

Most MPAs have been designed as Multiple Use reserves. These MPAs consider the needs of many different stakeholders and provide a mechanism for addressing a wide range of marine resources and habitat management conflicts. Multiple use MPAs are generally larger than no-take areas and may provide an increased ability to protect mobile organisms over wider geographic areas. This type of protection can help prevent conflict between several uses of the marine environment including recreation, tourism, and fishing. Multiple activities can be allowed to take place in the same area. Multiple use MPAs are beneficial because it allows for many uses and users, but it does not necessarily provide special protection to sensitive or critical areas.

MPAs that incorporate no-take zones or harvest refugia (for a single species or a group of species) can ensure the continuance of fisheries by protecting spawning stocks and population exploitation (Bohnsack 1993). These types of MPAs can help ensure against stock collapse. They provide a buffer against the risk and uncertainties associated with traditional fishery management, such as the lack of the precautionary principle in management decisions. They also can assists in rebuilding depleted stocks after a collapse faster than possible with other means. One of the major issues with rockfish protection in the Puget Sound is incidental bycatch mortality. No-take MPAs eliminate or at least greatly reduce bycatch mortality and protect these vulnerable and/or declining species.

The use of several different types of MPAs has been established around the Puget Sound with varying success in restoring rockfish populations. Models have been developed to help explain some of the many different factors that go into MPA design. The use of MPAs have shown promise for rockfish species, but the questions of efficacy between individual and networked MPA designs are still looming. The Puget Sound use of both individual and networked MPA designs makes it an ideal source to compare the effects of these designs on threatened rockfish populations.

## Fisheries Benefits and Optimal Design of Marine Reserves

Fishery population models have been developed to assess the potential for marine fisheries reserves to enhance long-term fishery yields. Models have included life history data and can allow for a more general analysis of the conditions under which reserves are likely to produce benefits and of the design attributes that will maximize these benefits. Several authors have built and analyzed models of MPAs which support the use of reserves.

Models were created to examine the role of marine reserves in the management of shortraker (*Sebastes borealis*) and rougheye rockfish (*S. aleutianus*) in the Gulf of Alaska (Soh et al. 2000). Shortraker (common) and rougheye (rarely) are also found in the north Puget Sound in the deepwater shelf assemblage. Models compared the future of biomass and fishing mortality between the current system with no harvest refuges and management with a refuge system in place over a twenty-year projection from a population dynamics model. Results under a fixed exploration rate for acceptable biological catch ($F_{ABC}$) found that the ending biomass of shortraker rockfish would increase by about 800 metric tons (t) in twenty years, but the stock would decrease by over 7000 t if current fishing intensity were continued (Soh et al. 2000). Rougheye rockfish scenarios were even more bleak. Under the $F_{ABC}$ and the actual fixed exploration rate (F) fishing scenarios, rougheye rockfish declined by about 5000-12000 t (Soh et al. 2000). Even though the actual fishing mortality was much lower than the fishing intensity for the recommended acceptable biological catch (ABC), rougheye stocks still declined. Under the refugia management strategy, ending biomass in the twenty-year future projections increased for both the $F_{ABC}$ and F. Under the $F_{ABC}$ scenario, ending biomass increased about 12% for shortraker and 16% for rougheye rockfish. Under the F scenario, ending biomass increased about 44% for shortraker and about 8% for rougheye rockfish when refugia management was employed (Soh et al. 2000). Biomass increases were found under various fishing intensity trajectories and size differences for the harvest refugia were found to have relatively little impact on the ending biomass estimates (Soh et al. 2000). This study essentially said that placing reserves in species richness hotspots would have two conservation benefits. Fist, they found that continuous depletion of high-density areas would be prevented. Secondly, they found that "topping off" of the bycatch allowance (these rockfish are only allowed to be harvested as a bycatch) would be more difficult because the fleet would be displaced to lower density areas where they could not as efficiently target these species to reach their bycatch limits.

One of the biggest proponents for establishing MPAs is the potential effect that they may have for supporting fisheries in the future. Primarily, two types of models have been looked at for enhancing fisheries outside of reserve areas, including adult spill over models and larval transport models. Models examining adult spillover (Polacheck, 1990; Nowlis and Roberts 1999) have looked at the likelihood of grown adults migrating outside of the park boundary to increase fisheries harvest catches. Eisenhardt (2003) expanded on this research and looked at home ranges for rockfish using acoustic telemetry. Acoustic transmitters were put on 14 adult copper rockfish off the west side of San Juan Island. During the two-month study, all but one fish stayed within 100 $m^2$. The single fish only moved about 1 km outside of the reserve area. Eisenhardt's research generally supports previous findings by Matthews (1990) of home range size and habitat use for rockfish. Matthews (1990) did transect studies and found that a high-relief natural habitat type was the only habitat type that is utilized consistently by rockfish throughout the year. Some movement into low-relief rocky reefs, artificial reefs, and eel grass beds happened during summer months, coincident with seasonal vegetation growth of bull kelp, understory kelps, and eelgrass. When vegetation died back, lowest densities of rockfishes were observed in these areas, suggesting only seasonal use of these habitat areas. Presumably, rockfishes utilize these habitats when structure and prey availability are highest. Home range size remained around $30m^2$ in Puget Sound on patch reefs with high substrate complexity, although fish did show range extension in the San Juan Islands where continuous, high substrate complex, rocky reef habitat is available.

Models have also been developed to look at larval transport. These models examine the dispersion of larvae outside of MPA boundaries when adults are sedentary within the reserve. With older, more productive fish protected, research has shown how marine reserves can act as a broodstock in certain areas, increasing production of larvae and juveniles that are dependent on the current and tidal movements to be exported to the surrounding area. This has been modeled to cause total biomass and landings in exploited fisheries to increase and length frequency distributions to shift upward (Bohnsack 1996). Several papers examine fisheries movements through larval transport (Quinn et al. 1993; Man et al. 1995; Holland and Brazee, 1996). In such studies, larva dispersed widely across reserve boundaries, resulting in an even density of new fish settlement in reserve and non-reserve areas. In fact, it has been found that most aquatic species disperse more widely as larvae than as adults (Boehlert, 1996). Consequently, larvae are more likely to have an impact on outside fishing than grown adults. Hastings and Botsford (1999) used a simplified larval transport model to examine the benefits of reserves in regards to traditional fisheries management. They demonstrated that a roughly equivalent yield is expected under traditional fishery management (fixed harvest rate) as compared to a no-take reserve. In the outline of this study they did make the conservative assumption that fecundity did not increase for fish protected by reserves, as opposed to fish outside of reserves (which we know is not true in the case of long-lived rockfish species). They showed that the fraction of habitat to remain open to fishing is always at least as great as the optimal proportion of adults harvested under traditional fishery management. When the authors allowed for harvest rate management outside of the reserves, the proportion of open areas could be larger and still provide equivalent yield. This result suggests that reserves could be either a cost-effective alternative or a supplement to more traditional measures used to achieve harvest rate. Nowlis and Yaklovich (1998) also used a larval transport model to look at bocaccio rockfish (*Sabastes paucispinus*) in fisheries off central and northern California. Research in this study also found that reserves enhanced fishery yields whenever the fishery was overfished. They also found that the optimum size of the reserve increased as fishing mortality increased.

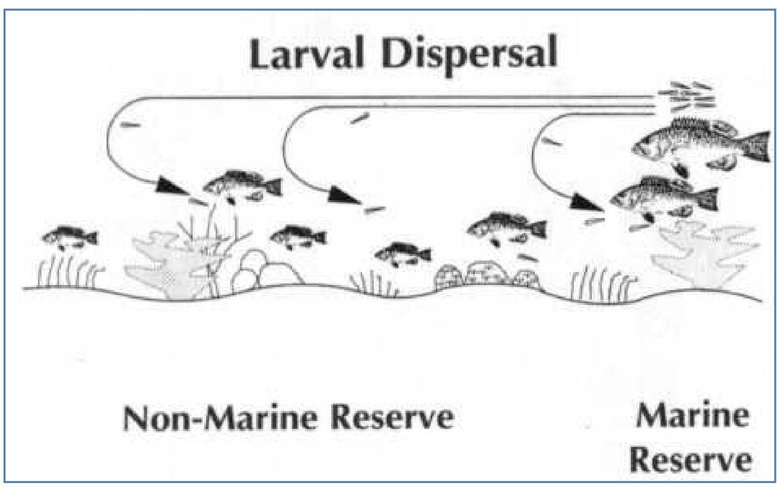


**Figure 1. 1. "Spill over" effect from a marine reserve to a non-marine reserve**

The spillover effect has been an advocated for all types of reserves, both individual and networked. Individual reserves have potential for the spillover of adults crossing reserve boundaries, as well as have the older population of fish that can act as a broodstock for the open fisheries. The networked reserves have these benefits too, but networked design focuses on MPAs that are close enough together where reserves can interact through larval transport, bringing in a greater genetic diversity into the reserves. Although different mediums, the concept of networked MPAs mirrors the theory of island biogeography by Robert MacArthur and E.O. Wilson. A protected marine reserve becomes an 'island' of species richness to outside fished areas. Immigration and emigration are affected by the distance of a MPA 'island' from another source of colonists (distance effect). The farther the distance of the 'island', the more isolated and less likely it is to receive immigrants to the 'island' area. As pointed out by MacArthur and Wilson, these isolated areas are more susceptible because neighboring source populations cannot immigrate and add biodiversity to prevent the risk of extinction. With networked MPAs, various reserves are better able to interact with each other with immigration and emigration of larvae and juvenile species. Larvae are free floating and at the mercy of the currents. Some will drift to the open ocean, some will drift into open fishing areas, some will eddy back into the original reserve area, but some will also drift to neighboring reserved areas increasing biodiversity to that site.

## Case Study: Looking at the Puget Sound

Much of the previous literature has discussed the fact that the design of the MPA will have a significant impact on the success of the marine reserve and the recovery of strained fish populations. Science has looked at the importance of site selection, size, areas of sinks and sources, and scale for MPA placement (Eisenhardt 2001; Bloch 2003; Ardon and Haggarty 2001; Botsford et al. 2001; Klinger and Ebbesmeyer 2001; Nowlis and Roberts 1999; Roberts 1998). Previous science has led to the assumption that a networked design of MPAs will increase the benefit of the reserves, but current literature has not compared networks to single MPAs. Networked designed MPAs have been theorized to increase fish populations because of increased connectivity and distribution between reserve sites, but this deduction not been properly reviewed in the current literature. In the Puget Sound, both individual and networked marine protected areas have been established, creating a diverse collection of protected intertidal and subtidal areas. These MPAs have developed incrementally and inconsistently into a patchwork of sites that vary considerably in their designation, purpose, resource protection offered, and level of management provided. There are currently over 100 marine reserves around the Sound. Most of the reserves are waters off of state parks which have no fishing restrictions. Only 21 MPAs have some type of ban on fishing of rockfish, with one reserve offering complete fishing protection.

## Table 1: Existing MPAs for Rockfish in Puget Sound

| Name/Location | Designation | Agency/organization |
|---|---|---|
| Bare island | Voluntary No-Take Bottom Fish Recovery Area | San Juan County |
| Point Lawrence | Voluntary No-Take Bottom Fish Recovery Area | San Juan County |
| Gull Rock | Voluntary No-Take Bottom Fish Recovery Area | San Juan County |

| | | |
|---|---|---|
| Kellett Bluff | Voluntary No-Take Bottom Fish Recovery Area | San Juan County |
| Limekiln Lighthouse | Voluntary No-Take Bottom Fish Recovery Area | San Juan County |
| Pile Point | Voluntary No-Take Bottom Fish Recovery Area | San Juan County |
| Charles Island | Voluntary No-Take Bottom Fish Recovery Area | San Juan County |
| Bell Island | Voluntary No-Take Bottom Fish Recovery Area | San Juan County |
| Edmonds Underwater Park | Underwater Park | City of Edmonds |
| Waketickeh | Bottom Fish Refuge | WDFW |
| Octopus Hole | Bottom Fish Refuge | WDFW |
| Sund Rocks | Bottom Fish Refuge | WDFW |
| Orchard Rocks | Bottom Fish Refuge | WDFW |
| Colvos | Bottom Fish Refuge | WDFW |
| Titlow | Bottom Fish Refuge | WDFW |
| False Bay | Bottom Fish Refuge | WDFW |
| Friday Harbor | Bottom Fish Refuge | WDFW |
| Argyle Lagoon | Bottom Fish Refuge | WDFW |
| Yellow & Low Islands Preserve | Bottom Fish Refuge | WDFW |
| Shaw Island | Bottom Fish Refuge | WDFW |
| Woodard Bay | Natural Resources Conservation Area | Department of Natural Resources |

## Individual MPA's – Edmonds Underwater Park

Individual MPAs are the most common form of MPAs in the Puget Sound and around the nation. These MPAs have primarily been established based on important habitat areas or for protection of a specific species. Individual MPAs are typically larger than smaller networked MPAs and it has been argued that they are easier to enforce because they are more widely known and boundaries are easier to define. Although several MPAs have been established in the Puget Sound, Edmonds Underwater Park is the only no-take area reserve and has sense been repeatedly used as an example for MPA assessments. In 1970, the City of Edmonds established the 27 acre subtidal park. The City enacted ordinance specifically prohibits the taking of any marine life from the underwater park and the use of any boat or watercraft of any kind within 200 feet of park boundaries (City of Edmonds Ordinance 5.32.070). City ordinance also prohibits the possession of devices for taking fish or any other marine life in or near the park. Supervision is provided by a group of local volunteers. The presence of scuba divers and their influence on visitors and the public have provided supervision and enforcement through peer-pressure when city police and beach ranges are not on site. Because of this, takings at Edmond Underwater Park are essentially zero.

Although Edmonds was designated a Recreational Marine Preserve, which was established and managed to provide a safe recreational site for scuba diving, the park has had direct effects on the increasing size and abundance of rockfish population in the area. Edmonds Underwater Park has now been in operation for

40 years and has become a baseline for studies that show that no-take MPAs can increase fish density, fish size, and reproductive output for surveyed bottomfish species within the protected park boundary in comparison to fished sites (Palsson and Pacunski 1995). Since 1992, WDFW has been monitoring and conducting scuba and video surveys at Edmonds, as well as at other Puget Sound MPAs and fished areas. Fish density and size are dramatically greater for surveyed bottomfish species within the protected park boundary in comparison to fished sites. Studies showed that copper rockfish abundance was 15 times greater at Edmonds than at other fished areas. At Edmonds, 85% of the copper rockfish are 40 cm in length or greater and 95% of the lingcod measure 70 cm or greater. Fish of these lengths were uncommon at fished sites despite being very common at Edmonds. The median density of copper rockfish at Edmonds was 0.25 fish per square meter. These targets are now being used as targets for newly established MPAs (Palsson 2001). The size and age of rockfish found in Edmonds suggest that these fish will have greater reproduction potential than fish outside of the reserve (Palsson et al. 2009; Berkley, 2004) and will be a source for larval transport as was displayed spillover models (Quinn et al. 1993; Man et al. 1995; Holland and Brazee, 1996).

Design elements for individual refuges (and networks) typically include biological criteria which included size and location (Yoklavich 1998, Palsson, 2001). The size of the MPA is important to assure that the refuge incorporates the extent of horizontal movements and territories occupied by the target species (Yoklavich 1998). As discussed earlier, Matthews (1990) estimated that the territory size of copper, quillback, and brown rockfishes living on natural, high-relief rocky reefs was 30 $m^2$, and that these rockfish has high site fidelity. The persistence of high densities of large rockfish and lingcod at the 7-hectare refuge at Edmonds Underwater Park (Palsson and Pacunkski 1996; Palsson 1998) suggests small refuges are appropriate for the small home ranges of these fish. The location of refuge needs to take into account a number of biological factors including ocean currents, heavily and lightly exploited populations, habitat characteristics and functions, and resources that are required to support spawning biomass (Yoklavich 1998). Some of these factors have been investigated for rockfish in the Puget Sound. Mathews 1990, found that site locations of MPAs should focus on high relief rocky habitats, but artificial reefs have also been found to be beneficial for rockfish, such as is found at Edmonds. Ocean currents are also identified as an important factor for planning marine refuges for rockfishes (Yoklavich 1998). Sites including coastal upwelling zones are considered beneficial because waters are typically nutrient rich. Upwelling zones (coastal) do not exist in Puget Sound proper, but other oceanographic features such as tidal gyres, tidal pumps, wind forcing, and estuarine circulation may be significant to the success of marine refuges. Tidal gyres were described by Ebbesmeyer (1999) along the eastern shore of the central Puget Sound basin between West Point and Mukilteo, WA. The gyres overlaid with the results of a one-time survey for young of the year rockfish suggest that young rockfish settle in the presence of the gyres on the east side of central Puget Sound while the opposite shore lacking tidal gyres has few if any young of the year rockfish (Doty 1995). Coincidentally, Edmonds Underwater Park is located centrally to the distribution of the gyres and where the young of the year were found. While the study did not know the source of the young of year rockfish, it does suggest that water circulation plays an important part of MPA design and may be contributing to the success at Edmonds.

Edmonds is not the only individual marine reserve that has shown promise to marine species. Dungan and Davis (1993) reviewed studies of existing marine parks and reserves that impose harvest restrictions and concluded that the higher abundance of target species within protected areas was the most detectable effect of MPA successes. They found that target species of fish, crustaceans and molluscs were as much as 25 times more abundant and mean individual size was as much as 200% greater within protected areas than outside of park boundaries. Evidence from existing marine reserves indicates that increased abundance, individual size, reproductive output, and species diversity occurred in a variety of marine species in refuges of various sizes and locations in communities ranging from coral reefs to temperate kelp forests. The theory behind these marine reserves is that fish populations can recover from the effects of intense fishing and act as a safeguard against overexploitation within reserve boundaries if fishing is banned. Once fish size, density, and fecundity increase, the reserve can act as source of larvae, juveniles, and adult fish for populations outside the reserve. In this way, the individual MPA can act as an "insurance policy" against overfishing for an entire stock (Botsford et al. 2001). Modeling approaches have also suggested that MPAs may increase resilience to overfishing (Quinn et al. 1993, Man et al. 1995, Lauck et al. 1998). However, in order for MPAs to be successful in this, it is necessary that the sub-population within an MPA be capable of restocking a fishery outside of the MPA boundary (Carr and Reed 1993, Tegner 1993) and that the MPA has a successful spillover and recruitment rate in order to replenish outside fishery stocks while also maintaining fecundity success within the reserve boundary.

## Networked MPAs – San Juan Islands Marine Reserves

A network approach to marine reserves is largely supported in the scientific community in order to replenish depressed fishery populations. The concept of networked design takes into account the requirements of individual refuges (such as shape and location), but has additional qualities that link and enhance refuge benefits that a single refuge cannot necessarily provide alone. Isolated marine reserves offer direct protection to all species within their borders, but networked MPAs have gained popularity because of their promise of protecting connectivity of marine populations. Connectivity is recognized as a key factor in maintaining viable populations on large geographic scales in the ability to provide recruits or migrants for each other. As stocks decline, once continuous populations can become restricted to isolated island like areas (individual MPAs). As species populations become reduced and isolated, they become more vulnerable to environmental change. Networks of marine reserves present a way to maintain biodiversity, spawning locations and continuous fish populations. Connectivity also allows resident populations to interact through dispersal and migration, which is often referred to as the “spillover” effect of MPAs. Spillover is discussed as a benefit from both individual and networked MPAs, but networked MPAs can act as connected source of population sources *and* sinks, rather than just a population source as described above with Edmonds Underwater Park.

Evidence, which shows the extent a MPA can actually act as a source for spillover, is unclear (Polacheck 1990, Russ and Alcala 1996). Nevertheless, MPAs ability to fulfill fisheries objectives centers on its ability to replenish both itself and non-protected areas. A marine reserve that is entirely self-replenishing will not be able to repopulate an exhausted stock, whereas a reserve that exports its entire larval production will not provide a secure insurance because it will lose its broodstock to outside fishing (Lundberg and Jonzén 1999). These factors may be minimized if MPA’s are organized in a network design.

The San Juan County Bottomfish Marine Reserves were established on these principles in order to create a network of MPAs that would interact with each other, increasing rockfish populations in and outside of the reserve areas. The San Juan County Marine Resources Committee responded to conflicting concerns from stakeholders regarding tribal treaty rights, recreational fishing, and the threatened population of rockfish and habitat concerns by enacting the Bottom Fish Recovery Program to compromise between stakeholder concerns and to further explore the effectiveness of using MPAs for the protection and recovery of rockfish and other local marine resources.

Part of the Bottom Fish Recovery Program implemented eight Voluntary No-Take Bottom Fish Recovery Zones (BRZs) in June of 1997. The BRZs' purpose was to recover populations of bottomfish through voluntary restrictions on bottomfishing. The unique aspect of these county-established MPAs is that their "no take" status for bottomfish was a community based, grassroots effort and compliance was on a voluntary basis only. Rather than enforcing through fines and regulations, bottomfish recovery is supported through education and community monitoring. In addition to the Voluntary No-Take Reserves, there are several other reserve sites that create an MPA network, including the San Juan Islands Marine Preserves that were formed in 1990 that restrict all forms of fishing except for salmon, herring, and in certain areas crab; and five WDFW Bottomfish Recovery Zones that are located in the San Juan Islands. Directed and commercial fisheries for rockfish using jig and troll gears were prohibited in the San Juan Islands in 1984. Commercial trawling is allowed outside of reserves, but rarely occurs in the San Juan Channel. The result of this is a total annual rockfish catch of less than 100 pounds since 1994 (Palsson 1997).

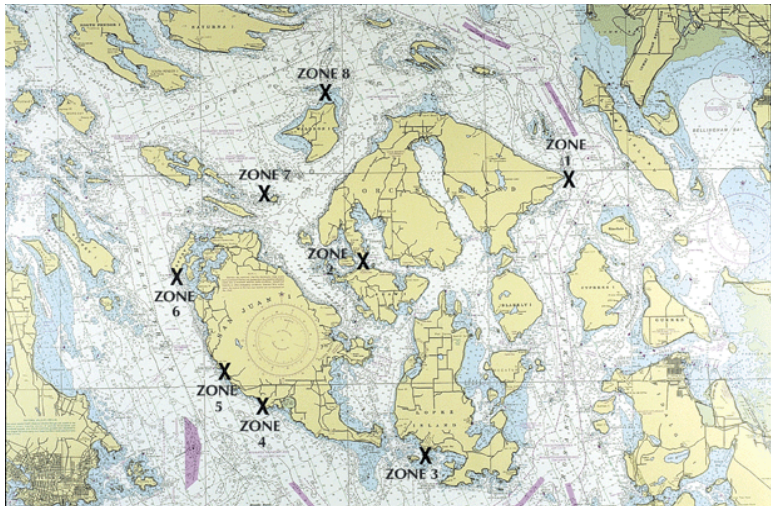


**Figure 2. Map of San Juan County Voluntary No-Take Marine Reserves**

Developing a networked system of MPAs, such those in the San Juan Archipelago, may be a way to support fishery recovery through habitat connectivity and to take a precautionary approach to endangered fish populations. Circulation patterns and other fundamental oceanographic features in the San Juan Islands imply a strong linkage between San Juan Reserves.  Klinger and Ebbesmeyer (2001) observed strong oceanographic linkages between the San Juan Archipelago and Victoria, Dungeness Spit, and the northwest shore of Whidbey Island.  The study reported that existing MPAs such as the San Juan Reserves are potentially "capable of supplying larvae to and receiving larvae from sites throughout the archipelago, and therefore are capable of functioning as a local network".  The likelihood of the refuge being self-sustaining will be increased with the inclusion of additional sites to fill in gaps of habitat representation and replication.  Despite the networked design, questions arise on whether greater benefits to the region would come with the inclusion of the San

Juan Reserves in a larger regional network of MPAs. Studies such as these may be able to help define geographic parameters for regional MPA networks.

Despite the theoretical studies that continually show the benefits of a networked approach to MPAs, actual survey data of the population responses within the network are mixed. In 1994, WDFW began research to study the effects of the networked bottomfish recovery reserves on fishery resources. The goal of the research was to determine whether bottomfish within WDFW refuges throughout the San Juan Islands and central Puget Sound were more abundant, larger, and have a greater reproduction potential than outside of the reserve boundary.


**Figure 3. Map of WDFW Bottomfish Refuges (Palsson 1994)**

Part of this study examined Shady Cove, a natural reef in the San Jan Islands which was established as a marine reserve in 1990. Several comparable and nearby fished areas, including a natural reef area, were also surveyed for comparison. Shady Cove was a refuge for only a few years when the study began. Despite the short establishment, copper rockfish were about twice as dense at Shady Cove as opposed to nearby fished sites, but there was no difference in size. Lingcod were more abundant and larger lingcod were more frequent too. Lingcod surveyed during the spawning season had three times the number of nests in the Shady Cove refuge than other fished areas. This research shows recovery, but also suggests that the responses of rockfish and lingcod to the creation of a refuge may take some time to be fully observed.

Biological assessments were also conducted in 2001 and 2006 to assess the effectiveness of the San Juan County's BRZs, which were created in 1997, compared to non-reserve controls by conducting visual band transects by observers utilizing SCUBA (Eisenhardt et al. 2002; Eisenhardt and Sea Doc Society 2006). Results from the study showed that there were no statistically significant differences in fish density between the BRZs and the associated non-reserve control sites with two exceptions. Copper rockfish were more abundant at one BRZ (Lime Kiln) compared to its control (Edwards Point). It was also found that both Puget Sound and quillback rockfish were less abundant at the BRZ (Charles Island) compared to the non-reserve reference site (Long Island). Habitat characterizations conducted for each BRZ and reference site pair revealed similar findings for substrate cover, densities of marcroinvertebrates, algal species composition, reef slope, aspect, and substrate complexity (Eisenhardt and Sea Doc Society 2006). The 2001 and 2006 results seem to show a consistent pattern of few differences in fish density and mean lengths of rockfish in reserve and non-reserve sites.

Similar limits on success have also been shown in Tuya, Soboil, Kido (2000). The abundance and body sizes of commonly collected fish and invertebrate species were collected at eight networked sights in the San Juan Archipelago. Three of the researched sites were located at an MPA established eight years prior, two sites were newly established MPAs, and three sites were unprotected. The study found that newly established MPAs and unprotected sites showed similar levels of abundance and size frequency distributions for the target species (including rockfish). Differences in abundance and size were not found among the three categories of sites. Because none of the protected areas had a significantly larger abundance in small urchins, scallops, sea cucumbers, lingcod and rockfish, it could imply that the protected areas have not enhanced population abundance within the refuges. This result was similar to that obtained by Cole et al. (1990), except that his study showed an increase in the number of lobsters in the protected areas. This heterogeneity could be attributed to poorly situated protected areas in which larval supply is inadequate due to unfavorable currents and poor recruitment. Authors also question the short time that these MPAs have been established and whether lack of effective protection and enforcement could be contributing to the lack clear success.

The issue of compliance was also questioned in an assessment done for San Juan Islands Marine Resources Committee, discussed above, on the successes of the bottomfish recovery program and voluntary marine reserves (Eisenhardt and Sea Doc Society 2006). Despite MPA being in existence for almost ten years, surveys of three bottomfish recovery zones and their respective reference sites revealed scant evidence for successful recovery of bottomfish inside the BRZ. The BRZs did appear to slightly benefit copper rockfish, but also showed a decrease in Puget Sound and quillback rockfish in comparison to non-reserve areas. The lack of differences in fishing pressure between the BRZs and the non-reserves sites was mentioned as potential reason for lack of recovery in reserve areas. Prior studies have shown little or no difference in fishing effort between BRZs and reference sites (Kaill 2001, Koski 2001, Davis 2003). Studies found limited fishing pressure on bottomfish in San Juan County in general, but did document anglers disregarding the voluntary fishing regulations inside the BRZ. In 2004, Kritzer investigated the effects of noncompliance on the success of alternative designs of marine protected areas for conservation and fisheries management. Studies examining the efficacy of MPAs rarely take into to account the potential for noncompliance, which can alter findings on successes and failures of reserve sites. The study found that violation of MPAs will typically occur near boundaries, so perimeter-to-area ratios will be important determinants of actual protection. As non-compliance increases, the protected population in the network of several small MPAs approaches zero, whereas the single, large MPA population declines much less. Going back to the SLOSS debate, several smaller reserves will have a higher perimeter-to-area ratio, which will potentially increase non-compliance than with larger reserves. Nevertheless, if we focus on larval dispersal, studies have shown that MPAs will need to be more numerous, widespread, and likely smaller in order to replenish many fished areas, which would support the networked approach of MPA design. Thus, there is a discord between the MPA network that would best achieve external replenishment and that would maximize compliance. Results of this study highlight the effects of noncompliance on MPA benefits and may explain why observed and expected effects from reserved areas may not correspond. This model shows the importance of compliance, but with lack of continued monitoring at MPA sites, it is impossible to determine whether it plays a role in the lack of success at some of the networked sites in the Puget Sound.

## DISCUSSION

While there is great enthusiasm for creating a network of MPAs in the Puget Sound, the debate continues on whether MPA design should create larger isolated MPAs or whether a networked approach will be more beneficial to threatened rockfish populations. The life history and biological characteristics of rockfish require that they be managed more conservatively than most marine fishes. Sustainable fishing of rockfish is difficult because of their low sustainable yield. Rockfish are long lived, slow growing and have a low natural mortality, which makes MPAs an insurance policy against critical stock populations. There is consensus throughout the current research that MPAs are an important factor in conserving rockfish populations from overfishing. MPAs can reduce the risk of stock collapse by serving as a precautionary control on fishing mortality. They also conserve biodiversity and enhance fishery yields through larval dispersal, adult and juvenile spillover, and protection of spawning and nursery areas. But with limited resources, are efforts best placed in developing individual MPAs or should a network of protected areas be established to protect rockfish populations?

Currently, there are 21 marine protected areas that provide specific protection for rockfish in the Puget Sound. With Edmonds Underwater Park being the only marine protected area offering complete protection, the other sites are beneficial, but still allow rockfish to be caught as bycatch from salmon and other fishing within the reserves. Individual MPAs, much like all reserved areas may act as a source for replenishing depressed fisheries through juvenile and adult spillover, but without a networked source of protected areas these MPAs may become population sinks that cannot replenish themselves. More studies need to be conducted to fully understand these concepts in regards to MPAs and population recruitment and dispersal.

The San Juan Island marine reserves have shown promise to act as a network for marine protection. Highly circulated waters are hypothesized to distribute larva between MPAs sites, which potentially have the benefit of increasing populations and species biodiversity. In addition, spillover of juvenile and grown rockfish into non-reserved areas may benefit the fisheries with increased populations. With several smaller reserves located in an area, you are more likely to run into the issue of people not knowing about the reserve or compliance with MPAs going down. These networked reserves have not had the same clear successes as individual reserves such as Edmonds. Non-compliance, the younger age of the networked reserves, or the smaller size of the reserve sites may explain differences in size and abundance of fish.

## CONCLUSION

Despite the emphasis of networked designed MPAs, which is reiterated in the current research on the topic, literature review of real-world monitoring efforts and site evaluations have not confirmed theoretical evidence from modeled research. Successes have been mixed for both networked and individual MPAs and with varying controls in which we are evaluating sites, it is difficult to determine performances of the various designs. Determining whether individual or networked reserves will show more benefit for rockfish species will have to take into account several different environmental factors, many of which are still unknown.

Research needs to continue to determine the effects of larval, juvenile, and adult spillover in marine protected areas and to determine their effects on fishery movements outside of the protected areas. Recruitment and spillover is closely linked to the success of an MPA. Understanding the effects of larva, juvenile, and adult distribution on a protected area is vital for understanding successes and potential failures and is important for both networked and individual success. With individual reserves, MPAs will act as a broodstock to outside fisheries. Networked reserves will also act as a broodstock from protecting older fish, but are also theorized to have the added benefit of working as a source and a sink with other networked reserves. This contributes the added benefit of increasing biodiversity as populations interact with other reserves. Until the research is completed to better evaluate larva, juvenile, and adult movements within a reserve, it cannot be determined whether efforts in protecting rockfish populations are best served through establishing larger individual MPAs or whether a networked design of MPAs should be deployed.

Both designs have their benefits as well as challenges, especially with potential enforcement issues. Current research has cited fishing pressures and lack of enforcement as a potential explanation for the lack of replicated successes in SCUBA studies, as is expected from modeled predictions. Poaching has always been and will continue to be an issue with fisheries management. Kritzer's models which investigated the effects of non-compliance found that violations typically occur near boundaries, which means that perimeter-to-area rations will be important determinates of actual protection. This would suggest that larger reserves may offer greater protection to reserves. Compliance also comes from the quality and quantity of protection and management of reserve sites. In order to be effective, MPAs for rockfish must have clear boundaries that are understandable to potential users. Fishing in reserved areas may simply come from a lack of understanding of MPA boundaries. While larger reserves are typically more known to potential users, increasing awareness of smaller networked reserves may increase success of these sites.

Networked and single reserves sites are also difficult to evaluate because the time differences in which our case studies have been in establishment. The

San Juan marine network has been in existence for over ten years in comparison to Edmonds Marine Reserve, which has now been established for over forty years. Because of the reproduction strategies of these long-lived fish, it is difficult to say that the San Juan networked MPAs are not showing the same successes because of the limited time that they have been established. It is true that ten years is enough time where there would be some expectations of improvements in a population, but research has not been completed to explain variations between species populations at various sites.

The one fact that remains is that the percentage of waters protected needs to increase in order to meet WDFW goal of protecting 20% of marine habitat which is likely needed to protect 40% of the un-fished biomass. This is currently the management goal for rockfish in Puget Sound (Paulson, 2001) and is going to be a vital part in their recovery. With the goal of protecting twenty percent habitat recommended for marine reserves, policy leaders should work to increase marine protection in the Puget Sound. The remaining debate over the benefits of individual versus networked reserves may prove unimportant in comparison to the clear and eminent need to set aside protected and establish MPAs through various designs and in diverse habitat areas. Until research can better determine the roles individual and networked MPAs play on rockfish population recovery, policy makers and resource managers should use a mix of designs, emphasizing larger reserves and connected reserves in order to protect rockfish populations in the Puget Sound.

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