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The Biology and Assessment of Rockfishes in Puget Sound

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Fish Program
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EXECUTIVE SUMMARY

This technical review supports and is a source document for the Puget Sound Rockfish Conservation Plan. It summarizes the current knowledge of rockfish biology in Puget Sound (life history, habitat usage, and ecosystem linkages), provides an overview of the exploitation history of rockfishes, and examines their current stock status. The review also includes a series of recommendations to improve the understanding and management of rockfishes in Puget Sound. Puget Sound includes all the inland marine waters of Washington including the U.S. portions of the Straits of Juan de Fuca and Georgia, the San Juan Islands, Puget Sound proper, and Hood Canal.

Rockfishes are bottomfishes managed under the auspices of the Puget Sound Groundfish Management Plan and are co-managed with the Treaty Tribes of Washington. The present management plan by the Washington Department of Fish and Wildlife implements a precautionary policy for groundfish management. However, previous management efforts have ranged from targeting recreational and commercial fisheries on rockfish to passive management. As rockfish stocks declined during the past three decades, the Department has progressively restricted the harvest opportunities for rockfish by eliminating targeted commercial fisheries, reducing recreational bag limits, and discouraging or eliminating recreational fisheries targeting rockfish in Puget Sound.

Rockfishes in Puget Sound are a diverse group that form mixed species assemblages and require species-specific habitats at different life-stages. Rockfish have evolved to complex life strategies adapted for long survival, slow growth, late age-at-maturity, low natural mortality rates, and high habitat fidelity. Reproduction follows a pattern of irregular successful recruitment events. Population structure is highly dependent upon the evolutionary and ecological patterns of each species. Copper, quillback, and brown rockfishes living south of Port Townsend form a unique population separate from northern waters. Rockfishes feed on a wide variety of prey, including plankton, crustaceans, and fishes. Rockfishes are prey for a variety of predators including lingcod and other marine fishes, marine mammals, and marine birds. Rockfishes are very susceptible to barotrauma or being captured and brought to the surface from depth.

The complex oceanography and benthic topography of Puget Sound influences rockfish distributions and population characteristics at all life-stages. Most adult rockfish are associated with high-relief, rocky habitats, but larval and juvenile stages of some rockfishes make use of open water and nearshore habitats as they grow. Nearshore vegetated habitats are particularly important for common species of rockfish and serve as nursery areas for juveniles and later provide connecting pathways for movement to adult habitats. A system of marine reserves in Puget Sound provides rockfishes with protection from harvest and provides a baseline for ecological and natural demographic information for stock assessment and conservation.

Rockfish have been harvested by Native Americans and commercial and recreational fishers in Puget Sound. Rockfish harvests prior to 1970 were small relative to those between the mid-1970s through the mid-1990s when both recreational and commercial fishing effort increased. In 1974, a federal court decision reallocated salmon harvest on an equitable basis between tribal and non-tribal harvesters. Bottomfish and their fisheries were popularized for their sport, value, and healthful benefits, and previous non-tribal effort shifted to fishing for bottomfish. Since 1995, tribal fishers can harvest up to 50% of the rockfish quota. However, tribal harvests have accounted for an average 1% the total rockfish harvest since 1991. Regulations enacted during the past decade to conserve rockfishes reduced recent harvests by 90%.

The present status of rockfishes in Puget Sound was characterized using fishery landings trends, surveys, and species composition trends to evaluate rockfish stocks' vulnerability to extinction. These evaluations

rely upon fishery-dependent and independent information to detect changes over time. Conventional age-structure population models or biomass dynamic models were not applied due the lack of long-term catch data and associated biological information. The American Fisheries Society's Criteria for Marine Fish Stocks were modified as a robust approach to establish stock status. These criteria are based upon life history parameters relating to population productivity and compare the magnitude of stock trends over ecologically appropriate time scales. Four status categories were based upon the magnitudes of trends and included Healthy, Precautionary, Vulnerable, and Depleted. Most rockfish species were in Precautionary condition, however, copper rockfish were Vulnerable in South Sound and quillback rockfishes were Vulnerable and Depleted in North and South Sound, respectively. Based upon stock assessments in adjacent coastal waters, yelloweye and canary rockfish were in Depleted status in North and South Sound. The relatively deepwater greenstriped rockfish, redstripe rockfish, and shortspine thornyheads were in healthy condition as were stocks of Puget Sound rockfish in South Sound.

The health of rockfish stocks in Puget Sound is impacted by factors that remove excessive numbers of individuals, chronically alter or degrade their habitats and block life history pathways, or affect other species that increase predation, disease, or competition. Many stressors potentially limit the productivity of rockfish stocks in Puget Sound and include fishery removals, age truncation, habitat disruption, derelict gear, hypoxia, predation, and fishery removals of larger and older individuals. These stressors may have even greater impacts when stocks are at low levels causing, higher mortality rates that can drive stocks to dangerously low levels. Among the potential stressors, fishery removals, derelict gear, hypoxia, and food web interactions are the highest relative risks to rockfish in Puget Sound. Chemical contamination is a moderate risk manifested by undetermined reproductive dysfunction associated with exposure to endocrine disrupting compounds, loading of larvae with persistent organics via maternal transfer, exposure of pelagic larvae to toxics via contaminated prey, and exposure of long-lived adults to toxics like polychlorinated biphenyl compounds that accumulate over the life of the fish. These are most likely to impact rockfish living in urban areas but may be more widespread in the food web.

Based upon this review of information and the condition of rockfish stocks in Puget Sound, a series of recommendations were developed to improve the conservation and management of rockfishes in Puget Sound. Principal recommendations are to improve our knowledge of rockfish in the ecosystem and their habitat requirements; better indentify, quantify, and control stressors on rockfish stocks; improve the management of rockfishes by evaluating the effectiveness of marine reserves, minimizing bycatch and accounting for all catch; and improve stock assessment by conducting comprehensive and frequent surveys, estimating life history parameters such as maturity, growth and mortality; better defining stocks and populations through genetic analysis; and developing quantitative models to reconstruct and analyze the abundance and demographic population structure.

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1 INTRODUCTION

Over two dozen species of rockfish occur in the inland marine waters of Washington, here defined as Puget Sound (Figure 1.1; See Section 3.1 **Species Diversity**). The Washington Department of Fish and Wildlife[1] (WDFW) manages these species, and the various commercial and recreational non-tribal fisheries that have either targeted these species or have caught them incidentally to other targeted species. Rockfishes and other groundfish are managed for non-tribal users following the Puget Sound Groundfish Management Plan (Palsson et al. 1998) and are co-managed with the Treaty Tribes of Washington. Although the terms "bottomfish" and "groundfish" both generally describe saltwater fishes associated with the bottom, WDFW legally defines species of bottomfish including rockfishes, codfishes, flatfishes, sharks, and others. Bottomfish, halibut, and unclassified marine fishes are collectively termed groundfish and are managed under the auspices of the Puget Sound Groundfish Management Plan.

Rockfishes (*Sebastes* spp.) and thornyheads (*Sebastolobus* spp.) are one of the most important groups of marine fishes in Puget Sound. Rockfishes are members of the family of scorpion fishes with spines that contain venom sacs that can be painful to humans. There are about 100 species of rockfish found worldwide, most of which can be found along the Pacific coast of North America (Love et al. 2002). In Puget Sound, twenty-eight species of rockfish have been recorded (Miller and Borton 1980, WFDW unpublished data), but of these only half are observed regularly. Rockfish have a long history of exploitation, by both commercial and recreational fisheries, and serve important ecological functions in the Puget Sound food web and ecosystem. Over the past two decades, stocks of many species of rockfish declined, some quite severely, resulting in increased scientific, economic, and social concern about the status of this resource and the economic viability of the related fisheries. Palsson et al. (1997) and PSAT (1998, 2000, 2002, 2007) have detailed the declining abundance of rockfish stocks in Puget Sound.

Rockfish, as a group, are difficult to manage because they are quite vulnerable to the effects of fishing (Parker et al. 2000) and to other natural and man-made factors. Rockfish grow slowly, have a long life span, have low natural mortality rates, mature late in life, have sporadic reproductive success from year to year, may display high fidelity to specific habitats and locations, and require a diverse genetic and age structure to maintain healthy populations (Love et al. 2002). These factors make them susceptible to overfishing, and once populations are at a low level, recovery can require decades. Rockfish that are caught and released often die from pressure-related trauma, thus making catch-and-release fisheries and size limits not generally feasible. Because several species of rockfish can be caught at the same location and their identification is confused, the selective management for individual species is difficult, especially if one species is less productive than the others in the catch. In some species, older rockfish appear to produce more fit offspring, so the maintenance of a diverse age structure in the populations is desirable.

Several analyses and studies focusing on rockfishes in Puget Sound have come to conclusion that stocks are in poor condition. A review of marine life in Puget Sound by West (1997) concluded that demersal rockfish were in decline, largely as a result of overharvesting. A special review by the American Fisheries Society found several species of rockfish to be "vulnerable" in Puget Sound and are among the most threatened marine fish stocks of fish in North America (Musick et al. 2000). In 1999, a petition was presented to the federal government to list several species of rockfish in Puget Sound under the federal Endangered Species Act. While NOAA Fisheries rejected the listing of the concerned rockfishes, they did identify rockfishes as vulnerable (Stout et al. 2001). Another petition to list quillback and copper rockfishes in Puget Sound under the ESA was submitted in 2006 but did not warrant reconsideration[2]. In

[1] The Washington Department of Fisheries was combined with the Washington Department of Wildlife in 1995. Prior to 1995, the WDFW will refer to WDF unless otherwise noted.
[2] Federal Register: January 23, 2007 (Volume 72, Number 14, pages 2863-2866).

2007, a third petition was filed to list five rockfishes (yelloweye, canary, greenstriped, redstripe, and bocaccio) in Puget Sound under the ESA[3], and NOAA Fisheries initially rejected accepting the petition for consideration[4]. The subsequent Biological Review Team found these species likely formed a distinct population segment in Puget Sound and that declining frequencies and population trends warranted protection for three of these species.[5] In April 2009, NOAA Fisheries recommended that bocaccio be considered as Endangered, and that yelloweye and canary rockfishes are in Threatened Status under the terms of the ESA. Local groups, most notably the San Juan County Marine Resources Committee and People for Puget Sound, have undertaken actions to voluntarily protect rockfish, by establishing voluntary no fishing zones in the county and convening a special workshop on rockfish and lingcod stocks in the county. The 2003 conference concluded that the outlook for rockfish was "grim" (Mills and Rawson 2004). All of these reviews and conclusions were based upon data and assessments conducted by WFDW. WDFW also has listed thirteen species of rockfish as Washington State Species of Concern.

These local declines in rockfish abundance have been matched by declines in rockfish stocks elsewhere along the West Coast (Ralston 1998, Love et al. 2002). The Pacific Fishery Management Council and the NOAA Fisheries have declared that seven coastal rockfishes including bocaccio, cowcod, canary, yelloweye, Pacific ocean perch, dark-blotched, and widow rockfishes to be over-fished (STARR Panel 2005) and have implemented severe fishing restrictions in federal waters (3 miles to 200 miles offshore). These measures include greatly reduced harvest quotas, non-retention for some rockfish species, and large areas closed to directed fishing or incidental take of rockfish, called Rockfish Conservation Areas (RCAs). State coastal waters (less than 3 miles from shore) have been closed for a number of years to all commercial, non-tribal fishing, other than for salmon and Dungeness crab to preserve populations of nearshore rockfish. In British Columbia, declines of rockfish have been noted in the Strait of Georgia and elsewhere and fishing restrictions have been enacted including reducing the recreational and commercial harvest and implementing an extensive series of RCAs (Yamanaka et al. 2004). In these marine protected areas, fishing for rockfish is prohibited.

In response to declines in rockfish abundance in Puget Sound, WDFW undertook a series of actions to protect rockfish resources. Commercial and recreational harvests of rockfish were progressively curtailed over a period of twenty years. Two commercial fisheries were prohibited throughout Puget Sound and others were restricted primarily to protect rockfish. A series of Marine Protected Areas (MPAs) were established throughout Puget Sound, largely to protect rockfish stocks. Additional studies and surveys were instituted to better understand the biology of rockfishes, causes for their decline, and to develop strategies to sustain rockfish stocks. Although a long-term decline in several rockfish species in Puget Sound is evident, the recent management actions by WDFW have likely stopped the declines of commonly-harvested species (copper, quillback, brown and black rockfish). This development led Governor Locke of the State of Washington to call for WDFW to produce a recovery plan for bottomfish species, including rockfishes, by the end of 2004. WDFW's strategy was to first focus the conservation planning effort on rockfishes that presently are the greatest problem for fisheries management. This effort has been slow, however, given the complexity of rockfishes, fisheries, and the lack of information.

[3] Federal Register, October 5, 2007. (Vol. 74, No. 193, Pages 56986-56990).
[4] Federal Register**.** March 17, 2008. (Vol. 73, No. 52, Pages 14195-14200).
[5] Federal Register, April 23, 2009. (Vol. 74, No. 77, Pages 18516-18542).

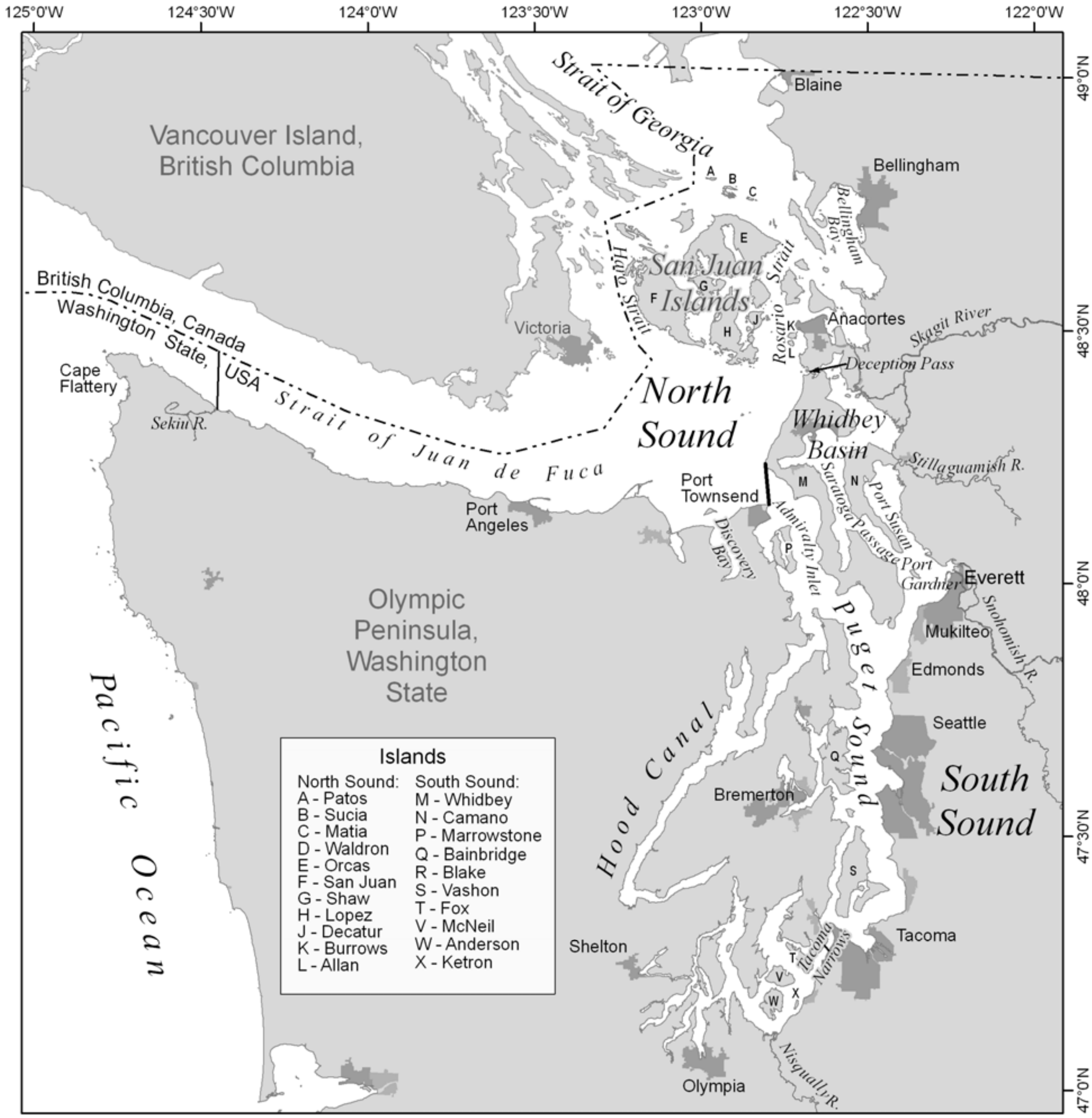


Figure 1.1. North and South Puget Sound.

2 MANAGEMENT HISTORY

Prior to the early 1970's, management of rockfish and other groundfish resources in Puget Sound received scant attention from management agencies. There were few or no perceived conservation needs and many of the Washington-based commercial vessels were fishing the lucrative rockfish grounds off of Canada. The Washington Department of Fisheries (WDF) developed the Food Fish Management Plan in 1970, but rockfish in Puget Sound were not mentioned in this plan (Washington Department of Fisheries 1970). WDF's actions were aimed at increasing the efficiency of Washington bottomfish fishermen to encourage the greater utilization of underutilized species and to reduce conflicts between recreational and commercial fisheries. Construction of rock breakwaters was encouraged to provide nursery areas for some bottomfish species and to expand recreational fishing opportunities. Prior to 1970 and continuing on through the late 1970s, WDF focused its management effort on other species, primarily salmon. This situation changed in the 1970's due to two events:

1. The Canadian government extended its jurisdiction over marine waters to 200 miles from shore. This was done as part of the Law of the Sea convention that was adopted by both the United States and Canadian governments. The impact of this extended jurisdiction was to preclude Washington-based vessels from fishing off of Canada. In response, many Washington vessels began fishing for groundfish in Puget Sound.

2. In 1974, the federal court issued a ruling that clarified treaty-fishing rights in Puget Sound (i.e. the "Boldt decision"). The effect of this decision was to reduce the fishing opportunity for salmon by non-treaty fisheries. As an alternative, policy makers encouraged these displaced non- tribal fishers to fish for groundfish in Puget Sound.

The groundfish resources were viewed as a "safety valve" to reduce the social and economic stress caused by turmoil in other fisheries. WDFW opened new commercial fisheries for Pacific cod and dogfish shark and expanded otter trawl opportunities throughout Puget Sound. As a result, the level of commercial fishing for groundfish greatly increased in the Puget Sound, nearly quadrupling in a few years. In addition, staff was assigned to publicize the fishing opportunities for rockfish and other species of groundfish in Puget Sound (e.g. Bargmann 1976, Mills 1978). The federal government joined in this task and assigned federal biologists to develop recreational fisheries for rockfish and other species in Puget Sound (Washington 1976, 1977).

By the early 1980's, signs of stress were apparent in the Puget Sound groundfish resources and WDF began to monitor the resources and fisheries, and WDF developed a first-time plan for managing the groundfish fisheries in Puget Sound (Pedersen and DiDonato 1982). Aside from catch accounting and a few scientific studies, rockfish were not formally included in any management plan until 1982 when they were identified as important species in commercial and recreational catches in the various basins of Puget Sound (Pedersen and DiDonato 1982). This plan established Acceptable Biological Catches (ABC's) based upon recent average catches for the time, and set an overall rockfish ABC of 671,000 lbs distributed among component species and basins. This plan also established management strategies that favored recreational fisheries in Hood Canal, Admiralty Inlet, Central Sound, and South Sound. In North Sound, the strategy was to keep recreational fishing as the dominant fishery and evaluate the commercial fishery, especially the prospect of using roller gear to fish trawls on rocky habitats. A series of rockfish regulations were implemented beginning in 1983 (Table 2.1) that resulted from management plans and studies. During the early 1980s, WDF had good information on the landed catch in the commercial fishery and limited information on the discarded portion of the catch. Much less information was available for the recreational fishery. Monitoring of the recreational fishery was tied closely to the salmon fishery and estimates of catch were incomplete and underestimated the true amount of the recreational harvest. Information on discarded catch in the recreational fishery was negligible.

The 1982 Groundfish Management Plan was updated in 1986 (Pedersen and Bargmann 1986), and again based ABCs and optimal yields on recent average catches totaling 851,000 lbs among basins and rockfish species. This plan reviewed recent management actions including the implementation of the 1983 reduction of the daily bag limit from 15 rockfish to ten rockfish in North Sound and to five rockfish in South Sound. For rockfish, the plan extended the preference to recreational fisheries over commercial fisheries to the San Juan Islands and the Strait of Juan de Fuca, with the exception of yellowtail rockfish caught in deepwater commercial trawl fisheries. Additionally, WDF applied for, and received, a grant from the U.S. Fish and Wildlife Service under the Federal Aid in Sport Fish Restoration Act. Beginning in 1985 and through 1999, this grant enabled WDF/WDFW staff to monitor the recreational fisheries for bottomfish and to research rockfish stocks directly. This program resulted in a limited management study discussing the options for recreational fisheries management (Bargmann et al. 1991). With the goals of sustaining stocks and improving recreational fisheries and angler satisfaction, three management approaches were examined: (1) simple management with simple but low bag limits and regulations, (2) a stock condition approach where regulations were changed based upon the above average, average, or poor condition of a stock, and (3) specialty fishery management based upon stocks in good condition determined with precise stock assessment information. The preferred approach was that of management based upon three stock conditions, and this approach was generally considered in subsequent stock assessments and management.

The preferred approach and two alternative approaches of Bargmann et al. (1991) were not implemented. In 1991, WDF underwent a change in strategy for management of groundfish in Puget Sound. This new strategy, called "passive management", ended all monitoring of commercial fisheries for bottomfish and collection of biological data. This decision was based in part on the reduction in the commercial fishery by the state legislature closing Puget Sound to bottom trawling south of Foulweather Bluff, in South Sound. Staff was reassigned to other duties. Beginning in 1994 and lasting until the 2000s, changes in recreational salmon fishing drastically affected the ability to estimate the recreational catch of bottomfish (see Section 5.4 Recreational Fisheries). The combination of the incomplete catch estimates and the passive management strategy created the situation that WDF knew more about the bottomfish harvest that occurred in the 1970's and 1980's than about the harvest occurring in the 1990's.

Despite the passive management strategy during the 1990s, a series of regulations were implemented during the 1980s and 1990s that acted to conserve rockfishes. Several regulations decreased or removed commercial fisheries on rockfish. These regulations included closing jig and troll fisheries in the San Juan Islands in 1984, prohibiting trawl fisheries in most of Puget Sound and Hood Canal in 1989, prohibiting roller gear in 1991, eliminating jig and troll fisheries east of Sekiu in 1992, and closing remaining trawl fisheries in Admiralty Inlet in 1994 (Table 2.1). To restrict trawlers from targeting rockfish, a 500 lb daily landing limit was implemented in 1998, and in 1999, WDFW prohibited the live take of rockfish and other species in order to prevent the management difficulties experienced by other live fish fisheries in other coastal states and provinces. These were the last major rules enacted to reduce or eliminate non-tribal, commercial fisheries directed for rockfish. In 1994, the recreational daily bag limit was reduced from the limits imposed in 1983, to five rockfish in North Sound and three rockfish in South Sound.

The policy of passive management during the early 1990s gave way to a new administrative framework and directions to update the groundfish management plan. In 1996, the newly formed Fish and Wildlife Commission established a policy for Puget Sound groundfish management which stated "*It is the policy of the Washington Fish and Wildlife Commission to manage Puget Sound groundfish, especially Pacific cod, in a conservative manner in order to minimize the risk of overharvest, and to ensure the long-term* *health of the resource."*[6] During the following two years, a Puget Sound Groundfish Management Plan (PSGMP) was written (Palsson et al. 1998) that developed specific goals and objectives to achieve the Commission's precautionary approach. The PSGMP provided for management based upon stock condition and called for the periodic development of Conservation and Use Plans for each major groundfish species and identified factors to consider in their management. This plan is currently in effect, but a lack of resources has prevented the successful completion of any species plans. In addition, a supplement to the PSGMP was drafted and titled as "Conservation Plan for Groundfish Resources and Fisheries in Puget Sound" (WDWF, unpublished) that elaborated the harvest strategies needed for precautionary management based upon biological reference points and recent information regarding the population dynamics of marine fish stocks.

The PSGMP was evaluated by Christiansen (2005) who compared it to other management plans for rockfish along the West Coast. She found the PSGMP too comprehensive and precautionary and was not effectively implemented because of a lack of funding to develop and implement the Conservation and Use Plans that were mandated by the plan. She also found the plan deficient in not incorporating an extensive public involvement process, adaptive management, and uncertainty. Christiansen did make specific recommendations and, in particular, suggested an experimental approach to examine the effects of different management practices, especially of the one-fish daily bag limit for recreational fisheries.

By the mid-1990's, signs of rockfish stock decline were evident, especially with the submission of a petition to list 17 species of bottomfish, including 14 rockfishes, in Puget Sound as endangered or threatened (Stout et al. 2001). The Washington State Legislature responded by providing a special funding source to rebuild the bottomfish (and herring) resources of Puget Sound. However, simultaneous with the awarding of this new funding, WDFW changed the objectives of the grant from the U.S. Fish and Wildlife Service and utilized the funding for other purposes. The new funding provided by the legislature was used to continue many of the activities formerly supported by the federal grant. New regulations were developed to mitigate the decline in rockfish stocks based upon new catch and biological information. A one fish daily bag limit for rockfish was imposed in 2000 for the recreational fisheries in both North and South Sound, and prohibitions for retaining yelloweye and canary rockfishes were implemented in 2002 and 2003 because of poor stock conditions assessed for Washington coastal waters (Table 2.1). In 2004, a series of regulations were imposed on the recreational fishery including only allowing rockfish harvest during open salmon and lingcod seasons in South Sound, a seasonal closure of rockfish from October to April in North Sound, the prohibition of spearfishing for rockfish east of Sekiu, and only allowing the retention of the first rockfish captured. One exception to the one rockfish daily bag limit was the allowance of the harvest of three black rockfish in the Sekiu area (Catch Record Area 5) that took advantage of healthy black rockfish stocks along the Washington coast. The retention of bottomfish was prohibited in Hood Canal in 2003 because of unusual behaviors and fish kills related to hypoxia (Palsson et al. 2008).

[6] Washington Fish and Wildlife Commission Policy POL-C3003 effective November 1, 1996.

Table 2.1. Significant Regulation Changes Affecting Rockfish in Puget Sound.

Year	Recreational	Commercial
1983	10 fish bag limit of rockfish for recreational anglers in North Sound, 5 fish in South Sound.	
1984		Permanent closure in San Juans to bottom fish jig and troll gears.
1989		Bottom trawling south of Admiralty Inlet banned by Washington Legislature.
1991		Directed trawl fisheries for rockfish and lingcod prohibited by banning roller gear on trawls east of Sekiu.
1992		Ban on bottomfish jig and troll gears east of Sekiu enacted.
1994	Rockfish daily bag limit reduced to five rockfish in North Sound and three in South Sound.	Bottom trawling prohibited in Admiralty Inlet, the eastern Strait of Juan de Fuca, and the San Juan Islands.
1998	Puget Sound Groundfish Management Plan adopted. Marine Protected Area Policy adopted. Neah Bay part of Puget Sound.	
		500 pound vessel trip limit for rockfish for trawl gear, 30 lb limit for set line gear.
1999		1999 Live fish fishery for rockfish and other species prohibited
2000	One rockfish bag limit enacted for all of Puget Sound east of Sekiu River. Emergency regulation temporarily increasing rockfish bag limit to 3 in Sekiu area to allow for black rockfish harvest.	
2002	May-Sept 30, west of Slip Point daily limit of 3, only 1 of which may be other than a black rockfish, permanent rule. Temporary prohibition of yelloweye and canary harvest.	Roller gear prohibited in Neah Bay.
	No yelloweye or canary rockfish may be retained.	
2003	Yelloweye and canary rockfish cannot be retained.	
2004	Daily limit is first legal rockfish. No yelloweye or canary rockfish may be retained. Closed to spearfishing for rockfish. Only open during lingcod and salmon seasons in South Sound. Open May to September in North Sound.	

2.1 Tribal Co-Management

Tribal groups in the northwest have a long history of harvesting rockfish (Stewart 1977). The Treaty Tribes were reserved the right to harvest under the Stevens treaties, and this was confirmed by the Rafeedie Federal Court decision (1994) upholding the treaty right to harvest in common with non-tribal users. Management of marine resources, including rockfish, is now conducted cooperatively with the treaty tribes. In comparison to the non-treaty fishery, the recent and current levels of rockfish harvest by tribal fishers are low. Between 1991 and 2007 the treaty harvest of rockfish has averaged about 1,172 pounds annually, which is less than one percent of the total Puget Sound harvest of rockfishes. From landing records, it appears that most of the treaty harvest of rockfish is taken incidental to other fisheries.

2.2 Management Areas

Puget Sound is defined for fishery management purposes as those inland marine waters of Washington east of Cape Flattery, north to the international boundary with Canada, and south including the waters of Hood Canal, Admiralty Inlet, Puget Sound as defined on nautical charts, Saratoga Passage, Port Susan, Tacoma Narrows and the southern inlets, and all adjacent marine waters to the outer most reaches of the tributaries. This expansive area has been subdivided by many schemes for commercial and recreational fisheries management (Evans 1998). For the purposes of this stock status analysis, Puget Sound is divided into a North Sound region extending east of the Sekiu River mouth to Port Townsend and Whidbey Island, and north to the international border (Figure 2.1). South Sound includes those marine waters south of Port Townsend and east of Deception Pass. The extreme western portion of the Strait of Juan de Fuca from Cape Flattery to the Sekiu River, also known as Neah Bay or West Juan de Fuca, is not included in this assessment due to the proximity to coastal fish stocks and interconnected management with coastal regulatory bodies.

Prominent basins within Puget Sound can be recognized and are important to the biology and management of many resources. These basins include the Strait of Juan de Fuca, San Juan Islands, southern Strait of Georgia, Admiralty Inlet, Hood Canal, the Whidbey Basin, Central Sound, and Southern Puget Sound (Figure 2.1). The basins roughly coincide with the Groundfish Management Regions defined by Pedersen and Didonato (1982) and are those defined by Schmitt et al. (1991).

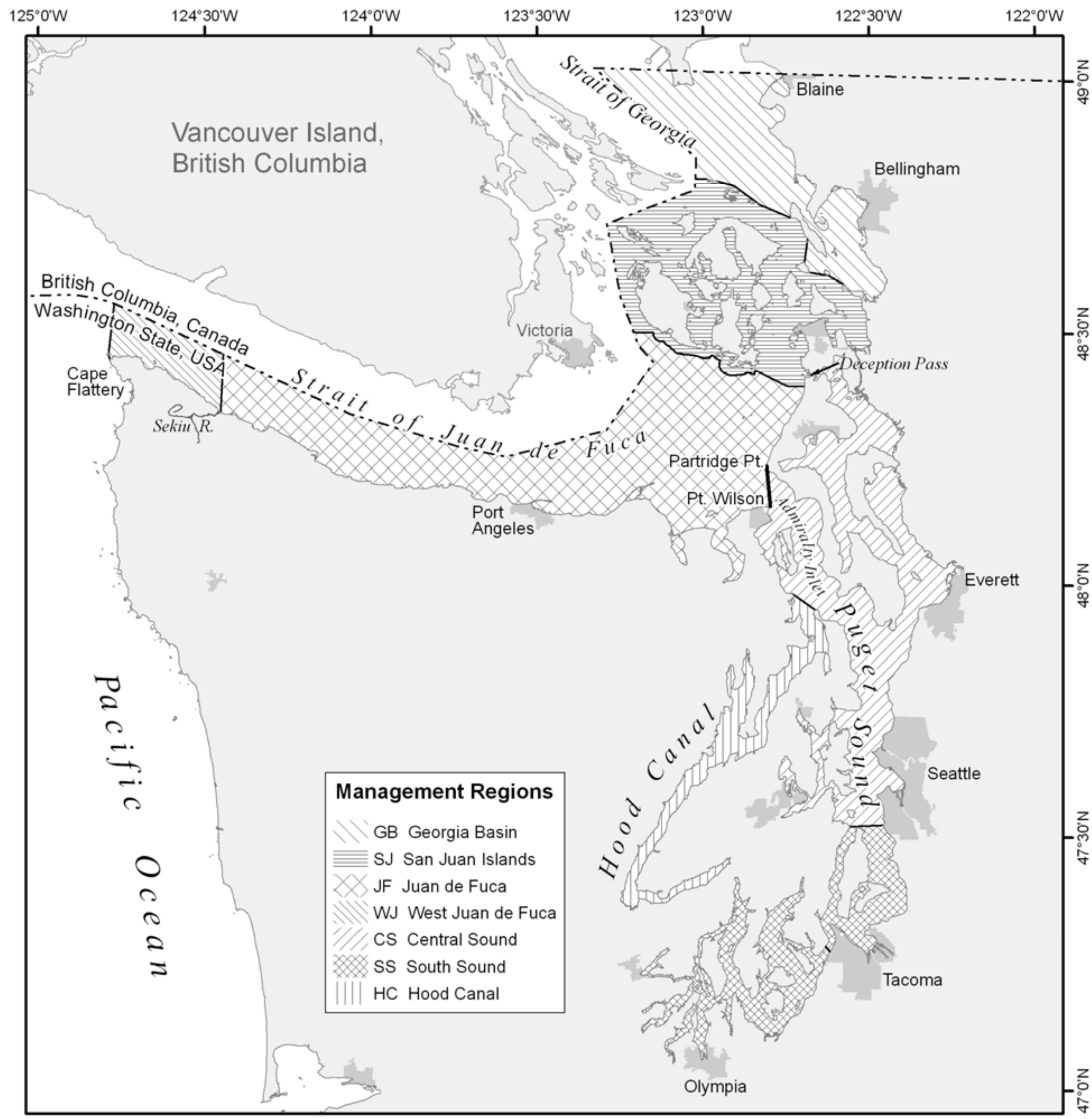


Figure 2.1. Major basins and Groundfish Management Regions of Puget Sound.

3 BIOLOGY

3.1 Species Diversity

Twenty-eight species of rockfish have been documented in the eastern portions of North Sound and South Sound (Miller and Borton 1980, WDFW, unpublished data, Table 3.1). Formal records of rockfish occurrence consist of events when one or more rockfish were identified at a site as observed from museum collections, University of Washington surveys, or literature sources (Miller and Borton 1980). Valid records do not include identifications by WDFW or other samplers who have not collected voucher specimens or photographs for professional confirmation. Eleven of these rockfish species have been recorded five times or less, and six including blue, China, rougheye, Pacific Ocean perch, and rosethorn rockfishes occurred nearer to the coast in the eastern Strait of Juan de Fuca or San Juan Islands. One additional species, the widow rockfish, only occurred once off the southwest corner of San Juan Island when twenty specimens were collected. While more records may be available since Miller and Borton (1980) conducted their review, this historic pattern represents the relative occurrence of rockfish species and can be used to characterize the species assemblages and targets for management in Puget Sound. The species richness in Puget Sound may be considered as limited fauna compared to the forty species that occur off the coast of Washington (Love et al. 2002). Based upon the occurrence of the historical records, copper rockfish, followed by quillback and brown rockfish, are the most common species in Puget Sound (Table 3.1). Brown rockfish are generally restricted to South Sound. Deepwater, benthic species such as bocaccio, silvergray, yelloweye, splitnose, and canary rockfishes have occurred in most north and south basins to South Sound. Species that are abundant on the coast, such as yellowtail, black, and vermilion rockfishes, may be limited to Puget Sound as immigrants or recruits from coastal stocks. Since 2004, vermilion rockfishes have been observed frequently in southern Hood Canal and in the central basin of South Sound indicating a strong influx from the coast. Adult yellowtail rockfish are not found in the San Juan Islands (Barker 1979) and young-of-the-year black rockfish have rarely been observed in Puget Sound (Garrison and Miller 1982), although in 2006 young-of-the-year presumed black and yellowtail rockfishes were observed in nearshore habitats along the Strait of Juan de Fuca (LeClair et al. 2007).

3.2 Assemblages

The species that have been observed in Puget Sound can be roughly categorized into several ecological assemblages based on their distribution patterns and habitat associations.

Sedentary species - These rockfishes, such as copper, quillback, brown, tiger, and China, are highly associated with rocky habitats (Love et al. 2002), and some show high affinity and at times high fidelity to high-relief rocky habitats (Matthews 1990 a, b, c). They also demonstrate small home ranges when living on high-relief, natural rocky habitats. These species can also be characterized as inhabiting shallow depths of 40 m or less (Table 3.2, Gunderson and Vetter 2006).

Pelagic species - Species such as black, yellowtail, Puget Sound, silvergray, bocaccio, and blue rockfishes are pelagic and occur in schools in the water column, above the bottom, or off of steep slopes (Moulton 1977, Washington 1977, Love et al. 2002). Some of these species are usually found in less than 40 m depth, as in the case of black, Puget Sound, and blue rockfishes (Table 3.2, Gunderson and

Vetter 2006). Others occur in depths of 50 to 500 m, such as silvergray, widow, canary, and bocaccio rockfishes. All of these species may still be associated with, or near, rocky habitats.

Deepwater species – Species, such as yelloweye rockfishes, inhabit rocky pinnacles (Washington 1977, Love et al. 2002) and boulder fields (Wang 2005) and are typically found in deep waters of 50 to 500 m (Table 3.2, Gunderson and Vetter 2006). Some rockfishes, including canary, greenstriped, and silvergray, are generalists and occur over a wide variety of habitat types off the Washington coast (Wang 2005). Other species found in shallow water can also occur among deep-water communities, including tiger rockfishes (Gunderson and Vetter 2006) and quillback, redstripe, and juvenile yellowtail rockfishes.

Many species of rockfish occupy the same habitats and depths (Moulton 1977, Love et al. 2002, Gunderson and Vetter 2006). It is not unusual for a single fishing trip to land several species of rockfish, often caught at the same location. This complex nature of multi-species fisheries makes it a challenge to fishery management.

3.3 Life History Pathways

Rockfishes are some of the longest-lived fishes known in Puget Sound, with maximum ages for several species spanning more than 50 years. Elsewhere in their range, rockfishes can attain ages between 100 years and 205 years (Munk 2001). Although many general life history traits are known for the *Sebastes* genus, few species have been studied in detail, especially in Puget Sound. Basic parameters such as the mean maximum age, growth rates, natural mortality rates, mean fecundity, and mean age at maturity have only been estimated for a limited number of Puget Sound species, and often, these estimates were made before the "break-and-burn" ageing technique (Chilton and Beamish 1982). This technique greatly extended the age structure of rockfish populations by a factor of two or more compared to the traditional technique of reading annular rings from the surface of an otolith. Even for many commercially or recreationally harvested species, much needed information concerning stock identification, genetic diversity, spawning behavior, bycatch levels, total fishery removals, and migration patterns are not known or are based on limited data from small or other geographic areas. Specific information on the growth, maturity, and life history characteristics of rockfish stocks in Puget Sound are presented in the species accounts in Section 6 **Stock Evaluation**. A general description of these traits is presented here. Rockfish undergo four distinct life history phases, beginning with the egg stage within the body cavity of the female, progressing to the larval stage once released from the female, metamorphosis from larvae to juvenile, and maturing into the adult stage. As discussed in Section 4 **Habitat Relationships**, each phase is associated with a specific habitat type.

Rockfish undergo a complex mating process involving courtship between males and females and insemination (Love et al. 2002), activities that typically occur during the autumn for common rockfishes in Puget Sound. The sperm is stored within the female until the winter when the eggs are fertilized (Takahashi et al. 1991, Love et al. 2002). The embryos develop over the course of the winter and spring when bulging, pregnant females are observed. The number of embryos produced by the female increases with size (DeLacy et al. 1964, Cooper 2003). Female copper rockfish that are 20 cm in length produce 5,000 eggs while a female 50 cm in length may produce 700,000 eggs. Rockfishes are viviparous and are primarily lecitotrophic, that is, the embryos receive most of their nourishment from their yolk during development within the mother (Wourms 1991). Some species such as black and copper rockfishes are matrotrophic since the newly hatched larvae absorb some nutrients before extrusion from the mother (parturition) (Boehlert and Yoklavich 1984, Dygert and Gunderson 1991). Gestation periods have been estimated at 43 days for copper rockfish (Dygert 1986). Female copper, quillback, and brown rockfishes release their 4 mm to 5 mm young from March through June. Puget Sound rockfish are different from most local rockfish in that they undergo courtship during the summer (Moulton 1975, W. Palsson, WDFW, personal observation).

Parturition, or birth, occurs during the spring for the common species of rockfishes in Puget Sound. Cooper (2003) estimated parturition dates for copper rockfish between mid-March and early May in the Strait of Georgia. Parturition dates are earlier for older females (11-20 years) than younger females (4-10 years), and older fish give birth in March. Parturition dates estimated by Cooper (2003) were comparable to those of Moulton (1977) for copper rockfish in the San Juan Islands, but slightly earlier then reported by DeLacy et al. (1964) for copper rockfish in central Puget Sound where parturition occurs until the end of May. DeLacy et al. (1964) also observed that brown rockfish are pregnant a month later than copper rockfish, with eyed-embryos still present in females in late June. This observation is also consistent with those of WDFW scuba studies (WDFW unpublished) in central Puget Sound where pregnant brown rockfish have been commonly observed in June and July. Weis (2004) reviewed the parturition studies for rockfishes found in the northeast Pacific and noted that female black rockfish release larvae from January to April, yellowtail rockfish release larvae from November to March, tiger rockfish release larvae in May, China rockfish release larvae from January to June, splitnose rockfish release larvae from April to August, yelloweye release larvae from April to September with a hiatus in June and July, and Puget Sound rockfish release larvae from August to September (Moulton 1975, Beckmann et al. 1998).

After parturition, rockfish larvae inhabit the water column. In Puget Sound, rockfish larvae have been found in most but not all years in Rich Passage during daytime sampling at the surface (Busby et al. 2000). In a one-time study, Waldron (1972) found rockfish larvae in the water column throughout Puget Sound. Weis (2004) conducted extensive ichthyoplankton surveys in San Juan Channel and obtained rockfish larvae measuring 4 mm to 6 mm from late March until mid-July. Peak abundance of larvae in San Juan Channel occurs in April and early May corresponding to the parturition period estimated by Cooper (2003) for copper rockfish.

By the end of the larval period, larvae grow into the pelagic juvenile life-stage about 20 mm in length, and resemble juvenile rockfish in appearance (Love et al. 2002). The length of the pelagic juvenile stage varies by species, and ends when the juveniles “settle-out” and become associated with kelp or other bottom (benthic) habitats (Love et al. 1991, Buckley 1997, Hayden-Spear 2006). Juvenile copper rockfish may spend several months or more in juvenile habitats (West et al. 1994, 1995, Buckley 1997) and for several years as sub-adults, immature fish associate with the rocky habitats that are inhabited by the adults.

Typically, rockfishes mature at about half the size of their maximum length (Haldorson and Love 1991, Love et al. 2002), but often they grow large enough to be caught and are vulnerable to fishing gear before they reach full maturity. Most rockfishes have maximum lengths between 50 and 66 cm, with the notable exceptions of yelloweye and bocaccio rockfishes that can grow to 91 cm and Puget Sound rockfish that only reach 18 cm in length (Table 3.2, Gunderson and Vetter 2006). Halving these values to approximate the size at maturity means that these species mature between 25 cm and 33 cm in length. Rockfish begin to enter the recreational fishery at approximately 20 cm (see Section 6 **Stock Evaluation**) meaning that some rockfishes that are harvested have not reached sexual maturity.

Rockfish mature as early as age 2 for Puget Sound Rockfish, but ages at maturity from 6 to 11 years old are more common for other species (Table 3.2, Gunderson and Vetter 2006). Notable exceptions are rougheye and yelloweye rockfishes that mature between 19 and 22 years old. The age at maturity for common rockfish has not been well studied in Puget Sound. Puget Sound studies prior to the 1980s relied upon ages obtained by surface readings of otoliths and not by the more accurate break-and-burn method. For copper rockfish, Cooper (2003) found copper rockfish as young as five years old have mature oocytes, but he did not estimate the age at 50% maturity. Surface-read ageing and maturity studies found copper rockfish maturing at four and five years for South and North Sound (Barker 1979, Gowan 1983), but Richards and Cass (1987) observed 50% maturity at ages of six years with the break-and-burn method for copper rockfish from the Strait of Georgia. Quillback rockfish mature between 4 and 5 years in Puget Sound as evaluated with the surface ageing method (Barker 1979, Gowan 1983), but Richards and Cass (1987) and Yamanaka and Lacko (2001) found female quillback rockfish in the Strait of Georgia mature at 11 years old. Richards and Cass (1987) determined that male quillback rockfish mature later at an age of 13 years.

The growth of copper, quillback, and brown rockfishes is variable and differs by North and South Sound for one species (for growth rates see Section 6 **Stock Evaluation)**. For any given length category greater than 20 cm, ages may range by ten or more years for all these species. Quillback rockfish grow more slowly and attain greater sizes and maximum ages in North Sound than in South Sound. Many species have sex-specific growth rates, which can result in different age-at-maturity and sex-specific natural mortality rates (Love et al. 2002). Most rockfish species have maximum longevities ranging from several decades to over 100 years in age. The rougheye rockfish can live to 205 years (Munk 2001). In contrast, the small Puget Sound rockfish lives to 22 years in some areas, but only thirteen years in Puget Sound, and only attains lengths of 18 cm (Beckman et al. 1998).

Natural mortality rates are difficult to estimate but generally relate to the productivity and fishery potential of a species. Hoenig's (1983) model can be used to estimate the mean natural mortality rates based upon the mean maximum age of a fish species. Using Gunderson and Vetter's (2006) observations, long-lived species such as rougheye, tiger, yelloweye, and Pacific Ocean perch have low natural mortality rates between 2% and 4% per year (Table 3.2). Copper, black, and brown rockfishes have intermediate rates between 8 and 12%, while Puget Sound rockfish have a relatively high natural mortality rate of 17% per year. These estimated natural mortality rates are reviewed along with observed values in the Section 6 **Stock Evaluation**.

The recruitment or survival of year classes is variable for many rockfishes along the West Coast (Love et al. 2002). A dominant feature of rockfish reproduction is a pattern of infrequent and irregular years, with successful recruitment during periods with favorable environmental conditions, and many years with poor recruitment (Hollowed et al. 1987, Hollowed and Wooster 1995, Ralston and Howard 1995). Reproductive success can be restricted to narrow spatial and temporal windows when conditions are favorable for larval survival. Specific information on rockfish recruitment is lacking for Puget Sound, but studies on settling juvenile copper rockfishes have found them to be common in some years or extremely rare in others. During the summer of 2006, an extraordinary recruitment of settling copper and quillback rockfishes was observed in the South Puget Sound (LeClair et al. 2007, WDFW, unpublished data). Settling young-of-the-year rockfishes were also observed in the Strait of Juan de Fuca and were likely to be black, yellowtail, or canary rockfishes.

Table 3.1. Number of Historical Records of Rockfishes within Puget Sound (after Miller and Borton 1980). [a]

Common Name	Scientific Name	East Juan de Fuca	Georgia-Bellingham	San Juan Islands	Hood Canal	Whidbey Basin	Central Sound	South Sound	Puget Sound General	Total
Rougheye rockfish	*Sebastes aleutianus*			1		1			2	4
Pacific ocean perch	*Sebastes alutus*	1								1
Brown rockfish	*Sebastes auriculatus*				9		93	19	1	122
Redbanded rockfish	*Sebastes babcocki*			1	1					2
Silvergray rockfish	*Sebastes brevispinis*			1				1		2
Copper rockfish	*Sebastes caurinus*	33	14	182	100	144	606	118	4	1168
Darkblotched rockfish	*Sebastes crameri*	2				1				1
Splitnose rockfish	*Sebastes diploproa*			1	7		1			9
Greenstriped rockfish	*Sebastes elongatus*	2		1	32	4	15	1	1	54
Puget Sound rockfish	*Sebastes emphaeus*			22		1	7			30
Widow rockfish	*Sebastes entomelas*			20						20
Yellowtail rockfish	*Sebastes flavidus*	12		15	6		61		1	83
Rosethorn rockfish	*Sebastes helvomaculatus*			1						1
Quillback rockfish	*Sebastes maliger*	17	16	114	29	98	128	24	3	412
Black rockfish	*Sebastes melanops*	34	12	76	11	22	147		6	274
Vermillion rockfish	*Sebastes miniatus*	1		3					1	4
Blue rockfish	*Sebastes mystinus*								2	2
China rockfish	*Sebastes nebulosus*	2		1					2	3
Tiger rockfish	*Sebastes nigrocinctus*			13			1		1	15
Bocaccio	*Sebastes paucispinis*	4	1		2	2	104		1	110
Canary rockfish	*Sebastes pinniger*	14	10	25	14	6	56	1	2	114
Redstripe rockfish	*Sebastes proriger*	1	1	3	10	2	8	2		26
Rosy rockfish	*Sebastes rosaceus*						1			1
Yelloweye rockfish	*Sebastes ruberrimus*	3	13	71	14	3	7	1	4	113
Stripetail rockfish	*Sebastes saxicola*				4	3	3	1		11
Halfbanded rockfish[b]	*Sebastes semicinctus*	2								2
Sharpchin rockfish	*Sebastes zacentrus*			2		2	9	1		14
Shortspine thornyhead	*Sebastolobus alascanus*			5			3			8

[a] Note: All the figures are observed frequencies and not the observed densities.

[b] From two recent records from the 2004 WDFW Bottom Trawl Survey extending the range of this species to in the western Strait of Juan de Fuca.

Table 3.2. General Life History Characteristics for Selected Rockfishes (adapted from Gunderson and Vetter 2006).

Species	Mean Age at Maturity (yr)	Mean Maximum Age (yr)	Mean Maximum Size (cm)	Mean Natural Mortality Rate (%)[1]
Shallow (less than 40 m)				
Black rockfish	6-8	50	69	8
Blue rockfish	6-11	44	53	8
Brown rockfish	4-5	34+	56	12
China rockfish	4-5	79+	45	5
Copper rockfish	6	50	66	8
Puget Sound rockfish	2	22	18	17
Quillback rockfish	7-11	95	61	4
Tiger		116	61	4
Deep (50 to 500 m)				
Bocaccio	4	50	91	8
Canary rockfish	7-9	84+	76	5
Pacific ocean perch	10	100+	53	4
Redstripe rockfish	7	55+	51	7
Rosethorn rockfish	10	87+	41	5
Rougheye rockfish	20	205	97	2
Sharpchin rockfish	6	58+	45	7
Silvergray rockfish		82+	82	5
Tiger rockfish		116	61	4
Widow rockfish	5-7	60+	59	7
Yelloweye rockfish	19-22	118+	91	3
Yellowtail rockfish	10	64+	66	6
[1] Based upon Hoenig (1983).				

3.4 Ecology and Behavior

3.4.1 Rockfish as Predators

Most prey studies conducted in Puget Sound and adjacent waters have focused on the diets of copper and quillback rockfishes and have found that shrimps, fishes, and crabs constitute the main components of their diets (Table 3.3). Rockfish size and location may be important factors in the types of prey selected. Murie (1995) studied rockfish diets in Saanich Inlet in the southwestern Strait of Georgia and found that copper rockfish mostly consume, by mass, Pacific herring (*Clupea pallasii*), coonstriped shrimp (*Pandalus danae*), kelp perch (*Brachyistius frenatus*), pile perch (*Rhacochilus vacca*), and squat lobster (*Munida quadraspina*). The diet of copper rockfish depends upon fish size. Copper rockfish smaller than 20 cm in length feed upon demersal crustaceans or pelagic fishes (on a mass basis), while larger copper rockfish principally feed upon pelagic fishes. These feeding patterns are consistent for copper rockfish diets in Puget Sound, except surfperches and other fish are the principal fishes eaten with few or no herring found in the stomach contents. In South Sound, Hueckel and Buckley (1987) found surfperches, pandalid shrimp, greenlings, other fishes, and crabs are the most important prey items. Copper rockfish in

South Sound eat pandalid shrimp, surfperches, and sculpins (Patten 1973). They also eat crabs and other fishes including Pacific herring, spiny dogfish (*Squalus acanthias*), eel-like fishes, and Pacific sand lance (*Ammodytes hexapterus*) (Washington et al. 1978). Juvenile copper rockfish from the Nisqually area of South Sound primarily feed upon crangonid and pandalid shrimps followed by fishes in importance (Fresh et al. 1978). Crabs are the second-most important prey item after fishes in the San Juan Islands (Moulton 1977). Miller et al. (1978) found that juvenile copper rockfish eat amphipods, fishes, and mysids as the three most important prey items.

Quillback rockfishes consume similar prey items compared to copper rockfish except that demersal crabs and shrimps are usually the most important or highest mass items (Table 3.3). In the most detailed study of quillback rockfish food habitats (Murie 1995) found that the majority of quillback rockfish of any size feed upon pelagic fishes and pelagic and demersal crustaceans, such as squat lobster, euphausids, and coonstriped shrimp on a mass basis. The most important pelagic fish is Pacific herring, but prey items vary by the size of rockfish. Small quillback rockfish less than 20 cm in length feed primarily on demersal crustaceans and pelagic fish, and to a lesser extent, pelagic crustaceans. In contrast, most of the food mass consumed by larger quillback rockfish (greater than 20 cm) consists of pelagic fishes. Studies from central Puget Sound also found that small and medium-sized quillback rockfishes primarily consume demersal crustaceans, including pandalid and hippolytid shrimp, amphipods, crabs, but also consume euphausids as an important prey category (Washington et al. 1978, Heuckel 1980). Large quillback rockfishes consume crabs, shrimp, fishes, and amphipods as their principal prey items, showing that fishes are important in larger rockfish diets, but there is still a high degree of dependence upon benthic invertebrates. Moulton (1977) examined stomachs from juvenile quillback rockfish from the San Juan Islands and found that crabs, fish, and shrimp are the most important constituents of their diets.

There is some seasonality to the feeding patterns of copper and quillback rockfishes. Copper rockfish feed throughout the year, but quillback rockfish tended to have fuller stomachs during the spring and summer than during the winter and fall (Murie 1995). Both copper and quillback rockfishes feed on pelagic fishes during all seasons but pelagic fishes are more prevalent in rockfish diets during the winter. Demersal crustaceans are more important on a mass basis for copper rockfish during the spring and summer. Murie (1995) found daily variation in the feeding patterns of copper and quillback rockfishes. Copper rockfish have higher percentages of full stomachs after sunrise and sunset indicating crepuscular feeding activities. In contrast, quillback rockfish feed at mid-day. Moulton (1977) found a similar crepuscular pattern in daily feeding patterns for copper rockfish, but found that quillback rockfish in the San Juan Islands are also crepuscular feeders, not mid-day feeders.

Limited food habit data for other rockfishes only allow for a general description and categorization of their feeding ecology. Brown rockfish in South Sound depend upon fish and demersal crustaceans, including crabs, pandalid and other shrimps, and isopods (Washington et al. 1978, Hueckel and Buckley 1987). One tiger rockfish sampled from the San Juan Islands only had crabs in its stomach, and one yelloweye rockfish had pandalid shrimp and nematodes (Miller et al. 1978). In South Sound, yelloweye rockfish feed on fishes, especially walleye pollock (*Theragra chalcogramma*), cottids, poachers, and Pacific cod (*Gadus macrocephalus*) (Washington et al. 1978). As expected, black rockfish feed upon pelagic prey including fishes such as Pacific sand lance, Pacific herring, and sculpins, hyperiid amphipods, euphausids, chaetognaths, gelatinous zooplankton, shrimps, and crabs. Yellowtail rockfish, which often co-inhabits pelagic schools with black rockfish, feed upon fishes, shrimp, chaetoghanths, and euphausids, similar to black rockfish, but their diets also include mysids, crab larvae, calanoid copepods, and polychaetes (Moulton 1977, Miller et al. 1978, Washington et al. 1978). The diet of Puget Sound rockfish consists of small prey items such as calanoid copepods, crab larvae, chaetognaths, hyperiid amphipods and siphonophores (Moulton 1977, Miller et al. 1978).

Table 3.3. Summary of Rockfish Food Habits in Puget Sound and Adjacent Waters

Species and Size	Study	Area	Five Most Dominant Prey by Index of Relative Importance, Weight or Frequency of Occurrence
Copper rockfish			
Size range	Murie et al. 1995	Saanich Inlet, Strait of Georgia	Pacific herring, coonstriped shrimp, kelp perch, pile perch, squat lobster
	Hueckel and Buckley 1987	South Sound	Surfperch, pandalid shrimp, greenlings, fishes, Cancer crabs
Most juveniles	Fresh et al. 1978	Nisqually	Crangonid and pandalid shrimp, shrimps, fishes
Juveniles	Miller et al. 1978	San Juans	Amphipods, fishes, mysids, hippolytid shrimp, isopods
Size range	Patten 1973	South Sound	Coonstriped shrimp, fishes especially surfperch and sculpins, other shrimp, crustaceans
Size range	Washington et al. 1978	South Sound	Crabs, fish, shrimp
Size range	Moulton 1977	San Juan Islands	Fish, brachyrynch, oxyrynch porcellanid crabs, shrimp
Quillback Rockfish			
Size range	Murie et al. 1995	Saanich Inlet, Strait of Georgia	Pacific herring, squat lobster, euphausids, coonstriped shrimp, mysids
Small	Hueckel 1980	Central Puget Sound	Pandalid shrimp, crustaceans, amphipods, crabs, euphausids
Medium	Hueckel 1980	Central Puget Sound	Pandalid shrimp, crabs, shrimp, hippolytid shrimp, Cancer crabs
Large	Hueckel 1980	Central Puget Sound	Crabs, shrimp, fishes, Cancer crabs, amphipods
Size range	Washington et al. 1978	South Sound	Other crustaceans, shrimp, crabs, fish
Adult, juvenile	Moutlon 1977	San Juan Islands	Brachyrynch and oxyrynch crabs, fish, shrimp, porcellanid crabs
Brown Rockfish			
	Hueckel and Buckley 1987	South Sound	Porcellanid crabs, shrimp, crangonid shrimp, isopods, crabs
Size range	Washington et al. 1978	South Sound	Fish, shrimp, other crustaceans, crabs
Black Rockfish			
Adult, juvenile	Moulton 1977	San Juan Islands	Fishes, shrimp, euphausids, chaetognaths, gelatinous zooplankton
	Miller et al. 1978	San Juan Islands	Hyperiid amphipods, fishes (sand lance and cottids), crabs
Size range	Washington et al. 1978	South Sound	Fish, crustaceans, jellyfish
Yellowtail Rockfish			
Juveniles	Moulton 1977	San Juan Islands	Fishes, shrimp, euphausids, mysids, polychaetes
	Miller et al. 1978	San Juan Islands	Calanoid copepods, mysids, fishes, crab larvae, chaetognaths
Size range	Washington et al.	South Sound	Fish, crab larvae, euphausids

Species and Size	Study	Area	Five Most Dominant Prey by Index of Relative Importance, Weight or Frequency of Occurrence
	1978		
Puget Sound Rockfish			
Adult	Moulton 1977	San Juan Islands	Copepods, chaetognaths, crabs, hyperiid amphipods, fishes
Adult	Miller et al. 1978	San Juan Islands	Calanoid copepods, siphonophores, crab larvae, hyperiid amphipods, crabs
Tiger Rockfish			
Adult	Miller et al. 1978	San Juan Islands	Crabs
Bocaccio			
	Washington et al. 1978	South Sound	Fish
Yelloweye Rockfish			
Adult	Miller et al. 1978	San Juan Islands	Pandalid shrimp, nematodes
Size range	Washington et al. 1978	South Sound	Fish

3.4.2 Rockfish as Prey

Rockfishes of all sizes are an important food resource for a variety of predators in Puget Sound. They are prevalent in the diets of lingcod, other marine fishes, marine birds, and marine mammals.

Marine mammals.- Rockfishes are consumed in varying but low amounts by marine mammals including harbor seals (*Phoca vitulina*), California sea lions (*Zalophus californianus*), and orca (*Orcinus orca*) in Puget Sound. Little diet information is available for the Steller sea lions (*Eumetopias jubatus*) in Puget Sound, but scat analysis reveals rockfish are present in 8.3% to 17% of the samples (Brown et al. 1995, Riemer and Brown 1996, 1997, Lance and Jeffries 2007). Rockfish are a minor component of Steller sea lion diets in the Gulf of Alaska (Winship and Trites 2003). Rockfish are consumed by harbor seals in British Columbia (Olesiuk et al. 1990) and along the California coast (NOAA 1997).

In a recent and extensive study of harbor seal diets in the San Juan Islands, rockfish were prevalent in seal diets in all areas but their occurrence in seal diets vary between years (Lance and Jeffries 2007). Overall, rockfish are present in 12% of harbor seal scats. Rockfish occurred in 2.3% of seal diets during 2005 to 2006 but increased to 12% of diets in 2006 to 2007. Pacific herring, salmon, walleye pollock, and other forage fishes are the more common diet items, and rockfishes were a seasonal component of seal diets. The frequency of occurrence of rockfishes is lowest during the spring at 3.1%, 9.2% during the summer, and increases to 23% during the winter. The seasonal changes indicate that seals switch their prey to abundant salmon during the summer and fall but sustain themselves on rockfish when salmon are not abundant during the winter. Because there are 7,000 seals in the San Juan Islands, seals may affect rockfish abundance when they are at low levels. Lance and Jeffries (2007) also observed that the most consumed rockfishes were less than 4 years in age corresponding to juveniles and sub-adults of common rockfish species.

The diet composition of harbor seals is poorly known for other areas in Puget Sound, but limited studies indicate that their diets consist nearly exclusively of squid and fish, such as whiting, tomcod, herring, sculpins and surfperch (Calambokidis et al. 1978, Everitt et al. 1981). In southern British Columbia 75% of the diet of harbor seals consists of two species, Pacific herring and Pacific whiting, while only 1% of the diet is rockfish (Olesiuk 1993). In the Strait of Juan de Fuca, one study found rockfish remains in

4% of the samples of harbor seal scat examined, while in Hood Canal, rockfish were found in less than 1% of seal scats (London et al. 2002).

The diet of California sea lions in Puget Sound is dominated by Pacific whiting, spiny dogfish, Pacific herring, and Pacific cod. Rockfishes are very rare in the diet (Everitt et al 1981). Although rockfishes are an important component of the diet of California sea lions in California (NOAA 1997, Lowry and Carretta 1999) and in Oregon where 21% of scats contain rockfish (Riemer and Brown 1996), California sea lions are not a major predator of rockfishes in Puget Sound at present.

There are two types of killer whales (Orca) that inhabit Puget Sound, the “resident” whales that spend their entire lives in the Sound and “transient whales that move in and out of the Sound. The transient whales primarily consume marine mammals, while the resident whales feed on fish (Wiles 2004). Limited studies of the diet of resident killer whales found that during the spring, summer, and fall 22 species of fish are consumed. However, approximately 96% of the diet during these times consist of chinook salmon (Wiles 2004). There has been one instance of a yelloweye rockfish being consumed by a killer whale (Wiles 2004).

Birds.- Rockfish are an important prey item for several species of marine birds. Juvenile rockfish can be an especially important food item while birds are feeding their young. The impact of marine birds is on rockfish productivity is not known in Puget Sound.

Marine fishes - Rockfish, especially juvenile rockfish, are an important prey item for lingcod, especially large lingcod (Matthews 1987, Beaudreau and Essington 2007). Overall, lingcod in the San Juan Islands consume rockfish 6.8% by number, 11% by mass, and 10.5% by frequency of occurrence. Although lingcod consume rockfish greater than 24 cm in length, rockfish measuring 4-24 cm in length are the most frequent in lingcod stomachs. Pelagic larval and juvenile life-stages of rockfish are major food resources for a variety of fishes, especially chinook salmon (*Oncorhynchus tschawytscha*), Pacific herring, and bottomfish (see diet study review in Buckley 1999).

3.4.3 Genetics and Stock Identity

Proper stock identification is important for management of rockfish resources in Puget Sound. Stock identity means that individuals of a species in a specific area are substantially isolated from other groups of the same species. These groups may be referred to as subpopulations or stocks and are defined by genetic or morphological differences, or though other auxiliary information such as movement or recruitment patterns. Subpopulations usually have different life history parameters, such as growth rates, mortality rates, or life spans. These differences in subpopulations may cause different responses to exploitation and fishery regulations. Therefore, management strategies reflecting the dissimilarity among stock units are essential. By properly identifying stock units, management can be tailored to the appropriate geographical units.

In 2000, a team of scientists from the National Marine Fisheries Service met to review the status of copper, quillback and brown rockfish in Puget Sound (Stout et al. 2001). Using genetic information and life history traits, such as mode of reproduction, length of larval life stages, habitat fidelity, and potential physical isolation, the team made the following conclusions for each of the three species:

Quillback rockfish: There are three distinct population segments of quillback rockfish in Washington waters. The first population segment in waters south of Admiralty Inlet and east of Deception Pass, the second population in northern Puget Sound south of the U.S.- Canadian border and east of a line from Point Wilson to Partridge Point, and the third population in coastal waters west of Cape Flattery. More local population differentiation may occur (P. Wemberger, Univ. of Puget Sound, personal communication).

Copper rockfish: The scientific team from National Marine Fisheries Service (Stout et al. 2001) concluded there were three distinct population segments for copper rockfish, similar to those for quillback rockfish. However, there was more uncertainty about the possible inclusion of copper rockfish found in southern British Columbia into the northern Puget Sound population segment.

Brown rockfish: The federal team concluded that brown rockfish south of Admiralty Inlet and east of Deception Pass comprise a distinct population with another poorly defined distinct population occurring in coastal waters. The team suggested that brown rockfish in the Puget Sound area may be a remnant population in "ecologically unique habitats" for this species (Stout et al. 2001).

Many of these stock characterizations resulted from two key studies on rockfish genetics. One study found that copper rockfish from south Puget Sound have lower genetic diversity, private alleles, and significant divergence from coastal rockfishes, indicating that they colonized Puget Sound after the last glaciation event and have had limited oceanographic exchange since (Bounaccorsi et al. 2002). Seeb (1998) similarly found that quillback rockfish from Puget Sound have alleles not present in nearby populations only 70 km away. In addition, she found that copper, quillback, and brown rockfishes are introgressing or hybridizing with each other in Puget Sound. Other studies using growth patterns have observed differences for quillback rockfish between northern and southern Puget Sound. Quillback rockfish live to greater ages and reach larger sizes in northern Puget Sound (see below). Bounaccorsi et al. (2005) examined coastal populations of brown rockfish, finding that brown rockfish from Puget Sound have a low microsatellite DNA diversity probably resulting from a post-glacial founder effect, introgression with copper and quillback rockfishes, and genetic isolation from coastal populations. They concluded that brown rockfish in Puget Sound form a distinct population segment.

With the advent of new genetic techniques, more information is becoming available about the population structure other rockfishes along the west Coast. Adult yellowtail rockfish have not been found in Puget Sound, though adult-sized fish have been collected in near Gulf Islands (WDFW, unpublished data). While no clear evidence exists, it is commonly believed that the yellowtail rockfish in Puget Sound are part of the ocean population and Puget Sound is primarily used as a nursery area for this species (Barker 1979, Love et al. 2002). In British Columbia, Yamanaka et al. (2000) did not detect genetic signs of distinct sub-populations of yelloweye rockfish but did find local differences in demographic factors. More recent data from Yamanaka, suggests some degree of population segmentation between Strait of Georgia and coastal populations (as cited in Wallace et al. 2006). Using otolith microchemistry, Gao et al. (2007) found evidence that yelloweye rockfish form a single coastal stock between Oregon and Washington, but that the differences in otolith chemistry with age is likely a function of changing habitats and prey bases with growth.

The population structure of black and other rockfishes has been reexamined with tagging studies, otolith microchemistry, and genetic techniques. Tagging results for black rockfish indicated some movement to coastal waters from Puget Sound (Mathews and Barker 1983; F. Wallace, WDFW, unpublished data). In contrast to yellowtail rockfish, adult black rockfish were commonly found throughout Puget Sound suggesting that populations may have a self-sustaining capacity. A more recent study of black rockfish populations along the west Coast found that microscopic elements in the otoliths and satellite DNA can be used to classify rockfish by their collection localities located 340 to 460 km apart (Miller et al. 2005) and that these same techniques showed that black rockfish larvae did not disperse between populations at these scales (Miller and Shanks 2004). Two populations of blue rockfish have been identified along the Pacific Coast, consisting of a northern population shared between Oregon and Washington and a Californian southern population (Cope 2004). Rosethorn rockfish also segregate into two populations along the coast, with a group from California to British Columbia with different genetic characteristics from those in Alaska (Rocha-Olivares and Vetter 1999). Shortspine thornyheads show genetic variation and structure, but clear geographic populations are not evident (Stepien et al. 2000). The population structure of Puget Sound rockfish was investigated by Sotka et al. (2005) who examined specimens from five localities throughout Puget Sound, finding no genetic differentiation among them indicating high gene flow.

In summary, the population structure of rockfish along the west coast is highly dependent upon the evolutionary and ecological patterns of each species. For benthic species such as copper, quillback, and brown rockfish, the observed strong differentiation between South Puget Sound and elsewhere is exceptional, but for pelagic species, the lack of differentiation is consistent with their tendencies of larger geographic movements or changes in habitat with life history. Some species such as yelloweye rockfish may show genetic differentiation between coastal and inland marine areas.

3.4.4 Behavior

Several aspects of behavior have already been discussed in regard to habitat associations, solitary or schooling tendencies, and feeding. Rockfishes do exhibit other significant behaviors in relation to mating, spawning, and habitat associations. Rockfishes may be territorial, transients, or non-territorial (Love et al. 2002). Some copper, quillback, and brown rockfishes in Puget Sound have year-round, small home ranges while living on natural, high-relief habitats, but other individuals are transients that move from artificial habitats to low relief nearshore habitats during the summer (Matthews 1990b,c). While Matthews (1990b) did not observe any evidence of agonistic behavior, WDFW divers have often observed copper rockfish displaying erect fins, back and forth movements in front of other individuals, and even biting other conspecifics that had approached their territories. These behaviors were most often observed during the fall mating period. WDFW divers have not witnessed these sedentary species in courtship displays, but have observed black and Puget Sound rockfishes displaying courtship behavior (W. Palsson, personal observation). A pair of black rockfish was observed in October with one fish erecting fins, shaking, and moving its body in front of and directly in contact with the side of another individual. This behavior was repeated several times over a period of several minutes. In another instance during August, a school of Puget Sound rockfish was observed with many individuals in groups of three or more. A larger fish, presumably a female, was courted by several males that circled the female and displayed erect fins and moved in front of and around the female. Each group slowly moved towards the surface, and males would then contact the females, ventrum to ventrum and shiver.

During the spring, female copper, quillback, and brown rockfish tend to be more reclusive by orienting in or near crevices. This may be the behavior of territorial females, however, transients and non-territorial individuals may move to specific habitats for parturition. Matthews (1990 a,b,c) noted that copper rockfish make use of low-relief vegetated habitats during the spring, and other surveys have occasionally encountered pregnant female copper rockfish in nearshore kelp beds during the spring. Other aspects of habitat associations and site fidelity are discussed in Section 4 **Habitat Relationships**.

Rockfish can exhibit avoidance and other behaviors to stimuli. Rockfish exhibit strong depth and geographic movements in response to hypoxic waters, apparently avoiding waters with dissolved oxygen concentrations of less than 2 mg/L (Palsson et al., 2008). Rockfish, however, may also avoid warm, stratified water greater than 11^{o} C, remaining below the thermocline but above the oxycline when hypoxic conditions are not too severe. Rockfishes exhibit startle and alarm responses when exposed to sounds from an air gun (Pearson et al. 1992). Rockfish exhibit alarm responses at 180 dB referenced at 1 uPa, and startle responses occur at 200 to 205 dB referenced at 1 uPa, and that more subtle behaviors are evident at 161 dB. Behaviors include forming tight schools, dropping to the bottom, becoming motionless, or rising to the surface. In response to feeding stimuli in a hatchery, brown rockfish show a behavioral syndrome of feeding and taking the risk of feeding in the presence of a predator (Lee and Bereijerkian 2007). However, individual feeding behavior is variable with showing a diverse behavior of feeding and taking predation risks over time.

3.4.5 Physiology

Few studies have examined the physiology of rockfishes in Puget Sound, and most studies have focused on their response to hypoxia, maturation, growth, or aspects of barotrauma. Aspects of maturation and growth are reviewed elsewhere.

In addition to their behavioral response to hypoxia, mass mortality events have killed approximately a quarter of all copper rockfish present at a marine reserve in Hood Canal. The mortality event occurred when dissolved oxygen concentrations were likely below 1 mg/L (Palsson et al. 2008), and smaller rockfish were affected more than larger rockfish.

Because of their anatomy and physiology, most rockfish captured from depths greater than 18 to 27 m are believed to die as a result of barotraumas. Rockfish have swim bladders into which gas can be secreted or absorbed from the blood, and they can gradually regulate the amount of air to attain neutral buoyancy. Rockfishes lack a direct connection between their swim bladder, which exacerbates the problem of depressurization when fish are rapidly brought up from depth. Because of the gradual physiological process of absorption and secretion of gasses in the swim bladder, the rapid rise of a fish captured from depth to the surface can cause the swim bladder to grossly expand leading to barotrauma and, sometimes, death. Parker et al. (2006) found that black rockfish take 48 hours to acclimate to a decrease of 4 atmospheres (30 m of sea water to the surface) and 168 hours to become neutrally buoyant when recompressed to the equivalent of the original depth. China rockfish are slower in their acclimation response requiring 250 hours to become neutrally buoyant.

The effects of rapid decompression also include over inflation and rupture of the swim bladder, inability to submerge when released, exposure to predation and solar radiation, abnormal or erratic swimming behavior, gas embolisms (in the blood vessel, gills, skin, and eyes), distortion of internal organs through the mouth, internal and external hemorrhaging, cloacal protrusions, and death (Kerr 2001, Meyer 2006, Parker et al. 2006, Rogers et al. 2008). Rogers et al. (2008) found that magnetic resonance images of a rockfish with extreme barotrauma had a ruptured swim bladder, everted stomach, and protruding eyes. The protruding eyes were due to gas in the interorbital space behind the eyes that displaced the eyes and stretched the optic nerve. Berry (2001) found bubble, clouded, or bulging eyes in a third to over half of quillback rockfish captured from depth and that eye damage is irreversible and permanent. From 2 to 3% of the quillback rockfish were bloated upon initial capture. For black, blue, and yelloweye rockfishes, increasing depth of capture causes progressively greater behavioral impairment with recompression (Hannah and Matteson 2007).

Signs of barotrauma at the surface are not necessarily good indicators of a species' ability to recover at depth, but extreme signs of barotrauma indicate an increased disability to recover after recompression and release. In field study, Hannah and Matteson (2007) found that behavioral impairment after capture, recompression, and release is variable among species but increases with depth for black, blue, and yelloweye rockfishes but not for canary rockfishes. Parker et al. (2006) found that all swim bladders of the tested black rockfish were ruptured when brought to the surface, but most survived when quickly recompressed back to depth. Meyer (2006) performed pressure experiments on copper rockfish captured from northern Puget Sound and examined similar aspects of physiology. He found signs of depressurization stress when fish are brought to the surface from 10, 20, and 30 meters simulated depths, and these signs include hyper-inflated swim bladder, hyper-inflated pericardial chambers, and gas bladder rupture. Injuries are more severe with increasing capture depths. Fish captured from a simulated 10 meters do not die and might be safely caught and released. Fish captured from greater depths have life threatening injuries. One of three captured from 20 meters died, but all fish captured from 30 meters died.

The mortality rates of rockfish brought to the surface can be very high (Parker et al. 2006). Jarvis and Lowe (2008) found that overall short-term survival is 68% for 17 species of rockfish from southern California, but that survival is species specific ranging from 36 to 82%. When released, fish are often unable to submerge, floating on the surface for many hours. As the fish floats helplessly, it is vulnerable to predation (McLeay et al. 2002). Four to five percent of quillback rockfish died when reeled to the surface (Berry 2001).

Focused studies reveal high mortality of fishes caught at depth and released, and studies have shown mixed results in ameliorating the effects of over-pressurization injuries. Techniques aimed at minimizing barotrauma have focused on reeling fishes up slowly, venting or deflation of the swim bladder, and rapid re-submergence.

The speed of reeling and the ascent rate does not lessen the effects of barotrauma on rockfishes. Black and blue rockfishes require several days to achieve neutral buoyancy at the surface (Parker et al. 2006), and their swim bladders rupture when retrieved from a depth of 30 m. Low-speed reeling does not improve the survival of copper rockfish (Meyer 2006), and holding experiments of quillback rockfish brought to the surface slowly and those brought to the surface rapidly do not differ in their survival following four to six weeks in captivity (Berry 2001). Berry (2001) did find a higher incidence of eye damage by faster reeling with power reels.

Venting (or “fizzing”) involves puncturing the swim bladder to remove pressure on the organs by allowing the captured gas to escape (Berry 2001, Kerr 2001, Meyer 2006, Wilde 2009). The puncture is usually performed with a hypodermic needle or other sharp object along the side of the fish. In a synthetic analysis of 17 studies among 22 species or species groups, Wilde (2009) found little support that venting improves the survival of fishes. Venting might be slightly beneficial to fish caught in shallow water but was increasingly detrimental to fish captured in deeper water. In an experimental study of copper rockfish, Meyer (2006) had success with artificial deflation with a hypodermic needle used to puncture the swim bladder through the skin and behind the posterior extent of the pectoral fin. He also found many fish reorient when returned to their capture depth and may survive if quickly re-pressurized especially for fish captured at depths greater than 30 m and showing signs of morbidity. Studies with quillback rockfish held in underwater cages following capture, found no difference in survival rates between vented fish and un-vented fish (Berry 2001). A study in California found similar results for blue rockfish (Gotshall 1964). Autopsies of vented and un-vented fish, four to six weeks following capture, indicate that vented fish have a lesser rate of swim bladder lesions than un-vented fish (Berry 2001). Following release, differences in behavior were noted between vented and un-vented rockfish (Gotshall 1964).

Reducing of the time at the surface or out of the water has more importance in increasing survival than venting rockfish (Berry 2001, Parker et al. 2006, Hannah and Matteson 2007, Jarvis and Howe 2008). Parker et al. (2006) tested the effect of re-submerging captured black rockfish immediately after capture and found that after 21 days, rapidly submerged rockfish only suffer 3.3% mortality. Hannah and Matteson (2007) found the success of recompression depends upon the species of rockfish, with blue rockfish showing the more behavioral impairment than black, canary, and yelloweye rockfishes. For copper rockfish, the increasing depth of capture results in greater external signs of barotrauma but artificial deflation and recompression offer potential benefits for minimizing the mortality of rockfishes (Meyer 2006). Berry (2001) found quillback rockfish rapidly recompressed to a depth of 15 m suffered less mortality and appeared more “normal” fish than fish slowly re-submerged to 15 m over the course of two days.

The mortality rate of rockfish caught in depths greater than 10 to 20 m is high, and educating anglers on proper venting or recompression techniques is difficult to achieve. In Wilde’s (2009) review of venting studies, fishes vented by anglers do not survive better than fishes vented by fisheries biologists. Consequently, the incidental catch and discard of rockfish during fishing continues to be a substantial threat to rockfish stocks in Puget Sound. There is some promise of rapid recompression limiting this mortality. ODFW has developed a simple system consisting of a weighted milk crate and line, into which anglers can immediately place an unhooked rockfish, place the crate upside down, and drop the rockfish back to depth (Theberge and Parker 2005). The practicality of using or requiring this treatment for rockfish bycatch in commercial or recreational fisheries has not been examined.

4 HABITAT RELATIONSHIPS

Whereas rockfishes may associate in assemblages and communities, individual species have complex habitat requirements that change with life history stage. The occurrence, distribution, and productivity of rockfishes are invariably linked with their evolved affinities for specific habitat characteristics. These characteristics include factors such as the type of seafloor, depth, oceanography, and life history stage. The relationships between these factors are still poorly defined for each rockfish species.

The lifecycle of rockfish in Puget Sound relies entirely on a complex sequence of natural processes, operating over many years, which enable rockfish populations to persist and thrive. These natural processes enable the small larvae released by the females into open-water (pelagic) habitats, to survive and grow to large reproductive-age adults living (usually) in association with rocky habitats. Rockfish change their habitats and food requirements many times as they grow, and this complex lifecycle is successful only if the marine ecosystem in Puget Sound has intact habitats and ample food resources required at each life-stage.

4.1 Oceanographic Features

The oceanography of Puget Sound is complex and influences the population characteristics of rockfishes. Rockfish larvae are pelagic and influenced by prevailing currents. Given the limited swimming capability of larval rockfish, the current patterns of Puget Sound may function to produce either genetic or recruitment isolation among the basins. The following description of Puget Sound is based largely on Stout et al. (2001) from the Biological Review Team examining the 1999 petition for rockfishes as an endangered or threatened species. Puget Sound is a fjord-like estuary located in northwest Washington State and covers an area of about 2,330 km^2, including 3,700 km of coastline. It can be divided into 7 or more sub basins (PSAT 2002) based upon the geomorphology and oceanography of each area, and these sub basins are approximated by the Groundfish Management Regions (Figure 2.1). The average depth of greater Puget Sound is 62.5 m at mean low tide, and the average surface water temperature is 12.8^oC in summer and 7.2^oC in winter (Staubitz et al. 1997). Tides, gravitational forces, and freshwater inflows drive estuarine circulation in greater Puget Sound. For example, the average daily difference between high and low tide varies from 2.4 m at the northern end of greater Puget Sound to 4.6 m at its southern end. Tidal oscillations substantially reduce the flushing rate of nutrients and contaminants.

4.1.1 North Sound

North Sound includes the Strait of Georgia, San Juan Islands, and Strait of Juan de Fuca sub-basins (Figure 2.1) and is a broad region bounded to the north by the U.S.-Canadian border, to the west by a line due north of the Sekiu River, to the south by the Olympic Peninsula, and to the east by a line between Point Wilson (near Port Townsend) and Partridge Point on Whidbey Island and the mainland between Anacortes and Blaine, Washington. North Puget Sound is bordered by rural areas with a few localized industrial developments (PSWQA 1988). About 71% of the area draining into North Puget Sound is forested, 6% is urbanized, and 15% is used for agriculture. Among the five greater Puget Sound basins, this basin is used most heavily for agriculture. The main human population centers in North Puget Sound include Port Angeles (19,200), Port Townsend (7,000), Anacortes (11,500), and Bellingham (58,300) (1996 population census, Rand McNally 1998).

Bathymetry and geomorphology —About 17% of the nutrients (in the form of inorganic nitrogen) entering North Sound originates from rivers carrying runoff from areas of agricultural and forest production (Embrey and Inkpen 1998). The Washington Department of Natural Resources (WDNR 1998) estimated that 21% of the shoreline in this area has been modified by human activities.

The Washington portion of the Strait of Georgia consists of unconsolidated sediments with depths to over 274 m. To the south, the basin has banks of coarse sediments that eventually give rise to the rocky shoreline of the San Juans. Several large, shallow, and sandy bays and channels border the Strait of Georgia to the east including Semiamhoo, Birch, Lummi, and Bellingham Bays.

The San Juan Islands consist of hundreds of islands, underwater banks and pinnacles and deep channels that contain exposed bedrock, boulder fields, and coarse sediments. Haro Strait is deep, ranging to 244 m, but contains Middle Bank that consists of a series of pinnacles and valleys.

The Strait of Juan de Fuca is 160 km in length, and 22 km in width at its western end and over 40 km in width at its eastern end (Thomson 1994). It can be subdivided into an east and western region at Port Angeles because a series of offshore banks create a sill along the width of the strait. Water depths extend to over 213 m in the western Strait and to 128 m in the eastern Strait.

Oceanography - The Fraser River dramatically structures the spring and summer current patterns with strong runoffs that primarily exit to the south. The Fraser River plume creates a productive pelagic zone with high nutrients and plankton production (Parsons et al. 1970). The oceanography of the San Juan Islands is heavily influenced by the Fraser River during the spring and summer runoff that primarily passes through Haro Strait and San Juan Channel. The Strait of Juan de Fuca is a weakly stratified, positive estuary with strong tidal currents (Thomson 1994). The western end of the Strait is strongly influenced by ocean processes, whereas the eastern end is influenced by intense tidal action occurring through and near the entrances to numerous narrow passages which results in vigorous vertical mixing (Ebbesmeyer et al. 1984). The Fraser River Plume exists through the northern half and oceanic or saltier water dominates the southern half (Thomson 1994, Newton et al. 2003). During periods of low runoff, the water properties become more saline and consistent between the northern and southern portions of the Strait. A retention area exists in the eastern Strait of Juan de Fuca while surface waters in the western strait are flushed to the ocean (Sauers et al. 2004). On average, freshwater runoff makes up about 7% of the water by volume in the Strait and is derived primarily from the Fraser River. Generally, the circulation in the Strait consists of seaward surface flow of diluted seawater (<30.0‰) in the upper layer and an inshore flow of saline oceanic water (>33.0‰) at depth (Thomson 1994, Collias et al. 1974). Exceptions include an easterly flow of surface waters near the shoreline between Port Angeles and Dungeness Spit, landward flows of surface waters in many of the embayments and passages, and flows of surface water southward toward the Main Basin near Admiralty Inlet (PSWQA 1987).

4.1.2 South Sound

South Sound consists of the Central Puget Sound, Whidbey, Hood Canal, and Southern Puget Sound sub-basins (Figure 2.1). It is bounded at the north end of Admiralty Inlet and demarked by a line between Point Wilson at Port Townsend and Partridge Point on Whidbey Island. South Sound is also bounded to waters of the Whidbey Basin to the west if Deception Pass.

4.1.2.1 Central Puget Sound

The areas and waters of Central Puget Sound or Main Basin include the major urban and industrial areas of the South Sound area: Seattle, Tacoma, and Bremerton. Human population sizes for these cities are about 522,500, 182,900, and 44,000, respectively (1996 census, Rand McNally 1998). Approximately 70% of the drainage area in this basin is forested, 23% is urbanized, and 4% is used for agriculture (Staubitz et al. 1997). About 80% of the total amount of waste discharged from point-sources into greater Puget Sound comes from urban and industrial sources in this region (PSWQA 1988). Moreover, about 16% of the waste entering greater Puget Sound enters this basin through its major river systems in the form of inorganic nitrogen (Embrey and Inkpen 1998). WDNR (1998) estimates that 52% of the shoreline in this area has been modified by human activities.

Bathymetry and geomorphology — Central Puget Sound extends from Port Townsend on the northern entrance to Admiralty Inlet, south to the entrances to Tacoma Narrows, Hood Canal and the Whidbey Basins that join the central basin. Many rivers enter into Central Sound creating a two-layered estuarine circulation pattern that varies seasonally. Several large islands breakup the basin and create many narrow channels. Admiralty Inlet can be considered a separate basin and consists of a shallow sill that substantially mixes the water exiting or entering the main basin. To the south, the fjord consists of deep basins to depths of 274 m bordered by steep walls and dominated by unconsolidated sediments ranging from mud in deep basins to cobble in narrow passages. The sills at Admiralty Inlet cause a great turbulence in waters transiting to and from the main basin. The turbulence results in extreme mixing at this sill and much of the surface water exiting the Sound is mixed with the deeper more saline water entering. While sills or channel restrictions cause a degree of oceanographic separation at each of the basin entrances, the combination of refluxing and the sill at Admiralty Inlet provides the strongest oceanographic division between the adjacent basins.

Oceanography - The water traveling southward in the Main Basin at depth is upwelled at the north end of the Tacoma Narrows, the sill dividing the Main Basin from the Southern Basin of the Sound. Refluxing recirculates some Southern Basin water at the Tacoma Narrows back south from this point. In addition to the estuarine circulation pattern and the major refluxing locations, other oceanographic features offer insights that may be relevant to rockfish recruitment processes. Puget Sound circulation is subject to the Coriolis force, which tends to move waters to the east in this latitude. In the Main Basin, surface currents are northward on the east shore and the deep water is drawn southward along the Kitsap shoreline on the west shore (Nairn et al. 2004). In part related to Coriolis force, the eastern shoreline of the Main Basin has a series of tidal gyres (Ebbesmeyer 1999). Water retention times are only 1 month (Table 4.1, Ebbesmeyer et al. 1984).

Major circulation patterns in the Main Basin are greatly influenced by decadal climate regimes (Ebbesmeyer et al. 1998). During cool periods with strong oceanic upwelling and heavy precipitation, the strongest oceanic currents entering from the Strait of Juan de Fuca flow near mid-depth when the basin is cooler than 9.7^{o}C. However, the strongest oceanic currents move toward the bottom of the basin, during warmer, dryer periods when waters are warmer than 9.7^{o}C. The unique structure and current patterns of the basin, apparently acts to entrain water and organisms within it. Surface currents rarely intrude into Admiralty Inlet based upon the results of surface drift card experiments (Klinger and Ebbesmeyer 2002), and the genetic isolation exhibited by several species of rockfish indicates that larval exchange is not frequent between North and South Sound.

Table 4.1. Temporal Scale for Water Retention of South Sound's Basins (From Ebbesmeyer et al. 1984).

Basin	Temporal Scale (months)
Central Puget Sound Basin	1.0
Hood Canal	9.3
Whidbey Basin	5.4
Southern Puget Sound	1.9

4.1.2.2 Whidbey Basin

The Whidbey Basin of South Sound is connected to Central Puget Sound at Possession Sound. Most of the Whidbey Basin is surrounded by rural areas with low human population densities. About 85% of the drainage area of this Basin is forested, 3% is urbanized, and 4% is in agricultural production. The primary urban and industrial center is Everett, with a population of 78,000.

Bathymetry and geomorphology - The Whidbey Basin includes the marine waters east of Whidbey Island and is delimited to the south by a line between Possession Point on Whidbey Island and Meadowdale, west of Everett. The northern boundary is Deception Pass at the northern tip of Whidbey Island. The Skagit River (the largest single source of freshwater in greater Puget Sound) enters the northeastern corner of the Basin, forming a delta and the shallow waters (<20 m) of Skagit Bay. Saratoga Passage, just south of Skagit Bay, separates Whidbey Island from Camano Island. This passage is 100 to 200 m deep, with the deepest section (200 m) located near Camano Head (Burns 1985). Port Susan is located east of Camano Island and receives freshwater from the Stillaguamish River at the northern end and from the Snohomish River (the second largest of greater Puget Sound's rivers) at southeastern corner. Port Susan also contains a deep area (120 m) near Camano Head. The deepest section of the basin is located near its southern boundary in Possession Sound (220 m). The WDNR (1998) estimated that 36% of the shoreline in this area has been modified by human activities.

Oceanography — Although only a few water circulation studies have been performed in the Whidbey Basin, some general observations are possible. Current profiles in the northern portion of this basin are typical of a close-ended fjord. The surface waters from the Skagit River diverge, with the surface water flowing south and the deep water flowing northward toward Deception Pass. Approximately 60% of the water from the Skagit River flows through Deception Pass, and this water flows directly into the Strait of Juan de Fuca (Ebbesmeyer et al. 1984). Current speeds through Deception Pass are among the highest in greater Puget Sound; a westward surface current speed of 37.37 cm/sec, and an eastward bottom current of 5.92 cm/sec were reported by PSWQA (1987). Currents through Saratoga Passage tend to move at moderate rates in a southerly direction. Due to the influences of the Stillaguamish and Snohomish River systems, surface currents in Port Susan and Port Gardner tend to flow toward the Main Basin, although there is some evidence of a recirculating pattern in Port Susan (PSWQA 1987). Water is retained in the Whidbey Basin for 5.4 months (Table 4.1, Ebbesmeyer et al. 1984).

4.1.2.3 Hood Canal

The Hood Canal Basin is connected to Central Puget Sound on the southern end of Admiralty Inlet. Hood Canal is one of the least developed areas in greater Puget Sound and lacks large centers of urban and industrial development. About 90% of the drainage area in this basin is forested (the highest percentage of forested areas of the five greater Puget Sound basins), 2% is urbanized, and 1% is in agricultural production (Staubitz et al. 1997). However, the shoreline is well developed with summer homes and year-around residences (PSWQA 1988).

Bathymetry and geomorphology — Hood Canal branches off the northwest part of the Main Basin near Admiralty Inlet and is the smallest of the greater Puget Sound basins, being 90 km long and 1-2 km wide. Like many of the other basins, it is partially isolated by a sill (50 m deep) near its entrance that limits the transport of deep marine waters in and out of Hood Canal (Burns 1985). The major components of this basin consist of the Hood Canal entrance, Dabob Bay, the central region, The Great Bend at the southern end, and Lynch Cove. Dabob Bay and the central region are the deepest sub-basins (200 and 180 m, respectively), whereas other areas are relatively shallow, <40 m for The Great Bend and 50-100 m at the Hood Canal entrance (Collias et al. 1974). The WDNR (1998) estimated that 34% of the shoreline in this area has been modified by human activities.

Oceanography — Aside from tidal currents, currents in Hood Canal are slow, perhaps because the basin is a closed-ended fjord without large-volume rivers. The strongest currents tend to occur near the Hood Canal entrance and generally involve a northerly flow of surface waters into Admiralty Inlet (Ebbesmeyer 1984). Water is retained for nine months in Hood Canal (Table 4.1, Ebbesmeyer et al. 1984), the longest of any Puget Sound basin. The water column may be highly stratified with a fresh layer on the top and salt layer below. Hood Canal, especially the southern portion, is susceptible to poor water quality during the summer and early fall (Newton et al. 1995, Warner et al. 2002). Mean surface temperature can range to 12.1^{o}C and dissolved oxygen values can be less than 2 mg/L in the southern areas.

4.1.2.4 Southern Puget Sound

The Southern Puget Sound basin connects to the southern end of Central Puget Sound or Main Basin. About 85% of the drainage for Southern Puget Sound is forested, 4% is urbanized, and 7% is in agricultural production. The major urban areas around the South Sound Basin are found in the western portions of Pierce County. These communities include west Tacoma, University Place, Steilacoom, and Fircrest, with a combined population of about 100,000. Other urban centers in the South Sound Basin include Olympia with a population of 41,000 and Shelton with a population of 7,200 (Puget Sound Regional Council 1998).

Bathymetry and geomorphology — The Southern Basin includes all waterways south of Tacoma Narrows. This basin is characterized by numerous islands and shallow (generally <20 m) inlets with extensive shoreline areas. The mean depth of this basin is 37 m, and the deepest area (190 m) is located east of McNeil Island, just south of the sill (45 m) at Tacoma Narrows (Burns 1985). The largest river entering the basin is the Nisqually River, which enters just south of Anderson Island. The WDNR (1998) estimated that 34% of the shoreline in this area has been modified by human activities.

Oceanography — Currents in the Southern Basin are strongly influenced by tides, due largely to the shallowness of this area. Currents tend to be strongest in narrow channels (Burns 1985). In general, surface waters flow north and deeper waters flow south. Among the five most western inlets, Case, Budd, Eld, Totten, and Hammersley, the circulation patterns of Budd and Eld inlets are largely independent of those in Totten and Hammersley inlets due largely to the shallowness of Squaxin Passage (Ebbesmeyer et al. 1998). These current patterns are characterized by flows of high salinity waters from Budd and Eld inlets into the south end of Case Inlet, and from Totten and Hammersley inlets into the north end of Case Inlet. Flows of freshwater into the north and sound ends of Case Inlet originate from surface water runoff and the Nisqually River, respectively. Most waters may be moderately stratified during the summer with surface temperatures reaching 14-15^{o}C in summer. The temperatures of subsurface waters generally range four to five degrees cooler than the surface (Washington Department of Ecology WDOE 1999). Waters is retained in the Southern Basin for 1.9 months (Table 4.1, Ebbesmeyer et al. 1984).

4.1.3 Other Research

Several researchers have focused on oceanography as a tool in developing information about fish recruitment, and the outcomes may have significance for rockfish populations in Puget Sound. Sauers et al. (2004) released over 40,000 drift cards in the area of the San Juan Islands. Klinger and Kido (2004) followed this initial release with placement of larval collection plates at the various sites. High concentrations of drift card returns did not accurately predict where larval invertebrates are likely to settle, and therefore, oceanographic circulation, in this case, could not predict where larvae might settle. However, strong recurrent current patterns might be useful in hypothesizing where larvae would not go.

Parker et al. (2003) found significant differences in the genetics of *Protothaca staminea* (native hardshell clams) in the Southern Basin when compared to the Main Basin and Hood Canal. The Tacoma Narrows sill, similar to the sill at Admiralty Inlet, was hypothesized as a major contributor to potential genetic isolation along with the long residence time of water in the Southern Basin. Other oceanographic features may also have an effect on larval retention. Gyres have been linked to local genetic isolation in barnacles on the coast and could function to retain rockfish larvae in certain areas of Puget Sound. Gyres as observed by Ebbesmeyer (1999) on the east side of the Main Basin may act to concentrate rockfish larvae from the long-term marine reserve at Edmonds along the eastern shoreline (Palsson 2002).

The strongest isolation is likely to occur between North Puget Sound and the Main Basin (Central Puget Sound) due to the sills at Admiralty Inlet. This is reflected in the genetic studies of rockfish in Puget Sound to date with copper rockfish showing genetic differences between fish found north and south of Admiralty Inlet. Some degree of interference with larval transport is likely at all the major sills. From the standpoint of management, Puget Sound should be considered as at least two separate basins (North and South). In addition, however, given the potential of additional isolating factors such as gyres and smaller sills, recruitment may be very dependent on local adults in many areas of the Sound.

4.2 Habitat Pathways

The life history pathways described previously are highly correlated with the changes in habitat associations with each life history stage. These habitat pathways likely differ among species, but some information is available for a number of rockfishes found in Puget Sound.

4.2.1 Larval and Juvenile Stages

Larval rockfish live in the open-water environment in coastal, shelf and slope waters along the west coast of North America and appear in the greatest numbers during the spring months (Moser and Boehlert 1991). As the summer progresses, rockfish larvae become more restricted to coastal waters and become patchily distributed and fewer in number during the fall. Some rockfish larvae may inhabit the surface layer (Moser and Boehlert 1991). Larvae in Puget Sound occupy the upper portions of the water column at or near the surface (Waldron 1972, Garrison and Miller 1982, Busby et al. 2000, Weis 2004). In San

Juan Channel, larval distributions were heterogeneous, both in the water column above a depth of 100 m and along and offshore (Weis 2004).

Juvenile rockfish "settling-out" or recruiting to nearshore habitats in Puget Sound move along specific "recruitment pathways" that include many types and a succession of habitats (Buckley 1997, Love et al. 1991). The recruitment pathways begin with the pelagic juvenile life-stages selecting specific benthic habitats as the first phase of substrate-associated recruitment, and these recruitment habitats may include nearshore vegetated habitats such as eelgrass, floating or understory kelp, or deep habitats consisting of soft and low relief rocky substrates (Buckley 1997, Love et al. 1991). For common species in Puget Sound, settling young may occasionally associate with eelgrass (Matthews 1991a) but at least for copper rockfish, first recruitment habitats are primarily kelp, algae and rocks (Buckley 1997, Hayden Spear 2006, LeClair et al. 2007). Settling rockfish might first associate with canopy kelp, shift to understory kelp or algae, and then gradually move deeper to cobble fields or small rock as they grow to first year and sub-adult fish (Buckley 1997). Early in the recruitment process, each successive habitat is occupied for short periods, varying from days to weeks, or one to two months. These recruitment pathways end at specific nursery habitats that are benthic, usually composed of rock substrate, and have abundant food resources. Juvenile rockfish usually occupy nursery habitats for several months. A 'bottleneck' or break at any step in the recruitment pathway, due to habitat degradation or habitat loss, can severely reduce the number of juvenile rockfish surviving to the second year-of-life (Buckley 1997).

Recruitment pathways for juvenile copper rockfish, quillback rockfish, and brown rockfish are primarily associations with complex biogenic (living) substrates composed primarily of kelp and other macrophytes (seaweeds) and seagrass (Haldorson and Richards 1987; Matthews 1990a; West et al. 1994, 1995; Doty et al. 1995; Buckley 1997, Hayden-Spear 2006, Hayden-Spear and Gunderson 2007). Juvenile copper rockfish first recruit from the pelagic habitat directly to attached macrophytes in very shallow water. The juveniles move in a short time (usually on the order of days) to benthic macrophyte habitats in deeper water, where they are may live together with juvenile quillback and brown rockfish. The first post-pelagic recruitment of juvenile quillback and brown rockfish may include benthic habitats in deep water. The composition of these habitats is unknown, but early in this first recruitment phase juvenile quillback and brown rockfish are associated with detached benthic macrophytes that have drifted offshore (Buckley 1997). Juvenile quillback and brown rockfish subsequently migrate to nearshore benthic vegetated habitats at shallower depths. In the most intensive study of young-of-the-year (YOY) rockfish to date in the San Juan Islands, Hayden-Spear (2006) and Hayden-Spear and Gunderson (2007) found that young rockfish, primarily copper and quillback rockfish, are exclusively associated with habitats with high densities of understory kelp and other seaweeds in shallow waters between 1.5 m to 4.5 m in depth during the fall. YOY rockfish were exclusively associated with kelp habitats despite the occurrence of kelp at only half of the six study sites examined. However, YOY rockfish were patchily distributed among the kelp habitats having been found in only 17% or less of the available kelp habitat between 1.5 m and 4.5 m in depth. During the summer 2006, a remarkable recruitment event was observed in Central and Southern Puget Sound where thousands of YOY rockfish were observed beginning in June in nearshore habitats (LeClair et al. 2007). They associated with floating and understory kelps and eelgrass and were present from south of Admiralty Inlet to at least Squaxin Island in southern Puget Sound. This event did not include southern Hood Canal. As the summer and fall progressed growth and color differentiation revealed that these YOY were a mix of copper and quillback rockfishes. They also transitioned from nearshore vegetated zones to adult rocky habitats, first associating with drift or anchored vegetation and then with rocky crevices.

These nearshore biogenic habitats function as refuge from predation and as nursery areas, and they provide connecting pathways for movement to adjacent habitats, usually rocky reef habitat at deeper depths, used by later life-stages. In isolated kelp beds and other nearshore habitats where there is no direct connection to subsequent recruitment habitats, juvenile rockfish move to these nearshore habitats with the seasonally detached, drifting benthic macrophytes (Buckley 1997). Presumably the movements of this benthic macrophyte habitat transport the juvenile rockfish offshore to rocky habitats. These marine vegetation habitats are critical to the survival and development of juvenile copper, quillback and brown rockfish in Puget Sound.

The recruitment pathways and larval and juvenile habitat associations of other rockfish species occurring in Puget Sound are poorly understood. Juvenile Puget Sound rockfish first recruit from the pelagic habitat to rocky habitats, particularly at the bases of current-swept walls and boulders during the winter. The juveniles use crevices in the rock substrates as refuge, and feed in the surrounding area. A small number of juvenile yellowtail rockfish are occasionally found on rocky habitats in Puget Sound, but there is no information on the substrate associations or habitat functions. For juvenile black rockfish it is likely that the first substrate association in benthic habitats is eelgrass, kelp and nearshore macrophytes as in other regions, but this has not been documented in Puget Sound. Several juvenile black rockfish have been seen in association with benthic macrophytes, but only as larger-sized juveniles have been observed and not as recent recruits. In summer 2006, a strong recruitment of YOY rockfish occurred in the Strait of Juan de Fuca but these YOY were different from those observed in central Puget Sound. Swarms of YOY rockfish were observed in nearshore floating and understory kelps but most of these animals possessed a black spot at the rear their dorsal fins indicating they were possibly black, blue, yellowtail, or canary rockfishes (LeClair et al 2007).

Mats of aquatic vegetation that coalesce and drift in surface-water currents are also important habitats for juvenile rockfish. Juvenile rockfish associate with these mats that are composed of detached drifting kelp and other macrophytes and seagrass that form both loose aggregations and complex, physically stable mats (Buckley et al. 1995, Buckley 1997). The formation of drifting habitat relies on production of abundant macrophytes and seagrass in nearshore areas, and the detachment of this vegetation by storms and biological processes. It is likely that some shoreline locations in Puget Sound have an increased potential to produce drift vegetation due to storm exposure and the composition of the invertebrate communities that dislodge the kelp and other macrophytes by grazing. These principal shoreline sources of vegetation for the drifting habitats are not known, and therefore may be inadequately protected from shoreline development impacts.

Splitnose rockfish are the dominant species in these drifting habitats in Puget Sound (Buckley 1997). The first substrate associated recruitment of pelagic juvenile splitnose rockfish is often to the loose aggregations of macrophytes and seagrass in tidal current areas. After short periods of growth (likely over days), the juveniles migrate, or are transported by tidal movements of the loose vegetation, to the more physically stable habitats created by mats of entangled kelp that entrain loose macrophytes and seagrass. These drifting habitats aggregate at tidal current fronts that are also areas with abundant plankton food resources, and the habitats function as nursery areas and as refuge from predation. Juvenile splitnose rockfish remain in drifting habitats for several months and then migrate (apparently directly) to rocky habitats at deep depths. The drifting habitats appear to be a vital or obligate recruitment habitat pathway for the juveniles to survive and transition from the pelagic life-stage to the benthic life-stage.

Tiger rockfish juveniles are infrequently found in the drifting habitats in Puget Sound (Buckley 1997) and rockfish found in drifting mats may include some juvenile redbanded rockfish. The recently recruited juveniles of these two species are similar in appearance and have been confused in drifting habitats in other regions. A few black rockfish juveniles have also been found in drifting habitats in Puget Sound. The small number of juvenile tiger, redbanded and black rockfish found in drifting habitats indicates that either this is not a major recruitment habitat pathway for these species in Puget Sound, or the recruitment surveys were conducted during low recruitment events.

The habitats for juvenile rockfishes are not limited to surface or nearshore vegetated habitats. In summer 2002, WDFW conducted a submersible survey of deep rocky habitats at depths of 100 to 225 m off the Washington continental shelf. Juvenile rockfish, though unidentifiable to species, comprised the majority of fish abundance observed throughout the survey (Wang 2005). Juvenile rockfish density was greatest in transects characterized by mixed sand, pebble, and boulder substrates and heterogeneous patches of different habitat types. Similar to stocks surveyed on Heceta Bank in Oregon (Pearcy et al. 1989), juvenile rockfish were often seen in schools hovering over the bottom, and associated with complex contiguous or stacked boulder piles. Association with invertebrate macrofauna may also play a role in juvenile rockfish habitat use. Richards (1986) noted that small rockfish on the coast of British Columbia used sponge 'gardens' as nursery habitat. Observations from the survey off the Washington coast suggest that juvenile rockfish in the area also respond to relief and structure provided by invertebrate groups such as sponges and crinoids, but crinoids are not typically found in Puget Sound.

4.2.2 Adult Stages

Copper, quillback, and brown rockfish, the three most commonly harvested rockfishes, are highly associated with rocky habitats in both North and South Sound (Patten 1973, Moulton 1977, Barker 1979, Matthews 1987, Matthews 1990 a,b,c; Pacunski and Palsson 2002, Tilden 2005, Valz 2007, Lopez 2007). Matthews (1990a) found that the subadult and adult stages of copper, quillback, and brown rockfish are most associated with high relief natural rocky and artificial habitats greater than 2 m in height in central Puget Sound compared to low relief rocky and sand-eelgrass habitats. In both North and South Sound, copper and quillback rockfish densities correlate directly with increasing vertical relief and increasing substrate complexity in terms of the number of crevices (Pacunski and Palsson 2002). In particular, these rockfishes show little association with scoured bedrock or low-relief rock ridges compared a high affinity to boulder fields and walls with high complexity. Lopez (2007) conducted transects with a remotely operated vehicle and confirmed that rockfish are associated with complex and rocky substrates. The distribution of rockfish can be predicted by mapping rocky substrates and by mapping habitat complexity (Tilden 2005). These sedentary species also occur to some extent on unconsolidated habitats such as cobble fields supporting understory and canopy vegetation and occasionally eelgrass (Matthews 1990a,b) but the use of these habitats appears to be more seasonal with fish moving in during the spring and summer months. Seasonality in copper rockfish distributions was also observed in the San Juan Islands by Moulton (1977) and by Valz (2007). Moulton found higher densities of copper rockfish in the 0 to 5 m nearshore depth zone between May and September. At Allan Island, one of Moulton's sites, Valz (2007) found the highest densities of copper rockfish in shallow transects (between 9 and 14 m) during the fall with near zero values during the remainder of the year. He found, higher densities along the deep transect (14 to 20 m) during the fall and summer and the least densities during the spring. These results were not consistent, however, with other eastern San Juan study sites. He found minimal densities along deep transects during the winter with progressively greater densities of copper rockfish during the spring, summer and fall. Along shallow transects, densities are the least during the winter then increase during the fall, spring, and summer.

The habitat associations for copper and quillback rockfish found in Puget Sound are similar to those in the nearby Strait of Georgia and elsewhere. In the Strait of Georgia, Richards (1986) and Murie et al. (1994) found that quillback rockfish densities are higher in complex habitats or walls compared to habitats consisting of coarse and fine sediments where rockfish occurred at low densities. Richards (1987) compared copper and quillback rockfish habitat associations in the Strait of Georgia finding that both species occur in the highest densities in high relief rocky habitats but quillback rockfishes are more specifically distributed on broken rock and habitats with bladed kelps. Depth is also an important factor for habitat associations with copper and quillback rockfish. Richards (1986) found that quillback rockfish occur between 21 m and 140 m, and only larger fish occur at deeper depths. Later, Richards (1987) found that copper rockfish occur in higher densities in waters 6 to 12 m in depth than at depths between 12 to 18

m. She found that quillback rockfishes occur in higher densities in the deeper zone than copper rockfish. Murie et al. (1994) found copper rockfish occur between 21 and 65 m as observed during submersible surveys and are slightly shallower than the observed 21 to 115 m depth range of quillback rockfish. They also found copper rockfish are most associated with complex habitats. Johnson et al. (2003) used a remotely-operated-vehicle and examined rockfish habitat relationships in southeastern Alaska. Similar to previous studies, copper and quillback rockfishes are most often found over complex boulder or vertical bedrock habitats, and copper rockfish occur in shallow waters with a mean depth of less than 30 m.

Copper, quillback, and brown rockfish have a high affinity for natural rocky habitats with high relief (Matthews 1990b,c). Most exhibit small home ranges of approximate 30 m^2 and exhibit high site fidelity. Rockfish were tagged and released at places different from their capture location that ranged from 50 m to 8 km away. More than 75% of these rockfishes returned to their original capture location, even the individual moved the farthest away. Mathews and Barker (1983) tagged 11 and 12 copper and quillback rockfish, respectively, at a rocky habitat in the San Juan Islands and recovered all but one quillback at the site of release indicating that these sedentary species also show restricted home ranges in North Sound. Eisenhardt (2003) examined home range size at two marine reserves Haro Strait by implanting 16 acoustic tags in copper rockfish. Most rockfish remained within the marine reserve boundaries and near their original capture location. However, one moved 500 m away.

Less is known about the specific habitat associations and distributions of other adult rockfish species in Puget Sound, but conclusions can be drawn from survey information and the results from studies in adjacent waters. Yelloweye and greenstriped rockfishes occur at depths beginning at 40 m and range to as deep as 140 m (Richards 1986, Murie et al. 1994). Yelloweye rockfish are associated with wall and complex habitats compared to greenstriped rockfish that are most associated with fine and coarse sediments. Tiger rockfish are also associated with complex and wall habitats (Murie et al. 1994) as were yellowtail rockfish. Black and yellowtail rockfishes have been found in rocky habitats in the San Juan Islands (Moulton 1977) and are found among shallow kelp beds in the Strait of Juan de Fuca. Puget Sound rockfish are also found in strong currents, steep slopes, and caves and crevices formed by cobbles, boulders, and cracks (Moulton 1975). They are also captured on bottom trawl surveys and often co-occur with juvenile redstripe rockfish. Adult splitnose rockfish are occasionally encountered in the deep basins of Puget Sound and especially in Dabob Bay of Hood Canal.

4.3 Habitat Distribution

The knowledge of the life history and habitat requirements of rockfishes provides the basis to define habitat types most of which are essential to the completion of life cycles and the overall health of rockfish stocks. Surveys conducted by WDFW and others also provide information to identify the general distribution of these habitats (Figure 4.1). Key surveys include quantitative video surveys targeting shallow-water rocky habitats less than 37 m in depth (Bradbury et al. 1998, Pacunski and Palsson 2002) and bottom trawl surveys targeting soft-bottom habitats greater than 9 m in depth (Quinnell and Schmitt 1991, Palsson et al. 2002, 2003).

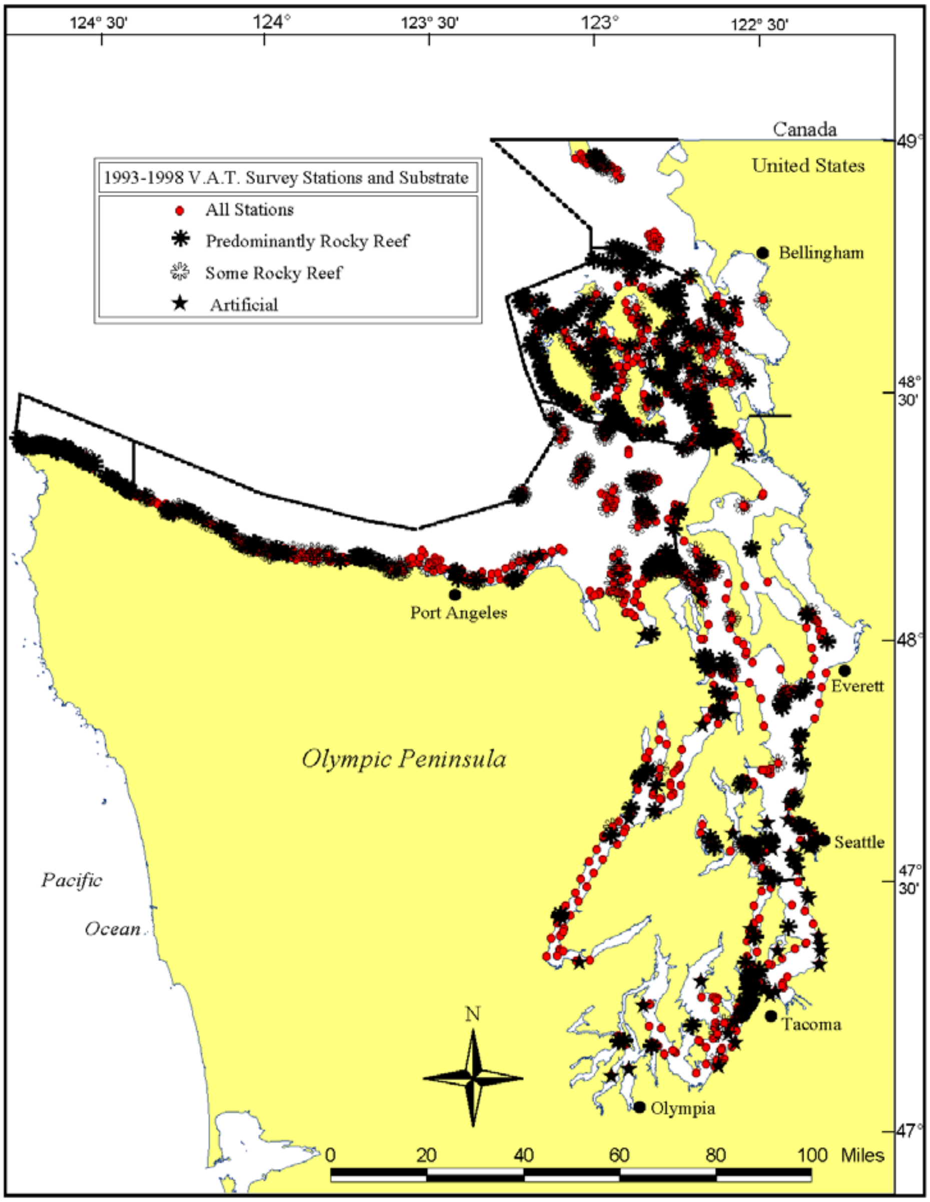


Figure 4.1. The distribution of nearshore rocky habitats in Puget Sound.

4.3.1 Nearshore Vegetated and Rocky Habitats

The primary habitat for nearshore rockfish is composed of pebble, cobble, boulder, bedrock, and hardpan substrates that are continuous or isolated and that form crevices or other structures to protect rockfish from currents and predators (Matthews 1990a,b,c, Buckley 1997, Pacunski and Palsson 2002). In shallow waters of less than 18 m, rocky habitats are typically covered with macroalgae including canopy and understory kelps, bladed and filamentous red and brown algae, and in high energy environments, surfgrasses (Mumford 2007). These formations are critical and essential to the health of juvenile and adult rockfishes as described above. Demersal species that use these habitats include copper, quillback, brown, and tiger rockfishes. Pelagic assemblage species also make use of these habitats, especially where there are steep drop offs. These species include black, yellowtail, and Puget Sound rockfishes.

Many of the nearshore rocky habitats have been mapped and surveyed in Puget Sound, and the surveys provide a basis to describe the distribution of common rockfishes. Rocky habitats are most common in the San Juan Islands (Figure 4.1) compared to the Strait of Georgia where rocky habitats are limited to the Point Roberts reef, several pinnacles near Lummi Island, or along the margins of some of the larger islands (Pacunski and Palsson 1998). The Strait of Juan de Fuca contains the second highest amount of rocky habitat among the sub-basins of Puget Sound, where rock and kelp occur in the extreme nearshore from Freshwater Bay to Sekiu, along the shore from Pillar to Slip Points, and at several rocky outcroppings or boulder fields on the tops of the banks or near Point Wilson and the entrance to Deception Pass. South of Port Townsend, rocky habitats, including hardpan ridges, are uncommon and typically occur in isolated areas associated with receding bluffs, fault zones, or isolated outcroppings. In the Central Sound Basin, most of the rocky habitats are found in Admiralty Inlet, along the southern border of Bainbridge Island at Port Blakely, Rich Passage, Blakely Rocks, Sunrise Beach, and Point Defiance, In Hood Canal, rocky habitat is limited to isolated rocky outcrops including Pulali Point, Seal Rock, the Brinnon Pinnacle, Black Point, Triton Head, Waketickeh Creek, Jorstad Creek, Dewatto, Octopus Hole, and Sund Rocks. In southern Puget Sound there are few nearshore rocky habitats consisting of boulders and hardpan ridges especially along the east side of Tacoma Narrows, at Z's Reef located along northeast Fox Island, east Fox Island, Day Island, Toliva Shoal, and Steamboat Island.

4.3.2 Deep-Benthic Habitats

Deep-benthic habitats for rockfish primarily include boulder, bedrock, and hardpan outcroppings in waters deeper than 37 m. These have not been well mapped but new bathymetric and geological surveys are being conducted in the San Juan Islands that comprehensively identified deep rocky habitats (Tilden 2005, Lopez 2007). Existing bathymetry data on other areas of Puget Sound do identify some of these habitats, especially where steep slopes or irregular features have been identified. Major deep-water rocky habitats include Middle Bank and other pinnacles in Haro Strait and many pinnacles and outcroppings in the San Juan Islands including those in Boundary Pass, San Juan Channel, President's Channel, and Rosario Strait. Isolated outcroppings and ridges occur in the Strait of Juan de Fuca including Hein Bank, Coyote Bank, the "Garbage Dump" off Port Angeles, and ridges off Tongue Point. In South Sound, deep rocky habitats are not as common but do occur in Admiralty Inlet, Restoration Point, and in Dalco Pass near Tacoma. Deepwater demersal species that make use of these habitats include yelloweye, canary, quillback, bocaccio, and redstripe rockfishes (Washington 1977).

Deep-water habitats also include extreme slopes of unconsolidated substrates, or sand, shell, and cobble fields often located in the periphery of rocky outcroppings. These deep unconsolidated habitats occur off many of the islands and Points of South Sound such as Camano Head, Possession Bar, Mukilteo, Jefferson Head, Point Edwards, Point Monroe, Skiff Point, Restoration Point, Blake Island, Southworth, Dalco Point, Tacoma Narrows, Fox and Ketron Islands, and along the steep walls of Hood Canal. In addition, quillback and other sedentary rockfishes are found to lesser degrees on habitats composed of coarse and fine sediments, and they are captured with regularity during the WDFW Bottom Trawl Survey in South Sound where rocky habitats are naturally limiting. The more common occurrence of copper, quillback, and brown rockfishes in South Sound indicates that these species may make use of isolated shelters created by benthic debris, sunken logs, or benthic vegetation mats swept into deep basins from the nearshore.

4.3.3 Open-Water Habitats

Open-water habitats include the water column both shallow and deep and the surface waters that include drift vegetation. This habitat may be segregated by the depth preferences of several rockfish species or be occupied by near benthic species. Several schooling species such as yellowtail, redstripe, and widow rockfish characterize the deeper segments of this habitat. Schools of yellowtail rockfish occasionally occur in deep waters of the western Strait of Juan de Fuca and widow rockfish were found once off the southwest corner of San Juan Island (Miller and Borton 1980). In shallower waters, near pinnacles and steep walls, black and Puget Sound rockfishes occupy open-water habitats.

The juveniles of some rockfish species make use of floating mats of vegetation in open water (Buckley 1997). These tend to occur throughout North Sound and the northern portions of South Sound and are often associated with tidal and other oceanographic fronts.

4.3.4 Artificial Habitats

Artificial habitats include piles of boulders, concrete wastes, tires, sewer pipes, breakwaters, shipwrecks, pilings, and other jettisoned or anthropogenic material not of natural geological origin. These structures mimic natural features of relief, crevice spaces, and settlement substrates for vegetation and invertebrates but may not provide equal functions as natural habitats. Artificial habitats include artificial fishing reefs that were once deployed to enhance fishing in South Sound and urban habitats where rocky habitats were naturally limiting (Buckley 1982). WDFW created nine offshore artificial reefs and four urban reefs (Figure 4.1) and others were created by the WDNR or by illegal or accidental dumping. Artificial habitats have been configured with smaller rock sizes than used on adult reefs in order to attract post-settlement rockfishes (West et al. 1994, 1995, Buckley 1987).

Rockfishes are found among artificial habitats (Matthews 1990a) and quickly colonize new artificial habitats soon after deployment. New habitats likely attract fish that are itinerant from the surrounding environment (Buckley and Hueckel 1985, Laufle and Pauley 1985) but how well the artificial reefs simulate the function natural habitats is unclear. Matthews (1990b) found that home ranges are greater for rockfishes living on artificial habitats than natural habitats, and fish living on artificial habitats are more likely to move to low relief natural rocky habitats during the summer. In contrast, rockfish living on natural high-relief rocky habitats (vertical relief greater than 2 m) apparently have more suitable conditions because they remain in smaller home ranges throughout the year. Moreover, most rockfish displaced from natural high-relief rocky habitats return to them after being displaced to artificial reefs, but rockfish displaced from artificial reefs to high relief natural reefs do not return and remain at the high-relief natural habitats. These findings indicate that artificial habitats may not serve as well as natural habitats because of overcrowded conditions and the need to search for food.

The use of artificial reefs for improving fisheries and stocks has questionable impacts on rockfish stocks and communities. Buckley (1982) identified the use of artificial reefs in Puget Sound as a fishery enhancement program to increase angler catches of marine fishes including rockfishes. Artificial and natural habitats that have been open to fishing in Puget Sound have fewer rockfish greater than 40 cm compared to marine reserves in natural and artificial habitats where fishing for bottomfish is prohibited (Palsson and Pacunski 1995, Palsson 1998). A plausible result from this observation is that artificial reefs increase fishing mortality rates on rockfish stocks with low productivity by attracting fish from surrounding but more diffuse natural habitats where they are not as likely subject to harvest. This hypothesis had strong credibility leading to a directive in the PSGMP that any new artificial habitat will be closed to fishing (Palsson et al. 1998).

Artificial habitats have been suggested as a habitat mitigation tool for the loss of natural habitats (Hueckel et al. 1989) because they attract concentrations of rockfish and other rocky habitat species, but the issues of habitat quality, function, and replacement of underlying natural habitats casts doubt for their use as replacement habitats.

4.4 Species Distributions

The distributions of rockfishes in Puget Sound are generalized by the results from extensive surveys conducted by WDFW and from key literature sources. The accompanying maps were generated from WDFW sampling activities that included bottom trawl surveys, quantitative video surveys (Video Assessment Technique or VAT), and scuba surveys conducted throughout North and South Sound. Scuba surveys included those targeting sub-adult and adult fishes living in association with rocky or artificial habitats that were conducted by WDFW between 1995 and 2006. Observations of nearshore vegetated sites targeting early Young-of-the-Year (YOY) rockfish were conducted by Buckley from 1991-1993 (Doty et al. 1995) and by LeClair et al. (2007) (YOY SCUBA). The methods for trawl and VAT surveys are described in Section 6 **Stock Evaluation.** VAT surveys were conducted between 1994 and 2004, and trawl observations resulted from surveys conducted between 1987 and 2005. Maps of species distributions present density data in numbers per hectare, counts, or as presence/absence at individual sites. Because these surveys do not necessarily cover every potential rockfish habitat, they are useful for describing the general but not inclusive distribution of rockfish species in Puget Sound. There is very limited information on the distributions and habitats for several rockfishes. Other distributional maps can be found in Washington (1977) and Miller and Borton (1980).

4.4.1 Copper Rockfish

Copper rockfish is an important species of the nearshore, benthic rockfish assemblage in Puget Sound and historically has been the most commonly encountered rockfish species (Miller and Borton 1980, Table 3.1). This species inhabits depths of less than 61 m (Murie et al. 1994) and associates with high-relief rocky habitats throughout the inland marine waters of Washington. Trawl, video, and special studies reveal that copper rockfish are primarily distributed throughout nearshore waters in North and South Sound but are most concentrated in the San Juan Islands (Figure 4.2) especially along the west side of San Juan Island, on the northern side of Orcas Island, along Matia, Sucia, and Patos Islands, on the western shore of Rosario Strait, and along Allan and Burrows Islands. Copper rockfish are uncommon in the southern Strait of Georgia, where they are most consistently found at nearshore stations along the reef south of Point Roberts. Copper rockfish are relatively rare in the Strait of Juan de Fuca where they are primarily found near Port Townsend, Dungeness Spit, and along the shore from Twin Rives to Sekiu. Few copper rockfish are caught away from shore, but some have been observed near Smith Island and on some of the shallow banks in the eastern Strait of Juan de Fuca. In South Sound, copper rockfish occur in nearshore habitats especially off Admiralty Head, along the eastern shore from Edmonds to west Seattle, on the southern end of Bainbridge Island, in southern Colvos Passage, off Tramp Harbor and in Tacoma Narrows (Figure 4.3). Copper rockfish are not common south of Tacoma Narrows and occur at Z's Reef, Day Island, Toliva Shoal, Tolmie Barges, and Steamboat Island. Copper rockfishes live in nearshore rocky habitats in Hood Canal especially near Pulali Point, and Toandos Head, and at isolated rocky habitats south to the Great Bend. Settling post-larval copper rockfish have been observed in nearshore habitats at Camano Head and Gedney Island in the Whidbey Basin, along the eastern shore of Central Puget Sound From Mukilteo to Seattle, and off Pt. Whitney in Hood Canal (Figure 4.3).

4.4.2 Quillback Rockfish

Quillback rockfish is the second most common rockfish in Puget Sound (Miller and Borton 1980, Table 3.1) and inhabits nearshore and deep waters to 213 m in Puget Sound. Surveys reveal that adult and sub-adult quillback rockfish occur in the highest densities along the shorelines of North and South Sound but are also observed in the central basins (Figures 4.4 and 4.5). The highest densities of quillback rockfish occur along the west coast of San Juan Island and along Speiden, Waldron, Sucia, and Patos Islands. Quillback rockfish occur in low densities off Point Roberts in the Strait of Georgia and throughout the

Strait of Juan de Fuca. Quillback rockfish were frequently observed in the central Strait of Juan de Fuca in association with boulder fields on the shallow banks and pinnacles. In South Sound, quillback rockfish occur in the highest densities in Admiralty Inlet, off Camano Head, along the eastern shore of Central Puget Sound, in Colvos Pass, and in the deep portions of Saratoga Pass and off Tacoma. Quillback rockfish are found in Southern Puget Sound in Tacoma Narrows, off Fox, McNeil, and Anderson Islands, and off Johnson Point. In Hood Canal, quillback rockfish occur along the entire fjord especially along the shores of Pt. Whitney, Black Point, Triton Head and south to the entrance of the Great Bend. Post-settlement quillback rockfish have been observed at Camano Head, Gedney Island, along the eastern shore of the central basin from Mukilteo to Seattle, off southeastern Bainbridge Island, and in northern Hood Canal (Figure 4.5).

4.4.3 Brown Rockfish

Brown rockfish is relatively rare in North Sound but is a common species in South Sound (Miller and Borton 1980, Table 3.1). It is a sedentary rockfish species that inhabits rocky habitats and may be able to live in less current-swept habitats than copper or quillback rockfishes. Surveys confirm that brown rockfish are rare in North Sound and only have been observed in Discovery Bay during video surveys. In South Sound, brown rockfish are commonly found in nearshore habitats and have been observed off Bainbridge Island, Blake Island, Colvos Passage, in Dabob Bay (Hood Canal), and along McNeil, Fox, and Anderson Islands in southern Puget Sound (Figure 4.6).

4.4.4 Black Rockfish

Black rockfish is a species that inhabits the water column in proximity to nearshore rocky habitats. Black rockfish occur throughout North and South Puget Sound, but has historically been more abundant in North Sound (Miller and Borton 1980, Table 3.1). Surveys reveal that black rockfish are much more limited in distribution than copper and quillback rockfishes (Figures 4.7 and 4.8). In North Sound, black rockfish primarily occur in the nearshore of the Strait of Juan de Fuca from Sekiu to Port Townsend, along the western shore of San Juan Island, in San Juan Channel and the entrance to Deception Pass. In South Sound, black rockfish occur in high current areas with steep drop offs especially off Admrialty Head, Possession Point, Admiralty Head, Marrowstone Island, Rich Passage, in and near Tacoma Narrows, Fox Island, and in Hood Canal where they occur at most rocky habitats.

4.4.5 Yelloweye Rockfish

Yelloweye rockfish is a deep-water species that is relatively sedentary living in association with high-relief rocky habitats and often near steep slopes (Love et al. 2002, Wang 2006). Yelloweye rockfish is less frequently observed in South Sound than North Sound (Miller and Borton 1980, Table 3.1). They are infrequent in trawl and video surveys with a single or few occurrences most sub-basins (Figures 4.9 and 4.10). Hood Canal, however, has the greatest frequency of yelloweye rockfish observed in both trawl and scuba surveys. Yelloweye rockfish are reported by anglers to occur off Middle Bank in Haro Strait, Waldron Island, Hood Canal, Foulweather Bluff, Jefferson Head, Mukilteo, and Bainbridge Island (Washington 1977, WDFW unpublished data).

4.4.6 Other Rockfish

<u>Yellowtail rockfish</u> occur primarily as juveniles in Puget Sound (Barker 1979) and once co-occurred with black rockfish in pelagic nearshore schools (Moulton 1977). Surveys reveal yellowtail are sporadic in occurrence in North and South Sound (Figures 4.11 and 4.12) with occurrences in the central Strait of Juan de Fuca, in Deception Pass, off the western shore of Camano Island in Saratoga Passage, off

Possession Point, between Edmonds and Seattle, and in Hood Canal off Pullali Point and in the Great Bend.

Canary rockfish is a deeper living rockfish associated with a variety of rocky and coarse habitats that have occurred throughout the basins of Puget Sound (Miller and Borton 1980, Table 3.1).

Bocaccio is a deepwater species often associated with steep slopes consisting of sand or rocky substrates and occurred in Central Puget Sound, Tacoma Narrows, and Ports Gardner and Susan, and along the Strait of Juan de Fuca (Miller and Borton 1980, Table 3.1). Surveys for young rockfish found canary rockfish in the western Strait of Juan de Fuca near Freshwater Bay (R. Buckley, WDFW personal communication).

Redstripe rockfish is a smaller schooling rockfish that associates with rocky and coarse habitats in broad range of depths from 18 m to almost 213 m and uncommonly occur throughout most basins in Puget Sound (Miller and Borton 1980, Table 3.1). They are commonly caught during bottom trawl surveys especially in the central Strait of Juan de Fuca, channels of the San Juan Islands, in the central Strait of Georgia, and in Admiralty Inlet (Figures 4.13 and 4.14). They are uncommon in other areas of South Sound, but have been observed in trawl samples off Point Defiance and Anderson and McNeil Islands.

Greenstriped rockfish is a deepwater species that occurs throughout Puget Sound (Miller and Borton 1980, Table 3.1) often associated with sand and coarse sediments at depths of 40 m to almost 213 m. They are occasionally caught during trawl surveys especially in the western Strait of Juan de Fuca, Strait of Georgia, and sporadically captured in Admiralty Inlet and Hood Canal (Figures 4.15 and 4.16).

Splitnose rockfish is a deepwater species and as adults, occurs on coarse habitats at depths of 91 m to almost 182 m at specific locations in Puget Sound (Miller and Borton 1980, Table 3.1, WDFW unpublished data). They have been most consistently collected in northern Hood Canal and sporadically in the western Strait of Juan de Fuca and in the Whidbey Basin (Figures 4.17 and 4.18).

Shortspine thornyhead is a deepwater species taken in depths of at least 152 m in the basins of Central Puget Sound, the Strait of Juan de Fuca, and the Strait of Georgia (Miller and Borton 1980, Table 3.1). They are collected during trawl surveys especially in the Strait of Georgia and occasionally in the central Strait of Juan de Fuca, Hood Canal, and Central Puget Sound off Mukilteo and the East Pass near Vashon Island (Figures 4.19 and 4.20).

Tiger rockfish uncommonly occurs in rocky habitats in the San Juan Islands (Miller and Borton 1980, Table 3.1) and presumably occurs in the Strait of Juan de Fuca.

Blue, vermilion and China rockfishes are generally limited to the western Strait of Juan de Fuca with few records east of Port Angeles (Miller and Borton 1980, Table 3.1). Blue rockfish co-occur with black rockfish schools in nearshore habitats. China rockfish is a sedentary species associated with rocky habitats in nearshore coastal waters. Vermilion rockfish, were only detected in the eastern Strait of Juan de Fuca and the San Juan Islands by Miller and Borton (Table 3.1) but have recently become more frequent in trawl and video surveys in the nearshore of the Strait of Juan de Fuca. In addition, individuals have recently observed during scuba surveys at the Keystone Jetty on Whidbey Island, at Sund Rocks and Waketickeh Creek Marine Reserves in Hood Canal, and at Orchard Rocks Marine Reserve in Central Puget Sound, and at Toliva Shoal in Southern Puget Sound. Why this species is expanding in Puget Sound is unclear but individuals in South Sound were typically between 30 cm and 40 cm indicating they did not recruit and grow in the area but rather moved from coastal waters.

Puget Sound rockfish is a small, fast growing and schooling species that is associated with high current and steep rocky habitats in both nearshore and deepwater habitats. This species occurs in high abundance in North Sound and are much less abundant in South Sound (Miller and Borton 1980, Table 3.1) and is rarely observed south of Restoration Point on Bainbridge Island. They occur from the depth of 3 m to over 152 m in Puget Sound but most occurrences are in depth of 91 m or less. Their settling young are observed during the winter at the base of nearshore walls in the San Juan Islands (WFDW unpublished data). Surveys confirm that the highest densities occur along nearshore, rocky habitats in the San Juan Islands, but they can occur in offshore trawl and other nearshore stations in the Straits of Georgia and Juan de Fuca, and Admiralty Inlet (Figures 4.21 and 4.22). Puget Sound rockfish sporadically occur in Central and South Puget Sound and the Whidbey Basin.

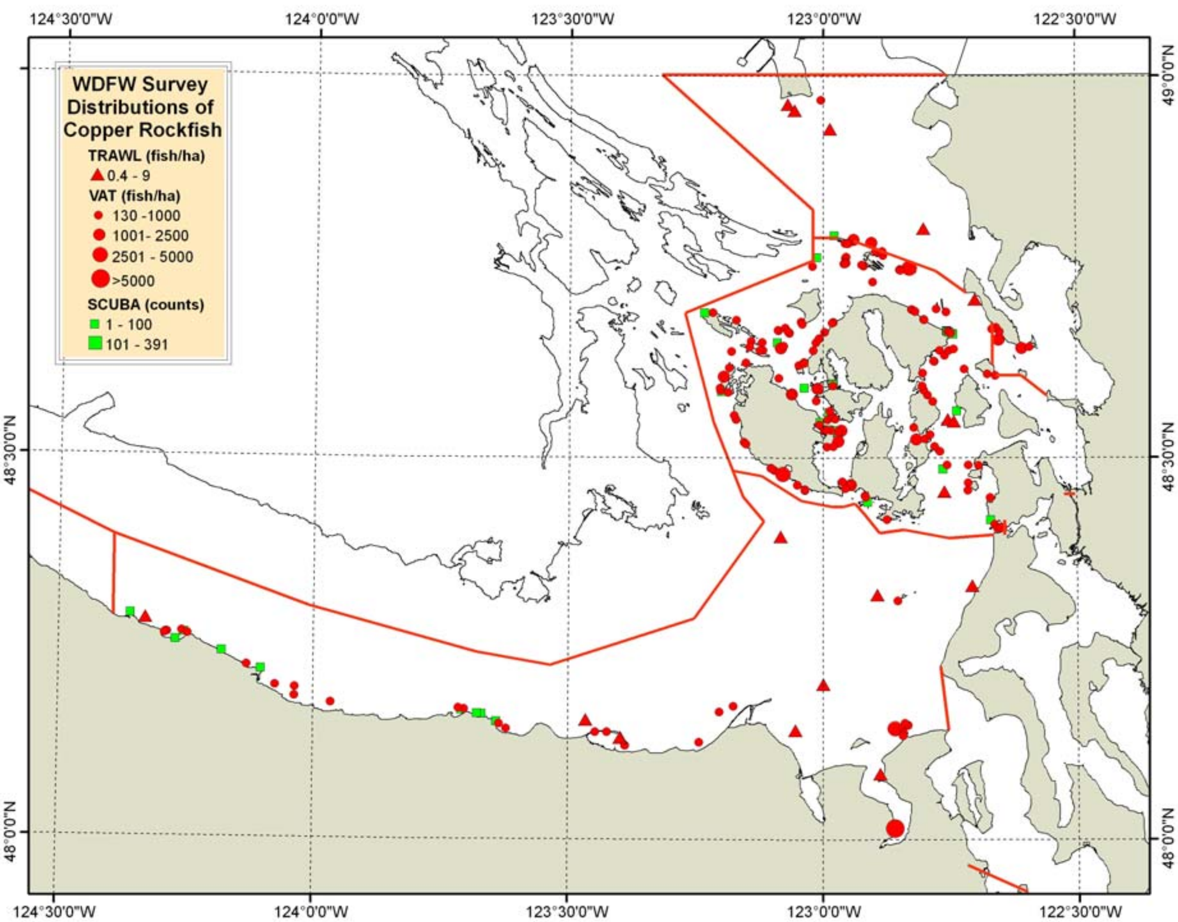


Figure 4.2. Distribution of copper rockfish in North Puget Sound determined from trawl, video, and scuba surveys.

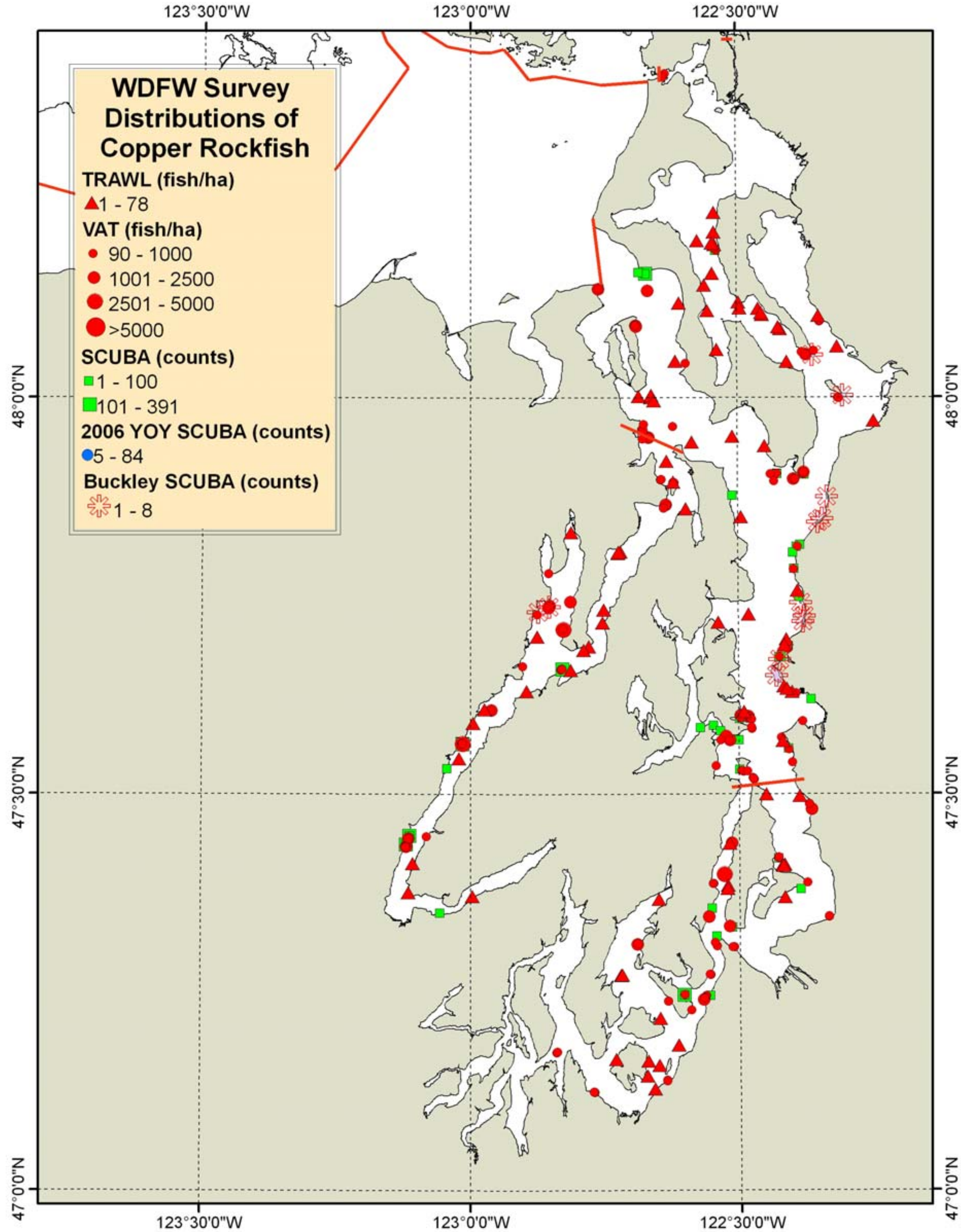


Figure 4.3. Distribution of copper rockfish in South Puget Sound determined from trawl, video, and scuba surveys.

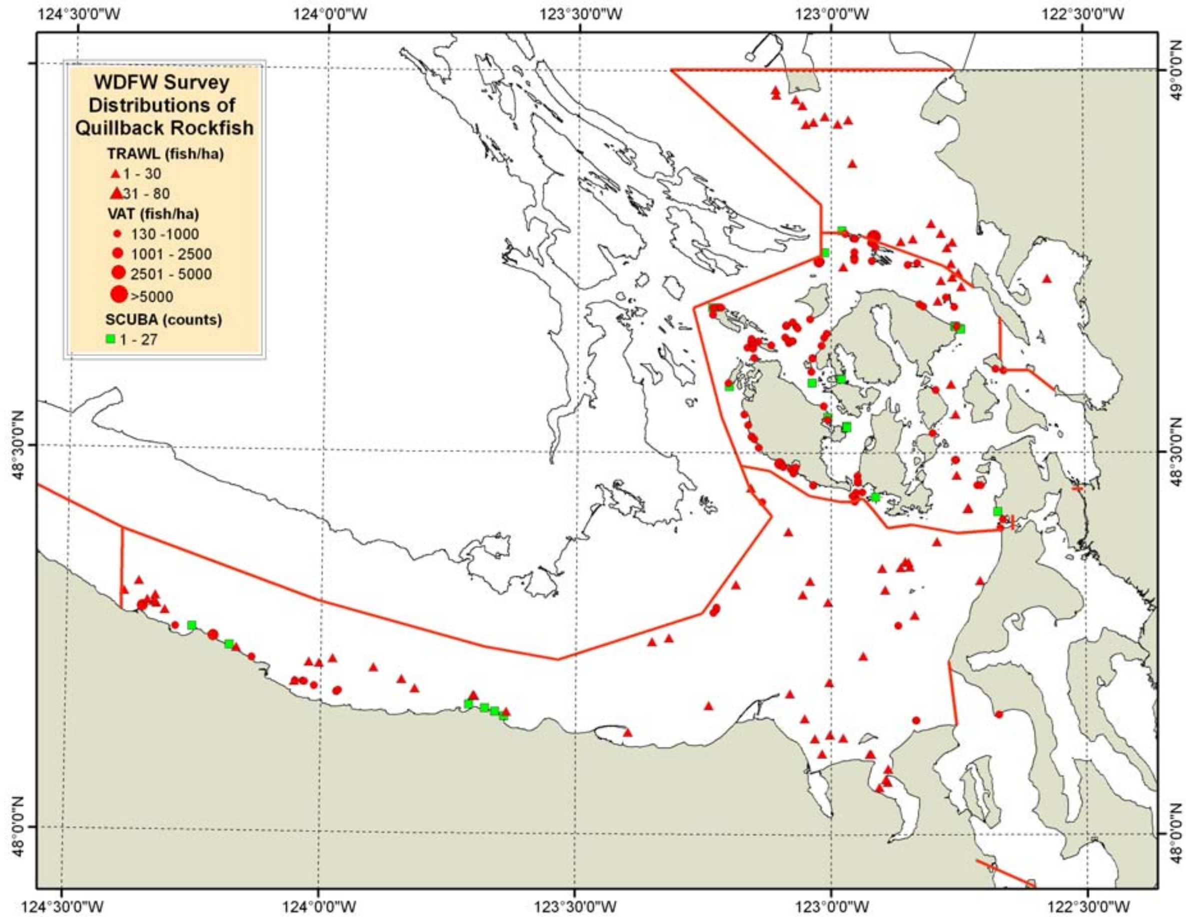


Figure 4.4. Distribution of quillback rockfish in North Puget Sound determined from trawl, video, and scuba surveys.

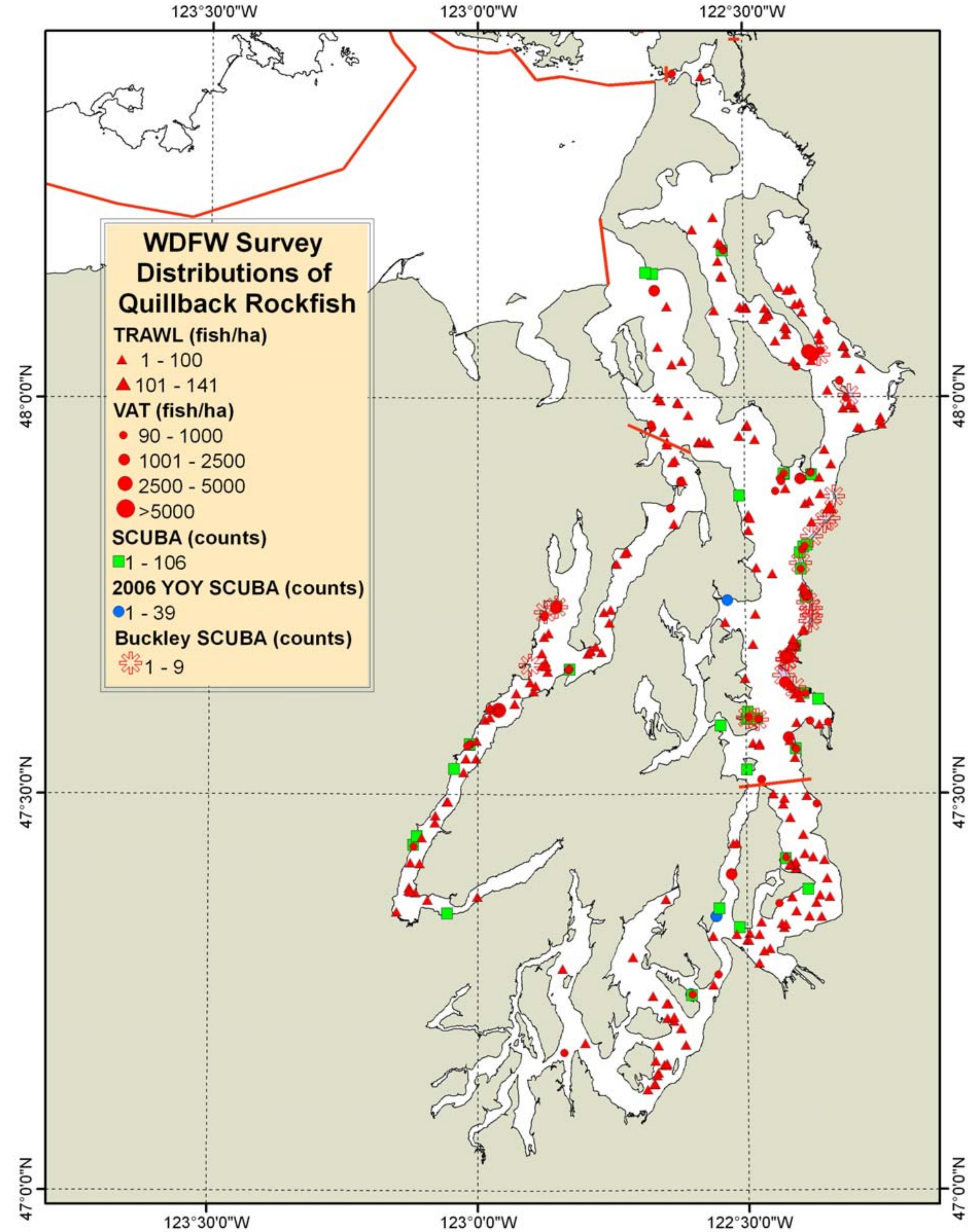


Figure 4.5. Distribution of quillback rockfish in South Puget Sound determined from trawl, video, and scuba surveys.

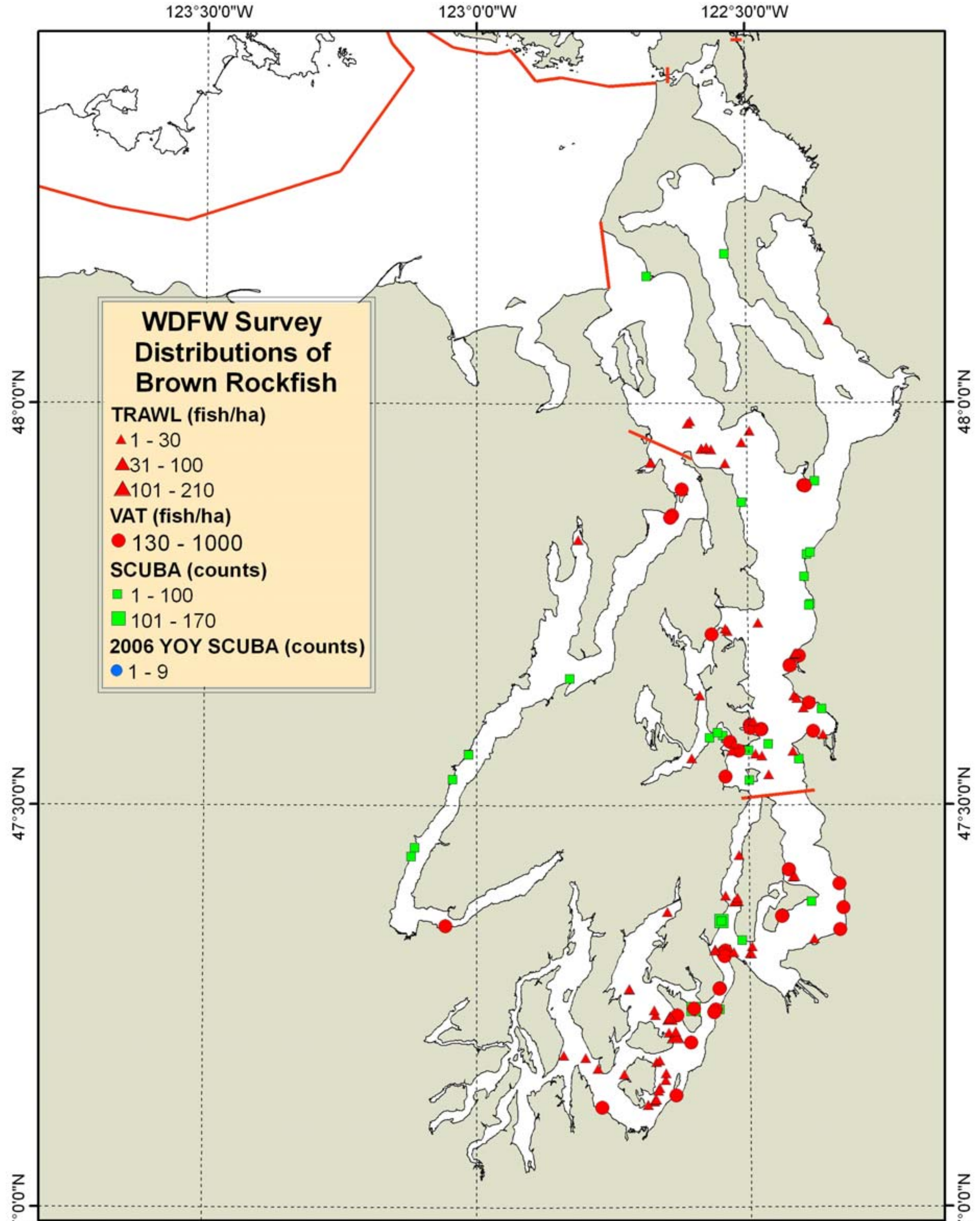


Figure 4.6. Distribution of brown rockfish in South Puget Sound determined from trawl, video, and scuba surveys.

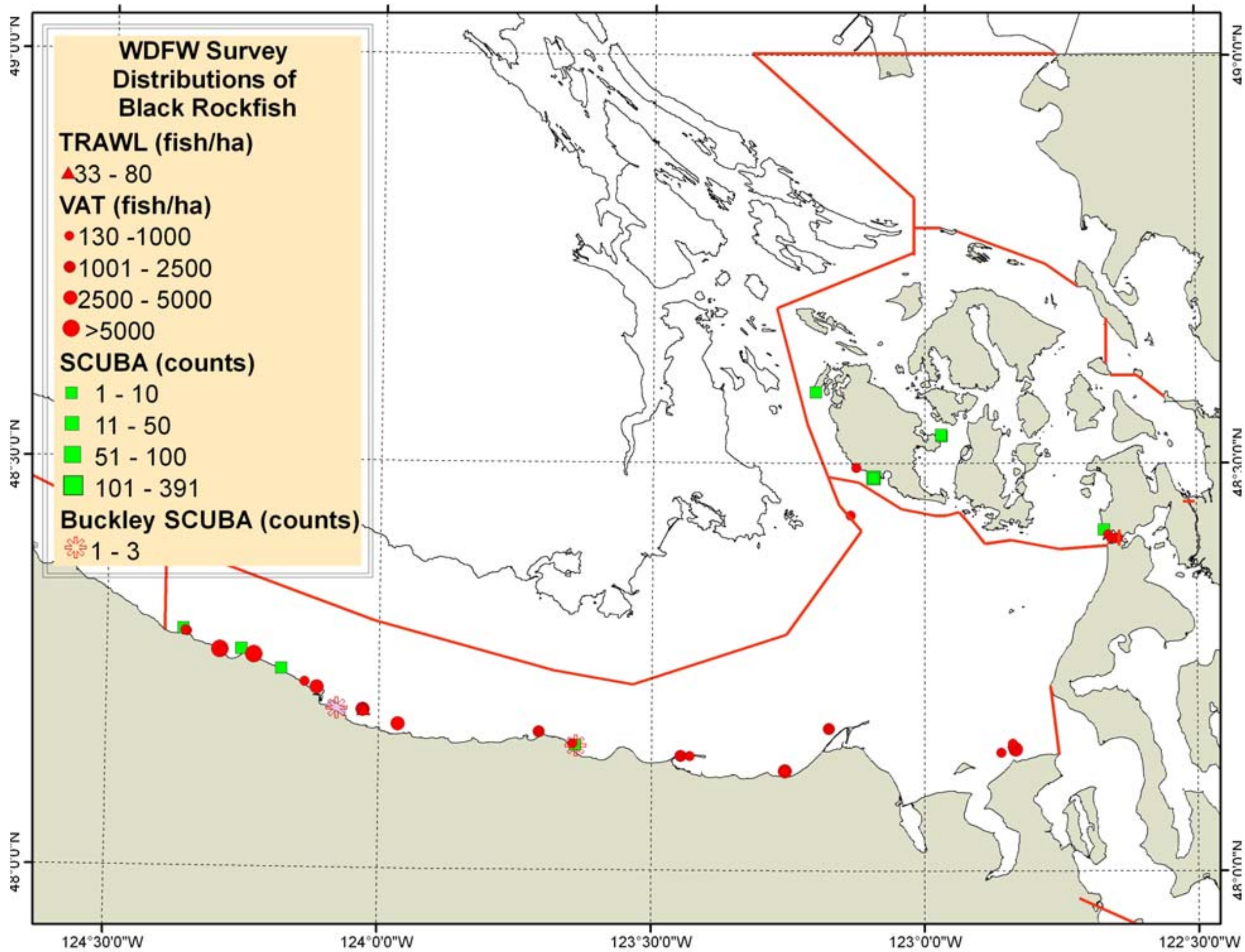


Figure 4.7. The distribution of black rockfish in North Puget Sound determined from trawl, video, and scuba surveys.

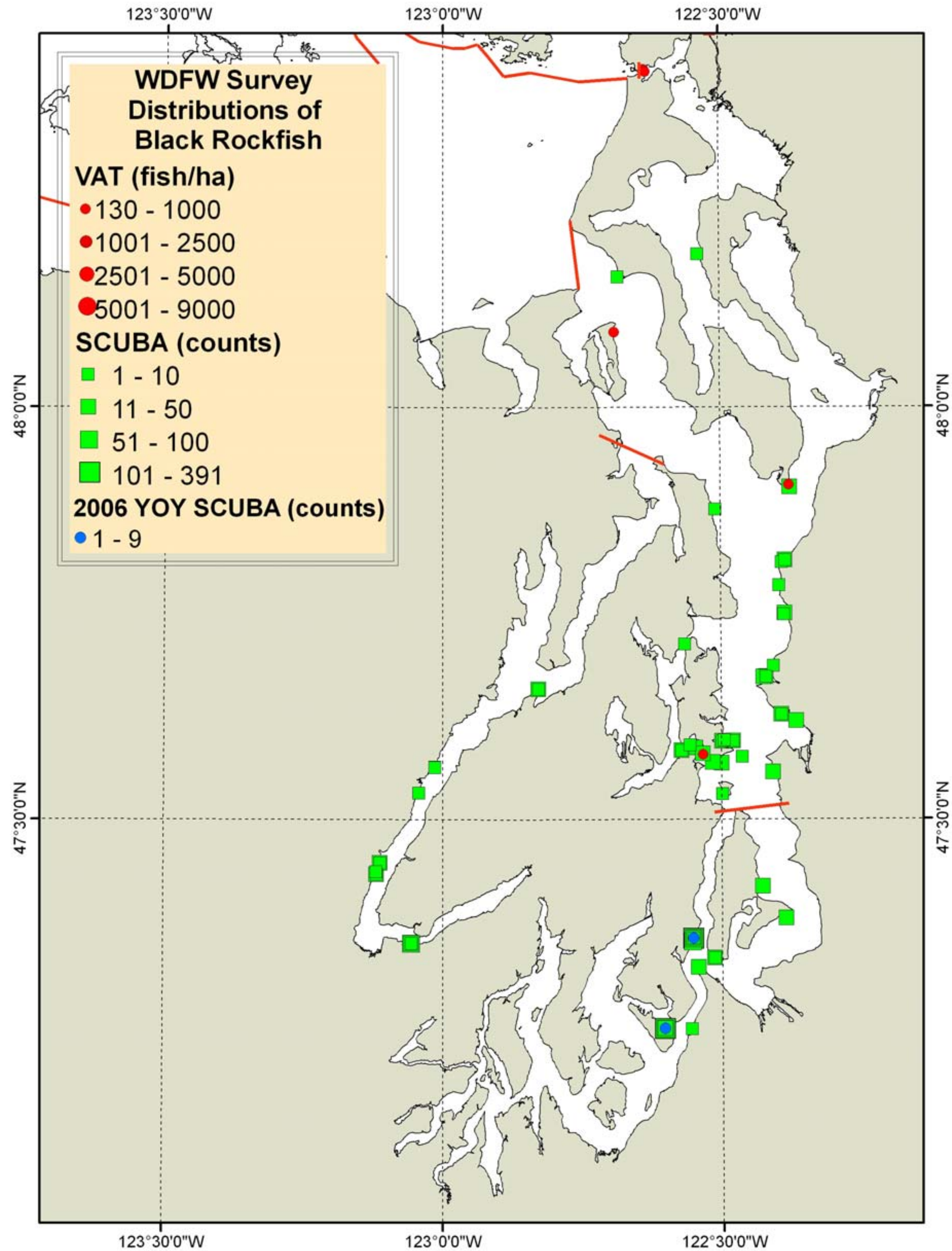


Figure 4.8. The distribution of black rockfish in South Puget Sound determined from trawl, video, and scuba surveys.

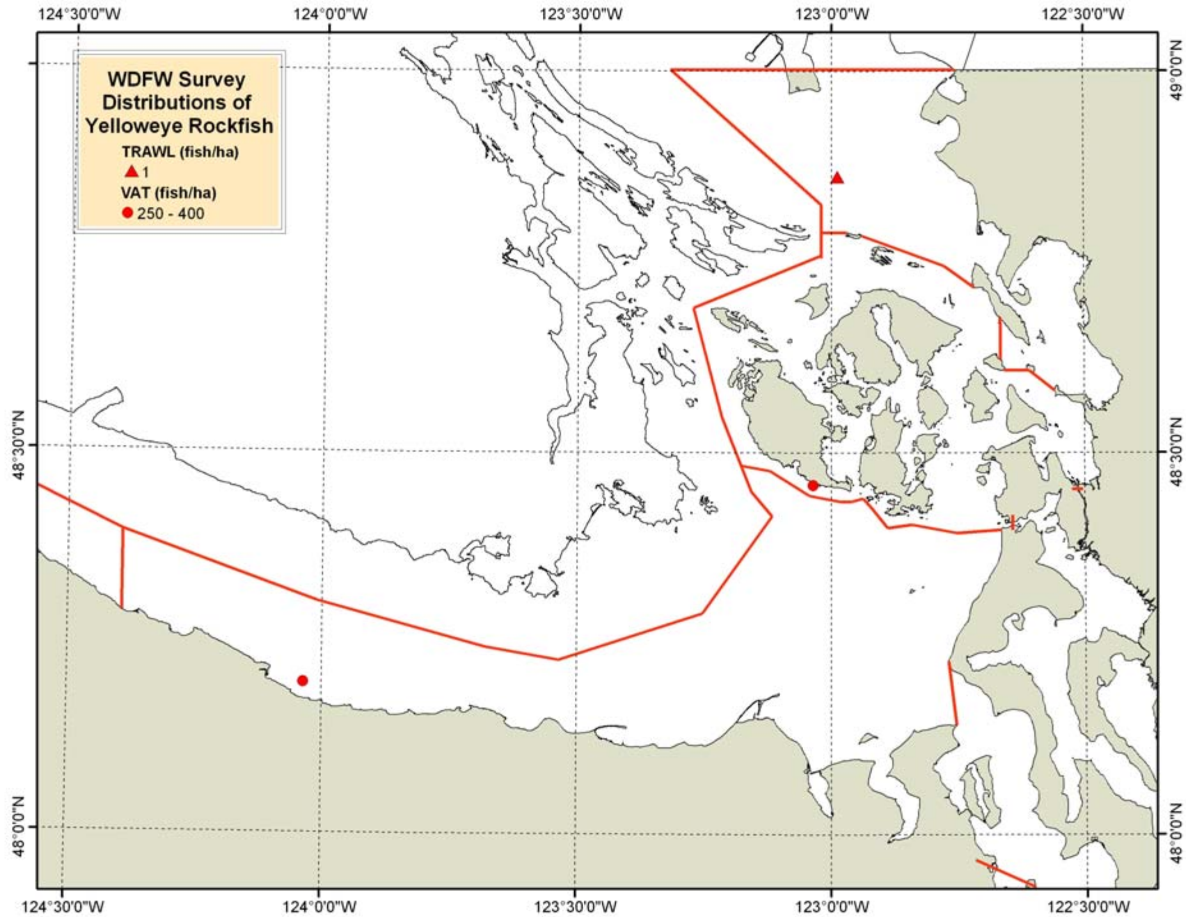


Figure 4.9. The distribution of yelloweye rockfish in North Puget Sound determined from trawl, video, and scuba surveys.

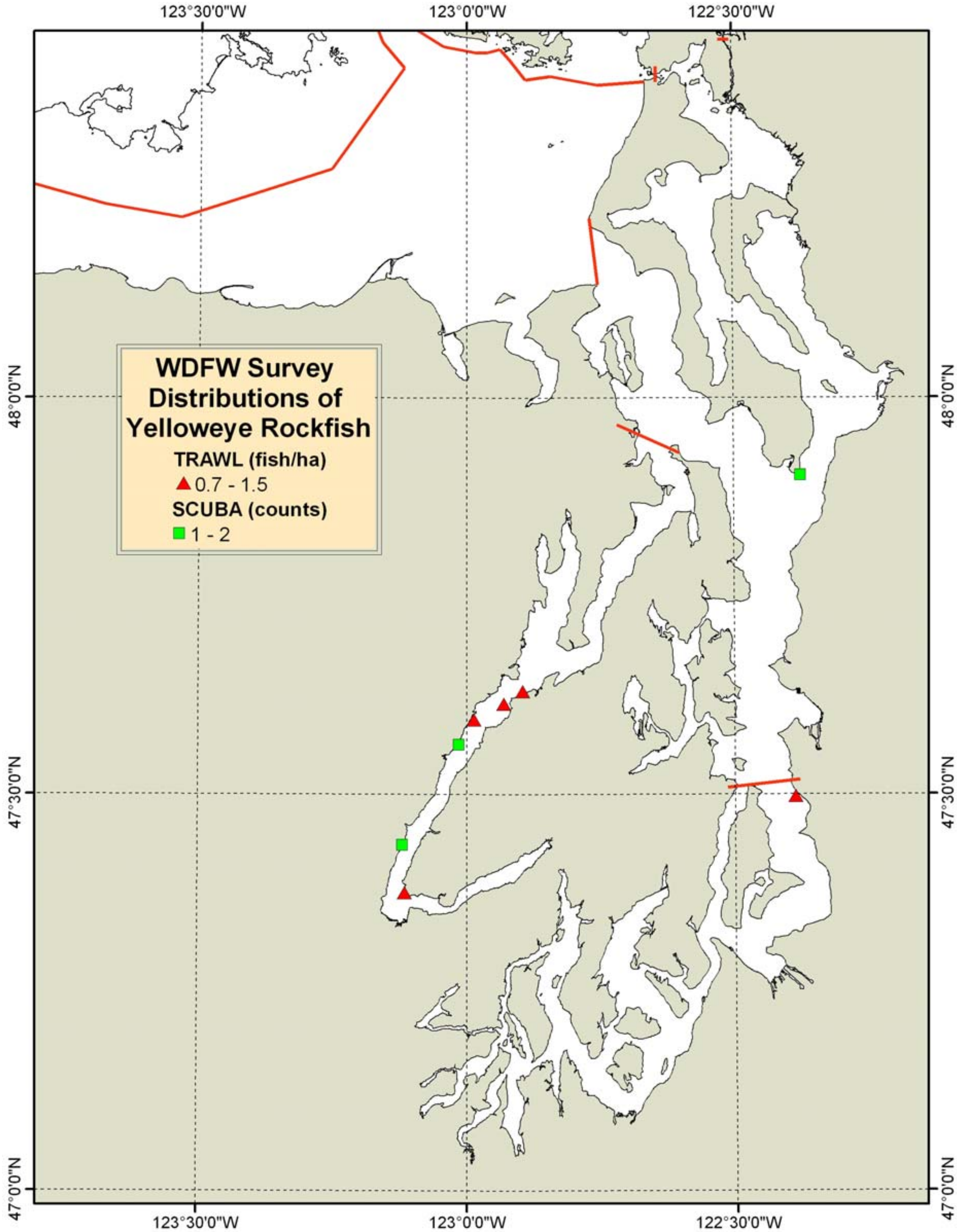


Figure 4.10. The distribution of yelloweye rockfish in South Puget Sound determined from trawl, video, and scuba surveys.

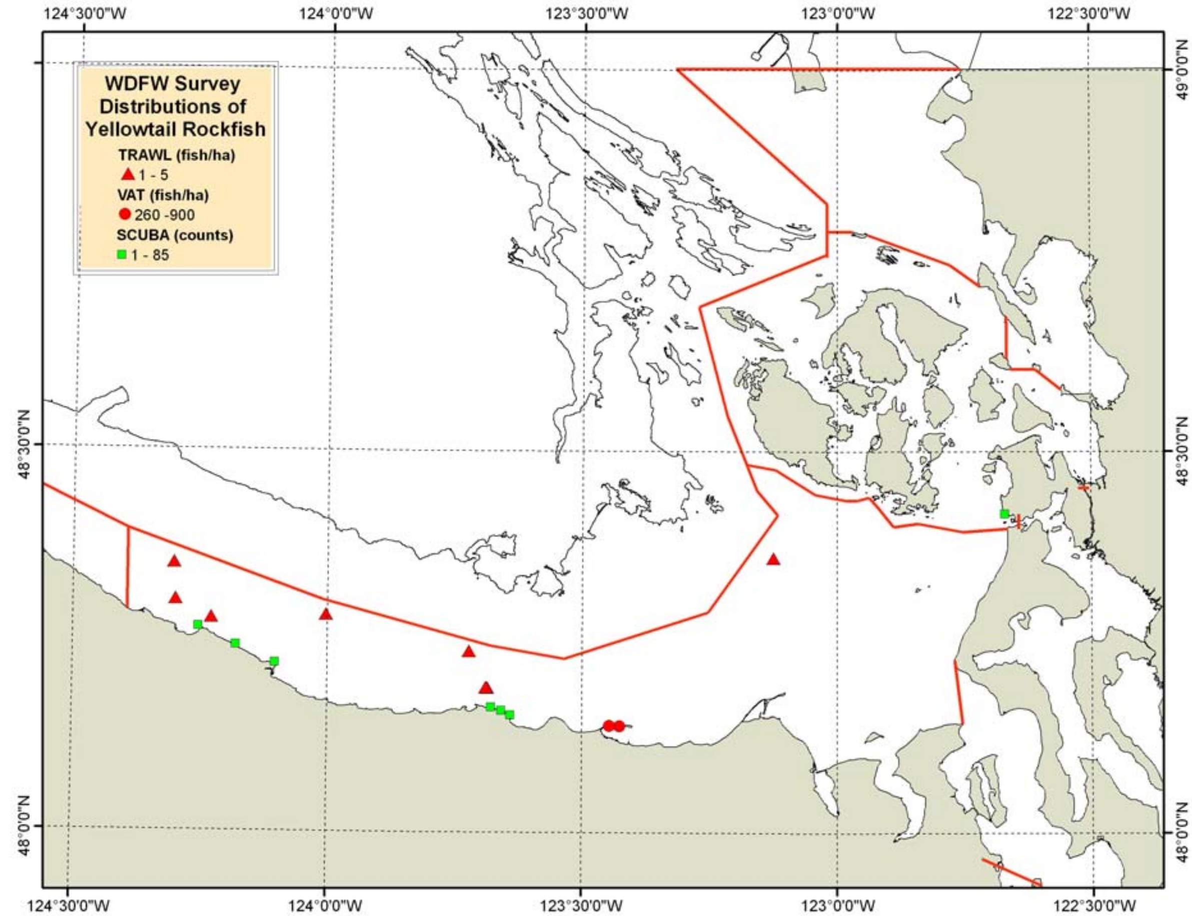


Figure 4.11. The distribution of yellowtail rockfish in North Puget Sound determined from trawl, video, and scuba surveys.

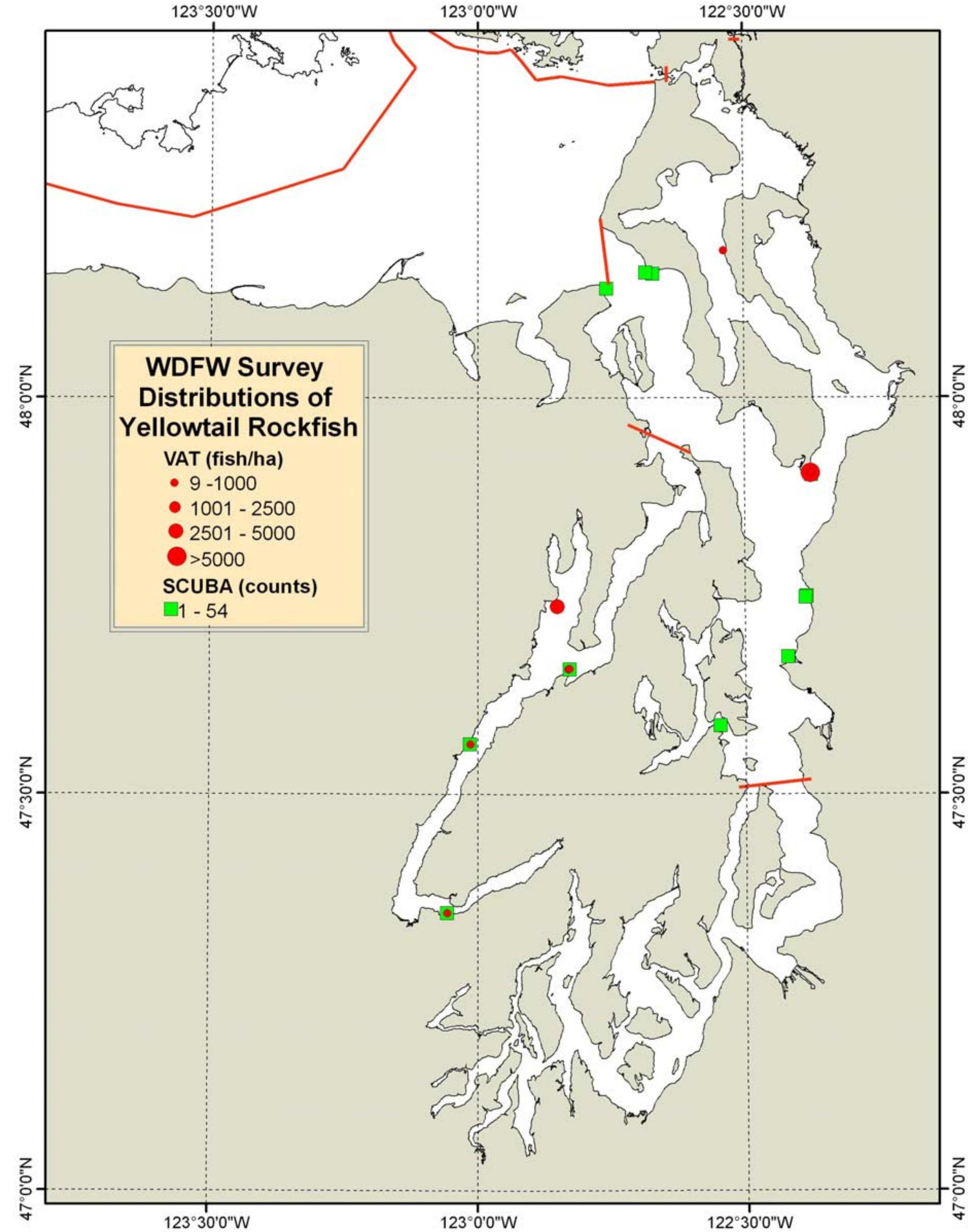


Figure 4.12. The distribution of yellowtail rockfish in South Puget Sound determined from trawl, video, and scuba surveys.

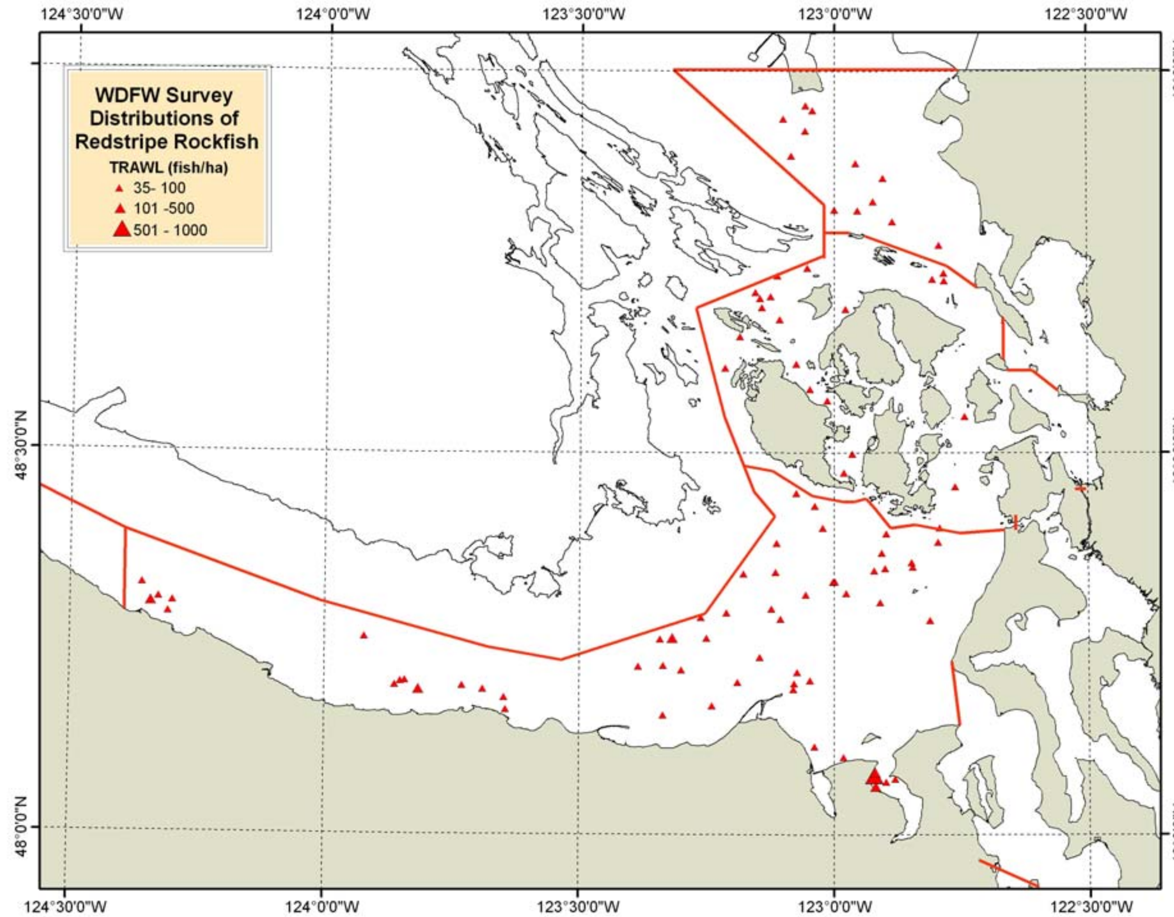


Figure 4.13. The distribution of redstripe rockfish in North Puget Sound determined from trawl, video, and scuba surveys.

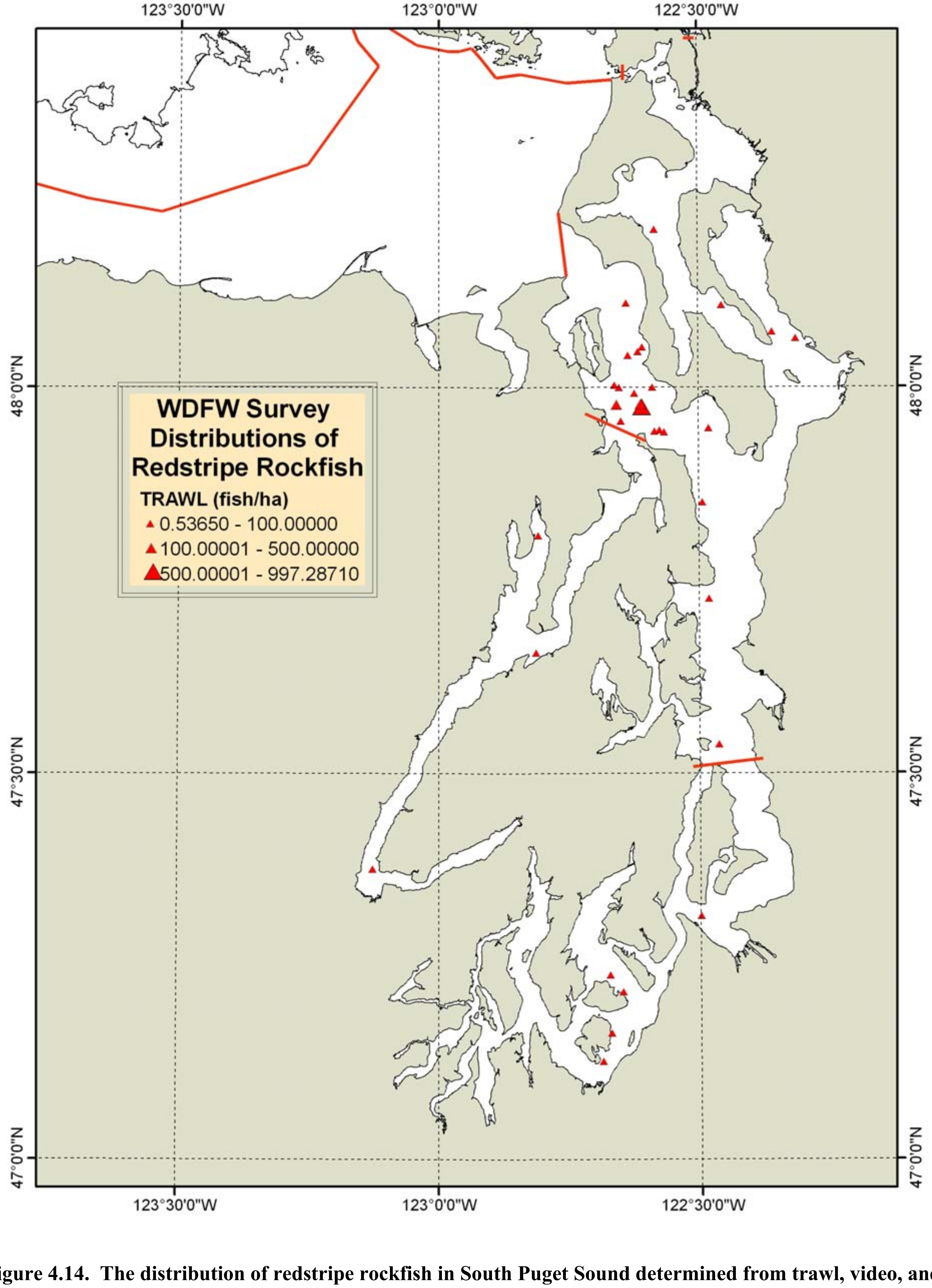


Figure 4.14. The distribution of redstripe rockfish in South Puget Sound determined from trawl, video, and scuba surveys.

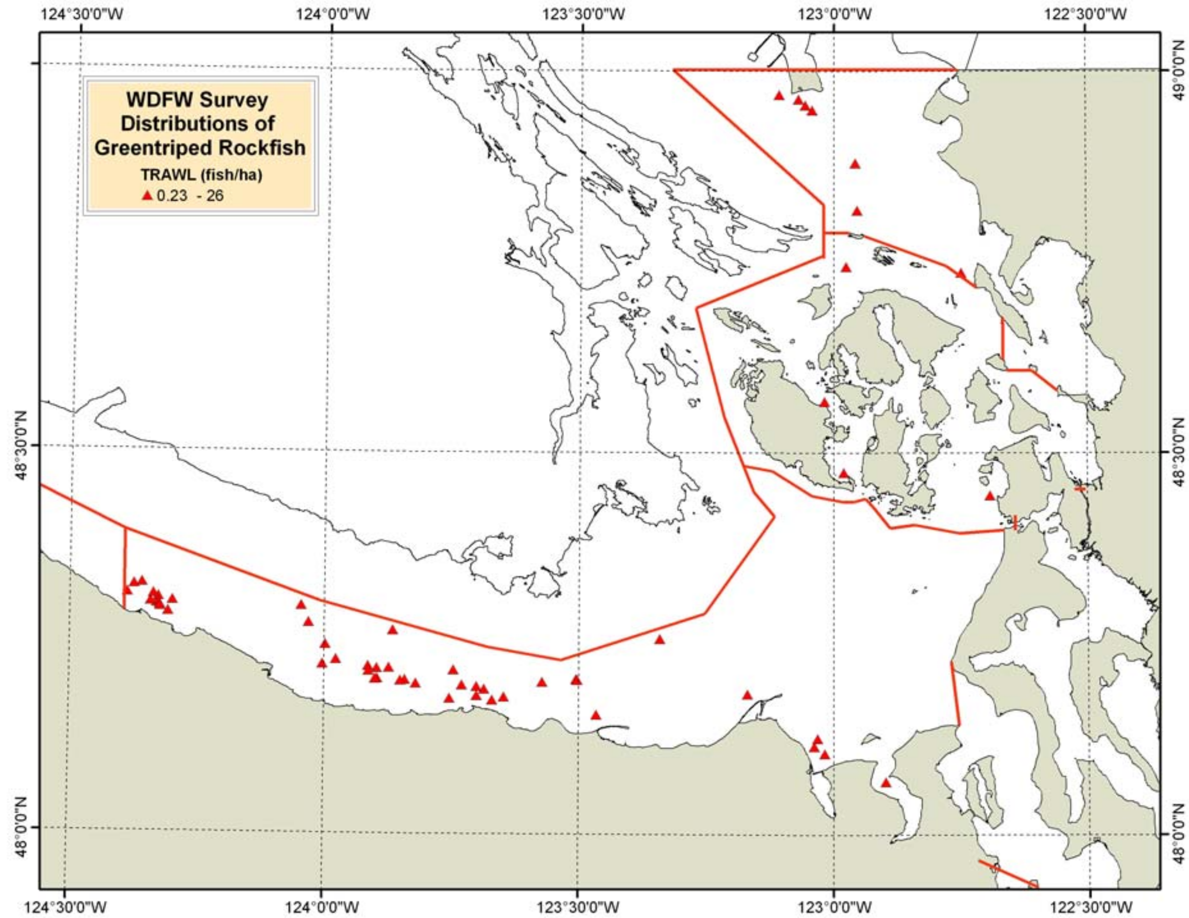


Figure 4.15. The distribution of greenstriped rockfish in North Puget Sound determined from trawl, video, and scuba surveys.

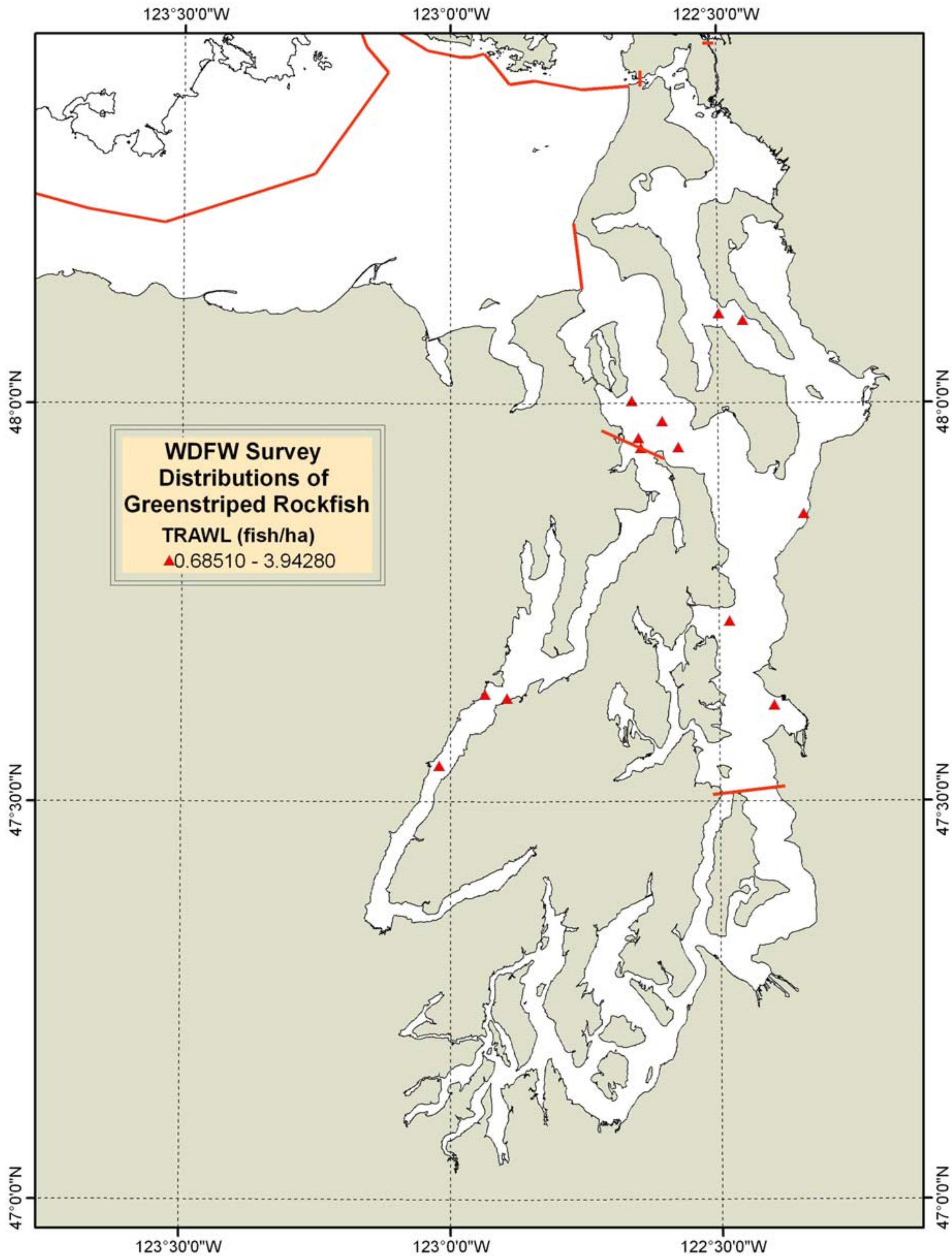


Figure 4.16. The distribution of greenstriped rockfish in South Puget Sound determined from trawl, video, and scuba surveys.

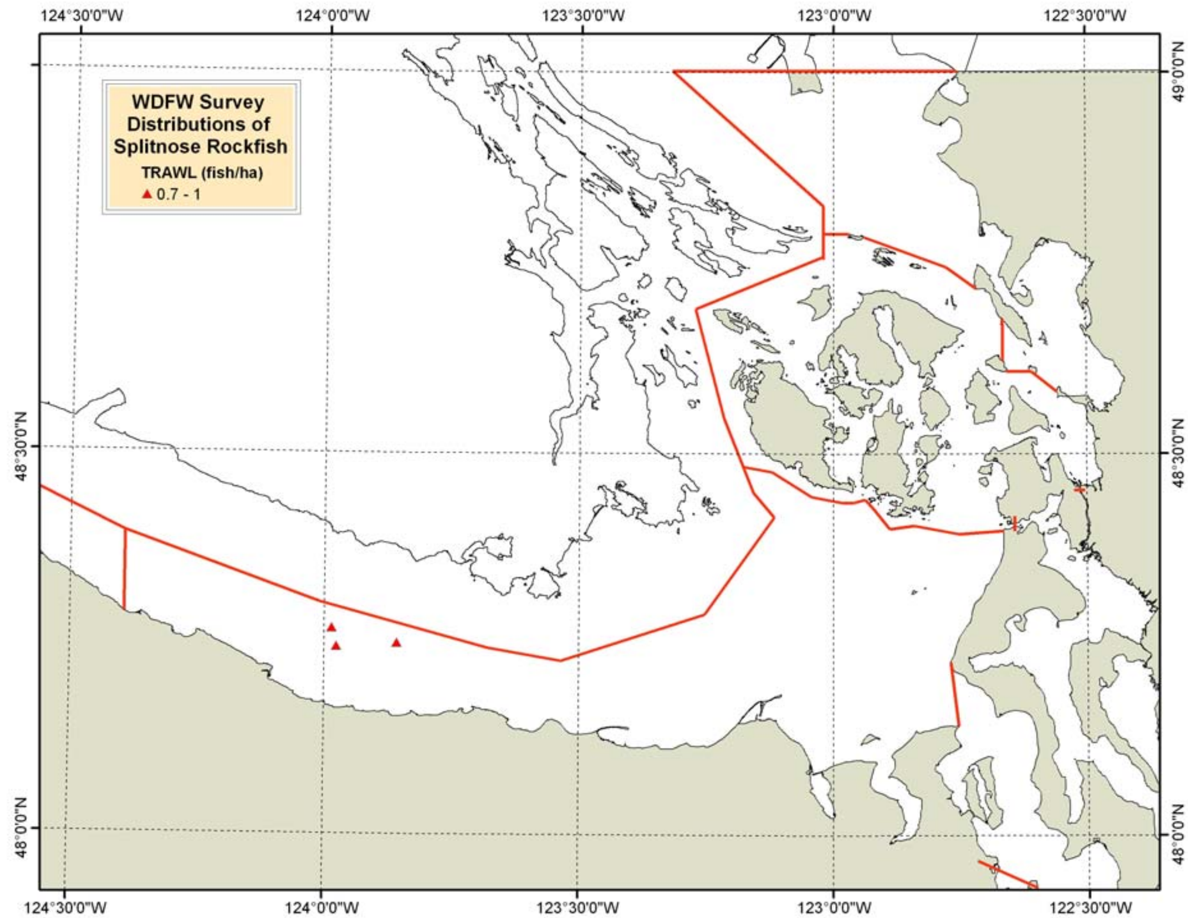


Figure 4.17. The distribution of splitnose rockfish in North Puget Sound determined from trawl, video, and scuba surveys.

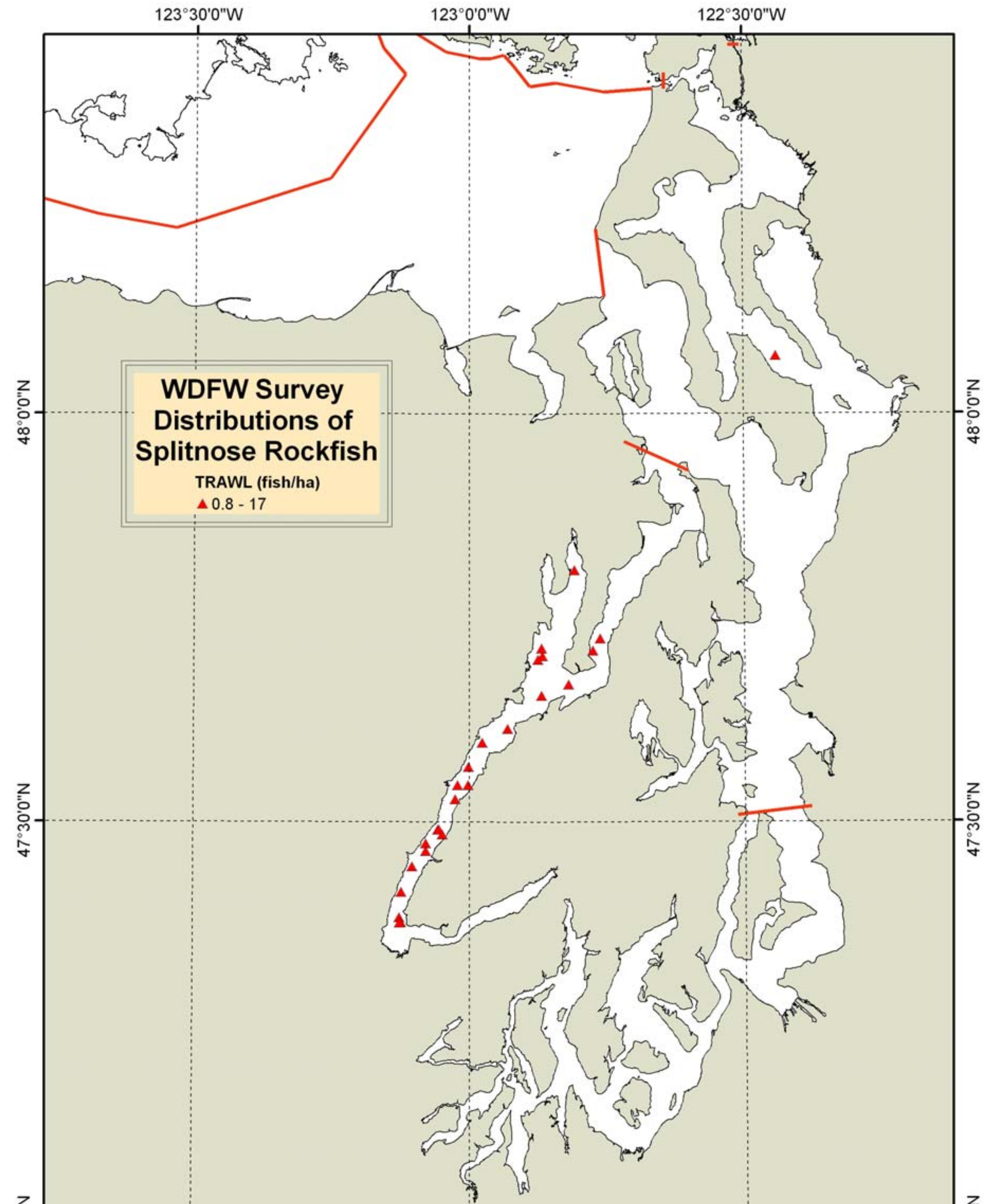


Figure 4.18. The distribution of splitnose rockfish in South Puget Sound determined from trawl, video, and scuba surveys.

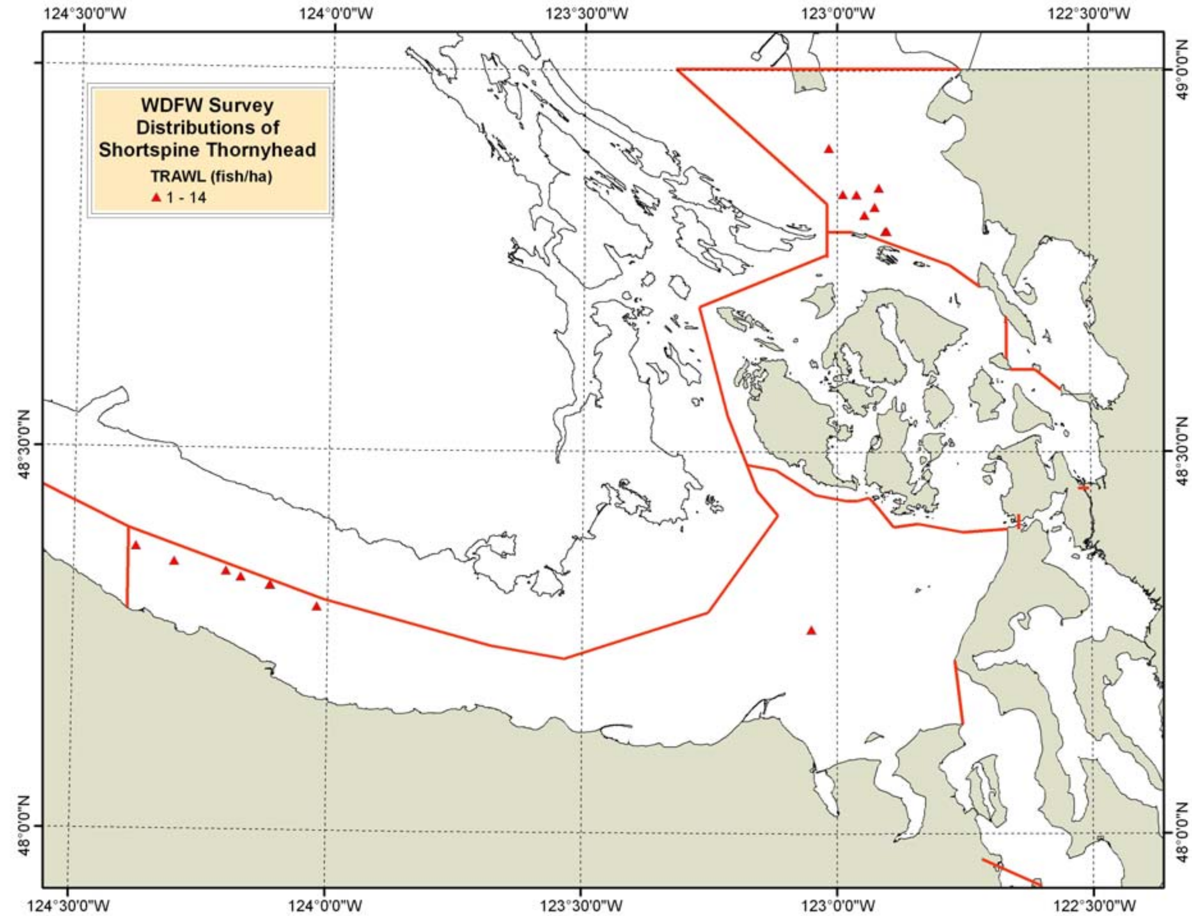


Figure 4.19. The distribution of shortspine thornyhead in North Puget Sound determined from trawl, video, and scuba surveys.

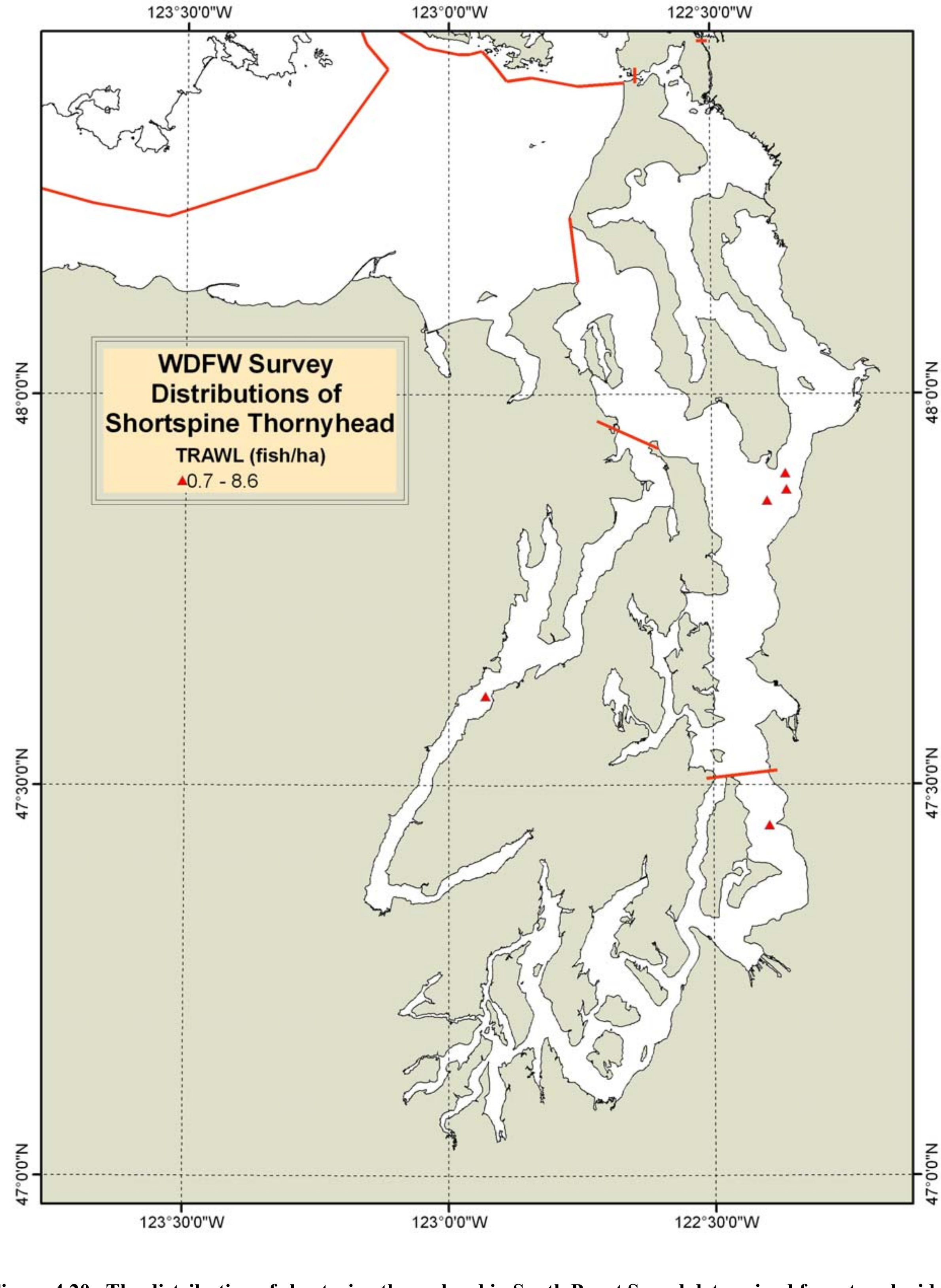


Figure 4.20. The distribution of shortspine thornyhead in South Puget Sound determined from trawl, video, and scuba surveys.

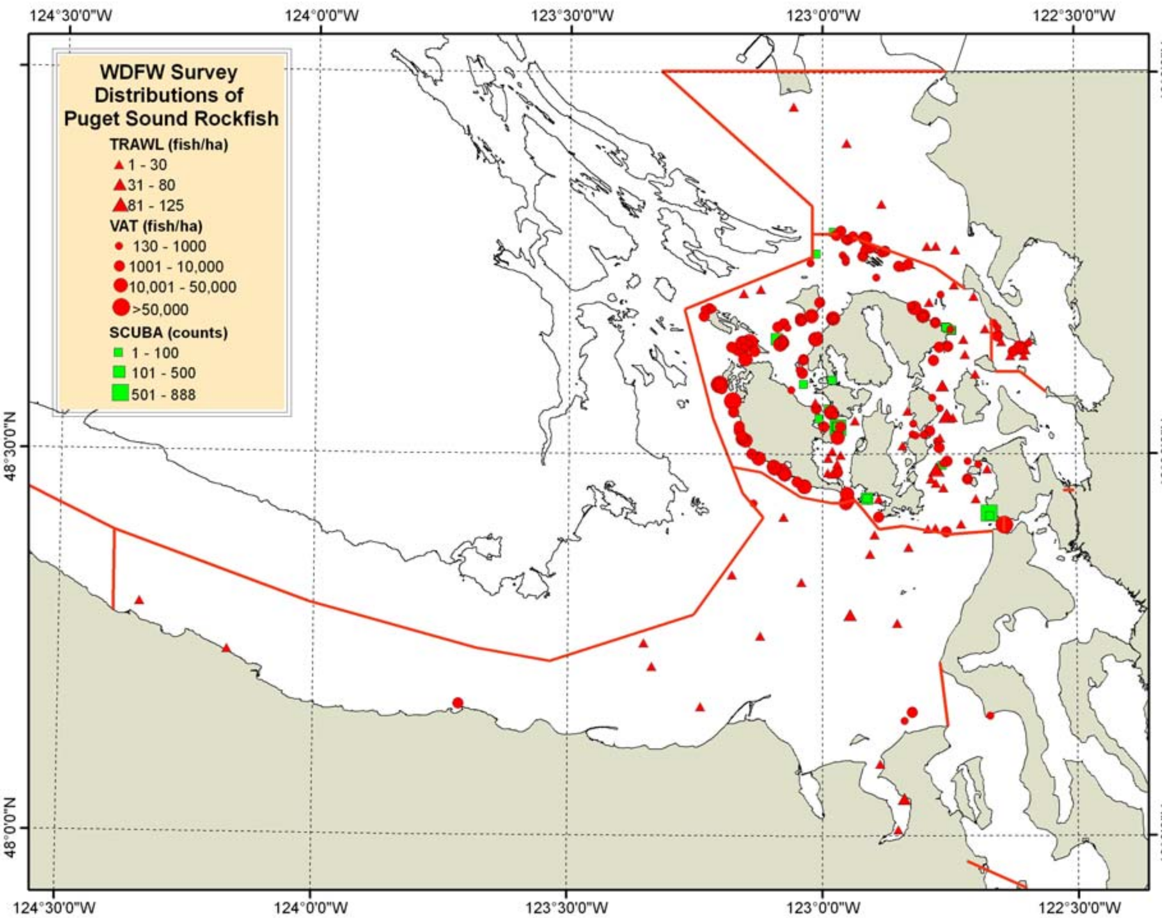


Figure 4.21. The distribution of Puget Sound rockfish in North Puget Sound determined from trawl, video, and scuba surveys.

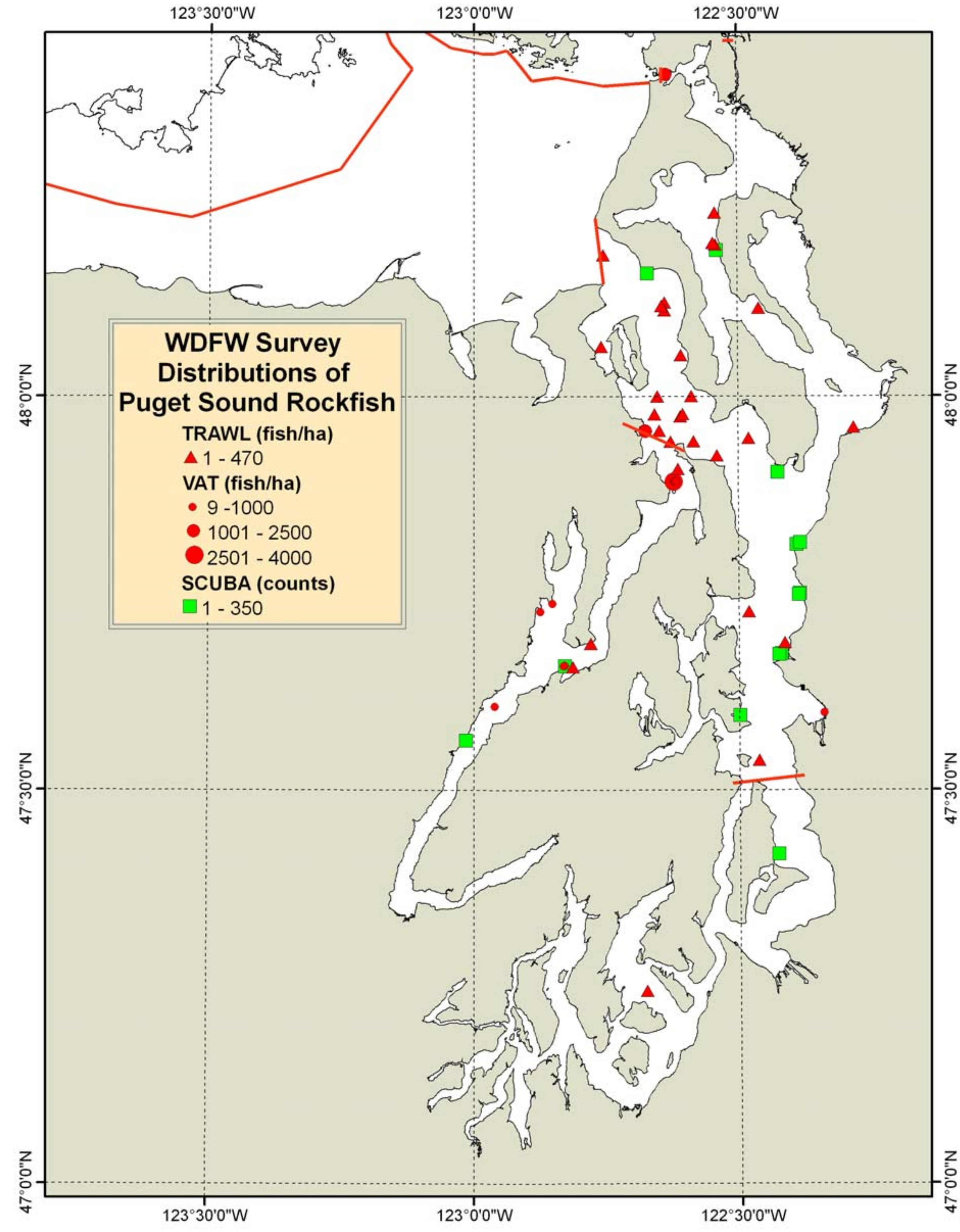


Figure 4.22. The distribution of Puget Sound rockfish in South Puget Sound determined from trawl, video, and scuba surveys.

4.5 Marine Reserves

Marine reserves are a form of marine protected area (MPA) where some or all fishing activity is prohibited by law or by community and personal choice (Gubbay 1995, Ward et al. 2001). Marine reserves around the world can benefit certain marine species by allowing for increased populations, size, reproductive output (Roberts and Polunin 1991, Halpern 2003) and may offer other benefits such as maintaining natural age, spatial, and sustainable community structures (Berkeley et al. 2004b). Their role at increasing fishery yields is more controversial, but marine reserves may provide benefits by increasing larval supply and emigrants that are caught outside the reserve. These benefits are still being explored and tested (Botsford et al. 2003, Hastings and Botsford 2003).

WDFW has a system of marine reserves (Figure 4.23), sixteen of which have rocky habitats and rockfishes. Reserves containing rockfish habitat include Yellow/Low Islands, Friday Harbor, Shaw Island, False Bay, Admiralty Head, Keystone Harbor, Brackett's Landing, Orchard Rocks, Saltwater State Park, Toliva Shoal, Colvos Passage, Titlow Beach, Zee's Reef, Waketickeh Creek, Octopus Hole, and Sund Rock. WDFW reserves include Conservation Areas where all non-tribal harvesting is prohibited and Marine Preserves where bottomfish and shellfish harvesting is typically prohibited but salmon fishing is allowed during open seasons. The oldest reserve containing rockfish habitat is the Brackett's Landing Marine Sanctuary (Edmonds Underwater Park) created in 1970, followed by the San Juan Marine Preserves in 1990 and then in 1994 through 2008 a series of reserves were created in Hood Canal, and Central and Southern Puget Sound. Other reserves exist including voluntary bottomfish recovery areas established by San Juan County, and other counties and entities are examining the expansion of marine reserves in Puget Sound and adjacent waters.

Investigators have examined the responses of rockfishes and other marine fishes to harvest protection in many of the WDFW reserves. Previous studies comparing fished and unfished areas have found higher fish densities, sizes, or reproductive activity than comparable nearby fished sites (Palsson and Pacunski 1995, Palsson 1998, Eisenhardt 2001, 2002; Palsson et al. 2004). Copper rockfish occurred in four times higher densities in the long-term Brackett's Landing reserve than among four fished natural and artificial habitats in central Puget Sound (Figure 4.24, Palsson and Pacunski 1995, Palsson 1998, Palsson et al. 2004). Copper rockfish were in slightly higher densities in the San Juan reserves than fished areas (Palsson and Pacunski 1995). Eisenhardt (2001, 2002) compared three reserves with matched fished areas in the San Juan Islands and found greater densities of copper and black rockfishes inside three reserves but higher densities of quillback rockfish in fished areas. In comparisons of fished versus unfished areas, the crucial assumption is that habitat and other conditions are matched between the two treatments. In a before-and-after study, Eisenhardt (2001, 2002) found a long-term increase in copper rockfish densities after reserve creation compared prior to reserve creation but found long-term decreases in quillback, black, and yellowtail rockfish densities. Copper rockfish were larger after ten years since reserve creation compared to before creation and were larger in the reserves compared to the comparable fished areas. Quillback rockfish were larger in fished areas than in reserves. The lack of response by quillback rockfish to reserve protection may be due to their slow growth and rare recruitment that may result in a longer time after reserve creation.

Marine reserves may also serve as a baseline for natural demographic information for stock assessment and conservation (Palsson et al. 1998). The size frequencies observed in long-term reserve at Brackett's Landing Marine Sanctuary demonstrate that 40 and 50 cm copper rockfish are the most common sizes in the unfished stock for observations pooled between 1999 and 2002 (Figure 4.25, Palsson et al. 2004). These size classes were less common in fished areas where 20 and 30 cm copper rockfish were the most frequent size classes. This result is similar to the size frequency distribution observed in early recreational catches (see Section 6 **Stock Assessment**).

Patterns of fish abundance may respond to factors other than fishing in marine reserves. Palsson et al. (2004) found a decreasing pattern in rockfish abundance at the long-term reserve at Brackett's Landing. Copper rockfish densities decreased while lingcod, a large predator, increased dramatically during the preceding five years. In other reserves, copper rockfish abundances were generally higher than comparable fished areas, but no dramatic increasing trends were observed in the San Juan or Central Sound reserves. Lingcod abundance and size have increased throughout the Sound including within the fished areas. The pattern of decreased or neutral densities of rockfish and increased lingcod abundance over time suggests that predation or prey competition may limit rockfish abundance in marine reserves and have the effects of a trophic cascade (Salomon 2002, Salomon et al. 2002. Beaudreau and Essington 2007, 2009).

Weis (2004) investigated larval rockfish distributions within and outside of marine reserves within Haro and San Juan Channels. She found a heterogeneous response with larval densities higher within reserves in Haro Strait than outside marine reserves, but the opposite trend for San Juan Channel. It was apparent that currents provide a mechanism for high connectivity among reserves and non-reserve sites.

The higher density distributions observed in long-term reserve may approximate unfished levels of abundance. This observation along with larger sizes of rockfish in the long-term reserve in comparison to fished areas infers that fishing is a major stressor to harvested rockfish stocks.

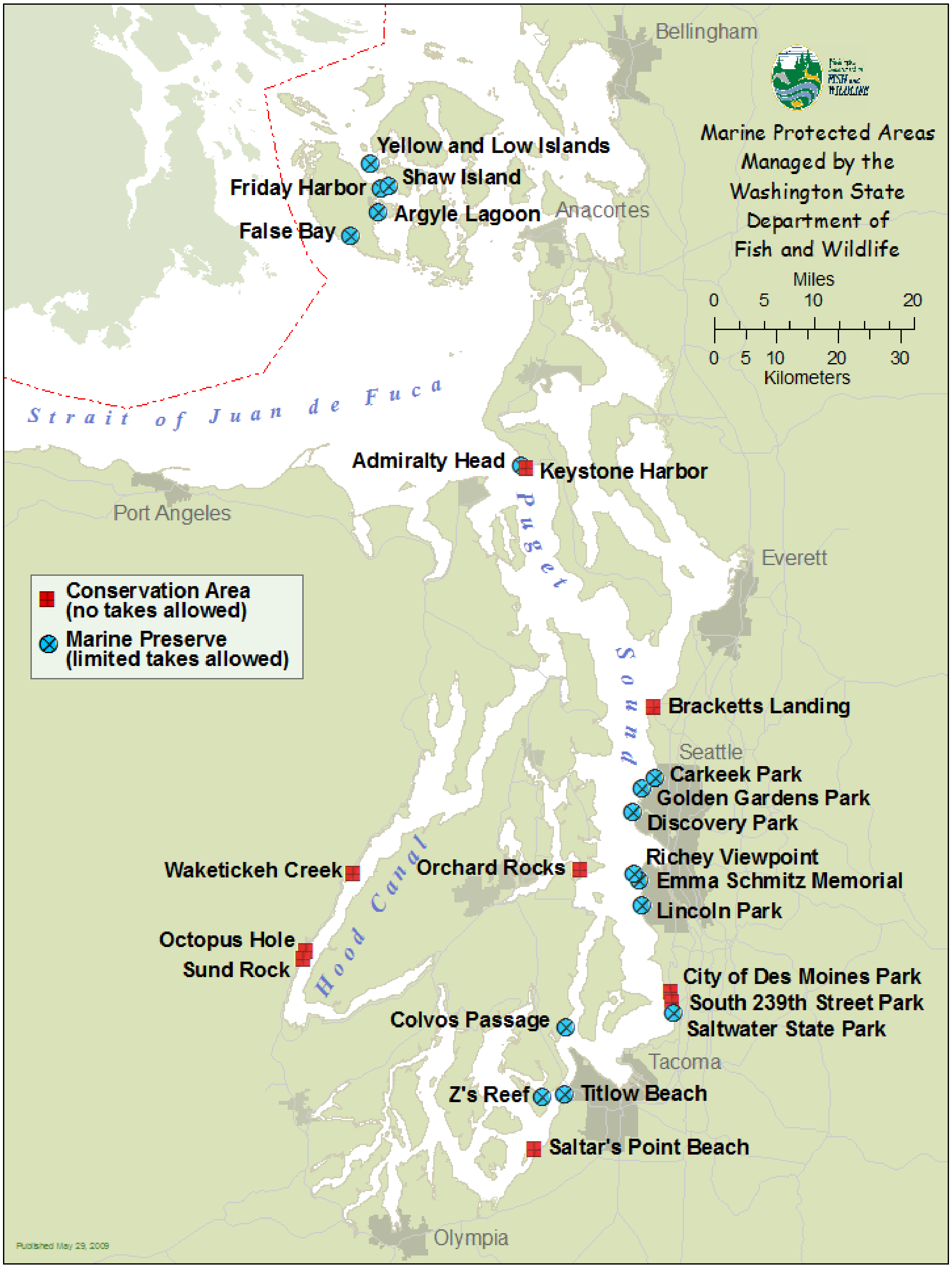


Figure 4.23. Marine reserves established by the Washington Department of Fish and Wildlife.

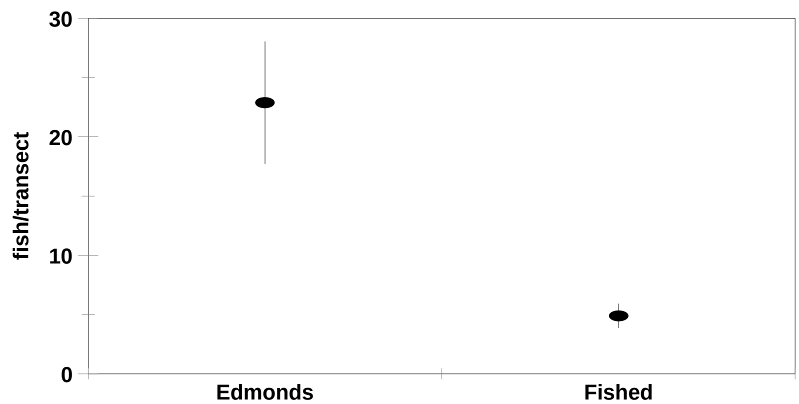


Figure 4.24. Density of copper rockfish within the Bracket's Landing Marine Reserve (Edmonds) compared to nearby fished areas, 1999-2002. (Error bars represent 95% confidence interval).

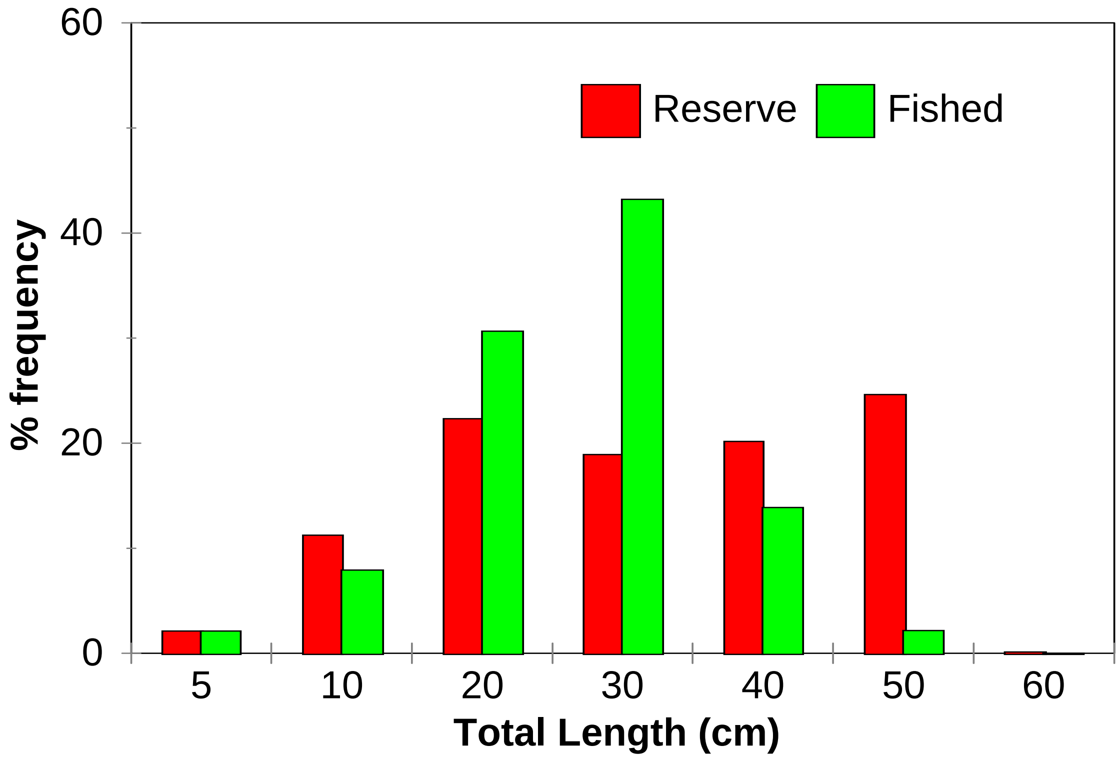


Figure 4.25. Length frequency distributions of copper rockfish from the Brackett's Landing Marine Reserve (Edmonds Reserve) and nearby fished areas, 1999-2002

5 FISHERIES AND CATCH STATISTICS

Puget Sound rockfishes have been harvested by tribal, commercial, and recreational fishers for decades and in some cases for hundreds of years. Certain terms are important to the understanding of catch statistics. The term “catch” refers to the amount of fish in terms of numbers or pounds that are “harvested” or “released”. Harvest refers to fish that are removed from the sea for food and are brought to shore at commercial processing facilities or at recreational boat ramps, docks, or other access points. Released catch are fish that are released back to the sea in live or dead condition. Bycatch is a term that includes released catch but also includes harvested fish that are caught incidentally to fisheries not targeting rockfish or some other specified group of fishes. Fishers have used a many different gears to catch rockfish including hooks on fishing line, trawls, and spears. The patterns rockfish fisheries have changed with time, and WDFW has been collecting or estimating some catches since the mid 1920s (Figure 5.1). Recent catches have been low relative to peak values observed during the late 1970s and early 1980s due to decreases in rockfish stocks and strong conservation measures.

5.1 Commercial Fisheries

Commercial fishers have harvested rockfish since the 1920s when net, line, and trap gear and markets were being developed and explored in Puget Sound. Many different types of commercial fishing gear are used in Puget Sound to catch groundfish. Some of these gears are designed to catch rockfish, and other types of gears are designed to catch other species of fish, such as salmon and flatfish but catch rockfish incidentally. The following is a brief description of the major types of commercial fishing gear used to harvest bottomfish in Puget Sound.

Trawl: This fishing gear consists of a large funnel shaped net that is pulled behind the fishing vessel. Most trawls are bottom trawls and are fished along the bottom; however, some nets are designed to fish above the bottom and are called midwater trawls. Trawling is the most efficient method of fishing for bottomfish and has contributed the bulk of the commercial bottomfish harvest in Puget Sound. A daily limit of rockfish equaling 500 pounds per day was instituted in 1998 in order to minimize vessels targeting on rockfishes (Table 2.1).

A special type of bottom trawl is the roller trawl that is modified to fish on rocky habitats. This trawl is equipped with bobbins or rubber rollers on the lower edge of the net, which allows the net to fish over rocky areas without becoming entangled. Roller trawl nets are intended to catch rockfish and other types of rocky habitat fish. The use of roller gear was introduced in Puget Sound in 1976. Use of this gear was low until 1980 when its use became more widespread in the trawl fleet. Analysis of the harvest patterns indicated that the use of roller gear substantially increased the catch of rockfish. In a study from June 1980 to November 1981, two vessels using roller gear averaged 242 and 663 pounds of rockfish compared to 49 pounds per landing for a otter trawl vessel fishing the same area without roller gear (Pedersen and DiDonato 1982). The use of roller gear has been prohibited in Puget Sound east of the Sekiu River since 1991 and in all Puget Sound waters in 2000 (Table 2.1).

Bottomfish jig: This gear has also been referred to as “hand line” jig and consists of fishing with a rod and reel or simply a line and is similar to recreational angling. The bait or lure is lowered to the bottom and “jigged” to attract a fish. Rockfish and lingcod were the primary target for this fishing gear, which was attractive to owners of small fishing vessels. Use of jig gear in Puget Sound was restricted in 1984 and prohibited in 1992 (Table 2.1).

Bottomfish troll: This fishery consists of a vessel moving forwarded slowly dragging one or more lines each with several hooks attached to it. This gear is well suited to fishing rocky outcrops. Lingcod was the main target for this gear but frequently took rockfish. Use of bottomfish troll in Puget Sound was restricted in 1984 and prohibited in 1992 (Table 2.1).

Set line: This gear consists of baited hooks attached to a long line that is stretched out along the bottom. The primary target of this gear is dogfish. However, rockfish are taken incidentally in this fishery, and a daily limit of 30 pounds of rockfish or lingcod in combination was instituted in 1998 to minimize targeting on rockfish, lingcod, and other species living on rocky habitats (Table 2.1).

Set net: This gear is essentially a sunken gillnet that lies vertically in the water while touching the bottom. Dogfish and historically, Pacific cod, are the main target species for this fishing gear.

Bottom trawling has accounted for the great majority of the recorded commercial harvest, averaging 84% of the commercial rockfish harvest since 1955. Other significant gears include set (long) line, bottomfish jig, set net, and bottomfish troll gears. While the target species is not specifically known for these gears, bottomfish troll and jig gears were typically used to target rockfishes and lingcod, and trawls at times were used to target rockfishes. Set line and set net gears primarily were used to target spiny dogfish (*Squalus acanthias*) (Palsson, In Press), and set net gears were once used to target Pacific cod (*Gadus macrocephalus*) in the Port Townsend area (Palsson 1990), but fisheries using these gears have resulted in significant landings of rockfishes. For some of the analyses below, non-targeting gear refers to set net, set line, and miscellaneous gears for salmon. Other types of fishing gear, such as beach seine and bottomfish pot are authorized for use in Puget Sound but rarely capture rockfish. Tribal fishers occasionally capture rockfish incidental to troll, setline, and seine fisheries for salmon and other species.

5.2 Recreational Fisheries

Several recreational fisheries have targeted rockfish or rockfish have been caught incidentally to other sport fishing activities. While recreational fishers have undoubtedly sought and harvested bottomfish prior to 1968 (Buckley 1967, 1968; Buckley and Satterthwaite 1970), statistical surveys were not implemented to estimate total recreational harvests in Puget Sound until 1970, and early estimates indicated that recreational harvests of rockfish were minimal (Palsson 1988). Targeted rockfish fisheries have included the boat-based hook-and-line fishery targeting bottomfish, the spearfishery, and the shore-based hook-and-line fishery. By far, boat-based anglers have accounted for the majority of harvested rockfish. These anglers, primarily using rod and reels bearing fishing lines attached to jigs, baited hooks, or other heavy tackle, target rockfish by discovering areas of high, rocky relief and suspending their baits and lures above the bottom. While fishing in the nearshore can result in untangled and successful castings, anglers using specialized synthetic lines and heavy weights can fish at depths to over 122 m on deep pinnacles or artificial structures. Rockfish are also caught incidental to halibut and lingcod fishing using similar fishing gear, and rockfish can be caught incidentally when fishers targeting salmon use mooching or downriggers near rocky or kelp habitats. Occasionally, rockfish anglers seeking black rockfish use fly fishing equipment or light spinning tackle when the fish are near the surface. Anglers fishing from shore occasionally catch rockfish using spinning gear and lures and baited hooks, in fact, the fishing piers developed by WDFW in the 1970s and 1980s are associated with artificial habitats just offshore of the piers. However, the catch of rockfish tends to be minimal by shore anglers (Bargmann 1982). Scuba and snorkel divers spear rockfish, and spearfishing is a sport that co-developed with the recreational diving. Divers using pole spears and spear guns have harvested rockfish in great numbers and can account for approximately a quarter of the total recreational harvest of rockfish in some areas and years (Bargmann 1984). Divers working from charter boats also speared a rockfish on one out of every three trips in the San Juan Islands (Palsson et al. 1991). Regulations have more recently restricted recreational fisheries of rockfish with the imposition of a one fish daily bag limit and the prohibition of spearfishing for rockfish (Table 2.1).

5.3 Data Sources for Fishery Statistics

WDFW has conducted surveys to collect fisheries related information, such as harvest, effort, bycatch, and species composition since the mid 1920s. For both commercial and recreational fisheries, harvest estimates were only available as the "total rockfish" category since sampling for species composition by trained observers has been erratic until 2003 when a regular training program was instituted for WDFW samplers. Some species composition data are available to approximate the species proportions in the harvest from other surveys or sampling efforts. Only recent or ancillary information is available for bycatch, the spearfishery, and the shore-based recreational fishery.

5.3.1 Commercial Fishery Harvest

WDFW has recorded rockfish commercial landings since the 1920s in the form of tax receipts or landing tickets. The poundage of rockfish landed by commercial fishers has been accounted for and well documented since 1955. Before then, WDFW queried fish processors on a regular basis as to what kind, when, from where, and how many fish were landed. After 1955, regulations required fish processors and commercial fishers to record their catch and associated information and report the catch on Fish Receiving Tickets that are sent to WDFW. When the fish are landed, fish processors are required to record the date, area of capture, gear, species, weight, and price paid on fish receiving tickets. These computer records are further processed with several modifications (Schmitt et al. 1991) to adjust for changes in fishing areas and converted into databases.

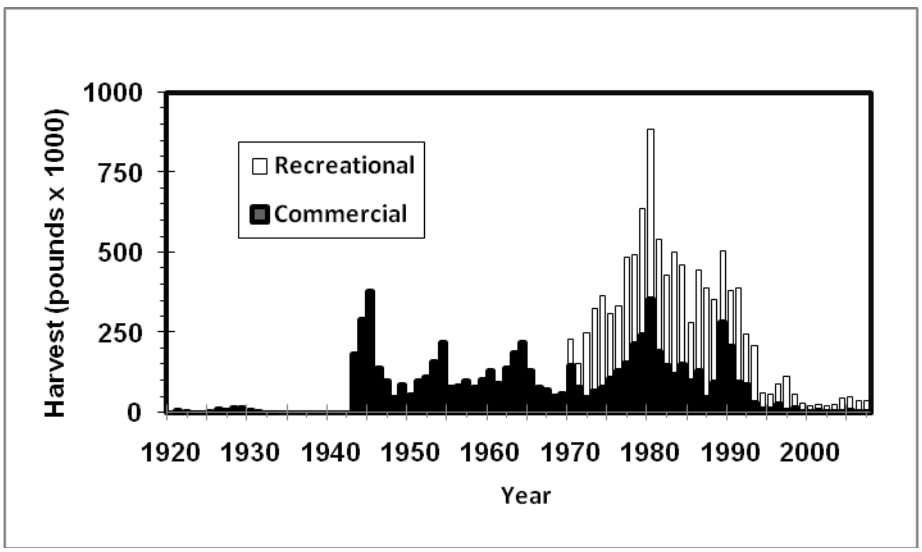


Figure 5.1. Reported or estimated harvest of rockfishes by recreational and commercial fisheries in Puget Sound.

5.3.2 Recreational Fishery Harvest

The foremost challenge in the last decade has been monitoring the dominant recreational fishery. Until 2004, bottomfish estimates from the WDFW recreational survey have depended upon open salmon fisheries and salmon catch record cards (Palsson 1988). This system necessitated year-round, open salmon fisheries to result in a complete estimate of bottomfish harvest by hook-and-line, boat-based fishers. Severe salmon fishery closures began in 1994 resulting in incomplete catch estimates for almost all catch areas until 2004 when a new catch estimation system was instituted. Other limitations exist for estimating catches for both commercial and recreational fisheries, including a lack of observed bycatch, consistent spearfishery estimates, and shore-based fishery estimates. A federal survey called the Marine Recreational Fisheries Survey (MRFSS) has inconsistently provided independent catch by species since 1980 for all of Puget Sound, however, comparisons between the estimates derived from WDFW and MRFSS surveys have left both surveys open to question. Beginning in 2004, a new WDFW survey has been initiated in Puget Sound and complete estimates of catch are available that are not affected by extensive closures of the recreational salmon fishery.

The primary survey of the recreational fishery in Puget Sound has been conducted by WDFW between 1970 and 2003. WDFW estimated the recreational catch of bottomfish by boat-based anglers through a combination of a system of required catch records from salmon anglers and a dockside creel survey of hook-and-line anglers (Palsson 1988, Conrad and Alexandersdottir 1993). When anglers harvest salmon in Puget Sound, they must record their harvest on a catch record card that is legally required to be returned to WDFW at the end of the year (note, harvests in this report are reported on an January to December basis). The salmon harvest is estimated by a subsample of the returned cards that are then used as a scaling factor for harvest information obtained from the creel survey. The corresponding creel survey is conducted at boat ramps, marinas and other public access points with sampling effort apportioned haphazardly to match the expected fishing effort among access points. Although exact computational methods changed after 1986, the creel survey is used to estimate the number of salmon caught per boat or fishing trip for each catch record area and month combination. This catch rate is then divided into the corresponding salmon catch to estimate the number of trips for the month and area. The bottomfish catch is estimated from this system by determining the catch per trip of bottomfish and multiplying by the number of trips for the month and area (Palsson 1988). The WDFW recreational catch estimates are made in terms of numbers of fish. The weight of the sport catch is approximated by averaging the pounds per rockfish from other surveys and data sources.

There are a number of limitations to the WDFW recreational catch estimates and time series. Beginning in 1994, large–scale closures occurred for the recreational salmon fishery, preventing successful bottomfish catch and effort estimates in many areas of Puget Sound. When an area is closed to recreational salmon fishing, there is no numerator to divide by then effort or bottomfish catch rate, preventing any point estimate of effort or bottomfish catch. Consequently, bottomfish catch and effort estimates have been severely underestimated from 1994 to 2003. Another limitation is that recreational catch estimates included in this report represent only those of the hook–and–line fishery from boats. Spearfishing and angling from piers and docks have not been regularly included in the recreational catch estimation scheme. These fisheries may have substantial catches that are not reported (Bargmann 1982, 1984). As with commercial catch data, WDFW has not monitored the bycatch, species composition, or age structure of the recreational catch on a consistent basis. However, beginning in spring 2003, anglers have been regularly asked how many and what kind of bottomfish they have discarded. In addition, training at bottomfish identification has been provided since 2003. Prior to that time, rockfish identifications by WDFW sport anglers have not been considered reliable, and only total rockfish harvest has been effectively estimated. A differential response bias has also affected the recreational catch estimates conducted by WDFW. The more successful salmon fishers have tended to return their catch record cards at greater rates than less successful anglers. In order to compensate for this overestimating bias, catch estimates prior to 1986 were decreased by 16.7% (Palsson 1988). After 1986, intensive, secondary creel surveys were conducted to better estimate the bias and salmon catch estimates were adjusted by a more complex formula.

The MRFSS has occurred in Washington State from 1980 through 1986, in 1989, and from 1996 through 2002. This federal survey is also a two-part survey that results in a state-wide catch and effort estimate for boat and shore-based recreational fisheries that includes the harvest by scuba divers and provides estimates of released and discarded catch (Witzig et al. 1992). The first stage of the survey is a bimonthly telephone survey of randomly-selected telephone numbers from coastal county residents that provides for angler trip estimates by shore or boat-based fishing modes. The second phase of the survey is a creel survey of boat and shore-based anglers and spearfishers with many similarities to the WDFW creel survey: Sampling effort is apportioned to expected effort and catch per trip information is collected to provide averages to partner with the effort estimates. More detailed information has been collected from the MRFSS creel survey but, overall, fewer interviews have been collected compared to the WDFW survey which has historically focused on the salmon fishery. The product of the trip estimates and mean catch rate yields estimates of catch by bottomfish species for the state. Since 1980, MRFSS samplers have been specially trained to identify bottomfishes particularly to discern the different species of rockfish. Several difficulties exist with the MRFSS survey. The survey during the 1980s did not capture the recreational fishery for salmon, so total marine effort and catch estimates were not possible. Also, since the survey is on a statewide basis, sampling effort has been difficult to apportion due to the very different patterns of the recreational fishery between the coast of Washington and Puget Sound. Finally, the MRFSS survey estimates are far greater than other survey estimates that have been conducted during the same time and area. Total catch estimates from the MRFSS have not been considered reliable by WDFW.

5.3.3 WDFW Phone-Creel Method

Beginning in 2004, WDFW instituted a new catch estimation scheme for boat-based, hook-and-line recreational fisheries that use a telephone survey of licensed fishers to estimate fishing effort and the existing WDFW creel survey that estimates catch rates. The new system replaces both the MRFSS and the WDFW system that was dependent upon open salmon fisheries. The new system also provides catch estimates of rockfish by target type and includes estimates of discarded catch also known as bycatch.

5.3.4 Species Composition

The similarity of rockfishes to each other has made the accurate identification of rockfishes by anglers and untrained samplers problematical (Bargmann 1981). Obtaining species composition information from commercial catches is hampered by the special effort required to sample commercial landings and the lack of precision by fish processors at identifying species. Commercial Fish Tickets do record species by several composite categories but have generally not been useful for describing harvest by species. Infrequent observations of rockfish landings have provided some information on the species caught in the commercial fisheries (Schmitt et al. 1991), but few recent observations have been made.

The identification of rockfish species in the recreational catch has been problematical. Official WDFW catch estimates from 1970 to 1986 were not necessarily based upon trained samplers. This systemic problem led Palsson (1988) to re-estimate the harvest of rockfish species from 1970 to 1986 by applying and average species composition to the total estimated rockfish harvest based upon mean species compositions observed from 1980 to 1986 by trained MRFSS samplers. From 1986 to 2003, WDFW recreational catch estimates were made recognizing the limits of accurate identification and were only made as the combined group of rockfishes. After 2003, WDFW samplers have been regularly trained in rockfish identification and harvest estimates of individual rockfish species were once again performed. For this report, MRFSS and trained WDFW observations were combined into a single database identified by North Sound and South Sound. Information is available for the years 1980-1986, 1989, and 1996-2007 as frequencies of species in the sampled but not estimated harvest. Early species composition observations are available for 1965 to 1967 based on expanded harvest estimates (Buckley 1967, 1968; Buckley and Satterthwaite 1970) and offer a glimpse into earlier species proportions of the rockfish harvest in North and South Puget Sound. Samplers at that time were developing their basis of species identifications and some observations may be questionable. Other species compositions by Bargmann (1977) were based, in part, during the time period of un-trained identifications and are not considered here. Because of these problems, nominal harvest estimates by year were not attempted.

5.3.5 Released Catch

The practice of releasing or discarding rockfish can have significant impacts on resources because many returned rockfish suffer direct or delayed barotraumas. Because of their anatomy and physiology, most captured rockfish from depths greater than 18 to 27 m are likely to die as a result of barotrauma (See Section 3.4.5).

Commercial harvest data do not include information on released catch, and there has been a lack of consistent, independent observations of catch on commercial fishing vessels. More information on released catch is available for recreational fisheries. Prior to mid-2003, WDFW samplers did not collect information on released catch during their interviews of recreational anglers. After 2004, the new WDFW protocol includes querying anglers of how many of which species are released back into the water. Similar questions were asked by MRFSS samplers during those years that the federal survey operated in Puget Sound. MRFSS estimates of released catch were divided by the total catch estimate to examine the trend in released catch rates over time. In both the new WDFW or MRFSS surveys, the estimates of released catch are dependent upon the veracity and accuracy of the reporting anglers. Direct observations of fishers have not been made to confirm released catch rates although rockfish have been observed as caught and released in some recreational fisheries in the outer Strait of Juan de Fuca (Noviello 1999).

5.4 Fishery Landing Trends

While commercial harvest of rockfish in Puget Sound may have started in the 1880's, no estimates of the landings were made until 1921 when record keeping began. However, the indications are that the commercial harvests of rockfish in Puget Sound were low until the early 1940's (Figure 5.1). Records indicate that less than 17,500 pounds per year of rockfish from Puget Sound were sold prior to World War II. During WWII, rockfishes were harvested at higher levels, peaking at 379,000 lbs in 1945. After the war, annual harvests decreased and fluctuated between 50,000 lbs and 220,000 lbs until 1970. Beginning in 1970, total harvest statistics include those from recreational fisheries and increases in harvest observed during the late 1970s and the declines seen during the 1990s have generally mirrored the increases and decreases in recreational and commercial fishing effort (Figure 5.2). Rockfish harvests increased to over 300,000 lbs per year in the mid-1970s and then increased to a historic peak of almost 900,000 lbs in 1980. Total harvests then fluctuated between 280,000 lbs and almost 540,000 lbs between 1981 and 1991 and then began to decrease to less than 200,000 lbs during the 1990s and declined again to less than 50,000 lbs during the 2000s. Between 1994 and 2003, however, total harvests do not include complete recreational harvests. Overall, the average annual rockfish harvest for Puget Sound between 1970 and 1993 was 400,000 lbs. Between 2004 and 2007 the average annual harvest was 42,000 lbs, an 89.5% reduction since full recreational harvest estimates were available and before directed fisheries on rockfish were restricted.

Harvest patterns are relatively similar between North and South Sound (Figures 5.3 and 5.4), with peak catches occurring in either 1979 or 1980. South Sound experienced a second peak series of catches of over 250,000 lbs in 1989 and 1990 that nearly equaled the historic catch in 1980. In both North and South Sound, rockfish harvests have substantially declined during the 1990s and early 2000s, but the decline can in part be attributed to incomplete recreational estimates. New catch estimates from 2004 through 2007 showed that annual rockfish harvests were between 32,000 lbs and 40,500 lbs, and much higher than annual recreational estimates from 2000 to 2003 when recreational harvest estimates were incomplete and the one-fish daily bag limit was in effect.

5.4.1 Commercial Fisheries

5.4.1.1 Harvest

Between 1970 and 2007, commercial harvests averaged 91,000 lbs per year in Puget Sound (Figure 5.1). Prior to 1998 when some commercial fisheries were still able to target rockfish, annual harvests averaged 118,000 lbs. The commercial rockfish harvest has averaged higher in North Sound than South Sound, averaging 52,000 lbs per year between 1970-2007 in North Sound and 32,000 lbs for the same period in South Sound (Figures 5.3 and 5.4). Commercial harvests peaked earlier in North Sound than South Sound with North Sound catches peaking at 263,000 lbs in 1980 and South Sound catches peaking later in 1989 at 215,000 lbs. Since 1999, commercial harvests from Puget Sound have averaged 4,600 lbs per year, a 96% reduction in commercial harvests since directed fisheries were restricted. For both North and South Sound, bottom trawls have been the dominant gear accounting for commercial rockfish harvests and averaging 74,000 lb per year since 1970 (Figures 5.5 and 5.6).

Commercial harvests in North Sound increased progressively from 1973 to the 1980 peak harvest with many annual harvests nearing 100,000 lbs before and after the peak (Figure 5.3). Annual harvests have averaged 52,000 lbs since 1970, but since 1999 commercial harvests in North Sound decreased to between 2,600 lbs and 8,700 lbs per year, averaging 4,500 lbs per year. Trawl gear has accounted for an average 75% of the total commercial harvest since 1970, averaging 38,000 lbs per year (Figure 5.5). The percentage of trawl harvest to commercial harvest has ranged from 27% in 1987 to 100% in 2003. During the 1970s, most commercially landed rockfish were by trawlers, but in the 1980s, other gears became equally or even more responsible for commercial rockfish harvests. On average, the bottomfish jig and troll gears that targeted rockfish and lingcod were responsible for 7% and 4% of the commercial rockfish harvest, but non-targeting gears, especially set lines accounted for an average 12% of the commercial harvest in North Sound. In the 1980s, set liners alone harvested up to 31,000 lbs of rockfish per year and accounting for the majority of the non-target gear catch. The imposition of rockfish quotas for set lines and the ban of bottomfish jig and troll gears in the mid 1990s resulted in the trawl gear once again accounting for the majority of the recent commercial rockfish harvest in North Sound. Since 1999, the annual trawl harvest has averaged 4,300 lbs in North Sound or 96% of the commercial harvest. Since 1999, non-targeting commercial fisheries excluding bottom trawls have landed less than 500 lbs of rockfish per year in North Sound and have averaged 150 lbs per year.

Commercial harvests of rockfish in South Sound doubled from the early 1970s to the early 1980s when harvests ranged between 60,000 and 90,000 lbs per year (Figure 5.4), Unlike North Sound, commercial harvests increased in South Sound during the late 1980s and early 1990s peaking at 215,000 lbs as a result of trawlers targeting rockfishes in Admiralty Inlet. Annual harvests averaged 39,000 lb per year in South Sound between 1970 and 2007 but the elimination of trawl fishing in all areas of South Sound in 1994 drastically altered fishing patterns. Prior to the ban, commercial harvests averaged 60,000 lbs per year, but since have averaged 70 lbs per year, ranging between 0 and 270 lbs per year. Prior to the 1994 trawl ban, trawling accounted for an average 89% of the commercial harvest or 53,500 lbs per year (Figure 5.6). During the 1970s and 1980s, trawl gear was the dominant source of the commercial harvest and bottomfish jig and troll gears were only a minor component of the harvest being limited by an earlier prohibition of these gears in most areas of South Sound. Non-target gears were important in South Sound for a brief period in the latter 1970s when set net gears accounted for the majority of the non-targeted, commercial harvest of rockfish. Setline and set net fisheries for dogfish and for Pacific cod (*Gadus macrocephalus*) and other miscellaneous gears landed between 14,000 and 27,000 lbs of rockfish per year between 1977 and 1981. Since 1970, these non-targeting gears have averaged 3,300 lbs per year but harvests have only averaged 70 lbs per year since 1995. Since 2004, rockfish harvested by all commercial fisheries has only averaged 39 lbs in South Sound.

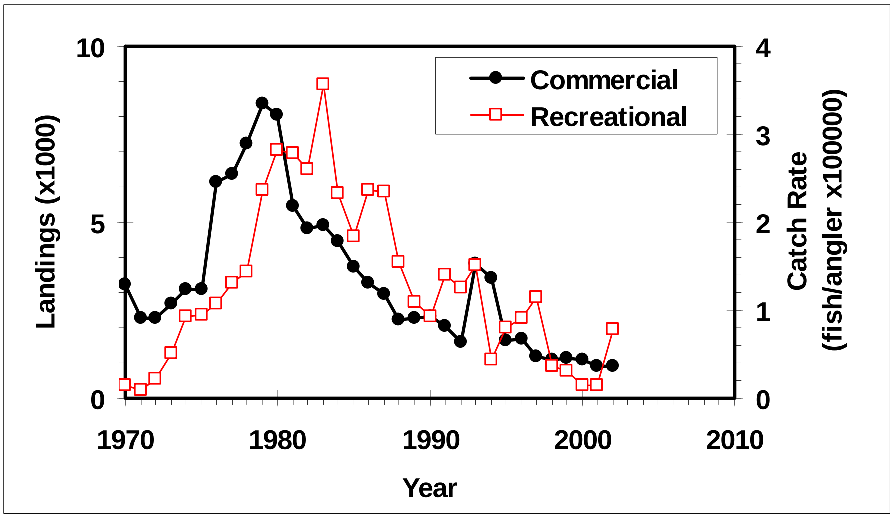


Figure 5.2. Fishing effort patterns for Puget Sound, 1970-2002: Commercial groundfish landings and boat-based recreational trips targeting bottomfish.

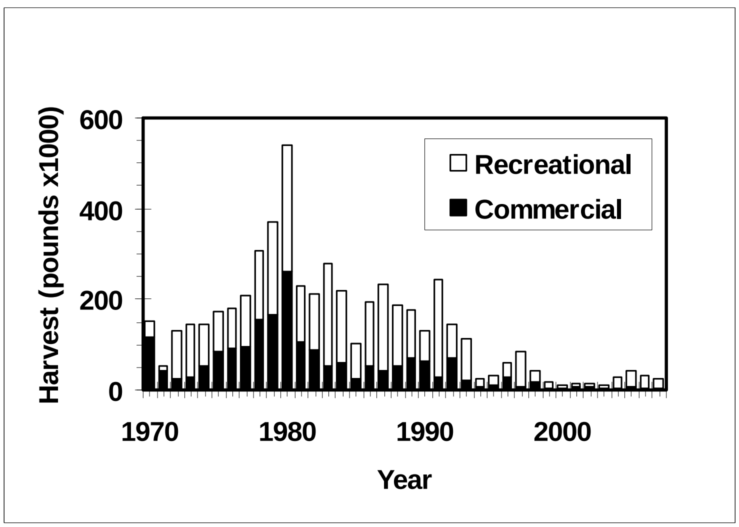


Figure 5.3. Recreational and commercial harvest (pounds) of rockfish from North Puget Sound.

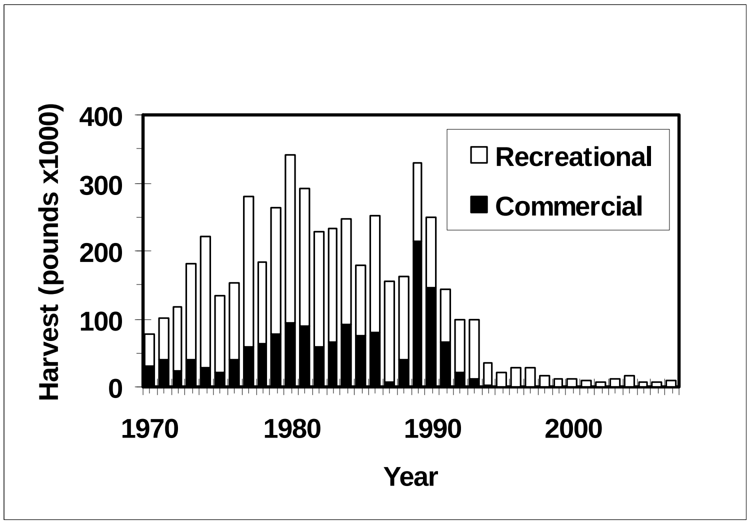


Figure 5.4. Recreational and commercial harvest (pounds) of rockfish from South Puget Sound.

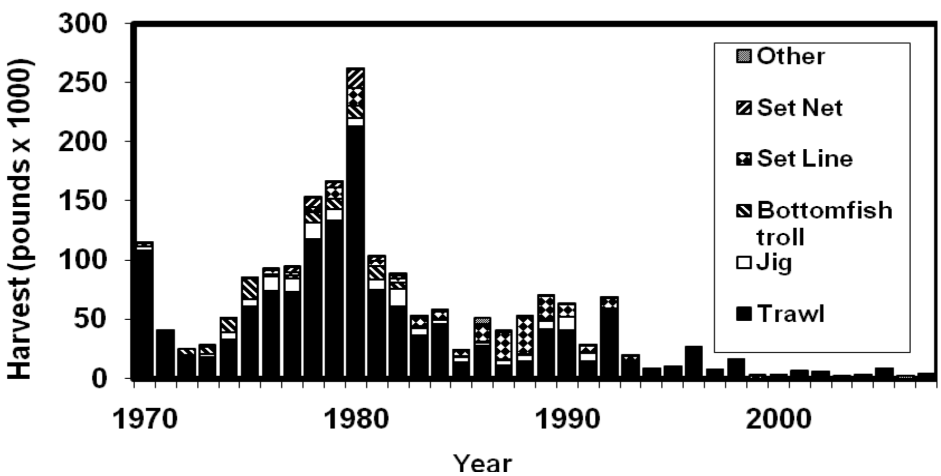


Figure 5.5. Commercial harvest (pounds) of rockfish by gear type for North Puget Sound.

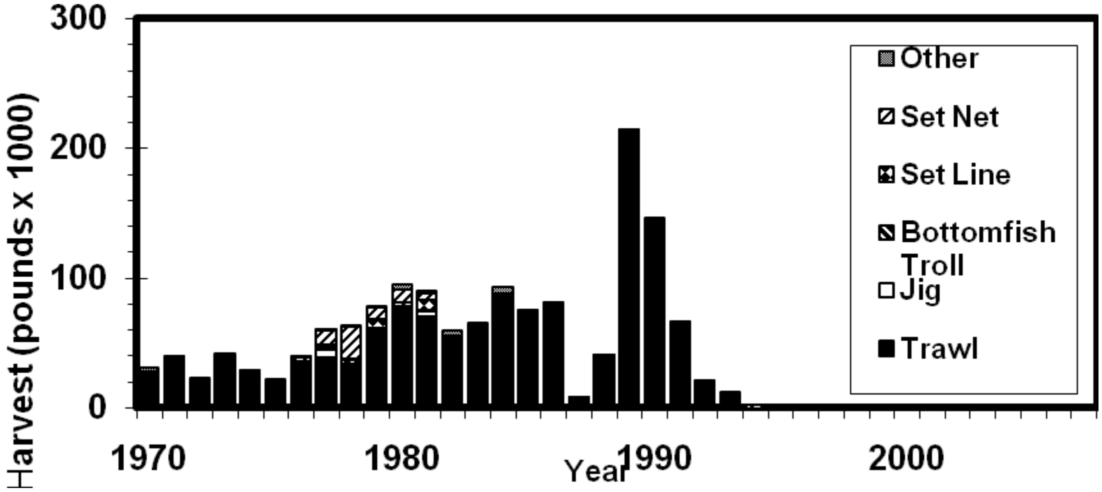


Figure 5.6. Commercial harvest (pounds) of rockfish by gear type for South Puget Sound.

5.4.1.2 Species Composition

Which rockfish species are harvested in commercial fisheries is not well known. In 1953, the species composition of the commercial catch was listed as 92% rockfish, 6% black rockfish, and 2% red rockfish. Schmitt et al. (1991) used species composition data taken from commercial landings at fish processing facilities by Pedersen and Bargmann (1986) and adapted these to their respective commercial fisheries for the period 1970-1987 and used new catch composition observations for 1988. Subsequent to that report, a few observations of commercial catches were made for 1989, 1990, 1991, and 1993 when the last observations of commercial rockfish compositions were taken. These species composition data applied to the total commercial harvests indicate that quillback yellowtail, and yelloweye rockfishes were the most frequently harvested rockfish in North Sound for commercial gears as a whole (Table 5.1). In South Sound, copper and quillback rockfishes were the dominant species in the commercial fishery (Table 5.2). In more recent years, commercial catch records include a specific yellowtail species category, and in 2004 to 2007, this species was the dominant rockfish landed in North Sound (Table 5.3).

The catch composition of the trawl gear in North Sound was unlike that of other commercial gears. Yellowtail rockfish dominated the trawl catch since 1988, especially resulting from fisheries in the Strait of Juan de Fuca (Table 5.1). During the 1970s through the mid1980s, quillback rockfish accounted for 42% of the trawl catch with copper rockfish accounting for only 12%, and yellowtail rockfish accounting for 43% of the North Sound trawl harvest. Yellowtail rockfish comprised 80% of the few mid-water trawl landings in the 1970s and 1980s with copper and quillback rockfishes equally comprising the remainder of the catch. For jig, bottomfish troll, and setline gears harvesting rockfishes in North Sound, quillback and yelloweye rockfish accounted for three quarters of the landed species. Quillback rockfish have dominated the landings of the jig gears, and yelloweye rockfish have dominated the species landed in the bottomfish and salmon and other troll and set line fisheries. Copper rockfish have comprised about 5 to 9% of the jig landings and 20 to 49% of the set net landings. Between 2004 and 2007, yellowtail rockfish comprised over 93% of the commercial rockfish catch with minor harvests of other rockfishes of less than 300 pounds per year (Table 5.3).

The catch composition of commercial gears in South Sound differs from that of North Sound. Most commercial gears, including the dominant trawl gear, harvested a mix of copper, quillback, and brown rockfishes (Table 5.2). From 1970 to 1989, the mix of these three species was approximately equal for the trawl fishery, but brown rockfish did vanish from the trawl fishery in subsequent years. The same pattern occurred for the jig fishery until it was closed in the remaining portion of South Sound in 1994. Set line, troll, and other gears had an equal mix of these principal species for the years when direct data were available. The one exception to the dominant species composition pattern in South Sound is for set nets that have primarily harvested bocaccio, a species that accounted for 70% of the rockfish catch throughout the 1970s and 1980s. Secondary species for this gear were copper and quillback that each comprised about 15% of the harvest. Annual commercial catches between 25 and 69 pounds of rockfish have been landed in South Sound between 2004 and 2007 (Table 5.3), and all were in the nearshore species category comprising brown, copper, or quillback rockfishes.

Table 5.1. Catch Composition (%) of Rockfishes from Commercial Fisheries in North Sound.

SPECIES	1970-87	1988	1989	1990	1991-2	1993-2003
Bottom Trawl						
Black	0.0	0.0	0.0	0.0	0.1	0.0
Bocaccio	0.0	0.5	0.0	0.0	0.0	0.0
Brown	0.0	0.0	0.0	0.0	0.0	0.0
Canary	0.0	0.2	0.7	0.0	2.7	0.4
Copper	11.9	11.3	8.8	8.3	8.7	8.8
Quillback	41.8	28.1	9.0	8.5	8.9	9.1
Yelloweye	1.1	0.8	0.0	0.0	0.3	0.0
Yellowtail	42.7	57.5	79.2	79.5	77.2	79.6
Other	2.5	1.5	2.2	3.6	2.1	2.1
Midwater trawl						
Black	0.0	0.0				
Bocaccio	0.0	0.0				
Brown	0.0	0.0				
Canary	0.0	0.0				
Copper	9.0	8.8				
Quillback	9.0	8.8				
Yelloweye	0.0	0.0				
Yellowtail	80.0	80.2				
Other	2.0	2.2				
Bottomfish Jig						
Black	9.2	7.3	9.7	9.6	9.9	10.1
Bocaccio	0.0	0.0	0.0	0.0	0.0	0.0
Brown	0.0	0.0	0.0	0.0	0.0	0.0
Canary	0.0	0.0	0.0	0.0	0.0	0.0
Copper	6.1	9.0	5.2	5.3	9.3	8.4
Quillback	42.3	47.9	40.7	40.9	44.5	43.1
Yelloweye	36.6	28.1	39.3	39.0	29.2	31.6
Yellowtail	0.0	0.0	0.0	0.0	0.0	0.0
Other	5.8	7.7	5.2	5.3	7.2	6.8
Bottomfish Troll						
Black	8.7	7.6	11.1			10.0
Bocaccio	0.0	0.0	0.0			0.0
Brown	0.0	0.0	0.0			0.0
Canary	0.0	0.0	0.0			0.0
Copper	0.0	0.0	0.0			0.0
Quillback	36.2	37.2	33.3			35.0
Yelloweye	47.4	43.4	55.6			50.0
Yellowtail	1.4	3.4	0.0			0.0
Other	6.3	8.3	0.0			5.0

Table 5.1. Catch Composition (%) of Rockfishes from Commercial Fisheries in North Sound. (continued)

SPECIES	1970-87	1988	1989	1990	1991-2	1993-2003
Salmon or Other Troll						
Black	9.8	10.3	9.2	9.4	10.0	7.7
Bocaccio	0.0	0.0	0.0	0.0	0.0	0.0
Brown	0.0	0.0	0.0	0.0	0.0	0.0
Canary	0.0	0.0	0.0	0.0	0.0	0.0
Copper	0.0	0.0	0.0	0.0	0.0	0.0
Quillback	35.0	35.3	35.9	35.4	35.1	34.3
Yelloweye	49.7	50.0	47.8	49.3	50.1	53.1
Yellowtail	0.4	0.0	1.2	0.3	0.0	0.0
Other	5.1	4.3	5.9	5.6	4.7	4.9
Set Line						
Black	0.0	0.0	0.0	0.0	0.0	0.0
Bocaccio	2.8	0.0	0.0	0.0	0.0	0.0
Brown	0.0	0.0	0.0	0.0	0.0	0.0
Canary	0.0	6.0	3.5	1.6	1.2	7.4
Copper	2.2	6.2	3.5	1.8	1.1	7.6
Quillback	62.0	36.3	19.6	12.6	5.4	34.4
Yelloweye	28.0	49.8	72.5	83.4	91.9	48.8
Yellowtail	0.0	0.0	0.0	0.0	0.0	0.0
Other	5.0	1.8	0.9	0.6	0.3	1.8
Set Net						
Black	0.0	0.0	0.0			0.0
Bocaccio	0.0	0.0	0.0			0.0
Brown	0.0	0.0	0.0			0.0
Canary	0.0	0.0	0.0			0.0
Copper	35.4	42.2	19.7			48.6
Quillback	60.5	53.6	74.2			48.6
Yelloweye	2.2	3.2	1.9			2.9
Yellowtail	0.0	0.0	0.0			0.0
Other	1.9	1.0	4.2			0.0
All Gears						
Black	1.6	0.8	1.0	1.8	1.6	0.1
Bocaccio	0.2	0.2	0.0	0.0	0.0	0.0
Brown	0.0	0.0	0.0	0.0	0.0	0.0
Canary	0.0	3.5	1.4	0.3	1.9	0.7
Copper	10.0	8.8	7.0	6.6	7.2	8.6
Quillback	44.2	35.5	16.3	15.2	13.6	10.0
Yelloweye	9.5	32.2	24.8	21.0	21.4	4.1
Yellowtail	31.0	16.6	47.2	51.7	51.7	74.3
Other	3.5	2.4	2.3	3.5	2.6	2.2

Table 5.2. Catch Composition (%) of Rockfishes from Commercial Fisheries in South Sound.

SPECIES	1970-87	1988	1989	1990	1991-2	1993-2003
Bottom Trawl						
Black	0.0	0.0	0.0	0.0	0.0	0.0
Bocaccio	0.0	0.0	0.0	0.0	0.0	0.0
Brown	36.0	36.1	1.4	0.0	0.0	0.0
Canary	0.0	0.0	0.0	0.0	0.0	0.0
Copper	29.4	39.6	86.4	45.0	45.0	45.0
Quillback	30.9	20.4	10.3	45.0	45.0	45.0
Yelloweye	0.0	0.0	0.0	0.0	0.0	0.0
Yellowtail	0.0	0.0	0.0	0.0	0.0	0.0
Other	3.6	3.9	2.0	10.0	10.0	10.0
Bottomfish Jig						
Black	0.0			0.0	0.0	0.0
Bocaccio	0.0			0.0	0.0	0.0
Brown	29.6			30.0	29.8	0.0
Canary	0.0			0.0	0.0	0.0
Copper	29.9			30.0	29.8	50.0
Quillback	30.5			30.0	29.8	50.0
Yelloweye	0.0			0.0	0.0	0.0
Yellowtail	0.0			0.0	0.0	0.0
Other	10.0			10.0	10.5	0.0
Bottomfish Troll						
Black	0.0	0.0	0.0			
Bocaccio	0.0	0.0	0.0			
Brown	21.2	30.2	33.3			
Canary	0.0	0.0	0.0			
Copper	21.2	30.2	33.3			
Quillback	21.2	30.2	33.3			
Yelloweye	0.0	0.0	0.0			
Yellowtail	0.0	0.0	0.0			
Other	36.3	9.3	0.0			
Set Line						
Black	0.0	0.0	0.0	0.0	0.0	0.0
Bocaccio	10.6	0.0	8.0	0.0	0.0	7.0
Brown	22.3	30.0	24.2	30.0	30.0	26.0
Canary	0.0	0.0	0.0	0.0	0.0	0.0
Copper	22.3	30.0	24.2	30.0	30.0	26.0
Quillback	32.0	30.0	31.5	30.0	30.0	32.2
Yelloweye	3.5	0.0	2.7	0.0	0.0	0.0
Yellowtail	0.0	0.0	0.0	0.0	0.0	0.0
Other	9.4	10.1	9.4	10.0	10.0	8.8

Table 5.2. Catch Composition (%) of Rockfishes from Commercial Fisheries in South Sound. (continued)

SPECIES	1970-87	1988	1989	1990	1991-2	1993-2003
Set Net						
Black	0.0	0.0	0.0	0.0	0.0	0.0
Bocaccio	67.4	69.8	69.9	70.7	69.8	70.5
Brown	0.0	0.0	0.0	0.0	0.0	0.0
Canary	0.0	0.0	0.0	0.0	0.0	0.0
Copper	13.1	13.0	12.8	12.2	13.5	13.4
Quillback	15.3	15.1	15.2	14.6	14.1	14.8
Yelloweye	0.3	0.0	0.0	0.0	0.0	0.0
Yellowtail	0.0	0.0	0.0	0.0	0.0	0.0
Other	4.0	2.0	2.1	2.4	2.6	1.4
All Gears						
Black	0.0	0.0	0.0	0.0	0.0	0.0
Bocaccio	4.0	0.7	0.2	0.0	0.2	11.2
Brown	32.8	35.4	1.4	0.3	1.3	17.6
Canary	0.0	0.0	0.0	0.0	0.0	0.0
Copper	27.6	39.0	86.1	44.8	44.3	28.2
Quillback	29.3	20.4	10.3	44.8	44.3	34.6
Yelloweye	0.1	0.0	0.0	0.0	0.0	0.0
Yellowtail	0.0	0.0	0.0	0.0	0.0	0.0
Other	6.2	4.6	2.0	10.0	10.0	8.3

Table 5.3. Pounds of Commercially Harvested Rockfish, 2004-2007 by General Receiving Ticket Categories.

	2004		2005	2006		2007	
SPECIES	North	South	North	South	North	North	South
Nearshore	18	25	116	14	69	46	63
Shelf	5		68			88	
Slope	144		27			9	
Reds	49		9	12		131	
Pacific Ocean Perch	15					4	
Shortspine Thornyhead			2				
Widow						13	
Yellowtail	3314		8515	2536		3985	
Grand Total	3545	25	8737	2562	69	4276	63

5.4.1.3 Released Commercial Catch

The commercial catch harvest described previously only includes the landed catch, i.e. the rockfish that are brought into port and sold. The amount of released catch is poorly known, but is thought to be small compared to the landed portion of the catch. Until 1998 there were no limits on the landing of rockfish by commercial fishers in Puget Sound, and since rockfish are valuable economically there has been no reason other than small size to discard marketable rockfish. Between 1979 and 1984 and at the height of the trawl fishery, WDFW placed observers on board trawlers in Puget Sound and found only trace amounts of rockfish were discarded (WDFW 1984). Since trawling produces the largest amount of landed rockfish catch, this implies that the overall rockfish discard rate is low; and some restrictions on landing rockfish have been recently enacted. These restrictions limit the amount of rockfish that can be landed during a single trawling trip. The inspection of landing records since 1998 indicates that few trawl landings reach the maximum daily limit of 500 lbs of rockfish.

5.4.2 Recreational Fisheries

5.4.2.1 Harvest

The harvest of rockfishes by boat-based, recreational anglers from Puget Sound has been consistently estimated between 1970 and 1993 and after 2004, but beginning in 1994 and until 2004, severe restrictions in the recreational salmon fishery compromised the completeness of these estimates. Recreational harvests have typically exceeded those of commercial harvests in each region and year (Figures 5.3 and 5.4). For Puget Sound, recreational harvests averaged 261,000 lbs per year between 1970 and 1993 when complete catch estimates were possible. Between 2004 and 2007, rockfish harvests have averaged 37,000 lbs per year representing an 86% reduction from early harvests. Recreational harvests from Puget Sound were relatively small during the first two years of consistent statistical estimation in 1970 and 1971 consisting of 61,000 pounds of fish for either region or year. Between 1972 and 1983, recreational harvests exceeded 88,000 lbs per year each in North or South Puget Sound, and during 1980, peak harvests occurred in North Sound at 279,000 lbs and in South Sound at 247,000 lbs. In terms of numbers of fish, the peak harvest was in 1980 when 279,000 fish were harvested from Puget Sound (Figure 5.7). Harvests typically fluctuated between 100,000 lbs and 200,000 lbs until 1991 in either region and then began to decline to less than 100,000 lbs until 1993 (Figures 5.3 and 5.4). After other fishing restrictions compromised the bottomfish catch estimation system in 1994, harvest information became incomplete and varied between 13,000 lbs and 33,000 lbs for most years in either region until 2000. After the adoption of the one fish daily bag limit in 2000, partial harvest estimates decreased to between 6,500 lbs and 9,300 lbs in North Sound for the years 2000 and 2003 and between 6,500 and 12,000 lbs in South Sound for the same period. When full harvest estimates began in 2004, the North Sound recreational harvest has ranged between 22,000 lbs and 35,000 lbs between 2004 and 2007 (Table 5.4). In South Sound the harvest of rockfish in South Sound has ranged from 6,000 and 17,000 lbs between 2004 and 2007.

The new WDFW system that was implemented in 2007 provides for reliable harvest estimates of individual rockfish species (Table 5.4). Just over 8,500 lbs of copper rockfish were harvested in North Sound in 2004, dominating the rockfish catch in that region and year, but the harvest of black rockfish was 24,000 and 18,000 lbs in 2005 and 2006, respectively showing that the relaxed catch limits in the Sekiu area highly influenced the species composition in North Sound. During the remaining years, the harvest of copper rockfish ranged between 4,900 lbs and 7,600 lbs and was once again the dominant rockfish harvested in North Sound in 2007. Quillback rockfish was the third most frequent species harvested in North Sound, and harvests ranged between 2,300 and 4,200 pounds. In South Sound, copper rockfish dominated the harvest between 2004 and 2007, ranging from a peak of 7,000 lbs in 2004 to a low of 2,900 in 2006, and again increasing to 4,730 lbs in 2007. Quillback rockfish was the second-most dominant rockfish since 2004 in South Sound with harvests ranging from a peak of 4,700 lbs in 2004 to equivalent catches of 1,400 lbs during the three subsequent years. Black and brown rockfishes have shared the rankings of the third and fourth most important species harvested in South Sound with harvests 185 lbs and 2,200 lbs.

WDFW's harvest statistics also provide information on how many rockfish are harvested by anglers fishing specifically for bottomfish versus anglers targeting salmon or anything. In the early 1970s, rockfish were harvested more by non-targeting anglers than by bottomfish anglers (Figure 5.7). As the 1970s progressed and through 2002, bottomfish anglers became the dominant source of the rockfish harvest accounting for 62% of the harvest, on average. Since 2004, non-targeting anglers accounted for 37% of the total recreational rockfish harvest, but overall, the average harvest by non-targeting anglers was 4,600 rockfish per year. The harvest by anglers not specifically targeting bottomfish has been reduce by 91% compared to an average 53,000 rockfish per year from 1970-1993 when complete harvest estimates were available (Figure 5.7). WDFW recreational statistics do not generally provide enough information to discriminate the unintentional catch of rockfish by anglers fishing for specific species of salmon.

The MRFSS provides a second series of recreational statistics for Puget Sound. These estimates include harvests from Neah Bay, Grays Harbor, and Willapa Bay and provide greater information on harvests by shore-based and spearfishers. The boat-based MRFSS catch trend differs from the WFDW time series (Figures 5.7 and 5.8) by a later and larger peak catch of over 700,000 rockfish 1989 instead of the peak catch of 279,000 fish that was estimated by the WDFW system in 1980 (Figure 5.7). MRFSS boat-based harvests of over 400,000 fish occurred in 1981 and 1982 and then trended downwards until the mid-1980s when they increased dramatically to peak levels in 1989 (Figure 5.8). Following the peak, catches declined from when the survey was resumed in 1996 through 2002, the last complete year of the separate survey. The MRFSS catch estimates have been consistently higher than WDFW estimates for the boat-based recreational fishery. During three years in the early and mid-1980s, the MRFSS boat-based catch exceeded the WDFW boat-based catch by a factor of 2 to 3. In 1989, the MRFSS estimates were more than 4 times the WDFW estimates. The MRFSS estimates of the 1990s and 2000s exceeded the incomplete WFDW estimates by factors from 3 to 12. The high estimates obtained from the MRFSS are suspect because they widely vary in magnitude and in comparison to WDFW's estimates. The peak MRFSS estimate of 1989 is contrary to the observed fishery pattern experienced by samplers and biologists.

Boat-based, hook-and-line anglers have been the primary source of the recreational rockfish fishery, however, anglers fishing from docks and spearfishers diving from both shore and boats also harvest rockfishes. WDFW has not been able to estimate the catch from these other fisheries on a regular basis, but did conduct two studies of the diving and shore-based fishery. A creel survey conducted in 1982 to 1983 found that spearfishing divers harvested an additional amount of rockfish that was equal to 26% of the total boat-based, hook-and-line catch in North Sound and 4% in South Sound (Bargmann 1984). MRFSS interviews provide a longer time series to evaluate the spearfishery. For Puget Sound, spearfishers harvest 7% of the boat-based harvest of rockfishes.

Based upon the relative MRFSS catch estimates between boat-based and shore anglers, the shore-based harvests of rockfish have always been a small fraction of the corresponding annual catch estimates for boat-based, recreational fishers (Figure 5.8). The shore-based harvest of rockfish was higher in the early 1980s when catches ranged from 26,000 to 49,000 fish then decreasing to 14,000 fish in 1989 and then fluctuating between 1,300 and 4,400 fish between 1996 and 2002. It is unknown if these catch values overestimate the shore-based catch, but their relative values indicate that shore-based fishers harvest an additional amount of rockfish that is equal to an average 5.6% of the boat-based catch estimate. In another creel survey, Bargmann (1982) found that shore-based anglers caught an additional rockfish harvest equal to 3.5% of the boat-based angler harvest in South Sound confirming that the shore-based catch of rockfish is relatively small compared to the boat-based fishery.

Table 5.4. Recreational Harvest (pounds) and Released Catch of Rockfishes, 2004 to 2007.

	2004		2005		2006		2007	
Species	**Harvest**	**Release**	**Harvest**	**Release**	**Harvest**	**Release**	**Harvest**	**Release**
North Sound								
Black	6741	4051	24208	13141	18072	5545	6986	4852
Blue	4	0	0	0	0	0	0	0
Brown	0	6	1	0	21	0	0	0
Canary	34	605	96	443	60	198	11	165
China	22	18	46	125	53	23	35	0
Copper	8505	7021	4870	4271	5028	3317	7614	2678
Greenstriped	0	0	0	0	0	0	12	5
Puget Sound	0	0	0	0	0	0	0	0
Quillback	2296	1109	2282	729	2454	1087	4195	1277
Redbanded	0	0	0	0	0	0	0	0
Redstripe	0	0	79	0	0	0	0	0
Stripetail	0	0	0	0	0	0	0	0
Tiger	2	0	16	1	9	0	0	0
Vermilion	3	44	31	24	0	40	2	0
Yelloweye	2	315	0	959	0	222	49	173
Yellowtail	1766	260	597	145	394	15	77	137
unidentified	4138	56839	2564	13135	1741	20448	2689	19502
All Rockfish	23513	70269	34791	32973	27831	30895	21671	28789
South Sound								
Black	2169	47	318	165	185	21	836	12
Blue	0	0	0	0	0	0	0	0
Brown	1552	183	436	94	992	46	706	219
Canary	615	1287	0	0	0	0	110	47
China	0	0	7	0	0	45	0	0
Copper	6946	1812	3245	1002	2913	1136	4730	697
Greenstriped	0	0	0	0	0	0	0	0
Puget Sound	0	0	0	0	0	0	0	0
Quillback	4728	3410	1380	82	1425	482	1401	304
Redbanded	0	75	0	0	0	149	0	0
Redstripe	0	0	0	0	0	0	0	0
Stripetail	0	0	0	0	0	0	0	0
Tiger	2	0	0	0	0	0	0	0
Vermilion	87	0	72	0	25	0	32	0
Yelloweye	0	6	0	21	0	5	0	86
Yellowtail	127	0	0	52	0	2	29	16
unidentified	782	34730	963	19290	1541	9920	2626	18314
All Rockfish	17008	41549	6421	20707	7081	11805	10470	19695
Puget Sound								
All Rockfish	40520	111818	41212	53680	34912	42701	32141	48483

5.4.2.2 Species Composition

The MRFSS and focused WDFW sampling efforts have provided species composition information for the recreational harvest at sporadic intervals during the past 27 years. Because the level of training for rockfish identification has varied among years, the historical comparisons of species compositions are based upon the frequencies of rockfish species observed by creel samplers pooled for each North and South Sound and are not based upon the expanded catch estimates. Between 1980 and 2002, MRFSS and specially trained WDFW samplers provided identifications, after 2003, all WDFW samplers have been trained in rockfish identification. In terms of frequencies of sampled species, copper, quillback, brown, and black rockfishes were the dominant species harvested in Puget Sound since 1980, but differences existed between North and South Sound (Table 5.6, Figures 5.9 and 5.10). In North Sound, copper, quillback, and black rockfishes dominated the catch, while in South Sound, the third most dominant species was usually brown rockfish after copper and quillback rockfishes. It should be noted that high proportions of unidentified rockfish were discarded and sampled during the two most recent years of recreational catch statistics.

The proportions of the dominant and minor species have changed over time in North Sound. In North Sound, copper and black rockfish were equally common in the harvest in 1980 (Table 5.6, Figure 5.9). After 1980, black rockfish decreased in the recreational harvest from 20% to less than 5% by 1989. Black rockfish resurged during the late 1998s and through 2007 in North Sound. More detailed analysis revealed that the black rockfish once common in the San Juan Islands in the early 1980s became virtually absent (WDFW, unpublished data). The resurgence of black rockfish in North Sound was likely due to an influx into the western Strait of Juan de Fuca from coastal waters and the regulation changes allowing greater black rockfish harvest in the Sekiu area. In 2006, black rockfish composed 37% of the inspected catch in North Sound, but less than 1% was taken from the San Juan Islands. Quillback rockfish in North Sound were more common in recreational creels during the early 1980s when they comprised 20% to over 40% of the harvest. In the 1990s and early 2000s, quillback rockfish comprised 10% to 30%, and only 20% of the most recent four years samples. Throughout the time series, copper rockfish has become the dominant species in the recreational catch. Copper rockfish comprised approximately 40% of the recreational catch in the 1980s, and then proportion increased to a peak 70% in 1996 and then has fluctuated between 30% and 60% of the catch in the 2000s. Yellowtail rockfish comprised approximately 10% of the North Sound Recreational catch during the 1980s but have become virtually absent in recent years.

During the past 27 years, uncommon species have tended to become less frequent in recreational catches in North Sound. In 1980s, the “other species” category comprised between 5% and 10% of the recreational catch but only comprised less 5% for most years since 1989 and less than 2.6% since 2004 (Figure 5.9). Regulations prohibiting the retention of yelloweye and canary rockfishes since 2002 may in part explain the most recent declines in some of the “other species” category. Yelloweye rockfish comprised between 2% and 5% of the North Sound recreational harvest prior to 2001, after which they were not recorded in the harvest. In North Sound recreational fisheries, canary rockfish constituted an average 1.4% for the recreational catch from 1980 to 1989, but their frequency decreased to an average 0.6% of the catch from 1996 until 2002 when their retention was prohibited (Tables 5.6 and 5.7). While the proportions of these recently prohibited species have comprised significant portions of the “other” category, other species appear to be declining in the recreational harvest in North Sound. Yellowtail rockfish occurred in 9% of the 1980 and 1982 recreational catch in North Sound (Table 5.6) and averaged 4.4% of the recreational rockfish catch during the 1980s (Table 5.7). Yellowtail comprised 1.8% of the recreational catch after 1996. Bocaccio comprised less than 0.2% of the recreational rockfish catch in North Sound between 1980 and 2007 (Table 5.6). Restripe rockfish is also very uncommon in North Sound recreational catches and only averaged 0.06% during the 1980s and then decreased to an average of 0.02% after 1996 (Table 5.7). Most other rockfish species have occurred in less than 0.5% of the average annual catches in North Sound since 1980 (Table 5.7)

The species composition in South Sound had similarities to the patterns observed in North Sound in that copper rockfish became more dominant in the sampled catch, increasing in the catch from 25% in the early 1980s to 67% in the 1990s and 2000s (Table 5.6, Figure 5.10). Quillback rockfish were the second-most common rockfish in the recreational catch but first comprised between 25% and 28% of the catch in the 1980 and 1981 and then increased to between 33% and 47% of the South Sound catch between 1983 and 1989. Quillback rockfish have become less frequent since 1996 ranging between 25% and 35% of the rockfish harvest and only accounted for 18 to 23% of the most recent four years inspected catch. Brown rockfish have been prevalent in the South Sound constituting 14 to30% of the catch between 1980 and 1989 but then decreasing and varying widely in frequency from 2% to 30% after 1996. Between 2004 and 2007, brown rockfish have attributed from 7% to 16% of the South Sound harvest. Black rockfish are far less common in the recreational catch of South Sound but once comprised up to 11% of the catch in 1981 and then fluctuated at lower levels of less than 15% in other years. During the most recent four years, black rockfish only comprised 5% or less of the recreational harvest in South Sound.

As in North Sound, uncommon species have trended downwards in the South Sound catch. During the early 1980s, the “other species” category comprised from 5% to 20% of the recreational catch in South Sound (Figure 5.10). During the 1990s and 2000s, the other species have been non-existent in the harvest or have comprised less than 7% of the harvest in all years except 2000 and since 2004 when they accounted for 2.2% of the catch. In 2000, canary rockfish was the most common species of the “other” category (Table 5.6). In South Sound, canary rockfish comprised an average 1.0% and 1.4% of the recreational rockfish catch for the time periods 1980 to 1989 and 1996 to 2002, respectively. In South Sound, yellowtail rockfish averaged 1.6% of the recreational rockfish catch prior to 1996 and then decreased in frequency to an average 0.3% for the period 1996 to 2007 (Table 5.7). Bocaccio averaged 0.2% in South Sound during the 1980s but prior to 1996, but was not encountered in South Sound after 1996. Redstripe rockfish once frequently occurred in recreational rockfish catches in South Sound where they once comprised 14% of the rockfish catch in 1980 (Table 5.6). Between 1980 and 1989, redstripe rockfish comprised an average 6% of the recreational catch in South Sound, but restripe rockfish have not been observed in the South Sound recreational catch after 1996 (Table 5.7). In South Sound, greenstriped rockfish occurred infrequently in recreational fisheries where they comprised an average 0.6% of the recreational rockfish catch prior between 1980 and 1989 and averaged 0.2% of the catch after 1996 (Table 5.7). Other species of rockfish have averaged less than 1% of the recreational rockfish catch in South Sound after 1980.

Early attempts at catch estimation for the recreational fishery in Puget Sound by Buckley (1968, 1986) and Buckley and Satterthwaite (1970) provides some basis to compare species compositions observed between 1965 to 1967 to more recent species compositions. These comparisons showed several marked differences in rockfish species occurrences over the past four decades (Table 5.7). For both North and South Puget Sound, quillback rockfish did not constitute more than 6% of the mean annual catch during the mid 1960s while during both the 1980s and 1996-2007 series, quillback rockfish comprised at least 25% of the recreational harvest of rockfishes. Copper rockfish in North Sound, however, constituted about half of the recreational harvest during the 1960s as they did after 1996. In South Sound, copper rockfish comprised three quarters of the recreational harvest of rockfish during the 1960s, while they only comprised a third of the harvest during the 1980s and 56% of the harvest after 1996. A number of rockfish species were more frequent in North and South Sound during the 1960s than later, including black, yelloweye, canary, and silvergray rockfishes. In particular, yelloweye rockfish was 2.4% of the harvest in North Sound during the 1960s, occurred in 2.1% of the harvest during the 1980s, but then decreased to an average 1% after 1996 until the prohibition for landing that species in 2002. In South Sound, yelloweye rockfish comprised 4.4% of the harvest during the1960s, only 0.4% during the 1980s, and 1.4% after 1996 until the prohibition. Canary rockfish occurred in 6.5% of the North Sound recreational harvests during the 1960s and then declined to 1.4% and to 0.6% during the subsequent two periods. During the 1960s, canary rockfish comprised 3.1% of the South Sound rockfish harvest and then declined to 1.0% and 1.4% of the respective 1980s and after 1996 recreational harvests. As noted above, species other than the most four frequent species in each region, constituted a greater proportion of the 1980s recreational harvests of rockfish than later. These "Other" species constituted even greater portions of the recreational harvest during the 1960s. In North Sound during the 1960s, an average 16% of the rockfish harvest was other species, falling to 11% and 5% during the subsequent two periods. Other species comprised 21% of the recreational harvest during the 1960s in South Sound, and the harvest became less diverse to 14% and 7% of the rockfish harvest in the 1980s and after 1996, respectively. Bocaccio was one of these minor species and was rare in North Sound during any period, but in South Sound, this species was more frequent at 1.4% during the 1960s and declined to 0.2% in the 1980s and were not detected after 1996. The high proportion of copper rockfish and low frequency of quillback rockfish during the 1960s may call into question the ability of the samplers then to distinguish between these two similar species.

Despite training or the early attempts at species identification, several rockfish species have been identified in creel surveys that have not been recorded by ichthyologists or as museum specimens. These observations include shortbelly rockfish (*Sebastes jordani*) from the 1965-1967 series (Table 5.7) and chilipeper rockfish (*S. goodei*) observed in South Sound in 1981 by MRFSS samplers. While these species occur off the Washington Coast (Love et al. 2002), they are unprecedented occurrences in Puget Sound and may demonstrate the dificulities of species identification of early sampling programs to identify the diverse but similar rockfish species.

Table 5.5. Recreational Harvest, Released Catch and Total Catch in Numbers from North and South Puget Sound by Target Type, 2004-2007

		Bottomfish	Halibut	Salmon	Anything	All Target
2004						
North	Harvest	6681	253	530	1047	8512
	Released	20636	187	3212	1305	25340
	Catch	27317	440	3742	2353	33852
South	Harvest	5030	0	962	878	6870
	Released	7935	19	6001	1188	15143
	Catch	12965	19	6962	2066	22012
Puget	Harvest	11710	253	1492	1926	15382
Sound	Released	28571	206	9212	2493	40482
	Catch	40281	460	10704	4419	55864
2005						
North	Harvest	4962	387	2172	2261	9781
	Released	6555	605	1673	1407	10240
	Catch	11517	992	3844	3668	20021
South	Harvest	1563	2	468	659	2693
	Released	2945	20	4419	168	7552
	Catch	4508	22	4888	827	10245
Puget	Harvest	6525	389	2640	2920	12474
Sound	Released	9500	625	6092	1575	17792
	Catch	16025	1014	8732	4495	30266
2006						
North	Harvest	3573	226	1575	2705	8079
	Released	4449	155	3981	2047	10632
	Catch	8022	382	5556	4752	18711
South	Harvest	2209	1	594	232	3037
	Released	2316	2	1960	81	4359
	Catch	4526	3	2554	313	7396
Puget	Harvest	5782	228	2169	2937	11116
Sound	Released	6765	157	5941	2128	14991
	Catch	12547	385	8109	5065	26107
2007						
North	Harvest	5138	422	709	1389	7658
	Released	6449	322	2251	916	9939
	Catch	11587	745	2960	2305	17597
South	Harvest	2242	7	943	1085	4277
	Released	3278	19	3519	373	7190
	Catch	5520	26	4463	1459	11467
Puget	Harvest	7380	429	1652	2474	11935
Sound	Released	9727	342	5771	1289	17129
	Catch	17107	771	7423	3763	29064
Average percentage of released fish to total catch, 2004-2007						
North		**60.9**	**46.9**	**69.3**	**44.2**	**59.8**
South		**59.3**	**79.9**	**83.1**	**32.3**	**66.0**
Puget Sound		**60.2**	**47.9**	**76.7**	**41.9**	**61.9**

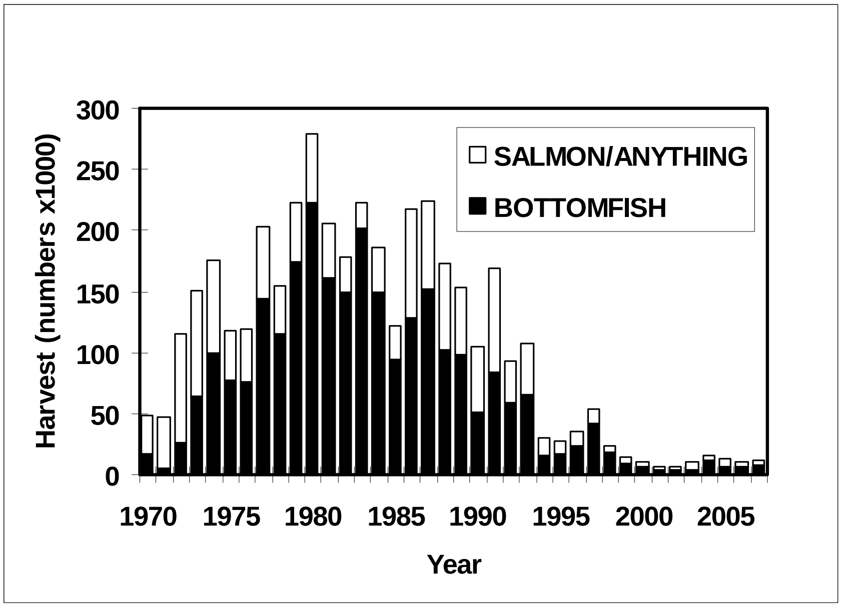


Figure 5.7. Recreational harvest of rockfish (in numbers) by bottomfish and salmon/anything targeting, boat-based, anglers in Puget Sound.

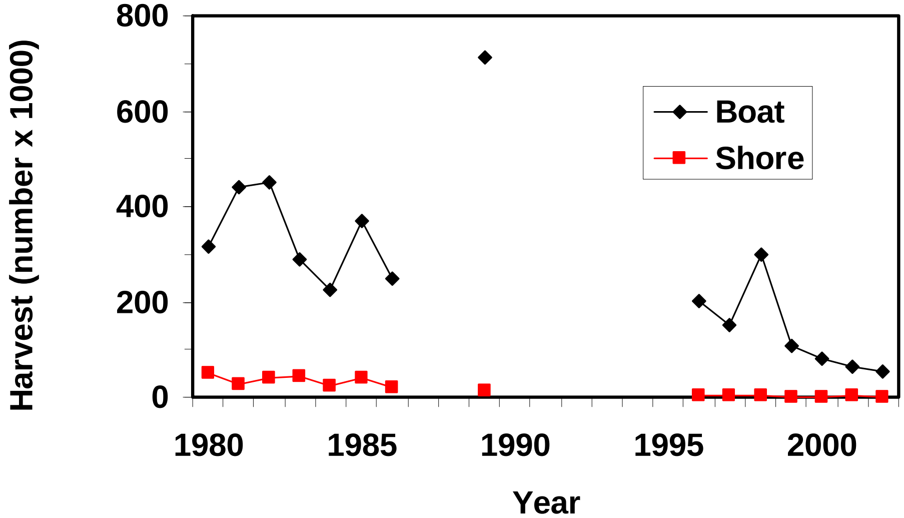


Figure 5.8. Recreational harvests estimates (numbers of fish) from the Marine Recreational Fisheries Statistical Survey for the inland marine waters of Washington.

Table 5.6. Percent Frequencies and Sample Sizes of Rockfishes Observed by Trained Recreational Fisheries Samplers in North and South Puget Sound.

Species	1980	1981	1982	1983	1984	1985	1986	1989	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
North Sound																				
Copper	26.9	34.3	37.1	31.2	46.5	42.2	43.9	51.7	70.9	52.9	63.9	46.5	57.4	39.0	38.5	45.9	44.9	42.9	43.9	59.3
Quillback	36.1	42.9	36.1	37.4	31.8	37.5	37.0	38.6	24.7	27.4	24.6	36.5	34.0	30.5	28.6	19.2	18.6	17.1	16.6	20.0
Black	24.2	8.3	10.4	19.0	13.2	10.8	10.4	4.8	2.1	8.1	9.7	10.5	6.2	25.4	31.9	30.2	30.3	35.7	37.0	18.2
Brown	0.4	0.7	3.2	0.3	3.8	1.4	0.0	0.2	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Yellowtail	7.2	9.0	8.9	3.4	1.3	2.5	2.3	0.2	0.7	1.8	0.4	3.5	0.6	1.7	0.0	2.7	3.6	3.1	1.9	1.8
Yelloweye	1.5	1.6	1.7	4.0	1.6	2.5	0.8	3.0	0.9	0.4	0.0	1.5	0.0	3.4						
Canary	1.5	1.8	1.7	2.2	1.3	1.9	1.0	0.0	0.3	0.4	0.6	1.0	1.2	0.0						
Blue	0.2	0.2	0.0	0.9	0.0	0.0	3.1	0.5	0.0	7.2	0.0	0.0	0.0	0.0	0.0	0.1	0.5	0.0	0.0	0.0
Vermilion	0.2	0.2	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.1	0.0	0.2	0.0	0.0
Tiger	0.1	0.0	0.2	0.3	0.6	0.8	1.0	0.0	0.2	0.9	0.6	0.5	0.6	0.0	1.1	0.1	0.2	0.0	0.2	0.0
Bocaccio	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Redstripe	0.1	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
Greenstriped	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
Widow	0.1	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Silvergray	0.4	0.2	0.2	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
China	0.7	0.5	0.0	0.6	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1.1	0.6	0.0	0.0
Rougheye	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pacific Ocean perch	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Shortspine Thornyhead	0.1	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sample Size	1121	434	404	321	318	360	519	433	578	223	496	200	162	59	91	715	613	490	513	275

Table 5.6. Percent Frequencies and Sample Sizes of Rockfishes Observed by Trained Recreational Fisheries Samplers in North and South Puget Sound.(continued).

Species	1980	1981	1982	1983	1984	1985	1986	1989	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
South Sound																				
Copper	24.1	22.0	21.9	32.8	42.6	30.3	34.6	30.3	60.5	67.1	59.4	43.2	36.2	53.8	63.5	51.0	55.6	59.4	63.2	67.1
Quillback	25.5	27.9	40.0	33.1	33.3	38.2	47.2	43.2	25.9	27.1	34.6	25.7	31.9	23.1	24.7	26.7	22.7	18.8	19.3	17.7
Black	1.3	10.7	3.0	3.6	3.2	1.2	1.1	3.6	0.5	0.0	0.0	1.4	0.0	15.4	2.4	3.0	3.7	4.8	2.4	5.3
Brown	29.5	22.5	18.4	17.0	15.1	20.8	13.9	20.1	5.9	4.7	1.5	29.7	21.3	7.7	9.4	16.9	15.8	16.4	14.5	7.8
Yellowtail	1.7	5.3	1.7	1.2	0.5	1.7	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.2	0.0	0.0	0.7
Yelloweye	0.4	0.8	0.4	0.1	0.0	0.3	0.1	0.3	5.9	1.2	2.3	0.0	0.0	0.0						
Canary	0.8	0.5	1.9	0.6	0.6	2.1	1.1	0.7	0.0	0.0	0.0	0.0	8.5	0.0						
Blue	0.7	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Vermilion	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.7	0.7
Tiger	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.5	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0
Bocaccio	0.5	0.0	0.4	0.0	0.0	0.4	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Redstripe	14.2	7.5	9.8	8.1	4.2	3.0	0.8	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Green-striped	0.7	0.5	0.8	2.1	0.2	0.2	0.0	0.4	0.5	0.0	1.5	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0
Puget Sound	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Widow	0.0	0.3	0.1	0.1	0.0	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0
Silvergray	0.4	0.8	1.2	0.5	0.2	0.5	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
China	0.1	0.1	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0
Rougheye	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pacific Ocean perch	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chillipepper	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Stripetail	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Shortspine Thornyhead	0.0	0.3	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Thornyhead uniden.	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sample size	1460	1027	965	937	985	1292	760	1004	185	85	133	74	47	26	85	367	322	335	296	283

5.4.2.3 Released Recreational Catch

The MRFSS and recent WDFW catch estimates provided useful information on the magnitude of released catch in the recreational fishery. The MRFSS released catch rate averaged 15% between 1980 and 1986 of the total catch, increased to 26% in 1989, and varied between 6% and 26% between 1996 and 2000 (average 15%, Figure 5.11). The MRFSS released catch rate was 22% of the total catch in 2001 and then increased sharply to 51% in 2002, the last year of comparable statistics. This recent increase was likely a result of a sharp decrease in the allowable daily catch of rockfish to one fish per day after 2000.

The recent high rates of released catch estimated by the MRFSS are substantiated by released catch estimates obtained from the WDFW Phone-Creel Surveys implemented since 2004 (Tables 5.4 and 5.5). On average, for every rockfish caught in Puget Sound, one and a half were released back into the water, or in other words, 62% of the total catch was released (Table 5.5). This average rate was slightly lower in North Sound where 60% of the catch was released and slightly higher at 66% in South Sound. During 2004, 25,000 rockfish were caught and discarded in North Sound but the released catch between 2005 and 2007 was 10,000 fish. In South Sound, 15,000 rockfish were released in 2004 compared and afterwards the released catch varied from 4,400 to 7,500.

Released catch rates varied by target type with bottomfish anglers releasing 60% of the total catch (Table 5.5), but salmon anglers releasing 77% of the rockfish catch. The discard rate by salmon anglers was higher in South Sound at 83% compared to North Sound where it was 69%. Halibut and anything anglers tended to retain higher proportions of the rockfish catch. On average, anglers fishing for halibut discarded one rockfish for every one kept (48%) and anglers fishing for anything discarded 42%.

5.4.2.4 Total Recreational Catch

With the estimation of both harvest and released catch for the recreational fishery, estimates of total catch were possible. Total rockfish catch for the Puget Sound recreational fishery was 55,900 fish in 2004, 30,300 fish in 2005, 26,100 in 2006 and 29,000 in 2007 (Table 5.5). In terms of pounds these estimates were 152,000 lbs in 2004, 94,900 lbs in 2005, 77,600 in 2006, and 80,624 in 2007 (Table 5.4). These recent catch levels are generally not as great as estimated recreational harvests during the 1970s and until 1993. During those earlier years, total catch was likely 15% greater due to released catch as indicated by the early years of the MRFSS. However, with depressed rockfish populations, the magnitude of the total harvest may be still limiting rockfish populations due to the recent increases of released catch.

For total catch estimates, the unidentified rockfish category accounted for the single greatest component of the species catch. This resulted from anglers reporting the general group of rockfish as released catch. When reconciling individual species catch, the substantial unidentified categories must be adjusted and added to nominal species catches by the application of the latter’s proportion of the total nominal catch.

Table 5.7. Mean annual species compositions of rockfishes (%) for three periods observed in the recreational harvest in North and South Puget Sound.

Species	1965-1967[a]	1980-1989	1996-2007
North Puget Sound			
Copper	48.06	39.24	50.49
Quillback	5.50	37.17	24.81
Black	30.38	12.65	20.44
Brown	0.44	1.26	0.07
Yellowtail	3.70	4.36	1.81
Yelloweye	2.41	2.09	1.03
Canary	6.46	1.43	0.61
Blue	1.52	0.61	0.65
Vermilion	0.18	0.08	0.05
Tiger	0.07	0.38	0.37
Bocaccio	0.00	0.02	0.01
Redstripe		0.06	0.02
Greenstriped	0.00	0.00	0.03
Widow		0.07	0.01
Silvergray		0.14	0.00
China	1.26	0.34	0.16
Rougheye		0.04	0.00
Pacific Ocean perch		0.02	0.00
Shortspine Thornyhead		0.05	0.00
South Puget Sound			
Copper	75.63	29.82	56.79
Quillback	2.45	36.07	24.25
Black	9.00	3.47	3.38
Brown	0.48	19.68	13.14
Yellowtail	2.49	1.58	0.27
Yelloweye	4.43	0.31	1.56
Canary	3.11	1.02	1.42
Blue	0.05	0.18	0.00
Vermilion	0.28	0.00	0.14
Tiger	0.00	0.03	0.14
Bocaccio	1.41	0.20	0.00
Redstripe		6.03	0.00
Greenstriped	0.15	0.61	0.17
Puget Sound		0.00	0.15
Widow		0.12	0.02
Silvergray		0.55	0.00
China	0.10	0.07	0.09
Rougheye		0.01	0.00
Pacific Ocean perch		0.10	0.00
Chillipeper		0.01	0.00
Stripetail		0.01	0.00
Rosethorn	0.03		
Shortbelly	0.05		
Shortspine Thornyhead		0.12	0.00

[a] From Buckley (1967, 1968); Buckley and Satterthwaite (1970)

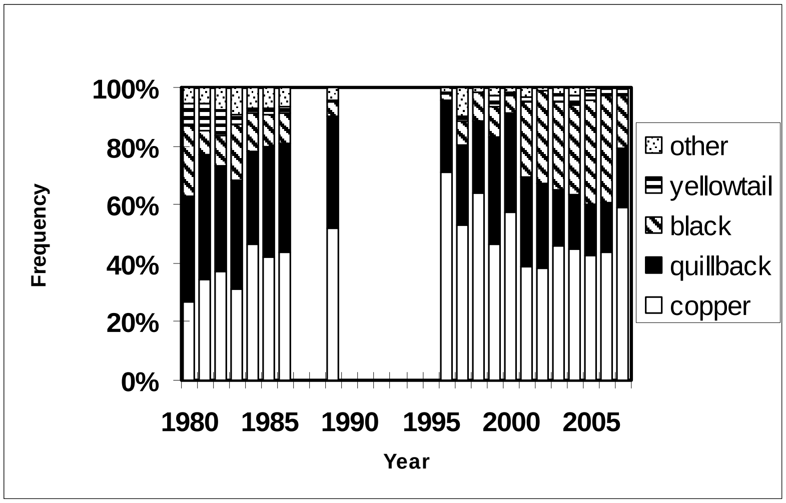


Figure 5.9. Recreational species compositions in North Sound.

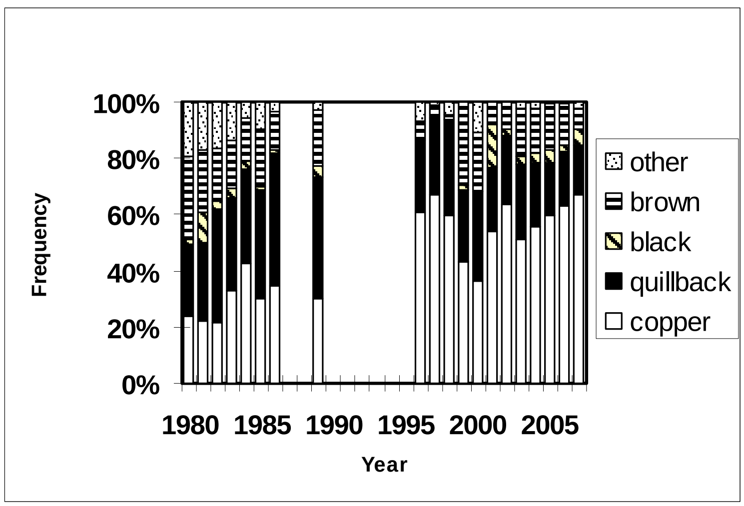


Figure 5.10. Recreational species compositions in South Sound.

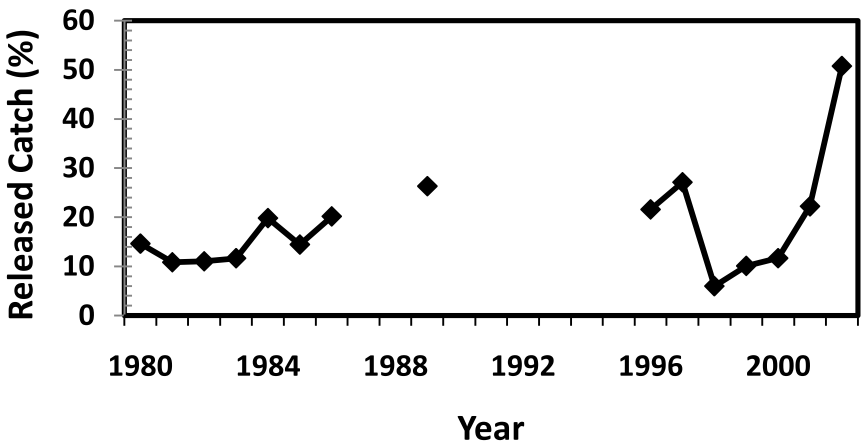


Figure 5.11. Percent released catch to total catch of rockfishes reported by anglers interviewed during the Marine recreational Fisheries Statistical Survey.

5.5 Tribal Fisheries

Rockfish bones have been found in native middens and archeological studies have shown that Native Americans historically harvested several species of rockfish (Stewart 1977). Rockfishes harvested by tribal fishers have contributed less than 2% to the total Puget Sound harvest for most years since 1991 (Table 5.8). The annual harvested poundage was the greatest in 1992 at 15,600 lbs and in 1998 when 1,371 lbs were landed. In both of these peak years, trawl gear was the primary gear of harvest. During other years, harvests have ranged to none to approximately 500 lbs with troll and other gears being the dominant source of the landings.

Table 5.8. Tribal Harvest (pounds) of Rockfish in Puget Sound by Gear Type.

YEAR	Setline	Setnet	Trawl	Troll	Jig	Other	Annual Total	% Total Puget Sound Harvest
1991	97		321	47	8	34	507	0.1
1992			15179	141	59	223	15,602	6.4
1993			519	32	2	22	575	0.3
1994				3		3	6	0.0
1995				21	105		126	0.2
1996	2	6		194		6	208	0.2
1997						53	53	0.0
1998			1328	34		9	1,371	2.4
1999				13		19	32	0.1
2000		35			99	11	145	0.7
2001	280				190		470	2.0
2002			29				29	0.2
2003								0.0
2004			3	191			194	0.4
2005	203			253			456	0.9
2006				34			34	0.1
2007				110		4	114	0.3

6 STOCK EVALUATION

6.1 Introduction

Stock evaluations provide information on the status (abundance, distribution, age structure, ecosystem influences, etc.) of fish stocks usually in support of management and conservation of the stocks. Fisheries stock assessments are always based on: fisheries information; resource surveys; knowledge of habitat requirements, life history, and behavior of the species; the use of environmental indices; and catch statistics. Ideally, these pieces of information are integrated into population dynamic models to determine the changes in the abundance of exploited fish populations in response to fishing, and to the extent possible, to predict future trends of stock abundance.

The type of assessment performed should be driven by management needs, but it is usually limited by the amount and type of available data. While assessments of coastal stocks of rockfishes are accomplished through detailed demographic analysis (Ralston 1998, Wallace et al. 1999, 2006, Tagart et al. 2000, Methot and Piner 2001, 2002, Methot and Stewart 2005), these assessment methods are impossible to apply to rockfish stocks in Puget Sound because of incomplete time series of catch data, the lack of age and size composition data, and the lack of other biological information. The most critical piece of information for conducting stock assessments is reliable long-term catch information. Since recreational catch estimates were incomplete between 1994 and 2003, we cannot properly estimate fishing mortality rates and stock size, nor can we adequately evaluate management performance based upon demographic models. Data-limited or poor fisheries management occurs when there is insufficient biological and other information to infer the exploitation status of targeted stocks (Vasconcellos and Cochrane 2005). Assessing rockfish stocks in Puget Sound, therefore, constitutes a data-limited condition where other means must be used to establish stocks trends either referenced to biological parameters or management actions.

The goal of this section is to characterize the present status of rockfishes in Puget Sound in reference to past information and conditions. Three approaches are used to establish the status of rockfish stocks in Puget Sound. The first is to use stock assessments for adjacent coastal species to establish the condition in similar stocks in Puget Sound. Second, for conditions where adequate size, fecundity, and catch per unit effort (CPUE) are available, compare historic spawning potentials to recent values to establish stock condition. Third, evaluate the trends of stock indicators in terms of their vulnerability to extinction. This third approach uses indicators from fishery-dependent and independent sources to evaluate the relative abundance of key stocks in terms of the American Fisheries Society's (AFS) Criteria for Marine Fish Stocks at Risk of extinction (Musick 1999). Additionally, information from marine reserve studies and mortality rate estimation is used to examine the effectiveness of recent management regulations for several species of rockfish.

6.2 Assessment History

Previous stock assessments of Puget Sound rockfishes have been conducted by WDFW staff (Palsson et al.1997, PSAT 1998, 2000, 2002, 2007). The 1997 assessment was based upon relative changes in CPUE from the recreational fishery and a measure of fish density from scuba surveys in South Sound. Status of rockfish as a group were classified on a relative scale based upon the degree of recent change of the CPUE compared to the long-term average (Palsson et al. 1997). Stocks were classified as below average for South Sound and average for North Sound. These findings were echoed in the PSAT's (1998) status document of Puget Sound's ecological health.

During the late 1990s a new approach was taken to determine the status of rockfish in Puget Sound. A comprehensive demographic stock assessment was not possible due to the lack of catch and age data, but the declining CPUEs and observed decreases in mean size of rockfish in the recreational catch led to the development of an index of spawning potential. The spawning potential was based upon a yield-per-recruit approach, with the amount of eggs being produced each year estimated by applying length-fecundity relationships (DeLacy et al. 1964), copper rockfish fecundity relationships were also applied to quillback rockfish) to each year's length frequency distribution on a per individual basis. Annual egg production was multiplied by the CPUE for each year (see below). An index of relative spawning potential was scaled the observed maximum value among all years. This index of spawning potential then estimated the relative amount of stock spawning activity relative to a historic peak but not the unfished spawning biomass or potential. The analysis of copper rockfish and quillback rockfish for North and South Sound resulted in the peak spawning potential occurring during the mid to late 1970s before the recreational and commercial fisheries peaked. Spawning potentials then declined substantially to values less than 30% of peak historical values. These findings led to the classification of these stocks as depressed (PSAT 2000, 2002, 2007).

A review of rockfish populations in Puget Sound was also conducted by NOAA Fisheries under the terms of the Endangered Species Act (ESA) as a response to an ESA petition made in 1999 that included thirteen species of rockfishes (Stout et al. 2001). This agency established a Biological Review Team (BRT) that reviewed biological and abundance information provided by WFDW, evaluated the existence of distinct population segments, and determined whether the distinct population segment for Puget Sound was likely to become extinct. The BRT only reviewed the status of copper, quillback, and brown rockfishes and came to the conclusion that these species were not at risk of extinction but were vulnerable to extinction under the terms of the AFS's criteria for marine fish stocks at risk (Musick 1999). Musick et al. (2000) also listed common rockfishes in Puget Sound as vulnerable under the terms of AFS criteria.

The ESA petition for five species of deepwater rockfish brought about the convening of another BRT in 2008 and 2009. Using WDFW and other information on species composition, genetics, catch rates, surveys, and size composition, they concluded that bocaccio, yelloweye, and canary rockfishes in Puget Sound and the Strait of Georgia formed distinct populations segments from coastal populations.[7] Redstripe and greenstriped rockfishes formed distinct population segments in South Sound that were distinct from North Sound and coastal waters. The BRT found that the abundance trends of redstripe and greenstriped rockfishes did not pose a danger of extinction in the near future. However, citing decreasing frequencies in recreational fisheries, overall declining population indices, and other factors, the BRT found that bocaccio was an Endangered species, and that canary and yelloweye rockfishes were Threatened with extinction in the near future.

6.3 Data Sources

Despite limited catch and other information, a number of data sources were available to establish stock statuses in a data-limited framework for Puget Sound rockfishes. Stock indicators developed from fishery-dependent and independent information were analyzed for change over time, and the magnitudes of these changes were compared to the stock status criteria (See below). Fishery-dependent information included catch (harvest and bycatch), species composition, mean length, catch per unit effort, and

[7] Federal Register, April 23, 2009.

spawning potential ratios. Fishery-independent information included trends from bottom trawl surveys, quantitative video surveys, and special scuba surveys at index sites.

6.3.1 Fishery-Dependent Information

6.3.1.1 Biological Samples

Biological data for identified rockfishes consisted of fork length measurements collected on a regular and irregular basis. The primary source of biological data was from dockside sampling of recreational catches, but for many years WDFW creel samplers have focused on salmon catches and were not specifically trained to identify marine fish or required to take length observations. Biological information for rockfish has been collected from specially-trained samplers, and these are the same data sources that have provided species composition information described in Section 5.4.2 **Recreational Fisheries** (see above). Several surveys contributed to this data series beginning with trained marine fish samplers employed by WDFW in late 1970s and then by trained samplers conducting the MRFSS between 1980 and 1986, 1989, and between 1996 and 2002. Marine fish samplers contributed length observations of copper and quillback rockfishes in 1987 and between 1991 and 1995. WDFW began to train some of the creel samplers in marine fish identification in the late 1990s, and all samplers by 2003. Fork length observations from the recreational fishery were used to examine interannual patterns in mean size, calculate the spawning potential ratio, and analyze total mortality rate trends.

6.3.1.2 Catch per Unit Effort

The catch rate data obtained from WDFW creel surveys provided a time series for evaluating the relative change in rockfish stocks independently of salmon catch records and the open salmon fishery. The indicator was the average daily catch of rockfish (of any species) by boat-based anglers targeting bottomfish. Using a catch rate time series to measure relative stock change depends upon the assumption that catchability does not change over the duration of the time series (Hilborn and Walters 1992). This assumption is clearly questionable given the change in daily bag limit for recreational anglers in 1983, 1994, and 2000, and the likely increase in angler effectiveness with electronic navigation equipment and fathometers. Catch rate trends tend to be hyperstable because the targeting dynamics of fisheries can mask or underestimate actual stock declines.

Daily catch rates for rockfish were tabulated and averaged for each Catch Record Area (CRA) using angler interviews collected at boat ramps throughout Puget Sound. For each CRA, the rockfish catch per bottomfish angler was calculated for each sampled site and day. Because CRA 8 was split into two areas during the time series, the two new areas were recoded as CRA 8 with the assumption that total sampling effort was proportionally allocated between the two areas. Also during the time series, new "special area" fisheries for salmon were established in many of the CRAs. These were recoded to the parent CRA, and sampling effort was assumed to be proportionally allocated to the fishing effort.

An annual, effective catch rate was calculated for each area by averaging site–day observations of catch per bottomfish angler when at least one bottomfish angler was interviewed at the site each day. Site–day observations were averaged over the entire year regardless of month. Since sampling effort was allocated in proportion to anticipated angler effort on a monthly basis, the resulting catch rates were effectively weighted by angler effort. The annual catch rates for each CRA were then averaged among the CRAs comprising each North and South Sound region. The resulting index reflects the rockfish catch rate in terms of rockfish caught per boat-based angler trip targeting bottomfish.

6.3.2 Fisheries-Independent-Monitoring Surveys

WDFW has undertaken several fishery–independent surveys and studies to estimate the relative abundance of various bottomfishes including rockfishes. These include surveys using bottom trawls, quantitative video cameras, and visual scuba observations.

6.3.2.1 Bottom Trawl Surveys

The foremost of the fishery-independent surveys has been the bottom trawl survey of Puget Sound that targets the bottomfishes that live in trawlable habitats (Palsson et al. 1997, 2002, 2003). WDFW has conducted a series of bottom trawl surveys in Puget Sound since 1987 (Quinnell and Schmitt 1991). The goals of these surveys were to estimate the abundance and describe the distribution of recreational and commercial groundfish species and to collect biological information from key species including rockfishes. Surveys were conducted within the many sub-basins of Puget Sound (Figure 2.1). During the first three surveys in 1987, 1989, and 1991, the goal was to synoptically survey all inside waters east of the Sekiu River, excluding the San Juan Islands. During these early surveys, 71 to 93 trawl samples were made each year. Regional sample sizes ranged between 7 and 30 trawl samples. Beginning in 1994, individual regions were surveyed with greater intensity, and four or fewer regions were surveyed during any year. Surveys of waters south of Port Townsend were staggered between 1995 and 1996 as were surveys of the eastern Strait of Juan de Fuca and the southern Strait of Georgia between 2000-2001. The estimates for each of these two series were combined, assuming rockfish stocks do not change dramatically from year to year. In 2002 and 2005, all waters south of Port Townsend and Deception Pass were surveyed in one year, with a total of 128 and 167 trawl samples, respectively. Only during 1987, 2003, and 2004 were waters east of Port Angeles surveyed, and therefore, only estimates from the eastern Strait of Juan de Fuca and Strait of Georgia are used for long-term comparisons in North Sound. Only in 2001 and 2004 was the San Juan Islands surveyed.

The trawl surveys were conducted from chartered fishing or government vessels. The vessel towed a 400 mesh Eastern net with a head rope 22 m in length and cod-end fitted with a 3 cm mesh liner (see Palsson et al. 2002, 2003 for a complete description of trawl survey methods). Stations were selected using a stratified-random or stratified-systematic approach based upon four depth zones for each region (5-20 fms, 21-40 fms, 41-60 fms, and >60 fms). The length of each tow was measured with Geographic Positioning System, LORAN C, or radar fixes. The width of the trawl path was obtained from gear mensuration studies. The product of width and tow length resulted in the area swept for each station. During most years, the net was fished for 10 to 20 minutes at a speed of 1.5 to 3 knots. After retrieval of the net, the catch was identified, weighed, and enumerated, and the weights and numbers of each species were divided by the area sampled to estimate species densities. Abundances, in terms of numbers of fish or biomass (mt), were estimated by averaging station densities within each stratum and multiplying these by the stratum area.

The important species of rockfish captured during the trawl survey were sampled for total length, sex, and otoliths. Total lengths were collected for individual rockfishes and their age was determined in the WDFW Ageing Laboratory with the break-and-burn technique (Chilton and Beamish 1982). For copper, quillback, brown, and splitnose rockfishes, growth rates and total mortality rates were estimated using von Bertalanffy and catch curve estimation techniques (Ricker 1975).

6.3.2.2 Quantitative Video Surveys

The Video Assessment Technique (VAT) was a survey method developed by WDFW to estimate the fish stocks living in association with rocky and high–relief habitats in the nearshore of Puget Sound (Bradbury et al. 1998, Pacunski and Palsson 1998, 2002). The technique consisted of deploying a video camera mounted on a tripod at pre-selected locations of known or suspected rocky habitats. The camera was rotated horizontally 360° and vertically with a motor to view and record fishes living within 2 m of the bottom onto a video tape. The VAT surveys were initially planned with a stratified-systematic design by using maps of potential rocky habitat as a sampling frame. Potential rocky habitat was defined as charted rocks and boulders, artificial structures and other such habitats that had a likelihood of containing rockfish, lingcod, greenling and other rocky-dwelling species. Charts and reef areas were stratified by regions, depth zones, and the potential for containing suitable habitat. Only rocky habitats from the tidal datum to a depth of 37 m (mean lower, low water) were surveyed. Video tapes were reviewed in the laboratory where all fish were identified and counted.

Analysis of the VAT data consisted of comparing rockfish counts between years and estimating the abundance of nearshore rockfishes for the most recent regional surveys. Trends in regional rockfish abundance were examined by comparing average station counts of each rockfish species between the initial and latest regional survey. Average station counts were estimated for those stations located on high relief or rocky habitat within a region and survey, and these averages were then compared for trends using analysis of variance techniques. Beginning in 1998, two lasers in parallel were added to the camera system to aid in the determination of the radius of the visual plot. This allowed for the estimation of rockfish densities at each station and the estimation of stock abundance. The density of fish at each station was determined by dividing the number of fish observed during the last rotation of the camera by the area of the circular plot using the estimated visual radius. Fish densities were averaged among regions and strata and stock estimates were obtained by multiplying the area of identified stratum by the average fish density. Numerical abundances were converted to biomass estimates using mean weight per rockfish species obtained from the MRFSS (www.psmfc.org).

6.3.2.3 Scuba Transects

Visual scuba surveys have been conducted in central Puget Sound to gather information on species composition, density, and size of rockfishes at representative rocky habitats. Visual transect methods were developed by Matthews (1990a) to evaluate the relative habitat use by rockfishes. The method was modified by Palsson and Pacunski (1995) who used the transect technique to evaluate marine refuges and inter–annual changes in rockfish densities (Palsson et al. 2004). This method entailed setting and surveying three 30 m permanent transect lines at selected index sites. Long–term index sites included artificial and natural rocky habitats including natural rocky ridges at Port Blakely and Orchard Rocks and the artificial habitat at Blake Island in central Puget Sound. Fish occurring within 1.5 m of either side of the transect line were identified, counted, and measured by divers. Thus, a total of 270 m^2 were surveyed at each site per sampling event. Sites were visited six times per year during the spring and fall seasons. It should be noted that fishing is allowed at Port Blakely and Blake Island, but Orchard Rocks became no-take refuge in 1998. Data were combined for all three sites in a month's sampling representing a transect area of 810 m^2. Mean monthly densities were compared inter–annually by using analysis of variance techniques.

6.4 Assessment Approach

Because formal stock assessments were not possible for any Puget Sound rockfishes, an alternate approach to establish stock status was developed for the data-limited situation. The AFS Criteria for Marine Fish Stocks at Risk (Table 6.1, Musick 1999, Musick et al. 2000) are used as a primary categorization scheme to assess stock status along with criteria developed from spawning potential ratio calculations. We define the stock status categories as depleted, vulnerable, precautionary, and healthy (Table 6.2). These categories of stock status are similar and consistent with the guidelines of the WDFW Commission's Policy for Groundfish, the PSGMP (Palsson et al. 1998), and a draft Groundfish Conservation Plan (WDFW, unpublished manuscript).

Though not a traditional stock assessment approach, the AFS has developed an evaluation method to assess the risk of marine fish stocks to extinction (Musick 1999, Musick et al. 2000). This method is applied especially in cases of limited quantitative information and makes use of biological information and life history parameters, including population increase rates, growth rates, age-at-maturity, fecundity-at-first maturity, and maximum age to evaluate the magnitude of population decline over ten years or three generation times, whichever is the longest (Table 6.1). Stocks can be classified as vulnerable if they have declined to critical thresholds that are based upon the productivity of the stock as measured from their life history parameters. The parameters are not of equal weight, and the application of the intrinsic rate of increase is the most preferable manner to classify stock productivity, followed by age-at-maturity and the growth coefficient, and maximum age with respect to maturity. Musick (1999) identified additional classifications, endangered or threatened, that may be imposed depending upon the likelihood of a vulnerable population becoming extinct in years or decades and upon special risk factors such as rarity, small ranges, or specialized habitat requirements. The time period considered for decline is the longer of a ten-year period or three-generation times.

Musick (1999) discussed various biological reference points, such as yield per recruit (YPR) and spawner-per-recruit (SPR) that are widely used in fishery management. The SPR is at maximum when there is no fishing and the population is at carrying capacity; and it decreases as fishing mortality increases. In 2000, the Pacific Fishery Management Council adopted $F_{50\%}$, the fishing mortality that reduces the SPR to 50% of the unfished level, as the proxy for the risk-neutral default harvest rate F_{MSY} for west coast rockfishes (PFMC 2000). The SPR ratio to the unfished condition is used as a B_{MSY} proxy, where B_{MSY} is the biomass needed to produce the maximum sustainable yield (MSY). The National Standard 1 guideline defines MSY as the largest long-term average catch or yield that can be taken from a stock or stock complex under prevailing ecological and environmental conditions (FR Doc. 98-11471). Fishing rates above F_{MSY} eventually result in biomass smaller than B_{MSY} and produce less harvestable fish on a sustainable basis.

While Musick (1999) does not discuss the nature of population indices to be used in trend determination, he refers to the International Union of Conservation Nature's (IUCN) list of indices for population decline: direct observation; an index of abundance appropriate for the taxon; decline in the area of occupancy, extent of occurrence, and/or quality of habitat; actual or potential levels of exploitation; and the effects of introduced taxa, hybridization, pathogens, competitors, or parasites , as listed in Table 2 of Musick (1999).

We used Musick's (1999) threshold for marine fish stocks at risk (Table 6.1) to establish Vulnerable and Depleted stock status categories (Table 6.2). We erected two other categories to identify stocks that are not in Vulnerable or Depleted conditions. Healthy stocks are stable, abundant, or increasing and Precautionary are stocks that are declining but not yet vulnerable or stocks with unknown trend or abundance information. Based on the combination of the above mentioned criteria, we use the following definitions for stock status and provide recommendation for harvest rules.

Healthy Stock Status: A healthy stock is one that does not meet the AFS Vulnerability Threshold, is stable at or increasing above historic levels; the biomass is at or above B_{MSY}; or the SPR is at least 50% of the unfished condition. When B_{MSY} and SPR information are lacking, Healthy stocks long-term indices trends that are stable, increasing, or vary without trend at or above historic levels.

Precautionary Stock Status: Precautionary stocks are those that do not meet AFS Vulnerability Criteria and conservation and management measures are in place to halt further decline or promote rebuilding. Precautionary stocks are those with biomass below B_{MSY} and above 50% B_{MSY}; or SPR ratios less than 50% but greater than 25%. When appropriate B_{MSY} and SPR information are lacking, Precautionary stocks have declining indices greater than 50% of historic levels but greater than the AFS vulnerability criteria for population productivity, effective management measures have halted the long-term decline, or when data are lacking and the stock status is unknown.

Vulnerable Stock Status: A vulnerable rockfish stock is one that meets or slightly exceeds the AFS Vulnerability Threshold. SPRs of vulnerable stocks are at or near 25%, their biomass is between 25-50% of B_{MSY}. When B_{MSY} and SPRs information are lacking, vulnerable stocks have indices are at or near the AFS vulnerability thresholds and do not have additional risk factors such as its rarity, limited range, or specialized habitat requirements. Management measures have halted long-term declines.

Depleted Stock Status: A depleted rockfish stock far exceeds the AFS Vulnerable Threshold and has an SPR much less than the AFS vulnerability threshold for population productivity. The SPR ratio of Depleted stocks is far below 25% and the biomass is below 25% of B_{MSY} or its other proxies. The stock has additional risk factors such as rarity, limited range, or specialized habitat requirements. Alternatively, depleted stocks have indices that are negative and exceed the AFS vulnerability criteria for stock productivity, do not have effective management measures in place, and the stock has additional risk factors such as rarity, limited range, or specialized habitat requirements.

Table 6.1. American Fisheries Society Stock Productivity Criteria and Vulnerability Thresholds (Musick 1999).[a]

	Productivity			
Parameter	**High**	**Medium**	**Low**	**Very Low**
r (yr^{-1})	>0.50	0.16-0.50	0.05-0.15	<0.05
Von Bertalanffy k	>0.30	0.16-0.30	0.05-0.15	<0.05
Fecundity (yr^{-1})	>10,000	100-1,000	10-100	<10
T_{MAT}	<1 yr	2-4 yr	5-10 yr	>10 yr
T_{MAX}	1-3 yr	4-10 yr	11-30 yr	> 30 yr
Decline Threshold of Vulnerability (over the longer duration of 3 Generation Times or 10 years)	0.99	0.95	0.85	0.70

[a] Parameters include intrinsic rate of population increase (r), von Bertalanffy growth coefficient (k), fecundity per year, age at maturity (T_{mat}), and maximum age (T_{max}).

Table 6.2. Rockfish Stock Status Criteria for Puget Sound.

Stock Status Category	AFS Risk Category	Description	Biological Reference Points
Healthy	Not At Risk	• No apparent risk of extinction • Lack of substantial reduction in abundance	• Biomass is above B_{MSY} or its proxies. • Positive or stable trend in stock index-AFS Vulnerability Criteria not met • Managed for productive fisheries
Precautionary	Conservation Dependent	• Reduced in abundance but stocks are stable or increasing	• Biomass is below B_{MSY} and above 50% of B_{MSY} or its proxies. • Significant decline in stock index but AFS Vulnerability Criteria not met • Unknown stock abundance or index • Conservative management measures
Vulnerable	Vulnerable	• Not Endangered or Threatened but falling into one of those categories in the near future	• Biomass is between 25% and 50% of B_{MSY} or its proxies. • AFS Vulnerability Criteria met or nearly met for the level of stock productivity • Management measures have halted declines • No risk factors

Stock Status Category	AFS Risk Category	Description	Biological Reference Points
Depleted	Endangered or Threatened	• High risk of extinction in the immediate (years) or near future (decade). • Overfished by federal standards	• Biomass is below 25% of B_{MSY} or its proxies. • AFS Vulnerability Criteria met or much less than threshold • Decline continuing • Risk factors of rarity limited range, or specialized habitat requirements present

6.5 Species Assessments

Stock status was determined for seventeen species of rockfish in North and South Puget Sound. When available, life history parameters were described and evaluated with respect to the AFS Vulnerability Criteria (Table 6.1). Then, trend information was described from fishery-dependent and independent time series and compared to the AFS Vulnerability Criteria productivity level of each species. Other information such as the availability of coastal stock assessments for some species, rarity, and special habitat needs were evaluated in determining the stock status. The status of each of the seventeen rockfish species is established with respect to their life histories, fishery and survey trends, and the stock assessment criteria established above. Available and pertinent life history information is reviewed for North and South Sound areas including growth patterns, maximum age, age at maturity, length trends, and natural mortality rates. For copper and quillback rockfishes, several indices are available to determine a trend. For other species, times series were limited to trends in the recreational composition, individual trends in surveys, or in some cases, the results from coastal stock assessments.

Information from several data sources and other stock assessments were evaluated to establish the stock condition of rockfish stocks in Puget Sound. The stock index or data used for each assessed species varied by the quality and quantity of available information. We used stock indices corresponding to those listed by the IUCN (Musick 1999). These indices included a modified spawning potential ratio for copper and quillback rockfishes and survey abundance trends. Additional information on changes in species and size composition was also presented but was not directly used for status determination. Because most rockfishes are long-lived, trends in stock abundance indices are compared over a three generation time period to determine if trends exceed the AFS vulnerability thresholds for the respective category of stock productivity (Table 6.1). We did not attempt to distinguish between threatened or endangered but classify the stock as Depleted. Our status categorization references SPR criteria for sustainable and overfished populations used by federal fishery managers (Table 6.2). For yelloweye and canary rockfishes in Puget Sound, stock status was determined by using the results of coastal stock assessments.

6.5.1 Spawner Per Recruit

The spawner-per-recruit ratio has become an effective way to estimate exploitation-rate goals (e.g. $F_{MSY)}$ and to evaluate management performance (Goodyear 1989; Clark 1991, Mace and Sissenwine 1993; Clark 1993; Dorn 2002). SPR is defined as the spawning stock biomass per recruit (SSBR) at the current fished stock level relative to the unfished level. The SSBR is a measure of a fish stock's reproductive potential. SPR can also be expressed as the ratio of annual egg production under harvest to the annual egg production for an unfished stock, i.e., the proportion of natural spawning that would be expected under a given harvest policy. The rationale for using SPR as a fisheries management tool lies in the density dependent effects of stock renewal. Specifically, compensatory changes in survival or fecundity, from the unfished state, are required for a stock to persist in the fished state. The value of SPR reflects the magnitude of this compensation. It is an alternative way to express the effects of any specific fishing rate on a fished stock. It also has the benefit of standardizing for differences in growth, maturity, fecundity, natural mortality, and fishery selectivity patterns. As a consequence, the Scientific and Statistical Committee of the Pacific Fishery Management Council recommends that SPR be used routinely for management purposes (PFMC 2004, 2006).

SPR can be easy to estimate and the critical SPR level should be established to protect fish stocks from recruitment overfishing. Given fishery selectivity patterns and basic life-history parameters, there is an inverse relationship between fishing mortality (F) and SPR. When there is no fishing, a new female recruit is expected to achieve 100% of its spawning potential. As fishing intensity increases, expected lifetime reproduction declines. The minimum SPR level that a given stock can endure is a function of the slope of the stock-recruitment curve at its origin. If fishing reduces SPR below this minimum, the population will decline toward extinction until fishing mortality is reduced. Walters and Martell (2004) state that the risk of recruitment overfishing starts to increase considerably for SPR< 0.3; Walters and Kitchell (2001) warn that SPR< 0.5 may invite long-term changes in the community structure that can lead to apparent depensatory declines in recruitment. Dorn (2002) suggests harvest policies for rockfish should use a SPR= 0.5 as a risk-neutral proxy for rockfish, and a SPR between 0.55 and 0.65 as a risk-averse alternative based on Bayesian meta-analysis of west coast rockfish stock-recruitment relationships.

Lacking information on the catch, the fishery selectivity, and the demographic structure of rockfish stocks in Puget Sound, a surrogate for SSBR was developed as an index of reproductive potential for SPR calculations. The spawning potential $SSBR'$ is defined as the product of size specific fecundity (E), size frequency in percentage (F), and catch rate (C). Therefore, spawning potential in year j is

$$SSBR'_j = \sum_i Eij \cdot Fi \cdot Cj \ ,$$

where i = the i^{th} size class.

Because we did not have past fishing mortality, catch-at-age, and selectivity data, we could not project backwards to estimate the unfished biomass. A proxy for the unfished spawning potential is the average of the early $SSBR'$s among the years 1977 and 1980 when length and catch rate data were available. The most recent $SSBR'$ is calculated for the years 1998 and 1999 prior to the imposition of the one fish daily bag limit. The %$SSBR'$ is expressed as:

$$\%SSBR' = \left(\sum_{1998}^{1999} SSBR'_j / 2 \right) / \left(\sum_{1977}^{1980} SSBR'_j / n_j \right) * 100 \ ,$$

where n_j is the number of years with $SSBR'$ estimates between 1977 and 1980.

This modified SPR index is limited compared to more standard demographic models that use natural mortality and fishery selectivity to estimate the population at length (O'Farrell and Botsford 2005), instead of the relative abundance index that is used for Puget Sound. As such, the spawning potential ratio estimates the egg production on a *SPBR's* basis, for the portion of the stock that was vulnerable to the fishery. The actual spawning potential may well be greater than the calculated index.

6.5.2 Trend Analysis

In addition to or absence of *SPBR'* time series, stock trends from fishery dependent and independent sources were evaluated with respect to the AFS Marine Fish Stocks at Risk and Stock Status criteria (Tables 6.1 and 6.2). Other stock indices included biomasses from the bottom trawl survey, quantitative video survey counts, and scuba transect densities. Change with time was evaluated for several time series of fishery-dependent and independent data, over the span of three generation times, when possible. Stearns (1992) defined Generation Time as the average age of mothers giving birth in a stable in a stock with a stable age distribution. An alternate definition used here is the Committee on the Status of Endangered Wildlife in Canada's definition as the average age of parents of a cohort (i.e. newborn individuals in the stock) (COSEWIC 2006). Generation Time is greater than the age at first breeding and less than the age of the oldest breeding individual, and it is likely underestimated in exploited stocks.

Comparisons of survey trends were made with statistical tests or by inspection for the overlap of the 95% confidence limit with point estimates within the series. Although catch per unit effort from the recreational creel survey had statistical errors for each CRA, the composite series for North and South Sound were averages of yearly point estimates for constituent CRAs and were considered as point estimates only. The *SPBR'* time series was composed of composite series and point estimates were considered without error. Trawl survey estimates had statistical errors with each point estimate and were compared by inspection for overlap of point estimates and 95% confidence limits. Densities or station counts from scuba transects or video surveys were tested with analysis of variance comparing the null hypothesis that densities or counts do not change over time.

6.5.3 Mortality Rate Analysis

Stock assessments were enhanced for several species by using length and age based methods to estimate total and fishing mortality rates. Catch cure analysis (Ricker 1975) was applied to the age frequency observations from rockfish otoliths obtained by the research bottom trawl survey. The frequencies of ages past the age of full recruitment were converted to natural logarithms. The slope of the logarithm regressed over time (years) provided estimates of the annual instantaneous, total mortality rate (Z). When natural mortality rate (M) estimates were available, they were subtracted from the total mortality rate estimate to approximate fishing mortality (F) where Z=F+M (Ricker 1975). Based recommendations by SSC (2000), a precautionary fishing mortality rate for rockfish should range from 0.5 to 0.7 of M. Canadian management strategies for inshore rockfish have adopted a similar approach (Yamanaka et al. 2004).

6.6 Recreational Catch Rate Trend

The recreational catch rate or CPUE trend, defined as the rockfish catch per bottomfish angler trip, has decreased in both North and South Sound since 1977 when the first observations were recorded (Figure 6.1, Table 6.3). A significant decline occurred between 1977 and 1982 amounting to more than a 50% change for North Sound and 25% for South Sound. In 1983, the daily bag limit was changed from 15 rockfish per day to 10 fish in North Sound and five in South Sound. The impacts of the regulation changes were not clear, but catch rates varied without much trend in North Sound from 1983 until 2000 and without much trend in South Sound until 1995. The change from a five fish daily bag limit to a three fish daily bag limit in South Sound may have affected and lowered catch rates between 1995 and 1999. Catch rates declined substantially in both North and South Sound after the adoption of the one fish daily bag limit in 2000. Since then, catch rates have been relatively stable. So, the observed declining trend in both North and South region might be due to a mixture of the changes of management, changes in spatial fishing patterns, changes of targeting species with time, and abundance changes. Further research is needed to identify the causes of the declining trends.

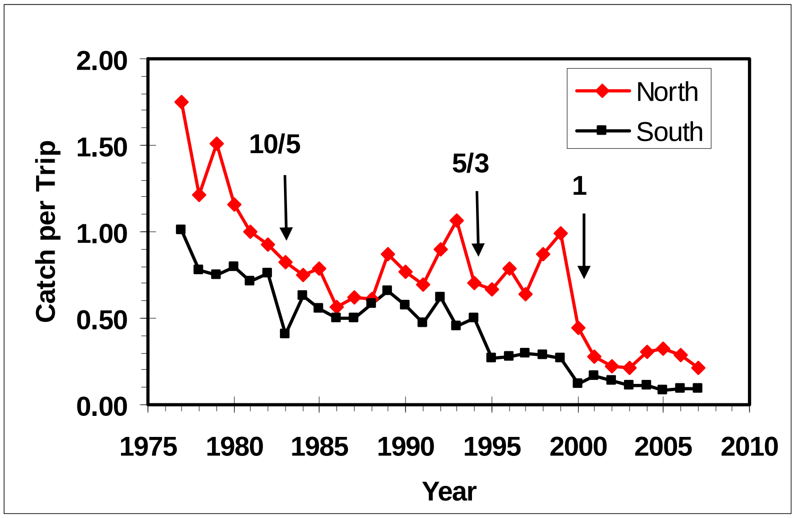


Figure 6.1. WDFW recreational catch rates of rockfish by bottomfish targeting, boat-based anglers, 1977-2007. Numbers and arrows point to years when the daily bag limits for rockfish were changed.

Table 6.3. Annual Estimates of Rockfish Catch Rates (Fish Per Angler Trip) by Boat-based Recreational Anglers Fishing for Bottomfish for Each Catch Record Area and Averaged Among North and South Sound Catch Record Areas.

	North			South						Averaged	
YEAR	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**North**	**South**
1977	2.60	1.09	1.56	0.39	1.29	0.76	1.22	1.03	1.33	1.75	1.01
1978	1.72	0.76	1.16	0.60	0.97	0.81	0.73	0.76	0.81	1.21	0.78
1979	2.45	0.98	1.10	0.59	1.20	0.75	0.50	0.79	0.68	1.51	0.75
1980	2.14	0.59	0.74	0.54	0.82	0.61	0.94	0.84	1.00	1.15	0.79
1981	1.47	0.78	0.76	0.25	1.18	0.68	0.69	0.40	1.08	1.00	0.71
1982	1.42	0.81	0.56	0.37	0.89	0.58	0.61	1.50	0.58	0.93	0.76
1983	1.01	0.69	0.77	0.22	0.37	0.32	0.40	0.56	0.57	0.82	0.41
1984	0.97	0.46	0.82	0.32	0.88	0.46	0.63	0.62	0.88	0.75	0.63
1985	1.10	0.43	0.84	0.35	0.86	0.67	0.31	0.59	0.53	0.79	0.55
1986	0.79	0.21	0.68	0.15	0.32	0.68	0.53	0.66	0.69	0.56	0.50
1987	0.61	0.41	0.84	0.18	0.97	0.50	0.58	0.29	0.50	0.62	0.50
1988	0.42	0.46	0.95	0.54	0.81	0.69	0.72	0.19	0.55	0.61	0.58
1989	0.78	0.81	1.01	0.33	0.99	0.85	0.68	0.35	0.73	0.87	0.66
1990	0.74	0.40	1.17	0.27	0.65	1.10	0.57	0.58	0.25	0.77	0.57
1991	0.76	0.47	0.84	0.22	0.42	0.55	0.55	0.76	0.31	0.69	0.47
1992	0.80	0.91	0.98	0.19	1.01	0.87	0.66	0.48	0.53	0.90	0.62
1993	1.36	0.61	1.24	0.26	0.90	0.57	0.47	0.20	0.30	1.07	0.45
1994	0.82	0.45	0.85	0.21	0.60	0.61	0.42	0.67	0.50	0.71	0.50
1995	0.78	0.53	0.69	0.20	0.48	0.39	0.30	0.00	0.26	0.67	0.27
1996	1.11	0.36	0.89	0.20	0.31	0.36	0.26	0.33	0.19	0.79	0.27
1997	0.81	0.37	0.73	0.20	0.26	0.47	0.19	0.48	0.20	0.64	0.30
1998	0.82	1.02	0.78	0.13	0.28	0.28	0.27	0.42	0.36	0.87	0.29
1999	1.34	0.78	0.85	0.14	0.11	0.32	0.24	0.60	0.20	0.99	0.27
2000	0.70	0.22	0.42	0.08	0.15	0.20	0.15	0.10	0.08	0.45	0.12
2001	0.51	0.07	0.26	0.08	0.17	0.14	0.35	0.14	0.10	0.28	0.16
2002	0.35	0.12	0.21	0.16	0.16	0.23	0.07	0.11	0.08	0.23	0.14
2003	0.34	0.14	0.17	0.10	0.10	0.18	0.13	0.03	0.11	0.22	0.11
2004	0.40	0.28	0.24	0.06	0.17	0.14	0.18	0.00	0.09	0.30	0.11
2005	0.70	0.10	0.16	0.07	0.12	0.09	0.12	Closed	0.04	0.32	0.09
2006	0.50	0.14	0.21	0.09	0.07	0.11	0.13	Closed	0.06	0.28	0.09
2007	040	0.04	0.19	0.10	0.07	0.13	0.13	Closed	0.02	0.21	0.09

Table 6.4. Important Life History Characteristics of Rockfishes in Puget Sound.[a]

Species	K	L_∞ (mm)	Age (yr) at 50% Maturity	Maximum Age (yr)	Fecundity at Maturity	Generation Time (yr)	M	Z	AFS Productivity	Source
Copper rockfish										
North Sound	0.14-0.18	357-507			13,833	7.7		0.15 BB	Low	This Study
	0.08 S	590 S	5 S	34 S			0.11 S	0.18 S		Barker (1979)
	0.18 S	400 S								Moulton (1977)
South Sound	0.13 BB	463 BB		27 BB	21,221	7.7		0.11-0.15 BB	Low	This Study
	0.12 male S 0.16 female S	520 S 460 S	4 S	19 S				0.23 S		Washington et al. (1978)
	0.12 S	500 S	4 S	18 S			0.13 S	0.23 S		Gowan (1983)
British Columbia			6 BB							Richards and Cass (1987)
Alaska				50 BB						Munk (2001)
Quillback Rockfish										
North Sound	0.16 BB	410 BB		73 BB	6,774	23.8		0.06-0.07 BB	Very Low	This Study
	0.09	470	5 S	37 S			0.13 S	0.15 S		Barker (1979)
South Sound	0.11-0.18 BB	320-360 BB		53 BB	5,218	12.1		0.12-0.13 BB	Very Low	This Study
	0.075 male S 0.041 female S	450 S 540 S	4 S	15 S				0.50 S		Washington et al. (1978)
	0.14 S	463 S	4 S				0.12 S	0.23 S		Gowan (1983)
Washington Coast										This Study
British Columbia			11 BB	95 BB			0.02-0.04 BB	0.02-0.11 BB		Yamanaka and Lacko

Species	K	L_∞ (mm)	Age (yr) at 50% Maturity	Maximum Age (yr)	Fecundity at Maturity	Generation Time (yr)	M	Z	AFS Productivity	Source
										(2001)
Brown Rockfish										
South Sound	0.14 BB	358 BB		46 BB		10.8		0.04 BB	Very Low	This Study
	0.21 male S 0.087 female S	350 S 470 S	4 S	14 S				0.27 S		Washington et al. (1978)
	0.06 S	530 S	4 S				0.11 S	0.27 S		Gowan (1983)
Alaska				50 BB						Munk (2001)
Black Rockfish										
North Sound	0.14 S	610 S	3 S	14 S			0.31 S	0.33 S	Low	Barker (1979)
	0.12 S	640 S								Moulton (1977)
South Sound	0.076 S	680 S	13 S					0.51 S		Washington et al. (1978)
	0.08 S	680 S		12 S			0.25 S	0.34 S	Low	Gowan (1983)
Washington Coast										
Alaska				50 BB						Munk (2001)
Yelloweye Rockfish										
North Sound				90 BB					Very Low	This Study
South Sound				55 BB					Very Low	This Study
				27 S						Washington et al. (1978)
Washington Coast	0.05 BB	675 BB					0.045 BB			Methot and Piner (2002)
British	0.04-0.06 BB	672-810	17 BB	115 BB			0.025			Yamanaka

Species	K	L_∞ (mm)	Age (yr) at 50% Maturity	Maximum Age (yr)	Fecundity at Maturity	Generation Time (yr)	M	Z	AFS Productivity	Source
Columbia		BB								and Kronlund (1997), Yamanaka and Lacko (2001)
Yellowtail Rockfish										
North Sound	0.36 S	410 S		7 S				0.99 S	Very Low	Barker (1979)
	0.20 S	531 S		7 S						Moulton (1977)
South Sound	0.43 S	390 S		9 S				0.52 S		Washington et al. (1978)
				8 S				0.52 S	Very Low	Gowan (1983)
Other				64 BB						Munk (2001)
Washington Coast	0.18 BB	490 BB		~50 BB			0.11 BB			Tagart (1988)
Canary Rockfish										
South Sound				9 S					Very Low	Gowan (1983)
	0.071 S	460 S		10 S						Washington et al. (1978)
British Columbia				84 BB						Munk (2001)
Bocaccio										
South Sound				12 S						Washington et al. (1978)
				11 S					Very Low	Gowan (1983)
Alaska				46 BB						Munk

Species	K	L_∞ (mm)	Age (yr) at 50% Maturity	Maximum Age (yr)	Fecundity at Maturity	Generation Time (yr)	M	Z	AFS Productivity	Source
										(2001)
Greenstriped Rockfish										
West Coast	Males: 0.11 Females: 0.08	Males: 301 Females: 374	Males: 10 Females: 7	46 BB			Males: 0.09 -0.14 BB Females: 0.09-0.15		Low	Shaw and Gunderson (2006)
Alaska				54 BB						Munk (2001)
Redstripe Rockfish										
Other				55 BB					Very Low	Munk (2001)
Splitnose Rockfish										
South Sound	0.08 BB	277 BB		64 BB					Very Low	This Study
British Columbia				86 BB						Munk (2001)
Shortspine Thornyhead										
West Coast	0.01-0.02 BB	728-945 BB	13 BB	>45			0.06 BB		Very Low	Piner and Methot (2001)
West Coast							0.01 BB			Pearson and Gunderson (2003)
Alaska				89 BB						Munk (2001)
Tiger Rockfish										
Alaska				116 BB					Very Low	Munk (2001)
China Rockfish										
Alaska				78 BB					Very Low	Munk (2001)
Blue Rockfish										
Oregon				30 BB					Low	Munk (2001)
Vermilion Rockfish										
Other				60 BB					Low	Munk

Species	K	L_∞ (mm)	Age (yr) at 50% Maturity	Maximum Age (yr)	Fecundity at Maturity	Generation Time (yr)	M	Z	AFS Productivity	Source
										(2001)
Puget Sound Rockfish										
North Sound	Male: 0.54 BB Female: 0.70 BB		2	13 BB	20,000	4.2	0.44 BB		Low	Beckmann et al. (1998)
	Male: 0.03-0.12 BB Female: 0.22-.0.41 BB	Male: 151-244 Female: 159-168				5	Male: 0.33 BB Female: 0.23-.040			Coates et al (2007)
	0.79	170		6 S						Moulton (1977)
Alaska				22 BB						Rosenthal et al. (1982)

a S=Surface-aged otoliths, BB=Break-and-burn technique for otoliths.

Table 6.5. Trawl Survey Biomass (mt) and Percent Standard Error (%SE) Estimates of Rockfish Stock Abundance in the combined East Juan de Fuca and Georgia Basin Trawl Survey Regions of North Puget Sound.

Species	1987	%SE	1989	%SE	1991	%SE	2000-2001	%SE	2004	%SE
Copper	60.5	84.3	0.0		0.0		2.9	100.0	0.0	
Quillback	28.6	74.7	96.2	40.8	18.3	61.5	29.0	51.1	45.8	79.8
Brown	0.7	99.7	0.0		0.0		0.0		0.0	
Yelloweye	0.0		0.0		0.0		0.0		0.7	99.7
Yellowtail	0.0		0.0		0.0		0.0		0.9	99.3
Redstripe	3.4	37.1	0.4	101.4	1.3	50.2	0.0		56.8	78.7
Greenstriped	0.0		0.0		0.0		0.0		0.4	100.0
Splitnose	0.0		0.0		0.0		0.0		0.0	
Shortspine thornyhead	0.0		0.0		0.0		1.8	75.8	1.0	72.0
Puget Sound	0.0		0.0		0.0		1.0	43.8	0.9	46.9
Other	0.1	108.8	0.0		0.0		0.0		1.5	70.8
Total rockfish	93.3	67.4	96.7	40.5	19.6	58.2	34.7	46.8	107.9	60.2

Table 6.6. Trawl Survey Biomass (mt) and Percent Standard Error (%SE) Estimates of Rockfish Stock Abundance in South Puget Sound.

Species	1987	%SE	1989	%SE	1991	%SE	1995-1996	%SE	2002	%SE	2005	%SE
Copper	93.7	65.1	1057.7	63.5	226.1	64.9	46.8	29.6	49.4	35.2	53.2	38.4
Quillback	432.6	26.3	300.6	49.1	231.9	25.3	306.5	34.2	142.2	26.9	105.5	19.3
Brown	707.4	98.1	22.6	65.6	11.7	48.9	9.5	62.8	10.9	32.5	32.9	29.7
Yelloweye	0.0		0.0		0.0		8.5	61.6	0.0		0.5	99.4
Yellowtail	0.0		0.0		0.0		0.0		0.0		0.0	
Redstripe	0.7	71.8	0.9	99.8	6.8	99.9	5.4	93.0	151.7	89.9	233.8	82.1
Greenstriped	0.0		0.0		0.4	99.0	1.2	77.4	1.6	63.8	1.3	57.3
Splitnose	22.4	75.2	8.1	100.0	0.0		5.6	92.6	8.5	34.3	8.6	32.0
Shortspine thornyhead	2.9	69.7	0.0		0.0		4.4	100.1	1.9	71.3		
Puget Sound	0.0		0.0		0.0		0.7	66.1	21.3	48.1	47.1	73.8
Other	6.2	91.3	30.0	98.6	0.0		0.0		0.4	59.7	0.5	100.0
Total rockfish	1265.8	56.3	1419.8	48.7	476.8	35.9	388.5	28.3	387.8	38.8	482.9	46.6

6.7 Stock Status

Many of the observed life history characteristics of Puget Sound rockfishes make them vulnerable species that are not suited to intense fishing pressure (Table 6.4). In particular, the longevities of all species, except Puget Sound rockfish, are in excess of the 30 year maximum age criterion for stocks of Very Low Productivity (Table 6.2). Among the individual species, however, there is variation in the life history characteristics and not all of the parameter values, especially growth, correspond to Low or Very Low Vulnerability Thresholds. Most species, however, fall into the Low or Very Low Vulnerability categories, requiring decline thresholds of 85% or 70% over three generations to be considered vulnerable or depleted. Since rockfish generation times are typically in excess of ten years, the three-decade scale fishery and survey data for rockfish is appropriate for determining trends and stock status. Several declining stock trends for these rockfishes exceed the vulnerability threshold with several time series resulting in Vulnerable or Depleted stock status determinations. Many key life history parameters, including natural mortality, fecundity and maturity, are not known for rockfishes found in Puget Sound.

6.7.1 Copper Rockfish

6.7.1.1 Life History Characteristics

One of the larger rockfishes found in Puget Sound, copper rockfish are relatively short-lived and fast growing, compared to quillback, yelloweye, and brown rockfishes. Their intermediate life history characteristics result in a Low Productivity AFS categorization (Table 6.1). The maximum age observed for copper rockfish in South Sound is 27 years (Table 6.4, Figure 6.2), however, Barker (1979) observed a maximum age of 34 years for copper rockfish in North Sound. This North Sound age determination was made by the surface-reading technique and likely underestimated the true age. Copper rockfish reach a maximum age of 50 years in Alaska (Munk 2001). Ninety percent of the copper rockfish were between 3 years and 15 years in age in North and South Sound (Figure 6.3). The age at maturity is not well known for copper rockfish in Puget Sound because surface ages were used to age fish in previous studies by Washington et al. (1978), Barker (1979), and Gowan (1983). Barker (1979) found 50% maturity at age 5 in the San Juan Islands, and Washington et al. (1978) and Gowan (1983) determined 50% maturity occurred at age 4 in South Sound (Table 6.4). These ages-at-maturity may not be accurate for Puget Sound, because copper rockfish in B.C. mature at 6 years and a length of 25 cm (Richards and Cass 1987). Fecundity at first maturity was 13,833 eggs in the North Sound and 21,221 eggs in the South Sound. Mean Generation Times were 7.7 years in North and South Sound using observed age frequencies greater than 4 years. Due to low sample size, a catch curve estimate of total instantaneous mortality was only possible in South Sound (Figure 6.3). The total mortality rate in South Sound ranged from 0.15 to 0.11 depending upon the assumed ages at full recruitment from 6 to 9 years. These total mortality rates are lower than the 0.23 obtained by Washington et al. (1978) and Gowan (1983), who used surface-read otoliths for copper rockfish in South Sound. Reliable natural mortality rates are not found in the literature. Gowan (1983) estimated natural mortality at 0.13, and this value was used by Gunderson (1997) to evaluate reproductive effort and survival in marine fishes. Barker (1979) used surface-read otoliths from copper rockfish in the San Juan Islands and estimated that total instantaneous mortality as 0.18 and natural instantaneous mortality was 0.11.

Copper rockfish in South Sound quickly attain 20 cm in total length within the first few years of life and can reach 50 cm in total length after age 10 (Figure 6.2). Copper rockfish vary widely in their growth patterns, with length varying by 10 to 20 cm at any age. The von Bertalanffy growth coefficient ranged from 0.14 to 0.18 in North Sound but was only 0.13 in South Sound (Table 6.4). Average fork lengths of copper rockfish caught by recreational fishers in both North and South Sound were 35 cm to 39 cm during the late 1970s but then declined during the early 1980s to approximately 30 cm in 1986 to 1987 (Figure 6.4). In North Sound, mean length for copper rockfish subsequently fluctuated between 30 and 33 cm until the implementation of the one fish bag limit in 2000 after which mean length increased to 34 cm. A similar pattern occurred in South Sound, where mean lengths ranged from 35 to 39 cm during the 1970s and then decreased to 30 cm during the 1980s. After the 1994 implementation of the three fish daily bag limit, mean size increased to 36 cm and then fluctuated between 32 and 34 cm into the 2000s. Copper rockfish as small as 10 cm were captured by recreational fisheries in North and South Sound, but most harvested fish measured between 20 and 40 cm (Figures 6.5 and 6.6). The increase in mean length after the implementation of restrictive bag limits in South Sound in 1994 and North Sound in 2000, suggests fishers were selecting larger fish for their single, daily harvest of rockfish.

Based upon these life history characteristics, copper rockfish in North and South Sound showed a predominant Low Productivity pattern (Table 6.2). Although the growth coefficients range in North Sound included the Medium Productivity category, the more important factors, maximum age and maturity, placed them in the Very Low and Low Productivity categories. In South Sound, the growth coefficient and maximum age placed copper rockfish in the Low Productivity category with age at first maturity not sufficiently understood for a determination. The Low Productivity category corresponded to a 0.85 vulnerability threshold (Table 6.1) for trends measured over a 40 year, three-generation period.

6.7.1.2 Status and Trends

Most fishery-dependent and independent indices indicated that copper rockfish stocks have decreased or now have less spawning output than during the late 1970s, declining trends well within the three-generation period. In both North and South Sound, the *SSBR'* in the late 1990s declined by 69%, or more, compared to the average historic *SSBR'* (Figure 6.5). The estimated *SSBR'* for a female copper rockfish in North Sound averaged 219,000 eggs per female between 1978 and 1980 and had annual values ranging between 116,000 and 280,000 eggs per female in 1979 (Figure 6.5). After 1980, the *SSBR'* declined by 50%, in 1982, and to levels 57% to 75% of the average historic *SSBR'* . The mean *SSBR'* was 67,000 eggs per female between 1998 and 1999, the two years prior to the implementation of the one fish daily bag limit. This average was 69% less than the average, historic *SSBR'* . The average, historic *SSBR'* between 1977 and 1980 in South Sound was 142,000 eggs per female, with annual values ranging from 83,000 eggs per female in 1980 to 259,000 eggs per female in 1977 (Figure 6.5). The *SSBR'* declined to 64,500 in 1982 (45%), and then to levels that were between 47.5% and 80% of the historic average. The mean *SSBR'* in 1998 and 1999 was 28,000 eggs per female, a value that was 20% of the historic average.

Fishery-independent surveys provided some independent confirmation of the declining trends observed from fishery-dependent time series. Copper rockfish have occurred sporadically in the bottom trawl surveys since 1987 (Tables 6.5 and 6.6) and although biomasses have trended downward during recent surveys, there is no statistical significant trend. For the combined East Juan de Fuca and Georgia Basin regions, copper rockfish dominated the rockfish biomass in 1987 with an estimated biomass of 60 mt (Table 6.5, Figure 6.8). This is the only year with a substantial catch of copper rockfish in North Sound. In South Sound, copper rockfish biomass fluctuated dramatically, from 100 to 1,100 mt, during the first three surveys (Table 6.6, Figure 6.9). Copper rockfish dominated the high biomass estimate of 1989 but during 1995-1996 and 2002, the copper rockfish biomass was only 50 mt. Due to the high variation in biomass estimates, these declining trends were not statistically significant.

Station counts of copper rockfish from quantitative video or, VAT, surveys have decreased in the largest sub-basins of North and South Puget Sound. In the San Juan Islands, copper rockfish counts at stations with rocky habitat declined more than 50%, from 0.8 fish per station in 1994 to 0.3 fish per station in 2000 (ANOVA, $p<0.05$, Table 6.7). In the Georgia Basin region to the north, copper rockfish were not encountered during the 1995 pilot survey but were observed at several stations in 1999. In the Strait of Juan de Fuca, copper rockfish counts averaged 0.9 fish per station in 1996, but declined to 0.23 fish per station in 2004 (ANOVA, $p<0.05$). Among the sub-basins making up South Sound, copper rockfish counts declined in Hood Canal and Central Sound, but increased in southern Puget Sound, south of

Tacoma Narrows (Table 6.7). Mean station counts for copper rockfish in Hood Canal declined from 2.3 fish per station in 1996 to 0.4 fish per station in 2002 (ANOVA, $p<0.05$). In particular, swarms of small copper rockfish were observed at many stations during the 1996 survey that were not subsequently observed. In Central Sound, the mean station count of copper rockfish declined 50% between 1995 and 2001. Only one station had copper rockfish during the 1995 survey in Southern Puget Sound south of Tacoma Narrows, but more were observed during the 2001 survey and a two-fold increase occurred. The declines in mean station count ranged between 58% and 76% in North Sound and between 59% and 81% in South Sound over the past decade indicating that stock decreases are continuing beyond the time period assessed by the spawning potential method, which ended in 1999. The VAT was also used to estimate the abundance of copper rockfish in nearshore waters during the last surveys. During the surveys conducted between 1999 and 2004, there was an estimated total of 361,000 copper rockfish in North Sound (Table 6.9, Standard Error=18.2%), and between 2001 and 2002, there was an estimated total of 22,724 copper rockfish in South Sound (Table 6.8, Standard Error=21.5%).

Scuba surveys in central Puget Sound corroborate the declining trends in copper rockfish abundance observed in the SPR and quantitative video survey time series. The abundance of adult and subadult copper rockfish has dramatically declined at three reference sites in central Puget Sound since Matthews (1990a) surveyed them in 1987 (Figure 6.10). Total copper rockfish counts obtained during scuba transects averaged approximately 56 fish per transect during the ten-year period between 1987 and 1997, and then decreased by 67% between the 1999 to 2003 period. More recent analysis of copper rockfish abundance at Brackett's Landing marine reserve and at Port Blakely and Blake Island, show recent stability since 1994 (See Section 4.5, Marine Reserves).

Since copper rockfish stocks in North and South Sound are Low Productivity and have Generation Times of 7.7 years, stock declines greater than 85% over 23 years would prompt a Vulnerable or Depleted stock status categorization. The dramatic decline in the spawning potential, video counts in the San Juan Islands, Central Sound, and Hood Canal, and scuba-observed densities in Central Sound dive sites, all corroborate the conclusion that copper rockfish stocks in both North and South Sound have declined since the mid-1970s over a 23 year time period (Table 6.9). The 69% decrease in the *SSBR'* index in North Sound between 1976 and 1999 does not meet the 85% decline threshold for a Low Productivity stock, but does exceed a 50% decline. The 58% decline in VAT station count over an approximate ten-year period also exceeds a 50% historic decline. Because copper rockfish in North Sound declined but were above the AFS the threshold, the stock has a Precautionary status. In South Sound, the 80% decline in the spawning potential over a 24-year period nearly met the 85% threshold for a low productivity stock. The declining trends in the VAT and scuba surveys during the past ten and twenty years, ranged from 58% to 81% and did not reach the threshold, but corroborated and extended the declining trends and determinations based upon the SPR trend. The South Sound stock of copper rockfish is, therefore, in Vulnerable status.

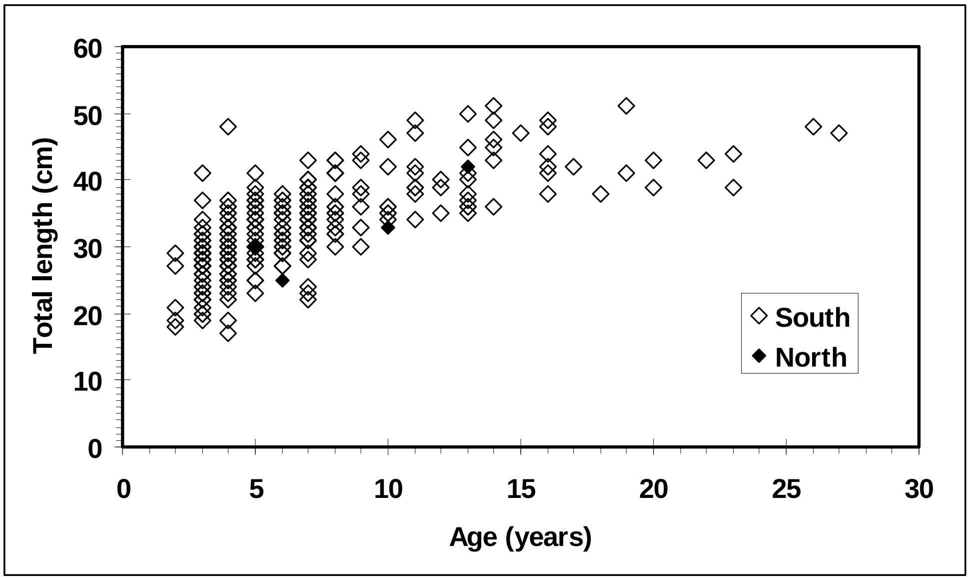


Figure 6.2. Growth of copper rockfish in North and South Puget Sound observed from bottom trawl and other research samples.

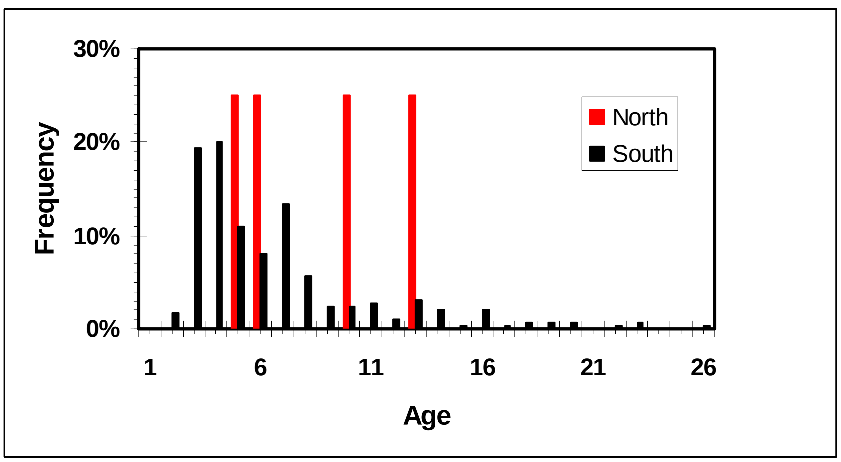


Figure 6.3. Age frequency distributions of copper rockfish for North and South Puget Sound, collected from from bottom trawl and other research surveys.

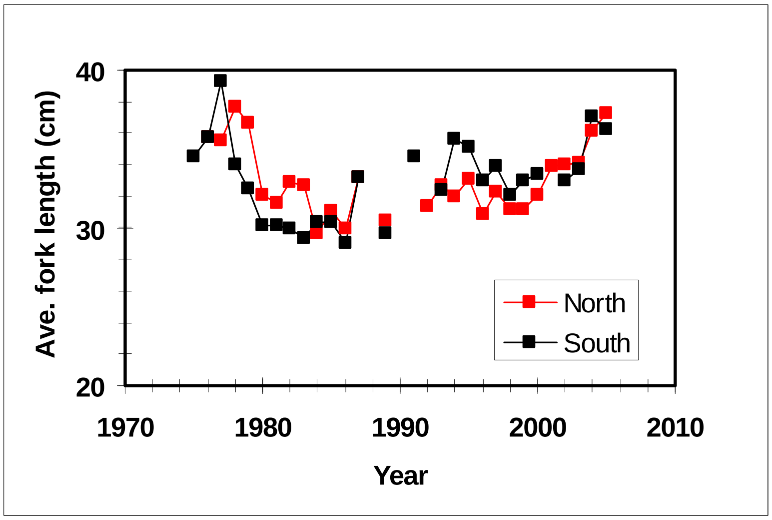


Figure 6.4. Average fork length (cm) of copper rockfish observed from recreational hook-and-line catches in North and South Puget Sound.

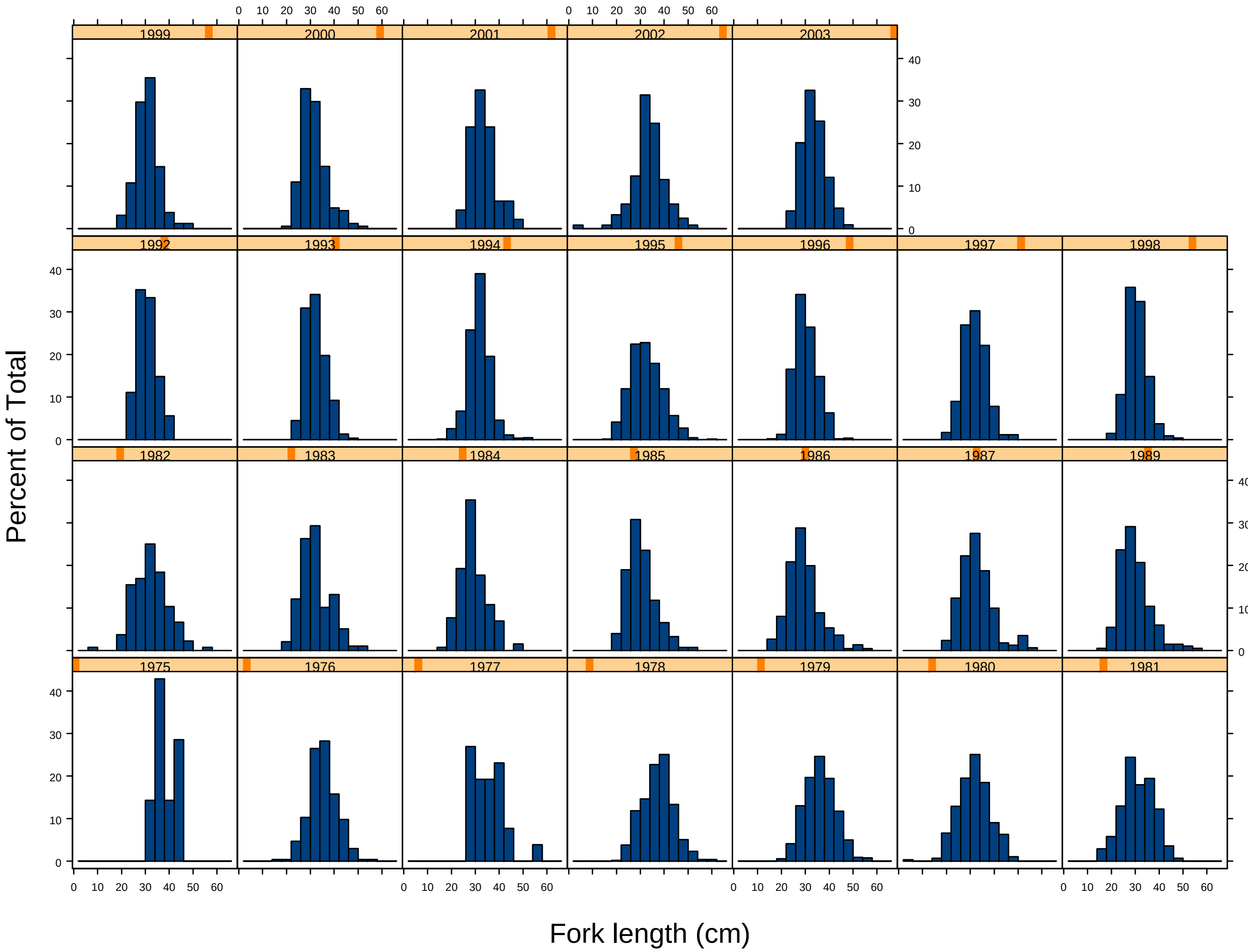


Figure 6.5. Copper rockfish length frequency distributions collected from North Puget Sound, 1975 to 2003.

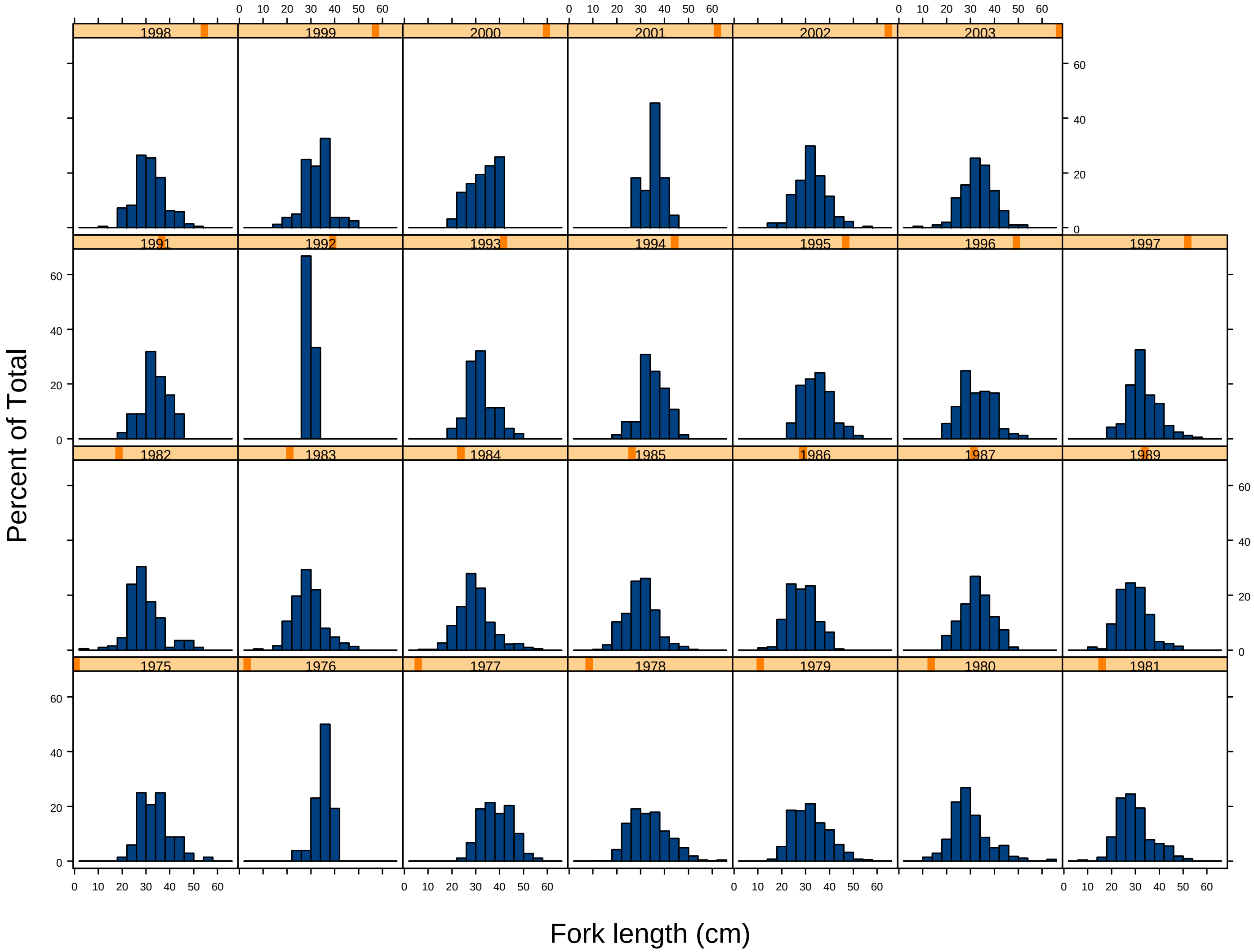


Figure 6.6. Copper rockfish length frequency distributions collected from South Puget Sound, 1975 to 2003.

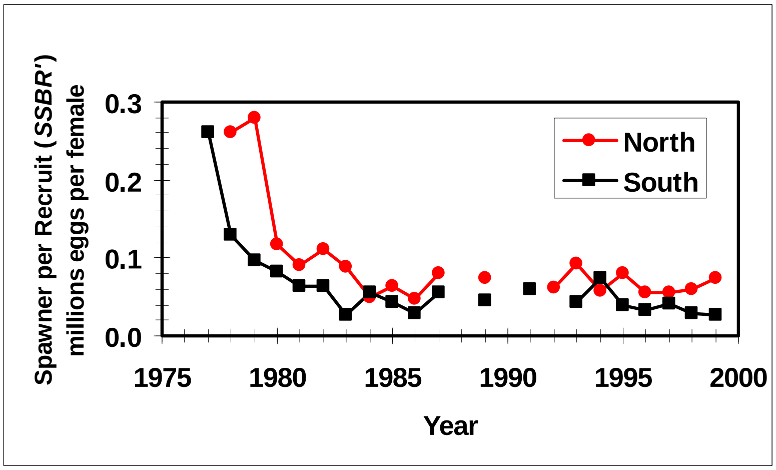
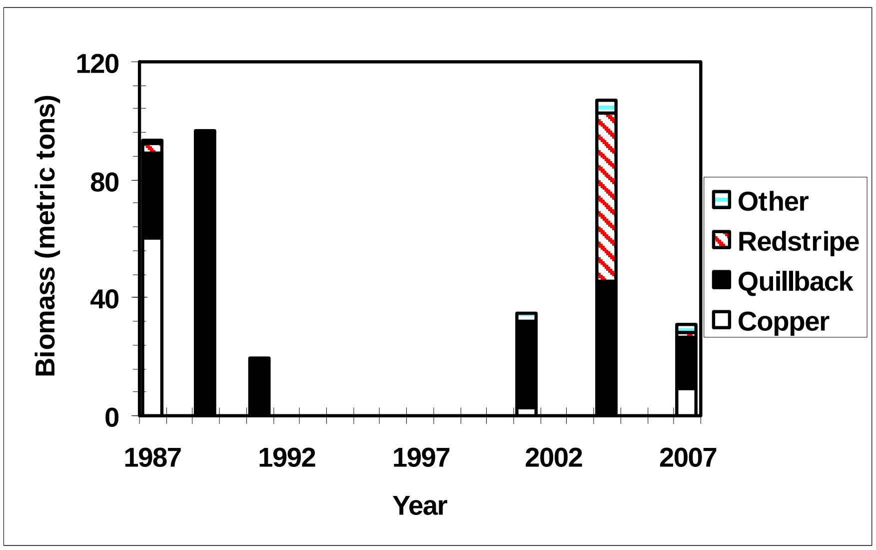


Figure 6.7. Spawning potential (*SSBR'*) curves for copper rockfish in North and South Puget Sound.



2003.

Figure 6.8. Biomass estimates of rockfish (metric tons) from WDFW bottom trawl surveys in the Georgia Basin and East Juan de Fuca regions of North Sound.

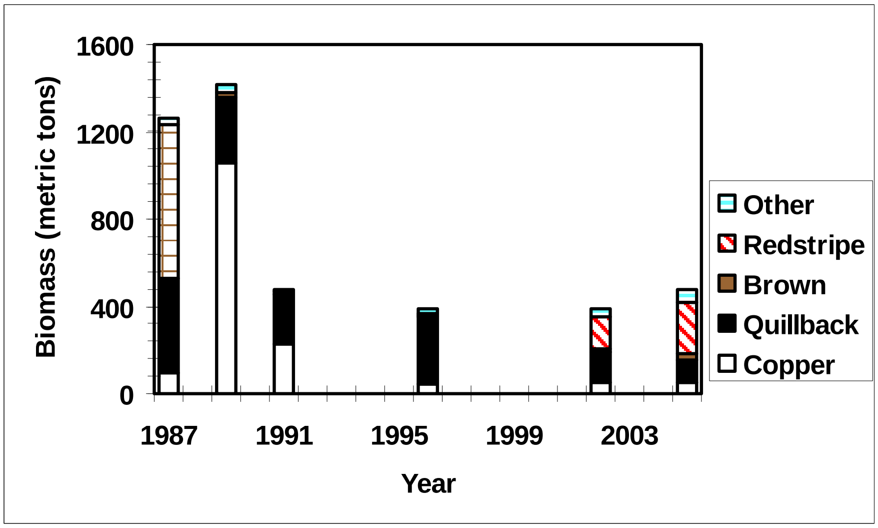


Figure 6.9. Biomass estimates of rockfish (metric tons) from WDFW bottom trawl surveys in South Sound.

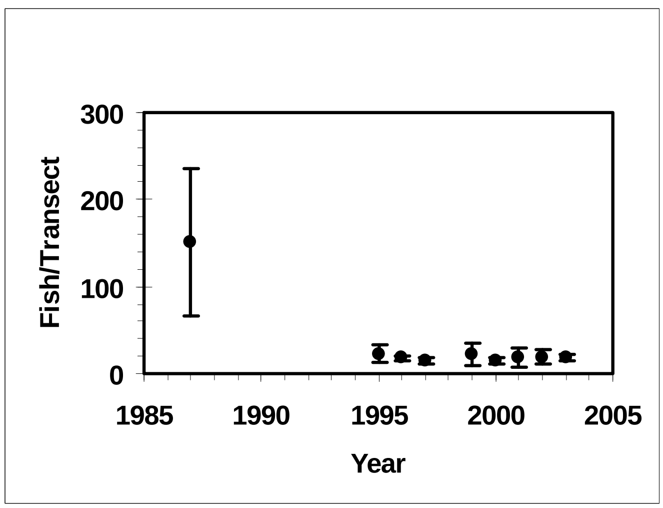


Figure 6.10. Densities of copper rockfish and 95% confidence limits observed by scuba divers among three index sites in Central Puget Sound.

Table 6.7. Mean Station Counts from Quantitative Video Surveys Conducted in Puget Sound for Copper, Quillback, and Puget Sound Rockfishes.

Region and Species	Year and Mean Count	% Standard Error	Year and Mean Count	% Standard Error
Georgia Basin	**1995**		**1999**	
Copper	0		0.05	38.3
Quillback	0		0.01	71.2
Puget Sound	0		0.35	45.5
No. of stations	50		330	
San Juan Islands	**1994**		**2000**	
Copper	0.81	18.1	0.34	14.3
Quillback	0.40	29.3	0.22	16.3
Puget Sound	15.10	21.3	5.68	19.0
No. of stations	222		490	
Juan de Fuca	**1996**		**2004**	
Copper	0.94	23.8	0.23	39.1
Quillback	0.23	58.3	0.14	50.0
Black	0.60	32.8	0.22	45.5
No. of stations	48		86	
Hood Canal	**1996**		**2002**	
Copper	2.27	41.9	0.43	61.6
Quillback	0.40	47.5	.0.13	
No. of stations	45		118	
Central Sound	**1995**		**2001**	
Copper	0.58	21.3	0.24	20.2
Quillback	0.39	27.4	0.24	28.2
Brown	0.14	26.2	0.11	23.7
No. of stations	218		517	
South Sound	**1995**		**2001**	
Copper	0.26	0.3	0.52	44.1
Quillback	0		0.05	70.0
Brown	0.19	81.7	0.17	42.8
No. of stations	27		82	

Table 6.8. Summary of the Most Recent Quantitative Video Abundance Estimates and Percent Standard Errors (%SE) from North Sound (1999-2004) and South Sound (2001-2002).

	North			South		
Species	**Numbers**	**% SE**	**Biomass (mt)**	**Numbers**	**%SE**	**Biomass (mt)**
Copper	361,308	18.2	289.0	22,724	21.5	18.2
Quillback	309,867	34.3	216.9	17,762	32.4	12.4
Black	167,769	71.0	201.3	1,971	60.4	2.4
Brown	0		0	10,332	23.8	4.1
Yellowtail	16,598	100.0	11.6	10,087	98.5	7.1
Canary	2,751	89.3	4.4	0		0
Vermilion	85,457	81.0	162.4	0		0
Puget Sound	3,264,745	29.3	163.2	3,878	68.7	0.2
Unidentified	295,152	67.5	354.2	5,799	24.8	7.0
Total	4,503,650	22.1	1,403.0	7,2552	18.1	51.3

Table 6.9. Summary of Fishery-Dependent and Independent Trends Observed for Rockfishes in Puget Sound.

	Spawner per Recruit (Late 1970s-1999)	Trawl Survey (1987-2007)	Video (Mid 1990s-early 2000s)	Dive (1987-2003)	Status
Copper					
North	69% decline	No trend	58% decline in SJ		Precautionary
South	80% decline	No trend	76% decline in JF 59% decline in CS 81% decline in HC 100% increase in SS, ns	67% decline	Vulnerable
Quillback					
North	73% decrease	No trend	No trend in SJ		Vulnerable
South	78% decrease	62% decline	No trend	97% decline	Depleted
Brown					
North					Unknown
South		90% decline	No trend	194% increase	Precautionary
Black					
North		Rare	Variable in JF		Precautionary
South		Not detected			Precautionary
Yelloweye					
North		Rare			Depleted
South		Rare			Depleted
Yellowtail					
North		Rare			Precautionary
South		Not detected			Precautionary
Canary					
North		Not detected			Depleted
South		Not detected			Depleted
Bocaccio					
North		Not detected			Precautionary
South		Not detected			Precautionary

Table 6.9. Summary of Fishery-Dependent and Independent Trends Observed for Rockfishes in Puget Sound. (continued)

	Spawner per Recruit	Trawl Survey	Video	Dive	Status
Redstripe					
North		No trend, but more common			Healthy
South		No trend			Healthy
Greenstriped					
North		No trend			Healthy
South		No trend			Healthy
Splitnose					
North		Not detected			Unknown
South		Recent estimates 61% lower than 1987			Precautionary
Shortspine					
North		No trend			Healthy
South		No trend			Healthy
Tiger					
North		Not detected			Unknown
South		Not detected			Unknown
China					
North		Not detected			Unknown
South		Not detected			Not detected
Blue					
North		Not detected			Unknown
South		Not detected			Not detected
Vermilion					
North		Not detected			Precautionary
South		Rare			Precautionary
Puget Sound					
North		Increasing	62.4% decrease in SJ		Precautionary
South		No trend			Healthy

6.7.2 Quillback Rockfish

6.7.2.1 Life History Characteristics

Quillback rockfish live longer and grow more slowly than copper rockfish and, thus, constitute a limiting stock to the management of Puget Sound rockfish fisheries. Their life history characteristics indicate they are in the Very Low Productivity category. The maximum age observed for quillback rockfish in North Sound was 73 years and for South Sound, 53 years (Table 6.4, Figures 6.11 and 6.12), far exceeded the AFS productivity criteria (30 years at maximum age) for a Very Low Productivity stock. They can live as long as 95 years in B.C. (Munk 2001, Yamanaka and Lacko 2001). Seventy percent, or more, of the quillback rockfish captured in North and South Sound ranged from age 3 to 15 years old, with most of the remainder older than 16 years (Figure 6.11). Few quillback rockfish in South Sound were older than 40 years, which contrasts with North Sound. In addition, instantaneous total mortality rates are lower in North Sound than in South Sound (Table 6.4). Catch curve analysis of quillback rockfish ages from WDFW research samples, pooled over all years, yielded total instantaneous morality rates of 0.06 to 0.07 in North Sound and 0.12 to 0.13 in South Sound. These were one half or less of the estimates by Washington et al. (1978), Barker (1979), and Gowan (1983) who used surface-age determinations. Instantaneous natural mortality of quillback rockfish in British Columbia was estimated at 0.02 to 0.04 based upon catch curve analysis of unfished or lightly fished stocks (Yamanaka and Lacko 2001). Barker (1979) estimated natural mortality at 0.13 in the San Juan Islands, but again the estimate was based upon surface otoliths ages that likely overestimated the rate. Natural mortality is probably higher in South Sound given faster growth and shorter longevities. Gowan (1983) estimated instantaneous natural mortality in South Sound at 0.12, but these were based upon surface ages.

Information is poor regarding the maturation of quillback rockfish in Puget Sound, since age and maturity studies have been based upon surface reading of otoliths. Quillback rockfish in the San Juan Islands show 50% maturity at age 5 (Barker 1979), while those in South Sound are 50% mature at age 4 (Washington et al. 1978, Gowan 1983, Table 6.4). In B.C., quillback rockfish stocks 50% are mature by age 11 (29 cm, Richards and Cass 1987), which is likely similar to quillback rockfish in North Sound. Based upon the age frequencies and the age-at-maturity observed in B.C., the Generation Time for quillback rockfish was 23.8 years in North Sound. In South Sound, the Generation Time was estimated at 12.1 years with a presumed age-at-maturity of four years (Table 6.4).

Quillback rockfish tended to grow faster in South Sound than in North Sound, but in either region showed much individual variation in growth. Most individuals measured 10 cm by their second year of life (Figure 6.12). By age ten, quillback rockfish measured between 20 cm and 40 cm. Quillback rockfish in South Sound were approximately 10 cm smaller than those in North Sound at any given age past five years old (Figure 6.12). Von Bertalanffy growth rates were between 0.09 and 0.16 for North Sound quillback rockfish and between 0.11 and 0.17 for South Sound quillback rockfish (Table 6.4). Estimated length-at-infinities were only 32 to 36 cm for South Sound quillback rockfish and between 41 and 46 cm for North Sound (Table 6.4). Growth appeared to be variable regardless of region: Within any age category of quillback rockfish, lengths typically ranged by ten cm or more.

The mean fork length of quillback rockfish in the recreational catch tended to be greater in North Sound than South Sound, but mean lengths declined in both North and South Sound during the past two decades (Figure 6.13). In North Sound, mean length ranged between 37 cm and 39 cm during the late 1970s and then decreased to 33 cm in the mid 1980s. Mean size fluctuated through several increases and decreases after 1984 and had a low of 31 cm in 1999 with a subsequent increase after 2000, to mean lengths between 33 and 38 cm. In South Sound, quillback rockfish mean length ranged between 31 cm and 36 cm in the late 1970s and then decreased to a low of 25 cm in 1986. Similar to North Sound, mean length fluctuated greatly after 1986, increasing to 37 cm in 1995, but declining to 30 cm or less during the late

1990s and early 2000s. Mean length subsequently increased to 34 cm in the mid 2000s. As with copper rockfish, increases in mean size of quillback rockfish after 1995 and again after 2000, may be associated with reductions in the daily bag limit and size selection recreational fishers. Quillback rockfish as small as ten centimeters were taken by sport fishers in Puget Sound, and quillback rockfish rarely exceed 50 cm in length in the recreational fishery (Figures 6.14 and 6.15). Fork length frequency distributions for quillback rockfish from recreational fisheries in North and South Sound, generally showed a shift to higher frequencies of smaller fish (30 cm or less) and a loss of larger rockfish (over 40 cm) over time (Figures 6.14 and 6.15).

Based upon the observed life history characteristics, quillback rockfish in both North and South Puget Sound were classified as stocks of Very Low Productivity (Tables 6.2 and 6.4). Since the maximum ages exceeded the maximum age criteria of 30 years, and the expected ages-at-maturity were likely older than those estimated by surface reading techniques and in excess of 10 years, the Very Low Productivity category was appropriate. Other factors, such as growth and fecundity-at-maturity, demonstrated productivity values in the Medium Productivity category, but maximum age and age-at-maturity took higher precedence in evaluating stock vulnerability (Musick 1999).

6.7.2.2 Status and Trends

Fishery-dependent data revealed that the mean length of quillback rockfish decreased in North and South Sound. If natural mortality estimates made by Yamanaka and Lacko (2001) for B.C. are applicable to quillback rockfish in North Sound, then total mortality estimates derived from composited age frequencies (Figure 6.11) put fishing mortality in the range of 0.04 to 0.05 for natural mortality equal to 0.02 and fishing mortality at 0.02 to 0.03 for natural mortality equal to 0.04. With the low range of the estimates, fishing mortality exceeds natural mortality by a factor of 2 to 2.5. For the high range, fishing mortality is less than natural mortality and in the range of a precautionary harvest rate. Without substantiation of natural mortality rates in Puget Sound, considering the lower estimates would be precautionary and indicate that fishing has been at unsustainable rates in North Puget Sound.

In both North and South Sound, the combination of declining rockfish catch rates and declining size for quillback rockfish resulted in the *SSBR'* decreasing after the historic peak values observed between 1977 and 1980 (Figure 6.16). In North Sound, the *SSBR'* for quillback rockfish averaged 287,000 between 1977 and 1980, with a range of 182,000 eggs per female to a peak of 382,000 eggs per female in 1977 (Figure 6.16). Subsequently, the *SSBR'* declined to 116,000 eggs per female in 1982, a 59% decline from the historic peak average. The *SSBR'* generally continued to decrease, ranging from 77,000 to 142,000 eggs per female during the remainder of the 1980s and 1990s. The 1998 to 1999 average *SSBR'* was 76,400 eggs per female which is 73% of the historic peak average. In South Sound, the average, peak historic *SSBR'* was 86,000 eggs per female, much lower than the North Sound value (Figure 6.16). For South Sound, the range in the *SSBR'* between 1977 and 1980 was 55,000 to 145,000 eggs per female. The *SSBR'* declined to 29,000 eggs per female in 1982, a 65% decline from the historic peak average, and subsequently ranged between 16,000 and 72,000 eggs per female. The average *SSBR'* between 1998 and 1999 was 18,700 eggs per female, a 78% decline from the average, historic peak spawning potential.

Fishery-independent surveys generally confirmed the decline of quillback rockfish observed with fishery-dependent trends in both North and South Sound. Quillback rockfish were regularly encountered during bottom trawl surveys of Puget Sound, and stocks in trawlable habitat were more abundant in South Puget Sound than in North Puget Sound. In East Juan de Fuca and Strait of Georgia regions of North Sound, quillback rockfish was the second most dominant rockfish in the trawl survey with a biomass of 29 mt in 1987 (Table 6.5, Figure 6.8), but became the most dominant rockfish during 1989, 1991, and 2001 surveys, with a peak biomass of almost 100 mt in 1989. Biomasses have since decreased, and were between 29 mt and 45 mt during combined 2000 and 2001 survey and 2004 survey, respectively. Variability in these estimates was too great to observe a statistically significant trend. Quillback rockfish biomass during the two most recent surveys in South Sound was significantly lower than that of the 1987 and 1989 surveys (Table 6.6, Figures 6.9 and 6.17). Quillback rockfish biomass was over 400 mt during the 1987 survey and then decreased to between 200 mt and 300 mt between the 1989 survey and the combined 1995 and 1996 surveys. The 2002 survey biomass was approximately 150 mt and the confidence limits excluded the point estimates from previous surveys, indicating a significantly lower estimate than during any previous survey. The 2002 and 2005 average estimate was 62% lower than average, historic peak biomass between 1987 and 1991.

The quantitative video survey targets nearshore and shallow habitats where quillback rockfish stocks showed declining but not significant trends in key areas. In the San Juan Islands, mean station counts of quillback rockfish have declined from 0.4 fish per station in 1994, to 0.2 fish per station in 2000 (Table 6.7). In the Georgia Basin, quillback rockfish were not encountered during the 1995 pilot survey but were observed at several stations in 1999. During the 1994 Strait of Juan de Fuca survey, the quillback rockfish mean station density was 0.2 fish per station but was only 0.1 fish per station in 2004, and the mean count was not statistically different. For Central Puget Sound and Hood Canal, mean station counts of quillback rockfish were lower during the combined 2001 and 2002 surveys than during the combined 1995 and 1996 surveys, but the estimates varied widely. Quillback rockfish were not encountered during the 1995 survey of Southern Puget Sound, but in 2001, mean station counts were 0.05 fish per station. The most recent VAT survey in North Sound conducted between 1999 and 2004 found an estimated 310,000 quillback rockfish (Table 6.8, Standard Error=34.3%). In South Sound there were only 17,800 quillback rockfish during the combined 2001 and 2002 surveys (Standard Error=32.4%).

The scuba surveys at three Central Puget Sound sites revealed a dramatic decline in quillback rockfish abundance since Matthews (1990a) first surveyed them in 1987 (Figure 6.18). Quillback rockfish counts averaged approximately 147 fish per transect in 1987. Mean scuba counts declined to 13 quillback rockfish per transect in 1995, and to one or two fish per transect during the most recent years.

Since quillback rockfish stocks are of Very Low Productivity, and Generation Times are 24 and 12 years for North and South Sound respectively, stock declines of 70% over 72 and 36 years, triggered Vulnerable or Depleted stock status conditions. The dramatic decline in spawner per recruit, greater than 73% in North Sound and 78% in South Sound over three decades, exceeded the AFS threshold for a Very Low Productivity stock (Table 6.9). In North Sound, the decline in spawning potential was not directly corroborated by the fishery-independent bottom trawl and quantitative video surveys, which both showed non-significant declines (Table 6.9). In South Sound, the 62% decline in biomass observed from the bottom trawl survey and the 97% decline in diver-observed densities at three reference sites, corroborated the decline in the spawning potential. For North Sound quillback rockfish, the spawning potential decline of 73% slightly exceeded the 70% decline threshold for a stock at risk. Because the one fish daily bag limit is in place and rocky habitat is extensive in North Sound, the status of this stock is in Vulnerable. For South Sound, the greater declines of quillback rockfish trends and more limited amounts of habitat places this stock in Depleted category. Research surveys in British Columbia have shown a mixed pattern of trends for quillback rockfish, either showing no trend or a maximum decline of 75% over an 18 year period (1986-2004, Yamanaka et al. 2006).

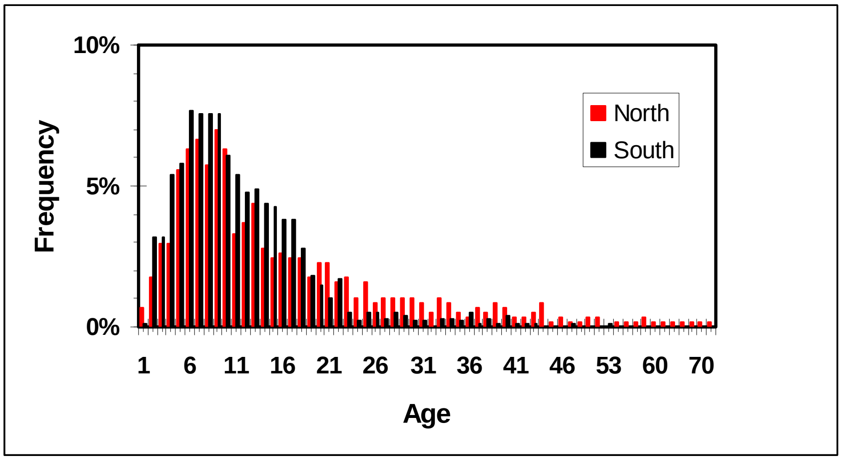


Figure.6.11. Age frequency distributions of quillback rockfish for North and South Puget Sound collected from bottom trawl and other research surveys.

Figure 6.12. Growth of quillback rockfish in North and South Puget Sound observed from bottom trawl and other research samples.

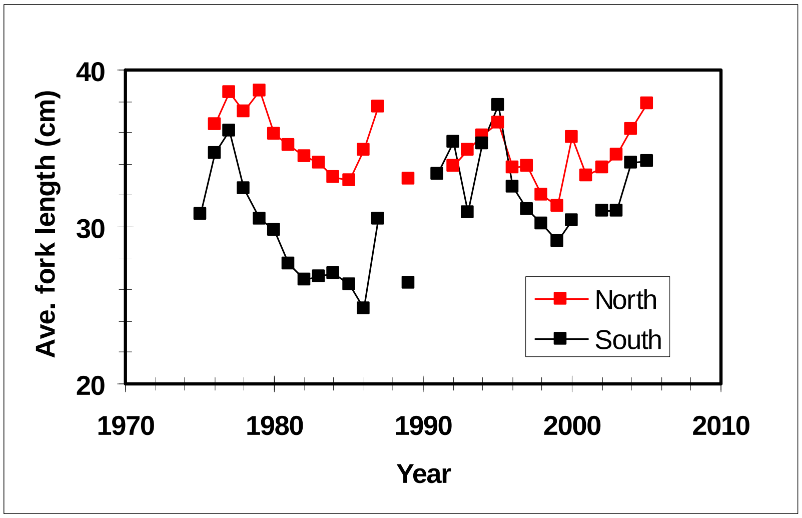


Figure 6.13. Mean fork length (cm) of quillback rockfish observed from recreational hook-and-line catches in North and South Puget Sound.

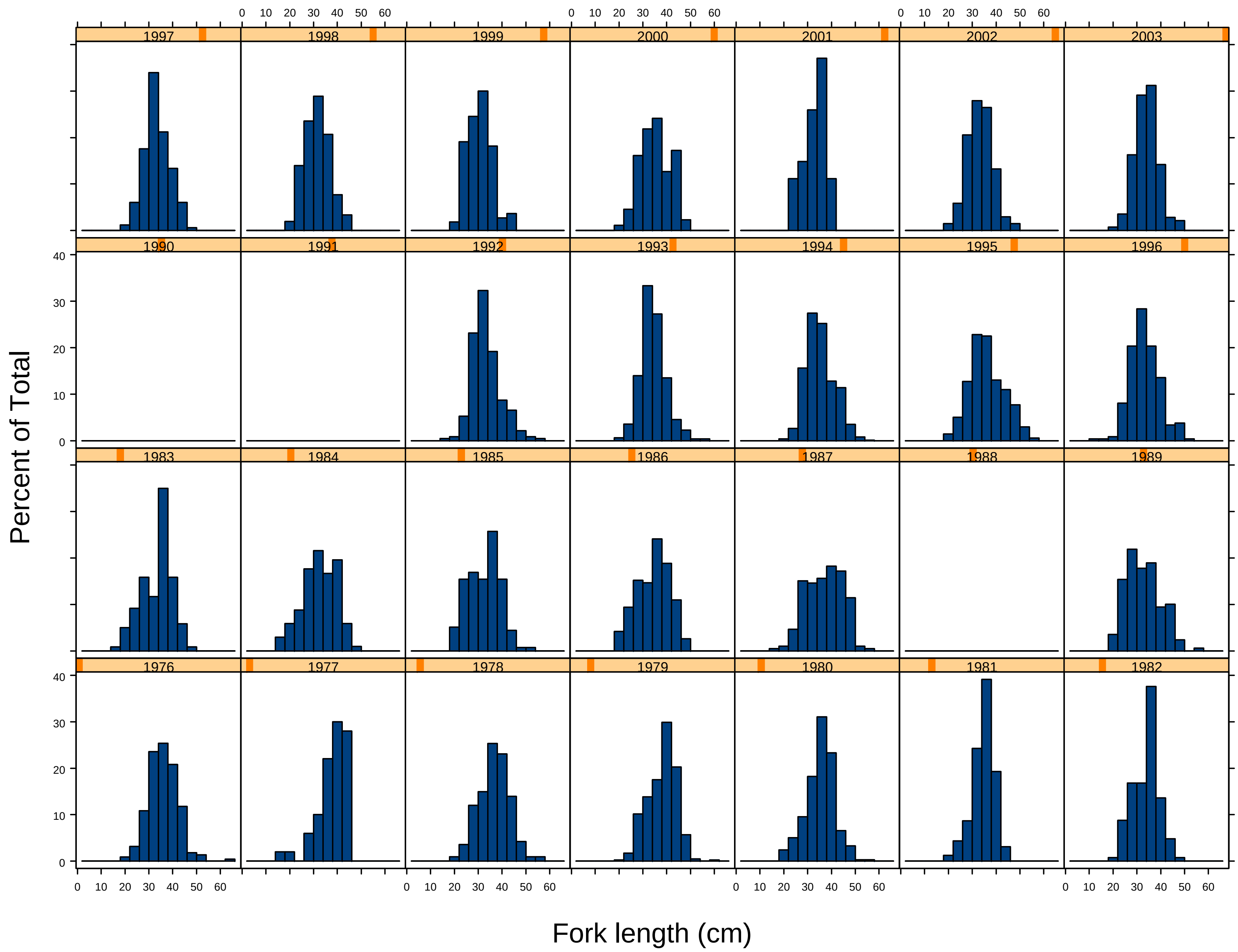


Figure 6.14. Quillback rockfish length frequency distributions for North Puget Sound, 1976 to 2003.

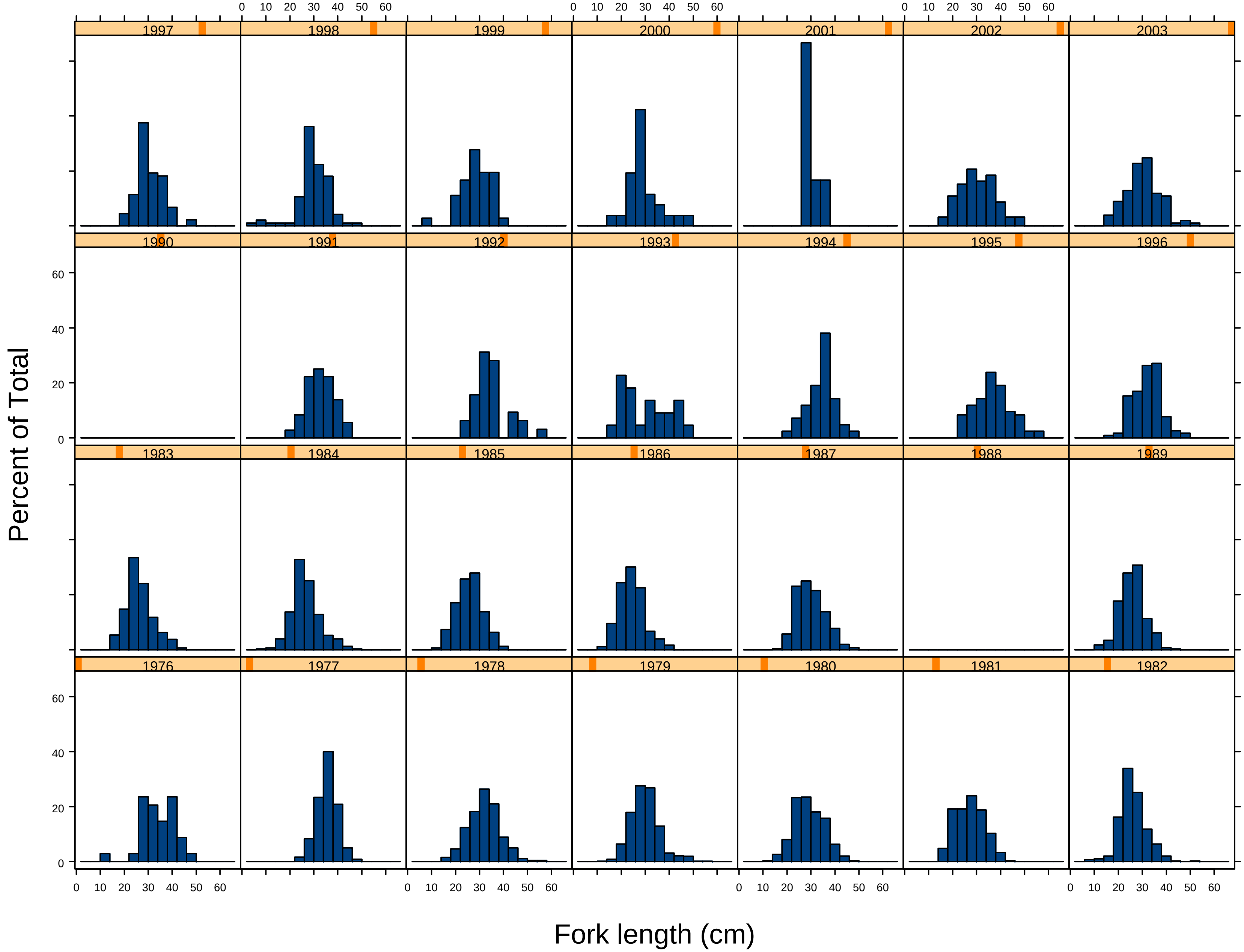


Figure 6.15. Quillback rockfish length frequency distributions for South Sound, 1976-2003.

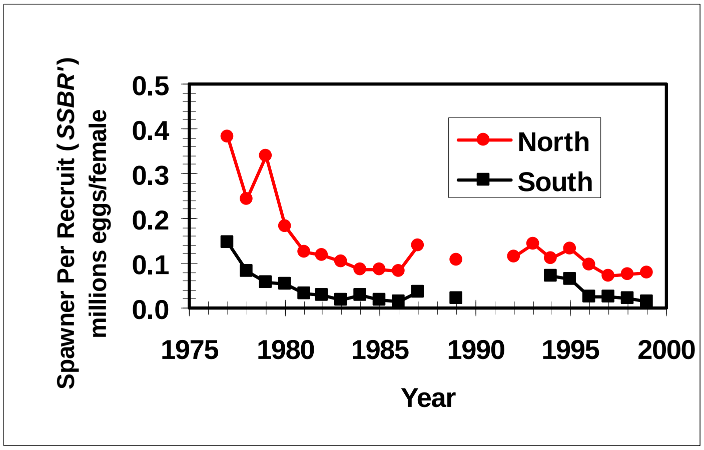


Figure 6.16. Spawning potential (*SSBR'*) curves for quillback rockfish in North and South Puget Sound.

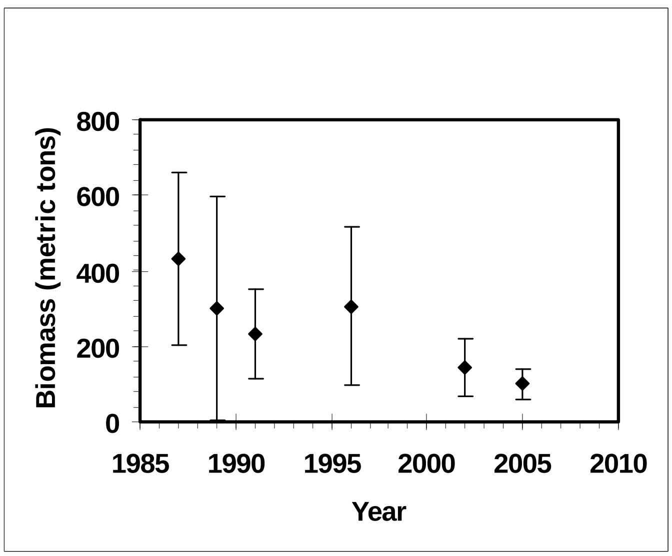


Figure 6.17. WDFW trawl survey estimates and 95% confidence limits for quillback rockfish in South Sound.

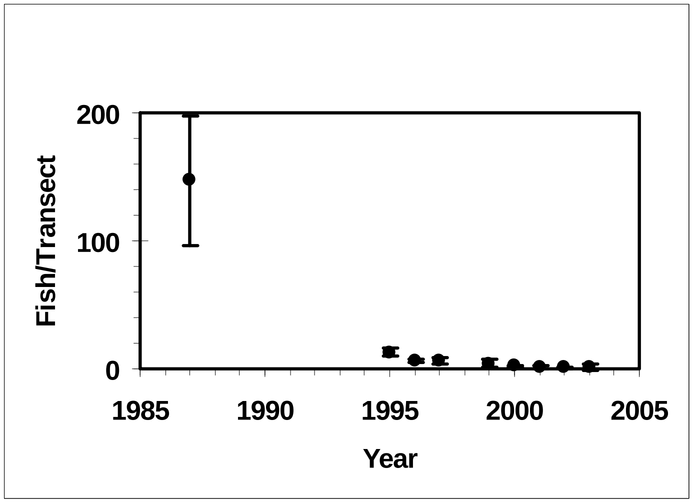


Figure 6.18. Densities of quillback rockfish and 95% confidence limits observed by scuba divers among three index sites in Central Puget Sound.

6.7.3 Brown Rockfish

6.7.3.1 Life History Characteristics

Brown rockfish are too rare in North Puget Sound to conduct a stock status determination. In South Sound, however, brown rockfish have become more common during the past decade. Brown rockfish possess life history characteristics classify them in the Very Low Productivity category. Their maximum age in South Sound is 46 years, but they reach 50 years elsewhere (Table 6.4, Munk 2001). This longevity exceeds the 30-year age threshold for T_{max} for a Very Low Productivity stock (Table 6.2). Washington et al. (1978) and Gowan (1983) determined 50% maturity of brown rockfish stocks in South Sound is 4 years, and Love et al. (2002) listed maturity between 3-5 years in California. However, a greater age-at-maturity is suspected because Washington et al. and Gowan used surface-readings of otoliths that may have underestimated the age. Generation Time was estimated at 10.8 years assuming an age-at-maturity of 4 years (Table 6.4). Eighty percent of the brown rockfish stock is between 3 and 15 years in age and 11% were 16 years or older (Figure 6.19). Washington et al.'s (1978) and Gowan's (1983) estimates of total mortality for brown rockfish was 0.27, and Gowan (1978) estimated natural mortality at 0.11, but WFDW catch curve analysis yielded an estimate of 0.05 for ages 12 to 34, a value that is one third the estimate of Gowan (1983).

Growth was variable with lengths ranging by 10 cm in any age category over five years old (Figure 6.20). Most brown rockfish reach a length of 20 cm by age 7 and 30 cm by age 30. The growth rate for South Sound brown rockfish was 0.14 (Table 6.4), a value that indicates a stock with Low Productivity. Brown rockfish sampled in the recreational fishery reached a fork length of 53 cm (WDFW, unpublished data). In South Sound, brown rockfish enter the recreational fishery at 11 cm, with only a few greater than 45 cm. The annual mean length of brown rockfish ranged between 28 cm and 31 cm during the 1980s.

Because of the importance of maximum age in determining the stock productivity, brown rockfish in South Sound are Very Low Productivity. Their 11 year Generation Time means that a decline of 70% over a 33-year period would result in a Vulnerable or Depleted stock status.

6.7.3.2 Status and Trends

Detailed fishery-dependent data are not available for brown rockfish in South Sound. Too few length observations have been collected and mean length shows no trend. The lack of consistent and sufficient length samples precludes the evaluation of the spawner per recruit for brown rockfish in South Sound.

Brown rockfish were encountered in fishery-independent surveys. During the 1987 bottom trawl survey, one large catch of brown rockfish weighing 530 lbs (231kg) resulted in an extremely large biomass estimate of 707 mt (Table 6.6). During subsequent trawl surveys, the biomass has never exceeded 33 mt and has varied without trend. Brown rockfish were encountered during quantitative video surveys in Central and Southern Puget Sound. Mean station counts were stable between early and recent surveys in both regions, ranging between 0.15 and 0.11 fish per station (Table 6.7). Brown rockfish were not encountered during video surveys in Hood Canal, but scuba studies in Hood Canal do reveal its presence as an uncommon species. The most recent VAT surveys estimated of 10,300 brown rockfish in South Sound (Table 6.8, Standard Error=23.8%).

Scuba surveys in Central Puget Sound, beginning in 1987, found brown rockfish in low abundance, averaging 13 fish per transect during the 1980s (Figure 6.21). When the surveys resumed in 1995, brown rockfish counts averaged 40 fish per transect and then increased to 128 fish per transect in 2003.

Brown rockfish stocks appear to be increasing in the main basins of South Sound with an unknown trend in Hood Canal (Table 6.8). Brown rockfish are infrequent in the recreational catch (Table 5.6, Figure 5.10), but the increasing trend in scuba surveys suggests that brown rockfish may not be as vulnerable to recreational fisheries as are copper and quillback rockfishes. The 90% decline in brown rockfish abundance, as determined from the bottom trawl survey, is heavily influenced by a single large catch of brown rockfish in 1987, following which, biomass varied without trend. There has been a two-fold increase in scuba survey densities after 1998 and a marked increase since 1987, and which strongly indicates brown rockfish are Healthy in Central Sound (Table 6.9). However, because their status is not known in Hood Canal, they have conflicting trends, and Very Low Productivity characteristics, brown rockfish are classified as Precautionary status in South Sound. Insufficient information on brown rockfish in North Sound results in a Precautionary status.

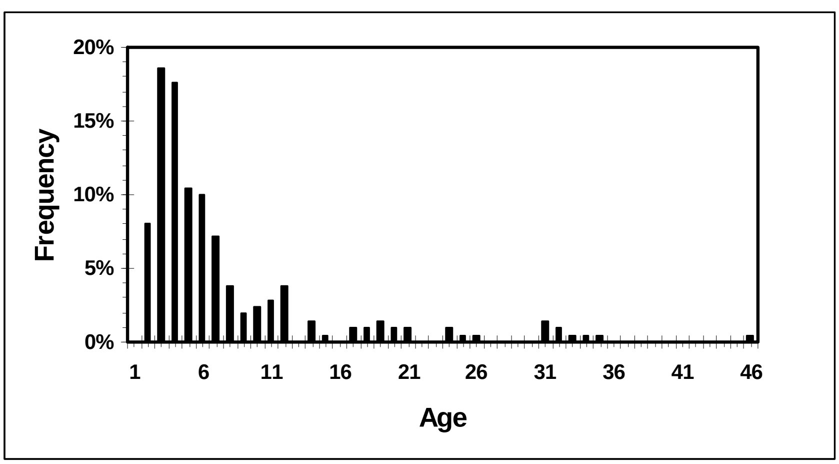


Figure 6.19. Age frequency distributions of brown rockfish for South Puget Sound collected from bottom trawl and other research surveys.

Figure 6.20. Growth of brown rockfish in South Puget Sound observed from bottom trawl and other research samples.

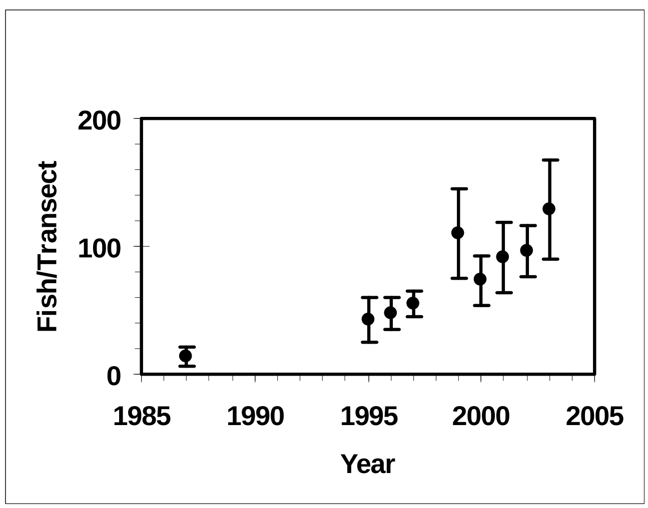


Figure 6.21. Densities of brown rockfish, with 95% confidence limits, observed by scuba divers among three index sites in Central Puget Sound

6.7.4 Black Rockfish

6.7.4.1 Life History Characteristics

There are few recent data to evaluate the life history characteristics for black rockfish in Puget Sound. Demographic statistics have only been estimated in Puget Sound using the results from surface reading of otoliths. Barker (1979) observed 14 years as the maximum age in the San Juan Islands (Table 6.4), and Washington et al. (1978) and Gowan (1983) observed 13 and 12 years, respectively, as the maximum age in South Sound. Black rockfish have been aged to 50 years in Alaska (Munk 2001), placing them in the Very Low Productivity category. Black rockfish mature at age 8 off the coast of Washington and Oregon (Bobko and Berkeley 2004), which places them in the Low Productivity category. Total instantaneous mortality rates are 0.33 and 0.34 in North and South Sound, respectively, and natural mortality rates are correspondingly 0.31 and 0.25 (Barker 1979, Gowan 1983). Washington et al. (1978) estimated total mortality at 0.51 using surface ages. For the Oregon and Northern California coast, Ralston and Dick (2003) estimated natural mortality at 0.14 and total mortality as 0.26 based upon a maximum age of 35 years.

Black rockfish enter the recreational fishery at a fork length of 18 cm, and anglers have caught black rockfish as large as 66 cm in Puget Sound (WDFW, unpublished data). Black rockfish catches have not been sampled sufficiently to evaluate length trends, but mean fork length fluctuated between 32 cm and 41 cm during the 1980s in North Sound.

6.7.4.2 Status and Trends

The only fishery-dependent data for black rockfish was from the quantitative video surveys in the Strait of Juan de Fuca. In 1996, the mean count was 0.6 fish per station for high-relief rocky habitats. In 2004, the mean station count declined to 0.22 fish per station, but wide variation meant the decline was not significant (Table 6.7). The quantitative video surveys in North Sound between 1999 and 2004 indicated that there were 167,800 black rockfish (Table 6.9, Standard Error=71.0%). In South Sound there were only 1,900 black rockfish (Standard Error=60.4%). LeClair et al. (2007) and subsequent scuba observations focusing on nearshore habitats indicate a strong 2006 year class of black rockfish has recruited to Puget Sound.

The status of Puget Sound black rockfish stocks may be highly dependent upon the status of coastal stocks. Wallace et al. (1999) found coastal stocks off Washington to be healthy but declining.

Insufficient data exist to establish the status of black rockfish in Puget Sound. This species should be considered as a Low Productivity species because of its intermediate characteristics of high longevity but early maturity. Given the apparent decline of black rockfish in the recreational species composition in the San Juan Islands and from recreational sampling during the 1960s (see Section 5.4.2.2 **Recreational Species Composition**), and its rarity in South Sound, the stocks are classified as Precautionary in both North and South Sound.

6.7.5 Yelloweye Rockfish

6.7.5.1 Life History Characteristics

Yelloweye rockfish is a long-lived species that can live to 90 years in North Sound and 55 years in South Sound (Table 6.4). Washington et al. (1978) observed yelloweye rockfish as old as 27 years in South Sound using surface-read otoliths. Yelloweye rockfish can reach ages of 115 years in B.C. (Yamanaka and Lacko 2001) and 118 years in Alaska (Munk 2001), qualifying them as Very Low Productivity species throughout their range. Their age-at-maturity has not been examined in Puget Sound, but in B.C., it is 17 years (Yamanaka and Lacko 2001) which classifies them as Very Low Productivity stocks. Yelloweye rockfish experience low natural mortality rates from 0.015 to 0.02 in British Columbia (Yamanaka and Lacko 2001).

Yelloweye rockfish exhibit slow growth rate coefficients of 0.04 to 0.06 along the West Coast, in Washington and B.C. (Yamanaka and Lacko 2001, Methot and Piner 2002). In Puget Sound, they enter the fishery when they are 19 cm (fork length) and have been caught as large as 86 cm. No more than 20 yelloweye rockfish have ever been observed in annual recreational fishery samples (Table 5.6), and the average fork length of yelloweye rockfish is 59 cm in North Sound and 45 cm in South Sound (WDFW, unpublished data).

6.7.5.2 Status and Trends

Yelloweye rockfish are not frequent in the recreational or commercial catches or in surveys, so a detailed analysis of stock status is not possible. Though not an index of stock abundance, their frequency in the recreational catch has declined in both North and South Sound since the 1960s (See Section 5.4.2.2 **Recreational Species Composition**).

The stock identity of yelloweye rockfish between coastal and inland marine waters is unclear (see Section 3.4.3 **Genetics and Stock Identity**). Insufficient data precludes any direct stock trend determination for yelloweye rockfish in Puget Sound. Since most recent genetic and other studies for yelloweye rockfish do not recognize distinct populations between coastal and inland stocks, information on coastal stocks can conservatively be used as a proxy for yelloweye rockfish in Puget Sound. The coastal stock of yelloweye rockfish is overfished and is at 18% of unfished spawning biomass on a coast-wide basis and 21% off Washington (Wallace et al. 2006). Since yelloweye rockfish is a Very Low Productivity species and the coastal spawning potential is far below 25% (Table 6.2), yelloweye rockfish is Depleted in Puget Sound. If inland marine stocks are found to be distinct from coastal stocks, then the decline in species composition and rockfish CPUE over time indicates yelloweye rockfish stocks are in poor condition in Puget Sound. The harvest of yelloweye rockfish was prohibited in Puget Sound in 2002.

6.7.6 Other Rockfish

Other rockfish species in Puget Sound have far less information available for conducting stock evaluations. None of the remaining species have spawner per recruit estimates and stock evaluations rely upon more rudimentary patterns from catch composition, single survey trends, or the coastal stock assessments.

<u>Yellowtail rockfish</u> are generally not abundant in Puget Sound and may only spend the immature portions of life in Puget Sound. Accurate age information was lacking for yellowtail rockfish in Puget Sound but the maximum age from surface-read otoliths is 7 years in North Sound (Barker 1979) and 8 to 9 years in South Sound (Washington et al. 1978, Gowan 1983, Table 6.4). Washington et al. (1978) and Barker (1979) determined that mature adult fish do not inhabit South Sound and the San Juan Islands and likely move to coastal waters upon maturity. In the coastal waters of Washington, yellowtail rockfish reach ages of nearly 50 years (Tagart 1988) and live to 64 years in British Columbia (Munk 2001). Off Washington, they mature at 10 to 11 years. Total morality rates for yellowtail rockfish were estimated at 0.99 in North Sound (Barker 1979) and 0.53 in South Sound (Washington et al. 1978, Gowan 1983), but these extremely high rates likely reflect the exodus of adults to coastal waters and the age underestimation bias caused by surface readings of the otoliths. The natural mortality rate for coastal yellowtail stocks is 0.11 (Tagart et al. 2000). Their longevity and late maturity classify yellowtail rockfish as a Very Low

Productivity species. The von Bertalanffy growth coefficients of yellowtail rockfish are variable off the Washington coast, ranging from 0.12 to 0.19 (Tagart et al. 2000).

Status and trends for yellowtail rockfish in Puget Sound cannot be directly established. Quantitative video surveys indicate there are 16,600 yellowtail rockfish in North Sound (Table 6.8). Yellowtail rockfish were only encountered in the 2004 trawl surveys of East Juan de Fuca, and the biomass estimate was 0.9 mt (Table 6.5). In South Sound, video surveys estimated 10,100 individuals (Table 6.8). Yellowtail rockfish stocks off the coast of Washington are in good condition being 158% above their target spawning biomass ($SPB_{40\%}$, Tagart et al. 2000). While yellowtail rockfish in Puget Sound may be a common stock with that of coastal waters, the decline of yellowtail rockfish in the recreational catch without a marked increase in catch rates conflicts with the coastal assessment of a healthy stock. The condition of yellowtail rockfish in Puget Sound is unknown, and therefore, is in Precautionary status in both North and South Sound.

Canary rockfish possess life history characteristics of a Very Low Productivity stock (Table 6.4). They can live to 84 years in British Columbian waters (Munk 2001) and to 69 off the US West Coast, where they mature at age 8 (Methot and Piner 2002). These life history characteristics place this species in either the Very Low or Low Productivity categories. Canary rockfish have a 23-year Generation Time and a natural mortality rate of 0.09 (Methot and Stewart 2005). Canary rockfish are infrequently observed in quantitative video surveys and during recent years, the nearshore component of the stock was estimated at only 2,800 individuals (Table 6.8). Over the past four decades, canary rockfish have become less frequent in recreational catches in Puget Sound (Table 5.7). In coastal waters, canary rockfish stocks have increased from being 13% of their unfished spawning biomass during the early 2000s (Methot and Stewart 2005) to 24% of the unfished biomass in 2009 (Stewart 2007, 2009). There is not any direct evidence of separate canary rockfish stocks between coastal and Puget Sound waters. Assessments of canary rockfish in British Columbia have resulted in a Threatened status determination under the terms of the Canadian Species and Recovery Act (COSEWIC 2007). This determination was the result of substantial long-term declines in survey indices. Because the coastal assessment of canary rockfish shows a 76% decline in the spawning potential, and this exceeds the 70% threshold for a Very Low Productivity stock; canary rockfish are in Depleted status in both North and South Sound.

Bocaccio is intermediate in their longevity among rockfishes with a maximum age of 46 years in Alaskan waters (Munk 2001), indicating that bocaccio are of Very Low Productivity (Table 6.4). They were once caught in localized areas in South Sound (Washington 1977) but they have not appeared in recent research or recreational catches. One bocaccio from South Sound was aged at 12 years using surface-read otoliths (Washington et al. 1978). Bocaccio were always infrequent in the recreational fishery, with a few erratic occurrences in North Sound but more consistent, low occurrences in South Sound (Table 6.7). Bocaccio has never been observed during WDFW bottom trawl, video, or dive surveys in Puget Sound. Bocaccio in British Columbia are designated as threatened under the terms of the Canadian Species and Recovery Act (COSEWIC 2002). This designation was primarily based upon low recruitment and survey trends off the British Columbian coast. The condition of bocaccio stocks in Puget Sound is unknown because of the lack of assessment information. This species is classified as Precautionary in North and South Sound.

Redstripe rockfish is a small species ranging from 6 to 31 cm in total length (average of 14.5 cm) based upon samples from the bottom trawl survey. They live up to 55 years in British Columbian waters (Munk 2001), and are, therefore, a species of Very Low Productivity (Table 6.4). Redstripe rockfish have not been important to commercial fisheries and have rarely been encountered in recreational fisheries in North Sound. Redstripe rockfish have been encountered during bottom trawl surveys in both regions. Prior to 2002, trawl survey biomass estimates of restripe rockfish did not exceed 7 mt in either North or South Sound (Tables 6.5 and 6.6). During recent surveys, redstripe rockfish biomass dramatically increased in North Sound to 57 mt in 2004 and in South Sound from 152 mt in 2002 to 234 mt in 2005. However, these increases were not statistically significant. The lack of a trend but recent increases in the bottom trawl survey abundance estimates indicates the status of redstripe rockfish is Healthy in both North and South Sound.

Greenstriped rockfish live to 54 years in Alaskan waters, indicating they are of Very Low Productivity. However, the age-at-maturity of the West Coast population ranges between seven and ten years, and the von Bertalanffy growth coefficient ranges between 0.08 and 0.11 placing greenstriped rockfish in the Low Productivity category. Total lengths observed from the bottom trawl survey ranged from 8 to 28 cm, averaging 19 cm. Females mature at age 7 and a minimum three-generation period is 21 years. This species was encountered in low numbers during bottom trawl surveys in Puget Sound. Greenstriped rockfish biomasses never exceeded 0.4 mt in North Sound or 1.6 mt in South Sound (Tables 6.5 and 6.6), and there was not any trend in their occurrence. The lack of a declining trend over the 20 year trawl survey period indicates that the status of greenstriped rockfish is Healthy in North and South Sound.

Splitnose rockfish were most frequently observed in Hood Canal during bottom trawl surveys. Their age ranged to 64 years, and splitnose rockfish have a von Bertalanffy growth coefficient of 0.08 (Table 6.4). Their average age was 27 years based on trawl survey samples, and they measured an average 25 cm in total length. Their longevity and slow growth rates indicate they are a Very Low Productivity species. In South Sound, trawl survey biomass estimates declined from 22 mt in 1987 to 8.5 mt estimated during the 2002 and 2005 trawl surveys. This 61% decline over a 20 year period (Table 6.6) likely spans a three-generation time period. Because of this long-term decline and their limited distribution in South Sound, the stock status of splitnose rockfish is Precautionary. Due to their rarity in North Sound, their status is unknown and, therefore, Precautionary.

Shortspine thornyhead is a Very Low Productivity species with maximum ages greater than 45 years off the Washington coast (Piner and Methot 2001) and 89 years in Alaskan waters (Table 6.4, Munk 2001). Their von Bertalanffy growth coefficient is the slowest for a rockfish ranging between 0.01 and 0.02, and age-at-maturity is 13 years confirming their Very Low Productivity (Piner and Methot 2001). In Puget Sound, shortspine thornyhead average 30.5 cm in total length among samples from recent bottom trawl surveys. This species made up less than 1% of the average recreational rockfish catch in North and South Sound between 1980 and 1989 but have not been observed between 1996 and 2007 (Table 5.6). Shortspine thornyhead was not observed in trawl surveys conducted in the Georgia Basin and East Juan de Fuca Regions of North Sound from 1987 to 1991 (Table 6.5). Biomass estimates for this species in North Sound were 1.8 mt in 2001 and 1.0 mt in 2004. Trawl survey biomass estimates for shortspine thornyhead in South Sound have been higher than those of North Sound (Table 6.6). In 1987, the South Sound biomass of shortspine thornyhead was 2.9 mt, but this species was not detected during the 1989 or 1991 surveys. Estimated biomass was 4.4 mt during the 1995-1996 combined survey of South Sound and 1.9 mt in 2002. They were not detected in South Sound during the 2005 survey. In both North and South Sound, there was no trend in the abundance based upon the bottom trawl survey over the past 20 years. The Generation Time is not known, but their 13 year age at maturity indicates that a minimum of three-generation period is 39 years. The lack of a trend in trawl survey biomass over a twenty-year period indicates this species is stable in low numbers and in a Healthy status. Their occurrence in Puget Sound only represents the upper depth range of this species (Jacobsen and Vetter 1996) which peaks at depths of 366 m.

Tiger rockfish is a very long-lived species that can live up to 116 years (Table 6.4, Munk 2001). Because of this longevity, it is a Very Low Productivity species. Tiger rockfish were rare in recreational catches comprising 0.4% of the average recreational rockfish catch in North Sound and less than 0.1%, on average, in South Sound (Table 5.6). They are not frequently encountered during surveys but are observed during winter surveys for lingcod in the San Juan Islands (WDFW, unpublished data). There are no data to infer their stock status. Therefore, tiger rockfish are in Precautionary status in North and South Puget Sound.

Blue rockfish live to 30 years (Munk 2001) and are a Low Productivity species (Table 6.4). They constitute an average 0.6% of the recreational rockfish catch in North Sound (Table 5.6), but their occurrence has been erratic since 1996, reaching 7% in 1997, but more frequently 0%. Their occurrence of less than 0.2% in the South Sound recreational catch is suspect because they have never been positively identified in South Sound (see Table 3.1). They were encountered during the 1996 quantitative video survey of the Strait of Juan de Fuca but they were not observed during the 2004 survey. Because trend information is lacking, they are of unknown status and designated as Precautionary in North Sound and not detected in South Sound.

China rockfish can live up to 78 years in Alaska (Table 6.4, Munk 2001) and are as a Very Low Productivity stock. They were occasionally caught by recreational fishers in North Sound but never comprised more than 1% of the rockfish catch, on average (Table 5.7). Their average occurrence of less than 0.1% in the South Sound recreational catch is suspect to be a misidentification because other information indicates they typically occur close to the ocean and have not been positively identified in South Sound (see Table 3.1). They were not encountered during any recent WDFW surveys. There is insufficient information to warrant a determination of stock status of China rockfish so their status is unknown and therefore, Precautionary in North Sound and not detected in South Sound.

Vermilion rockfish can live to 60 years (Munk 2001) and mature by 5 years (Love et al. 2002). They are a Low Productivity species. Until recently, they have been rare in Puget Sound. Since 2000, vermilion rockfish have been observed along the Strait of Juan de Fuca, in the San Juan Islands, in southern Hood Canal, in Central Puget Sound and in Southern Puget Sound. They are still rare in recreational catches, comprising less than 0.1%, on average, in North or South Sound (Table 5.7). They were encountered in recent video surveys in North Sound where 85,500 individuals were estimated (Table 6.8). Because vermilion rockfish only appear to be recently invading Puget Sound and because they are of Low Productivity, their status is Precautionary in both North and South Sound.

Puget Sound Rockfish reach a maximum age of 13 years (Table 6.4, Beckmann et al. 1998) and mature at 2 years. Their von Bertalanffy growth coefficients are variable ranging from 0.03 to 0.12 as a function of age and year (Coates et al. 2007). Beckman et al. (1998) estimated the growth coefficient at 0.78, much higher than the more recent study by Coates et al. (2007). In trawl surveys, their total length ranged from 6 to 18 cm and averaged 13.9 cm. Their growth and maturity rates place them in the Low Productivity category, although their early maturity indicates a species of of Medium Productivity. Using estimates of age-at-maturity and natural mortality rates (Table 6.4), their Generation Time was approximated at 5 years.

Because of their small size, Puget Sound rockfish are rarely captured in recreational or commercial fisheries. They never have been observed in recreational rockfish catches in North Sound, and only occurred during one year in South Sound, when they comprised 2% of the rockfish catch (Table 5.7). They were relatively rare during the 1970s in the San Juan Islands (Moulton 1977, Coates et al. 2007), dramatically increased during the 1990s due to strong year classes during the 1990 and 1991 (Coates et al. 2007). Their increase in abundance may have been enhanced by low abundances of lingcod and larger rockfish. In more recent years, Puget Sound rockfish declined in abundance (Coates et al. 2007), perhaps due to weak recruitment and a resurgence of lingcod in the San Juan Islands.

Puget Sound rockfish have been frequently encountered during WDFW video and trawl surveys during the past decade. In the eastern Strait of Juan de Fuca and Georgia Basin, Puget Sound rockfish were not detected in bottom trawl surveys until 2001, but biomasses were1 mt in 2001 and 2004 (Table 6.5). The quantitative video survey in the San Juan Islands showed a declining pattern, opposite from the trawl survey result for the Georgia Basin and East Juan de Fuca regions. Between 1994 and 2000, the mean video count of Puget Sound rockfish significantly declined from 15.1 to 5.7 fish per station in the San Juan Islands (Table 6.7). The 62.4% decrease in the mean video counts, within a ten-year time period that is less than the 15-year period spanning three generations indicated the majority of the North Sound stock is in Precautionary Status. This conclusion is based on the recent survey trend, but recognizes Puget Sound rockfish in the San Juan Islands may typically be an uncommon species with episodic increases (Coates et al. 2007).

In South Sound, the trawl survey did not detect Puget Sound rockfish until 1996, when their biomass was estimated at 0.7 mt in South Sound (Table 6.6). Their abundance increased in South Sound to 21 mt in 2002 and 47 mt in 2005, but the more recent estimates were not significantly different from zero. They were not frequently detected during video surveys in South Sound. Because Puget Sound rockfish in South Sound appear to vary without trend, their status is Healthy in South Sound.

6.8 Summary of Stock Status

The majority of rockfish stocks in Puget Sound are in Precautionary status, but several species once important to recreational fisheries are in Vulnerable or Depleted status. The patterns of stock status are generally similar between the two regions for the 17 species of rockfish examined (Table 6.10). Seven (22%) of the 32 stocks present in either North or South Sound are in Healthy status. Eighteen stocks (56%) are in Precautionary status, while two stocks (6%) are in Vulnerable status, and five stocks (16%) are in Depleted status. Many of the Precautionary ratings reflect a lack of information regarding the stock.

Stock condition is related to the frequency of that species in the recreational catch with more common species being in poor condition and smaller and deeper species, which are seldom caught, being in the healthiest status. Copper and quillback rockfishes have been the two most important species in the recreational fishery and have three of four stocks in Vulnerable or Depleted status. Yelloweye and canary rockfishes, infrequently harvested from Puget Sound, are in Depleted status. Six species in North Sound and seven species in South Sound are in Precautionary status. These species, such as black, yellowtail, splitnose, and bocaccio, have been secondary species of importance in recreational and commercial fisheries. Black rockfish in the western portion of the Strait of Juan de Fuca, were an exception to the overall Precautionary status, perhaps because this area is likely benefiting from the spillover of black rockfish from coastal areas. Stocks of brown rockfish in South Sound are another exception: This stock is Healthy but generally not common in recreational catches. Other Healthy status stocks include the deepwater redstripe rockfish, greenstriped rockfish, Puget Sound rockfish in South Sound, and shortspine thornyhead. All of these species appear to be uncommon or rare in inspected catches. Many species in Precautionary status are classified in this condition because of a lack of any stock evaluation information. These species are often rare in catches or in surveys and include tiger, China, blue, brown, and splitnose rockfishes in North Sound and tiger rockfish in South Sound. Several species are generally not detected in South Sound, including China and blue rockfishes in South Sound. Vermilion rockfish appear to be invading Puget Sound from coastal waters, but their status is Precautionary until more assessment information is obtained.

The results of this assessment for individual rockfish stocks were slightly different from the assessment results presented in previous Puget Sound Updates (Palsson et al. 1997; PSAT 2000, 2002, 2007). In these previous stock evaluations, rockfish were considered as a group and evaluated by the trend in the recreational CPUE. In later assessments in the series, specific information was presented for spawner-per-recruit pattern for copper rockfish. In previous evaluations, the spawning potential for copper rockfish was referenced to the single, peak value of the observed spawning potential. This present assessment used an average of the historic spawning potential from 1977 to 1980, as a reference standard to compare late 1990s spawning potentials. Because of this and recent stability in fish densities observed at scuba reference sites, the stock statuses were slightly relaxed for copper and quillback rockfishes. Copper rockfish were in Precautionary status in the North Sound and Vulnerable status in South Sound, reflecting the greater productive capacity of this species and less drastic changes in spawner per recruit as compared to previous analyses and quillback rockfish. Quillback rockfish were in Vulnerable status in North Sound and Depleted in South Sound, reflecting continued strong declines in both regions of this long-lived species. Because these two species are both frequently caught in recreational fisheries, the more dire condition of quillback rockfishes may indicate a weak stock that may limit the harvest of more productive species.

This evaluation of stock status has many limitations as discussed throughout this document, most notably the lack of complete recreational catch estimates between 1994 and 2003, the lack of discard and poor quality of species composition data from the commercial fishery, unknown influences of changing bag limits on the interpretation of the recreational catch rate trend, and the lack age and other biological data. In addition, the approach to the assessment has other limitations. The key limitations are the longevity of many of the rockfishes and the rather recent analysis of biological and trend data that was conducted. Since rockfish have been appreciably harvested since the 1920s, and since life spans of four or more decades are observed for quillback, yelloweye, canary, and other species harvested in Puget Sound, the reference period used to establish baseline conditions for trend analysis from the late 1970s or 1980s are not likely to reflect unfished conditions. Mortality rates, ages-at-maturity, growth rates, Generation Time, and other biological parameters may also reflect the responses of stocks to exploitation and are likely conservative estimates. The approach to using the AFS Vulnerability Criteria is a response to the assessing stocks in a data-limited situation and may serve the robust nature of this stock evaluation. Another key limitation includes using the copper rockfish fecundity relationships for quillback rockfish and should only be considered as a proxy for the latter species.

The NOAA Fisheries Biological Review Team (BRT) evaluated the stock status of copper, quillback, and brown rockfishes against the AFS Criteria for the extinction risk of marine fishes (Stout et al. 2001, Musick et al. 2000). For all three species, the BRT concluded that the stock trends and life history characteristics met the definitions of Vulnerable status, meaning that there was a risk that these stocks might become Threatened or Endangered in the future. The continued monitoring of the stocks has shown greater and continued declines for copper and quillback rockfishes and but increasing stock sizes for brown rockfish. These patterns justify the conclusion that the copper and quillback rockfishes are Vulnerable under AFS criteria but a reconsideration of brown rockfish is warranted. Moreover, most other rockfishes in Puget Sound, especially those in Precautionary status, undoubtedly warrant the Vulnerable classification because of their suspected declining trends, longevity, prolonged maturation, and other life history characteristics adapted for low productivity. Musick et al. (2000) includes brown, copper, quillback, black, tiger, and yelloweye rockfishes as specifically vulnerable in Puget Sound, but we determined that yelloweye and canary rockfishes are in Depleted status in Puget Sound. The results of the present stock assessment suggest that brown rockfish are not Vulnerable, based upon their increasing trend, but may still be considered, based upon their limited distribution in Puget Sound. Our results also show that copper rockfish stocks in North Sound are not vulnerable because the more detailed analysis of change over time did not meet the AFS standards. It should be noted that canary rockfish and bocaccio have been listed as Threatened in British Columbia through the Canadian Species at Risk Act process (COSEWIC 2002, 2007).

The conclusions of this analysis differ slightly from those of the second BRT that reviewed five deepwater species of rockfish in Puget Sound under the terms of the Endangered Species Act. Both found that greenstriped and redstripe rockfishes were in relatively stable condition. Both studies found that yelloweye rockfish were poor condition but used different approaches to reach the same conclusion. This present study used information from coastal stock assessments assuming stock unity with Puget Sound to determine that yelloweye rockfish were in Depleted status. The BRT approach used declining frequencies of yelloweye rockfish from recreational catches and a series of integrated population indicators to assert that genetically distinct yelloweye rockfish were threatened with extinction in the near future in North and South Sound. The BRT similarly concluded that canary rockfish were threatened with extinction with the same reasoning, and this present assessment relied on coastal stock assessments and assumed stock unity to conclude that stocks were in Depleted status. This present study did not heavily weight the low frequencies of bocaccio in historic or recreational catch records and recent rarity to conclude that the stock was in any condition but Precautionary status. This present study did not consider the question of bocaccio as a distinct population segment in inland marine waters. Direct surveys and further studies of these species will be required to better understand their stock status in Puget Sound and adjacent waters.

Table 6.10. **Summary of the Status of Rockfish Stocks in Puget Sound.**

Species	North Sound	South Sound
Copper rockfish	Precautionary	Vulnerable
Quillback rockfish	Vulnerable	Depleted
Brown rockfish	Precautionary	Precautionary
Black rockfish	Precautionary	Precautionary
Yelloweye rockfish	Depleted	Depleted
Yellowtail rockfish	Precautionary	Precautionary
Canary rockfish	Depleted	Depleted
Bocaccio	Precautionary	Precautionary
Redstripe rockfish	Healthy	Healthy
Greenstriped rockfish	Healthy	Healthy
Splitnose rockfish	Precautionary	Precautionary
Shortspine thornyhead	Healthy	Healthy
Tiger rockfish	Precautionary	Precautionary
China rockfish	Precautionary	Not Present
Blue rockfish	Precautionary	Not Present
Vermilion rockfish	Precautionary	Precautionary
Puget Sound rockfish	Precautionary	Healthy
Number Healthy	3	4
Number Precautionary	11	7
Number Vulnerable	1	1
Number Depleted	2	3
Total Stocks Examined	17	15

7 ECOSYSTEM STRESSORS AND LIMITING FACTORS

7.1 Approach

A number of identified and potential stressors and limiting factors may negatively impact rockfish populations by causing direct mortality, reducing fitness, increasing vulnerability to predation or disease, or otherwise reducing stock productivity. Many stressors on rockfish have been identified by West (1997), and their potentials to limit productivity and recovery of rockfish stocks in Puget Sound are discussed in this section (Table 7.1). Each stressor will be reviewed for documented information, its intensity, and spatial extent. The relative risk of the stressor will be rated as a composite the criteria including available documentation, intensity, and extent. Intensity refers to whether the stressor causes direct mortality, reduces fitness, or impairs the health of the stock. Extent refers to the frequency or spatial extent of the stressor. The definitions for each risk criterion are as follows:

Documentation-

Best:	Known references in Puget Sound.
Fair:	Inferred in this species from published studies in nearby areas.
Poor:	Inferred in Puget Sound from published studies in a proxy species.
Unknown:	Conceivably possible, but no publications that establish relationship.

Intensity-

High:	Stressor causes direct mortality.
Medium:	Stressor reduces fitness by increasing susceptibility to predation or disease or impairs reproduction.
Low:	Stressor is unlikely to impact health.
Unknown:	Intensity is unknown.

Extent-

High:	Stressor acts continuously and over broad regions.
Medium:	Stressor is either episodic or acts over restricted areas within a region.
Low:	Stressor is infrequent or acts only over limited range.
Unknown:	Spatial distribution and frequency unknown.

Relative Risk-

High:	Overall the stressor has been documented in Puget Sound, causes direct mortality, is frequent and acts on a regional basis and dramatically limits rockfish stocks in Puget Sound.
Moderate:	The documented stressor causes direct mortality on episodic or local scales or continuously or episodically reduces fitness on local or regional scales.
Low:	The poorly documented stressor is infrequent and acts on local scales.
Unknown:	The stressor is possible but its intensity and extent is not documented.

The criteria for each stressor were scaled by a simple 1, 2, or 3 corresponding to Poor or low, Fair or Medium, or Best or High, respectively. Average scores were then calculated and scaled to the same ordinal scale for Relative Risk. If an Unknown condition was rated for any criterion, the Relative Risk was rated as Unknown.

Table 7.1. Likely Stressors Limiting Rockfish Stocks in Puget Sound.

Factor	Documented	Intensity	Extent	Relative Risk
Fishery Removals	Best	High	High	High
Age Truncation	Fair	Medium	High	Moderate
Habitat Disruption	Unknown	Medium	Unknown	Unknown
Derelict Gear	Best	High	High	High
Climate	Unknown	Unknown	Unknown	Unknown
Hypoxia/Nutrients	Best	High	Medium	High
Chemical Contamination	Fair	Medium	Medium	Moderate
Species Interactions				
Food Web	Best	High	High	High
Competition	Poor	Unknown	Unknown	Unknown
Salmon Hatchery Practices	Unknown	Unknown	Unknown	Unknown
Diseases	Poor	Unknown	Unknown	Unknown
Genetic Changes	Poor	Unknown	Unknown	Unknown

7.2 Fishery Removals

Fishing activities have the potential to affect rockfish populations in a number of different manners. Direct fishery removals at unsustainable rates can reduce population productivity and affect the size and age structure of the population. Measures may be taken to reduce fishing pressure, but unintentional catch from fisheries targeting on other species may still limit the productivity of rockfish populations.

Observations from marine reserve studies in Puget Sound strongly indicate that fishing drastically affects rockfishes in both time and space. The higher densities or larger sizes observed for rockfish in marine reserves compared to fished areas and higher densities of rockfish observed after reserve creation indicates that removals by past fishing activities affect the abundance and demographic structure of rockfish stocks (see Section 4.5 **Marine Reserves**). Decreases in stock abundance and fish size also correspond to periods of high fishery harvests (see Section 5 **Fisheries and Catch Statistics** and Section 6 **Stock Evaluation).** Fishing success for rockfish declined after peak harvests in the late 1970s and early 1980s, and the mean length of copper and quillback rockfishes decreased concomitant with high rockfish harvests during the late 1970s and early 1980s. The pattern of decreased fishing success and mean length after high fishery removals corresponds to the pattern of greater size and density of copper rockfish observed in the long-term marine reserve than in fished areas. This correspondence indicates that density and size differences are attributable to differences in fishing pressure. The observation by Eisenhardt (2001) that fish abundance increases after the creation of a marine reserve supports the conclusion that fishing greatly influences the abundance of rockfishes.

Although past fishery harvests were high, restrictions on commercial and recreational fisheries since 1994 and 2000, respectively, have reduced recent average harvests by 90%. Due to the longevity of rockfishes, the harvests of past fisheries are likely still affecting the structure of rockfish stocks in Puget Sound. These past harvest estimates prior to 2004 do not include released catch. For the dominant recreational fishery, MRFSS released and harvest catch estimates prior to 2001 indicate that total catch was likely 16 to 20% higher than harvest estimates. Since 2004, 62% of the total catch is released catch. The reduction in total catch after the 2000 daily bag limit change to one fish per day may actually range between 80% and 90%. The review of barotraumas induced in rockfishes brought to the surface indicates that the mortality of released catch is high, but that some promising techniques may be developed to rapidly resubmerge rockfish or minimize their capture (see Section 3.4.5 **Physiology**). Whether the catch level currently limits rockfish productivity is not known.

Fishery impacts are well documented for rockfishes in Puget Sound, therefore, the Documentation quality is Best. The Intensity of Fishery Removals is High because they cause direct mortality and likely limit productivity. Fisheries in Puget Sound have operated during most of the year and over broad regions, so the Extent is High. The mean of the rating is 3.0, so the Relative Risk of fishery removals is High.

7.3 Age Truncation

Age truncation as a result of fishing may affect rockfish stocks in Puget Sound by reducing the number of larvae produced and in some circumstances, reducing the fitness of the larvae produced, and reducing the period during which larvae are produced. All three of these factors may act to diminish the chances of successful recruitment in Puget Sound but these effects need to be studied in greater depth.

While the differences in the age structure of rockfishes between reserves and fished areas and before and after peak fishery catches have not been examined, length is correlated with age, and it is likely that fishing has caused the truncation of older ages in rockfish stocks in Puget Sound. Age truncation, the removal of older fish, can occur at even moderate levels of fishing for rockfish (Berkeley et al. 2004b), but the impacts on populations have only been recently investigated. For long-lived fish such as rockfish, age truncation can have “catastrophic” effects (Longhurst 2002). A study of black rockfish revealed that age truncation occurs along the central coast of Oregon, and that older fish release their young earlier in the spring than younger fish (Bobko and Berkeley 2004). Further, older fish produce better quality embryos with larger oil globules and have higher absolute fecundities (Berkeley et al. 2004a, Bobko and Berkeley 2004). These and other results led Berkeley et al. (2004a) to examine other effects of fishing besides the removal of biomass. They provided evidence that older rockfishes produce larvae that are better able to withstand starvation and grow faster than the offspring of younger fish.

In addition, the composition of year classes depends upon portions of the population from spatially and temporally isolated units. A lengthy period of larval release is thought to increase the chances of successful recruitment (Berkeley et al. 2004b). Berkeley and Markle (1999) concluded that successful recruitment in black rockfish came from a narrow window of time within the spawning season. In other rockfishes, recruits of shortbelly rockfish (*Sebastes jordani*) exhibited reduced genetic variability compared to the adult population, suggesting that only a small fraction of the adults successfully reproduce (Larson et al. 1995). A study of darkblotched rockfish found that the breeding population is several orders of magnitude less than the spawning stock size (Gomez-Uchid and Banks 2006). For rockfish, body condition and lipid reserves increase disproportionally with fish length or age (Larson 1991); indicating that the larger, older fish have greater reserves of energy than younger, smaller fish. These energy reserves may be used in reproduction or overwintering maintenance (Larson 1991) and may allow larger fish to survive and reproduce under a wider range of environmental conditions than younger, smaller fish (Berkeley et al. 2004a).

Another evaluation of the effect of maternal age on the larval production, O'Farrell and Botsford (2006) disagreed with the conclusions of Berkeley et al. (2000 a,b) finding that the observed decrease in larval survival from older females did not substantially contribute to the larval production of the fished population (O'Farrell and Botsford 2006). Therefore, the effects of age truncation on black rockfish did not grossly overestimate the reproductive potential with conventional assessments, and drastically reducing fishing mortality to avoid age truncation would not offer any advantages over managing with a low fishing mortality appropriate to a long-lived species.

Age truncation has not been documented for rockfishes in Puget Sound, but has been documented for other rockfish species elsewhere. The Documentation level is Fair. Since age is correlated with length, the decreases in mean size observed in recreational fisheries in both North and South Sound during the early 1980s and the smaller sizes of rockfish outside of the long-term reserve strongly suggest that age truncation has occurred in Puget Sound. Because age truncation is implicated to reduce the fitness of rockfish populations, the Intensity is Medium. The Extent is High because the decrease in size has been observed in both North and South Sound and has likely operated over long time periods. The averaged score is 2.3 representing a Relative Risk of Medium for Age Truncation as a stressor.

7.4 Habitat Disruption

Habitat disruption and loss includes natural and human-caused activities that temporarily or permanently alter existing natural habitats. Examples of natural habitat disruption include siltation, seismic events, or currents overlaying rocks with sediment. Humans may disrupt habitats by filling, dumping dredge spoils, sedimentation, trawling, constructing beach bulkheads, installing pipelines and cables, sunken vessels, and constructing artificial habitats. Impacts of shoreline or deepwater modifications and disruptions could impact rockfish habitats; however, the most vulnerable rockfish habitats to disruption are shallow-water vegetated areas and deeper rocky habitats.

Juvenile rockfish are highly associated with submerged and floating aquatic vegetation including eelgrass and kelp, while kelp is prevalent in the shallow portions of adult rockfish habitats (see Section 4.2 **Habitat Pathways**). The disruption of submerged aquatic vegetation could pose a threat to the habitat quality of rockfishes. Surveys by WDNR suggest that eelgrass abundance hasn't changed during recent years, but localized increases and decreases have occurred (Berry et al. 2003, Dowty et al. 2005, PSAT 2007). The amount of kelp beds along the Strait of Juan de Fuca varies greatly from year to year and in some specific areas, such as near Protection Island, has shown long-term declines (Berry et al. 2002).

In other areas of Puget Sound, kelp beds are increasing due in part to kelp growing on manmade structures (Levings and Thom 1994). One third of the Puget Sound's shoreline has been modified by human activities including bulkheading, filling, overwater structures, and boat ramps (Bailey et al. 1998). Shoreline structures that extend over or through the subtidal zone alter fish communities compared to shore zones consisting of sand, cobble, or shallow rip-rap (Toft et al. 2004). The quality of habitats adjacent to the man-made structures could diminish the value of these habitats for rockfish.

Another potential threat to rockfish is habitat disruption resulting from the introduction of exotic aquatic vegetation into Puget Sound. *Sargassum muticum*, an exotic brown alga, was accidentally introduced into Puget Sound from oyster aquaculture activities and now is ubiquitous in the extreme nearshore, where rocks and cobbles are present (Britton-Simmons 2004). These are the same habitats that post-larval copper rockfish settle in, but whether *S. mutium* affects rockfish settlement is not completely known. In North Sound, settling juvenile copper rockfish transition to *S. mutium* as the first substrate-associated recruitment in areas with minimal kelp habitat (Buckley 1997).

Adults of many species are closely associated with rocky habitats. The amount of this habitat is naturally limited, especially in Southern Puget Sound. A WDFW study (Pacunski and Palsson 1998) estimated 207 sq kilometers of rocky habitat exists in North Puget Sound and only 10 square kilometers occurs in South Puget Sound. This rocky habitat may be affected by the deployment of mobile fishing gear, cables and pipelines, construction of bridges, sewer lines, and other submerged structures, and burying by sediments from dredge spoils, dam removal, and natural subtidal slope failures. The construction of artificial habitats as reviewed in Section 4.3.4 **Artificial Habitats** poses a problem by concentrating rockfish where they become susceptible to predation, disease, or fishing and by the habitat quality not equaling that of natural habitats.

In Puget Sound, some commercial bottom trawl activities have targeted rockfish living on rocky habitats. Around the world, mobile fishing gear reduces physical and biological structure on the seafloor, and leaves long-lasting impacts on the seafloor (Auster 1998, Dorsey and Pederson 1998, Kaiser 1998). In Puget Sound, trawling is presently limited to the Strait of Georgia, the San Juan Islands, and the western Strait of Juan de Fuca. Roller gear, which can enhance the ability of trawls to fish on rocky habitats, has been banned in Puget Sound. Also, a daily landing limit on rockfishes minimizes the chance that commercial fishers will target on rockfish and their habitats with bottom trawls. The extent of habitat disruption by bottom trawling in Puget Sound is not clear, but they are thought to be minimal (Bargmann et al. 1985).

Overall, the Documentation for habitat disruption is Unknown. The potential Intensity is Medium through reducing fitness by displacing or disrupting naturally functioning habitats. The Extent is Unknown as seafloor maps have not been comprehensively mapped and evaluated. The Relative Risk is Unknown..

7.5 Derelict Gear

Abandoned fishing gear, especially gillnets, is a threat caused by fishing for salmon and marine species. Nets used for salmon fishing or trawling can become entangled on rocky habitats or obstructions, are often cut loose to sink to the bottom and are distributed throughout Puget Sound (Figure 7.1). Derelict nets can continue to fish and capture rockfish, other fish, and shellfish species (NRC 2008a). During surveys for derelict nets in Puget Sound, divers found 140 derelict nets in 8.5 days of surveying. Divers recovered 125 gillnets and six purse seines over a 52 day operational period. They found 87 fish representing 15 species were found in the nets. Seven percent were rockfishes including three dead copper rockfish, one live quillback rockfish, one dead Puget Sound rockfish, and one dead unidentified rockfish. NRC (2008b) examined mortality and decomposition rates for captured fish found in four nets in Puget Sound over periods of up to 28 days. While rockfish were not observed during this short-term study, fish are caught at a rate of 0.42 fish per day. Fish disappeared quickly from the net, usually within 3 to 4.5 days. This study also examined the drop-out rates of carcasses, finding that 32% fall out of the net upon retrieving the net to the surface. There are an estimated 3,900 derelict nets remaining in Puget Sound (Northwest Straits Foundation 2007). Given these observations, 61,000 rockfish may be caught in derelict fishing gear per year, a magnitude of mortality greater than or comparable to recent annul recreational harvests and bycatch of rockfish in Puget Sound (see Section 5.4.2 **Recreational Fisheries**).

Derelict nets alter other components of the ecosystem that affect rockfish. Derelict nets drape over or cover marine habitats preventing fishes, invertebrates, and aquatic vegetation from recruiting to or using the covered substrates. Derelict nets can sweep the bottom and substrates removing benthic organisms or trap sediments that alter the sediment characteristics (June and Antoneli 2009). Divers and biologists scored the relative abundance of fish, invertebrates, and sessile organisms at net-impacted sites and comparable control areas and found that abundances are less in areas with derelict nets than in nearby control areas. One year after net removal, relative abundances increase at the former net sites and are more comparable to the control areas (June and Antoneli 2009). Derelict nets have the capacity to alter food webs as they capture other fishes, seabirds, and marine mammals (NRC 2008a).

The Documentation of the impacts of derelict gear is Best showing direct mortality of rockfish that is of High Intensity. The Extent of derelict gear is High with derelict gear occurring at many sites throughout Puget Sound and causing mortalities approaching those of the fishery catch. The average score of the risk categories is 3.0, and the Relative Risk is High.

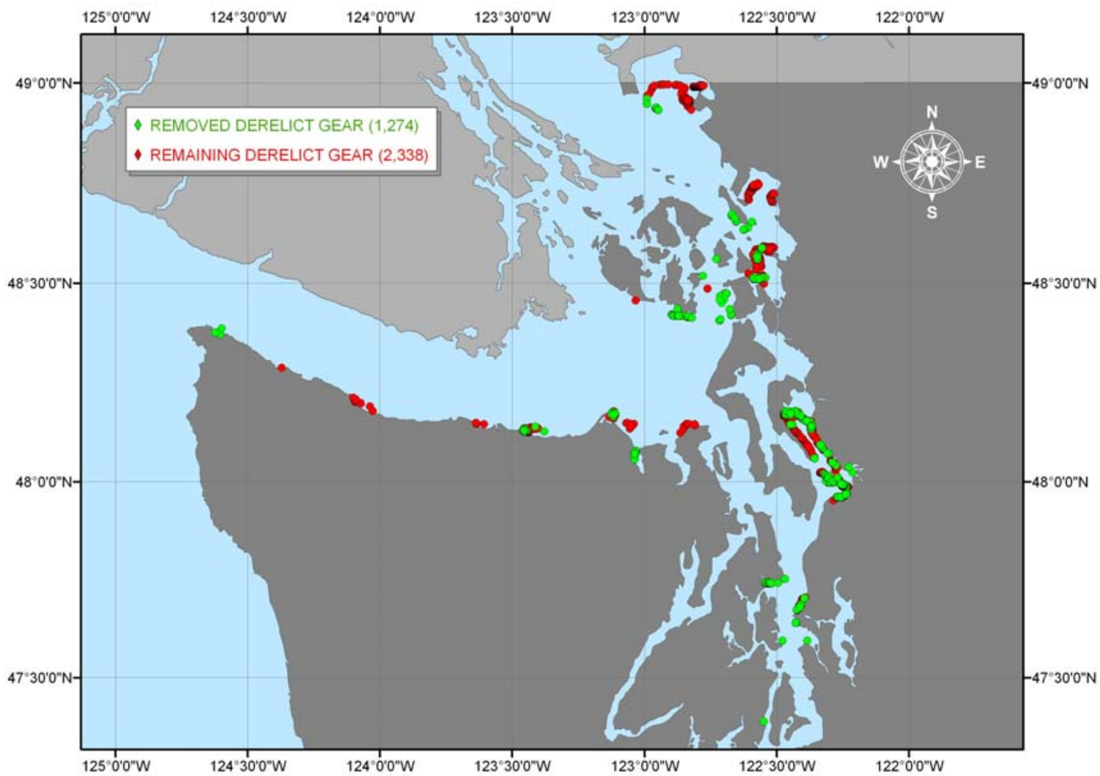


Figure 7.1. Locations of known and removed pieces of derelict gear, 2006. Courtesy of Natural Resource Consultants, Inc.

7.6 Climate

The survival and recruitment of marine fishes including rockfishes may be related to oceanic conditions that are affected by climate. The oceanography of Puget Sound and adjacent coastal waters are interlinked and affected by patterns that operate on seasonal, annual, decadal, and intermittent scales.

Already, an increase in sea surface temperature of 1.7°C has been detected at Race Rocks, north of Port Angeles, since the early 1970s (Mantua et al. 2007). Potential climatic patterns that affect biological processes include upwelling (Hsieh et al. 1995), Pacific Decadal Oscillations (Ebbesmeyer et al. 1991, Hare and Mantua 2000), El Niño or Southern Oscillation events (Pearcy and Schoener 1987, Newton 1995), droughts (Newton et al. 2003), and climate change (Mantua et al. 2007). If waters become warmer due to climate change, one logical expectation is that species from warmer southern waters may invade Puget Sound while cold-tolerant species may become less common due to differential recruitment and mortality, advection of recruits, or even direct movement of adults (Mantua et al. 2007).

How climatic changes directly affect rockfish in Puget Sound is unclear, but biological effects of climate change can affect the year-to-year success of reproduction for rockfish, other groundfish, and salmonids. For example, successful year classes for different rockfishes appear to be linked to warm, intermediate, and cold oceanographic conditions (Hollowed et al. 1987, Hollowed and Wooster 1995). Moser et al. (2000) found that juvenile rockfish abundance of several species was negatively correlated with warm and El Niño events in the California current system. Major perturbations have been observed with many extreme El Niños affecting the Northeastern Pacific (Pearcy and Schoener 1987). A common pattern of rockfish recruitment, observed along the west coast, is infrequent and irregular years of successful recruitment, with many years of poor recruitment (Parker et al. 2000). The synchronous recruitment event of 2006 in Puget Sound observed for copper and quillback rockfishes in South Sound and black and yellowtail rockfishes in North Sound (LeClair et al. 2007), suggests rockfish productivity is affected by sporadic recruitment events, likely related to broad-scale climatic events. Many rockfish species along the West Coast exhibit sporadic recruitment among decades (Hollowed et al. 1987, Moser et al. 2000). Synchrony of rockfish recruitment in the California Current System appears to predominate on coast-wide rather than smaller regional scales suggesting that large-scale climatic factors are affecting rockfish recruitment (Field and Ralston 2005). In contrast, different Californian regions can show different patterns in catch per unit effort for rockfish in response to El Niño conditions (Bennett et al. 2004). For example, as El Niño conditions developed or as ocean climate turned warm after 1977, catch rates for rockfish declined in southern California and increased in the north.

A recent study of climate change by the University of Washington concluded that profound changes have occurred in the Puget Sound environment over the past century and that the next several decades will see even more changes (Snover et al. 2005). Projected changes that could impact rockfishes include increases in water temperature and flooding, accelerated rates of sea level rise, loss of nearshore habitat, changes in plankton, and increased likelihood of algae blooms and low levels of dissolved oxygen.

Unfortunately, time series of recruitment are not readily available for any species of rockfish in Puget Sound, so the impact or potential impacts of climatic change on recruitment cannot be directly addressed. The Documentation is of climate impacts on rockfish in Puget Sound is Unknown. The Intensity and Extent are also Unknown, though likely to be high or medium once understood. The Relative Risk is Unknown.

7.7 Dissolved Oxygen and Nutrients

Throughout most of Puget Sound, the water quality (temperature, salinity, nutrient concentrations, dissolved oxygen) is suitable for rockfish survival and growth. Most waters of Puget Sound are classified as “Excellent” by the Department of Ecology but Hood Canal remains a glaring exception. Other areas including Budd Inlet, Discovery Bay, and Penn Cove may have water quality parameters that limit fish stocks, especially during warm summer temperatures or periods of hypoxia.

Excessive concentrations of nutrients may result in marine waters becoming hypoxic, and hypoxic conditions have been observed throughout Puget Sound (Table 7.2). Nutrients are chemical compounds needed by organisms for metabolism, growth, and other functions. Nutrients in Puget Sound come from rivers, streams, and the Pacific Ocean. Humans can add nutrients to the waters of Puget Sound through sources such as sewage, septic tank drainages, and other non-point sources of pollution (Paulson et al. 2006). The nutrients are not utilized directly by rockfish, but could impact rockfish stocks indirectly. The addition of relatively small amounts of nutrients could increase rockfish prey such as crustaceans, which feed on the organic material, while the addition of larger amounts could reduce water quality by causing hypoxia. The addition of nutrients can stimulate the growth of algae during the summer months through a process called eutrophication. The algae dies, sinks to the bottom and decomposes, a process that utilizes dissolved oxygen. Therefore, increased levels of nutrients may lead to lower levels of dissolved oxygen in places such as Hood Canal. Increased nutrients from septic systems may be exacerbating naturally-caused hypoxia in Hood Canal (Newton et al. 2007), and this human source, as well as natural sources of nitrogen, may be causing the hypoxia that adversely affects rockfish populations (Palsson et al. 2008).

In Hood Canal, persistent and increasing areas of low levels of dissolved oxygen or hypoxia have been noted during the past decade (Newton et al. 1995, 2002, 2005, Warner et al. 2002). This exposure to low oxygen results in abnormal behavior by rockfish in Hood Canal manifested by rockfish avoiding waters with less than 2 mg/L of oxygen by moving to nearshore, shallow waters less than 9 m in depth (Palsson et al. 2008). Extreme hypoxia results in massive fish kills in Hood Canal (Palsson et al. 2008). In 2003, strong winds upwelled water containing less than 2 mg/l of oxygen to the surface causing a 26% direct mortality of the copper rockfish at the Sund Rock Conservation Area (Palsson et al. 2008). As a precautionary measure, WDFW has prohibited the harvest of rockfish and other bottomfish by both commercial and recreational fisheries in Hood Canal until water conditions permanently improve. There are indications that periods of low dissolved oxygen are becoming more widespread in the waters south of Tacoma Narrows, but at present the impact of hypoxia is localized and moderate in Puget Sound (Newton et al. 2002).

The Documentation on hypoxic effects on rockfish is High. The Intensity is High as direct mortality and population effects have been shown. The Extent is Medium as hypoxia affects localized areas on an episodic basis. The composite average is 2.7 resulting in a Relative Risk of High.

Table 7.2. Relative Dissolved Oxygen Levels Among Basins and Embayments in Puget Sound (high->5 mg/l, low 3-5 mg/l, and very low-<3 mg/l; Adapted from PSAT 2002.

Location	Dissolved Oxygen
Budd Inlet	Very Low
S. Hood Canal	Very Low
Penn Cove	Very Low
Possession Sound	Low
Commencement Bay	Low
Bellingham Bay	Low
Sinclair Inlet	Low
Elliott Bay	Low
Discovery Bay	Very Low
N. Hood Canal	Low
Carr Inlet	Low
Quartermaster Harbor	Low
Holmes Harbor	Low
Skagit Bay	Low
Port Susan	Low
East Sound	Low
Dungeness	Low
Port Gamble	Low
Sequim Bay	Low
Port Townsend	Low
Strait of Georgia	Low

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7.8 Chemical Contamination

Toxic compounds such as polychlorinated biphenyls (PCBs) found in urban and contaminated habitats pose a risk to the health and fitness of rockfish in Puget Sound. These compounds can be bioaccumulative and amplified during the long lives of many rockfish adults. The risks posed by toxics may also include exposure to endocrine disrupting compounds, resulting in reproductive dysfunction in urban rockfish populations. Central and Southern Puget Sound pelagic larvae may be exposed to high levels of toxics via contaminated prey and via maternal transfer.

Urban and industrial embayments in Puget Sound such as Elliott Bay, Sinclair Inlet and Commencement Bay contain high concentrations of a wide range of toxic contaminants including metals, organohalogens, and hydrocarbons. High concentrations of PCBs and mercury are observed in long-lived quillback rockfishes from these embayments (West and O'Neill 1998; West et al. 2001; PSAT 2007). The highest tissue concentrations occur in fish from urban and industrialized areas, however even in the rural San Juan Islands, older rockfish have high concentrations of mercury, resulting from accumulation of naturally-occurring environmental mercury (West et al. 1998). Because of these body burdens of PCBs and mercury, the Washington Department of Health has advised people to avoid consuming any demersal rockfish from Elliott Bay and Sinclair Inlet, and to limit consumption of demersal rockfish from all other Puget Sound locations to two meals per month (DOH 2006).

Risks to rockfish health associated with their exposure to toxic contaminants can occur at all life history stages. Larval, juvenile, or adults rockfishes either in demersal or pelagic habitats can all be exposed to a wide range of toxic contaminants. Larvae, in particular, face unique additional risks associated with maternal transfer of toxics via maternal nutrients they receive during gestation. In addition, toxicopathic (disease related to toxics) may affect reproduction. Most exposure to contaminants for Puget Sound fishes occurs via dietary intake (excepting the maternal transfer mentioned above). Waterborne (dissolved) toxics can cross skin and cell membranes, however this pathway is thought to be negligible for adults and juveniles. Hence, rockfish adults, juveniles, or larvae that live in contaminated habitats and consume locally contaminated prey or migratory prey contaminated from other areas, are at greatest risk. Within Puget Sound, some contaminants such as methylmercury, PCBs, polybrominated byphenyls (flame retardants, or PBDEs), and chlorinated pesticides such as DDT (and its metabolites) are known to accumulate in rockfish tissues as the fish grows, and toxicity increases as body burden (and concentration) of the chemical increases. Other toxics, such as polycyclic aromatic hydrocarbons (PAHs) or many endocrine disrupting compounds (EDCs), are metabolized and do not accumulate in fish tissues, but can still adversely affect the health of rockfishes and other species feeding in Puget Sound.

Sub-adult and adult rockfish, as demersal, long-lived, and mid-level predators, have increased exposure to contaminated sediments in Puget Sound (West et al. 2001). These contaminants can be patchily distributed which may affect rockfish that also demonstrate high site fidelity. Rockfish in urban or industrialized habitats have less relief from contaminants than other urban species with larger home ranges, whose feeding ranges might include cleaner, non-urban areas, or highly migratory species that spend little time in contaminated habitats. As a result, demersal rockfishes in urban or industrialized areas of Puget Sound have exhibited some of the highest tissue concentrations of mercury, PCBs, and DDTs of any species monitored for chemical contaminants (West et al. 2001).

Both male and female rockfish from two of the most contaminated embayments in Puget Sound, Elliott Bay and Sinclair Inlet, exhibit high age-specific mercury concentrations. PCB accumulation, however, differed markedly between the sexes at Elliott Bay. Male quillback rockfish accumulate PCBs to concentrations exceeding the effects threshold of 2400 ng/g lipid (Meador et al. 2002), whereas Elliott Bay females accumulate a lower body burden of PCBs that remain constant or decline as the fish ages (Figure 7.2, PSAT 2007). In addition, male quillback rockfish exhibit a lesser growth rate than females in Elliott Bay, a pattern that was unique to this location, compared to quillback length-at-age samples from 98 other locations in Central Puget Sound, Admiralty Inlet, Georgia Basin, and the Strait of Juan de Fuca (WDFW, unpublished data, Jim West). This unique sex-specific disparity in growth pattern may relate to the high levels of PCBs that accumulate in male rockfish in Elliott Bay.

Additional toxicopathic reproductive effects could also occur via maternal transfer of persistent lipophilic ("fat-loving") toxics to larvae. The sex-specific disparity in accumulation of PCBs noted above almost certainly results from the transfer of lipid-associated PCBs from females to their progeny with transfer of fat and nutrients during gestation (e.g., Miller 1993). Visceral fat in females declines with development and subsequent release of larvae, (Guillemot et al. 1984) as females transfer nutrients to their progeny via yolk and ovarian fluids. This means that rockfish larvae from urban females are born with a pre-existing body burden of PCBs, thereby increasing the risk of compromised fitness at this sensitive life stage.

Like demersal adult and juvenile rockfish, pelagic larvae and juveniles can be exposed to toxics via contaminated prey. After birth, larvae spend weeks or months in pelagic habitats. Monitoring results for PCBs, DDTs, PBDEs, and PAHs in the pelagic Pacific herring (*Clupea pallasii*), suggest that the pelagic food web is contaminated with these toxics (O'Neill and West 2001, West et al. 2008), and are therefore available to pelagic biota, including rockfish larvae. Further, herring contaminant patterns indicate that Southern and Central Puget Sound pelagic habitats are more contaminated than more northerly basins that are remote from urban centers (Figure 7.3). Thus, pelagic larval and juvenile rockfish feeding in the central and southern Puget Sound basins are exposed to higher contaminant levels than rockfish feeding in the northern Puget Sound.

Rockfish in contaminated habitats also probably experience some reproductive dysfunction related to their exposure to EDCs. Rockfish in Elliott Bay occupy habitats near English sole (*Parophrys vetulus*) that have exhibited disruption of their endocrine function (which indicates exposure to EDCs), including the presence of vitellogenin (an egg-protein) in males and abnormal spawn timing and maturation in females (Lomax 2004). This coincidence suggests that the risk of reproductive dysfunction in rockfish may be higher for populations occupying contaminated habitats. Additional studies on endocrine disruption must be conducted to evaluate this hypothesis.

The contribution of urban rockfish to the full reproductive output of all Puget Sound stocks is unknown and needs to be quantified. Collections of rockfish in urban locations, such as Elliott Bay and Sinclair Inlet indicate that these areas may act as *de facto* refuges, likely because it is either difficult to fish the habitats (e.g., habitats near ferry lanes) or access is restricted to fishers (e.g., at military bases like Sinclair Inlet's Puget Sound Naval Shipyard). WDFW has sampled some of the oldest and largest specimens of quillback and brown rockfishes in Puget Sound from these urban or restricted locations. How contamination impacts the larvae of these older rockfish living in urban areas is unknown, but the importance of older parents (Berkeley et al. 2004a, b) may be compromised in these areas. Because most rockfish habitat and fisheries are located in uncontaminated areas away from urban centers, and because rockfish living in these fished areas are smaller and in low abundance, one could argue that uncontaminated rockfish stocks have received disproportionately high fishing pressure. This may result in a higher proportional contribution of urban rockfish to the overall spawning potential of rockfish in Puget Sound. If this is indeed the case and rockfish reproductive fitness in urban stocks is compromised, the need for (1) reducing toxic contaminants in Puget Sound and (2) protection of non-urban rockfish stocks should be central components of a rockfish conservation plan.

In summary, the Documentation of the impacts on rockfish in Puget Sound is Fair as most of the inferences regarding chemical contamination is from other species in Puget Sound but with some direct information on rockfish in Puget Sound. The Intensity is Medium as chemical contamination reduces the fitness of rockfish though reproductive dysfunction of rockfish with exposure to EDCs, loading of larvae with persistent organics via maternal transfer, exposure of Central and Southern Puget Sound pelagic larvae to toxics via contaminated prey, and exposure of long-lived adults to bioaccumulative toxics like PCBs in urban or other contaminated habitats. The Extent is Medium as chemical contamination is highest in localized urban embayments, but future work may show the effects are prevalent on a regional scale. The average score of the criteria is 2.3 resulting in a relative risk of Moderate.

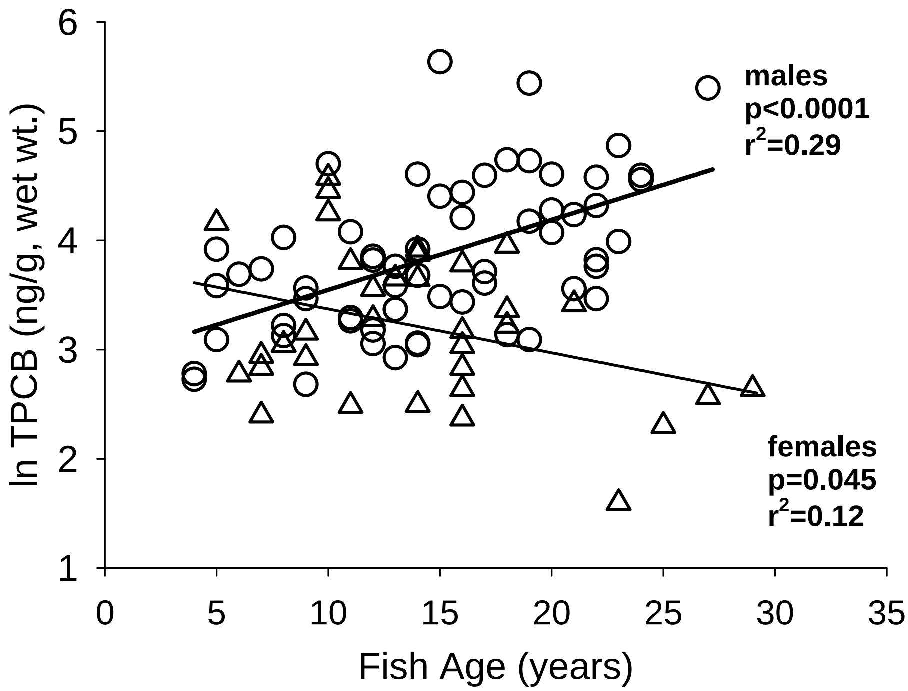

Figure 7.2. Total PCBs (TPCB, log-transformed) in quillback rockfish (*Sebastes maliger*) accumulates in males (circles) but not females (triangles) from the highly urbanized Elliott Bay, Puget Sound Washington. One unusually old (40 year old) male rockfish was excluded from the analysis.

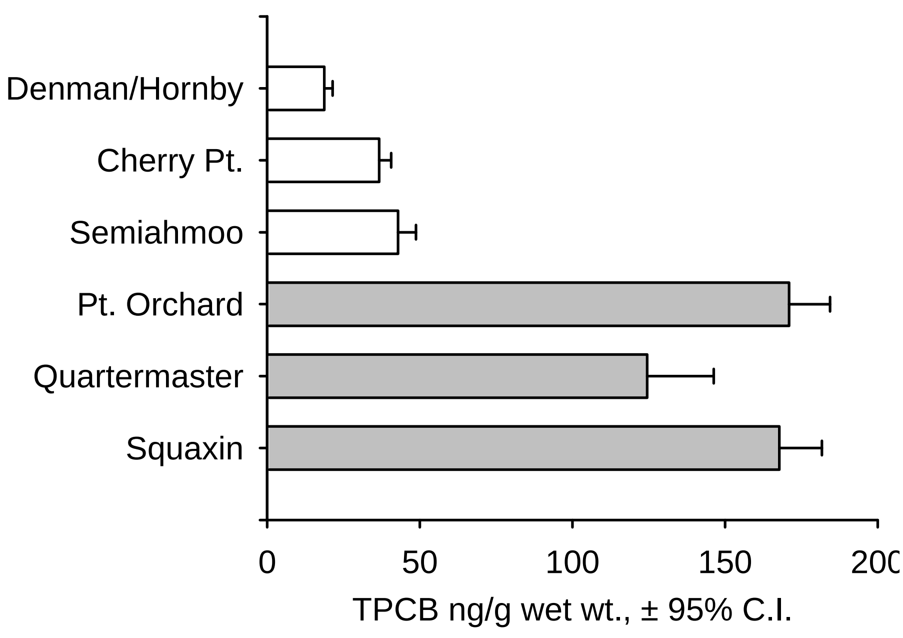

Figure 7.3. Total PCBs (TPCB) in Pacific herring (*Clupea pallasi)* indicate toxic contamination of the pelagic food web. TPCB concentrations in Central and Southern Puget Sound stocks (grey bars) were roughly 3 times that of stocks from Northern Puget Sound or the Georgia Basin (white bars). Levels of other toxics including organochlorine pesticides, polycyclic aromatic hydrocarbons, and polybrominated diphenyl ethers exhibit the same pattern.

7.9 Species Interactions

Rockfish have naturally evolved to persist and thrive in the presence of other species in Puget Sound. However, the perturbations in community structure caused by fishing, habitat alteration, and other stressors may negatively affect or create an imbalance in the natural structure of marine communities. This may cause natural predation, disease resistance, competition, and habitat disturbance.

7.9.1 Food Web Dynamics

Rockfish function as both predators and prey in the complex food web of Puget Sound (See Section 3.4 **Ecology and Behavior**). Some of these linkages have been examined through diet studies, and only recently are food web interactions for rockfish and other species in Puget Sound (PSP 2008) being integrated into a conceptual and quantitative model of food web structure. Simenstad et al. (1979) identified copper rockfish as an important secondary carnivore of rocky, subtidal habitats in northern Puget Sound. One previous ecosystem model developed for South Puget Sound included rockfish as groundfish species and the results showed that a shift occurred in the ecosystem between the 1970s and early 1980s and the present (Preikshot and Beattie 2001). Salmon, forage fish, and groundfish generally declined while seal populations increased. Reum and Essington (2008) have examined the diet seasonality of 21 fish species occurring in Puget Sound bottom trawl samples and identified seven significant guilds. However, rockfish were not identified as a member of any of these guilds.

Predation by abundant marine mammals and by lingcod may result in significant natural morality of depleted rockfish stocks. Steller sea lions inhabit Puget Sound, especially in the entrance waters at Tatoosh Island and in the San Juan Islands, where dozens are present during the spring (S. Jeffries, WDFW, personal communication). Steller sea lions have been increasing in abundance in the northern portion of the western United States, currently, 800 to 1,000 animals inhabit northern Puget Sound during the fall and winter months (PSAT 2007). In Washington waters, they inhabit Whale Rocks, Bird Rock, Peapod Rocks, and sites in Speiden Channel. During sea lion surveys conducted in April and May, hundreds of Steller sea lions forage between East Point and Patos Island in President's Channel. The impact of these large mammals on rockfish is unknown, but in the Gulf of Alaska, Steller sea lions consume high percentages of codfishes and Atka mackerel, while rockfishes are only minor items in their diets (Winship and Trites 2003). In the San Juan Islands, rockfishes occurred in 8.3% of Steller sea lion scats (Lance and Jeffries 2007). Because Steller sea lions feed on salmon, Pacific herring, Pacific hake, and rockfish, they may have an impact on rockfish stocks.

Harbor seals are year round residents of Puget Sound, and the population of seals has expanded greatly since the 1970's, increasing from a few hundred to over 12,000 in 1999 (Schmitt et al. 1995, Jefferies et al. 2003) and 14,000 recently (PSAT 2007). There are indications that the growth rate of the seal population is decreasing and that the population may be reaching its maximum carrying capacity in Puget Sound (Jefferies et al. 2003). The average weight of harbor seals in Puget Sound is approximately 140 pounds and daily food consumption rates are approximately 4% of the body weight (Schmitt et al. 1995). Based on these numbers, the estimated consumption of food by harbor seals in Puget Sound is quite high, over 5 million pounds annually. In the San Juan Islands, where the seal population numbers approximately 7,000, rockfish comprise 12% of seal diets annually and 23% during the winter (Lance and Jeffries 2007). Lance and Jefferies (2007) concluded that the consumption patterns of seals may be an important impact on reduced stocks of rockfish.

Like harbor seals, California sea lions were not recently common in Puget Sound until the 1970's (PSAT 2007). The first large aggregation in recent times was observed in 1979. Since then, the abundance of

California sea lions has been in the hundreds and occasionally over 1,000 animals (Schmitt et al. 1995). Up to 5,000 occur in northern coastal waters of Washington during the fall, and additional 1,000 to 1,500 are seasonally present in British Columbian waters (PSAT 2007). California sea lions are seasonal migrants in Puget Sound occurring primarily from September through June. The average weight per animal is between 180 and 277 kg (450 to 700 pounds). Antonelis and Perez (1984) estimated the daily food consumption to be 5% to 10% of the body weight. Therefore, a 500 pound California sea lion would eat 25 to 50 pounds per day. In a review of predation by marine mammals in Puget Sound, no evidence was found of a significant consumption of rockfish by California sea lions (Schmitt et al. 1995). However, California sea lions consume rockfish off of California, so the lack of rockfish in the diet of California sea lions in Puget Sound may be due to low rockfish abundance, or a poor seasonal and geographic data on California sea lion diets. The great numbers of harbor seals and some aggregations of sea lions in Puget Sound may result in significant natural morality of depleted rockfish stocks.

Consumption of rockfish by orca whales in Puget Sound is a rare event (Wiles 2004) and likely is low, even if rockfish stocks increase.

Rockfish are an important prey item for several species of marine birds. Juvenile rockfish can be especially important while birds are feeding their young. There has been no known increase in populations of marine birds that would likely affect rockfish stocks, and several species of marine birds are in decline in Puget Sound (PSAT 2002).

Rockfish, especially juvenile rockfish, are an important prey item for lingcod (*Ophiodon elongatus*) and may even be their primary food item (Matthews 1987, Beaudreau and Essington 2007). Abundances of lingcod have been low in Puget Sound prior to the mid 1990s but have been increasing in recent years to almost high levels (PSAT 2007), suggesting that lingcod may affect the abundance of rockfishes. In marine reserves, lingcod may cause a "tropic cascade" and structure the marine fish community (Salomon 2002, Salomon et al. 2002), and the high densities of lingcod observed in the long-term marine reserves in Puget Sound may reduced the abundance of rockfish through predation upon adult and juvenile rockfishes (Palsson et al. 2004). Rockfish were three times more likely to occur in the diets of lingcod captured from marine reserves in the San Juan Islands than from fished areas (Beaudreau and Essington 2007). Lingcod are five to ten times more likely to consume rockfish in marine reserves than in fished areas (Beaudreau and Essington 2009). Therefore, increased abundances of lingcod and management practices promoting lingcod conservation may impact the abundance and recovery of rockfish stocks in Puget Sound.

The Documentation that predation affects rockfish stocks is Best and the direct mortality and community impacts results in the Intensity as High. Lingcod and marine mammals co-occur on a continual basis with rockfish stocks indicating that the Extent is High. The average of the criteria is 3.0 and the Relative Risk of predation is High.

7.9.2 Competition

Rockfishes have been shown to have competitive interactions, or to partition their environment to avoid competition with other rockfish species (Larson 1980, Hallacher and Roberts 1985). In Central Puget Sound, the increase in brown rockfishes may be a result of the removal of the more aggressive copper and quillback rockfishes by the fishery, allowing for brown rockfish to invade an open niche. The impacts of competition may also be exacerbated or caused by the removal of prey items, such as shrimp by recreational and commercial fisheries. The Documentation of competition as a stressor is Poor, the Intensity and Extent is Unknown and the Relative Risk is Unknown.

7.9.3 Salmon Hatchery Practices

West (1997) suggested that a potential stress to rockfish in Puget Sound was predation of larval and juvenile rockfish by "delayed-release", hatchery-reared salmon. Delayed-release salmon are chinook salmon (*Oncorhynchus tshawytscha*) and coho salmon (*O. kisutch*) which have been held longer in hatcheries or net pens, so they are less likely to migrate to sea and more likely to remain in Puget Sound. Since chinook and coho salmon consume rockfish, especially in the larval and juvenile stage (Buckley 1997), releases of larger hatchery salmon may impede the productivity of rockfish stocks in Puget Sound (West 1997). Hatchery releases of delayed released Chinook and coho into Puget Sound averaged 21.2 million fish annually from 1983 to 2000 (Figure 7.4). After 2000, these releases have averaged 14.7 annually; a 34% decline (WDFW unpublished data) Overall, there is a lack of information on the direct impacts of hatchery releases on rockfish stocks in Puget Sound and all criteria and Relative Risks are Unknown.

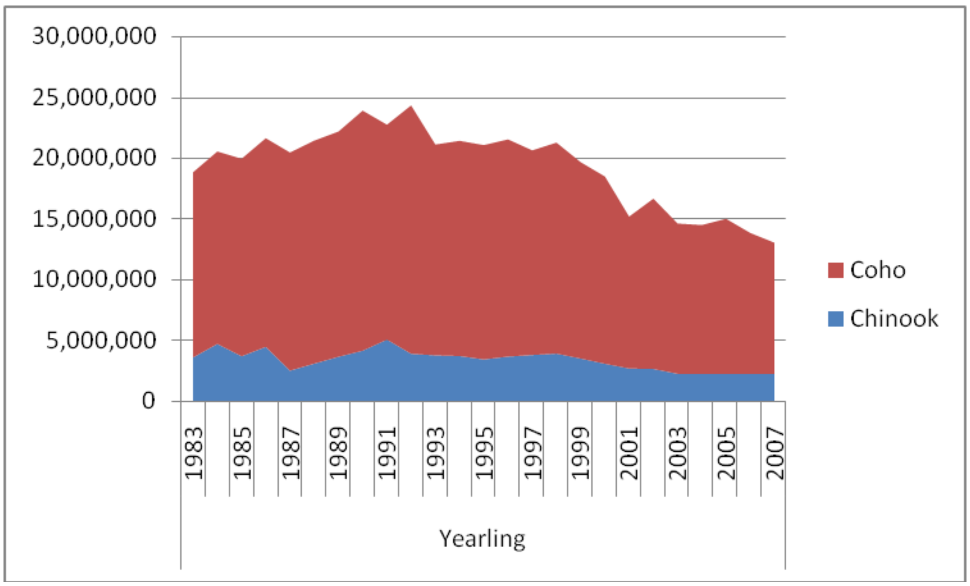

Figure 7.4. Annual releases of hatchery salmon in Puget Sound.

7.10 Diseases

Rockfish are susceptible to diseases and parasites (Love et al. 2002), but how they affect rockfishes in Puget Sound is not known. The parasite I*chthyophonus* has been detected in 11% of Puget Sound rockfish in the San Juan Archipelago and Puget Sound but there will no clinical signs observed (Halos et al. 2005). Extensive scale loss on rockfishes in Puget Sound has occurred on individuals living in high densities or in poor water quality. Sub-adult quillback rockfishes living on the Boeing Creek Artificial Reef had a disease causing scale loss attributed to a protozoan parasite (W. Palsson, WDFW, unpublished data). Copper rockfish concentrated in dense schools during events of low dissolved oxygen in Hood Canal had extensive scale loss (W. Palsson, WDFW, unpublished data). Conboy and Speare (2002) found the eggs of a nematode infesting rockfish in a British Columbia fish market, but the pathology of the fish was not known. A wide variety of parasites and diseases affect rockfish (Love et al. 2002) and stress, such as in Hood Canal during low dissolved oxygen events, may exacerbate the incidence and severity of naturally occurring diseases to the point of sublethal or lethal effects. Although one study documents the occurrence of diseases in Puget Sound, the lack of focused studies results in a Poor rating for Documentation. As such, the Intensity and Extent is Unknown. Overall, the Relative Risk is Unknown for diseases affecting rockfish stocks in Puget Sound.

7.11 Genetic Change

The genetic differentiation of rockfish stocks between North and South Sound suggests that genetic changes due to any future rockfish aquaculture/hatchery practices, trans-basin introductions, and fishing may threaten the integrity of the genetic structure of wild rockfish stocks. Hatcheries that may eventually produce rockfish for stock supplementation or commercial sale by limited, artificial or selective breeding programs may threaten the genetic integrity and disease resistance of natural populations (West 1997). The collection, transportation, and release of rockfish from one basin or region to another, offer the potential for altering the genetic constitution of wild rockfish in the receiving basin. Any scientific collection or commercial transportation of live rockfish for sale should assure that accidental or intentional trans-basin releases do not occur. Aquariums often collect rockfish from coastal waters for display in open or semi open circulation systems. Culture practices should assure that releases do not occur and that reproduction does not cast larvae into the local waters.

Fishing can alter the genetic characteristics of fish populations by lowering genetic diversity and by artificial selection (Kenchington 2003). Fishing can artificially select larger and typically faster growing individuals thus promoting the survival of individuals with slower growth rates (Biro and Post 2008). Overall population growth rates may decrease, and other effects such as smaller size at maturity, smaller size at age, and smaller maximum sizes can occur (Law 2000). For example, fishing on haddock selected for small size and early maturation in Atlantic cod (Beacham 1983a) and for early maturation (Beacham 1983b).

The impacts of genetic change are likely subtle and need at least 30 generations to be expressed for long-lived rockfishes. Thus, it may require several hundred years to identify any genetic changes. However, genetic change may be exacerbated when population sizes are low or naturally limited. The Documentation on genetic effects is Poor. The Intensity and Extents are Unknown, resulting in a Relative Risk of Unknown.

8 RESEARCH AND DATA NEEDS

The following recommendations are provided to assure the continuance of Healthy rockfish stocks in Puget Sound and the recovery of stocks that are in poor condition:

8.1 Habitat

1. Identify juvenile and adult rockfish habitats.
2. Establish and further the develop the knowledge about the relationships and associations between habitats and critical life history phases of rockfishes occurring in Puget Sound.
3. Map subtidal habitats using multibeam, laser scanning, sidescan sonar, and video technologies in order to identify the location, type, and spatial extent of rockfish habitats.
4. Identify and include important rockfish habitats in WDFW's Priority Habitats and Species program and in other programs that protect the habitats of sensitive species.

8.2 Ecosystem Stressors

1. Investigate the quantitative impact of derelict gear in terms of habitat impairment and rockfish mortality.
2. Investigate the impacts of climate and climate change on the recruitment, physiology, ecology, survival, and habitat quality of rockfishes.
3. Research the behavioral responses and physiological and lethal tolerances of rockfishes to low dissolved oxygen.
4. Conduct detailed studies evaluating the short and long-term effects to rockfish stocks to the exposure to PCB's, PAH's, heavy metals, and other toxic compounds found in marine environments.
5. Develop a detailed understanding and model of the predator-prey and food web relationships of rockfishes and dominant members of the marine community including lingcod, greenlings, crustaceans, forage fishes, seabirds, and marine mammals.
6. Understand the impact of fisheries for crustaceans and forage fishes on rockfish stocks, and balance harvest of these fisheries with the needs of limiting stocks of rockfishes.
7. Research and manage the impact of salmon and other aquaculture practices on rockfishes, especially if hatchery-reared fish swarm and prey upon young rockfish stages.
8. Investigate diseases that affect rockfish, especially under crowding and low dissolved oxygen conditions.
9. Investigate and prevent negative impacts of intentional and accidental releases of cultured rockfishes upon wild stocks.

8.3 Management

1. Conduct studies to evaluate the effectiveness of marine reserves for preserving species, age, and genetic diversity.

2. Establish if marine reserves have population benefits outside of the reserves.

3. Conduct studies to determine whether reserves are economically and politically feasible.

4. Conduct research to minimize or eliminate bycatch through conservative fishing practices.

5. Conduct survival and other studies to determine the extent of barotrauma and hooking mortality and if these can be minimized.

6. Develop systems to account for all rockfish catch.

8.4 Stock Assessment and Research

1. Institute comprehensive video surveys of shallow and deep-water rocky habitats using remote operated vehicles in order to estimate the abundance of rockfish by the basins of Puget Sound.

2. Enhance the bottom trawl surveys to include complete coverage of North and South Sound in alternating years and include a small trawl survey of habitats less than 9 m in depth.

3. Develop methods to assess uncommon species, especially those that are decreasing in their catch frequencies.

4. Implement a comprehensive commercial monitoring program that includes regular inspection and sampling of commercial catches and observed fishing activities at sea.

5. Implement enhanced rockfish sampling for commercial and recreational catches that include the identification of rockfishes with trained technicians and the collection of otoliths and other samples.

6. Conduct life history studies on all species of rockfish to identify and estimate key parameters including fecundity-at-length, maturity-at-age, growth, generation times, natural and fishing mortality rates, and habitat requirements. A special need it to determine the length-fecundity relationship for quillback rockfish.

7. Develop methods to estimate the recruitment of rockfish and understand factors affecting larval and juvenile survival. Develop recruitment indices based upon index sites.

8. Examine the nature of self-recruiting populations with the inland marine waters versus those populations that principally recruit from or emigrate from coastal waters.

9. Conduct advanced studies examining stock structure, hybridization, and genetic diversity, especially within and among sub-basins.

10. Understand the fine-scale patterns of recruitment within and among rockfish conservation areas and areas of high and low productivity.

11. Develop quantitative models to recapitulate the demographic history of rockfish stocks and project rebuilding and harvest plans into the future.

12. Incorporate uncertainty and risk into management schemes and demographic models.

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