The Development of Criteria for Establishing and Monitoring No-take Refuges for Rockfishes and Other Rocky Habitat Fishes in Puget Sound

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Abstract

Rockfish populations in Puget Sound have shown declines in size, abundance, and reproductive success since the mid-1970s to such an extent that they are being considered under the Endangered Species Act as threatened or endangered. Previous research has shown that rockfishes and lingcod living in no-take refuges are larger, more abundant, and have higher reproductive capacities than in comparable fished areas. These results and others factors have prompted many agencies and organizations to begin planning the creation of no-take refuges throughout Puget Sound to promote the recovery of depressed species and to insure ecosystem integrity. While general guidelines for the creation of no-take refuges exist, specific criteria for creating or monitoring the success of a refuge system for rockfishes and other reef species are lacking.

In recent years, the Washington State Department of Fish and Wildlife has undertaken a number of studies specifically aimed at determining reef fish stock abundance, habitat requirements, and responses to no-take refuges. The results from these studies provide the basis for establishing a refuge network and targets for network success. Pertinent results include maps of nearshore rocky reef habitats, preferred habitat characteristics, historical and refuge size frequencies of key fish species, and fish density observations from long-term refuges. These specific criteria are integrated with recent and published guidelines for rockfish and other refuges throughout the world into a planning scheme for a Puget Sound reef refuge system.

Introduction

No-take refuges are becoming an increasingly popular concept as a conservation tool for marine ecosystems throughout the world (Gubbay 1995; Agardy 1997). In the northeastern Pacific, refuges have been identified as a tool for better managing rockfishes (Yoklavich 1998; Murray and others 1999; Parker and others 2000), and several studies have shown that rockfishes and lingcod respond to protection from harvest by occurring in higher densities and providing increased fishery catch rates, becoming larger, or exhibiting greater reproductive potential (Palsson and Pacunski 1995; Gunderson 1996; Paddack and Estes, 2000; Martell and others 2000). Many of these responses have been demonstrated within Puget Sound, and these findings along with the development of marine protected area (MPA) science and polices have called for a greater network of refuges to achieve habitat and population conservation (West 1997; Palsson and others 1998; PSAT, 2001). The Washington Department of Fish and Wildlife has created a number of no-take refuges for rocky habitat species such as rockfishes (*Sebastes* spp.) and lingcod (*Ophiodon elongatus*) in Puget Sound (Figure 1) and planning is in progress

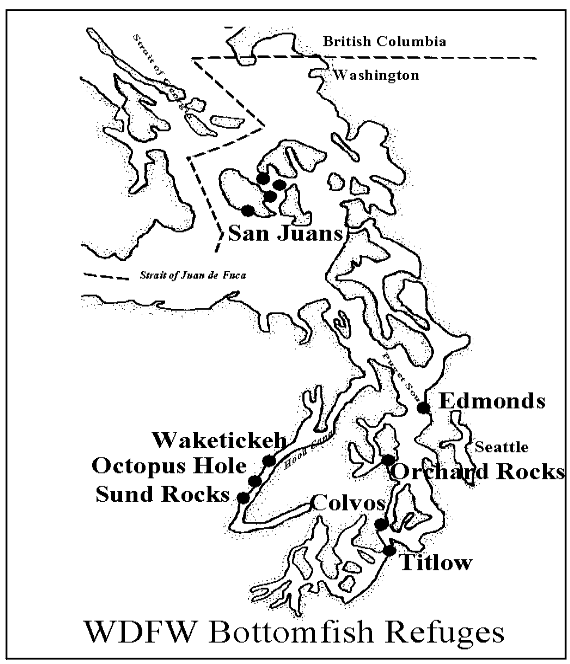

Figure 1. Bottomfish refuges created by the Washington Department of Fish and Wildlife.

that will result in more refuges formed into regional networks.

While there is great enthusiasm for creating MPAs and refuge networks, there is no consensus as to the goals and objectives for the creation of a network and a lack of specific criteria for designing a scientifically based network. Unfortunately, the science of MPA design is still in its infancy, but a number of books and articles do provide approaches to designing a network system (Gubbay 1995; Agardy 1997; Yoklavich 1998). For rockfish, the proceedings of the Marine Harvest Refugia for West Coast Rockfish Workshop (Yoklavich 1998) provides an outline and a number of specific guidelines for designing refuges for rockfishes. Design elements for individual refuges and networks typically include biological criteria such as size, shape, location, habitat or species protected, and distance from other refuges. Other design elements include social, economic and pragmatic criteria among others (Salm and Price 1995). Goals may include the total amount of habitat to be protected, a target population level of a species, or achieving a "healthy" ecosystem.

Presently, two general goals for creating refuges in Puget Sound are being considered: refuges for rockfishes, lingcod, and other rocky habitat fishes and refuges for maintaining the integrity of ecosystem functions. A number of common approaches can be taken to design refuge networks including identifying and protecting areas rich in biological diversity and identifying areas that are unique or important habitats. Fisheries scientists may take a different approach that considers population models, habitat preferences, and survey data to locate and design refuges. Which approach is taken will depend upon the goals and measurable objectives established for each refuge network and will also depend on the amount and quality of data available to design the network.

Work that has been conducted by the Washington Department of Fish and Wildlife (WDFW) and other organizations in Puget Sound can provide valuable information for designing and selecting individual refuges and building individual refuges into a viable network. Much of this research has involved measuring the responses of rockfishes, lingcod, and other reef fishes to marine refuges, examining the habitat preferences of these species, and conducting regional surveys to estimate their abundance. Using this information, biological attributes will be identified for use in the design and implementation of criteria for selecting individual reserves and building a reserve network for rockfishes, lingcod, and other rocky habitat fishes.

Approach and Methods

During the past 15 years, a number of studies and surveys have focused attention on describing the life history, habitat requirements, and population status of rockfishes and lingcod. Many of these studies have occurred in Puget Sound and are extremely pertinent to the questions of individual refuge and network design. Specific published studies will be examined with respect to a variety of siting and design criteria. In addition, WDFW staff have been conducting quantitative video surveys documenting the distribution of nearshore rocky reef habitat, the densities of rocky reef fish living in these habitats, and the relationship of these fishes to their habitat (Pacunski and Palsson 2001).

The categories used to develop criteria for individual refuge and network were adapted from Yoklavich (1998). These categories include size, shape, and location, and each category was examined with respect to individual refuges and networks of refuges.

Results and Discussion

Individual Refuges

A variety of biological criteria may be considered for siting and designing an individual marine refuge in Puget Sound. For rockfish, some of these factors are size, shape, and location (Yoklavich 1998). While most guidelines for selecting individual refuge sites have been general to date, knowledge gained from studies on rockfish and lingcod in Puget Sound and in nearby areas provides an opportunity to identify specific needs and criteria for selecting refuges for rocky habitat species.

Size. Many factors may be considered for determining the size of individual refuges. A primary criterion should be assuring that the refuge incorporates the extent of horizontal movements and territories occupied by the target species (Yoklavich 1998). Matthews (1990a, 1990b) 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 rockfishes had high site fidelity. Although lingcod may make large scale movements, especially in coastal populations (Jagielo 1999), most tend to stay remain within the tagging area (LaRiviere 1981; Matthews 1992). Smith and others (1990) found lingcod ranged within 34 km of release sites after one year at large in the Strait of Georgia, but focused dive and sonic tagging studies found lingcod ranged less than 1 km from the tagging area and exhibited homing and site fidelity (Matthews 1992). The persistence of high densities of large rockfish and lingcod at the 7-hectare refuge at Edmonds Underwater Park (Palsson and Pacunksi 1995; Palsson 1998) suggests small refuges are appropriate for the small home ranges of lingcod and rockfishes. However, whether such small refuges have benefits outside the park is unknown but circumstantial evidence does suggest areas of greater rockfish settlement along the shoreline surrounding small refuge at Edmonds (see below).

Although small-scale refuges such as Edmonds and other refuges recently created by WDFW may provide pockets of high biomass, reproductive potential, and local recruitment, they may not contribute greatly to seeding fished areas or improving ecosystem functions. Modeling work by Walters (2000) demonstrates that a few large refuges provide greater benefits in terms of dispersal, effort concentration, and trophic conditions than do small refuges. This results primarily from small refuges having more edges to area than large refuges. Instead of Puget Sound rocky refuges being on the order of several hectares (the most common current size), they should be on the order of hundreds or thousands of hectares to achieve the greatest biological effects according to this modeling work.

Shape. Refuge shape is region specific, may encompass onshore and offshore corridors that protect shallow and deep water fishes, and may be of a configuration that is effective for enforcement (Yoklavich 1998). One guideline for refuge shape is to assure that they are oriented onshore to offshore to include the greatest biological and life-stage diversity by encompassing a range of depth strata (Yoklavich 1998). This guideline might also be considered for Puget Sound, however, the convoluted nature of the fjords, basins, and bays may require a greater diversity of refuge shapes. Biological criteria for shape may not only consider shallow and deep-water habitats but onshore-offshore and long-shore life history pathways and movement corridors. Refuge shapes should account for diel and seasonal movement patterns of rockfish, lingcod and other reef fishes (Moulton 1977; Matthews 1990c), and shapes and regulations should protect the nearshore settlement habitat of copper rockfishes, which subsequently move offshore to adult reefs (West and others 1995; Buckley 1997).

Location. Biological factors to consider for locating refuges include ocean currents, heavily and lightly exploited populations, habitat characteristics and functions, and resources required to support spawning biomass (Yoklavich 1998). Some of these factors have been investigated for rocky habitat species in Puget Sound and should be taken into consideration for siting individual refuges.

The relationship between rockfishes, lingcod, and other rocky habitat species and their preferred habitats has been investigated by a number of researchers in Puget Sound and in the Georgia Basin, and their results can be used to define criteria for selecting rocky habitats as marine refuges. Copper (*Sebastes. caurinus*), quillback (*S. maliger*), and brown rockfishes (*S. auriculatus*) prefer high relief rocky habitats (Matthews 1990c) and habitats with high complexity (crevices) and relief (Pacunski and Palsson, In Press; Murie and others 1994; Richards 1987). Piled boulder fields and walls were found to contain the greatest complexity and relief and hence the greatest abundance of sedentary rockfishes. Copper rockfish occur in shallow depths less than 39 m (Richards 1987; Pacunski and Palsson, In Press), and quillback rockfish may occur in shallow depths, but often range to depths greater than 100 m (Richards 1986; Murie and others 1994). While these are the requirements for the adult rockfish habitat, juveniles prefer small rocks and nearshore vegetated habitats (West and others 1995; Buckley 1997). Other rocky habitat species have different preferred habitats. Lingcod and kelp greenling (*Hexagrammos decagrammus*) were found to be more generalists, preferring a wider range of substrates and being less dependent on complexity and relief factors than rockfishes (Pacunski and Palsson, 2001). Much of the habitat preference work has occurred in shallow water. Submersibles have demonstrated the deep depth preference of yelloweye rockfish (*Sebastes ruberrimus*) (Richards 1986).

Depending upon the target species or reef communities, the habitat preference studies provide substantial knowledge of what substrates and other features should be selected for rocky habitat refuges. As sites for marine refuges are considered for various species assemblages, these habitat preferences should be investigated further and the sites inspected to assure that sufficient amounts of the preferred habitats are contained in the proposed site. Many of the shallow (less than 39 m depth) rocky habitats have been identified in Puget Sound (Figure 2) during quantitative video surveys conducted by WDFW and should be considered along with the specific habitat information as a framework for identifying rocky habitat refuges.

Ocean currents were identified as a factor to consider in siting marine refuges for rockfishes (Yoklavich 1998) and sites including coastal upwelling zones were considered to be beneficial. In Puget Sound, upwelling zones do not exist, but other oceanographic features such as tidal gyres, tidal pumps, wind forcing, and estuarine circulation may be significant to the success of marine refuges. Some of these oceanographic features may establish larval retention areas or recruitment hot spots that can be considered source habitats and beneficial to refuge location. The importance of source versus sink habitats in marine refuge design has been considered by Roberts (1998) and Crowder and others (2000) who both concluded that siting refuges in source areas is beneficial. The relationship between oceanographic features in Puget Sound and source or sink habitats is not known at present but knowledge of oceanography may help in the comparing oceanographic effects among different refuges.

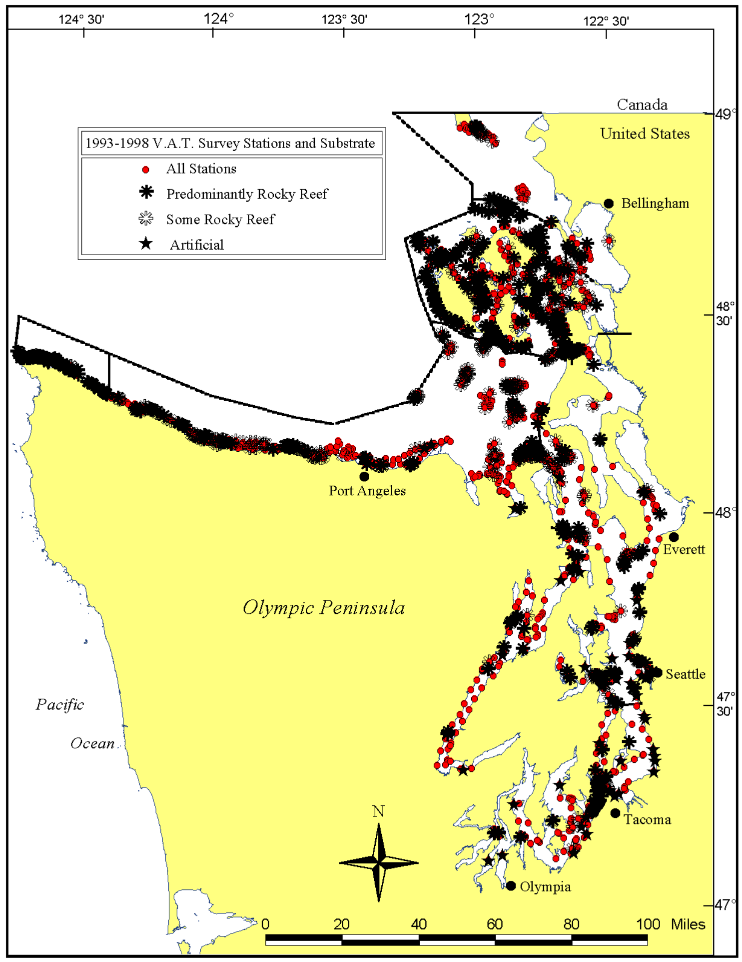

Figure 2. The distribution of nearshore rocky habitats obtained from quantitative video surveys in Puget Sound.

One intriguing circumstance suggesting the importance of oceanographic features comes from tidal gyres that were described by Ebbesmeyer (1999) along the eastern shore of the central Puget Sound basin between West Point and Mukilteo (Figure 3). These 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 had few if any young of the year (Doty and others 1995). Coincidentally, the Edmonds Underwater Park is located centrally to the distribution of the gyres and where the young of the year rockfish were found. While these studies lack replication and the source of the young fish was not known, it suggests tidal gyres and other larval retention features may be significant in Puget Sound and considered a criterion for the siting of marine refuges. More tidal gyres and areas of surface current accumulation are being identified by Ebbesmeyer (1999) and Klinger (In Press) in northern Puget Sound, and follow up studies are needed to examine the importance of oceanography to young rockfish and other larvae as a criterion for locating marine refuges in Puget Sound.

Sites should be considered for marine refuges that have been both heavily fished and lightly exploited because these extremes will either provide a greater, but long-term response to protection or provide immediate benefits by maintaining spawning biomass (Yoklavich 1998). In Puget Sound, most nearshore, shallow areas have been heavily exploited and many deep reefs have also been heavily fished. A few insular reefs may not have been found by fishers and may serve as refuge candidates. As these lightly or un-fished areas are discovered, they should receive high priority for protection. Voluntary marine refuges in the San Juan Islands have been selected based upon where recreational fishers were once successful at fishing but were subsequently fished out (Kaill 1999). A more comprehensive map of present and historical fishing effort is needed to establish clear criteria for siting refuges within lightly and heavily fished areas.

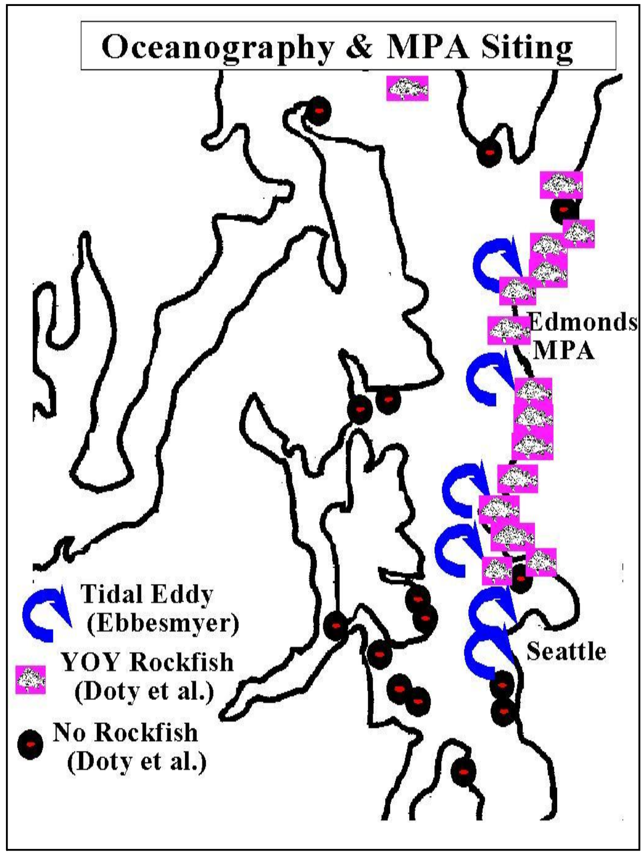

Figure 3. Tidal gyres, young-of-the-year rockfish locations, and the Edmonds Underwater Park in central Puget Sound.

Marine refuge sites should have adequate resources to support the recovery of spawning biomass of rockfishes (Yoklavich 1998) and other reef fishes. Besides habitat preference research and some diet studies, there have been no studies to comprehensively document the food habits, prey abundance, and productivity of reef habitats in Puget Sound. Surrogate inferences may be drawn by identifying sites with greater biological diversity. Sites with high biological diversity may have more prey resources, be of greater diversity because they are productive sites, and have more stable ecological functions. Quantitative video, dive, trawl and other surveys have been underway throughout Puget Sound, and these and other data are being compiled into maps of biological diversity by several organizations (Bloch and others In Press) which will be available soon for use by refuge planners.

Network Design

Most organizations advocating the creation of marine protected areas set them in a context of network. A refuge network will consist of individual refuges but has additional qualities that link and enhance refuge benefits that a single refuge cannot provide alone. In a network of refuges, individual refuges are not isolated but have effects upon adjacent fished areas and nearby or distant refuges. Such an attribute of interconnection provides insurance against the loss of individual refuges, provides adjacent refuges with recruits or migrants for each other, and provides benefits to non-reserve areas in between network refuges. The replication of individual reserves allows for the scientific requirement to test that the effects of refuges are not unique. For Puget Sound, less information is available to guide the development of criteria than there is information for individual refuges.

Refuge networks must be set in the context of biological regions (Yoklavich 1998) that consist of geographically distinct habitat and oceanographic features and that contain some degree of uniqueness. Very limited characterizations of biological regions have been undertaken for Puget Sound. At present, the best characterization of Puget Sound's biological regions are encompassed by the main basins including the Strait of Juan de Fuca, San Juan Archipelago, the Strait of Georgia and its adjacent bays, Hood Canal, main basin from Admiralty Inlet to Tacoma Narrows, the Whidbey Basin including Possession Sound, Port Susan, Saratoga Passage, Skagit Bay, and Deception Pass, and South Puget Sound south of Tacoma Narrows. Network planning should begin to consider sustainable refuges within each of these basins, and as more clarity is gained by understanding the association of biological communities in these basins, some modification of these biological regions may occur.

At least two refuges should be established within each biological region (Yoklavich 1998) to insure that other refuges are intact if one is compromised by catastrophic events and to provide repeated observations of refuge responses. Beside the need for two refuges in a region, there is much uncertainty regarding the optimal number, size and distance from each other. The one time observation of young of the year settlement for rockfish along the eastern shore of the main Puget Sound basin (Doty and others 1995) suggests that the larval response may be limited to scales of tens of kilometers and therefore refuges should be spaced relatively close together to obtain mutual effects. Modeling such as conducted by Walters (2000) will aid in determining refuge size, number, and distance within a refuge network, but direct field studies and experiments will ultimately determine these functional criteria.

Much work has been devoted to how large refuge networks should be to maintain ecosystem integrity, maintain sustainable fisheries, and rebuild and perpetuate fish populations. A total refuge sizes between 10% and 20% of a marine ecosystem have been suggested or are being implemented in different areas of the world. For rockfish refuges, total network size varied with intent: for heritage and research, refuges need to be up to 5% of the target habitat; for target species with existing regulations refuges need to be between 5 and 20%; and for use as a complete alternative strategy, refuge size needs to be between 20% and 50% of the available habitat (Yoklavich 1998). For a refuge network protecting Puget Sound rocky habitat fishes, 20% may be a beginning target goal. Fishery data and refuge studies suggest that little reproduction occurs in fished areas. In order to rebuild and protect 40% of the unfished spawning biomass, a management goal for rockfish populations (Parker and others 2000), a larger network of marine refuges greater then 20% may be required along with continued conservative regulations to maintain or rebuild spawning biomass within each basin. The development of criteria for a refuge network can begin with some of these guidelines and concepts, but it will be necessary to be pragmatic and scientific in implementing a refuge network in Puget Sound. The resolution and development of network criteria must result from testing, monitoring, and modeling the effectiveness of new criteria and must be expected to evolve over time.

Monitoring for Success

Refuges and networks should be created with clear goals and measurable objectives. While conceptual goals and targets may be easy to establish, meaningful responses must be monitored in refuge networks. Historical fishery data, refuge research results, and regional surveys and assessments may provide the criteria and targets for some of these needed measurable objectives.

Three main responses of reef fishes to the creation of marine refuges in Puget Sound have been observed. Rockfish and lingcod occur in greater densities, they are larger, and reproduce more in refuges compared to fished areas (Palsson and Pacunksi 1995; Palsson 1998). The quantitative estimates of these responses, especially from the long-term refuge at Edmonds, can be considered as targets for newly created refuges to achieve. At Edmonds, 85% of the copper rockfish are 40 cm in length or greater and 95% of the lingcod measure 70 cm or greater. The median density of copper rockfish at Edmonds was 0.25 fish per square meter (Figure 4). Density as a criterion may be more variable than length frequency distributions, but the medians of fish density may be set as targets for a mature rocky habitat refuge for other species in Puget Sound. Observations of lingcod reproduction in terms of nest densities may provide a target criterion for reproduction in rocky habitat refuges. Observations of lingcod nesting in the San Juan refuges 10 years after protection have resulted in lingcod nest densities ranging from 85 nests/ha to 160 nests/ha (WDFW, unpublished data). Greater lingcod reproduction may be achieved with mature refuges, and the work by Johnson (In Press) documents very high numbers of lingcod nests at the Edmonds Underwater Park.

Perhaps the most important variable to monitor for testing the success of a marine refuge network for reef fishes is whether the total population of reef fishes has increased to desired and sustainable abundances and spawning biomass. Monitoring fished and unfished index sites provides a partial picture of population abundance but one that will not encompass the full range and variability of the population. Comprehensive regional surveys have been conducted for fishes living on nearshore rocky habitats throughout Puget Sound (Pacunski and Palsson, In Press), and as these surveys improve and are coupled with age-structured population models, a complete assessment of the regional and temporal trends of reef fish populations is possible. Such assessment efforts will be able to tell whether the refuge network is achieving the increased abundance, greater recruitment, and higher spawning biomass that is defined in the goals and objectives of the refuge network.

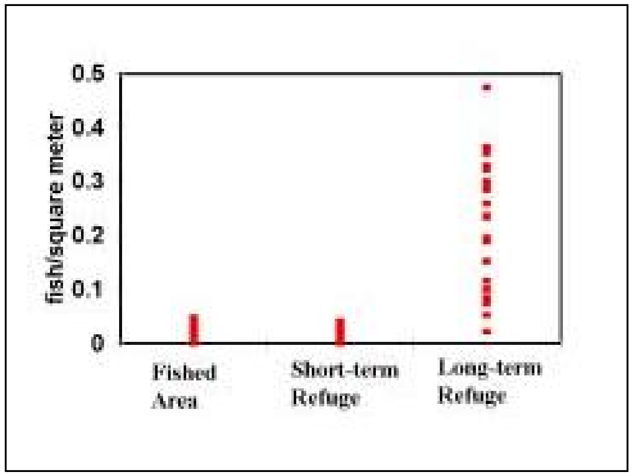

Figure 4. Densities of copper rockfish observed in fished areas, short-term, and long-term refuges in Puget Sound.

Conclusions

A complete set of criteria are not presently available to design a comprehensive network system for rocky habitat fishes in Puget Sound. However, many of the main biological criteria needed to design individual sites are available and networks of individual refuges can be formed with more limited information for use in initial network designs. Organizations and agencies engaged in the planning process of refuges and networks should use such biological criteria and guidelines as a planning baseline and then further develop and identify key criteria for siting and monitoring refuges. Without measurable scientific objectives, criteria for success, and a corresponding monitoring program, successful refuge planning and implementation may be threatened.

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