NOAA Technical Memorandum NMFS-NWFSC-108

Status Review of Five Rockfish Species in Puget Sound, Washington

Bocaccio (*Sebastes paucispinis*),
Canary Rockfish (*S. pinniger*),
Yelloweye Rockfish (*S. ruberrimus*),
Greenstriped Rockfish (*S. elongatus*),
and Redstripe Rockfish (*S. proriger*)

December 2010

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service

NOAA Technical Memorandum NMFS-NWFSC Series

The Northwest Fisheries Science Center of the National Marine Fisheries Service, NOAA, uses the NOAA Technical Memorandum NMFS-NWFSC series to issue scientific and technical publications. Manuscripts have been peer reviewed and edited. Documents published in this series may be cited in the scientific and technical literature.

The NMFS-NWFSC Technical Memorandum series of the Northwest Fisheries Science Center continues the NMFS-F/NWC series established in 1970 by the Northwest & Alaska Fisheries Science Center, which has since been split into the Northwest Fisheries Science Center and the Alaska Fisheries Science Center. The NMFS-AFSC Technical Memorandum series is now being used by the Alaska Fisheries Science Center.

This document should be referenced as follows:

Drake J.S., E.A. Berntson, J.M. Cope, R.G. Gustafson, E.E. Holmes, P.S. Levin, N. Tolimieri, R.S. Waples, S.M. Sogard, and G.D. Williams. 2010. Status review of five rockfish species in Puget Sound, Washington: bocaccio (*Sebastes paucispinis*), canary rockfish (*S. pinniger*), yelloweye rockfish (*S. ruberrimus*), greenstriped rockfish (*S. elongatus*), and redstripe rockfish (*S. proriger*). U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-108, 234 p.

NOAA Technical Memorandum NMFS-NWFSC-108

Status Review of Five Rockfish Species in Puget Sound, Washington

Bocaccio (*Sebastes paucispinis*), Canary Rockfish (*S. pinniger*), Yelloweye Rockfish (*S. ruberrimus*), Greenstriped Rockfish (*S. elongatus*), and Redstripe Rockfish (*S. proriger*)

Jonathan S. Drake, Ewann A. Berntson, Jason M. Cope, Richard G. Gustafson, Elizabeth E. Holmes, Phillip S. Levin, Nick Tolimieri, Robin S. Waples, Susan M. Sogard,* and Gregory D. Williams

Northwest Fisheries Science Center
2725 Montlake Boulevard East
Seattle, Washington 98112

* Southwest Fisheries Science Center
110 Shaffer Road
Santa Cruz, California 95060

December 2010

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service

Most NOAA Technical Memorandums NMFS-NWFSC are available online at the Northwest Fisheries Science Center web site (http://www.nwfsc.noaa.gov)

Copies are also available from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone orders (1-800-553-6847)
e-mail orders (orders@ntis.fedworld.gov)

Table of Contents

List of Figures

List of Tables

Executive Summary

This report describes the conclusions of the National Marine Fisheries Service's (NMFS) Puget Sound Rockfish Biological Review Team (BRT) on the status of five species of rockfish—bocaccio (*Sebastes paucispinis*), canary rockfish (*S. pinniger*), yelloweye rockfish (*S. ruberrimus*), greenstriped rockfish (*S. elongatus*) and redstripe rockfish (*S. proriger*)—in Puget Sound, Washington, under the U.S. Endangered Species Act (ESA).

The BRT has determined that populations of each of the five species in either Puget Sound Proper (inland marine waters south and east of Admiralty Inlet) or Puget Sound/Georgia Basin (inland marine waters east of the central Strait of Juan de Fuca and south of the northern Strait of Georgia) are a "species" under the ESA, as they meet the biological criteria to be considered a distinct population segment (DPS) as defined by the joint U.S. Fish and Wildlife Service-NMFS interagency policy of 1996 on vertebrate distinct population segments under the ESA. Specifically, based on information related to rockfish life history, genetic variation among populations, and the environmental and ecological features of Puget Sound and the Georgia Basin, the BRT has identified a Puget Sound/Georgia Basin DPS for bocaccio, canary rockfish, and yelloweye rockfish and a Puget Sound Proper DPS for greenstriped rockfish and redstripe rockfish.

The BRT concluded that the Victoria sill represents the western boundary of the Puget Sound/Georgia Basin DPS; however, there is uncertainty in this boundary designation and there was some support within the BRT for a more westerly boundary near the Seikiu River. The Puget Sound Proper DPS boundaries for greenstriped rockfish and redstripe rockfish are the same as the previously identified DPS boundaries for copper (*S. caurinus*), quillback (*S. maliger*), and brown (*S. auriculatus*) rockfish (Stout et al. 2001a). Considerable uncertainty characterizes all of the DPS designations due to limited genetic and demographic information available for the species in question.

The BRT ranked threats to the each DPS. In each case, the BRT ranked lethal low levels of dissolved oxygen, chemical contaminants, harvest, and habitat loss as the most serious threats to the persistence of each DPS. Variability in ocean conditions and bycatch were scored as moderate risk in each DPS.

Based on an evaluation of abundance trends, spatial structure, and diversity, as well as the threats listed above, the BRT determined that Puget Sound/Georgia Basin DPS of bocaccio is at high risk of extinction throughout all of its range, that the Puget Sound/Georgia Basin DPSs of yelloweye rockfish and canary rockfish are at moderate risk of extinction throughout all of their range, and that the Puget Sound Proper DPSs of greenstriped and redstripe rockfish are not at risk of extinction throughout all of their range.

Introduction

On 9 April 2007, the National Marine Fisheries Service (NMFS) received a petition from Mr. Sam Wright, Olympia, Washington, to list distinct population segments (DPSs) of bocaccio (*Sebastes paucispinis*), canary rockfish (*S. pinniger)*, yelloweye rockfish (*S. ruberrimus*), greenstriped rockfish (*S. elongatus*), and redstripe rockfish (*S. proriger*) in Puget Sound, Washington, as endangered or threatened species under the U.S. Endangered Species Act (ESA) and to designate critical habitat. NMFS declined to initiate a review of the species' status under the ESA, finding that the petition failed to present substantial scientific or commercial information to suggest that the petitioned actions may be warranted (72 Federal Register 56986, 5 October 2007).

On 29 October 2007, NMFS received a letter from Mr. Wright presenting information that was not included in the April 2007 petition, and requesting that NMFS reconsider its 5 October 2007 "not warranted" finding on the petition submitted in April 2007. NMFS evaluated the new information to determine whether the petitioner provided "substantial information" as required by the ESA to list a species. Additionally, NMFS evaluated whether information contained in the petition might support the identification of DPSs that may warrant listing as species under the ESA. NMFS found that this new petition did present substantial scientific or commercial information, or cited such information in other sources, indicating that the petitioned actions may be warranted, and subsequently, NMFS initiated a status review of these five rockfish species in Puget Sound.

NMFS formed the Puget Sound Rockfish Biological Review Team (BRT)[1]—consisting of scientists from the Northwest Fisheries Science Center and the Southwest Fisheries Science Center—and the team reviewed and evaluated scientific information compiled by NMFS staff from published literature and unpublished data. Information presented at a public meeting in June 2008 in Seattle, Washington, and data submitted to the ESA Administrative Record from state agencies and other interested parties were also considered.

The BRT proceeded on directives included in a memo that was received from the Northwest Region in draft form on 19 May 2008. In that memo, the BRT was asked to consider whether the petitioned species meet the criteria for being considered a DPS as defined by the joint USFWS-NMFS Distinct Population Segment (DPS) Policy (61 Federal Register 4722, 7 February 1996). If a DPS or DPSs were identified for any of the species in Puget Sound, the BRT was requested to evaluate the level of extinction risk faced by each DPS throughout its range, assessed as either "high risk," "moderate risk," or neither, where high and moderate risk were defined with respect to specific reference levels of extinction risk (see discussion in The

---

[1] The BRT for Puget Sound rockfish consisted of Ewann Berntson, Jason Cope, Jonathan Drake (cochair), Rick Gustafson, Elizabeth Holmes, Phillip Levin (cochair), Nick Tolimieri, Robin Waples, Northwest Fisheries Science Center; and Susan Sogard, Southwest Fisheries Science Center.

Extinction Risk Question section below). Finally, the BRT was requested to document the consideration of threats to the species according to the statutory listing factors (ESA section 4(a)(1)(A)–(C), and (E)): the present or threatened destruction, modification, or curtailment of its habitat or range; overutilization for commercial, recreational, scientific, or educational purposes; disease or predation; and other natural or man-made factors affecting its continued existence.

An earlier draft of this document was the preliminary report of the BRT conclusions on the status of the five petitioned rockfish species from Puget Sound, Washington. The status review process included public comments, external peer review, and BRT responses to those technical comments and reviews (Appendix A and Appendix B). This technical memorandum is the final report.

The Species Question

As amended in 1978, the ESA allows listing of DPSs of vertebrates as well as named species and subspecies. The joint U.S. Fish and Wildlife Service (USFWS)-NMFS interagency policy on vertebrate populations (USFWS-NMFS 1996) provides guidance on what constitutes a DPS. To be considered “distinct,” a population, or group of populations, must be “discrete” from the remainder of the taxon to which it belongs and “significant” to the taxon to which it belongs as a whole. Discreteness and significance are further defined by the services in the following policy language (USFWS-NMFS 1996):

> Discreteness: A population segment of a vertebrate species may be considered discrete if it satisfies either one of the following conditions:
>
> 1. It is markedly separated from other populations of the same taxon as a consequence of physical, physiological, ecological, or behavioral factors. Quantitative measures of genetic or morphological discontinuity may provide evidence of this separation.
> 2. It is delimited by international governmental boundaries within which differences in control of exploitation, management of habitat, conservation status, or regulatory mechanisms exist that are significant in light of section 4(a)(1)(D) of the [Endangered Species] Act.
>
> Significance: If a population segment is considered discrete under one or more of the above conditions, its biological and ecological significance will then be considered in light of congressional guidance (see Senate Report 151, 96th Congress, 1st Session) that the authority to list DPSs be used “sparingly” while encouraging the conservation of genetic diversity. In carrying out this examination, the services will consider available scientific evidence of the discrete population segment’s importance to the taxon to which it belongs. This consideration may include, but is not limited to, the following:
>
> 1. Persistence of the discrete population segment in an ecological setting unusual or unique for the taxon,
> 2. Evidence that loss of the discrete population segment would result in a significant gap in the range of a taxon,
> 3. Evidence that the discrete population segment represents the only surviving natural occurrence of a taxon that may be more abundant elsewhere as an introduced population outside its historic range, or
> 4. Evidence that the discrete population segment differs markedly from other populations of the species in its genetic characteristics.

The joint policy states that international boundaries within the geographical range of the species may be used to delimit a distinct population segment in the United States. This criterion is applicable if differences in the control of exploitation of the species, the management of the species' habitat, the conservation status of the species, or regulatory mechanisms differ between countries that would influence the conservation status of the population segment in the United States. However, in past assessments of DPSs in marine fish, NMFS has placed the emphasis on biological information in defining DPSs and has considered political boundaries only at the implementation of ESA listings. Therefore, the BRT focused only on biological information in identifying DPSs of the petitioned rockfish species.

Approaches to Addressing Discreteness and Significance

The BRT considered several kinds of information to delineate DPS structure in Puget Sound rockfish. The first kind of information considered was geographical variability in life history characteristics and morphology. Such traits often have an underlying genetic basis, but are also often strongly influenced by environmental factors that vary from one locality to another. An understanding of the biology of the species, however, including habitat preferences, movements, distribution, and demographics, is also important for placing other information, such as patterns of genetic variation or potential environmental isolating mechanisms, into the correct context. The second kind of information dealt with ecological features of the oceanic and terrestrial environment. Information related to this category included patterns of marine species' distribution (zoogeography) that may indicate changes in the physical environment that are shared with the species under review. The third kind of information consisted of traits that are inherited in a predictable way and remain unchanged throughout the life of an individual. Differences among populations in the frequencies of markers at these traits may reflect isolation between the populations. The analyses of these kinds of information are discussed briefly in the following subsections.

Life History and Morphology

Isolation between populations may be reflected in several variables, including differences in life history variables (e.g., spawning timing, seasonal migrations), spawning location, parasite incidence, growth rates, morphological variability (e.g., morphometric and meristic traits), and demography (e.g., fecundity, age structure, length and age at maturity, mortality), among others. Although some of these traits may have a genetic basis, they usually are also strongly influenced by environmental factors over the lifetime of an individual or over a few generations. Differences can arise among populations in response to environmental variability among areas and can sometimes be used to infer the degree of independence among populations or subpopulations. Begg et al. (1999) emphasize the necessity to examine the temporal stability of life history characteristics in order to determine whether differences between populations persist across generations.

General Rockfish Life History

Rockfish are gonochores (two distinct sexes), and there is no evidence of sequential or simultaneous hermaphroditism. All rockfish have internal fertilization and bear live young (Wourms 1991, Love et al. 2002). After parturition, larvae are pelagic for several months prior to settling to demersal habitat. At release, larvae are often well developed with functional organs and the capacity to swim and regulate buoyancy. This live-bearing life history is in contrast to the majority of bony fishes in which fertilization and development occur externally.

The exact nature of their embryonic development is not clear. Rockfish have been thought of as lecithotrophically viviparous (ovoviviparous), deriving all of their energy for embryonic development from the egg yolk (Love et al. 2002). However, evidence from the study of developmental energetics suggests that at least some species are matrotrophically viviparous (viviparous), and embryos derive additional energy directly from the mother. This maternal energy appears to come from dead embryos and unfertilized eggs that are resorbed into the ovarian fluid and transferred to the viable embryos (Wourms 1991).

Rockfish are iteroparous and typically long-lived (Love et al. 2002). As such they are examples of populations that may persist through what has been termed “the storage hypothesis” (Warner and Chesson 1985, Tolimieri and Levin 2005). Recruitment is generally poor because larval survival and settlement are dependent upon the vagaries of climate, abundance of predators, oceanic currents, and chance events. Being long-lived allows the adult population to persist through many years of poor reproduction until a good recruitment year occurs.

Bocaccio General Biology

Geographical distribution and habitat

Bocaccio are found from Stepovac Bay on the Alaska Peninsula to Punta Blanca in central Baja California. They are most common from Oregon to California and were once common on steep walls in Puget Sound (Love et al. 2002). Genetic analyses suggest that there may be three general population regions of bocaccio along the west coast: a Queen Charlotte Island population, one from Vancouver Island to Point Conception, and a third south of Point Conception (Matala et al. 2004).

Larvae and pelagic juveniles tend to be found close to the surface, occasionally associated with drifting kelp mats (Love et al. 2002). They have been found as far as 480 km offshore. Juveniles settle to shallow, algae covered rocky areas or to eelgrass (*Zostera marina*) and sand (Love et al. 1991). Several weeks after settlement, fish move to deeper waters in the 18–30 m range where they are found on rocky reefs (Feder et al. 1974, Carr 1983, Johnson 2006, Love and Yoklavich 2008). Adults inhabit waters from 12 to 478 m but are most common at depths of 50–250 m (Feder et al. 1974, Love et al. 2002). Adults are also commonly found on oil platforms in central and southern California (Love et al. 2005, Love and York 2005, Love et al. 2006), and occur in deeper waters to the south than in the north (Love et al. 2002). While generally associated with hard substrata, adults do wander onto mud flats. They are also typically found well off the bottom (as much as 30 m) (Love et al. 2002).

Reproduction

In northern and central Californian waters, age at first maturity is 3 years for males and females, although males (32 cm) are somewhat smaller than females (36 cm). Fifty percent of males are mature by age 3 (42 cm), and all are mature by 7 years (55 cm). Fifty percent of females are mature by their fourth year (48 cm), and all are mature by age 8 (60 cm) (Wyllie-Echeverria 1987). Off southern California, 50% of males are mature at 35 cm and all are reproductive at 42 cm. Fifty percent of females are mature at 36 cm and all are reproductive at 44 cm. Off Oregon, bocaccio mature at larger sizes with females beginning to mature at 54 cm and all are mature by 61 cm (Love et al. 2002). There is some evidence that fish may have begun to mature at earlier ages as population size had declined dramatically (MacCall 2002).

Bocaccio are fecund with females producing between 20,000 and 2,298,000 eggs annually (Love et al. 2002). Copulation and fertilization occurs in the fall generally between August and November (Love et al. 2002). Females release larvae between November and May off northern and central California with a peak in February. In Southern California, parturition occurs between October and March but peaks in January. Off Washington and Oregon, larval release begins in January and runs through April and February, respectively (Lyubimova 1965, Moser 1967, Westrheim 1975, Wyllie-Echeverria 1987, Love et al. 2002).

Growth and development

Larvae are 4.0–5.0 mm long at release. They transform into pelagic juveniles at 1.5–3.0 cm (Moser 1967, Matarese et al. 1989, Love et al. 2002). Most bocaccio remain pelagic for 3.5 months before settling to shallow areas, although some may remain pelagic as long as 5.5 months. Juveniles are typically 3.0–4.0 cm in length at settlement, although in central California larvae may settle as small as 1.9 cm. Pelagic juveniles grow quickly at 0.56–0.97 mm day (Love et al. 2002). Females grow more quickly and attain larger sizes than do males (MacCall 2003). Maximum size is 91 cm and 6.8 kg (Love et al. 2002). Maximum age is estimated at 54 years (Ralston and Ianelli 1998).

Migrations and movements

Juvenile bocaccio move to deeper water as they age. Tagging studies have recaptured juveniles between 0.9 and 148 km from their tagging location after 2 years (Hartmann 1987). In the same study, adults were recaptured at their tagging location as much as 827 days later. Acoustic tagging work has shown more complex behavior at more local scales. Approximately one-half of adult bocaccio stayed within areas around 200–400 ha the majority of time, although they made frequent small movements out of these home ranges, with some fish utilizing the entire 12 km^2 study area as well as disappearing from the acoustic array for periods of time before returning. Some individuals remained at fairly constant depths while other changed depth by as much as 100 m, generally moving to more shallow depths during the day (Starr et al. 2002).

Trophic interactions

Bocaccio larvae are planktivores, feeding on larval krill, diatoms, and dinoflagellates. Pelagic juveniles are opportunistic feeders taking fish larvae, copepods, krill, and other prey. Larger juveniles and adults are primarily piscivores eating other rockfishes, hake (*Merluccius productus*), sablefish (*Anoplopoma fimbria*), anchovies (*Engraulis mordax*), lanternfishes, and squid (Love et al. 2002). Chinook salmon (*Oncorhynchus tshawytscha*), terns, and harbor seals (*Phoca vitulina*) are known predators on smaller bocaccio (Love et al. 2002).

Fishery

Historically bocaccio were heavily targeted in recreational and commercial fisheries from the Canadian border south into Mexico. Catches of bocaccio are attributed to set nets, trawls, and hook-and-line gear. The largest captures are mainly south of Cape Mendocino into the southern California Bight. Bocaccio populations are highly dynamic and the fishery is often reliant on one large cohort to maintain catches over several years. Since the 1980s, bocaccio populations have declined precipitously and are currently declared overfished off California (MacCall 2007), though a population increase has been detected due mostly to a very strong recruitment event in 1999.

Canary Rockfish General Biology

Geographical distribution and habitat use

Canary rockfish are found from the western Gulf of Alaska to northern Baja California, but are most abundant from British Columbia to central California (Miller and Lea 1972, Hart 1973, Cailliet et al. 2000, Love et al. 2002). In Canadian waters (British Columbia), canary rockfish are managed as two stocks: one on the west coast of Vancouver Island and a Queen Charlotte Sound stock (COSEWIC in press). Adults are most common from 80 to 200 m but have been found as deep as 439 m (Love et al. 2002). Juveniles are found in intertidal surface waters, and occasionally as deep as 838 m (Love et al. 2002). Larger fish tend to inhabit deeper waters with the mean size increasing in the 55–90 m depth range and remaining stable thereafter (Methot and Stewart 2005). Adults inhabit shallower areas in the north than in the south.

The larvae and pelagic juveniles of canary rockfish are found in the upper 100 m of the water column (Love et al. 2002). Estimates of larval duration range 1–2 months (Moser 1996a) to 3–4 months (Krigsman 2000, Love et al. 2002) after which they settle to tide pools, rocky reefs, kelp beds, low rock, and cobble areas (Miller and Geibel 1973, Love et al. 1991, Cailliet et al. 2000, Love et al. 2002). Juveniles may occur in groups near the rock-sand interface in the 15–20 m depth range during the day, then move into sandy areas at night (Love et al. 2002). Juveniles remain on rocky reefs in shallower areas for as much as 3 years before moving to deeper waters (Boehlert 1980, Methot and Stewart 2005). Fish move deeper as they increase in size (Vetter and Lynn 1997) and adults are found on rocky shelves and pinnacles (Phillips 1960, Rosenthal et al. 1988, Starr 1998, Cailliet et al. 2000, Johnson et al. 2003, Tissot et al. 2007). They are generally seen near but not resting on the bottom. Canary rockfish were once considered fairly common in the greater Puget Sound area (Holmberg et al. 1967).

Reproduction

Off northern and central California, estimates for age at first maturity are 3–4 years (18–28 cm) (Wyllie-Echeverria 1987, Lea et al. 1999) with 50% of males mature by 7 years (40 cm) and all mature by 9 years (45 cm). Females attain first maturity at 4 years (27 cm). Fifty percent of females are mature by 9 years (44 cm) and all attain maturity by 13 years (54 cm) (Wyllie-Echeverria 1987). Off Oregon, the majority of females and males are mature at 7–9 years (35–45 cm) and 7–12 years (41 cm), respectively. In waters off Vancouver Island, 50% of females are mature at 41 cm and males at 48 cm (Westrheim 1975).

Females produce between 260,000 and 1.9 million eggs per year with larger females producing more eggs. On the coast, the relationship between egg production and female size does not seem to vary geographically (Gunderson et al. 1980, Love et al. 2002).

Fertilization occurs as early as September off central California (Lea et al. 1999), peaking in December (Phillips 1960, Phillips 1964, Wyllie-Echeverria 1987). Parturition occurs between January and April and peaks in April (Phillips 1960). Off Oregon and Washington, parturition occurs between September and March with peaks in December and January (Wyllie-Echeverria 1987, Barss 1989). In British Columbia, parturition occurs slightly later with the peak in February (Hart 1973, Westrheim and Harling 1975). Canary rockfish spawn once per year (Guillemot et al. 1985).

Growth and development

Eggs are 0.84–1.45 mm in diameter (Waldron 1968). Larvae measure 3.6–4.0 mm SL at birth (Waldron 1968, Richardson and Laroche 1979, Stahl-Johnson 1985). Estimates of larval duration range 1–2 months (Moser 1996a) to 3–4 months (Krigsman 2000, Love et al. 2002). Juveniles settle at approximately 18.5 mm SL (Richardson and Laroche 1979, Moser 1996b).

Females grow larger and more quickly than do males (Lenarz and Echeverria 1991, STAT 1999), although growth does not appear to vary with latitude (Boehlert and Kappenman 1980). A 58 cm female is approximately 20 years of age; a male of the same age is approximately 53 cm. Maximum age of canary rockfish is at least 84 years although 60–75 years is more common (Cailliet et al. 2000). Maximum reported length is 76 cm (Williams et al. 1999, Love et al. 2002, Methot and Stewart 2005).

Migrations and movements

Canary rockfish tend to move to deeper water as they grow larger (Vetter and Lynn 1997). In terms of alongshore movements, they are transient (DeMott 1983, Casillas et al. 1998) and resident (Gascon and Miller 1981). Demott (1983) tagged 348 fish off Oregon between 1978 and 1982. Of the 23 recaptures, 12 fish moved more than 100 km north or south with one fish moving as much as 236 km. Other tagging studies have shown that some individuals move up to 700 km over several years (Lea et al. 1999, Love et al. 2002). They also appear to make a seasonal migration of 160–210 m in the late winter to 100–170 m in the late summer (COSEWIC in press).

Trophic interactions

Canary rockfish larvae are planktivores and feed primarily on nauplii and other invertebrate eggs and copepods (Moser and Boehlert 1991, Love et al. 2002). Juveniles are zooplanktivores, feeding on crustaceans (e.g., harpacticoids), barnacle cyprids, and euphasiid eggs and larvae. They also consume juvenile polychaetes (Gaines and Roughgarden 1987, Love et al. 1991) and are diurnal feeders (Singer 1982). Predators on juvenile canary rockfish include other fishes, especially rockfishes, lingcod (*Ophiodon elongatus*), cabezon (*Scorpaenichthys marmoratus*), and salmon (*Oncorhynchus* spp.), as well as birds and porpoises (Miller and Geibel 1973, Morejohn et al. 1978, Roberts 1979, Ainley et al. 1981, Love et al. 1991).

Adult canary rockfish are planktivores and carnivores consuming euphasiids and other crustaceans, small fishes such as shortbelly rockfish (*Sebastes jordani*), and myctophids and stomiatiods (Cailliet et al. 2000, Love et al. 2002). Canary rockfish predators include yelloweye rockfish, lingcod, salmon, sharks, dolphins, seals (Merkel 1957, Morejohn et al. 1978, Antonelis and Fiscus 1980, Rosenthal et al. 1982), and possibly river otters (*Lontra canadensis*) (Stevens and Miller 1983).

Canary rockfish are parasitized by the following families: Bothriocephalidae, Phyllobothriidae, Tentaculariidae, Bomolochidae, Caligidae, Chondracanthidae, Lernaeopodidae, Naobranchiidae, Philichthyidae, Bucephalidae, Hemiuridae, Lepcreadiidae, Opecoelidae, Sanguinicolidae, Syncoelidae, Casalidae, Anisakidae, and Caratomyxidae (Liston et al. 1960, Love and Moser 1983).

Fishery

Canary rockfish supported an important commercial fishery off California for more than a century (Love et al. 2002). The commercial trawl is the main fishery, though commercial and recreational hook-and-line fisheries also contribute to removals. Major removals of canary rockfish are accounted for since the mid-1940s and populations have suffered large declines from estimated prefishing levels (Stewart 2007). Though canary rockfish have been declared overfished off the U.S. West Coast, the population has increased since the 1990s.

Yelloweye Rockfish General Biology

Geographical distribution and habitat

Yelloweye rockfish range along the U.S. and Canadian west coast, with individuals recorded from the Aleutian Islands to northern Baja California. The major portion of abundance is found from Alaska to central California; they are rare in Puget Sound (Love et al. 2002). Yelloweye rockfish use a broad depth range throughout their life history, with individuals recorded from 15 to 549 m. Juveniles settle in the shallowest depth of this range and move deeper as they get older. Adults are most commonly found from 91 to 180 m (Love et al. 2002).

Yelloweye rockfish juveniles settle primarily in shallow, high-relief zones, crevices, and sponge gardens (Love et al. 1991, Richards et al. 1985). As they grow and move to deeper waters, adults continue to associate with rocky, high-relief areas (Carlson and Straty 1981, Richards 1986, Love et al. 1991, O'Connell and Carlisle 1993). Submersible dives document the high affiliation yelloweye rockfish adults have to caves and crevices, while spending large amounts of time lying at the base of rocky pinnacles and boulder fields (Richards 1986, Yoklavich et al. 2000). Recent documentation of yelloweye and other rockfish associations with deepwater corals demonstrated an association of some rockfishes to their habitats (Andrews et al. 2002, Krieger and Wing 2002). Yelloweye rockfish are infrequently found in aggregations, but are generally solitary, demersal residents (Coombs 1979, DeMott 1983, Love et al. 2002).

Reproduction

Yelloweye rockfish are internally fertilized and store sperm for several months until fertilization occurs, commonly between September and April, though fertilized individuals may be found in most months of the year, depending on where they are observed (Wyllie-Echeverria 1987). Fertilization periods tend to get later from south to north in their range (Hitz 1962, DeLacy et al. 1964, Westrheim 1975, O'Connell 1987, Lea et al. 1999). Larvae are extruded after a typical gestation period of several months, peaking from April to August for California (Eigenmann 1891) and extending to later months in Alaska (O'Connell 1987). In Puget Sound, yelloweye rockfish are believed to fertilize eggs during the winter to summer months, giving birth in early spring to late summer (Washington et al. 1978).

Though yelloweye rockfish are generally thought to spawn once a year (MacGregor 1970), a study in Puget Sound offered evidence of at least two spawning periods per year (Washington et al. 1978). Larvae are extruded at about 4 to 5 mm (DeLacy et al. 1964, Matarese et al. 1989) and remain pelagic for up to 2 months (Moser 1996b), settling at around 25 mm (Love et al. 2002). Female yelloweye rockfish can produce from 1.2 million to 2.7 million eggs over a reproductive season, with a mean eggs per gram of body weight of 300 (MacGregor 1970, Hart 1973). Reports on maturity for yelloweye rockfish vary among areas and are ambiguous, given the use of whole otoliths for ageing in some studies, but generally seem to reach 50% maturity at around 40 to 50 cm and ages of 15 to 20 years (Rosenthal et al. 1982, Wyllie-Echeverria 1987, Yamanaka and Kronlund 1997).

Growth and development

Yelloweye rockfish have the potential to grow large during their long life spans. Mean asymptotic size in Alaska is documented at 69 cm for males and females (Rosenthal et al. 1982). A study in British Columbia (Westrheim and Harling 1975) estimated this parameter at 67.6 and 65.9 cm for males and females, respectively (Yamanaka et al. 2006). A study in California also noted males obtaining a mean size greater than females (Lea et al. 1999). Maximum size is reported as 91 cm (Love et al. 2005) and maximum age as 118 years (Munk 2001). Natural mortality rates are estimated at 0.02 to 0.046 (Yamanaka and Kronlund 1997, Wallace 2007).

Migrations and movements

An inshore to offshore ontogenetic movement of yelloweye rockfish is documented, with juveniles moving from shallow rock reefs to deeper pinnacles and rocky habitats. Yelloweye rockfish adults do not move much and are generally considered to be site-attached (Love 1978, Coombs 1979, DeMott 1983).

Trophic interactions

Yelloweye rockfish are opportunistic feeders, targeting different food sources during different phases of their life history. Early life stages follow typical rockfish predator-prey relationships. Because adult yelloweye rockfish obtain such large size, they can handle much larger prey, including smaller yelloweye, and are preyed upon less frequently (Rosenthal et al. 1982), though predation by killer whales (*Orcinus orca*) has been reported (Ford et al. 1998). Typical prey of adult yelloweye rockfish include sand lance (*Ammodytes* spp.), gadids, flatfishes, shrimp, crabs, and gastropods (Love et al. 2002, Yamanaka et al. 2006).

Fishery

Yelloweye rockfish are a prized catch of recreational hook-and-line fishers. They are also an important component of groundfish trawl and hook-and-line fisheries and are a major species taken in the Pacific halibut sport fishery. Yelloweye rockfish numbers in the southern coastal portion of the range (south of the U.S.-British Columbia boarder) have decreased substantially over the past 40 years and the species is currently considered overfished (Wallace 2007). A yelloweye rockfish conservation area was established in 1998 off the Washington coast. This area was closed to the Pacific halibut sport fishery in the same year, and in 2003 this closure was extended to the groundfish fishery.

Greenstriped Rockfish General Biology

Geographical distribution and habitat

Greenstriped rockfish are a typically wide-ranging North Pacific rockfish, with individuals recorded from the Aleutian Islands to central Baja California (Shaw 1999). They are most abundant from British Columbia south to northern Baja California (Love et al. 2002). Greenstriped rockfish are also found in South Puget Sound (SPS) (Palsson et al. 2009). Greenstriped rockfish span a broad depth range, with individuals recorded from 12 to 495 m. Juveniles are often found in shallower depths, making an ontogenetic shift to deeper waters. Adults are most commonly found between 150 and 200 m (Shaw and Gunderson 2006).

Though rockfish are often associated with hard substrate, greenstriped rockfish are unusual in that they are most commonly found on soft sediments and mud-sand-silt-cobble interfaces. Juveniles settle to the bottom of sand-cobble substrates and, as they move deeper, reside mainly on mud or rock rubble. Individuals are less frequently encountered among hard, high-relief substrate (Love et al. 1991). Greenstriped rockfish are mostly a solitary species, lying on the seafloor bottom, but may occur in large numbers.

Reproduction

Greenstriped rockfish are internally fertilized and store sperm for several months until fertilization occurs, commonly between February and May in areas north of California (O’Connell 1987). Fertilized individuals are found earlier in more southerly areas (Lea et al. 1999). Larvae are extruded after a typical gestation period of several months, peaking in June for areas from Alaska to Oregon (O’Connell 1987, Shaw 1999) and from March to June in California (Reilly et al. 1994). Greenstriped rockfish are generally believed to spawn once a year (Shaw and Gunderson 2006), but evidence of multiple spawning has been reported (Love et al. 1990). Larvae are extruded at about 5 mm (Matarese et al. 1989) and remain pelagic for up to 2 months (Moser 1996), settling at around 30 mm (Johnson 1997). Individual greenstriped rockfish of both sexes start to mature at 15 cm and 5 years of age, with 50% mature at 23 cm and 7–10 years (Wyllie-Echeverria 1987, Shaw and Gunderson 2006). Females annually produce 11,000 to 300,000 eggs.

Growth and development

Growth of greenstriped rockfish has been documented from California to British Columbia, with individuals reaching a mean asymptote of 37.5 cm in British Columbia (Westrheim and Harling 1975) and 30.0 and 37.5 cm for males and females, respectively, from California to Washington (Shaw and Gunderson 2006). Maximum sizes obtained are 43 cm (Shaw and Gunderson 2006). Growth rates for newly settled fish were measured to 0.17mm/day and overall growth rates (von Bertalanffy *k* parameter) range from 0.08 to 0.12. Maximum age reported is 54 years.[2] Natural mortality rates are estimated between 0.092 and 0.149.

Migrations and movements

No tagging studies exist for the greenstriped rockfish, so movement and migrations within stage classes are not understood. An inshore to offshore ontogenetic movement is documented, with juveniles moving from fine sand and pebbles out to mud, cobble, and rubble habitats. Greenstriped rockfish adults are generally considered to be site-attached.

Trophic interactions

Greenstriped rockfish are active and opportunistic feeders, targeting different food sources at during different phases of their life history. Larvae are diurnal, with nauplii, eggs, and copepods representing important food sources (Sumida et al. 1985, Moser and Boehlert 1991). Siphonophores and chaetognaths commonly prey on greenstriped larvae (Yoklavich et al. 1996). Juveniles are diurnal zooplanktivores and feed mainly on calanoid copepods and barnacle cyprids (Allen 1982, Gaines and Roughgarden 1987, Love et al. 1991). Juvenile greenstriped rockfish are preyed upon by birds, nearshore fishes, salmon, and porpoises (Morejohn et al. 1978, Love et al. 1991, Ainley et al. 1993). Adults may also include nocturnal feeding behavior, consuming bigger crustaceans, fish, and cephalopods (Allen 1982). Greenstriped rockfish adults have been recovered in the stomachs of sharks, porpoise, salmon, seals, and possibly river otters (Merkel 1957, Morejohn et al. 1978, Antonelis and Fiscus 1980).

Fishery

Greenstriped rockfish comprise a common component of the west coast groundfish trawl fishery, though they are often discarded due to their small size (Love et al. 2002). They are more commonly retained in British Columbia where they obtain larger sizes (Love et al. 2002). They are also frequently taken, but not targeted, in recreational fisheries and often discarded.

Redstripe Rockfish General Biology

Geographical distribution and habitat

Redstripe rockfish are wide ranging from the Aleutian Islands to southern Baja California (Love et al. 2002), including Puget Sound. Their abundance is highest from southeast Alaska to central Oregon (Love et al. 2002). The depth range of redstripe rockfish is likewise wide, with individuals recorded from 12 to 425 m.

---

[2] K. Munk, Alaska Dept. Fish and Game, Juneau, AK. Pers. commun., July 2008.

Juveniles settle in shallower depths and move to deeper habitat as adults. Adult redstripe rockfish are most commonly found between 150 and 275 m on a variety of substrates, from hard, high-relief reefs to sand-cobble interfaces. Juveniles settle to the bottom of sand-cobble substrates (Moser and Boehlert 1991) and move as adults onto deeper rocky reefs and low-relief rubble bottoms. Redstripe rockfish can be found alone or in aggregations, usually near the seafloor bottom (Love et al. 2002).

Reproduction

Redstripe rockfish are internally fertilized and store sperm for several months until fertilization. Fertilization occurs between April and May in areas north of California (O'Connell 1987, Wyllie-Echeverria 1987, Shaw 1999). Larvae are extruded after a typical gestation period of several months, peaking in July for British Columbia (Westrheim 1975) and June in Oregon (Wyllie-Echeverria 1987, Shaw 1999). Redstripe rockfish spawn once a year (Shaw 1999). Larvae are extruded at about 5.4 mm (Matarese et al. 1989) and remain pelagic for up to 2 months (Moser 1996). Settling size is unrecorded. Recorded size at first maturity is 21 to 22 cm (Shaw 1999). Size at 50% maturity was recorded in the 1970s as 28 and 29 cm (Westrheim 1975) for males and females, respectively, differing for samples collected in the 1990s (24.3 and 26.2 cm for males and females [about 7 years old], respectively, Shaw 1999). Whether this represents changes in size at maturity over time or differential representation of individuals that geographically mature larger is not known. No information is available on individual fecundity.

Growth and development

Growth of redstripe rockfish has been documented from California to British Columbia, with males and females showing sex-specific growth curves. Females are bigger and grow slower, reaching a mean asymptote of 41 to 42 cm in British Columbia, while males reach mean asymptotic at 33 to 34 cm (Westrheim and Harling 1975). Individual redstripe rockfish taken from California to Washington were estimated to reach a mean asymptotic size of 29.5 to 38.3 cm for males and females, respectively (Shaw 1999). Maximum sizes obtained are 51 cm (Shaw 1999). Maximum age has been reported at 40 years.[3] Natural mortality rates are estimated between 0.01 (for males) and 0.17 (for females).

Migrations and movements

No tagging studies exist for the redstripe rockfish, so movement and migrations within stage classes are not understood. An inshore to offshore ontogenetic movement is documented, with juveniles moving from fine sand and pebbles out to deeper cobble and rocky habitats. Adults are generally considered to be site-attached.

Trophic interactions

Redstripe rockfish are active and opportunistic feeders, and show feeding habits similar to greenstriped rockfish. Larvae are diurnal, with nauplii, eggs, and copepods representing important food sources (Sumida et al. 1985, Moser and Boehlert 1991). Siphonophores and chaetognaths commonly prey on redstripe rockfish larvae (Yoklavich et al. 1996). Juveniles are

---

[3] T. Laidig, Southwest Fisheries Science Center, Santa Cruz, CA 95060. Pers. commun., July 2008.

diurnal zooplanktivores and feed mainly on calanoid copepods and barnacle cyprids (Allen 1982, Gaines and Roughgarden 1987, Love et al. 1991). Juvenile greenstriped are preyed upon by birds, nearshore fishes, salmon, and porpoises (Morejohn et al. 1978, Love et al. 1991, Ainley et al. 1993). Adults may also include nocturnal feeding behavior, consuming bigger crustaceans, fish, and cephalopods (Allen 1982). Adult greenstriped rockfish have been recovered in the stomachs of sharks, porpoises, salmon, seals, and possibly river otters (Merkel 1957, Morejohn et al. 1978, Antonelis and Fiscus 1980).

Fishery

Redstripe rockfish are commonly taken in the west coast groundfish trawl fishery from Oregon to British Columbia and were targeted as food as early as the 1880s off Alaska (Love et al. 2002).

Ecological Features and DPS Discreteness

Many marine species are characterized by extended pelagic periods of early life history stages that are believed sufficient to connect populations at long distances (Palumbi 1994, Waples 1998). In the case of rockfishes, the larval and pelagic juvenile phases can last several months (Matarese et al. 1989). Given the large geographic ranges of most rockfishes and lack of migration and movement in the adult phase, these pelagic phases were often considered the bridge connecting populations along the coast. Despite this potential for connectivity, recent work describing *Sebastes* as a rapidly evolving “species flock” (Johns and Avise 1998, Burford and Bernardi 2008) and evidence of intrapopulation structure (Cope 2002, Miller and Shanks 2004) reveal many mechanisms by which rockfish populations are structured and, in some cases, function in relative isolation.

Oceanographic mechanisms (combining the effects of hydrographic forces and geographic features) received the greatest amount of attention from the BRT when explaining potential sources of population structure. Onshore current, eddies, upwelling shadows, and various localized circulation events create conditions that retain larvae rather than distribute them (Owen 1980, Graham et al. 1992, Wing et al. 1998). Larger barriers to dispersal have also been identified in many rockfishes (Williams and Ralston 2002, Cope 2004, Matala et al. 2004), potentially dividing the coast into broader segments of population interactions. Additional, behavioral modifications by juvenile rockfishes also promote local retention (Larson et al. 1994). Adult behavior often maintains the structure produced from the early life history via high site fidelity and low movement rates. Assortative mating and territoriality can also increase the amount of structure among populations (Narum et al. 2004, Hyde et al. 2008).

Puget Sound is a unique area that promotes a greater amount of local retention for rockfish larvae than is found along the coast. For example, studies looking at connectivity between populations of copper rockfish (*Sebastes caurinus*) found strong separation between coastal and inland populations (Buonaccorsi et al. 2002). This separation may be maintained through a very low exchange of water (Ebbesmeyer et al. 1984), thus promoting the isolation of Puget Sound populations from coastal conspecifics.

Analysis of ecological features or habitat characteristics may indicate that a population segment occupies an unusual or distinctive habitat, relative to the biological species as a whole. One criterion that may be useful for evaluating discreteness as articulated in the joint DPS policy (USFWS-NMFS 1996) relates to the population being "markedly separated from other populations of the same taxon as a consequence of … ecological … factors." In addition, the persistence of a discrete population segment in an ecological setting unusual or unique for the taxon is also a factor identified in the joint DPS policy that may provide evidence of the population's significance. Oceanographic and other ecological features may also contribute to isolation between marine populations.

Marine Zoogeography

Marine zoogeography attempts to identify regional geographic patterns in marine species distribution and delineate faunal provinces or regions based largely on the occurrence of endemic species and unique species assemblages (Ekman 1953, Hedgpeth 1957, Briggs 1974, Allen and Smith 1988). These province boundaries usually coincide with changes in the physical environment such as temperature and major oceanographic currents. Similar to the above ecological features category, boundaries between zoogeographic provinces may indicate changes in the physical environment that are shared with the species under review.

Marine Zoogeographic Provinces Relevant to Puget Sound Rockfish DPS Determinations

Ekman (1953), Hedgpeth (1957), and Briggs (1974) summarized the distribution patterns of coastal marine fishes and invertebrates and defined major worldwide marine zoogeographic zones or provinces. Numerous schemes have been proposed for grouping the faunas into zones or provinces along the coastline of the boreal eastern Pacific, which extends roughly from the eastern Bering Sea to Point Conception, California. A number of authors (Ekman 1953, Hedgpeth 1957, Briggs 1974, Allen and Smith 1988) have recognized a zoogeographic zone within the lower boreal eastern Pacific that has been termed the Oregonian Province. Another zone in the upper boreal eastern Pacific has been termed the Aleutian Province (Briggs 1974). However, exact boundaries of zoogeographic provinces in the eastern boreal Pacific are in dispute (Allen and Smith 1988). Briggs (1974) and Allen and Smith (1988) reviewed previous literature from a variety of taxa and fishes, respectively, and found the coastal region from Puget Sound to Sitka, Alaska, to be a "gray zone" or transition area that could be classified as part of either province: Aleutian or Oregonian (Figure 1 through Figure 3). The southern boundary of the Oregonian Province is generally recognized as Point Conception, and the northern boundary of the Aleutian Province is similarly recognized as Nunivak Island in the Bering Sea or perhaps the Aleutian Islands (Allen and Smith 1988).

Briggs (1974) placed the boundary between the Oregonian and Aleutian provinces at Dixon Entrance, based on the well-studied distribution of mollusks, but indicated that distributions of fishes, echinoderms, and marine algae gave evidence for placement of this boundary in the vicinity of Sitka. Briggs (1974) placed strong emphasis on the distribution of littoral mollusks (due to the more thorough treatment received by this group) in placing a major faunal break at Dixon Entrance. The authoritative work by Valentine (1966) on distribution of marine mollusks of the northeastern Pacific shelf showed that the Oregonian molluscan assemblage extended to Dixon Entrance with the Aleutian fauna extending northward from that

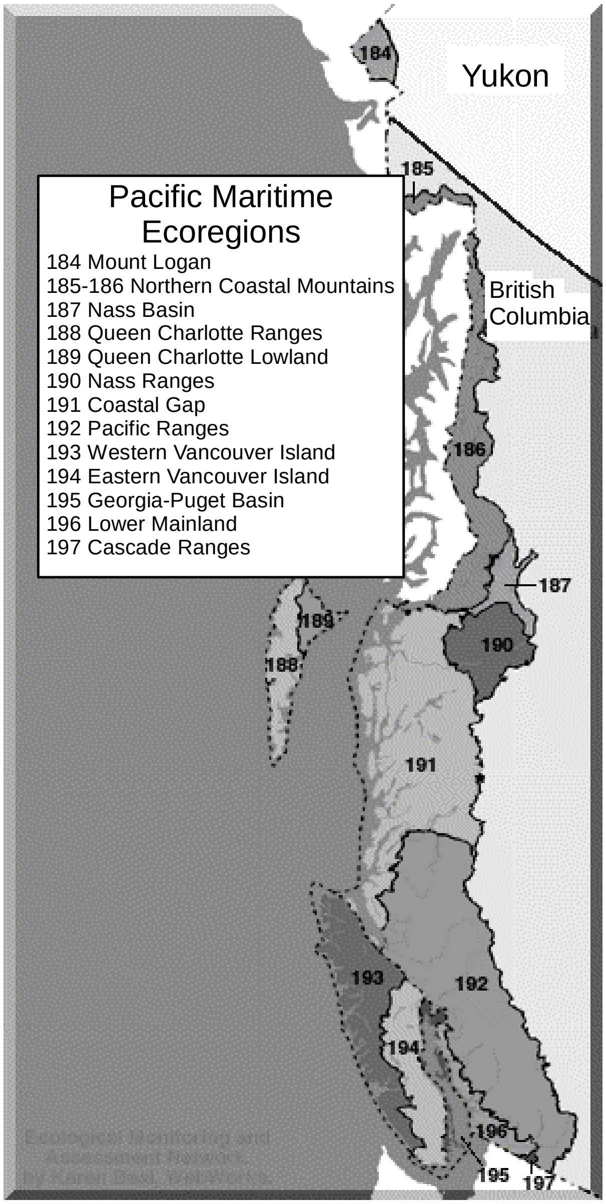


Figure 1. Ecoregions in the Pacific Maritime Ecozone of British Columbia. (Map modified from online source: http://ecozones.ca/english/zone/PacificMaritime/ecoregions.html.)

area. Valentine (1966) created the term Columbian Subprovince to define the zone from Puget Sound to Dixon Entrance.

Several lines of evidence suggest that an important zoogeographic break for marine fishes occurs in the vicinity of Southeast Alaska. Peden and Wilson (1976) investigated the distributions of inshore fishes in British Columbia and found Dixon Entrance to be of minor importance as a barrier to fish distribution. A more likely boundary between these fish faunas was variously suggested to occur near Sitka, off northern Vancouver Island, or off Cape Flattery, Washington (Peden and Wilson 1976, Allen and Smith 1988). Chen (1971) found that of the

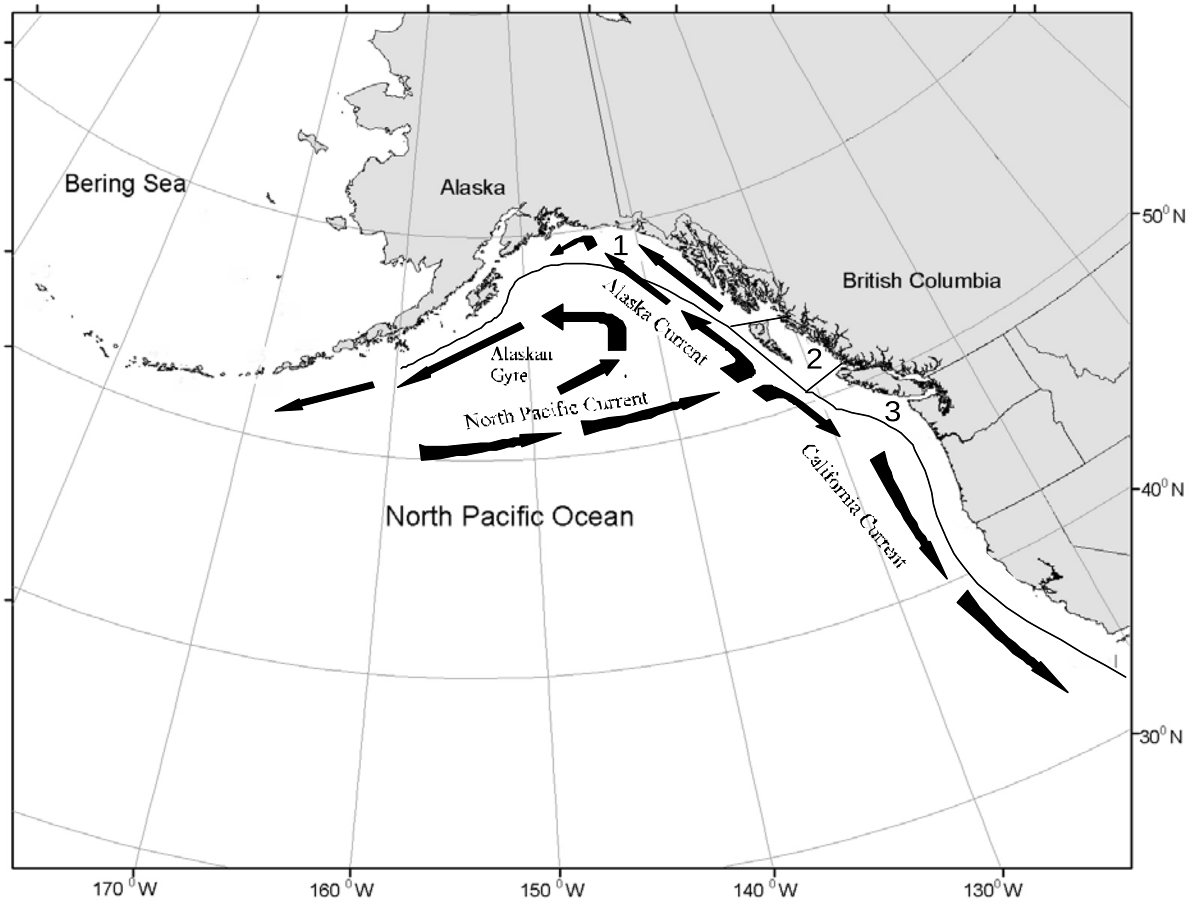


Figure 2. Approximate locations of oceanographic currents, oceanic domains (Ware and McFarlane 1989), and coastal provinces (Longhurst 2006) in the Northeast Pacific Ocean. 1–Alaska Coastal Downwelling Province, 2–Transition Zone, and 3–California Current Province.

more than 50 or more rockfish species belonging to the genus *Sebastes* that occur in northern California, more than two-thirds do not extend north of British Columbia or Southeast Alaska. Briggs (1974, p. 278) stated that "about 50 percent of the entire shore fish fauna of western Canada does not extend north of the Alaskan Panhandle." In addition, many marine fish species common to the Bering Sea extend southward into the Gulf of Alaska but apparently occur no further south (Briggs 1974). Allen and Smith (1988, p. 144) noted that "the relative abundance of some geographically displacing [marine fish] species suggest that the boundary between these provinces [Aleutian and Oregonian] occurs off northern Vancouver Island."

Blaylock (et al. 1998) examined the distribution of more than 25 species of parasites in 432 juvenile and adult Pacific halibut (*Hippoglossus stenolepis*) sampled over much of its North American range and found evidence of three zoogeographic zones as determined by parasite clustering: northern, central, and southern. Similar to studies with other invertebrates, Blaylock et al. (1998, p. 2,269) found a breakpoint between zoogeographic zones "in the vicinity of the Queen Charlotte Islands."

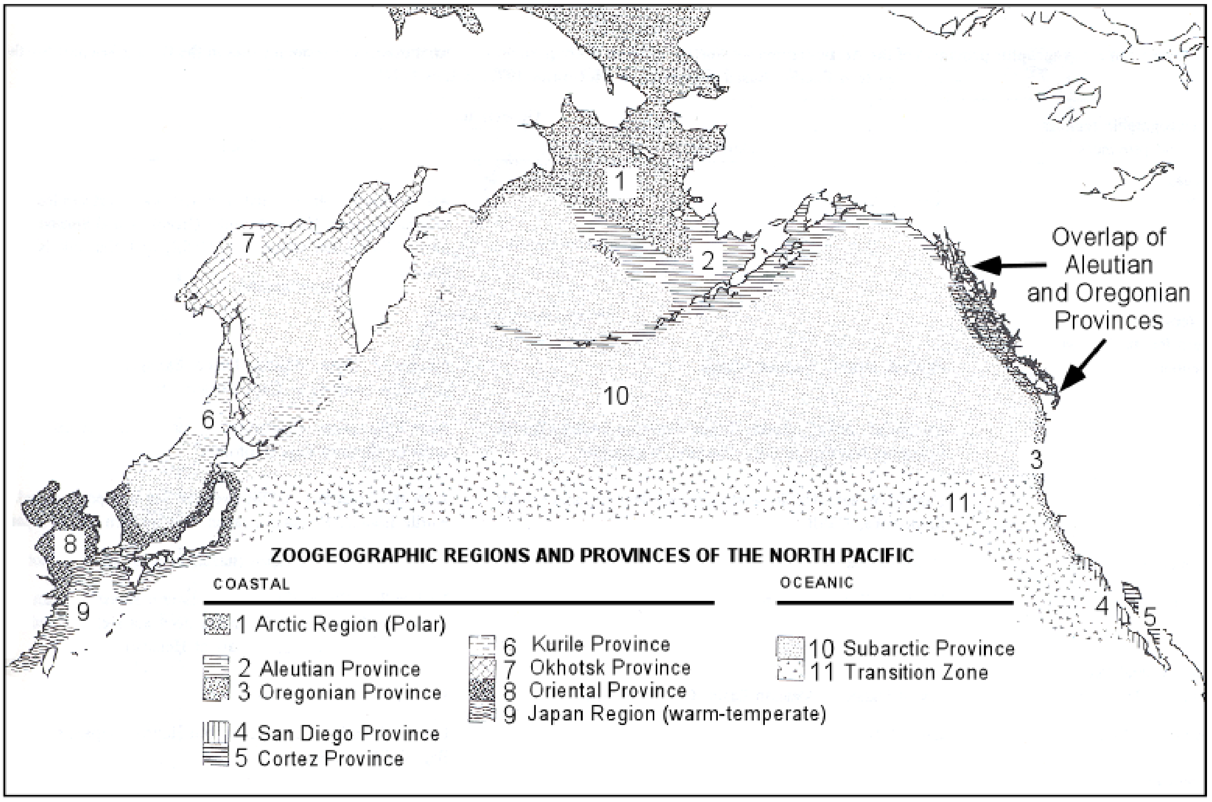


Figure 3. Marine zoogeographic provinces of the North Pacific Ocean. (Map modified from Allen and Smith 1988.)

Environmental History and Features of Greater Puget Sound Relevant to DPS Determinations for Puget Sound Rockfish

This subsection describes the physical, oceanographic, and climatic features in greater Puget Sound that may contribute to isolation among populations of the five rockfish species considered in this status review. This subsection, along with Appendix C and Appendix D, provides a basis for identifying climatic and biological factors that may contribute to extinction risk for these species. The following summary focuses primarily on the marine waters of greater Puget Sound that lie south of the boundary between Canada and the United States. However, because the five species are also found throughout the extensive inland waterway that also encompasses the Strait of Georgia in Canada, we present a brief description of this larger system.

Greater Puget Sound is a fjord-like estuary located in northwest Washington State that covers an area of approximately 2,330 km^2, including 4,000 km of shoreline. Puget Sound is part of a larger inland system situated between southern Vancouver Island and the mainland coasts of Washington State and British Columbia that encompasses the straits of Georgia and Juan de Fuca (Burns 1985). This extensive system (the Georgia-Fuca system) is a series of interconnected basins separated by shallow sills. These sills define the geometry of the basins and play a pivotal role in basin dynamics through lateral water exchange (Thomson 1994). Puget Sound is directly linked to the Pacific Ocean through the Strait of Juan de Fuca, whereas to the north, a narrow more circuitous connection exits through the constricted channels of Johnstone and Queen Charlotte straits.

The estuarine component of circulation is a dominant feature throughout the system, with net seaward outflow in the upper portion of the water column driven by winter rainfall and summer snowmelt, and net landward inflow of high salinity ocean water in the lower portion of the water column (Thomson 1994, Masson 2002). Other fundamental mechanisms that affect flow include tidal forcing, wind forcing generated by atmospheric gradients (Matsuura and Cannon 1997), and coastal ocean forcing propagated by oceanic events originating over the continental margin (Cannon 1990).

In this document, we delimit greater Puget Sound as the lands from the crests of the Cascade and Olympic mountains to the shores of marine waters extending from the entrance to the Strait of Juan de Fuca east, including the San Juan Islands, and south to Olympia. As with the more extensive Georgia-Fuca system, Puget Sound's geometry and circulation is shaped and defined by shallow sills, including those at Admiralty Inlet (65 m depth), near Tacoma Narrows (45 m depth), and the mouth of Hood Canal (Burns 1985, Babson et al. 2006, Yang and Khangaonkar 2008). Based primarily on these features, which affect geomorphology, extent of freshwater influence and residence times, and oceanographic conditions, greater Puget Sound is often subdivided into five major basins or regions: 1) North Puget Sound (NPS), 2) Main Basin, 3) Whidbey Basin, 4) South Puget Sound (SPS), and 5) Hood Canal (Figure 4). When considered DPS designations for the petitioned species, the Main Basin, Whidbey Basin, SPS, and Hood Canal are collectively referred to as Puget Sound Proper (PSP). Each of these basins differs in features such as temperature regimes, water residence and circulation, biological conditions, depth profiles and contours, processes, species, and habitats, described in more detail below.

On average, Puget Sound south of Admiralty Inlet has a depth of 62.5 m at low tide, but ranges to nearly 300 m at its deepest. Estuarine circulation in greater Puget Sound is driven by tidal currents, the surface outflow of freshwater from Puget Sound rivers and deep inflow of saltwater from the ocean, and wind strength and direction (Ruckelshaus and McClure 2007). Tidal currents dominate the circulation, and typically a two-layered pattern of estuarine circulation is superimposed on the tides (Ebbesmeyer and Barnes 1980). 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. The movement of water due to tides is about 5–10 times larger than the actual estuarine circulation observed throughout the sound. As tidal currents flow past points of land, the water forms eddies in the lee of the points. These tidal eddies provide a transport mechanism for offshore water to reach the shoreline, bringing nutrients and plankton to nearshore communities. Tidal currents in the Main Basin of Puget Sound, a region with depths of 200 m or more, typically are less than 0.25 meter per second. In contrast, tidal currents in shallow sills at Admiralty Inlet and Tacoma Narrows can be as large as 2.2 and 3.3 m/s, respectively.

Shallow sills within Puget Sound substantially reduce the flushing rate of freshwater, sediments, nutrients, contaminants, and many organisms. Concentrations of nutrients (i.e., nitrates and phosphates) are consistently high throughout most of greater Puget Sound, largely due to the flux of oceanic water into the basin (Harrison et al. 1994).

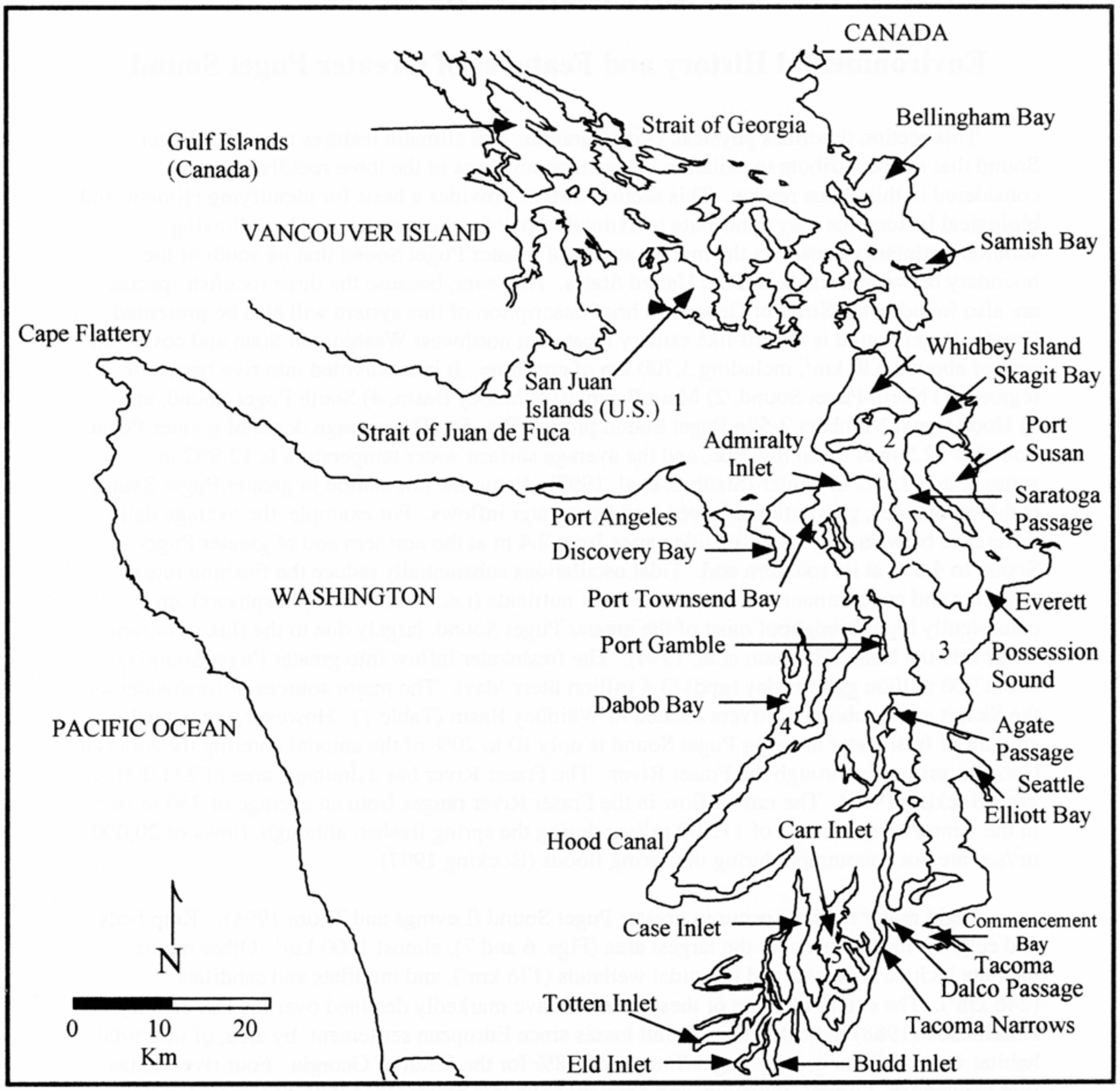


Figure 4. Regional water masses and subareas of greater Puget Sound. 1–NPS, 2–Whidbey Basin, 3–Main Basin, 4–Hood Canal, and (centered on Carr Inlet) 5–SPS. (Reprinted from Stout et al. 2001a.)

Coastal areas within Puget Sound generally are characterized by high levels of rainfall and river discharge in the winter, while inland mountains are characterized by heavy snowfall in the winter and high snowmelt in late spring and early summer. This local weather pattern creates two major periods of freshwater runoff into Puget Sound, with maxima in December and June. Freshwater inflow into the lower basins of Puget Sound is about 3.4 trillion liters per day. The major sources of freshwater are the Skagit and Snohomish rivers, located in the Whidbey Basin (Figure 4). However, the annual amount of freshwater entering Puget Sound is only 10 to 20% of the amount entering the Strait of Georgia, primarily through the Fraser River (Gustafson et al.

2000). Water circulation, transport, and residence times within each basin are predicted to vary as much between years as between seasons, primarily due to the high degree of variability in river discharge (Babson et al. 2006).

Puget Sound has more than 4,000 km of shoreline, ranging from rocky sea cliffs to coastal bluffs and river deltas. Most of the shoreline is coastal bluffs, which are composed of erodable gravel, sand, and clay deposited by glaciers more than 15,000 years ago (Downing 1983, Shipman 2004). Extensive development of coastal bluffs has led to the widespread use of engineered structures designed to protect upland properties, railroads, and roads. These modifications have increased dramatically since the 1970s, with demonstrated negative impacts on the health of the ecosystem (Thom et al. 1994). A synthesis of the geomorphology and dynamics of Puget Sound's shoreline and a discussion of shoreline mechanisms affected by armoring is reviewed by Finlayson (2006).

Characteristics of the physical habitat such as depth, substrate, wave exposure, salinity, and gradient largely determine the plants and animals that can use particular areas of Puget Sound. Eight major nearshore habitats have been characterized and quantified: rocky reefs, kelp beds, mixed sediment intertidal beaches, salt marsh, tide flats, subtidal soft sediments, eelgrass beds, and open water/pelagic habitats (Dethier 1990, Levings and Thom 1994, Ruckelshaus and McClure 2007). The shallow nearshore areas of Puget Sound contain vegetated eelgrass and seaweed habitats that support most marine fish and invertebrate species at some time during their life cycle. Kelp beds and eelgrass meadows cover the largest area (Figure 5 and Figure 6); floating kelps are found primarily over hard substrate along the Strait of Juan de Fuca and San Juan Islands, whereas eelgrass beds are estimated to cover 200 km^2 throughout Puget Sound, with the exception of SPS (Nearshore Habitat Program 2001, Mumford 2007).

Other major habitats include subaerial and intertidal wetlands (176 km^2) and mudflats and sand flats (246 km^2). In pelagic areas, the euphotic zone extends to about 20 m in the relatively clear regions of NPS, and to 10 m in the more turbid waters of SPS. Most of the bottom of Puget Sound is comprised of soft sediments, ranging from coarse sands to fine silts and clay. Rocky reefs, composed of bedrock or a mixture of boulder and cobble substrates, are often characterized by strong currents and tidal action and support benthic suspension feeders and multiple species of fish, including several species of rockfish. Approximately 95% of the rocky reef habitat in greater Puget Sound is located in NPS (Palsson et al. 2009).

Oceanographic and Geomorphological Features of the Various Basins Relevant to DPS Determinations for Puget Sound Rockfish

North Puget Sound

Bathymetry and geomorphology—NPS encompasses the southern Strait of Georgia as well as the San Juan Islands and is demarcated to the west by the entrance to the Strait of Juan de Fuca near Cape Flattery, to the south by the Olympic Peninsula and Admiralty Inlet, and to the east by Whidbey Island and the mainland between Anacortes and Blaine, Washington (Figure 4). The predominant feature of NPS is the Strait of Juan de Fuca, which is 160 km long and 22 km wide at its western end to more than 40 km wide at its eastern end (Thomson 1994). Other

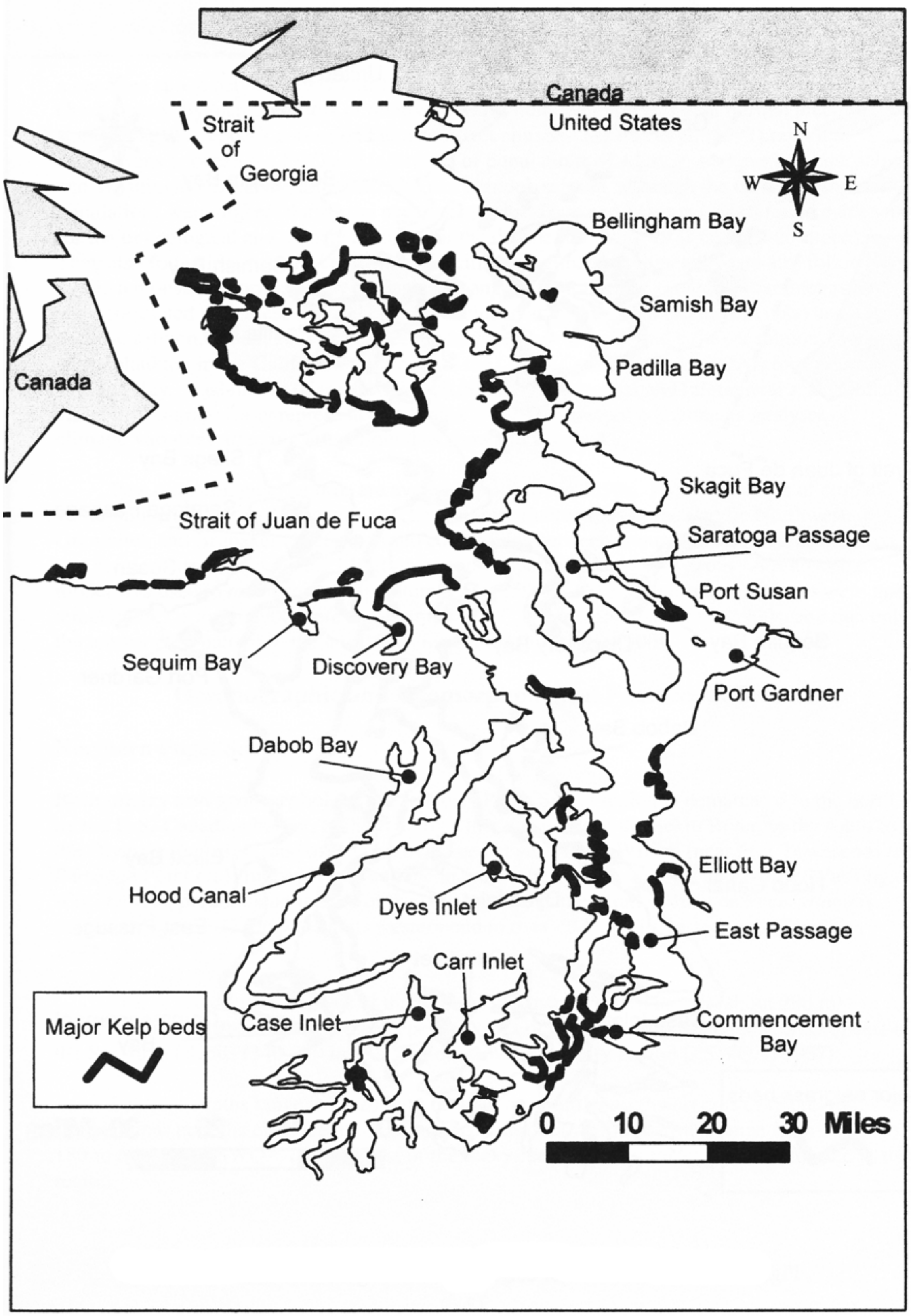


Figure 5. Locations of major kelp beds in Puget Sound. (Reprinted from Stout et al. 2001a.)

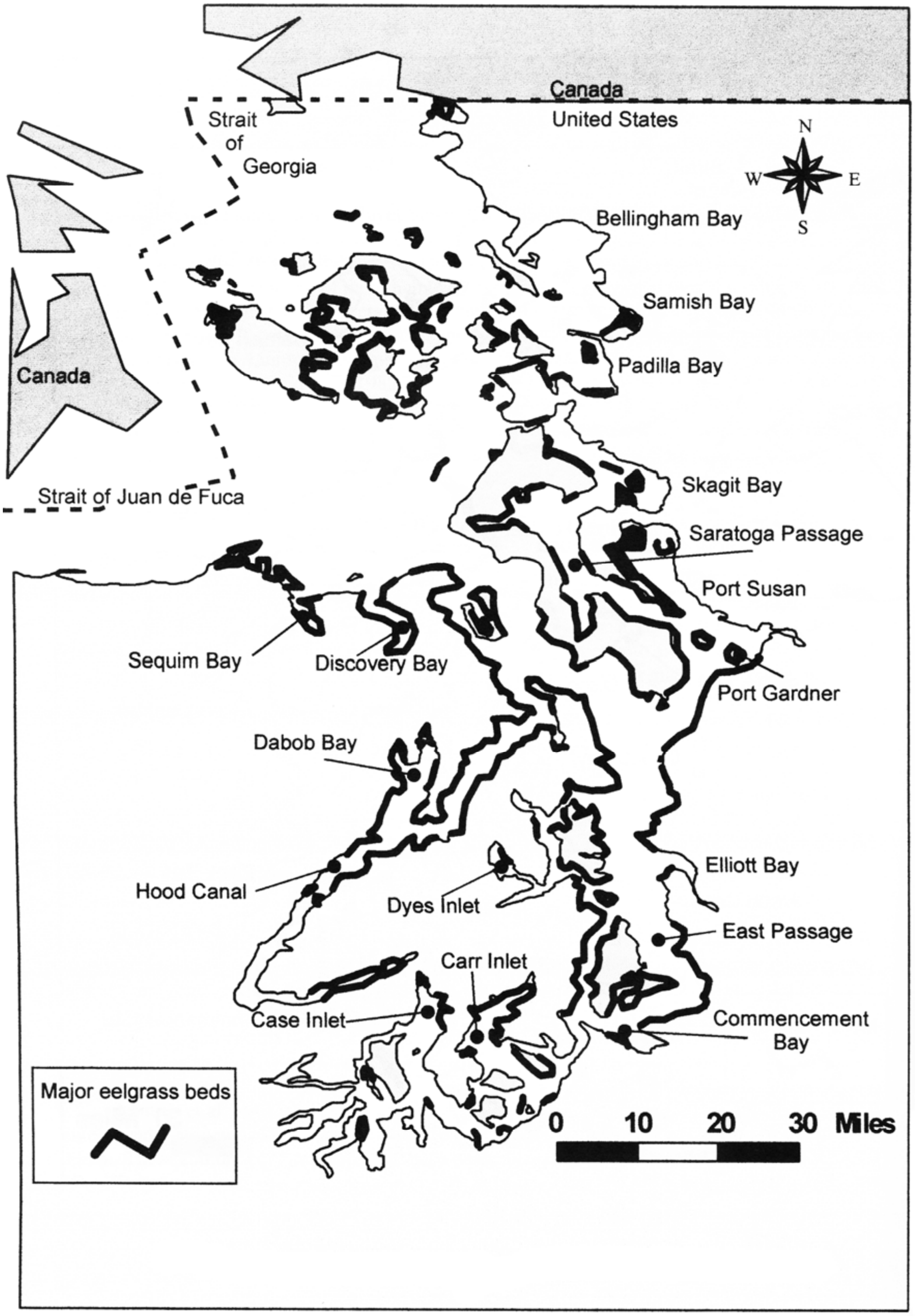


Figure 6. Locations of major eelgrass beds in Puget Sound. (Reprinted from Stout et al. 2001a.)

notable geographic features include Admiralty Inlet, the San Juan Islands, and the southern portion of the Strait of Georgia.

One of the deepest sections of this region is near the western mouth (about 200 m) (Holbrook et al. 1980), whereas the deepest sections of eastern portions are located northwest of the San Juan Islands (340–380 m) (PSWQA 1987). Subtidal depths range 20–60 m in most of the northwest part of the region. Deeper areas near the entrance to the Main Basin north of Admiralty Inlet range 120–180 m in depth (PSWQA 1987).

The vast majority (approximately 93%) of the rocky reef habitat in greater Puget Sound is located in NPS. Pacunski and Palsson (1998) estimated that about 200 km^2 of shallow (<39 m MLLW) rocky reef habitat were present in NPS, whereas only about 14 km^2 were found in the remaining Puget Sound basins.

Sediment characteristics—The surface sediment of the Strait of Juan de Fuca is composed primarily of sand, which tends to be coarse, including some gravel, toward the eastern portion of NPS and gradually becomes finer towards the mouth (Anderson 1968). Many of the bays and sounds in the eastern portion of NPS have subtidal surface sediments consisting of mud or mixtures of mud and sand (PSWQA 1987, WDOE 1998). The area just north of Admiralty Inlet is primarily gravel in its deeper portions and a mixture of sand and gravel in its shallower portions, whereas the shallow areas north of the inlet on the western side of Whidbey Island and east of Protection Island consist of muddy sand (Roberts 1979). The majority of the subtidal surface sediments among the San Juan Islands consists of mixtures of mud and sand. Within the intertidal zone, 61.2 ± 49.7% of the area also has mixed fine sediment and 22.6 ± 27.5% has sandy sediment (Bailey et al. 1998).

Currents and tidal activity—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) (Figure 7). Seasonal variability in temperature and salinity is small because the waters are vertically well mixed (Thomson 1994). 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, circulation in the strait consists of a seaward surface flow of diluted seawater (<30.0 practical salinity units [psu]) in the upper layer and an inshore flow of saline oceanic water (>33.0 psu) at depth (Collias et al. 1974, Thomson 1994). Exceptions include an easterly flow of surface waters near the shoreline between Port Angeles and Dungeness Spit (Figure 8), 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).

Water quality—Temperatures generally range between 7° and 11°C, although occasionally surface temperatures reach as high as 14°C (WDOE 1999). In the eastern portion of NPS, temperature and salinity vary from north to south, with waters in the Strait of Georgia slightly warmer than waters near Admiralty Inlet. Waters near Admiralty Inlet also tend to have higher salinities than waters to the north (WDOE 1999). Dissolved oxygen (DO) levels vary seasonally, with lowest levels of about 4 mg/L at depth during the summer months and highest

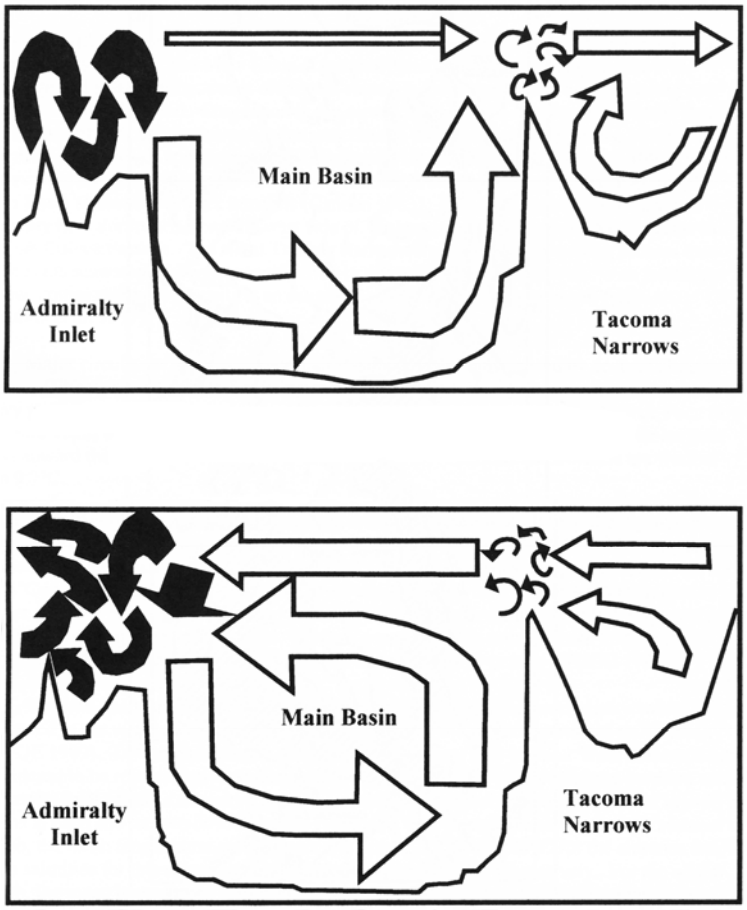


Figure 7. Schematic of circulation in PSP during flood tide (upper diagram) and ebb tide (lower diagram). Black arrows represent strong vertical mixing. (Reprinted from Stout et al. 2001a.)

levels of about 8 mg/L near the surface during the winter. However, in a study conducted between 1996 and 1997, the Washington Department of Ecology (WDOE) reported DO levels in the southern end of Discovery Bay below 3.0 mg/L (PSWQAT 2000).

Macrovegetation—Eelgrass is the primary vegetation in the intertidal areas of the Strait of Juan de Fuca, covering 42.2 ± 27.2% of the intertidal area (Figure 6), and ephemeral green algae (e.g., Ulva and Enteromorpha spp.) is the second most common, covering 4.4 ± 3.7% of the intertidal area (Nearshore Habitat Program 2001). About 45% of the shoreline of this region consists of kelp habitat, compared to only 11% of the shoreline of the other four PSP basins (Mumford 2007). Nevertheless, both areas each have approximately 50% of the total kelp resource. Most kelp species are associated with shoreline exposed to wave action, whereas eelgrass is found in protected areas, such as Samish and Padilla bays (Figure 5). Some of the densest kelp beds in greater Puget Sound are found in the Strait of Juan de Fuca. Kelp beds at the north end of Protection Island declined drastically between 1989 and 1997, decreasing from about 181 acres to “nothing.” The cause of this decline is currently unknown (Mumford 2007).

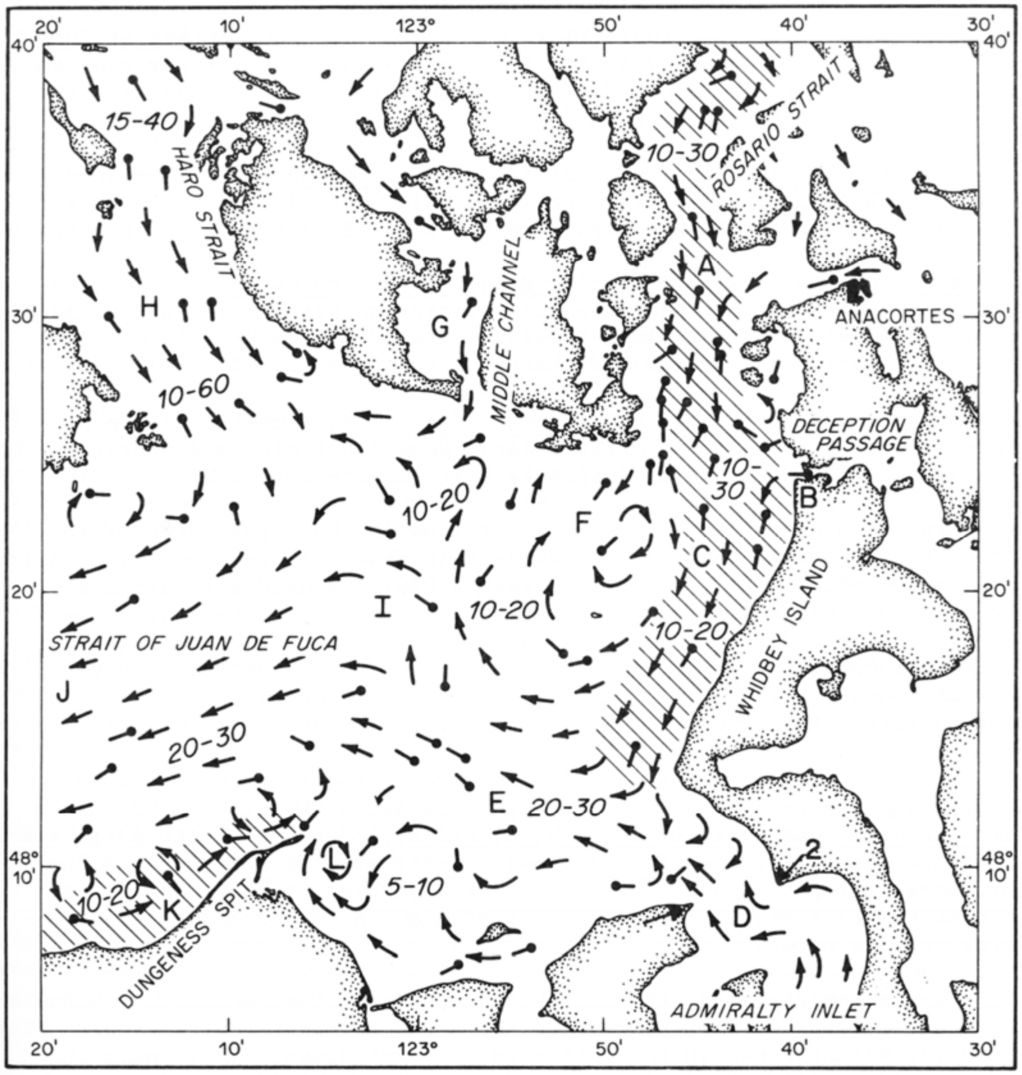


Figure 8. Plan view of net circulation in the upper layer (30 m) of the eastern end of the Strait of Juan de Fuca in NPS. Dots with sticks denote sites of measured currents and current direction. Arrows represent the flow pattern inferred from the observations. Numbers denote approximate current speed (cm s^{-1}) near the water surface. Hatching denotes areas of single layer net flow. (Reprinted from Ebbesmeyer et al. 1984.)

Urban, industrial, and agricultural development—The NPS basin is bordered primarily by rural areas with a few localized industrial developments (PSWQA 1988). About 71% of the area draining into NPS is forested, 6% is urbanized, and 15% is used for agriculture (Ruckelshaus and McClure 2007). Among the five greater Puget Sound basins, this basin is used most heavily for agriculture. The main human population occurs in Bellingham (71,289), Port Angeles (18,397), Anacortes (14,557), and Port Townsend (8,334) (U.S. Census Bureau 2003). About 10% of the total amount of wastes discharged from point sources into greater Puget Sound come from urban and industrial sources in this basin (PSWQA 1988). About 17% of the nutrients (in the form of inorganic nitrogen) entering greater Puget Sound originate from rivers carrying runoff from areas of agricultural and forest production (Embrey and Inkpen 1998). The

Washington Department of Natural Resources (WDNR) (Nearshore Habitat Program 2001) estimated that 21% of the shoreline in this area has been modified by human activities.

Main Basin

Bathymetry and geomorphology—The 100 km-long Main Basin is delimited to the north by a line between Point Wilson (near Port Townsend) and Partridge Point on Whidbey Island, to the south by Tacoma Narrows, and to the east by a line between Possession Point on Whidbey Island and Meadow Point near Everett (Figure 4) (Burns 1985). The western portion of the Main Basin includes Sinclair and Dyes inlets and Colvos and Dalco passages. Large embayments on the east side include Elliott and Commencement bays.

Among of the most important bathymetric features of the Main Basin are the sills at its northern and southern ends. The sill at the north end of Admiralty Inlet is 30 km wide and rises to a depth of 65 m at its shallowest point. The sill at Tacoma Narrows is 45 m deep (Burns 1985). South of Admiralty Inlet, depths generally range from 100 to 140 m in the central part of the basin and 10 to 100 m in the waterways west of Bainbridge and Vashon islands. The central basin consists of five subbasins: 1) near the southern end of Admiralty Inlet, west of Marrowstone Island, with depths to 190 m; 2) near the southern tip of Whidbey Island with depths to 250 m; 3) west of Port Madison, north of Seattle with depths to 400 m; 4) northeast of West Point in Seattle with depths to 350 m; and 5) south of Seattle, near Point Pulley, with depths to about 250 m (Burns 1985). Elliott and Commencement bays, associated with Seattle and Tacoma, respectively, are relatively deep, with depths in excess of 150 m. Freshwater flows into Elliott Bay through the Duwamish-Green River System and into Commencement Bay through the Puyallup River.

Sediment characteristics—Subtidal surface sediments in Admiralty Inlet tend to consist largely of sand and gravel, whereas sediments just south of the inlet and southwest of Whidbey Island are primarily sand (PSWQA 1987). Sediments in the deeper areas of the central portion of the Main Basin generally consist of mud or sandy mud (PSWQA 1987, WDOE 1998). Sediments in the shallower and intertidal areas of the Main Basin are mixed mud, sand, and gravel. Bailey et al. (1998) reported that 92% of the intertidal area of the Main Basin consisted of mixed sand and gravel. A similar pattern is found in the bays and inlets bordering this basin.

Currents and tidal activity—About 30% of the freshwater flow into the Main Basin is from the Skagit River. The Main Basin is generally stratified in the summer, due to river discharge and solar heating, and is often well mixed in winter due to winter cooling and increased mixing by wind. Circulation in the central and northern sections of the Main Basin consists largely of outflow through Admiralty Inlet in the upper layer and inflow of marine waters at depth (below approximately 50 m) (Figure 9) (Strickland 1983, Thomson 1994). Oceanic waters from the Strait of Juan de Fuca flow over the northern sill at Admiralty Inlet into the Main Basin at approximately two-week intervals (Cannon 1983). In the southern section, currents generally flow northward along the west side of Vashon Island and southward on the east side through Colvos Passage (Figure 9). The sill at Tacoma Narrows also causes upwelling that reduces the seawater/freshwater stratification in this basin. Sediment deposition from freshwater inflow accumulates at an estimated rate of 0.18 to 1.2 grams/cm^2/year (Staubitz et al. 1997).

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 middepth when the basin is cooler than 9.7°C. However, the strongest oceanic currents move toward the bottom of the basin during dryer periods when waters are warmer than 9.7°C.

Water quality—Water temperature, salinity, and concentration of DO in Main Basin waters are routinely measured by WDOE at six sites (WDOE 1999). Subsurface temperatures are usually between 8° and 12°C; however, surface temperatures can reach 15°C to 18°C in summer, and temperatures at depth can get as low as 7.5°C in winter. Salinities in the deeper portions of the Main Basin are generally approximately 30 psu in summer and fall, but decrease to approximately 29 psu during the more rainy months. Surface waters are also usually about 29 psu, but occasionally have salinities as low as 25–27 psu during the rainy season (WDOE 1999). The midbasin has consistently higher temperatures and lower salinity relative to the NPS region (WDOE 1999). DO varies seasonally, with lowest levels of about 5.5 mg/L occurring at depth in summer months, and highest levels of about 7.5 mg/L near the surface. Occasionally, summertime highs reach 13–14 mg/L at the surface.

Macrovegetation—The Main Basin has a relatively small amount of intertidal vegetation, with 28.3 ± 10.4% of the intertidal area containing vegetation (Nearshore Habitat Program 2001). The predominant types are green algae (12.0 ± 4.4%) and eelgrass (11.4 ± 6.6%). Most eelgrass is located on the western shores of Whidbey Island and the eastern shores of the Kitsap Peninsula (Figure 6) (PSWQA 1987). A recent report by the Puget Sound Water Quality Action Team (PSWQAT 2000) indicates that only 8% of the shoreline has a continuous distribution of eelgrass beds and 40% of the shoreline has a patchy distribution.

Urban, industrial, and agricultural development—Areas bordering the Main Basin include the major urban and industrial areas of greater Puget Sound: Seattle, Tacoma, and Bremerton. Human population sizes for these cities are about 569,101, 196,790, and 39,597, respectively (U.S. Census Bureau 2003). Approximately 70% of the drainage area 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, overall, enters this basin through its major river systems in the form of inorganic nitrogen (Embrey and Inkpen 1998). It is estimated that 52% of the shoreline in this area has been modified by human activities (Nearshore Habitat Program 2001).

Whidbey Basin

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 (Figure 4). 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

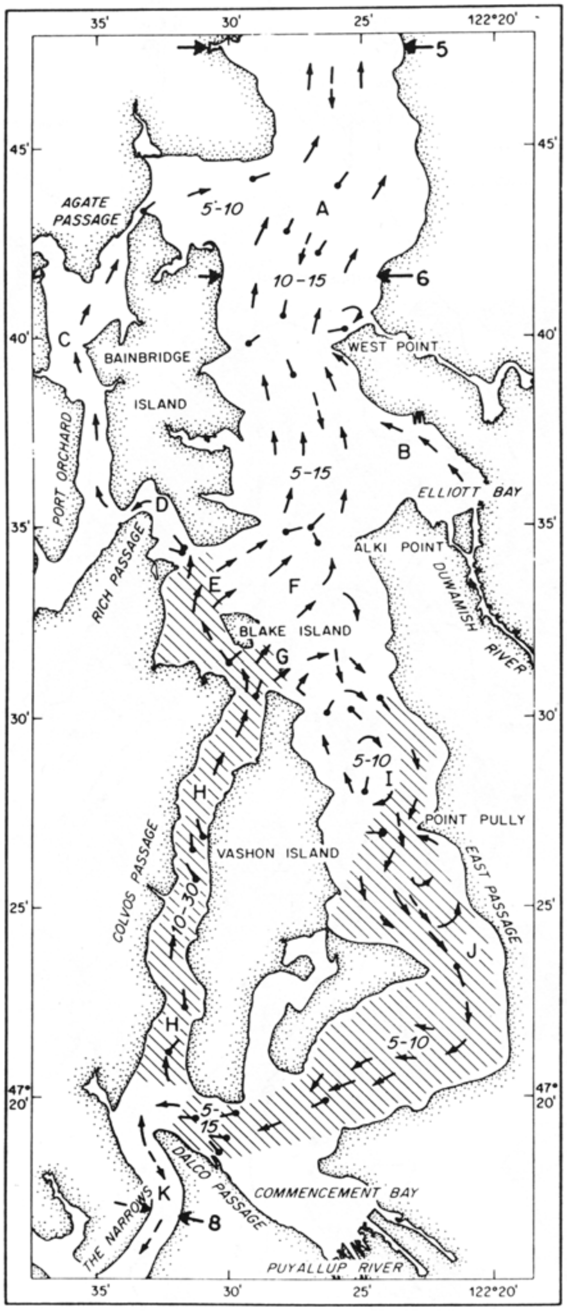


Figure 9. Plan view of net circulation in the upper layer (30 m) of the Main Basin of PSP. Dots with sticks denote sites of observed currents and current direction. Arrows represent the flow pattern inferred from the observations. Numbers in the water represent net speed (cm s^{-1}) toward the water surface. Hatching denotes areas of single layer net flow. (Reprinted from Ebbesmeyer et al. 1984.)

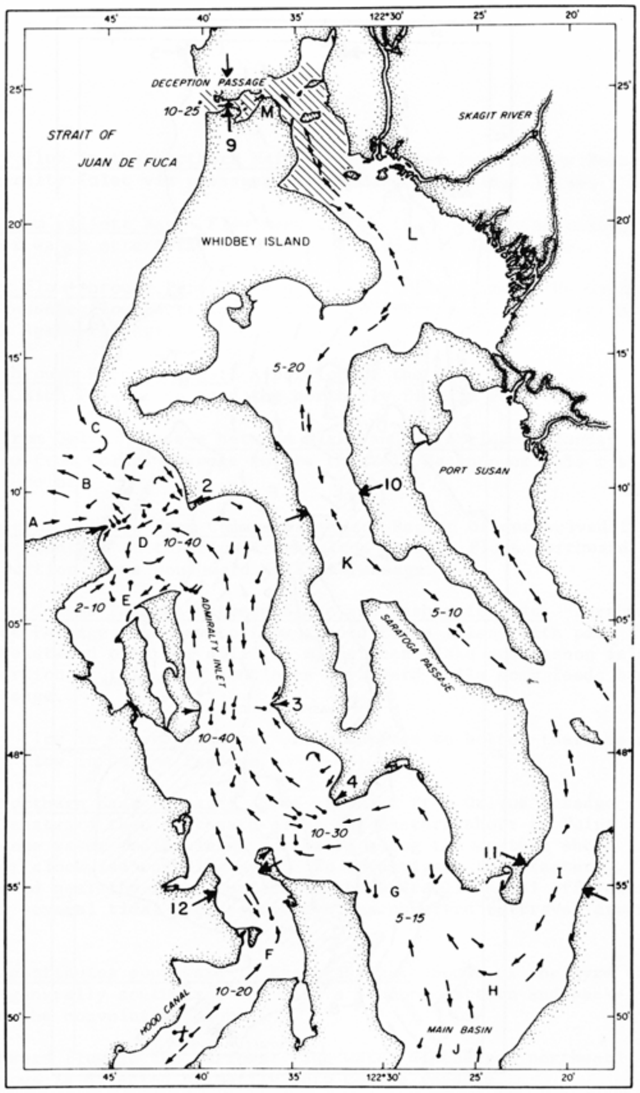


Figure 10. Plan view of net circulation in upper layer (30 m) of Admiralty Inlet and Whidbey Basin in PSP. Dots with sticks denote sites of observed currents and current direction. Arrows represent the flow pattern inferred from the observations. Numbers in the water represent net speed (cm s^{-1}) toward the water surface. Hatching near Deception Pass denotes areas of single layer net flow. (Reprinted from Ebbesmeyer et al. 1984.)

Camano Island and receives freshwater from the Stillaguamish River at the northern end and from the Snohomish River (the second largest of the greater Puget Sound rivers) at the 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).

Sediment characteristics—The most common sediment type in the intertidal zone of the Whidbey Basin is sand, representing 61.4 ± 65.5% of the intertidal area. Mixed fine sediments are the next most common sediment type covering 25.6 ± 18.9% of the intertidal area (Bailey et al. 1998). Similarly, subtidal areas near the mouths of the three major river systems are largely sand. However, the deeper areas of Port Susan, Port Gardner, and Saratoga Passage have surface sediments composed of mixtures of mud and sand (PSWQA 1987, WDOE 1998). Deception Pass sediments consist primarily of gravel.

Currents and tidal activity—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 north 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 Puget Sound; PSWQA (1987) reported a westward surface current speed of 37.37 cm/sec and an eastward bottom current of 5.92 cm/sec. Currents through Saratoga Passage tend to move at moderate rates in a southerly direction (Figure 10). 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 quality—The waters in this basin are generally stratified, with surface waters warmer in summer (generally 10–13°C) and cooler in winter (generally 7–10°C) (Collias et al. 1974, WDOE 1999). Salinities in the southern section of the Whidbey Basin in Possession Sound are similar to those of the Main Basin. In Port Susan and Saratoga Passage, salinities of surface waters (27.0–29.5 psu) are generally lower than in the Main Basin, due to runoff from the two major rivers; moreover, after heavy rain these salinities range 10–15 psu. However, salinities in deeper areas often parallel those of the Main Basin (WDOE 1999).

Concentrations of DO in the waters of the Whidbey Basin are routinely measured by WDOE in Saratoga Passage and in Port Gardner (WDOE 1999). Concentrations were highest in surface waters (up to 15 mg/L) and tended to be inversely proportional to salinity. Samples collected during spring runoff had the highest concentrations of DO. The lowest values (3.5 to 4.0 mg/L) were generally found at the greatest depths in fall. However, in a study conducted between 1996 and 1997, WDOE reported DO levels in the west end of Penn Cove below 3.0 mg/L (PSWQAT 2000).

Macrovegetation—Vegetation covers 23.6 ± 8.8% of the intertidal area of the Whidbey Basin (Nearshore Habitat Program 2001). The three predominant types of cover include green algae (6.8 ± 6.2%), eelgrass (6.5 ± 5.8%), and salt marsh (9.0 ± 9.4%). Eelgrass beds are most abundant in Skagit Bay and in the northern portion of Port Susan (Figure 6) (PSWQA 1987).

Urban, industrial, and agricultural development—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 2003 population of 96,643 (U.S. Census Bureau 2003). Most waste includes discharges from municipal and agricultural activities and a paper mill. About 60% of the nutrients (as inorganic nitrogen) entering greater Puget Sound enter through the Whidbey Basin by way of its three major river systems (Embrey and Inkpen 1998). WDNR (Nearshore Habitat Program 2001) estimated that 36% of the shoreline in this area has been modified by human activities.

South Puget Sound

Bathymetry and geomorphology—SPS includes all waterways south of Tacoma Narrows (Figure 4). This basin is characterized by numerous islands and shallow (generally <20 m) inlets with extensive shoreline areas. The mean depth 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 which enters just south of Anderson Island.

Sediment characteristics—A wide assortment of sediments is found in the intertidal areas of this basin (Bailey et al. 1998). The most common sediments and the percent of the intertidal area they cover are: mud, 38.3 ± 29.3%; sand, 21.7 ± 23.9%; mixed fine, 22.9 ± 16.1%; and gravel, 11.1 ± 4.9%. Subtidal areas have a similar diversity of surface sediments, with shallower areas consisting of mixtures of mud and sand and deeper areas consisting of mud (PSWQA 1987). Sediments in Tacoma Narrows and Dana Passage consists primarily of gravel and sand.

Currents and tidal activity—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 mainly 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.

Water quality—The major channels of the southern basin are moderately stratified compared to most other greater Puget Sound basins, because no major river systems flow into this basin. Salinities generally range 27–29 psu and, although surface temperatures reach 14–15°C in summer, the temperatures of subsurface waters generally range 10–13°C in summer and 8–10°C in winter (WDOE 1999). DO levels generally range 6.5–9.5 mg/L. Salinity in the inlets tends to be similar to those of the major channels, whereas temperatures and DO levels in the inlets are frequently much higher in summer. Two of the principal inlets, Carr and Case, have surface salinities ranging 28–30 psu in the inlet mouths and main bodies, but lower salinities range 27–28 psu at the heads of the inlets (Collias et al. 1974). Summertime surface waters in Budd, Carr, and Case inlets commonly have temperatures that range 15–19°C and DO values of

10–15 mg/L. Temperature of subsurface water tends to be elevated in the summer (14–15°C); however, temperatures are similar to those of the main channels in other seasons of the year (WDOE 1999).

Macrovegetation—Among the five basins of greater Puget Sound, the SPS basin has the least amount of vegetation in its intertidal area (12.7 ± 15.5% coverage), with salt marsh (9.7 ± 14.7% coverage) and green algae (2.1 ± 1.9% coverage) the most common types (Nearshore Habitat Program 2001).

Urban, industrial, and agricultural development—About 85% of the area draining into this basin is forested, 4% is urbanized, and 7% is in agricultural production. The major urban areas around the SPS 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 SPS include Olympia with a population of 43,944 and Shelton with 8,681 (U.S. Census Bureau 2003). Important point sources of wastes include sewage treatment facilities in the cities and a paper mill in Steilacoom. Furthermore, about 5% of the nutrients (as inorganic nitrogen) entering greater Puget Sound enter into this basin through nonpoint sources (Embrey and Inkpen 1998). WDNR (Nearshore Habitat Program 2001) estimated that 34% of the shoreline in this area has been modified by human activities.

Hood Canal

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, at 90 km long and 1–2 km wide (Figure 4). 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 (Burns 1985). The major components of this basin consist of the Hood Canal entrance, Dabob Bay, the central region, and the Great Bend at the southern end. Dabob Bay and the central region are the deepest subbasins (200 and 180 m, respectively), whereas other areas are relatively shallow, less than 40 m for the Great Bend and 50–100 m at the Hood Canal entrance (Collias et al. 1974).

Sediment characteristics—Sediment in the intertidal zone consists mostly of mud (53.4 ± 89.3% of the intertidal area), with similar amounts of mixed fine sediment and sand (18.0 ± 18.5% and 16.7 ± 13.7%, respectively) (Bailey et al. 1998). Surface sediments in the subtidal areas also consist primarily of mud, with the exception of the Hood Canal entrance, which consists of mixed sand and mud, and the Great Bend and Lynch Cove, which have patchy distributions of sand, gravelly sand, and mud (PSWQA 1987, WDOE 1998).

Currents and tidal activity—Because the basin is a closed-ended fjord without large-volume rivers, aside from tidal currents, currents in Hood Canal are slow. The strongest currents tend to occur near the Hood Canal entrance and generally involve a northerly flow of surface waters into Admiralty Inlet (Ebbesmeyer et al. 1984).

Water quality—Portions of Hood Canal are stratified, with marked differences in temperature and DO between the entrance and the Great Bend. Water temperature, salinity, and concentration of DO in Hood Canal are routinely measured by WDOE at two sites, near the Great Bend and near the entrance (WDOE 1999). Salinities generally range from 29–31 psu and tend to be similar at both sites. In contrast, temperature and DO values are often markedly different between the two sites.

Macrovegetation—Vegetation covers 27.8 ± 22.3% of the intertidal area of the Hood Canal basin. Salt marsh (18.0 ± 8.8%) and eelgrass (5.4 ± 6.3%) are the two most abundant plants (Nearshore Habitat Program 2001). Eelgrass is found in most of Hood Canal, especially in the Great Bend and Dabob Bay (Figure 6).

Urban, industrial, and agricultural development—The Hood Canal basin 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-round residences (PSWQA 1988). A small amount of waste is generated by forestry practices and agriculture. Nutrients (as inorganic nitrogen) from nonpoint sources in this basin represent only 3% of the total flowing into greater Puget Sound annually (Embrey and Inkpen 1998). WDNR (Nearshore Habitat Program 2001) estimated that 34% of the shoreline in this area has been modified by human activities.

Environmental Features of Georgia Basin and the Strait of Georgia

The Georgia Basin is an international water body that encompasses the marine waters of greater Puget Sound and the Strait of Georgia (Figure 11). The coastal drainage of the Georgia Basin is bounded to the west and south by the Olympic and Vancouver Island mountains and to the north and east by the Cascade and Coast mountains. At sea level, the basin has a mild maritime climate and is dryer than other parts of the coast due to the rain shadow of the Olympic and Vancouver Island mountains. At sea level, air temperatures range 0–5°C in January and 12–22°C in July; winds are typically channeled by the local topography and blow along longitudinal axes of the straits and sounds. Winds are predominantly from the southeast in winter and the northwest in summer.

The Strait of Georgia (Figure 11) has a mean depth of 156 m (420 m maximum) and is bounded by narrow passages (Johnstone Strait and Cordero Channel to the north and Haro and Rosario straits to the south) and shallow submerged sills (minimum depth of 68 m to the north and 90 m to the south). The Strait of Georgia covers an area of approximately 6,800 km^2 (Thomson 1994), is approximately 220 km long, and varies from 18.5 to 55 km in width (Tully and Dodimead 1957, Waldichuck 1957). Both southern and northern approaches to the Strait of Georgia are through a maze of islands and channels: the San Juan Islands and Gulf Islands to the south and a series of islands to the north that extend for 240 km to Queen Charlotte Strait (Tully and Dodimead 1957). Both northern channels (Johnstone Strait and Cordero Channel) are from 1.5 to 3 km wide and are effectively two-way tidal falls, in which currents of 12–15 knots occur at peak flood (Tully and Dodimead 1957). However, both lateral and vertical constriction of water flow at the narrowest points in these northern channels are even more severe. Constrictions occur at Arran Rapids, Yuculta Rapids, Okisollo Channel, and to a lesser degree at Seymour Narrows (0.74 km wide, minimum depth of 90 m) in Discovery Passage (Waldichuck 1957). Overall, these narrow northern channels have only about 7% of the cross-sectional area as do the combined southern entrances into the Strait of Georgia (Waldichuck 1957).

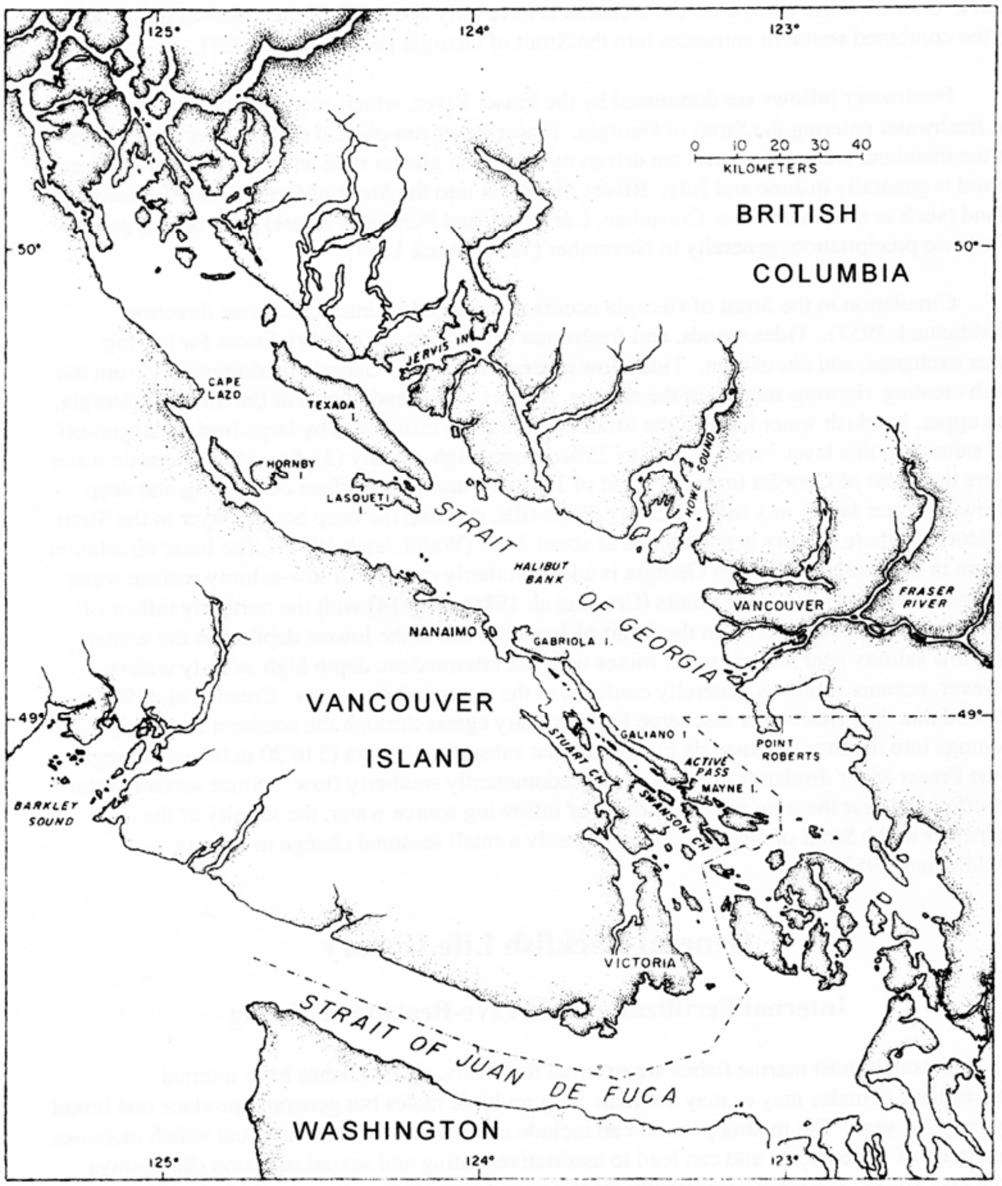


Figure 11. Geographic locations in the Strait of Georgia and southern British Columbia considered in this technical memorandum. (Reprinted from Stout et al. 2001a.)

Freshwater inflows are dominated by the Fraser River, which accounts for roughly 80% of the freshwater entering the Strait of Georgia. The Fraser River has a drainage area of 234,000 km^2 (Bocking 1997). Its rate of flow ranges from an average of 750 m^3/sec in the winter to an average of 11,500 m^3/sec during the spring freshet, although flows of 20,000 m^3/sec are not uncommon during the spring floods (Bocking 1997). Fraser River runoff and that of other large rivers on the mainland side of the strait are driven by snow and glacier melt and their peak discharge period is generally in June and July. Rivers that drain into the Strait of Georgia from Vancouver Island (such as the Chemainus, Cowichan, Campbell, and Puntledge rivers) peak during periods of intense precipitation, generally in November (Waldichuck 1957).

Circulation in the Strait of Georgia occurs in a general counterclockwise direction (Waldichuck 1957). Tides, winds, and freshwater runoff are the primary forces for mixing, water exchange, and circulation. Tidal flow enters the Strait of Georgia predominantly from the south, creating vigorous mixing in the narrow, shallow straits and passes of the strait. The upper, brackish water layer in the strait is influenced by large freshwater runoff; salinity in this layer varies from 5 to 25 psu. Deep, high-salinity (33.5 to 34 psu) oceanic water enters the strait from the Strait of Juan de Fuca. The surface out flowing and deep inflowing water layers mix in the vicinity of the sills, creating the deep bottom layer in the Strait of Georgia, where salinity is maintained at about 31 psu (Waldichuck 1957).

The basic circulation pattern in the southern Strait of Georgia is a southerly outflow of low-salinity surface water through Rosario and Haro straits (Crean et al. 1988) (Figure 12) with the northerly inflow of high-salinity oceanic water from the Strait of Juan de Fuca at the lowest depths. In winter, cool, low-salinity, near-surface water mixes with the intermediate depth high-salinity waters; however, oceanic inflow is generally confined to the intermediate depths. Crean et al. (1988) reported that "the freshwater discharge finds primary egress through the southern boundary openings into the Strait of Juan de Fuca" and that subsurface waters (5 to 20 m below the region of the Fraser River discharge) also have "a predominantly southerly flow." Since surface water runoff peaks near the time of peak salinity of inflowing source water, the salinity of the deep water in the Strait of Georgia undergoes only a small seasonal change (Waldichuck 1957).

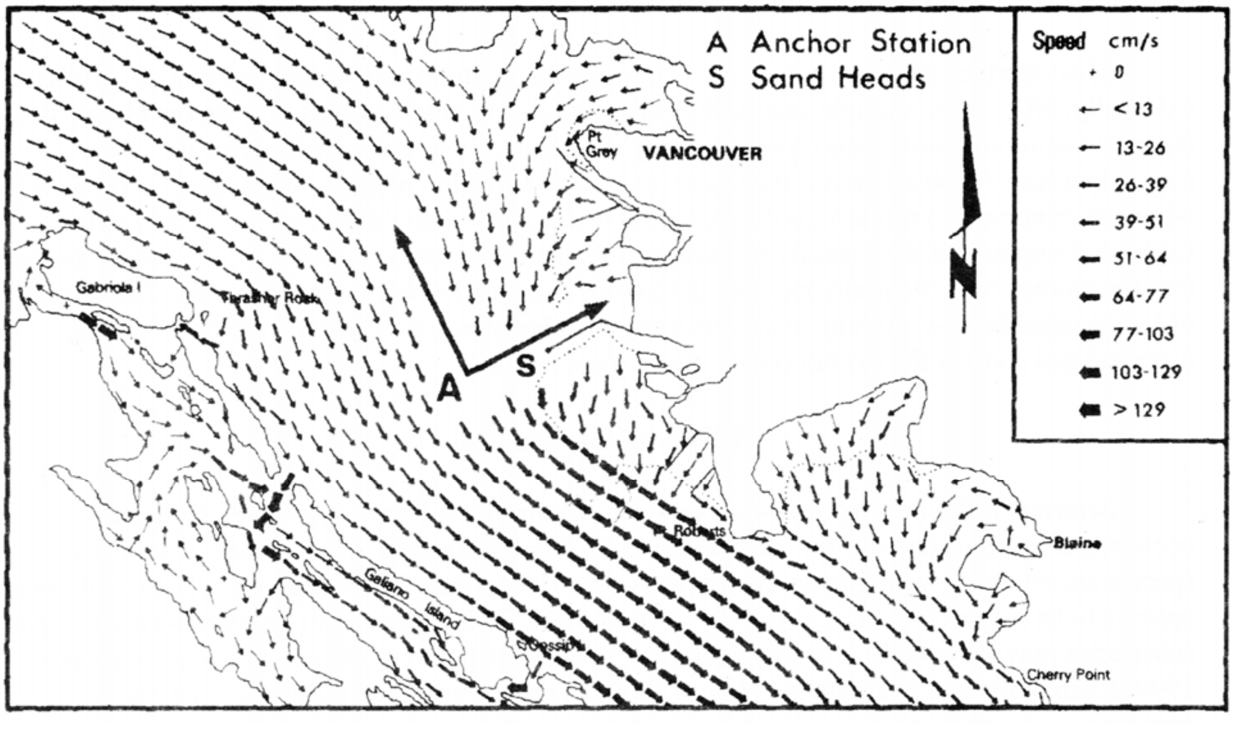


Figure 12. Representative ebb velocity vectors in the general vicinity of the Fraser River mouth in the Strait of Georgia. (Reprinted from Stout et al. 2001a.)

Genetic Differentiation

Analysis of the geographical distribution of genetic variation is a powerful method of identifying discrete populations. In addition, such analysis can sometimes be used to estimate historical patterns of dispersal, equilibrium levels of migration (gene flow), and past isolation. Commonly used molecular genetic markers include protein variants (allozymes), microsatellite loci (variable numbers of short tandem DNA repeats), and mitochondrial DNA (mtDNA). One widely used method of population analysis is sequence or RFLP (restriction fragment length polymorphism) analysis of mtDNA, a molecular that codes for about a dozen genes not found in the cell nucleus.

Mitochondrial DNA differs from nuclear DNA (nDNA) in two ways. One difference is that recombination is lacking in mtDNA, so that gene combinations (haplotypes) are passed unaltered from one generation to the next, except for new mutations. Second, mtDNA is inherited from only the maternal parent in most fishes, so that gene phylogenies correspond to female lineages. These characteristics permit phylogeographical analyses of mtDNA haplotypes, which can potentially indicate dispersal pathways for females and the extent of gene flow between populations (Avise et al. 1987). Although the lack of recombination allows for some types of analysis that are difficult to conduct with other markers (e.g., microsatellites), inferences of population structure (or lack thereof) from mtDNA are limited by the fact that the entire mitochondrial genome is inherited genetically as a single locus. Mitochondrial studies are therefore most useful for detecting deep patterns of population structure, and may not be very powerful for detecting structure among closely related populations.

Microsatellite DNA are nuclear markers that can potentially detect stock structure on finer spatial and temporal scales than can other DNA or protein markers, because of higher levels of polymorphism typically found in microsatellite DNA (reflecting a high mutation rate). Relatively high levels of variation can increase the statistical power to detect stock structure, particularly among closely related populations. In addition, microsatellite studies usually involve analysis of multiple genetic loci, which increases the power to detect differentiation among populations.

Overview of Genetic Variation in Rockfish

A principal challenge of rockfish genetic research has been to make generalizations about this ecologically diverse group of closely related species. With a few exceptions, it is not possible to make broad statements about patterns of radiation and divergence. For example, it is not the case that particular evolutionary clades correspond to particular morphological or ecological guilds. For example, species with more pelagic life histories are not necessarily more closely related to one another than they are to more demersal taxa. Instead, these traits appear to have evolved multiple times in different lineages. Moreover, rockfish radiation appears to have been relatively abrupt, with pulses of diversification occurring approximately 9–8 million years ago (MYA) and 8–6 MYA, resulting in poor resolution of internal phylogenetic nodes (Hyde and Vetter 2007). A great deal of diversity exists among species, with frequent exceptions to otherwise general patterns or expectations. More effort must therefore to be directed toward individual species and individual oceanographic boundaries before general insights can be gained.

Patterns of population differentiation vary within rockfish species, and range from no notable population structure over large geographic ranges, to isolation by distance (no strong discontinuities but closer genetic affinities among nearby populations), to genetic structure corresponding to oceanographic features, to fine-scale differentiation on the scale of Puget Sound (Table 1). These patterns do not appear to follow particular life history attributes of rockfishes; rather, they appear to depend on a combination of factors including habitat, life history traits, and population dynamics. One important point, discussed further below, is that multiple studies have found evidence that rockfish that inhabit geographically isolated areas, such as Puget Sound, tend to be genetically differentiated from other populations.

Bocaccio

No published studies have compared genetic characteristics of bocaccio from Puget Sound and outer coastal areas, but there have been several studies of variation in bocaccio along

Table 1. Summary of published studies by type of population structure found. Note that multiple patterns may be evident within a single species.

Population structure	Species	Source
No population structure detected	Chilipepper rockfish (*Sebastes goodei*)	Wishard et al. 1980
	Mexican rockfish (*S. macdonaldi*)	Bernardi et al. 2003, Rocha-Olivares et al. 2003
	Kelp rockfish (*S. atrovirens*)	Gilbert-Horvath et al. 2006
Isolation by distance	Darkblotched rockfish (*S. crameri*)	Gomez-Uchida and Banks 2005
	Canary rockfish	Wishard et al. 1980
	Goldeye rockfish (*S. thompsoni*)	Sekino et al. 2001
	Pacific ocean perch (*S. alutus*)	Wishard et al. 1980, Seeb and Gunderson 1988
	Copper rockfish	Seeb 1998, Buonaccorsi et al. 2002
	Quillback rockfish (*S. maliger*)	Seeb et al. 1998
	Brown rockfish (*S. auriculatus*)	Seeb et al. 1998, Buonaccorsi et al. 2005
	Kelp rockfish	Taylor 2004
	Grass rockfish (*S. rastrelliger*)	Buonaccorsi et al. 2004
Genetic differentiation, but not consistent with isolation by distance	Shortraker rockfish (*S. borealis*)	Matala et al. 2004b
	Quillback rockfish	Burr 1999
Influence of oceanographic features	Pacific ocean perch	Withler et al. 2001
	Blue rockfish (*S. mystinus*)	Cope 2004
	Grass rockfish	Buonaccorsi et al. 2004
	Vermilion rockfish (*S. miniatus*)	Hyde 2007
	Rosethorn rockfish (*S. helvomaculatus*)	Rocha-Olivares and Vetter 1999
	Bocaccio	Matala et al. 2004a
Possible hybridization	Copper rockfish	Seeb et al. 1998, Buonaccorsi et al. 2005
	Quillback rockfish	Seeb et al. 1998, Buonaccorsi et al. 2005
	Brown rockfish	Seeb et al. 1998, Buonaccorsi et al. 2005

the outer coast. Wishard et al. (1980) examined allozyme variation in 9 coastal sampling locations ranging from Baja California to southern Oregon, with sample sizes ranging from n equals 12 to more than 100 individuals per locality. They found two highly polymorphic loci and three others with low levels of variation. They found overlapping confidence intervals for allele frequencies across sampling locations and no evidence for differentiation among populations.

More recently, Matala et al. (2004) examined genetic variation in bocaccio at 7 microsatellite loci in samples (n = 30–67) from 8 locations from Baja California to British Columbia, including both sides of Point Conception. Samples were adults except in the Santa Barbara channel, where age-0 fish were taken. A contingency G-test across all samples and all loci provided significant ($P = 0.037$) evidence for departures from global panmixia, indicating that coastal bocaccio are not a single, randomly breeding population. A large-scale pattern of isolation by distance was not observed in the data, and levels of differentiation were extremely low (F_{ST} averaged over all loci and populations was –0.0001). However, using a series of comparisons of smaller, geographically contiguous subsets of samples, the authors found some evidence that geographically proximate samples tended to be more similar genetically. They suggested that these results might best be explained by the interacting effects of oceanographic patterns and the species' life history, with current patterns restricting larval exchange in certain geographic areas. A reanalysis of the Matala et al. (2004) data conducted by Field et al. (2009) found no evidence of population structure among the coastal samples. Field et al. (2009) did conclude, however, that despite an apparent lack of genetic differentiation, there are sufficient demographic differences between northern and southern populations to suggest they are demographically independent.

Canary rockfish

No published studies have compared genetic characteristics of canary rockfish from Puget Sound and outer coastal areas. The allozyme study mentioned above (Wishard et al. 1980), which examined large samples (n > 100) from 8 eight coastal locations in northern California, Oregon, and Washington, found low levels of heterozygosity in this species and some evidence for stock structure. In particular, samples taken south of Cape Blanco (southern Oregon) lack an allele that occurs at low frequency in populations to the north. In some localities, allele frequencies at the phosphoglucomutase locus differed significantly between samples taken at different depths. Nine microsatellite loci have been developed for canary rockfish (Gomez-Uchida et al. 2003), but to date no genetic surveys have been published using these loci.

Yelloweye rockfish

No published studies have compared genetic characteristics of yelloweye rockfish from Puget Sound and outer coastal areas. A Canadian study (Yamanaka et al. 2006) using nine microsatellite loci in yelloweye rockfish collected from Oregon to southeast Alaska found small allele frequency differences among all the coastal samples; however, three samples from the inside waters of the Strait of Georgia and Queen Charlotte Strait had significantly reduced levels of genetic variability and formed a distinctive genetic cluster. The authors suggested that these results imply restricted gene flow between inner and outer populations and a lower effective size for populations within the Strait of Georgia. Yamanaka et al. (2006) calculated F_{ST} values (a measure of genetic differentiation) among pairs of samples and found substantially higher values for comparisons of inside versus outside populations than for comparisons among outside populations (mean $F_{ST} = 0.017$ for inside-outside vs. 0.0008 for outside-outside).

Subsequently, samples taken in 2005–2007 from waters between Vancouver Island and mainland British Columbia have been screened at the same nine polymorphic microsatellite loci.[4] Preliminary analysis of these new samples shows that the patterns remain consistent; all samples from inside waters form a coherent genetic cluster, and inside-outside comparisons typically yield much higher F_{ST} values than do comparisons of two outside samples or two inside samples (Figure 13). In the north, there appears to be a fairly sharp transition between inside and outside forms in the vicinity of Gordon Channel. Whether a similar pattern occurs in the south is not known, as no samples from Puget Sound have been analyzed and only a single fish was collected from the Strait of Juan de Fuca.

Greenstriped rockfish

Very little genetic information is available for greenstriped rockfish. A preliminary study of mtDNA control region sequences (J. Hess unpubl. data) compared data from coastal samples (British Columbia, Washington, and California) and samples collected from the Strait of Juan de Fuca. Preliminary results are consistent with those for coastal populations of other rockfish

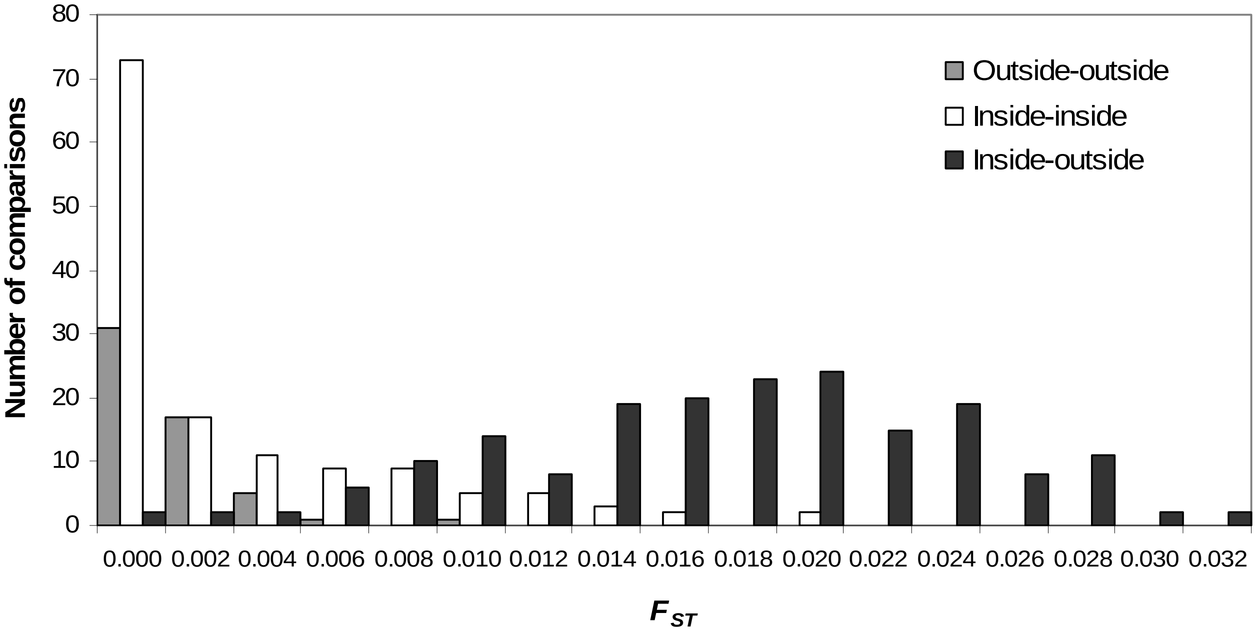


Figure 13. Distribution of pairwise F_{ST} values for 28 samples of yelloweye rockfish collected from coastal populations ("outside") or the Strait of Georgia and Queen Charlotte Strait ("inside"). (Based on Yamanaka et al. 2006 and Withler.[5])

---

[4] R. Withler, Dept. Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, BC. Pers. commun., July 2008.

[5] See footnote 4.

species; most haplotypes shared by more than one individual were found in all populations sampled, and the only significant pairwise comparison was Washington coast versus California. However, sample sizes were low (12–40 individuals), so power to detect differences was also low. Furthermore, because no samples were available from PSP, this preliminary study provided no information about the relationship between greenstriped rockfish in Puget Sound and the Pacific coast.

Redstripe rockfish

No published studies have examined population genetic structure of redstripe rockfish in the Northeast Pacific. The NWFSC is in the process of analyzing samples of redstripe rockfish, which are likely to be useful for future assessments.

Population Genetics of Other Rockfishes that Include Samples from Puget Sound

As is clear from the above, essentially no genetic data were available that included samples of the petitioned species from Puget Sound. The BRT, however, concluded that the biology and ecology of the petitioned species were sufficiently similar to species that have been subject to genetic analysis and that did include samples from Puget Sound that patterns of variation from these “surrogate species” should be considered when evaluating potential DPSs for the less-studied petitioned species.

Despite the lack of genetic studies targeting the five petitioned species, some information is available for other rockfish species found in Puget Sound. Copper, brown, and quillback rockfish are three closely related species that were the subject of a previous biological review team (Stout et al. 2001a). Both allozyme and microsatellite analysis of these three species found Puget Sound populations to be distinct from outer coastal populations, even when little or no differentiation was found among the coastal populations of the same species from California to Alaska (Seeb 1998, Buonaccorsi et al. 2002, Buonaccorsi et al. 2005, Johansson et al. 2008).

Estimated F_{ST} values for quillback rockfish were 0.005 in samples from northern California, Washington coast, and Southeast Alaska, but jumped to 0.028 when Puget Sound samples were included (allozymes, Seeb 1998). Estimated F_{ST} values for copper rockfish were 0.007 among four coastal samples from southern California to British Columbia, but 0.087 between coastal and Puget Sound (microsatellites, Buonaccorsi et al. 2002). An additional microsatellite study of copper rockfish along the West Coast from southern California to northern Washington measured an even lower F_{ST} of 0.004 (Johansson et al. 2008). Brown rockfish showed a similar pattern, with estimated F_{ST} values of 0.009 for coastal populations from Baja to California, and 0.057 with the inclusion of Puget Sound samples (Buonaccorsi et al. 2005). Alleles characteristic of brown and copper rockfish were found in quillback rockfish within Puget Sound but not outside Puget Sound, suggesting introgression may be occurring among these species within Puget Sound (Seeb 1998), which may in part be contributing to their distinctiveness from coastal populations.

In addition to studies of brown, quillback, copper, and yelloweye rockfish, a study of Pacific ocean perch found patterns of genetic variation that indicated the existence of three separate populations within British Columbia, one on the west side of Vancouver Island and two populations co-occurring to some extent on the east and west sides of the Queen Charlotte Islands (Withler et al. 2001). The study looked at five microsatellite loci, and this pattern was maintained for samples collected in March through September.

Genetic Differentiation of Other Marine Fishes in Puget Sound

Several nonrockfish species have been studied within and outside of Puget Sound, including Pacific hake, Pacific cod (*Gadus macrocephalus*), walleye pollock (*Theragra chalcogramma*), lingcod, and Pacific herring (*Clupea pallasii*), with a variety of conclusions reached regarding population differentiation (Table 2). These species are very different from rockfishes in their biology and life histories. The first three were the subjects of a biological review team in 2000 (Gustafson et al. 2000). Allozyme analyses in Pacific hake showed differentiation between Puget Sound and Strait of Georgia populations (Iwamoto et al. 2004) as well as between offshore and Puget Sound regions (Utter and Hodgins 1971). Herring from Puget Sound and the Strait of Georgia showed considerable similarity among sampling sites with two exceptions: Cherry Point in the Strait of Georgia and Squaxin Pass in SPS (Small et al. 2005). Differences in spawn timing (Cherry Point) and physical isolation (Squaxin Pass) were suggested as the factors leading to the differentiation seen.

The remaining species showed little evidence of genetic differentiation. Pacific cod sampled from Puget Sound to the Yellow Sea showed only two distinct genetic groupings as differentiated by allozymes, a North American group and a western North Pacific group (Grant et al. 1987). Walleye pollock, too, show population structure only at an ocean-basin scale (O’Reilly et al. 2004). No evidence of genetic differentiation was found using allozymes and microsatellites in lingcod among populations from Puget Sound, the Strait of Juan de Fuca, and the outer Washington coast (LeClair et al. 2006).

Taken together, the dearth of information on genotypic distributions and temporal genetic variation indicate that additional research is needed to identify appropriate sampling and data

Table 2. Summary of studies of genetic differentiation found in marine fish that included samples from Puget Sound.

Differentiation	**Species**	**Results**	**Source**
Low	Pacific cod (*Gadus macrocephalus*)	Differentiation on ocean basin scale	Grant et al. 1987
Low	Walleye Pollock (*Theragra chalcogramma*)	Differentiation on ocean basin scale	O’Reilly et al. 2004
Low	Lingcod (*Ophiodon elongatus*)	No differentiation found among Puget Sound, Strait of Juan de Fuca, and coastal Washington populations	LeClair et al. 2006
Medium	Herring (*Clupea pallasii*)	Puget Sound and Strait of Georgia populations similar, with two exceptions	Small et al. 2005
High	Pacific hake (*Merluccius productus*)	Differentiation found between Puget Sound, Strait of Georgia, and offshore populations	Iwamoto et al. 2004; Utter and Hodgins 1971

collection strategies to fully characterize genetic relationships among Puget Sound rockfish populations. The lack of genetic data hampered the BRT in making its DPS determinations, and additional genetic studies would be useful for making better informed conclusions regarding DPS structure of the petitioned rockfish species in Puget Sound.

Other Marine Fish DPS Designations

To further inform DPS determinations, the Puget Sound Rockfish BRT reviewed the size and complexity of other designated DPSs of marine fish that have undergone the status review process and have been considered both discrete and significant to their respective biological species. By comparing DPS determinations among species with a variety of life history attributes, the BRT sought insight on what types of life history traits influence population structure as it pertains to the ESA. DPSs have been designated for portions of the range of Pacific hake, Pacific cod, walleye pollock (NMFS 2000), copper rockfish, quillback rockfish, brown rockfish (NMFS 2001), bocaccio (NMFS 2002), and smalltooth sawfish (*Pristis pectinata*) (NMFS 2003). Several marine fish DPSs cover geographic areas larger than the Georgia Basin. For example, Pacific cod and walleye pollock DPSs extend from Puget Sound to Southeast Alaska. Two west coast DPSs of bocaccio were designated off Washington and Oregon (the northern DPS) and off California and Mexico (the southern DPS) (MacCall and He 2002), and all smalltooth sawfish in U.S. waters were designated a single DPS.

At smaller geographic scales, a Georgia Basin Pacific hake DPS was separate from coastal hake, and three DPSs each of copper and quillback rockfish (PSP DPS, NPS DPS, and coastal DPS) and two of brown rockfish (PSP DPS and coastal DPS) were identified. Some of these DPSs (e.g., Pacific herring) include a number of identifiable subpopulations with numerous isolated spawning locations and a substantial level of life history and ecological diversity (Gustafson et al. 2000, Stout et al. 2001a).

Of particular interest to the current BRT, the previous BRT that was assembled to consider Puget Sound populations of copper, quillback, and brown rockfish (Stout et al. 2001a) faced similar questions to the current petition regarding the DPS designation for rockfish found in the inland marine waters of Washington state. With regard to discreteness, Stout et al. (2001a) based their DPS decisions largely on genetic data that were directly relevant to the three species in question, as well as life history traits and the environmental features of Puget Sound. Regarding significance, Stout et al. (2001a) primarily noted the distinct ecology of Puget Sound which differs substantially from other marine areas as well as the range gap that would result from the extinction of Puget Sound populations. A brief summary of the evidence used to make the DPS decisions follows, listed by species.

Stout et al. (2001a) were unanimous in their decision for a PSP DPS for copper rockfish, distinct from an NPS DPS (including the Canadian Gulf Islands) and a coastal DPS, based primarily on genetic evidence. Allozyme and RFLP data from Seeb (1998) showed no particular genetic divergence for PSP specimens, but microsatellite data from Wimberger (in prep.) and Buonaccorsi et al. (2002) showed large differences between populations within PSP and populations outside PSP. Wimberger sampled copper rockfish from California, British Columbia, the San Juan Islands, the Canadian Gulf Islands, Admiralty Inlet, central Puget Sound, and Hood Canal (the latter three populations are within PSP). Wimberger found significant divergence between central Puget Sound and Admiralty Inlet populations, and all populations found outside PSP. Equal divergence was found among PSP populations compared with San Juan Islands, Gulf Islands, and coastal populations as well.

Buonaccorsi et al. (2002) used a different set of microsatellite loci to compare populations from PSP, Canadian Gulf Islands, Queen Charlotte Islands, and coastal California. They also found highly significant divergence among all sampling sites, indicating a clear divergence between populations within PSP and the Canadian Gulf Islands. Buonaccorsi et al. (2002) also identified private alleles in PSP, further evidence for isolation of PSP populations from other neighboring regions. In addition to genetic information, Stout et al. (2001a) pointed out that copper rockfish are live-bearers and have internal fertilization, a short pelagic larval stage, and high habitat fidelity. All of these traits, combined with the physical isolation of PSP, could lead to reproductive isolation of the PSP DPS.

Stout et al. (2001a) were somewhat divided regarding the appropriate DPS for quillback rockfish, but 66% of the BRT supported a PSP DPS, as distinct from an NPS DPS and a coastal DPS. The preponderance of evidence was again genetic, from Seeb (1998) and Wimberger (in prep.). Seeb (1998) sampled four sites within PSP, one in the San Juan Islands, and coastal sites from California, Washington, and Alaska. Both allozyme and RFLP analyses indicated large differences in allele frequencies between PSP and the San Juan Islands. When the PSP samples were removed from the analysis, however, no significant divergence was found among the remaining populations. Wimberger (in prep.) found significant differences in microsatellite allele frequencies between PSP and the San Juan Islands. The San Juan Islands population was more similar to Sitka, Alaska, than it was to PSP. In addition to the genetic data, quillback rockfish have very similar life history traits to copper rockfish (as stated above) leading the previous BRT to conclude that a PSP DPS was appropriate for quillback rockfish as well.

Brown rockfish have a distribution that is very different from copper and quillback rockfish, as they are found in PSP but only rarely occur in NPS, Georgia Basin, or the Washington and Oregon coastline (Stout et al. 2001a). The large disconnect between PSP and coastal populations of brown rockfish suggested to the previous BRT that the PSP population might be a remnant population in an ecologically unique habitat. Genetic data available at the time supported a divergence between PSP and California populations (Seeb 1998). Stout et al. (2001a) noted that a microsatellite study was underway which would also compare coastal and Puget Sound populations (Buonaccorsi et al. 2005). Buonaccorsi et al. (2005) sampled three sites within PSP and compared them to coastal populations ranging from California to Mexico. They found significant divergence among the populations, and even between two of the PSP populations. PSP populations exhibited extremely low genetic divergence compared to coastal samples, which suggested to the authors a potential founder effect combined with reproductive isolation, or a low effective population size.

Methodology for Incorporating Uncertainty in DPS Designations

To allow for uncertainty in identifying the boundaries of Puget Sound rockfish DPSs, the BRT adopted a “likelihood point” method, often referred to as the FEMAT method because it is a variation of a method used by scientific teams evaluating options under former President Bill Clinton’s Forest Plan (Forest Ecosystem Management: An Ecological, Economic, and Social

Assessment Report of the Forest Ecosystem Management Assessment Team [FEMAT 1993, http://reo.gov/library/reports/newroda.pdf]). This method has also been used in all recent status review updates for federally listed Pacific salmon and steelhead (*Oncorhynchus mykiss*) evolutionarily significant units (e.g., Good et al. 2005) as well as reviews of killer whales (Krahn et al. 2002, 2004) and herring (Gustafson et al. 2006).

In this approach, each BRT member distributes 10 likelihood points among a number of proposed DPS scenarios, reflecting his or her opinion of how likely that proposal correctly reflects the true DPS configuration (Table 3). Thus if a member were certain that the DPS scenario that contains Puget Sound rockfish was PSP, he or she could assign all 10 points to that scenario. A member with less certainty about DPS boundaries could split points among multiple DPS scenarios. Ultimately each BRT member distributed his or her 10 likelihood points among these 4 possible DPS scenarios. With 9 BRT members, for each species there were a total of 90 likelihood points distributed among the DPS scenarios.

DPS Scenarios

After consideration of hydrography and bathymetry of Puget Sound and the Georgia Basin, the life history of the petitioned species, patterns of population structure for marine fish generally, and previous DPS designations for Puget Sound species, the BRT developed four possible DPS scenarios that could incorporate the petitioned Puget Sound rockfish species:

1. DPS Scenario 1 is a PSP DPS identical to the PSP DPS defined by Stout et al. (2001a) for copper, quillback, and brown rockfish. This scenario posits a DPS consisting of the members of the species in question inhabiting the waters south or east of Admiralty Inlet and Deception Pass. This is the DPS structure that was identified in the petition.
2. DPS Scenario 2 (greater Puget Sound) hypothesisizes a DPS that includes PSP and NPS (which includes the San Juan Islands and Canadian Gulf Islands).

Table 3. Sample worksheet for evaluating potential DPS(s) of Puget Sound rockfishes using the “likelihood point” method (FEMAT 1993).

Puget Sound rockfish DPS delineation

FEMAT method (distribute 10 likelihood points among the DPS scenarios)*

Scenario 1: Puget Sound Proper	**Scenario 2: Greater Puget Sound**	**Scenario 3: Puget Sound/ Georgia Basin**	**Scenario 4: Part of coastal DPS**	**Total = 10**

* Each biological review team member distributes 10 likelihood points among the DPS scenarios. Placement of all 10 points in a given scenario reflects 100% certainty that this is the DPS configuration that incorporates the entire population segment. Distributing points between scenarios reflects uncertainty in whether a given scenario reflects the true DPS delineation.

3. DPS Scenario 3 (Puget Sound/Georgia Basin) hypothesizes a DPS that includes all inland marine water east of the central Strait of Juan de Fuca and south of the northern Strait of Georgia.
4. DPS Scenario 4 consists of a coastal DPS whose northern and southern terminus were not defined, but also includes the region described in DPS Scenario 3.

Factors Considered in Common to All Species

Based on the earlier DPS designations for copper, quillback, and brown rockfish (Stout et al. 2001a), the BRT generally assumed that in the absence of information indicating otherwise, the five petition species were likely to have DPSs in inland marine waters distinct from coastal populations. The reasoning for this is that the ecological and environmental factors considered by Stout et al. (2001a) and reviewed in earlier sections of this report—including the relatively site-attached nature of rockfish, the unique features of the Puget Sound/Georgia Basin ecosystem compared to the outer coast, and the environmental features of Puget Sound that serve to limit the potential for migration—all apply more or less equally to all rockfish, not just the three species considered by Stout et al. (2001a). The BRT also noted that relatively large genetic differences have been found between inner (Puget Sound or Strait of Georgia) and outer (California Current) populations for every rockfish species for which such comparisons have been made. This suggests that the same patterns might be expected in other rockfish species, unless their life history differs in ways that may have a substantial effect on dispersal and connectivity. The BRT therefore concluded that, in the absence of other information, rockfish of all species that inhabit the Georgia Basin or Puget Sound are likely to meet the “discreteness” criteria of the DPS policy.

The BRT also concluded that, in the absence of other information, all rockfish species in Georgia Basin or Puget Sound that are discrete are also likely to meet the “significance” criteria of the DPS policy. As highlighted earlier and in Appendix E, Puget Sound/Strait of Georgia is a unique environment, and the environmental conditions experienced by rockfish in this region are distinct from those elsewhere in their range. In particular, Puget Sound circulation is highly influenced by freshwater input, relatively shallow sills limit exchange among subbasins of the system, waters are typically highly stratified for part of the year, the bathymetry results in a very limited shallow water habitat, and there is a strong link between biogeochemical dynamics in freshwater watersheds and the marine system. These features, among others, make the Puget Sound/Strait of Georgia region substantially different than the rest of the California Current Large Marine Ecosystem.

We discuss below what specific additional information was available for each of the petitioned species, and how the BRT used this information (or lack thereof) to come to conclusions regarding distinct population segments.

Bocaccio

DPS Scenario 3 (Puget Sound/Georgia Basin) received the most votes (43 pts), followed by DPS Scenario 4 (part of coastal DPS, 32 pts) and DPS scenario 1 (PSP, 15 pts).

Discreteness of the DPS

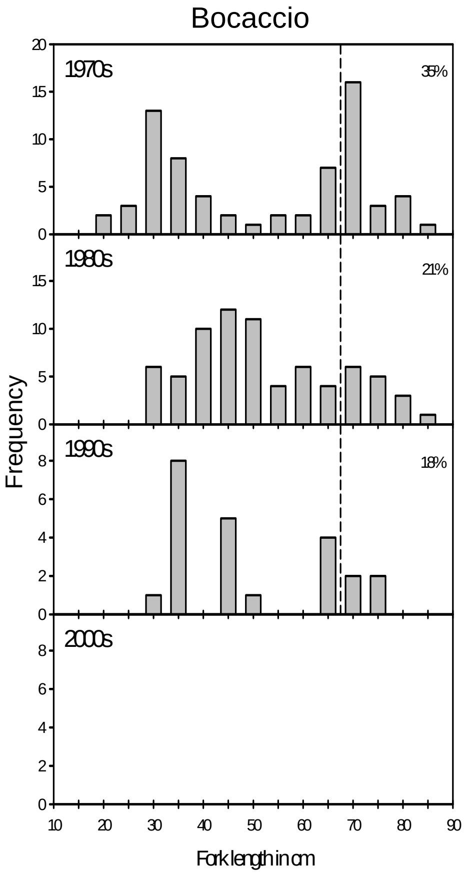
As discussed above, the BRT generally assumed that all rockfish are likely to have at least one DPS in inland marine waters. Thus the approach of the BRT was to evaluate the evidence contradicting or supporting this assumption. The absence of published studies comparing genetic characteristics of bocaccio from Puget Sound and outer coastal areas required the BRT to evaluate other less direct measures of discreteness.

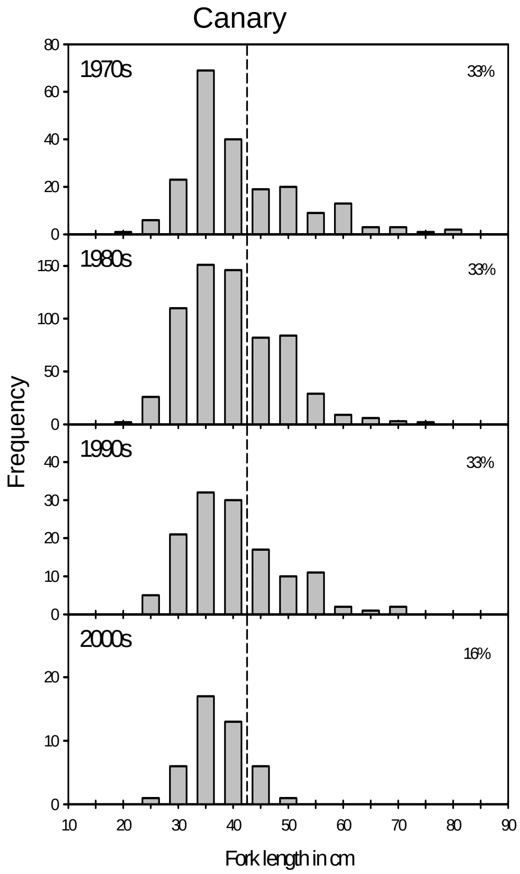
The BRT noted that studies of coastal bocaccio populations have found little genetic differentiation over large geographic distances (discussed above). In addition, compared to some other rockfishes, bocaccio appear to have greater potential to move long distances (see Bocaccio General Biology subsection above) than some rockfishes, suggesting that a DPS for bocaccio could encompass a greater area than a DPS for more sedentary species such as copper, quillback, and brown rockfish. Thus the BRT considered the hypothesis that Puget Sound bocaccio are either the result of a rare recruitment event and never were a viable population distinct from the coastal populations, or are regularly connected to coastal populations by dispersal. The only evidence available to address this hypothesis was length frequency data (Figure 14). Using these data, the BRT used von Bertalanffy growth parameters for bocaccio (from Tolimieri and Levin 2005) to convert length to age. Since the year that fish were sampled is known, it is then possible to estimate the birth year of fish. These estimates revealed strong year classes in 1967, 1976–78, and 1993 (Figure 15). In contrast, the strong coastal year classes were 1962–1963, 1978, 1989, and 1999.

Given that the ages the BRT estimated were approximate, it is possible that there is some correspondence between the strong late 1970s year classes in Puget Sound and the coast. However, the strong 1989 and 1999 coastal year classes are virtually absent in Puget Sound. Similarly, the strong 1967 and 1993 Puget Sound year classes do not correspond to strong coastal year classes. Importantly, Tolimieri and Levin (2005) used data from the California populations of bocaccio, and thus these patterns should be interpreted with some caution. However, substantial spatial synchrony in recruitment of several rockfish species that have been studied occurs at the scales of 500–1,000 km (Field and Ralston 2005). In addition, the BRT noted that the 1999 year class was strong for many rockfish in the northern portion of the California Current (e.g., Hamel 2007, Stewart 2007), suggesting to the BRT that the strong 1999 recruitment for bocaccio south of Cape Mendicino was likely to have also occurred in more northerly locations.

These size frequency data also revealed the presence of individuals large enough to be sexually mature (Figure 14). Given the retentive circulation patterns of Puget Sound, the BRT discussed that a significant fraction of larvae released by bocaccio (especially in more inland portions of the sound) could be retained within the sound.

Taken together, the limited available information on bocaccio provides some evidence supporting the hypothesis that Puget Sound and coastal populations are discrete. In their deliberations, the BRT considered this evidence suggestive of an inland DPS rather than conclusive.





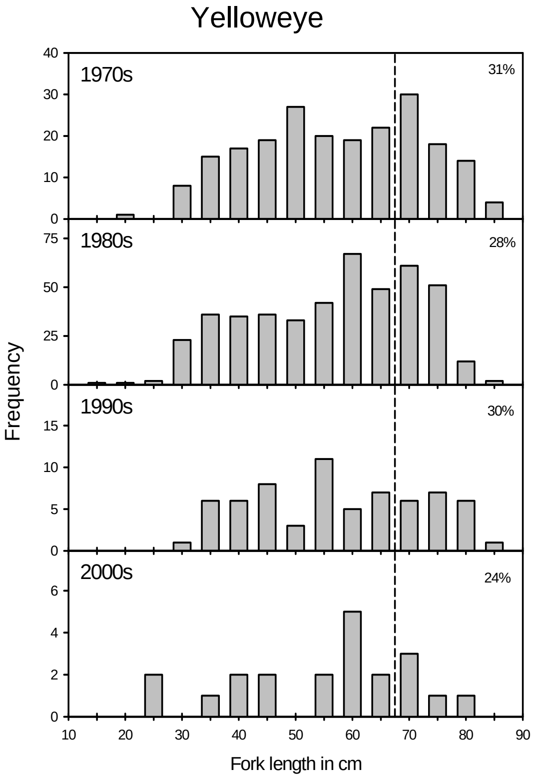


Figure 14a. Length frequency distributions of three of the five petitioned species over time. Sizes binned in 5 cm classes and within decades. All data are from WDFW recreational fisheries records. Vertical lines depict the size at which about 30% of the population was comprised of fish larger than the rest of the population in the 1970s, providing a reference point for comparison with later decades. Note that the scale for the frequencies varies among decades.

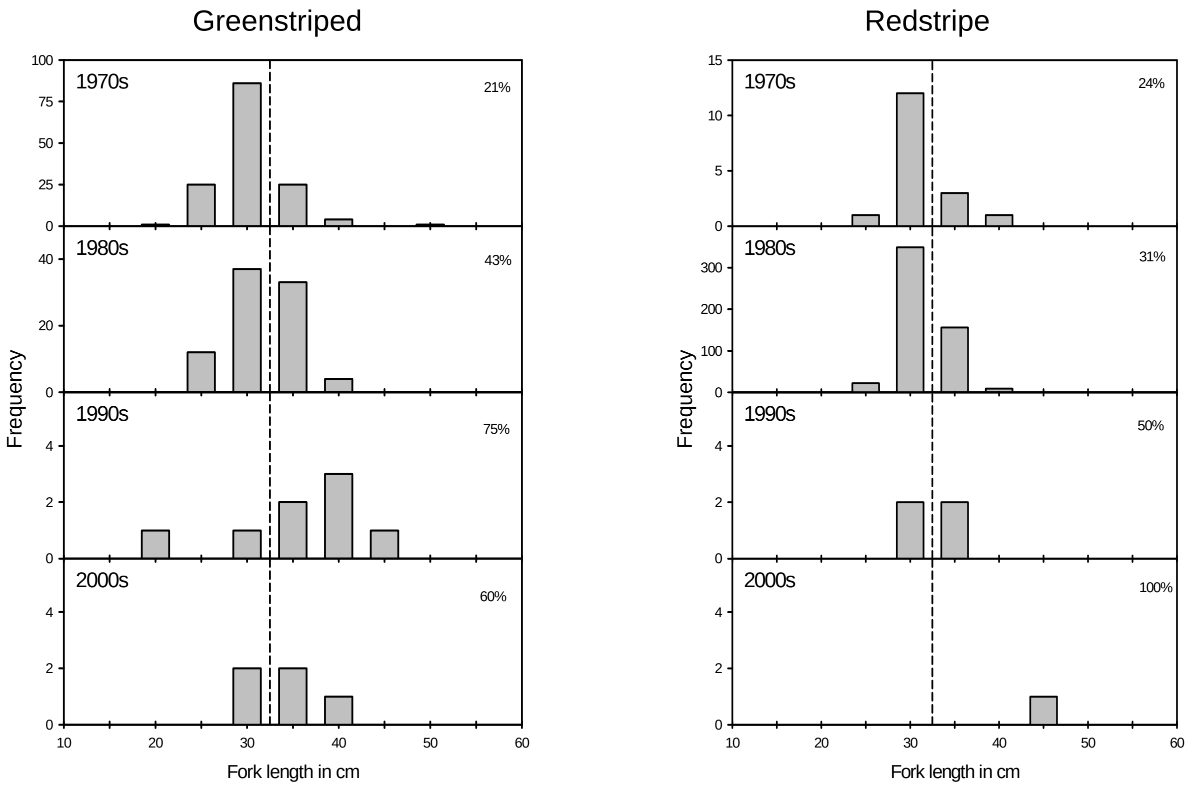


Figure 14b. Length frequency distributions of two of the five petitioned species over time. Sizes binned in 5 cm classes and within decades. All data are from WDFW recreational fisheries records. Vertical lines depict the size at which about 30% of the population was comprised of fish larger than the rest of the population in the 1970s, providing a reference point for comparison with later decades. Note that the scale for the frequencies varies among decades.

The final distribution of BRT votes on DPS scenarios reflected uncertainty resulting from the lack of direct genetic evidence. Scenario 3, the Puget Sound/Georgia Basin DPS, drew 48% of the votes. A DPS that included the coastal populations (Scenario 4) also received significant support (35% of the votes), and a PSP DPS received votes (16%). Thus while the BRT recognized that there is some evidence supporting a coastal DPS, on balance the BRT did not consider this evidence strong enough to refute the starting assumption of an inland DPS.

Significance of the DPS

In addition to the factors considered in common to all rockfish species discussed above, the BRT noted that Puget Sound/Strait of Georgia is distant from the center of the bocaccio distribution (in California, as discussed above), suggesting that the Puget Sound populations occupy a particularly unique environment for this species.

Relationship to coastal DPSs

In a previous ESA status review of bocaccio off the California coast, MacCall and He (2002) determined that there were at least two DPSs of coastal bocaccio, a southern and a northern DPS, with the boundary between them occurring at the California/Oregon border. The

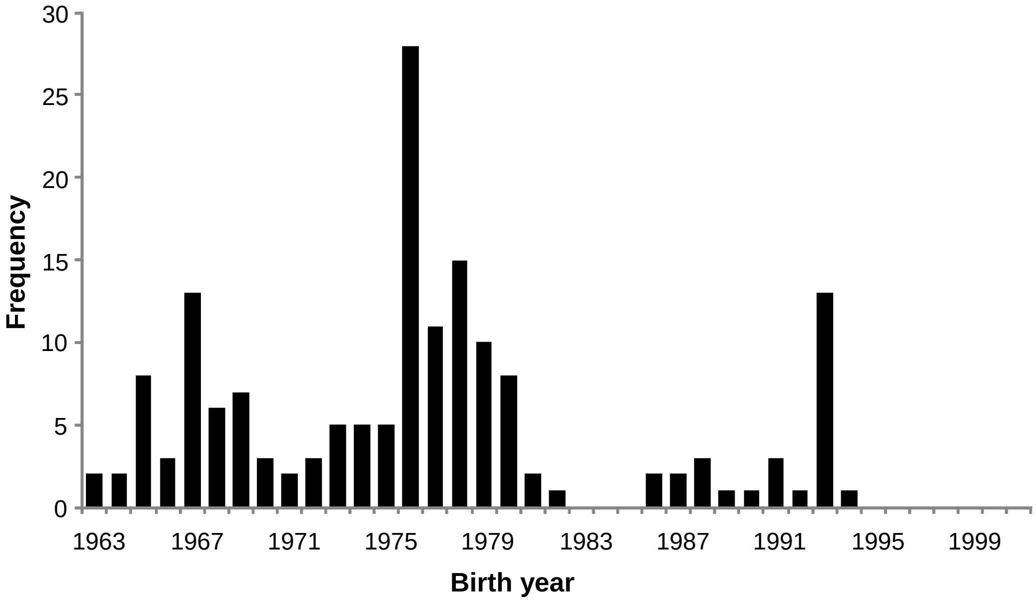


Figure 15. Frequency distribution of Puget Sound bocaccio birth years derived from the length frequency information shown in Figure 14a and Figure 14b.

Puget Sound/Georgia Basin bocaccio DPS identified in this status review is therefore a third bocaccio DPS, distinct from both the southern and northern coastal DPSs.

Yelloweye Rockfish

DPS Scenario 3 (Puget Sound/Georgia Basin) received the most support (49 pts), followed by DPS Scenario 1 (PSP, 34 pts) and DPS Scenario 4 (part of a coastal DPS, 7 pts). Although BRT members thus concluded that DPS Scenario 3 is most compatible with available information for yelloweye rockfish, substantial uncertainties remain, especially with regard to the extent dispersal between Puget Sound and the Strait of Georgia.

Discreteness of the DPS

In addition to the general consideration in common to all rockfish species summarized above, members of the BRT used several lines of evidence to support their identification of a Puget Sound/Georgia Basin DPS for yelloweye rockfish. In particular, Yamanaka et al. (2006) and R. Withler (unpubl. data) report on genetic differences in this species between samples from inland marine waters. Their samples, collected from interior waters between Vancouver Island and mainland British Columbia, formed a discrete genetic cluster that differed consistently from coastal samples. The BRT took this as reasonable evidence suggesting that yelloweye rockfish from the Georgia Basin are also likely to be genetically differentiated from the coastal population.

In addition, two aspects of the life history of yelloweye rockfish discussed earlier favor genetic and potentially demographic isolation. First, both adult and juvenile yelloweye rockfish are closely associated with rocky substrata (or invertebrates associated with hard substrate). Such habitat is infrequent and patchy in its distribution in NPS and the Strait of Georgia, and is very rare in Puget Sound inside Admiralty Inlet. Second, yelloweye rockfish show very limited movement as adults. Thus any disruption in gene flow resulting from the retentive patterns of circulation of the Puget Sound/Strait of Georgia is reinforced by the lack of adult movement.

Given the available genetic data and life history of yelloweye rockfish in concert with the hydrography of the region, the BRT largely ruled out DPS scenarios 2 and 4. While genetic information indicates that PSP might be genetically distinct from the rest of the region, the BRT relied on historic distribution information and habitat availability in its assessment. In particular, the BRT believed that the historical abundance of yelloweye rockfish was greater in NPS (Appendix F, Palsson et al. 2009), and this was the result of the lack of appropriate rocky habitat in PSP (Palsson et al. 2009). Thus even if PSP supported, at times, a semidiscrete subpopulation, the BRT was not convinced that it would be distinct demographically or ecologically from yelloweye rockfish inhabiting the greater Georgia Basin. As a result, the BRT concluded that the DPS should extend northward to include the San Juan Islands and Strait of Georgia where rockier habitat is available and yelloweye rockfish are currently found.

Significance of the DPS

See above subsection, Factors Considered in Common to all Species.

Relationship to other DPSs

The BRT concluded that Puget Sound/Georgia Basin yelloweye rockfish are a DPS distinct from coastal yelloweye rockfish populations. Coastal populations of yelloweye rockfish therefore consist of one or more DPSs distinct from the Puget Sound/Georgia Basin DPS. The BRT's focus was on the Puget Sound/Georgia Basin population that was the subject of the petition, and the BRT therefore made no attempt to determine whether coastal populations of yelloweye rockfish consist of a single versus multiple additional DPSs.

Canary Rockfish

DPS Scenario 3 (Puget Sound/Georgia Basin) received the most support (58 pts), followed by DPS Scenario 4 (part of a coastal DPS, 17 pts) and DPS scenario 1 (PSP, 15 pts). BRT members agreed that DPS Scenario 3 coincides best with available information for canary rockfish, although substantial uncertainties remain, especially with regard to the extent of the NPS and Strait of Georgia boundaries.

Discreteness of the DPS

As was the case for other species, the fact that all available genetic information suggests considerable separation among populations of rockfish dwelling in the California Current versus Georgia Basin suggested to the BRT that there was a high probability that similar partitioning would occur in canary rockfish. Thus the BRT did not believe that a combined coastal/inland DPS (Scenario 4) was likely, although it did receive some support due to the relatively high potential for movement in this species. However, due to this high movement potential, a separation of PSP from the Strait of Georgia also seemed unlikely to the BRT. Examination of historical records of abundance and distribution revealed large populations of canary rockfish in SPS (Appendix F). The BRT thought that, while abundant in SPS, this segment of the population would not be distinct from the portion of the population north of Admiralty Inlet because of the propensity for adult movement in canary rockfish.

Significance of the DPS

See above subsection, Factors Considered in Common to all Species.

Relationship to other DPSs

The BRT concluded that Puget Sound/Georgia Basin canary rockfish are a DPS distinct from coastal canary rockfish populations. The coastal populations of canary rockfish therefore consist of one or more DPS distinct from the Puget Sound/Georgia Basin DPS. The BRT's focus was on the Puget Sound/Georgia Basin population that was the subject of the petition, and the BRT therefore made no attempt to determine whether coastal populations of canary rockfish consist of a single versus multiple additional DPSs.

Redstripe Rockfish

DPS Scenario 1 (PSP) received the most votes (40 pts), followed by DPS Scenario 3 (Puget Sound/Georgia Basin, 31 pts) and DPS scenario 4 (part of coastal DPS, 19 pts).

Discreteness of the DPS

No genetic data were available for this species at the time of the status review, although the NWFSC is in the process of analyzing some samples. Compared to other rockfish species, redstripe rockfish tend to occur in the mud and sand habitat that characterizes much of PSP. With very little information to go on, the BRT therefore largely relied on the information from other species, particularly the previous status review of copper, quillback, and brown rockfish (Stout et al. 2001a) to make DPS conclusions. In particular, the BRT found no compelling information to suggest that populations of redstripe rockfish in PSP would be any less distinct from other Georgia Basin populations than was the case for the previously reviewed species.

Significance of the DPS

Consistent with the earlier conclusions of Stout et al. (2001a), the BRT concluded that PSP is an ecologically unique environment distinct from other parts of Georgia Basin. In addition, the BRT noted that historical records indicated a long-standing presence of this species in PSP (Appendix F).

Relationship to other DPSs

The BRT concluded that PSP redstripe rockfish are a DPS distinct from redstripe rockfish in other parts of the Georgia Basin and coastal populations. Redstripe rockfish outside PSP therefore consist of at least one, and possibly more than one, additional DPS. The BRT did not attempt to determine how many additional DPSs of redstripe rockfish may exist.

Greenstriped Rockfish

DPS Scenario 1 (PSP) received the most votes (41 pts), followed by DPS Scenario 3 (Puget Sound/Georgia Basin, 31 pts) and DPS scenario 4 (part of a coastal DPS, 18 pts).

Discreteness of the DPS

Almost no genetic data were available for this species, and no genetic samples were available from PSP. Compared to other rockfish species, greenstriped rockfish tend to occur in the mud and sand habitat that characterizes much of PSP. With very little information to go on, the BRT therefore largely relied on information from other species, particularly the previous status review of copper, quillback, and brown rockfish (Stout et al. 2001a) to make DPS conclusions. In particular, the BRT found no compelling information to suggest that populations of greenstriped rockfish in PSP would be any less distinct from other Georgia Basin populations than was the case for the previously reviewed species.

On the other hand, the BRT noted that the Strait of Juan de Fuca contains areas of good habitat for greenstriped rockfish, as reflected in survey trawl catch records there and in the Strait of Georgia. However, the BRT noted that this species was not captured in a large area north of Admiralty Inlet and south of San Juan Islands, which supports the concept of PSP as a discrete population. Countering this, some BRT members thought that the apparent interannual variability in greenstriped rockfish biomass in Puget Sound observed in the WDFW trawl survey could result from movement into NPS from coastal populations. Thus the BRT was unable to reach a firm conclusion on the boundaries of this DPS, although based on the general considerations discussed above for all rockfish, the BRT concluded that a DPS in inland marine waters distinct from the coast was likely.

Significance of the DPS

Consistent with the earlier conclusions of Stout et al. (2001a), the BRT concluded that PSP is an ecologically unique environment distinct from other parts of Georgia Basin. In addition, the BRT noted that historical records (Appendix F) indicate a long-standing presence of this species in PSP.

Relationship to other DPS

The BRT concluded that PSP greenstriped rockfish are a DPS distinct from greenstriped rockfish in other parts of the Georgia Basin and coastal populations. Greenstriped rockfish outside PSP therefore consist of at least one, and possible more than one, additional DPS. The BRT did not attempt to determine how many additional DPSs of greenstriped rockfish may exist.

Western Boundary of the Puget Sound/Georgia Basin Bocaccio, Yelloweye Rockfish, and Canary Rockfish DPSs

The BRT noted that the Strait of Juan de Fuca is a transition zone between the oceanic waters of the California Current and inland waters of Puget Sound/Georgia Basin. There was general agreement among BRT members that there is unlikely to be a sharp boundary that separates populations residing in these two systems. Consequently, the BRT noted there is uncertainty about the exact location of the western boundary of the Puget Sound/Georgia Basin DPSs for bocaccio, yelloweye rockfish, and canary rockfish. The BRT considered two possible western boundaries: the Sekiu River and the Victoria sill (Figure 16).

The Sekiu River is used as the western boundary in the WDFW assessment of rockfishes (Palsson et al. 2009). The BRT considered the Sekiu River a precautionary boundary in that it is very unlikely that any biologically relevant divisions would occur west of that point. The Victoria sill bisects the Strait of Juan de Fuca and runs from east of Port Angles north to Victoria (Figure 16). This sill is a significant oceanographic feature in the Strait of Juan de Fuca. The deep oceanic water in the Juan de Fuca Strait extends up to a depth of about 100 m at the Pacific end of the strait, and its thickness diminishes along the strait to just a few meters at the Victoria sill (Masson 2002). Patterns of circulation created by the sill create discontinuities in temperature, salinity (Masson and Cummins, 2000), nitrogen (Mackas and Harrison, 1997), primary production (Foreman et al. 2008), and water column organic carbon (Johannessen et al. 2008). The Victoria sill also appears to have the potential to restrict larval dispersal (Engie and Klinger 2007).

Using the FEMAT voting procedure described previously, BRT members distributed 10 votes among the two western boundary options. Victoria sill received 43 votes, while the Seikiu River received 17 votes (note that three BRT members were absent for this vote). Thus the BRT concluded that the Victoria sill is the more likely western boundary for the Puget Sound/Georgia Basin DPSs, although there is clearly some uncertainty in this designation.

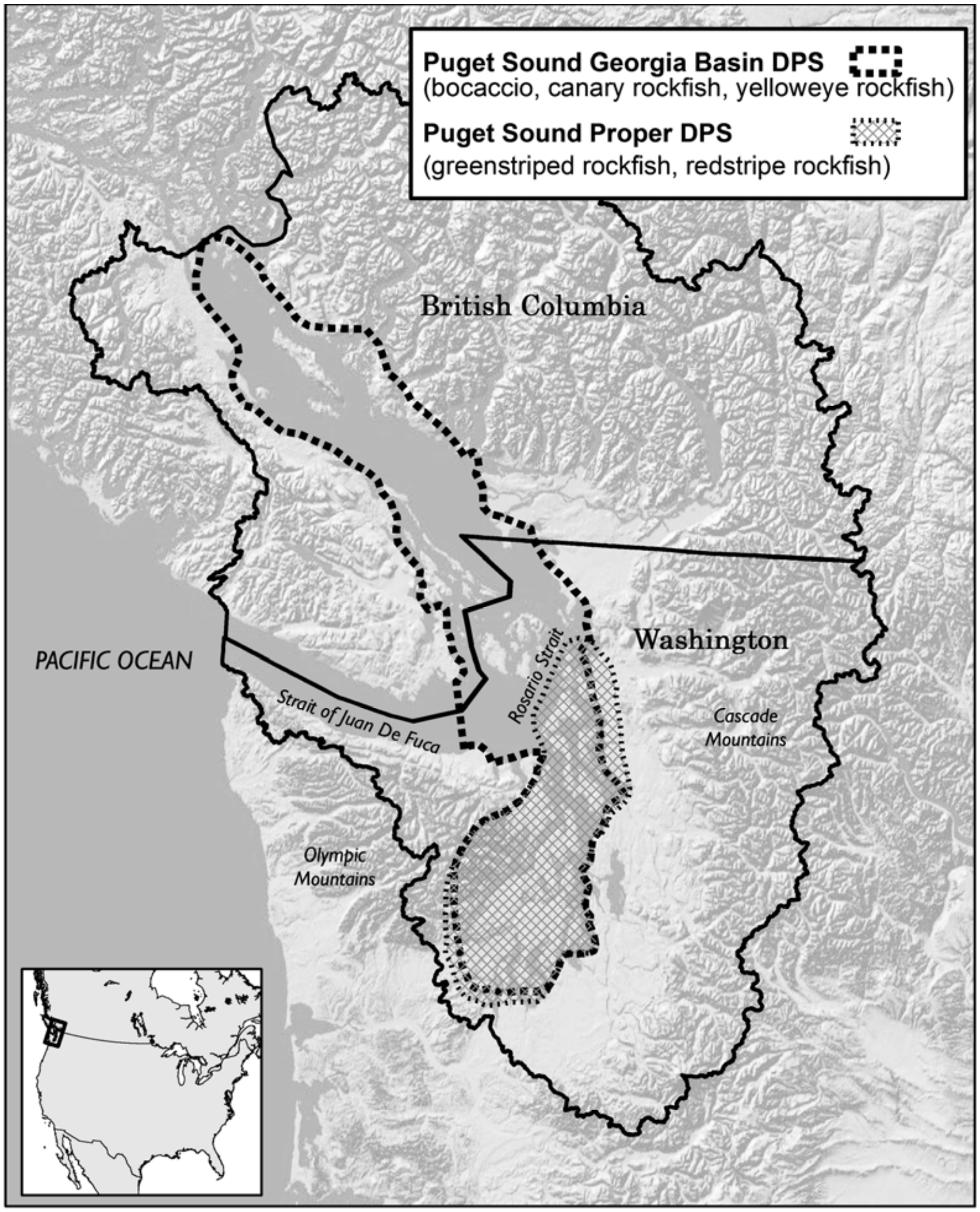


Figure 16. Map depicting the approximate DPS boundaries for the Georgia Basin/Puget Sound and PSP DPSs. Figure is for purposes of illustration only and should not be used to identify precise boundaries.

The Extinction Risk Question

Approaches to the Determination of Extinction Risk

The ESA (Section 3) defines endangered species as “any species which is in danger of extinction throughout all or a significant portion of its range.” Threatened species is defined as “any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range.” NMFS considers a variety of information in evaluating the level of risk faced by a DPS, including: 1) absolute abundance of fish and their spatial and temporal distributions; 2) current abundance in relation to historical abundance and carrying capacity of the habitat; 3) trends in abundance based on indices such as catch statistics, catch per unit effort (CPUE), and spawner-recruit ratios; 4) natural and human-influenced factors that cause variability in survival and abundance; 5) possible threats to genetic integrity (e.g., selective fisheries and interactions between cultured and natural populations); and 6) recent events (e.g., climate change and changes in management) that have predictable short-term consequences for the abundance of a DPS. Additional risk factors, such as disease prevalence or changes in life history traits, also may be considered in the evaluation of risk to a population.

Absolute Numbers

The absolute abundance of individuals in a population is important in assessing two aspects of extinction risk. First, the size of small populations can be an indicator of whether the population can sustain itself in the face of environmental fluctuations and small-population stochasticity, even if the population currently is stable or increasing. This conclusion follows from consideration of Allee effects and the theory of minimum viable populations (Gilpin and Soulé 1986, Thompson 1991). Second, present abundance in a declining population is an indicator of the time expected until the population reaches critically low numbers. This follows from the idea of “driven extinction” (Caughley and Sinclair 1994). In addition to absolute abundances, the spatial and temporal distributions of adults are important in assessing risk to a DPS. Spatial distribution is important, both at the scale of the spawning population and the metapopulation.

Assessments of marine fish populations have focused on determining abundance and trends from models fit to catch, survey, and biological data. Catch records, fishery and survey CPUE, and biomass estimates from research cruises constitute most of the data available to estimate abundance. The estimated numbers of reproductive adults is the most important measure of abundance in assessing the status of a population. Data on other life history stages can be used as a supplemental indicator of abundance. In the case of the five petitioned species, very little information is available on their absolute abundance in the Puget Sound/Georgia Basin area. The BRT therefore focused largely on trends in various abundance indices, which are described in greater detail below.

Historical Abundances and Carrying Capacity

The relationship of present abundance to present carrying capacity is important for evaluating the health of a population, but a population with abundance near the carrying capacity of the habitat it occupies does not necessarily indicate that the population is healthy. Population abundances near carrying capacity imply that the effectiveness of short-term management actions is limited in increasing population abundance. The relationship between current abundance and habitat capacity to the historical relationship between these variables is an important consideration in evaluating risk. An understanding of historical conditions provides a perspective of the conditions under which present populations evolved. Estimates of historical abundances also provide the basis for establishing long-term abundance trends. Comparisons of past and present habitat capacity can also indicate long-term population trends and potential problems stemming from population fragmentation.

Trends in Abundance

Short-term and long-term trends in abundance are primary indicators of risk in natural populations. Trends may be calculated with a variety of quantitative data, including catch, CPUE, and survey data. Trend analyses for the five species considered in this status review are greatly limited by the lack of long time series of abundances in greater Puget Sound for these species. In addition, although abundance time series are available for other, more common Puget Sound rockfish species, these time series are characterized by a lack of regular sampling, use of different survey methods for a species, and, for harvest data, the imposition of harvest regulations. The BRT took several approaches to utilize the best available data in order to estimate the abundance trends; these are discussed in greater detail below.

Factors Influencing Abundance

Several natural and anthropogenic factors influence the degrees of risk facing populations of marine fish in greater Puget Sound. Recent changes in these factors may influence the degree of risk of a population without apparent changes in abundance, because of time lags between the events and the effects on the population. Thus a consideration of these effects extends beyond the examination of recent trends in abundance. The BRT considered documented physical and climatic changes, but did not consider possible effects of recent or proposed conservation measures. Population variability in itself may not be an indication of risk. Habitat degradation and harvest have most likely weakened the resilience of populations in greater Puget Sound to climate variability and impacts such as predation by other species.

Threats to Genetic Integrity

Artificial propagation and enhancement of populations in greater Puget Sound does not presently appear to be a risk factor for the species considered here. However, mariculture of some species is under development and the effects of hatchery releases (either of the species in question or of species that prey upon or compete with the petitioned species) on natural populations may be important in the future. The interbreeding of cultured and natural fish can potentially lead to a loss in fitness of naturally spawning populations. The genetic effects of artificially propagated releases of species with high fecundities, as is common for many marine fishes, could be substantial. Ryman and Laikre (1991), Waples and Do (1994), and Ryman et al. (1995) discussed possible risks associated with enhancement of marine populations, but these risks are difficult to quantify and to incorporate into risk analysis. The chief concern is that the release of propagated fish, which may be inadvertently modified by breeding practices and novel rearing environments, may lead to the erosion of genetic diversity and fitness in natural populations. In addition, there are ecological risks, such as predation or competition, to be considered when evaluating the effects of releasing propagated fish.

Human activities other than population enhancement can also influence the genetic characteristics of natural populations. These include size-selective harvest methods (Nelson and Soulé 1987); introductions of nonnative species; and alterations of marine habitats by shoreline development, increased siltation in river runoff, and pollution. At the present time, empirical information documenting the genetic effects of these kinds of changes is largely lacking.

Climate Variability

Coupled changes in atmospheric and ocean conditions have occurred on several different time scales and influenced the geographical distributions, and hence local abundances, of marine fishes. On time scales of hundreds of millennia, periodic cooling produced several glaciations in the Pleistocene Epoch (Imbrie et al. 1984, Bond et al. 1993). The central part of greater Puget Sound was covered with ice about 1 km thick during the last glacial maximum about 14,000 years ago (Thorson 1980). Since the end of this major period of cooling, several population oscillations of pelagic fishes, such as anchovies and sardines (*Sardinops sagax*), have been noted on the west coast of North America (Baumgartner et al. 1992). These oscillations with periods of about 100 years have presumably occurred in response to climatic variability.

On decadal time scales, climatic variability in the North Pacific and North Atlantic oceans has influenced the abundances and distributions of widespread species, including several species of Pacific salmon (Mantua et al. 1997, Francis et al. 1998) in the North Pacific, and Atlantic herring (*Clupea harengus*) (Alheit and Hagen 1997) and Atlantic cod (*Gadus morhua*) (Swain 1999) in the North Atlantic. Recent declines in marine fish populations in greater Puget Sound may reflect recent climatic shifts; however, we do not know whether these climatic shifts represent long-term changes or short-term fluctuations that may reverse in the near future.

Size Distributions

Size data provides some insight about the degree to which populations of the petitioned species were the result of rare (even single) recruitment events versus multiple, less episodic events. The former may indicate that Puget Sound represents a sink population that is part of a larger DPS, while the latter is more suggestive of a self-sustaining population. Length frequency data also provides information about the degree to which large size classes have been removed from the populations, the implications of which are discussed in detail under the Threats Assessment for Petitioned Species of Rockfish subsection.

Risk Assessment Methods

One of the greatest difficulties in the status review process is organizing a large amount of information regarding the biology of the species, genetics, and population trends over time.

Often the ability to measure or document risk factors is limited, and information is not quantitative and very often lacking altogether. In assessing risk, it is often important to include both qualitative and quantitative information. In previous NMFS status reviews, BRTs have used a risk matrix method (Table 4) to organize and summarize the professional judgment of a panel of knowledgeable scientists. This approach is described in detail by Wainright and Kope (1999) and has been used in Pacific salmonid status reviews (e.g., Good et al. 2005, Hard et al. 2007), as well as in reviews of Pacific hake, walleye pollock, Pacific cod (Gustafson et al. 2000), Puget Sound rockfishes (Stout et al. 2001a), Pacific herring (Stout et al. 2001b, Gustafson et al. 2006), and black abalone (*Haliotis chracherodi*) (VanBlaricom et al. 2009).

In the risk matrix approach, the collective condition of individual populations is summarized at the DPS level according to four demographic risk criteria: abundance, growth rate/productivity, spatial structure/connectivity, and diversity. These viability criteria, outlined in McElhany et al. (2000), reflect concepts that are well-founded in conservation biology and generally applicable to a wide variety of species. These criteria describe demographic risks that individually and collectively provide strong indicators of extinction risk. The summary of demographic risks and other pertinent information obtained by this approach is then considered by the BRT in determining the species' overall level of extinction risk.

Population viability analysis (PVA) is generally defined as the use of quantitative methods to predict the future status of a population. Future status typically refers to the probability of the population reaching some minimum size within some specified time horizon. Because of data limitations described below, the BRT did not conduct a formal quantitative PVA. However, as detailed in the following subsections, data were available that allowed an estimate in the trend in abundance of rockfishes and the BRT considered this information.

After reviewing all relevant biological information for the species, each BRT member assigned a risk score to each of the four demographic criteria. The scores were tallied (means, modes, and range of scores), reviewed, and the range of perspectives discussed by the BRT before making its overall risk determination. Although this process helps to integrate and summarize a large amount of diverse information, there is no simple way to translate the risk matrix scores directly into a determination of overall extinction risk. For example, a DPS with a single extant subpopulation might be at a high level of extinction risk because of high risk to spatial structure and connectivity, even if it exhibited low risk for other demographic criteria. Another species might be at risk of extinction because of moderate risks to several demographic criteria.

Scoring Population Viability Criteria

Risks for each demographic criterion are ranked on a scale of 1 (very low risk) to 5 (very high risk):

1. Very low risk: It is unlikely that this factor contributes significantly to risk of extinction, either by itself or in combination with other factors.
2. Low risk: It is unlikely that this factor contributes significantly to risk of extinction by itself, but some concern that it may, in combination with other factors.

Table 4. Template for the risk matrix used in BRT deliberations. The matrix is divided into five sections that correspond to the four VSP parameters (McElhany et al. 2000) plus a recent events category.

Risk Category	Score
Abundance[a] Comments:	
Growth rate/productivity[a] Comments:	
Spatial structure and connectivity[a] Comments:	
Diversity[a] Comments:	
Recent events[b]	

[a] Rate overall risk to the DPS on 5-point scale: 1–very low risk, 2–low risk, 3–moderate risk, 4–high risk, and 5–very high risk.

[b] Rate recent events from double plus (+ +) strong benefit to double minus (– –) strong detriment.

3. Moderate risk: This factor contributes significantly to long-term risk of extinction, but does not in itself constitute a danger of extinction in the near future.
4. High risk: This factor contributes significantly to long-term risk of extinction and is likely to contribute to short-term risk of extinction in the foreseeable future.
5. Very high risk: This factor by itself indicates danger of extinction in the near future.

Recent Events

The "recent events" category considers events that have predictable consequences for DPS status in the foreseeable future but have occurred too recently to be reflected in the demographic data. Examples include a climatic regime shift or El Niño that may be anticipated to result in increased or decreased predation in subsequent years. This category is scored as follows:

+ +	expect a strong improvement in status of the DPS
+	expect some improvement in status
0	neutral effect on status
–	expect some decline in status
– –	expect strong decline in status

Data Reviewed by the BRT

The demographic risk data reviewed by the BRT are summarized in this report. Information, in addition to that submitted as part of the administrative record, that was most useful as sources of both quantitative and qualitative data pertinent to the demographic risk analysis is described below and in Appendix D.

Recreational Fishery Data

The main data available on Puget Sound rockfish trends are from surveys of recreational anglers conducted by the Washington Department of Fish and Wildlife (WDFW) (Buckley 1967, 1968, 1970, Bargmann 1977, Palsson 1988, Palsson et al. 2009). These data are collected from punch cards sent in by licensed anglers and from dockside surveys. WDFW extrapolates the rockfish per angler data up to total catch using an estimate of number of trips derived from the salmon recreational fishery (Palsson et al. 2009). The data are reported both for the targeted catch (targeting bottomfish) and the incidental catch (targeting salmon). For the trend analyses here, only data from the fishery targeting bottomfish were used. The data for PSP (punch card areas 8–13, Figure 17), NPS (punch card areas 5–7, Figure 17), and all Puget Sound (punch card areas 5–13, Figure 17) are plotted in Figure 18. The raw numbers are given in Table 5, Table 6, and Table 7. Note that all sources analyze the same raw data (WDFW creel survey data), but different adjustments have been made to the data.

The Department of Fisheries and Oceans Canada (DFO) has also conducted a creel survey of the recreational fishery in the waters of the Strait of Georgia (DFO statistical areas 13–19, 28, and 29). We did not include these data in the trend analyses because the effort data

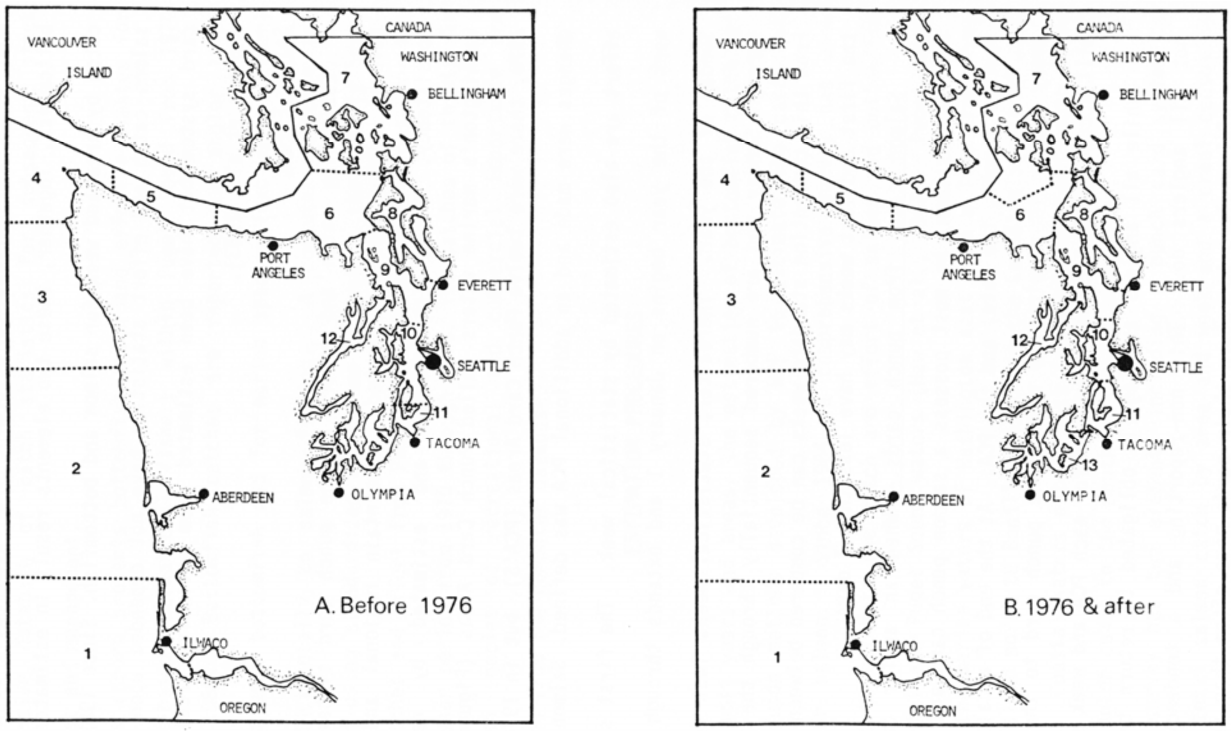


Figure 17. Punch card areas for WDFW recreational data. PSP (areas 8–13) and NPS (areas 5–7) are used in this analysis. (Reprinted from Palsson 1988.)

(angler trips) and catch data (total rockfish) that we were able to obtain included both salmon-targeted trips and groundfish-targeted trips. Information on trends of bocaccio, canary rockfish, and yelloweye rockfish in Canadian waters in the Strait of Georgia are included in the subsections on individual species.

The recreational data have numerous limitations reviewed in Palsson et al. (2009). In particular during 1994–2003, the total catch was still estimated using salmon fishery data, yet restrictions on the salmon fishery lead to limited information from that fishery. In addition, the bag limit on rockfish was lowered from 15 fish in 1983 to 1 rockfish per trip in both NPS and PSP in 2000. Reductions in bag limits directly reduces the fish per trip by capping the maximum and may lead to changes in angler targeting, leading to reductions in the number of rockfish taken per trip. To correct for the effects of bag limits and changes in angler targeting, the trend analyses treat each bag limit period as a separate data set and a scaling parameter to adjust the mean for each period is estimated.

Commercial Data

Commercial data with effort information are available from records on the bottom trawl fishery operating until 1988 (Holmberg 1967, PMFC 1979, Schmitt et al. 1991). Effort data (hours trawled) are available from 1955 (Table 8). While other commercial fisheries have operated in Puget Sound, there was no effort information available. Data for other gears were

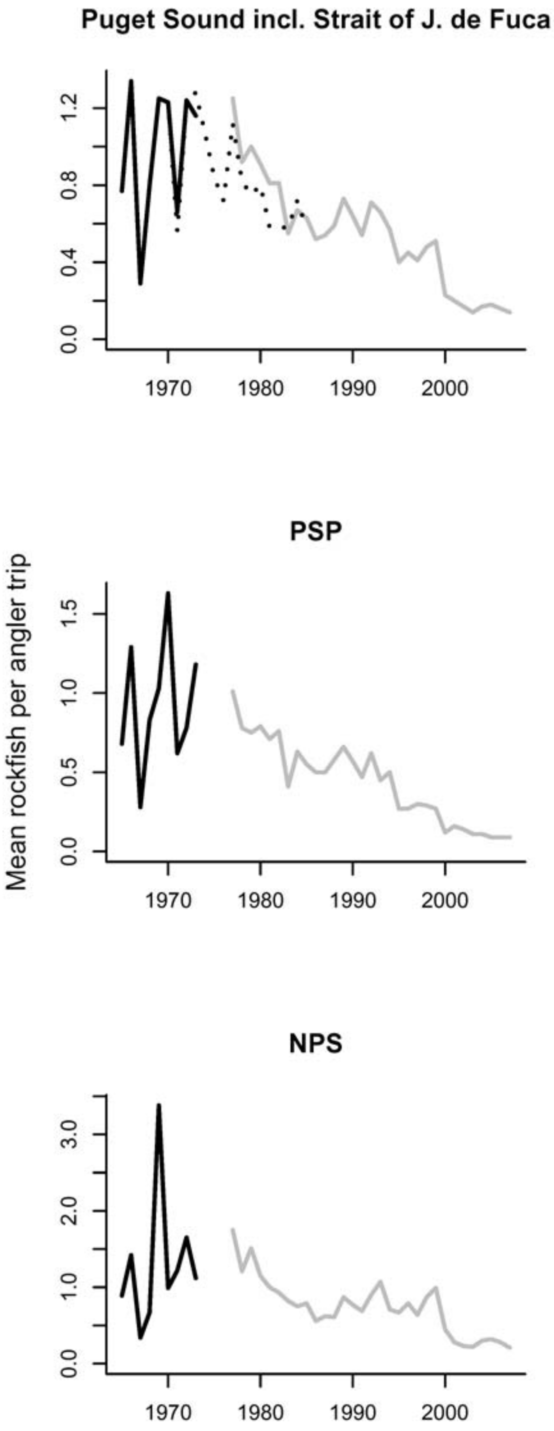


Figure 18. Rockfish per angler trip for bottomfish-specific recreational fishery. Black line refers to data from Buckley (1967, 1968, 1970) and Bargmann (1977). Dotted line refers to data from Palsson 1988 and gray line refers to data from Palsson et al. 2009.

Table 5. Total rockfish CPUE data from recreational bottomfish for the entire Puget Sound, including Strait of Juan de Fuca. Data estimates average rockfish per trip (total catch in punch card areas 5–13 [6–12 for Buckley and Bargmann] divided by the total trips in areas 5–13 [or 6–12]). Regions 7, 8, and 12 had no data in 1971 and regions 7 and 8 in 1973. Buckley and Bargmann data from Buckley (1967, 1968, 1970) and Bargmann (1977).

Year	Buckley and Bargmann	Palsson et al. 2009	Palsson 1988
1965	0.77		
1966	1.34		
1967	0.29		
1968	0.80		
1969	1.25		
1970	1.23		1.23
1971	0.66		0.56
1972	1.24		1.24
1973	1.16		1.28
1974			1.07
1975			0.84
1976			0.72
1977		1.25	1.12
1978		0.92	0.82
1979		1.00	0.75
1980		0.91	0.80
1981		0.81	0.58
1982		0.81	0.58
1983		0.55	0.58
1984		0.67	0.72
1985		0.63	0.57
1986		0.52	
1987		0.54	
1988		0.59	
1989		0.73	
1990		0.64	
1991		0.54	
1992		0.71	
1993		0.66	
1994		0.57	
1995		0.40	
1996		0.45	
1997		0.41	
1998		0.48	
1999		0.51	
2000		0.23	
2001		0.20	
2002		0.17	
2003		0.14	
2004		0.17	
2005		0.18	
2006		0.16	
2007		0.14	

Table 6. Total rockfish CPUE data from the recreational bottomfish-specific fishery for PSP. These data estimate rockfish per angler trip, calculated from the total catch in punch card areas 8–13 divided by the total trips in areas 8–13 (8–12 for Buckley 1967, 1968, 1970 and Bargmann 1977). For 1971, regions 8 and 12 are missing from the data, and for 1973, region 8 is missing.

Year	Buckley and Bargmann	Palsson et al. 2009*
1965	0.68	
1966	1.29	
1967	0.28	
1968	0.83	
1969	1.03	
1970	1.63	
1971	0.62	
1972	0.78	
1973	1.18	
1974		
1975		
1976		
1977		1.01
1978		0.78
1979		0.75
1980		0.79
1981		0.71
1982		0.76
1983		0.41
1984		0.63
1985		0.55
1986		0.50
1987		0.50
1988		0.58
1989		0.66
1990		0.57
1991		0.47
1992		0.62
1993		0.45
1994		0.50
1995		0.27
1996		0.27
1997		0.30
1998		0.29
1999		0.27
2000		0.12
2001		0.16
2002		0.14
2003		0.11
2004		0.11
2005		0.09
2006		0.09
2007		0.09

* In that document's usage, South Puget Sound includes Hood Canal and Whidbey Basin, which corresponds to our PSP designation.

Table 7. Total rockfish CPUE data from the recreational bottomfish-specific fishery for NPS. For Palsson et al. (2009), data are total catch divided by the total trips in areas 5–7. For Buckley (1967, 1968, 1970) and Bargmann (1977), data are total catch divided by total trips in punch card areas 6 and 7; 1971 and 1973 are based on data from punch card area 7 only.

Year	Buckley and Bargmann	Palsson et al. 2009
1965	0.89	
1966	1.42	
1967	0.34	
1968	0.67	
1969	3.38	
1970	0.99	
1971	1.22	
1972	1.65	
1973	1.12	
1974		
1975		
1976		
1977		1.75
1978		1.21
1979		1.51
1980		1.15
1981		1.00
1982		0.93
1983		0.82
1984		0.75
1985		0.79
1986		0.56
1987		0.62
1988		0.61
1989		0.87
1990		0.77
1991		0.69
1992		0.90
1993		1.07
1994		0.71
1995		0.67
1996		0.79
1997		0.64
1998		0.87
1999		0.99
2000		0.45
2001		0.28
2002		0.23
2003		0.22
2004		0.30
2005		0.32
2006		0.28
2007		0.21

Table 8. Total rockfish CPUE from the commercial bottom trawl data for the whole of Puget Sound, including the Strait of Juan de Fuca. These data are estimates of pounds (× 1,000) of rockfish per hour trawled in PMFC catch area 4A or Washington statistical area 18.

Year	PMFC 1979	Schmitt et al. 1991	Holmberg et al. 1967
1955			13.63
1956			11.22
1957			20.96
1958			14.76
1959			17.51
1960			14.67
1961			13.72
1962	3.97		19.57
1963	9.12		46.80
1964	5.37		21.27
1965	5.19		
1966	3.44		
1967	4.30		
1968	2.53		
1969	2.95		
1970	7.13	8.44	
1971	4.78	3.63	
1972	2.86	3.29	
1973	4.32	4.68	
1974	3.59	4.15	
1975	4.40	4.73	
1976	5.64	6.30	
1977	5.00	5.74	
1978	6.05	7.46	
1979	6.77	11.41	
1980		13.40	
1981		6.47	
1982		5.55	
1983		5.72	
1984		6.59	
1985		5.34	
1986		4.92	
1987		0.94	
1988		3.31	

reported as tons per landing, but “landing” is an inconsistent effort metric so these data are not reported. Due to concerns about CPUE from commercial fisheries being unrelated to actual population abundances, these data were not used for the trend analyses.

WDFW Trawl Survey

Data from the WDFW trawl survey (a fishery-independent survey) were included in the trend analysis. The survey is described in detail by Palsson et al. (2009). These trawl surveys cover 1987–2000, are depth stratified, and done in 12 regions (Table 9). The sampling is

Table 9. WDFW trawl survey sampling effort by region, depth, and year. CJ = east BC Juan de Fuca, CS = central Puget Sound, DB = Discovery Bay, GB = U.S. Strait of Georgia, GC = BC Strait of Georgia, HC = Hood Canal, JE = east U.S. Juan de Fuca, JF = BC Haro Strait and Boundary Pass, JW = west U.S. Juan de Fuca, SJ = U.S. San Juan Archipelago, SS = South Puget Sound, and WI = Whidbey Basin.

	0–20 fathoms											
Year	**CJ**	**CS**	**DB**	**GB**	**GC**	**HC**	**JE**	**JF**	**JW**	**SJ**	**SS**	**WI**
1987		8		1		2		2			5	
1988												
1989		6		7		2		5			4	
1990												
1991		6		6		2		2			4	
1992												
1993												
1994				16								
1995		16										
1996						10					10	
1997				17	12							
1998												
1999												
2000	5		6				9					
2001				20						15		
2002		12				7					8	7
2003	6		4				9		6			
2004				15			7		5	8		
2005		10				8					14	12
2006				18						11		
2007			6				9		4			
2008		2		2		2	2		2	2	2	
	21–40 fathoms											
1987		6		1				6			5	
1988												
1989		4		3		2		6			3	
1990												
1991		4		3		2		3			3	
1992												
1993												
1994				6								
1995		11										
1996						9					10	
1997				6	11							
1998												
1999												
2000	6		6				9					
2001				8						7		
2002		13				6					8	6
2003	7		10				10		6			
2004				9			9		5	8		
2005		10				9					13	9
2006				7						9		
2007			6				9		5			
2008		2		2		2	2		2	2	2	2

Table 9 continued. WDFW trawl survey sampling effort by region, depth, and year. CJ = east BC Juan de Fuca, CS = central Puget Sound, DB = Discovery Bay, GB = U.S. Strait of Georgia, GC = BC Strait of Georgia, HC = Hood Canal, JE = east U.S. Juan de Fuca, JF = BC Haro Strait and Boundary Pass, JW = west U.S. Juan de Fuca, SJ = U.S. San Juan Archipelago, SS = South Puget Sound, and WI = Whidbey Basin.

	41–60 fathoms											
Year	**CJ**	**CS**	**DB**	**GB**	**GC**	**HC**	**JE**	**JF**	**JW**	**SJ**	**SS**	**WI**
1987		5		2		3		9			2	
1988												
1989		4		2		2		7			2	
1990												
1991		4		2		2		6			2	
1992												
1993												
1994				4								
1995		9										
1996						3					8	
1997				6	10							
1998												
1999												
2000	7						11					
2001				7	3					6		
2002		10				6					6	6
2003	8						10		12			
2004				6			10		10	7		
2005		13				15					7	8
2006				6						9		
2007							12		10			
2008		4		4		4	4		4	4	4	2
	61–120 fathoms											
1987		9		7		2		13			5	
1988												
1989		5		5		2		9			3	
1990												
1991		6		5		3		3			3	
1992												
1993												
1994				9								
1995		3										
1996						3					11	
1997				11	25							
1998												
1999												
2000	7						11					
2001				15	11					12		
2002		14				7					5	7
2003	6						11		15			
2004				20			15		20	14		
2005		13				8					8	11
2006				19						15		
2007							15		22			
2008		6		4		4	4		4	4	4	2

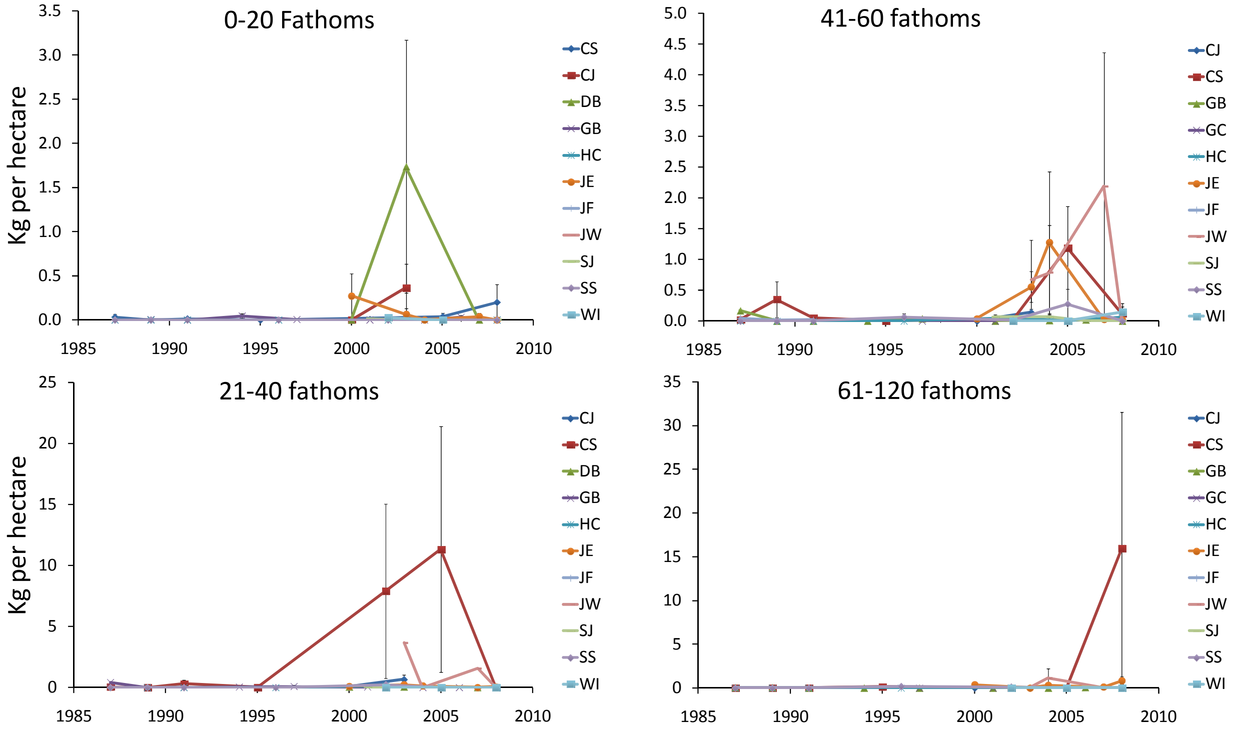
Table 9 continued. WDFW trawl survey sampling effort by region, depth, and year. CJ = east BC Juan de Fuca, CS = central Puget Sound, DB = Discovery Bay, GB = U.S. Strait of Georgia, GC = BC Strait of Georgia, HC = Hood Canal, JE = east U.S. Juan de Fuca, JF = BC Haro Strait and Boundary Pass, JW = west U.S. Juan de Fuca, SJ = U.S. San Juan Archipelago, SS = South Puget Sound, and WI = Whidbey Basin.

	Greater than 121 fathoms											
Year	**CJ**	**CS**	**DB**	**GB**	**GC**	**HC**	**JE**	**JF**	**JW**	**SJ**	**SS**	**WI**
1987												
1988												
1989												
1990												
1991												
1992												
1993												
1994												
1995												
1996												
1997					11							
1998												
1999												
2000												
2001					5							
2002												
2003												
2004												
2005												
2006												
2007												
2008												

somewhat episodic with some regions sampled infrequently, only once, or only at the beginning or the end of the survey (Table 9). Four main regions—central Puget Sound, Georgia Basin (U.S. waters), Hood Canal, and SPS—were sampled most frequently and with the greatest temporal consistency. Sampling effort was also uneven, with some regions having as few as two replicate hauls in a depth zone in a given year while others may have as many as 25 replicate hauls. The rocky habitat used by bocaccio, canary rockfish, and yelloweye rockfish is not effectively sampled by trawl gear, while the unconsolidated habitat used by redstripe rockfish and greenstriped rockfish can be trawled effectively. As a result, we used the WDFW trawl survey primary with respect to the latter two species.

Examination of the raw trawl samples indicated that the redstripe rockfish data contain what appear to be outlier events. In particular, the estimates in 2002 and 2005 in PSP were increased upward by a single trawl sample in each year with extremely large numbers of redstripe rockfish. While redstripe rockfish comprised 1–2% of the survey in 1987, 1989, 1991, and 1996, in 2002 and 2005 they comprised 39% and 48%, respectively (Figure 19 through Figure 21). Redstripe rockfish are known to occur in dense aggregations, thus outlier events such as these are not surprising. For the trend analyses, redstripe rockfish were removed for the calculation of “total rockfish.” The total rockfish estimated abundances with redstripe rockfish removed are shown in Table 10.

Greenstriped rockfish



Redstripe rockfish

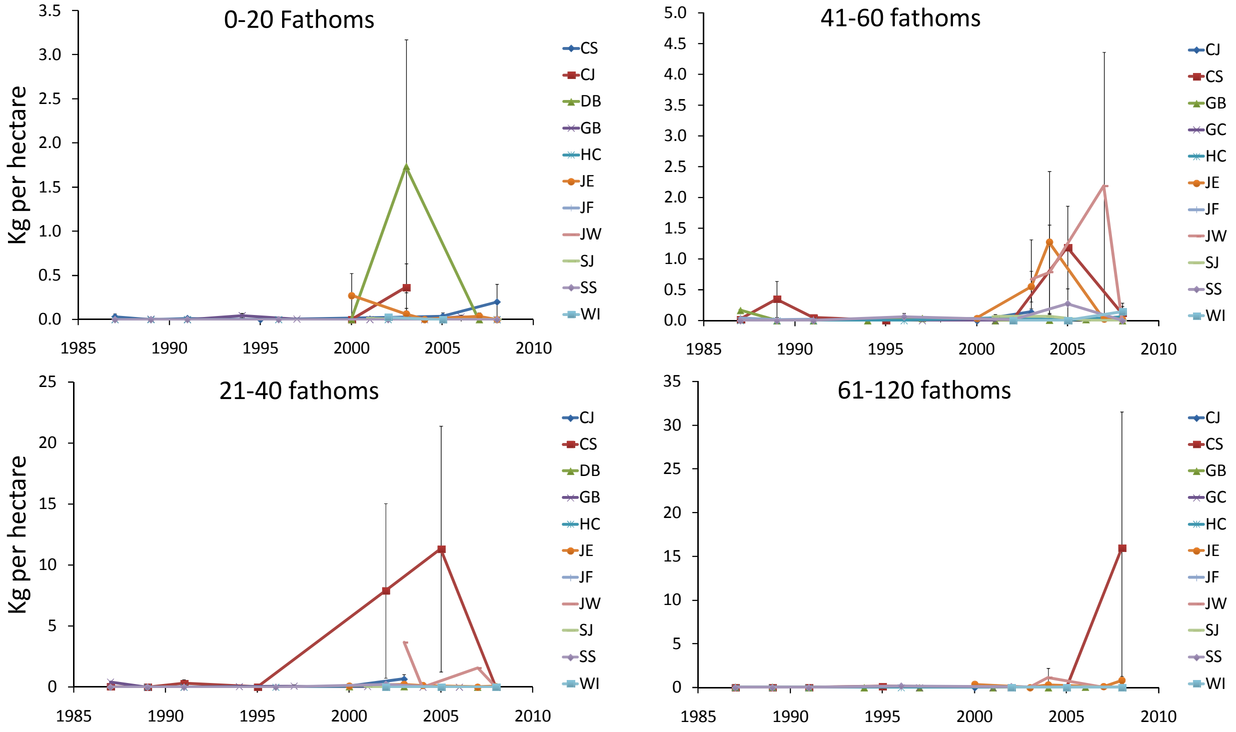


Figure 19. Hauls (kilograms per hectare) by depth zone and year for greenstriped rockfish (upper graphs) and redstripe rockfish (lower graphs). CJ = east BC Juan de Fuca, CS = central Puget Sound, DB = Discovery Bay, GB = U.S. Strait of Georgia, GC = BC Strait of Georgia, HC = Hood Canal, JE = east U.S. Juan de Fuca, JF = BC Haro Strait and Boundary Pass, JW = west U.S. Juan de Fuca, SJ = U.S. San Juan Archipelago, SS = South Puget Sound, and WI = Whidbey Basin.

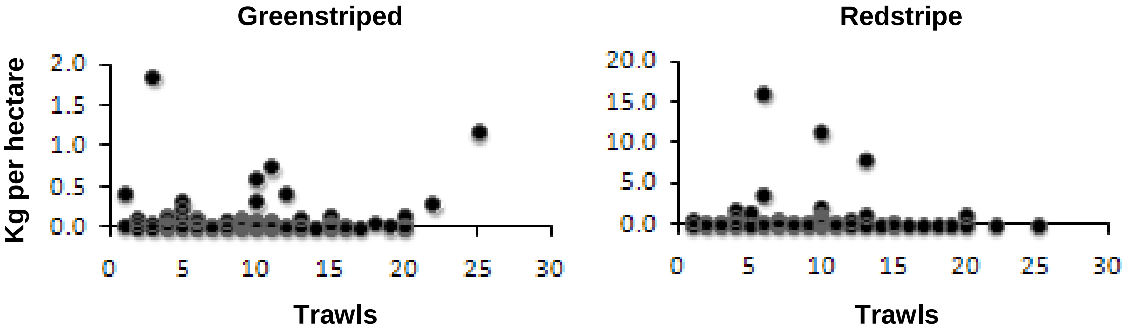


Figure 20. Hauls (kilograms per hectare) as a function of the number of WDFW trawls for greenstriped rockfish and redstripe rockfish.

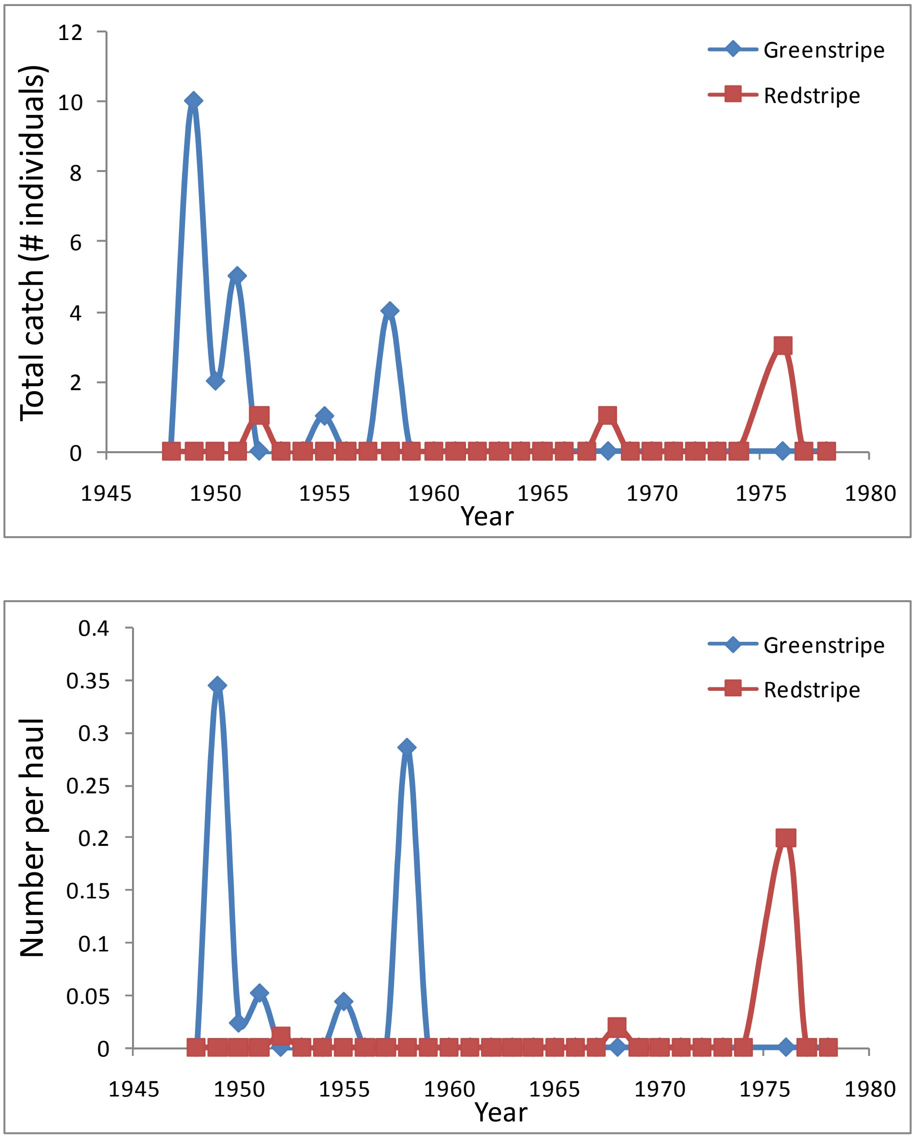


Figure 21. Total catch (number of individual fish) and number per haul over time from University of Washington combined trawl data.

Table 10. Total rockfish CPUE from the WDFW trawl survey (Palsson et al. 2009) and the REEF dive surveys (REEF 2008). The WDFW trawl survey is reported as an estimate of abundance in NPS and PSP. The estimate for PSP is an order of magnitude larger than the estimate for NPS, which is contrary to our assumptions about relative abundances in these areas. Therefore, these estimates should be treated as relative abundance indices (like all the other data in this trend analysis). The REEF data are the average minimum abundance of rockfish, any species, recorded in dive locations throughout PSP and NPS. Most of the dives occurred in PSP.

Year	WDFW Trawl Survey (PSP)	WDFW Trawl Survey (NPS)	REEF 2008 (PSP)	REEF 2008 (NPS)
1987	1,265.2	89.9		
1988				
1989	1,419.0	96.2		
1990				
1991	470.1	18.3		
1992				
1993				
1994				
1995				
1996	383.2			
1997				
1998			15.62	48.89
1999			9.91	24.00
2000			4.34	22.40
2001		34.70	6.99	8.48
2002	236.20		6.33	19.91
2003			7.78	14.63
2004		51.20	10.25	27.61
2005	249.60		7.58	12.35
2006			8.29	16.95
2007			10.74	16.74
2008			9.14	15.11

REEF Dive Surveys

Another data source included in the trend analysis is sightings of rockfish by recreational scuba divers throughout Puget Sound as part of a program by REEF.org (REEF 2008) that trains recreational divers to identify and record fish species during recreational dives. The data are reported in abundance categories: single = single fish, few = 2–10 fish, many = 11–100 fish, and abundant = 100+ fish. The REEF (Reef Environmental Education Foundation) database was used to determine presence or absence per dive (at any abundance) and also to determine “min” and “max” rockfish by using the upper and lower ends of the categories to convert categorical levels to numerical levels. The data for “all rockfish” in the REEF database are shown in Table 10.

Additional Information on Rockfish Distribution and Abundance in Puget Sound

In addition to the data sources described above, the BRT reviewed numerous historical documents, short-term research projects, and graduate theses from regional universities (Appendix F). In general, historical reports confirm that the five petitioned species have consistently been part of the Puget Sound fish fauna. For example, Kincaid (1919) noted that the family Scorpaenidae constituted "one of the most important and valuable groups of fishes found on the Pacific Coast." He produced an annotated list of Puget Sound fishes that documented 13 species of rockfish that were known to inhabit Puget Sound, including two of the petitioned species: the "orange rockfish" (*S. pinniger*) that was "abundant in deep water," and the "red rockfish or red snapper" (*S. ruberrimus*), the largest of this group, "common in deep water" and "brought to market in considerable quantities."

Smith (1936) provided one of the first scientific reports on Puget Sound commercial fisheries focused on the fleet of otter trawlers that targeted flatfish landed for market in Seattle. The fishery occurred primarily over relatively soft bottom areas. Seven rockfish species were indicated as being taken by this fishery, including three of the petitioned species "orange rockfish," "red snapper," and "olive-banded rock cod" (*S. elongatus*).

Haw and Buckley's (1971) text on saltwater fishing in Washington marine waters, including Puget Sound, was designed to popularize recreational sport (hook-and-line) fishing in the region to the general public. Fishing locations and habitat preferences were indicated for three species of rockfish: canary, yelloweye, and bocaccio. Canary rockfish were found at depths greater than 150 feet and were not restricted to rocky bottom areas. This species occurred in certain locations as far south as Pt. Defiance and was taken in good numbers at Tacoma Narrows, but was considered more abundant in the San Juan Islands, NPS, and Strait of Juan de Fuca. Rockfish were found at depths of more than 150 feet on rocky bottoms and primarily occurred in NPS, the strait, and the outer coast. Finally, bocaccio were frequently caught in the Tacoma Narrows.

Two documents (DeLacy et al. 1972, Miller and Borton 1980) compiled all available data on Puget Sound fish species distributions and relative number of occurrences since 1971–1973 from the literature (including some records noted above), fish collections, unpublished log records, and other sources. Listed in the documents are 27 representatives of the family Scorpaenidae, including all five species considered in this status review (total records in parentheses): greenstriped rockfish (54), most records occur in Hood Canal although also collected near Seattle, primarily associated with otter trawls; bocaccio (110), most records occurring from the 1970s in Tacoma Narrows and Appletree Cove (near Kingston), associated with sport catch; canary rockfish (114), most records occurring from the 1960s to 1970s in Tacoma Narrows, Hood Canal, San Juan Islands, Bellingham, and Appletree Cove, associated with sport catch; redstripe rockfish (26), most records from Hood Canal sport catch although a few were also taken in central Puget Sound/Seattle; and yelloweye rockfish (113), most records occurring from the early 1970s in the San Juan Islands (Sucia Island) and Bellingham Bay, associated with the sport catch.

Summary of Previous Assessments

WDFW conducted an extensive review of the current status of all Puget Sound rockfishes (Palsson et al. 2009). This included a review of historic patterns of abundance, results of WDFW surveys, ecosystem stressors, and a qualitative risk assessment. Palsson et al. (2009) note a precipitous decline in several species of rockfish, including bocaccio, yelloweye rockfish, and canary rockfish. They conclude that fishery removals (including bycatch from other fisheries) are highly likely to limit recovery of depleted rockfish populations in Puget Sound. In addition, they establish habitat disruption, derelict fishing gear, low DO, chemical toxicants, and predation as moderate threats to Puget Sound rockfish populations.

WDFW evaluated the status of rockfishes in Puget Sound using information on fishery landings trends, surveys, and species composition trends (Musick 1999, Musick et al. 2000). Its evaluation was based on American Fisheries Society (AFS) criteria for marine fish stocks. This method uses biological information and life history parameters such as population growth rates, age at maturity, fecundity, maximum age, etc. These parameters in concert with information regarding population trends are used to classify populations as depleted, vulnerable, precautionary, or healthy. WDFW interpreted depleted to mean that there is a high risk of extinction in the immediate future, while vulnerable was considered likely to be endangered or threatened in the near future. Precautionary was interpreted to mean that populations were reduced in abundance, but that population size was stable or increasing.

After applying the AFS criteria, WDFW concluded that yelloweye and canary rockfish were depleted in NPS and PSP. Greenstriped rockfish and redstripe rockfish were both considered to be healthy. Bocaccio were given a precautionary status, which was the result of a lack of information as well as their increased rarity in PSP.

An evaluation on the status of yelloweye rockfish was prepared for the Canadian Committee on the Status of Endangered Wildlife in Canada (COSEWIC). COSEWIC concluded that there are two designatable units (DU) of yelloweye rockfish in Canada: an inside DU that encompasses the Strait of Georgia, Johnstone Strait, and Queen Charlotte Strait, and an outside DU that extends from southeast Alaska to northern Oregon. The two DUs are distinguished on the basis of genetic information indicating restricted gene flow and age at maturity. For the inside DU, submersible surveys in 1984 and 2003 showed statistically nonsignificant declines in mean, median, and maximum sightings per transect. Commercial handline and longline CPUEs declined 59% and 49%, respectively. Age and length information indicate that the proportion of old individuals declined into the early 1990s. Overall, the COSEWIC report concludes that yelloweye rockfish abundance has declined more than 30% in one-third of a generation.

COSEWIC also conducted status reviews for canary rockfish and bocaccio; however, these reports focused on coastal populations. In both cases, populations were deemed threatened.

Coastal populations of yelloweye rockfish, canary rockfish, and bocaccio are considered overfished by the Pacific Fishery Management Council. A previous ESA status review of the southern bocaccio DPS (California and Mexico) determined that the DPS had declined to 3.6% of its estimated unfished biomass in 2002, but that the DPS had a low probability of extinction if rebuilding catch rates were maintained (MacCall and He 2002).

Species Composition Trends

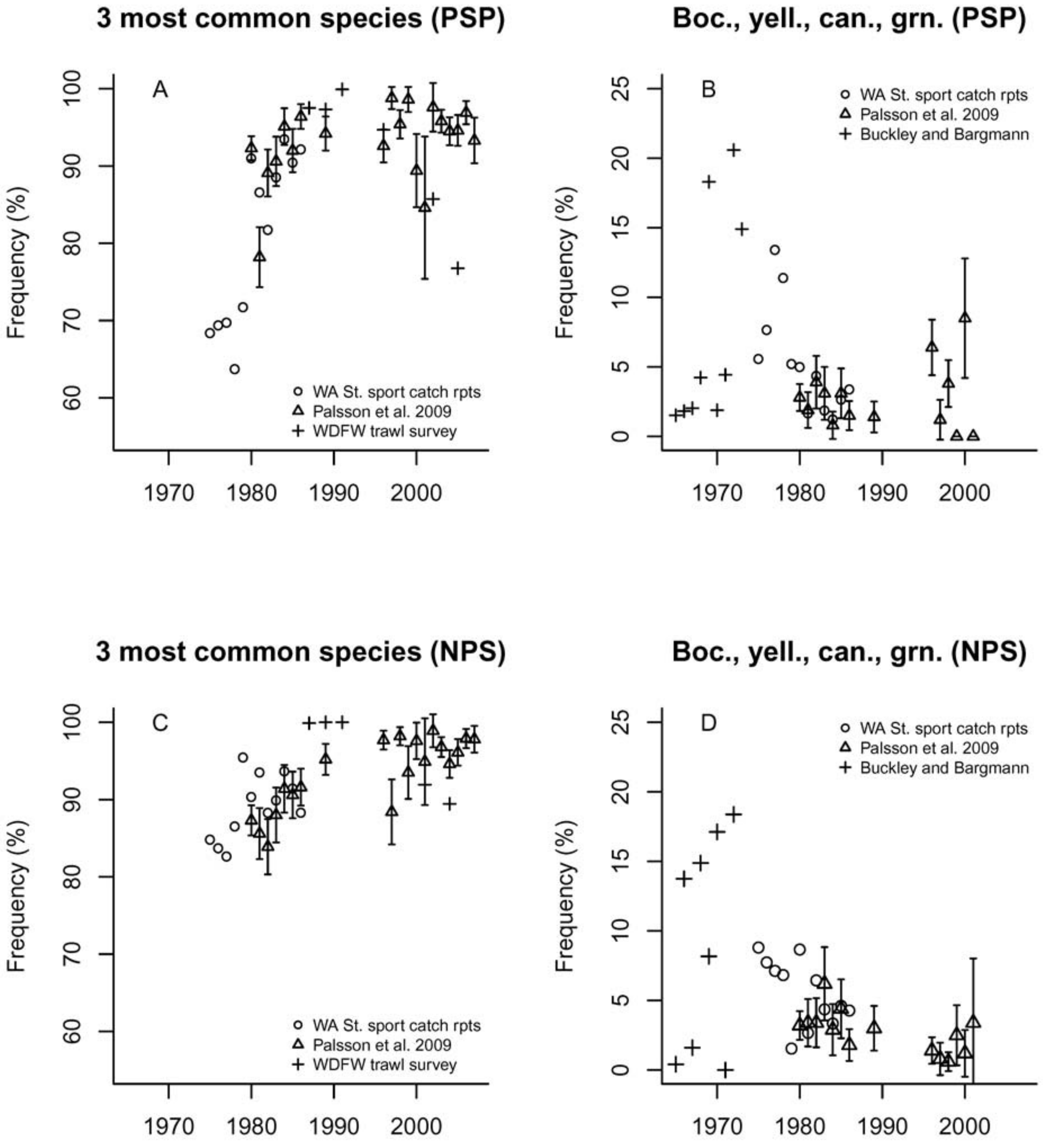
Species frequency data have been collected as part of WDFW's monitoring of recreational fisheries and for a limited number of years the commercial fisheries. Data prior to 1975 are available from Buckley (1967, 1968, 1970) and Bargmann (1977). From 1975 to 1986, WDFW published the Washington State Sport Catch Reports (WDF 1975–86) which report estimates of species frequency information in the recreational catch. For 1980–2007, see Table 7.5 of Palsson et al. (2009)for a summary of the species identification data. Likewise, see Table 6.1 in Palsson et al. (2009) for a summary of the commercial fisheries data.

The precision of the species frequencies may be influenced by small sample sizes. Sample sizes are not reported for the pre-1980 years, however the variability in the early data, especially from the Bargmann and Buckley reports, is suggestive of low sample size. The variability in the early data may also be due to inconsistent identification or changes in which species were categorized as "unclassified." In addition to these limitations, bag limits in the recreational fishery likely have affected the species frequencies in the catch. A bag limit was imposed in 1983 and further reduced in 1994 and 2000. This may have led to discarding less desirable (smaller) species.

Despite limitations, the recreational data in particular show some patterns. The three most common species during 1965–2007 in NPS (black rockfish [*Sebastes melanops*], copper rockfish, and quillback rockfish) and PSP (brown rockfish, copper rockfish, and quillback rockfish) increased in proportion from 1980 through 1990 and currently comprise approximately 90% of the recreational catch (Figure 22). Four of the five petitioned species (bocaccio, canary, greenstriped, and yelloweye rockfish) became progressively less frequent in the recreational catch during the same time period (Figure 22). However, during 1988–1993, declines were not seen in the commercial gear that catch bocaccio (set line and set net in PSP), canary rockfish (bottom trawl and set line in NPS), and yelloweye rockfish (multiple gear types in NPS). Thus the commercial data, while much more limited in number of samples than the recreational data, contradicts this pattern of declines in the petitioned species in the 1980s and 1990s. Recent data for the commercial fisheries have not been collected to our knowledge.

Bocaccio

Bocaccio were infrequently recorded in the recreational catch data reported by Bargmann and Buckley for PSP from the mid-1960s into the early 1970s (Table 11). However, bocaccio were reported up to 8–9% of the catch in the late 1970s from the Washington State Sport Catch Reports (WDF 1975–1986) (Figure 23 and Figure 24). The majority of the catch (66%) during 1975–1986 was from punch card area 13 (as reported in the Washington Sport Catch Reports); Point Defiance and the Tacoma Narrows were historically reported as local areas of high bocaccio abundance in punch card area 13. Bocaccio appear to have declined in frequency relative to other species from the 1970s through the 1980s to the 1990s. From 1975 to 1979, bocaccio were reported as an average of 4.63% of the catch (sample size unknown, reference Washington State Sport Catch Reports). In 1980–1989, they were 0.24% of the 8,430 rockfish identified (Palsson et al. 2009). From 1996 to 2007, bocaccio were not observed out of the 2,238 rockfish identified in the dockside surveys of the recreational catches (Palsson et al. 2009). In a sample this large, the probability of observing at least 1 bocaccio would be 99.5% assuming it



3 most common species (PSP)

Boc., yell., can., grn. (PSP)

3 most common species (NPS)

Boc., yell., can., grn. (NPS)

Figure 22. Species frequency data from recreational bottomfish fisheries in PSP and NPS. See Figure 34 and Figure 35 for details on the data sources. Approximate 95% confidence intervals were calculated for the frequencies reported in Palsson et al. (2009) using the normal approximation for a binomial confidence interval: $\hat{p} \pm z_{\alpha/2}\sqrt{\hat{p}(1-\hat{p})/n}$ where n is the sample size, $\hat{p}$ is the frequency estimate, and $z_{\alpha/2}$ is the $1 - \alpha/2$ percentile of a standard normal distribution. Redstripe rockfish has been removed from the data sets when calculating changes in frequencies because of concerns that discarding and high aggregation led to large biases in the recreational and WDFS trawl data, respectively. The three most common species are: for PSP, brown rockfish, copper rockfish, and quillback rockfish; for NPS, black rockfish, copper rockfish, and quillback rockfish.

Table 11. Species frequency data for bocaccio in PSP. Data are from the recreational fishery and are calculated from dockside surveys in punch card areas 8–13. The 1980–2007 data are in Table 7.5 in Palsson et al. (2009). Reported sample sizes (fish identified) are given in parentheses if available.

Year	WA sport catch reports	Palsson et al. 2009	Buckley and Bargmann
1965			0.00 (NA)
1966			0.41 (NA)
1967			1.01 (NA)
1968			0.00 (NA)
1969			0.00 (NA)
1970			1.51 (NA)
1971			3.12 (NA)
1972			0.00 (NA)
1973			0.00 (NA)
1974			
1975	1.38 (NA)		
1976	2.50 (NA)		
1977	9.35 (NA)		
1978	8.03 (NA)		
1979	1.89 (NA)		
1980	1.11 (NA)	0.58 (1,460)	
1981	0.37 (NA)	0.00 (1,027)	
1982	1.15 (NA)	0.44 (965)	
1983	0.63 (NA)	0.00 (937)	
1984	0.01 (NA)	0.00 (985)	
1985	0.00 (NA)	0.41 (1,292)	
1986	0.24 (NA)	0.30 (760)	
1987			
1988			
1989		0.00 (1,004)	
1990			
1991			
1992			
1993			
1994			
1995			
1996		0.00 (185)	
1997		0.00 (85)	
1998		0.00 (133)	
1999		0.00 (74)	
2000		0.00 (47)	
2001		0.00 (26)	
2002		0.00 (85)	
2003		0.00 (367)	
2004		0.00 (322)	
2005		0.00 (335)	
2006		0.00 (296)	
2007		0.00 (283)	

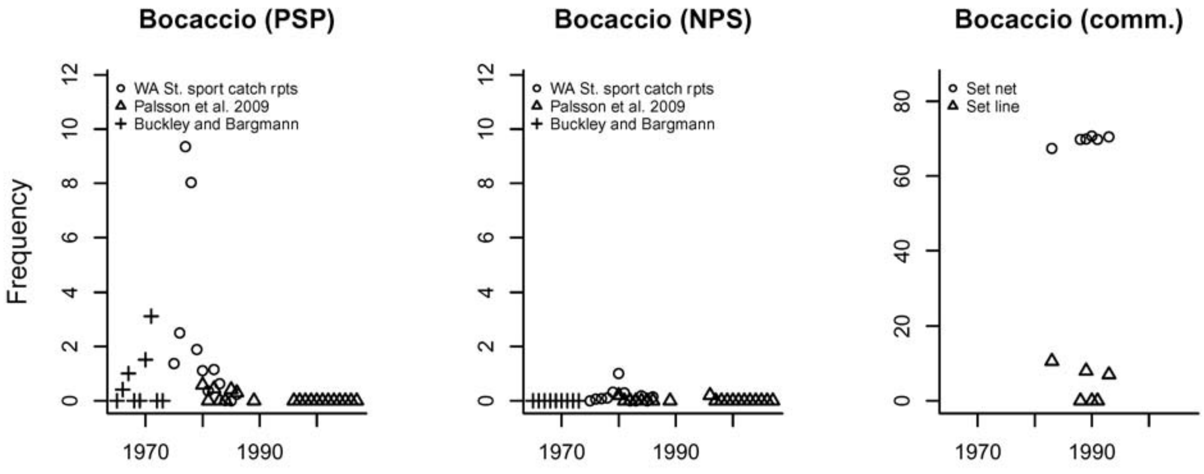


Figure 23. Frequency estimates (% total) for bocaccio in the recreational catch in PSP and NPS, and commercial catch (comm.) in PSP. Bocaccio do not appear in commercial catch records in NPS.

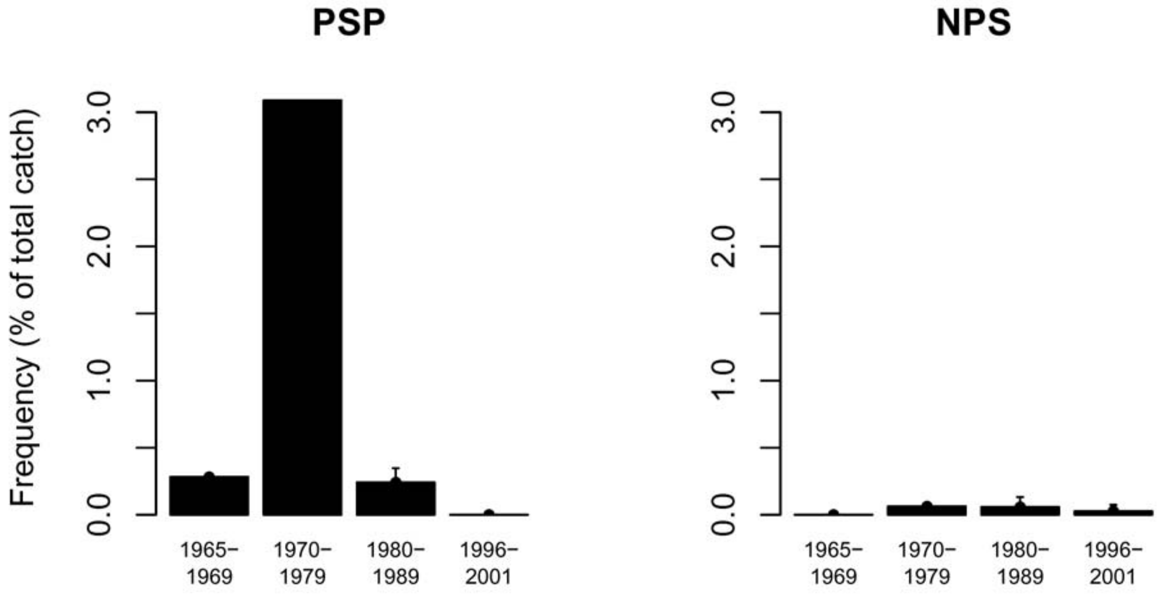


Figure 24. Frequency (% of total) for bocaccio in the recreational catch in PSP and NPS averaged across decades.

was at the same frequency (0.24%) as in the 1980s. Also, as expected as a result of their habitat preferences, bocaccio have not been observed in WDFW fisheries independent trawl surveys (Palsson et al. 2009, their Table 7.5).

In conclusion, there is strong support in the data for a decline in the frequency of bocaccio relative to other species in PSP (Figure 23 and Figure 24). The magnitude of the decline cannot be ascertained since we have no estimates of current frequency. We do know that although rare, bocaccio rockfish were present in PSP into the early 2000s. In WDFW size surveys, bocaccio have been recorded in 1994, 1996, 1997, and 1998 (punch card areas 5, 6, and 7). The latest record in the size database is 1999 when 4 fish were recorded (3 from punch card area 13 and 1 from punch card area 11). There is 1 report of a bocaccio sighting (2–10 fish) in punch card area 11 (central Puget Sound at the Les Davis Pier Artificial Reef in Commencement Bay, Tacoma) in 2001 from a REEF scuba survey. This is the last reported identification we have of bocaccio in PSP.

In NPS, bocaccio have always been rare in surveys of the recreational fishery (Table 12 and Table 13). In the Strait of Georgia, bocaccio have been documented in some inlets, but records are sparse, isolated, and often based on anecdotal reports (COSEWIC 2002). Bocaccio have not been noted in any fishery-independent longline, submersible, or jig surveys conducted for bottomfishes throughout the Strait of Georgia over the past two decades (Yamanaka et al. 2004). Furthermore, they do not appear in any recreational catch records, although rockfish were only identified to species level in this region's recreational surveys in the last decade (DFO 2008).

Canary Rockfish

Canary rockfish occur more consistently in the recreational catch than bocaccio and yelloweye rockfish, but are still infrequently observed (typically 1–2% in PSP and 2–5% in NPS). Like bocaccio, canary rockfish appear to have become less frequent in the catch data since 1965 (Table 14 through Table 16, Figure 25 and Figure 26). From 1980 to 1989, they were reported at a frequency of 1.1% (sample size 8,430) and 1.4% (sample size 3,910) in PSP and NPS, respectively. From 1996 to 2001, they were reported at a frequency of 0.73% (sample size 550) and 0.56% (sample size 1,718) in PSP and NPS, respectively. The decadal trends along with 95% confidence intervals for the data with sample sizes are shown in Figure 25. Note the early data do not report sample size (number of individuals identified), thus uncertainty in the early estimates cannot be calculated. Species misidentification should not be a problem for canary rockfish, but their reported frequency may be affected by nonrandom reporting of species in the catch in the 1960s and early 1970s. The tables from Bargmannn and Buckley for 1965–1973 suggest that only a few (2–3) common species were being recorded in some punch card areas.

Since 2002 fishing for canary rockfish is prohibited, thus no frequency data are available from the recreational fishery since then. Canary rockfish have not been observed in WDFW fishery-independent trawl surveys (Palsson et al. 2009, their Table 7.5). In the REEF scuba data (REEF 2008), canary rockfish were not observed in the first 3 years of the survey, 1998–2000, when the number of dives ranged 100–130 per year. Since 2001, however, the number of dives per year has increased substantially, to 400–1,000 dives per year, and canary rockfish have been reported consistently since 2001 in 0.5 to 3.6% of dives with no evidence of a temporal decline in sightings (REEF 2008).

Canary rockfish have been documented in the Strait of Georgia (see Figure 27 for statistical reporting areas), but the overwhelming research focus is on the large stocks that are commercially harvested off the west coast of Vancouver Island and in Queen Charlotte Strait (COSEWIC in press). The prevalence of this species in recreational fishing in the Strait of

Table 12. Species frequency data for bocaccio in NPS. Data are all from the recreational fishery and are calculated from dockside surveys in punch card areas 5–7. The 1980–2007 data are in Table 7.5 in Palsson et al. (2009). Reported sample sizes (fish identified) are given in parentheses if available.

Year	WA sport catch reports	Palsson et al. 2009	Buckley and Bargmann
1965			0 (NA)
1966			0 (NA)
1967			0 (NA)
1968			0 (NA)
1969			0 (NA)
1970			0 (NA)
1971			0 (NA)
1972			0 (NA)
1973			0 (NA)
1974			
1975	0.00 (NA)		
1976	0.06 (NA)		
1977	0.08 (NA)		
1978	0.11 (NA)		
1979	0.32 (NA)		
1980	1.01 (NA)	0.2 (1,121)	
1981	0.29 (NA)	0.0 (434)	
1982	0.00 (NA)	0.0 (404)	
1983	0.00 (NA)	0.0 (321)	
1984	0.18 (NA)	0.0 (318)	
1985	0.00 (NA)	0.0 (360)	
1986	0.15 (NA)	0.0 (519)	
1987			
1988			
1989		0.0 (433)	
1990			
1991			
1992			
1993			
1994			
1995			
1996		0.2 (578)	
1997		0.0 (223)	
1998		0.0 (496)	
1999		0.0 (200)	
2000		0.0 (162)	
2001		0.0 (59)	
2002		0.0 (91)	
2003		0.0 (715)	
2004		0.0 (613)	
2005		0.0 (490)	
2006		0.0 (513)	
2007		0.0 (275)	

Table 13. Species frequency data from commercial catch data for bocaccio rockfish in PSP. The 1983–1984 data point is reported in Pedersen and Bargmann (1986). It is not clear from this document precisely when the species composition data were collected; however, other species identification data are specified as being collected in 1984. This data point is later presented as 1970–1987 in Table 6.1 in Palsson et al. (2009), but the original identifications appear to have been done in a single year. The 1988, 1989, 1990, 1991, and 1993 data were from surveys of the commercial catches those years, but no identifications have been done on the commercial catch since 1993 (according to Palsson et al. 2009). Data from commercial gear with which bocaccio rockfish are not caught are not shown. Blanks indicate missing years, not zeros.

Year	Set net	Set line
1983–1984	67.4	10.6
1984		
1985		
1986		
1987		
1988	69.8	0.0
1989	69.9	8.0
1990	70.7	0.0
1991	69.8	0.0
1992		
1993	70.5	7.0

Georgia indicates that they are probably well distributed but rare (1% total rockfish catch) in enclosed waters and inlets (DFO 2008). However, wide interannual variations in some recreational catch data suggest that catch estimates may be unreliable due to poor species identification and changing bag limits (COSEWIC in press). Recent longline surveys throughout the Strait of Georgia collected 10 canary rockfish from 2 shallow sets in statistical areas 16 and 17. All were adults (mean size 529 mm) in postspawning condition (Lochead and Yamanaka 2007). They have also been documented in Strait of Georgia jig surveys (Yamanaka et al. 2004).

Yelloweye Rockfish

Yelloweye rockfish occur more consistently in the recreational catch than bocaccio but at lower frequency than canary rockfish and are still infrequently observed (typically 1–2% in PSP and 2–5% in NPS). The frequency of yelloweye rockfish in PSP appears to have increased from a frequency of 0.34% (sample size 8,430) in 1980–1989 to a frequency of 2.7% (sample size 550) in 1996–2001 (Figure 28 and Table 17). There were 3 recent years (1999–2001) when yelloweye rockfish were not reported in the recreation catch; however, the sample sizes were low these years and zeros are expected for an infrequent species when sample sizes are low.

In NPS, in contrast, the frequency of yelloweye rockfish decreased between the 1980s and 1990s in the catch surveys (Table 18 and Table 19). From 1980 to 1989, they were reported at a frequency of 1.9% (sample size 3,910), and from 1996 to 2001, they were reported at a frequency of 0.65% (sample size 1,718). Since 2002 fishing for yelloweye rockfish is prohibited, thus no frequency data are available since then from the recreational fishery.

Table 14. Species frequency data for canary rockfish in PSP. The data all come from the recreational fishery and are calculated from dockside surveys in punch card areas 8–13. The 1980–2007 data are in Table 7.5 in Palsson et al. (2009). Since 2002 no catch of canary rockfish is allowed in the recreational fishery, thus no frequency data are available. Reported sample sizes (fish identified) are given in parentheses if available.

Year	WA sport catch reports	Palsson et al. 2009	Buckley and Bargmann
1965			0.53 (NA)
1966			0.18 (NA)
1967			0.84 (NA)
1968			3.75 (NA)
1969			6.90 (NA)
1970			0.36 (NA)
1971			0.00 (NA)
1972			2.00 (NA)
1973			12.77 (NA)
1974			
1975	1.44 (NA)		
1976	2.06 (NA)		
1977	2.45 (NA)		
1978	1.17 (NA)		
1979	0.78 (NA)		
1980	1.25 (NA)	0.93 (1,460)	
1981	0.84 (NA)	0.54 (1,027)	
1982	1.23 (NA)	2.11 (965)	
1983	0.24 (NA)	0.66 (937)	
1984	0.52 (NA)	0.63 (985)	
1985	1.77 (NA)	2.16 (1,292)	
1986	1.81 (NA)	1.11 (760)	
1987			
1988			
1989		0.70 (1,004)	
1990			
1991			
1992			
1993			
1994			
1995			
1996		0.00 (185)	
1997		0.00 (85)	
1998		0.00 (133)	
1999		0.00 (74)	
2000		8.50 (47)	
2001		0.00 (26)	

Table 15. Species frequency data for canary rockfish in NPS. The data all come from the recreational fishery and are calculated from dockside surveys in punch card areas 5–7. The 1980–2007 data are in Table 7.5 in Palsson et al. (2009). Since 2002 no catch of canary rockfish is allowed in the recreational fishery, thus no frequency data are available. Reported sample sizes (fish identified) are given in parentheses if available.

Year	WA sport catch reports	Palsson et al. 2009	Buckley and Bargmann
1965			0.00 (NA)
1966			12.42 (NA)
1967			1.60 (NA)
1968			10.29 (NA)
1969			7.73 (NA)
1970			0.00 (NA)
1971			0.00 (NA)
1972			13.21 (NA)
1973			51.90 (NA)
1974			
1975	6.94 (NA)		
1976	5.23 (NA)		
1977	5.41 (NA)		
1978	3.00 (NA)		
1979	1.17 (NA)		
1980	2.05 (NA)	1.50 (1,121)	
1981	1.43 (NA)	1.80 (434)	
1982	1.27 (NA)	1.71 (404)	
1983	1.61 (NA)	2.21 (321)	
1984	1.54 (NA)	1.30 (318)	
1985	1.88 (NA)	1.90 (360)	
1986	1.87 (NA)	1.00 (519)	
1987			
1988			
1989		0.00 (433)	
1990			
1991			
1992			
1993			
1994			
1995			
1996		0.30 (578)	
1997		0.40 (223)	
1998		0.60 (496)	
1999		1.00 (200)	
2000		1.20 (162)	
2001		0.00 (59)	

Table 16. Species frequency data from commercial catch data for canary rockfish in NPS. The 1970–1987 data point is from accumulated data over this period. Reference is Palsson et al. (2009, their Table 6.1). Data from gear with which canary rockfish are not caught are not shown.

Year	Bottom trawl	Set line
1983–84	0.0	0.0
1984		
1985		
1986		
1987		
1988	0.2	6.0
1989	0.7	3.5
1990	0.0	1.6
1991	2.7	1.2
1992		
1993	0.4	7.4

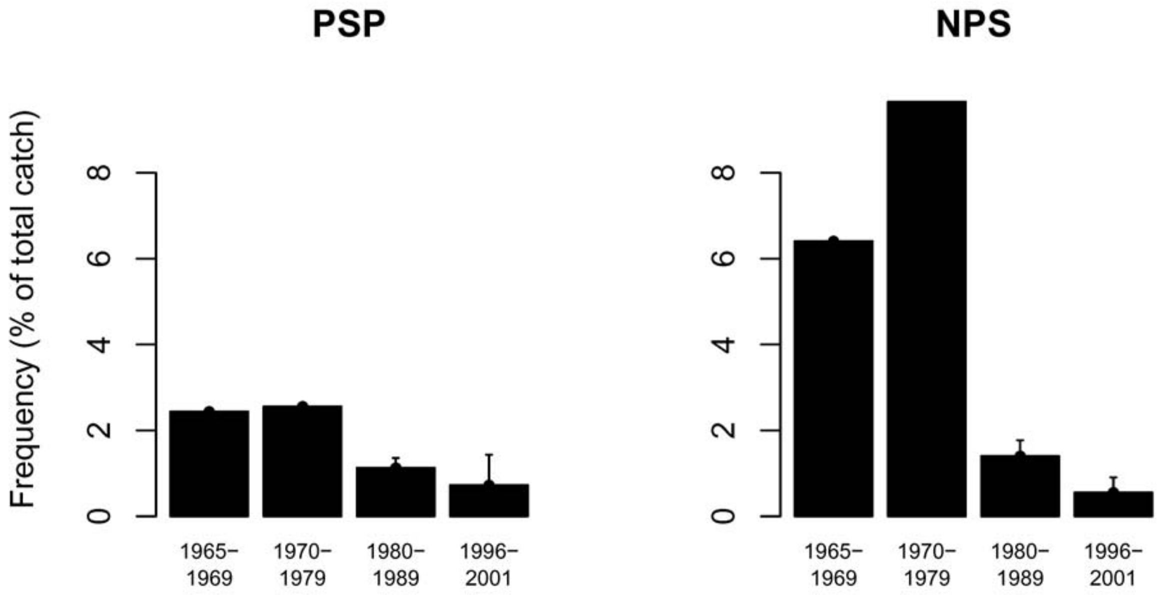


Figure 25. Frequency (% of total) for canary rockfish in the recreational catch in PSP and NPS averaged across decades.

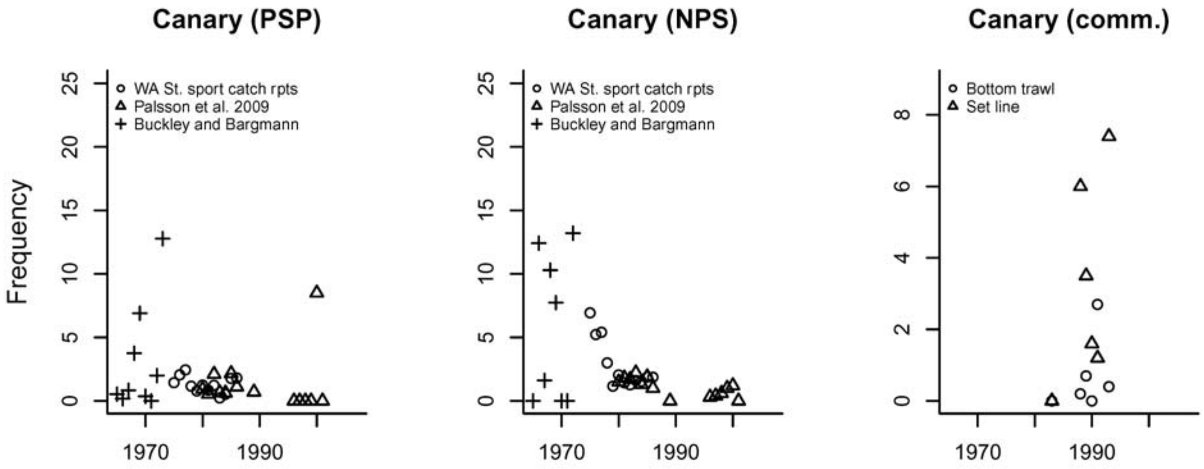


Figure 26. Frequency estimates (% of total) for canary rockfish in the recreational catch in PSP and NPS, and commercial catch (comm.) from NPS. Canary rockfish do not appear in commercial catch records in PSP. The outlier point (1973 in NPS) for the Buckley and Bargmann data is at 52%.

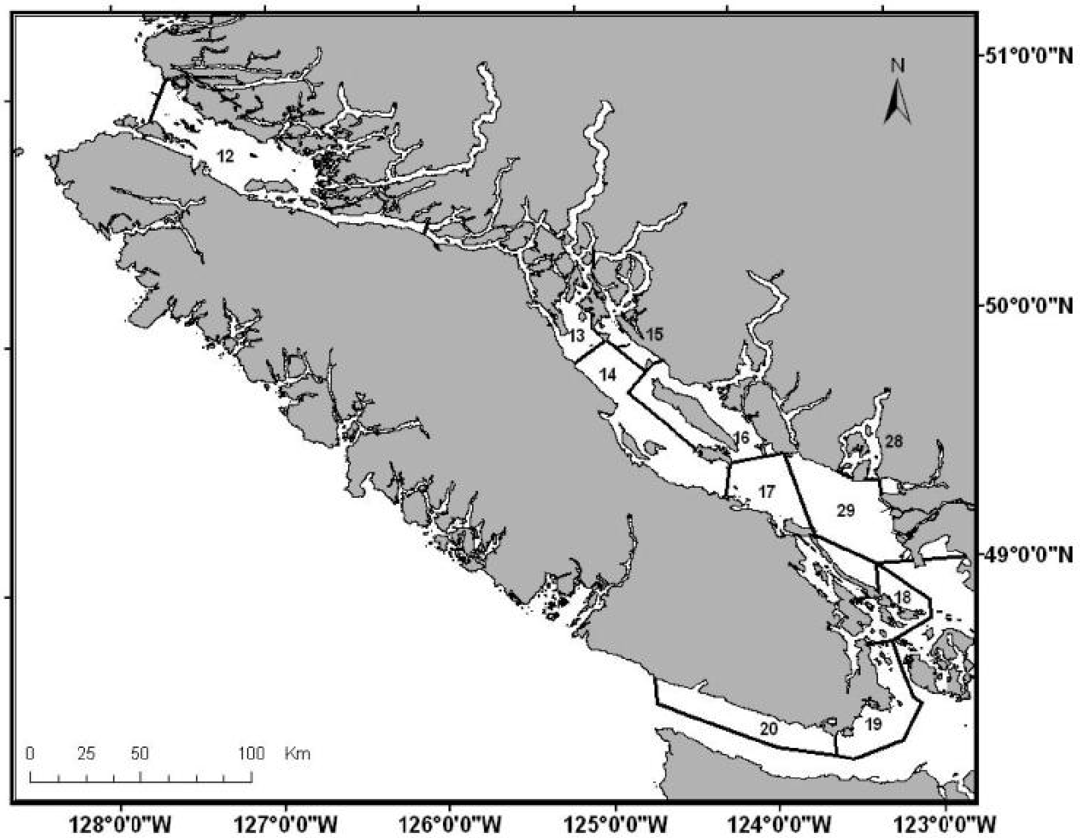


Figure 27. Statistical reporting areas divided into numbers 12–20 and 28–29, as used by the Department of Fisheries and Oceans Canada. (Reprinted from COSEWIC 2002.)

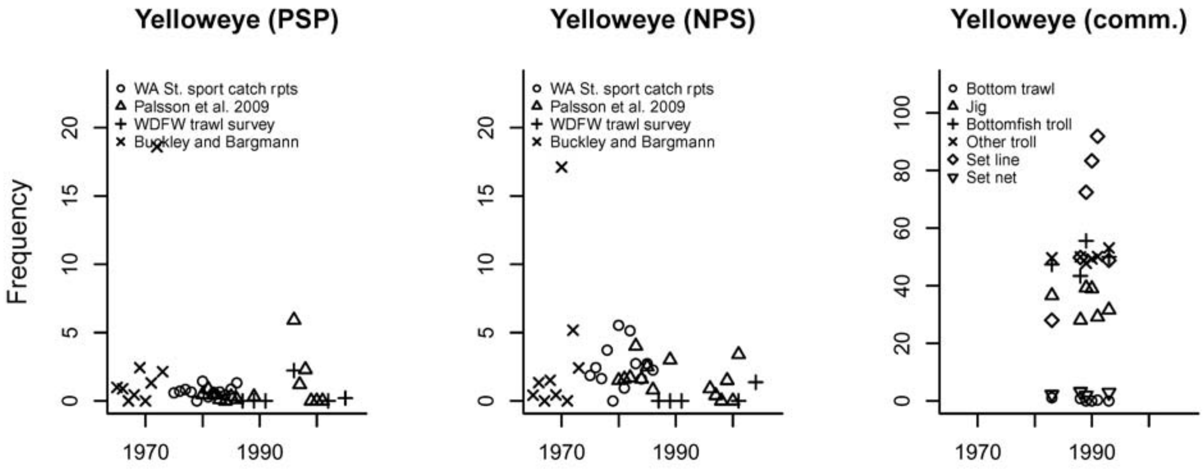


Figure 28. Frequency estimates (% of total) for yelloweye rockfish in the recreational catch in PSP and NPS, and commercial catch (comm.) from NPS. Yelloweye rockfish do not appear in commercial catch records in PSP.

Figure 29 shows the decadal trends along with 95% confidence intervals for the data with sample sizes. Note the early data do not report sample size (number of individuals identified), thus uncertainty in the early estimates cannot be calculated. Species misidentification should not be a problem for yelloweye rockfish, but their frequency may be affected by nonrandom reporting in the 1960s and early 1970s. The tables from Bargmann and Buckley for 1965–1973 suggest that only a few (2–3) common species were being recorded in some punch card areas.

As expected, yelloweye rockfish have been observed infrequently in WDFW fishery-independent trawl surveys (Table 17) in PSP, and in NPS, yelloweye rockfish were not observed in the WDFW trawl survey in 1987, 1989, 1991, or 2001, but were caught in 2004 (0.65% of the catch). In REEF scuba survey data, yelloweye rockfish have been sighted consistently throughout Puget Sound (north and south) since 2001 at an average frequency of 0.5% of dives in PSP reporting a sighting of yelloweye rockfish and 2% of dives in NPS reporting a sighting. There is no evidence of a decline in the probability of sightings during dives (Table 20).

In the Strait of Georgia, yelloweye rockfish are common in recent recreational catches; the proportion of yelloweye rockfish in the 2006 and 2005 recreational catch (DFO catch data) was 17.1% and 7.5%, respectively. The high frequency of yelloweye rockfish in the recreational catch may reflect targeting for this species, as yelloweye rockfish are a small proportion of the rockfish observed in the few fishery-independent surveys that are available. In a genetic tagging study in 2003 (Yamanaka et al. 2004), where data were collected from tissue taken from hooks, 1% of samples were yelloweye rockfish. In a 2003 pilot camera study designed to estimate rockfish biomass (Yamanaka et al. 2004, their Table 10), 439 rockfish were observed of which 1 (0.2%) was a yelloweye rockfish. Another remotely operated vehicle (ROV) survey in 2004 in the southern Strait of Georgia identified 105 rockfish species of which 5 (4.8%) were yelloweye rockfish.

Table 17. Species frequency data for yelloweye rockfish in PSP. The recreational fishery data are calculated from dockside surveys in punch card areas 8–13. The 1980–2007 data are in Palsson et al. (2009, their Table 7.5). Since 2002 no catch of yelloweye rockfish is allowed in the recreational fishery thus no frequency data are available. Note: redstripe rockfish have been removed from the original data when calculating species frequencies. Reported sample sizes (fish identified) are given in parentheses if available.

Year	WA sport catch reports	Palsson et al. 2009	WDFW trawl survey	Buckley and Bargmann
1965				0.99 (NA)
1966				0.88 (NA)
1967				0.00 (NA)
1968				0.44 (NA)
1969				2.43 (NA)
1970				0.00 (NA)
1971				1.32 (NA)
1972				18.60 (NA)
1973				2.14 (NA)
1974				
1975	0.59 (NA)			
1976	0.71 (NA)			
1977	0.84 (NA)			
1978	0.66 (NA)			
1979	0.00 (NA)			
1980	1.44 (NA)	0.47 (1,460)		
1981	0.29 (NA)	0.86 (1,027)		
1982	0.62 (NA)	0.44 (965)		
1983	0.66 (NA)	0.11 (937)		
1984	0.43 (NA)	0.00 (985)		
1985	0.86 (NA)	0.31 (1,292)		
1986	1.32 (NA)	0.10 (760)		
1987			0.00 (NA)	
1988				
1989		0.30 (1,004)	0.00 (NA)	
1990				
1991			0.00 (NA)	
1992				
1993				
1994				
1995				
1996		5.92 (185)	2.22 (NA)	
1997		1.20 (85)		
1998		2.30 (133)		
1999		0.00 (74)		
2000		0.00 (47)		
2001		0.00 (26)		
2002		NA (85)	0.00 (NA)	
2003		NA (367)		
2004		NA (322)		
2005		NA (335)	0.20 (NA)	

Table 18. Species frequency data for yelloweye rockfish in NPS in the recreational fishery. Species composition was calculated from dockside surveys in punch card areas 5–7. The 1980–2007 data are in Palsson et al. (2009, their Table 7.5). Since 2002 no catch of yelloweye rockfish is allowed in the recreational fishery thus no frequency data are available. Note: redstripe rockfish have been removed from the original data when calculating species frequencies. Reported sample sizes (fish identified) are given in parentheses if available.

Year	WA sport catch reports	Palsson et al. 2009	WDFW trawl survey	Buckley and Bargmann
1965				0.41 (NA)
1966				1.33 (NA)
1967				0.00 (NA)
1968				1.51 (NA)
1969				0.44 (NA)
1970				17.12 (NA)
1971				0.00 (NA)
1972				5.17 (NA)
1973				2.41 (NA)
1974				
1975	1.87 (NA)			
1976	2.44 (NA)			
1977	1.63 (NA)			
1978	3.72 (NA)			
1979	0.00 (NA)			
1980	5.53 (NA)	1.50 (1,121)		
1981	0.94 (NA)	1.60 (434)		
1982	5.14 (NA)	1.71 (404)		
1983	2.73 (NA)	4.02 (321)		
1984	1.61 (NA)	1.60 (318)		
1985	2.73 (NA)	2.50 (360)		
1986	2.26 (NA)	0.80 (519)		
1987			0.00 (NA)	
1988				
1989		3.00 (433)	0.00 (NA)	
1990				
1991			0.00 (NA)	
1992				
1993				
1994				
1995				
1996		0.90 (578)		
1997		0.40 (223)		
1998		0.00 (496)		
1999		1.50 (200)		
2000		0.00 (162)		
2001		3.40 (59)	0.00 (NA)	
2002		NA (91)		
2003		NA (715)		
2004		NA (613)	1.37 (NA)	

Table 19. Species frequency data from commercial catch data for yelloweye rockfish in NPS. The 1970–1987 data point is from accumulated data over this period; reference is Palsson et al. (2009, their Table 6.1). Data from gear with which yelloweye rockfish are not caught are not shown.

Year	Bottom trawl	Jig	Bottomfish troll	Other troll	Set line	Set net
1983–1984	1.1	36.6	47.4	49.7	28.0	2.2
1984						
1985						
1986						
1987						
1988	0.8	28.1	43.4	50.0	49.8	3.2
1989	0.0	39.3	55.6	47.8	72.5	1.9
1990	0.0	39.0		49.3	83.4	
1991	0.3	29.2		50.1	91.9	
1992						
1993	0.0	31.6	50.0	53.1	48.8	2.9

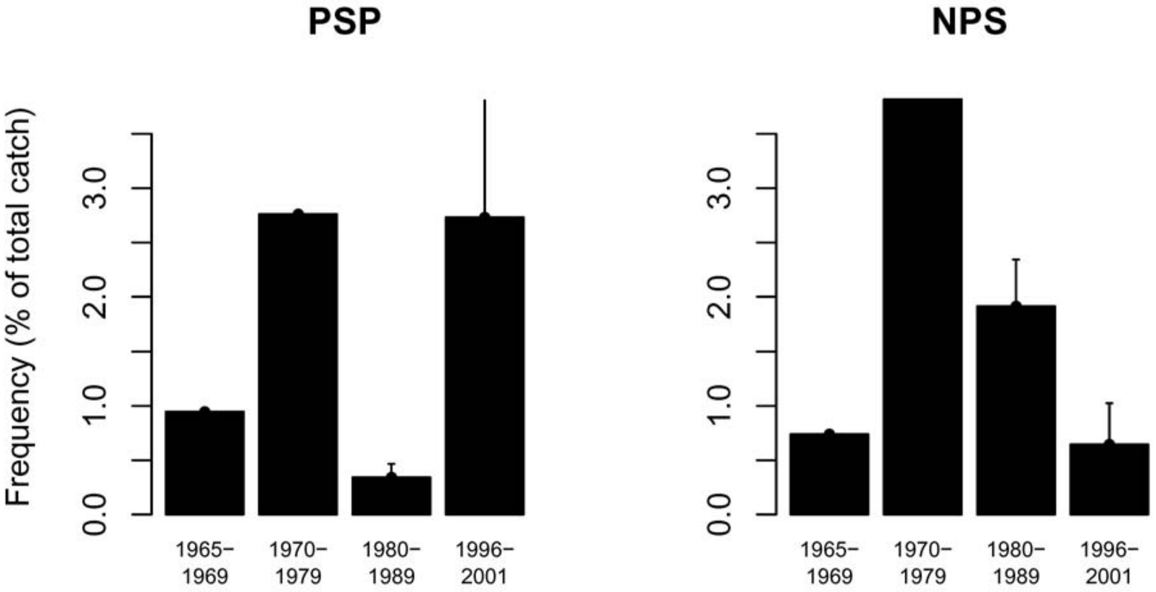


Figure 29. Frequency (% of total) for yelloweye rockfish in the recreational catch in PSP and NPS averaged across decades.

Table 20. Percent of dives in which yelloweye rockfish were sighted (at any abundance) from the REEF recreational scuba dive surveys for all dive sites in Puget Sound. The number of dives is given in parentheses.

Year	PSP	NPS
1998	1.05 (95)	0.00 (27)
1999	0.00 (95)	0.00 (8)
2000	0.00 (93)	0.00 (15)
2001	0.53 (379)	0.00 (33)
2002	0.27 (376)	0.00 (74)
2003	0.71 (421)	0.00 (51)
2004	1.07 (469)	3.03 (66)
2005	0.47 (428)	0.00 (54)
2006	0.49 (608)	2.56 (156)
2007	0.60 (826)	2.44 (164)
2008	0.00 (383)	1.89 (53)

There appears to be limited information on population trends of yelloweye rockfish in the Strait of Georgia. Data from the recreational creel survey conducted by DFO is of limited value because species composition information and groundfish-targeted effort is lacking; salmon-targeted and groundfish-targeted trips are reported together. Submersible surveys were conducted in 1984 and 2003 in statistical areas 12 and 13 in the Strait of Georgia (Yamanaka et al. 2004). Between the two surveys, there was a decline in the mean number of yelloweye rockfish per transect (8.57 to 4.65), but the difference was not statistically significant. Trend data are also available from the commercial longline fishery (Yamanaka et al. 2004). These data show generally declining trends in CPUE from the late 1980s through the 1990s, but interpretation is difficult given the effects of market forces and management regulations on commercial fisheries.

Greenstriped Rockfish

Greenstriped rockfish do not occur in the recreational catch data from NPS and occur very infrequently in the PSP recreational catch data and WDFW trawl survey (greenstriped occurred in 143 of 1,555 [9%] total hauls of the WDFW trawl survey across all years and regions). In the mid-1960s to mid-1970s data (Buckley 1967, 1968, 1970, Bargmann 1977), greenstriped rockfish appear much less frequently than in the mid-1970s to mid-1980s (Figure 30 and Figure 31). This suggests that greenstriped rockfish were not being consistently recorded during dockside identifications of the 1960s and 1970s. From 1975 to 1980 (WDF 1975–1986), greenstriped rockfish were recorded at a 1–2% frequency in PSP (Figure 30, Table 21 and Table 22). After 1980 the frequency of greenstriped rockfish declined in the recreational data and since 1996 the species very rarely appears in the recreational catch data. Bag limits were imposed in 1983 and the bag limit was further reduced in 1994 and 2000. Since greenstriped rockfish are smaller than other species; the bag limit may lead to discarding and thus underrepresentation of greenstriped rockfish in the recreational catch.

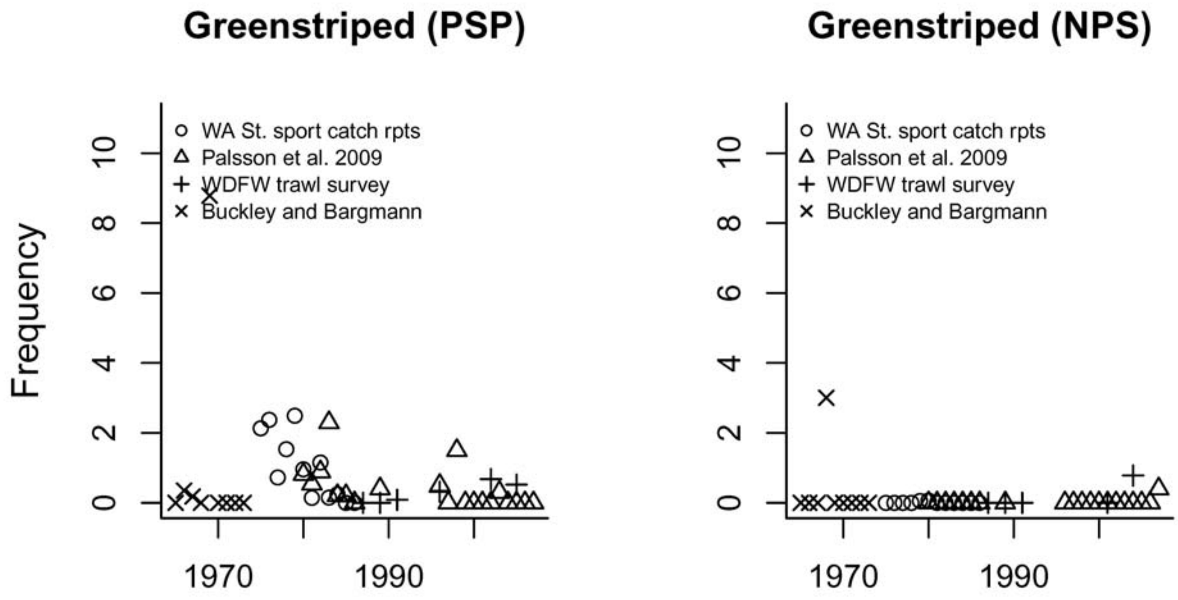


Figure 30. Frequency estimates (% of total) for greenstriped rockfish in the recreational catch in PSP and NPS. They are not recorded in the commercial catch.

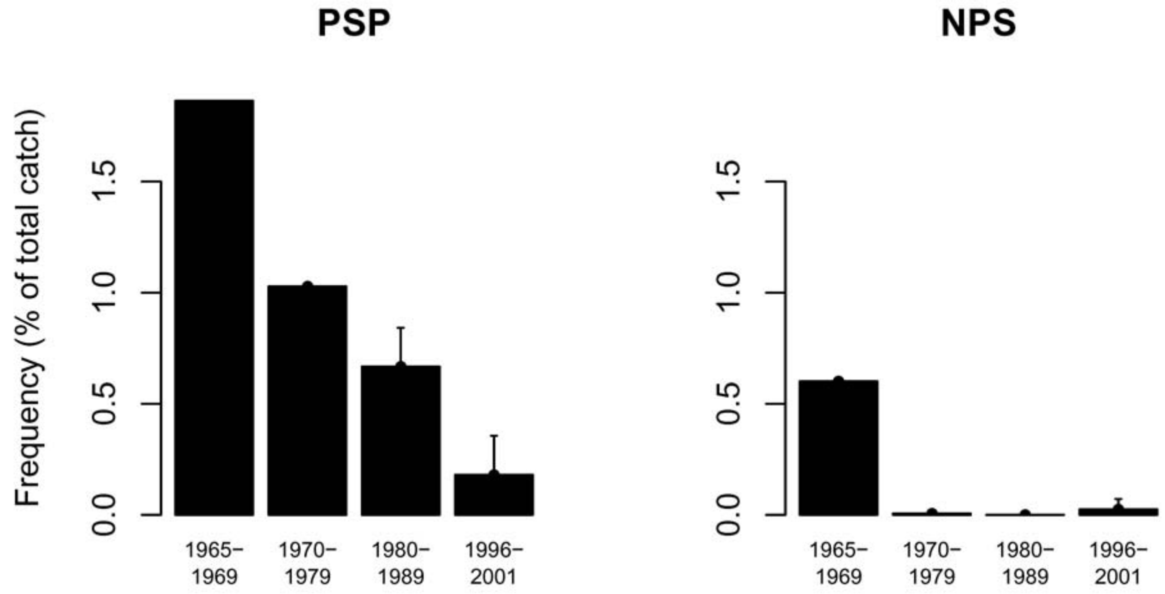


Figure 31. Frequency (% of total) for greenstriped rockfish in the recreational catch in PSP and NPS averaged across decades.

Table 21. Species frequency data for greenstriped rockfish in PSP. The data all come from the recreational fishery and are calculated from dockside surveys in punch card areas 8–13. The 1980–2007 data are in Palsson et al. (2009, their Table 7.5).

Year	WA sport catch reports	Palsson et al. 2009	WDFW trawl survey	Buckley and Bargmann
1965				0.00 (NA)
1966				0.35 (NA)
1967				0.18 (NA)
1968				0.00 (NA)
1969				8.78 (NA)
1970				0.00 (NA)
1971				0.00 (NA)
1972				0.00 (NA)
1973				0.00 (NA)
1974				
1975	2.13 (NA)			
1976	2.37 (NA)			
1977	0.73 (NA)			
1978	1.53 (NA)			
1979	2.49 (NA)			
1980	0.96 (NA)	0.82 (1,460)		
1981	0.14 (NA)	0.54 (1,027)		
1982	1.15 (NA)	0.89 (965)		
1983	0.15 (NA)	2.30 (937)		
1984	0.25 (NA)	0.21 (985)		
1985	0.00 (NA)	0.21 (1,292)		
1986	0.00 (NA)	0.00 (760)		
1987			0.00 (NA)	
1988				
1989		0.40 (1,004)	0.00 (NA)	
1990				
1991			0.09 (NA)	
1992				
1993				
1994				
1995				
1996		0.50 (185)	0.31 (NA)	
1997		0.00 (85)		
1998		1.50 (133)		
1999		0.00 (74)		
2000		0.00 (47)		
2001		0.00 (26)		
2002		0.00 (85)	0.68 (NA)	
2003		0.30 (367)		
2004		0.00 (322)		
2005		0.00 (335)	0.52 (NA)	
2006		0.00 (296)		
2007		0.00 (283)		

Table 22. Species frequency data for greenstriped rockfish in NPS. The data all come from the recreational fishery and are calculated from dockside surveys in punch card areas 5–7. The 1980–2007 data are in Palsson et al. (2009, their Table 7.5).

Year	WA sport catch reports	Palsson et al. 2009	WDFW trawl survey	Buckley and Bargmann
1965				0.00 (NA)
1966				0.00 (NA)
1967				0.00 (NA)
1968				3.00 (NA)
1969				0.00 (NA)
1970				0.00 (NA)
1971				0.00 (NA)
1972				0.00 (NA)
1973				0.00 (NA)
1974				
1975	0.00 (NA)			
1976	0.00 (NA)			
1977	0.00 (NA)			
1978	0.00 (NA)			
1979	0.05 (NA)			
1980	0.07 (NA)	0.00 (1,121)		
1981	0.00 (NA)	0.00 (434)		
1982	0.00 (NA)	0.00 (404)		
1983	0.00 (NA)	0.00 (321)		
1984	0.00 (NA)	0.00 (318)		
1985	0.00 (NA)	0.00 (360)		
1986	0.00 (NA)	0.00 (519)		
1987			0.00 (NA)	
1988				
1989		0.00 (433)	0.00 (NA)	
1990				
1991			0.00 (NA)	
1992				
1993				
1994				
1995				
1996		0.00 (578)		
1997		0.00 (223)		
1998		0.00 (496)		
1999		0.00 (200)		
2000		0.00 (162)		
2001		0.00 (59)	0.00 (NA)	
2002		0.00 (91)		
2003		0.00 (715)		
2004		0.00 (613)	0.78 (NA)	
2005		0.00 (490)		
2006		0.00 (513)		
2007		0.40 (275)		

Greenstriped rockfish appear in low frequency in the WDFW fishery-independent trawl survey (Table 21), and they were caught in the most recent years 2002 and 2005 of the WDFW trawl survey in PSP. However, the high variance in the data makes detecting any patterns difficult. Simple analysis of variance (ANOVA) models with region (Hood Canal, Main Basin, SPS, Whidbey Island), depth (four depth zones), and year as categorical, fixed variables did not detect differences among years for greenstriped rockfish ($x' = \ln(x + 1)$, $F_{7, 561} = 0.24$, $P = 0.97$). Thus although greenstriped rockfish have been almost entirely absent from the recreational catch from 1999 to 2007, they are still present in PSP.

Greenstriped rockfish also do not appear in the 2005 and 2006 species composition data from the recreational catch in the Strait of Georgia (DFO creel survey data). However, they have appeared in other fishery-independent surveys such as longline, jig, and ROV surveys (Yamanaka et al. 2004, their Table 4). In statistical area 13, they were 1.5% of rockfish caught in a longline survey (Lochead and Yamanaka 2007). In the 2005 ROV survey in the southern Strait of Georgia (Martin et al. 2006), they comprised 50% of the rockfish observed (52 out of 105 rockfish identified to species). This appears to be an unusual occurrence, as they are not reported at such high frequencies in other surveys.

Redstripe Rockfish

Redstripe rockfish do not occur in the catch data from NPS. In PSP, however, redstripe rockfish appeared frequently in the recreational catch (between 1 and 14%) during 1980 to 1985 (Figure 32, Figure 33, and Table 23). Previous to that, from 1965 to 1979, redstripe rockfish appeared much less frequently (<1%) (see Bargmann and Buckley references and Washington State Sport Catch Reports). It is not known whether redstripe rockfish were being consistently recorded during dockside identifications in the 1960s and 1970s, but their absence suggests that they may not have been. After 1985 the frequency of redstripe rockfish declined in the recreational data and since 1996 they do not appear in the catch data. A bag limit was imposed in 1983, which was further reduced in 1994 and 2000. Since redstripe rockfish are smaller than other species, bag limits may lead to discarding and thus underrepresentation of redstripe rockfish in the recreational catch.

In the 1980s and 1990s, redstripe rockfish appeared at a low frequency (<1.5%) in the WDFW trawl survey (Table 24), however, in 2002 and 2005 redstripe rockfish comprised 39% and 48% of the individuals caught, respectively. Examination of the individual trawl samples indicates that this was caused by outlier trawl samples in each of those years, which suggests that these high estimates are not indicative of an actual increase in abundance in recent years. However, an ANOVA model with region (Hood Canal, Main Basin, SPS, Whidbey Island), depth (four depth zones) and year as categorical, fixed variables did detect interannual variability in redstripe rockfish ($x' = \ln(x + 1)$, $F_{7, 651} = 2.30$, $P = 0.026$). Biomass of redstripe rockfish in the trawls was 0.28 kg ha^{-1} (±0.089 SE), lower in 1995 than in 2008 (Tukey-Kramer test, $P < 0.05$), indicating a potential increase in abundance. Importantly, the presence of redstripe rockfish in the WDFW trawl survey indicates that redstripe are present in Puget Sound but are no longer being recorded in the dockside surveys of the recreational catch, for undetermined reasons.

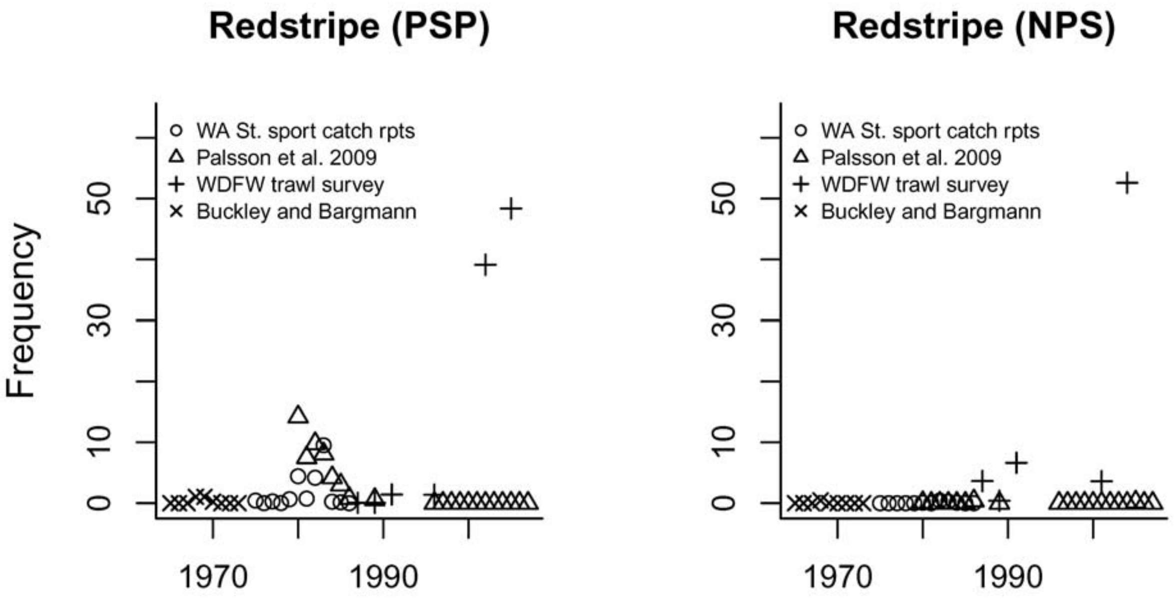


Figure 32. Frequency estimates (% of total) for redstripe rockfish in the recreational catch in PSP and NPS. They are not recorded in the commercial catch.

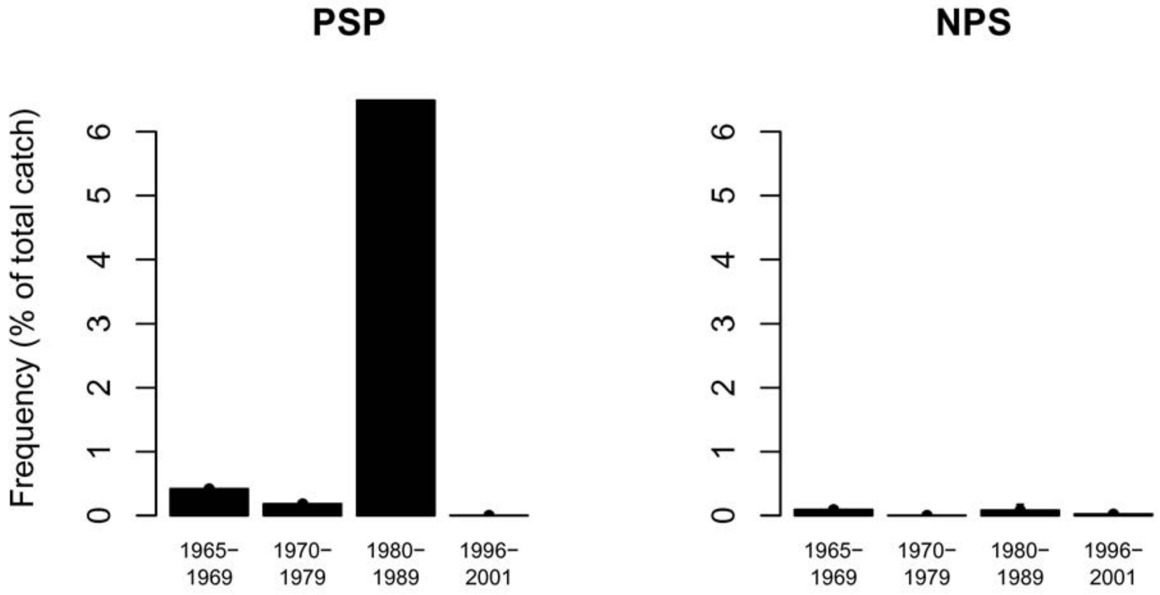


Figure 33. Frequency (% of total) for redstripe rockfish in the recreational catch in PSP and NPS averaged across decades.

Table 23. Species frequency data for redstripe rockfish in PSP. The data all come from the recreational fishery and are calculated from dockside surveys in punch card areas 8–13. The 1980–2007 data are in Palsson et al. (2009, their Table 7.5).

Year	WA sport catch reports	Palsson et al. 2009	WDFW trawl survey	Buckley and Bargmann
1965				0.00 (NA)
1966				0.00 (NA)
1967				0.00 (NA)
1968				1.05 (NA)
1969				1.03 (NA)
1970				0.24 (NA)
1971				0.00 (NA)
1972				0.00 (NA)
1973				0.00 (NA)
1974				
1975	0.43 (NA)			
1976	0.01 (NA)			
1977	0.29 (NA)			
1978	0.02 (NA)			
1979	0.65 (NA)			
1980	4.44 (NA)	14.20 (1,460)		
1981	0.75 (NA)	7.50 (1,027)		
1982	4.19 (NA)	9.80 (965)		
1983	9.53 (NA)	8.10 (937)		
1984	0.25 (NA)	4.20 (985)		
1985	0.16 (NA)	3.00 (1,292)		
1986	0.00 (NA)	0.80 (760)		
1987			0.06 (NA)	
1988				
1989		0.60 (1,004)	0.06 (NA)	
1990				
1991			1.43 (NA)	
1992				
1993				
1994				
1995				
1996		0.00 (185)	1.39 (NA)	
1997		0.00 (85)		
1998		0.00 (133)		
1999		0.00 (74)		
2000		0.00 (47)		
2001		0.00 (26)		
2002		0.00 (85)	39.11 (NA)	
2003		0.00 (367)		
2004		0.00 (322)		
2005		0.00 (335)	48.37 (NA)	
2006		0.00 (296)		
2007		0.00 (283)		

Table 24. Species frequency data for redstripe rockfish in NPS. The data all come from the recreational fishery and are calculated from dockside surveys in punch card areas 5–7. The 1980–2007 data are in Palsson et al. (2009, their Table 7.5).

Year	WA sport catch reports	Palsson et al. 2009	WDFW trawl survey	Buckley and Bargmann
1965				0.00 (NA)
1966				0.00 (NA)
1967				0.00 (NA)
1968				0.46 (NA)
1969				0.00 (NA)
1970				0.00 (NA)
1971				0.00 (NA)
1972				0.00 (NA)
1973				0.00 (NA)
1974				
1975	0.00 (NA)			
1976	0.00 (NA)			
1977	0.00 (NA)			
1978	0.00 (NA)			
1979	0.00 (NA)			
1980	0.07 (NA)	0.10 (1,121)		
1981	0.00 (NA)	0.00 (434)		
1982	0.43 (NA)	0.00 (404)		
1983	0.27 (NA)	0.00 (321)		
1984	0.09 (NA)	0.00 (318)		
1985	0.00 (NA)	0.00 (360)		
1986	0.00 (NA)	0.40 (519)		
1987			3.64 (NA)	
1988				
1989		0.00 (433)	0.41 (NA)	
1990				
1991			6.63 (NA)	
1992				
1993				
1994				
1995				
1996		0.00 (578)		
1997		0.00 (223)		
1998		0.00 (496)		
1999		0.00 (200)		
2000		0.00 (162)		
2001		0.00 (59)	3.61 (NA)	
2002		0.00 (91)		
2003		0.00 (715)		
2004		0.00 (613)	52.59 (NA)	
2005		0.20 (490)		
2006		0.00 (513)		
2007		0.00 (275)		

Redstripe rockfish appear in the 2006 and 2005 species composition data from DFO for Strait of Georgia statistical areas 13–20 and 28–29, comprising 0.08% and 0.1% of the rockfish catch, respectively. They have appeared in other fishery-independent surveys such as charter and jig surveys (Yamanaka et al. 2004, their Table 4), although these surveys included area 12 and it is unclear whether redstripe rockfish were collected farther south. Redstripe rockfish did not appear in the 2004 longline survey of statistical area 13 (only in area 12) (Lochead and Yamanaka 2007). Two redstripe rockfish (out of 105 rockfish recorded to species) were reported in a 2005 ROV survey in southern Strait of Georgia (Martin et al. 2006).

Absolute Abundance Estimates

Because of a lack of systematic sampling targeting rare rockfishes, absolute estimates of population size of the petitioned species cannot be generated with any accuracy. However, a rough estimate of the order of magnitude of population size can be determined from information assembled by WDFW. Palsson et al. (2009) extrapolated results from a video survey to estimate the population size of the major rockfish species (copper rockfish, quillback rockfish, black rockfish, and brown rockfish) in PSP at approximately 40,683 and in NPS at 838,944. When we apply the percent frequency of the petitioned species in the recreational catch to these numbers, it is clear the population sizes of the rarer species are quite small—probably less than 10,000 in Georgia Basin and less than 1,000 in PSP.

Estimates of Rockfish Trends in Puget Sound

Synopsis of the Trend Analysis

A trend analysis based on time series analysis of count data was performed on the data for “total rockfish” in the different DPSs for Puget Sound rockfish. This type of analysis is standard for population time series data (Dennis et al. 1991); however, the analysis used recent advances to deal with observation error in the data (Holmes 2001, Holmes and Fagan 2002, Lindley 2003, Dennis et al. 2006, Holmes et al. 2007) and to combine multiple time series for a single population. These analyses were used to estimate the trend parameter (mean annual population growth rate) and the two variance parameters (process and observation variance) which govern forecasts of future trends.

It is important to realize that the common species (copper rockfish, quillback rockfish, brown rockfish, and black rockfish) comprise approximately 90% of “total rockfish” in the different data sources used in the trend analysis. The goal of the analysis is to determine the 1965–2008 trend in total rockfish (i.e., what the actual population rate of decline has been from 1965 to 2008). This analysis makes no assumptions about the composition of total rockfish; it is known that the frequency of the common species relative to each other has changed. The estimated trend for total rockfish is used to make inferences about the petitioned species by looking for evidence that the frequency of the petitioned species has increased or decreased in the total rockfish assemblage. If the frequency of a petitioned species has remained constant, it can be inferred that the petitioned species has shown a similar trend to the total rockfish trend.

Quantitative estimates for the individual five species in the current petition are not generated because low sampling of the catches in many years, particularly early years, provides insufficient yearly estimates for the petitioned species. Instead the BRT was forced to use data on total rockfish trends and trends in species composition of the total rockfish assemblage. We recognize that the trend in total rockfish does not equal the trend in the petitioned species. However, this does not mean the BRT lacked information on trends in the petitioned species. Using the trend analysis in combination with the species frequency analysis described above allowed the BRT to:

1. Evaluate the trend in total rockfish abundance using all available data and multiple ways of looking at the data.
2. Evaluate evidence that the prevalence of each petitioned species has been increasing in abundance relative to the total, that is, that the ratio of the abundance of the petitioned species to the total rockfish abundance has been increasing.

More formally,

$N_{petitioned}(t) = (N_{petitioned}(t) / N_{total}(t)) \times N_{total}(t)$

Thus,

If $N_{petitioned}(t) / N_{total}(t)$ is constant, then the trend in N_{total} = the trend in $N_{petitioned}$.

If $N_{petitioned}(t) / N_{total}(t)$ has been going down, then the petitioned species is declining faster than the total.

If $N_{petitioned}(t) / N_{total}(t)$ has been going up, then the petitioned species is not declining as fast as the total.

Problems with Analyzing Composite and CPUE Data

The total rockfish time series is a composite of multiple species, and it is well-known that making inferences about individual species from composite CPUE data is problematic. The main problems can be summarized as: 1) the trend in the total catch will be dominated by the most abundant species, and the signal from infrequent species is lost; 2) CPUE data from fisheries are strongly influenced by targeting and by changes in the efficiency of gear and fish-locating technology (switching targeted species occurs as one species declines, and this means that the trends in multispecies catch-per-unit data may have little relation to the individual species); and 3) changes in management will alter, sometimes dramatically, the targeting for a group (such as rockfish) and discarding of individual species. This means that total rockfish CPUE may not be actually measuring rockfish abundance (if targeting changes) and the actual trends are masked (if discarding is occurring). The following approaches were used to limit these recognized problems.

Problem 1 cannot be addressed by changes in the analysis (or data used). It should be kept in mind that the estimated trends are trends for the most common species, not the petitioned species. Because of the nature of the available data, the BRT was forced to use the overall trend in rockfish (heavily influenced by common species) to make inferences about the magnitude of trend in the petitioned species by looking for changes in the frequency of the petitioned species relative to the common species. Thus we examined evidence for changes in the frequency of the petitioned species in the recreational catch, WDFW trawl surveys, and REEF dive surveys.

If the petitioned species are not declining as fast as the total rockfish time series, then their frequency should be increasing relative to other more common species. They should become less frequent if they are instead declining faster. A problem with this approach is that many of the petitioned species occur at frequencies of 0.5–3% of the catch. Sample sizes for the species identifications have been too small to detect even a 4-fold increase in frequency from, say, 1 to 4%. A second concern is that greenstriped rockfish and redstripe rockfish may be especially susceptible to being discarded when bag limits are low, and that the WDFW trawl estimates for this species have been strongly influenced by sample size and outlier events. More fishery-independent surveys focused on rockfish in Puget Sound are needed.

To address problem 2, CPUE data from the commercial bottom trawl (1965–1980) were not used. These were the only commercial data with good effort data (hours trawled), but it is known that there were many changes in gear that were leading to increases in the catch-per-hour trawled. Also rockfish catch in commercial data is highly susceptible to changes in which species are targeted (and whether rockfish are targeted) and to discarding. The data from the recreational fishery, since it is not driven by seafood market forces, is assumed to be less susceptible to these factors. Also the spatial scale at which the recreational fishery has been monitored is much finer than the commercial fishery, and this helps us determine whether there have been targeting changes.

To address problem 3, the recreational data were split into time periods with constant bag limits and the trend line was fit to each segment separately. The slope of the trend line is forced to be equal between segments, but the intercept is allowed to change. This means that if the catch per trip drops after the bag limit is changed, that bag limit–induced drop does not influence the estimated trend.

Methods

Summary of Methods

The basic concept involves using a maximum likelihood approach to fit a trend model with one underlying population process (total rockfish) simultaneously to different data sources. The different data sources are assumed to be measuring the same population process, but in different ways. Their observation variances can be different and how they scale relative to the total population can be different. The main analysis uses only one type of data (recreational catch data) and we assume that these data are measuring the same segment of the population. The secondary analysis uses WDFW trawl data and REEF dive surveys. For this analysis, it is allowed that the data sources might be sampling a different segment of the population (e.g., a different age/size segment or a different region of Puget Sound) and that the trend in a specific time period might be different among data sources that survey different segments of the population. However, the long-term trends should still be the same.

The different data sources that were used depended on which analysis was being done. The data sources can be summarized as 1) rockfish per angler trip data for different time periods with different bag limits within one DPS, 2) rockfish per angler trip data for different time periods with different bag limits within multiple DPSs, and 3) rockfish per angler trip data plus WDFW trawl data and REEF dive data.

The Model

To characterize population growth, a discrete-time Gompertz model (Reddingius 1971) is used to model density-dependent population dynamics. This model can approximate most common types of density dependence (Ives et al. 2003) and density-independent population growth (when $b = 1$). The stochastic Gompertz equation written in log-space is

$$X_t = a + bX_{t-1} + E_t \tag{1}$$

where X_t is the log population density (or density index such as CPUE) of the population at time step t, a is the intrinsic rate of increase, and b represents the strength of density dependence; a and b are assumed to be shared since all time series are assumed to be measuring the same population process (just with different errors and scalings). E, termed the process error, represents the random deviations in population change from time step to time step. E represents the real deviations in population change which are not equal to the observed deviations since the observed deviations also have observation error added. Because population change is a multiplicative process, it is additive in log-space. Additive stochastic processes lead to normal errors. Thus E is a random normal variate with a mean of zero and variance σ^2. Equation 1 is a univariate autoregressive, first order or AR(1) process.

The true population process exists but cannot be seen; instead, it is observed and these observations are governed by an observation process. We can write a general observation process for a multivariate AR(1) process as

$$\mathbf{Y}_t = \mathbf{D} + X_t + \boldsymbol{\varepsilon}_t \tag{2}$$

where $\mathbf{Y}_t$ is an $n \times 1$ vector of the n observed time series (Hinrichsen and Holmes 2009), each of which is observing with different observation variance and scaling the underlying population process. $\boldsymbol{\varepsilon}_t$ is an $n \times 1$ vector representing the observation errors, which have some statistical distribution with a mean of 0 and an $n \times n$ covariance matrix $\mathbf{R}$. The $n \times 1$ vector $\mathbf{D}$ represents bias in observation errors, and the off-diagonal elements of $\mathbf{R}$ represent the spatial correlation between the observation errors for the n observed time series. $\mathbf{D}$ allows us to model differences in observability (or catchability) of different data sources (i.e., gear types or fisheries). For our analysis, we assume that the errors across the different data sources have independent and unique variances and biases; thus the $\mathbf{R}$ and $\mathbf{D}$ matrices have the following structure:

$$\mathbf{R} = \begin{bmatrix} \eta_1^2 & 0 & \cdots & 0 \\ 0 & \eta_2^2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \eta_n^2 \end{bmatrix} \mathbf{D} = \begin{bmatrix} d_1 \\ d_2 \\ \vdots \\ d_n \end{bmatrix} \tag{3}$$

Model Fitting and Parameter Estimation

Equation 1 and Equation 2 together form a state-space model for the observations of the stochastic "total rockfish" process. State-space is a statistical term referring to a model with an unseen state process (in our case, the state process is the population process) combined with a observation process. It is a standard term in time series analysis for the type of AR(1) model that is being used and has a long history within the field of time series analysis.

Given time series of total rockfish abundance indices ($Y_1, Y_2, \ldots Y_T$) from a set of *n* data sources, the goal is to estimate the parameter *a* and process variance σ^2 that describe total rockfish dynamics. We use the traditional maximum likelihood estimation method for this type of state-space model: a Kalman filtering approach combined with an expectation-maximization algorithm (Shumway and Stoffer 2006). In preliminary analyses using model selection criteria, it was determined that there was no data support for including the *b* parameter. Thus in the analyses to follow, *b* was set equal to 1 (density-independent dynamics) and *a* is then interpreted as the long-term population growth rate or trend.

How is This Different than just Fitting a Line Through the Log Data?

Fitting a line through the data means using a model with observation error only, whereas our models have both process and observation error. Observation-error-only models give estimates of what happened. Process plus observation error models give estimates of the underlying population dynamics (the process mean and variance) and are used to forecast what will happen (if the past dynamics continue). Both types of models are used by population analysts and the choice depends on the purpose of the analysis. Models with process variance are also used to ask: Could these data have been produced by a population with a different underlying trend (i.e., did the population increase just by a few chance good years, when it normally would be declining)?

It is important to recognize, however, that the trend estimates will be the same for both models. What changes are the variance estimates and thus the estimates of confidence intervals on the trend estimate. In particular, the confidence intervals become wider when process variance is included. The estimates of the future population size will also be quite different—the median future population size will be the same but the variance of the projections will be very different. The variance is zero for the observation-error-only model and is process variance times forecast length for the model with both variance sources.

Data Used for Trend Analyses

The data used for each analysis are shown in Figure 34 and Figure 35. The four different analyses were:

PSP-R—Puget Sound Proper using only the recreational fish per angler trip for bottomfish-specific trips.

PS-R—Puget Sound (PSP plus NPS including the Strait of Juan de Fuca) using only the recreational fish per angler trip for bottomfish-specific trips.

PSP-RT—Puget Sound Proper using the recreational fish per angler trip for bottomfish-specific trips and WDFW trawl data from PSP.

PS-RTS—Puget Sound (PSP plus NPS including the Strait of Juan de Fuca) using the recreational fish per angler trip for bottomfish-specific trips, WDFW trawl survey for PSP and NPS, and the REEF diver survey data for all of Puget Sound.

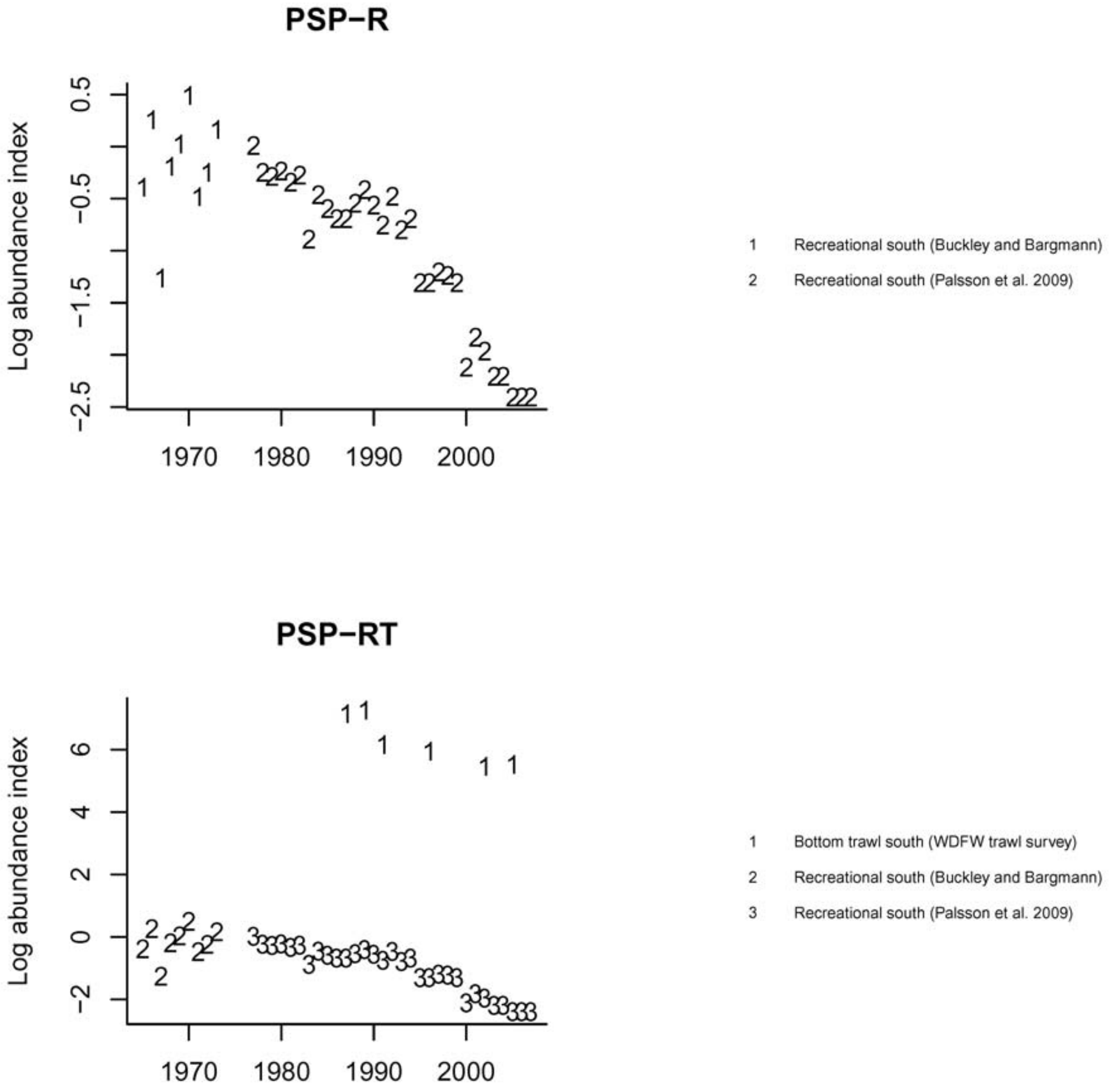


Figure 34. Data used for two PSP analyses, recreational and recreational/trawl. Data from the trawl survey were treated as separate (but not independent) processes because the trawl survey may be sampling a different segment of the total rockfish assemblage (age or size). Each process has the same long-term population growth rate (the *a*-parameter), because over the long term one segment of a population cannot have a different trend than another segment. But over the short term, different population segments can certainly have different trajectories. Modeling the trawl data as its own process allows that this segment of the population could have different process variance and a different trajectory than the recreational data, but the *a*-parameter is forced to be shared.

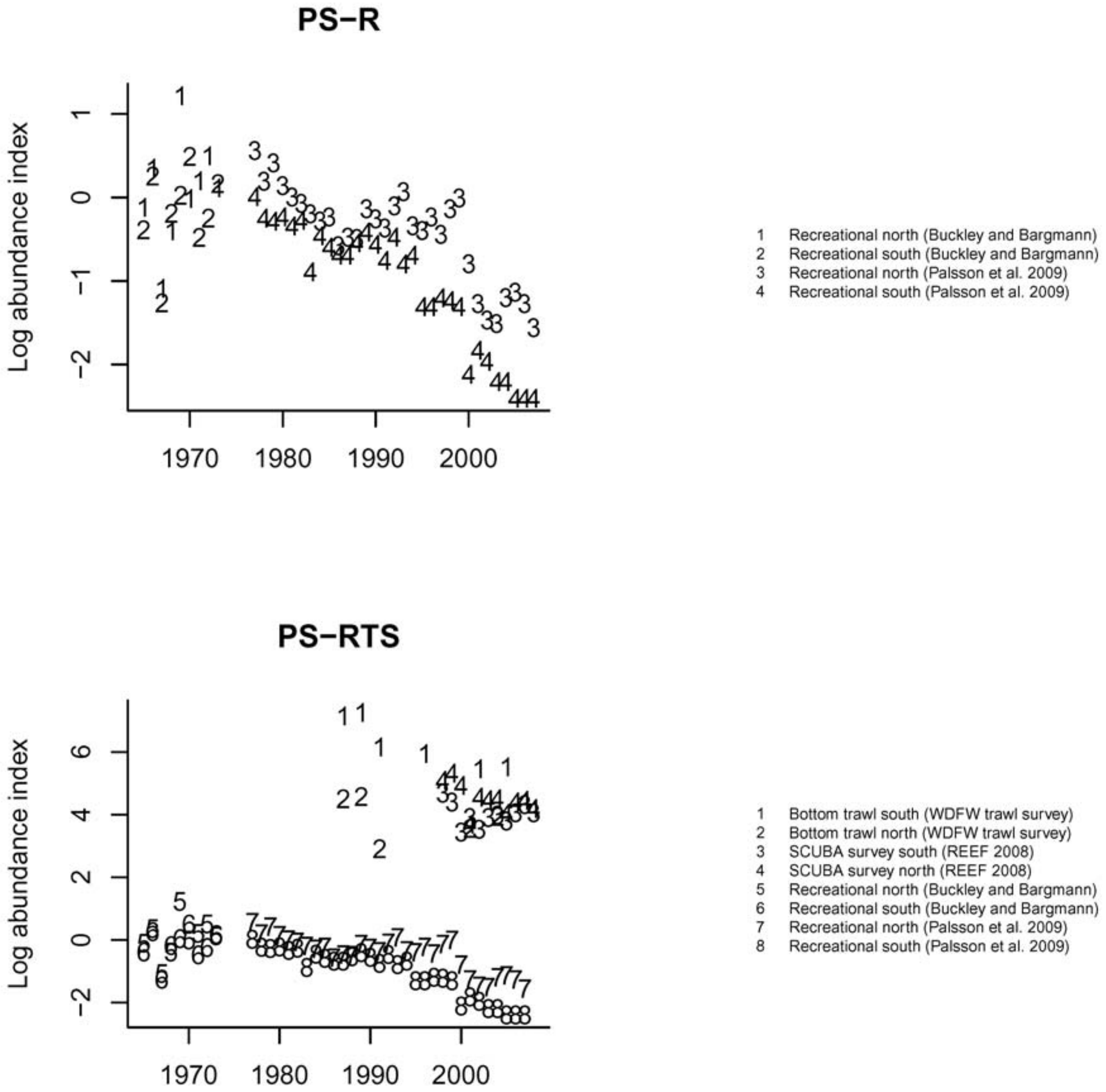


Figure 35. Data used for two Puget Sound (NPS plus PSP) analyses, recreational and recreational/trawl/scuba. The recreational, trawl, and scuba data were treated as separate (but not independent) population processes (three processes). See Figure 34 comments.

Note that when data from different survey types are combined, the multivariate AR(1) model is used to allow different data sources to monitor a different segment (age/size or region) of the population. Data that are treated as monitoring the same segment of the population have the same shading. The numbering shows which data are allowed to have different biases relative to the population. This allows, for example, the data from the 1-bag limit period to have a lower scaling relative to the population. It has a lower scaling because the maximum fish per trip has been capped (by the bag limit) at 1.

Long-term Mean Population Growth Estimates

Estimates of the trend in the total population of rockfish in Puget Sound were approximately –3% per year, although this figure varied depending on what assumptions were included in the model estimating the trend (Figure 35). This rate of annual decline corresponds to an average decline of about 70% over the 1965–2007 time period that the BRT examined. Since the frequency of the petitioned species declined, the BRT concluded that the decline of the petitioned species must have been greater than the 70% observed in the total rockfish. Figure 36 shows the estimates of the long-term mean population growth rate (1965–2007) by regions. Estimates are shown for different assumptions about the underlying structure of the population and the data from different gear types.

The assumption of one population trajectory means that there is one population process and all the data sources are sampling that same process. Their estimates will be different because different data sources have different levels of observation error and are scaled differently relative to the population abundance. The latter means that fish per angler trip in NPS equals x times abundance while scuba sightings per dive in PSP equals y times abundance and x does not equal y.

For the "all Puget Sound" analysis, the assumption of one population trajectory means that the most common rockfish in Puget Sound are mixed sufficiently to cause mixing throughout Puget Sound, and, as such, data collected in NPS and PSP should be highly correlated. This assumption is unsupported by the data as evidenced by the different trends in NPS and PSP (the upper and middle panels of Figure 36), and by the separation of NPS and PSP into separate DPSs for copper rockfish and quillback rockfish. These estimates are shown by the black symbols in the lower panel. They are plotted for completeness, but little weight should be given to these estimates.

For a single region, NPS or PSP, the assumption of one population trajectory means that the gears are sampling the same population process. This is a poor assumption if different gears are sampling different segments of the population (age/size) or very different segments of the rockfish community and these segments are behaving differently (different trends). It is likely that the hook-and-line recreational data, WDFW bottom trawls, and REEF dive data are sampling different population segments and different segments of the rockfish community; however, it is unclear whether the additional model complexity from assuming separate population processes for each data source is warranted given the limited data from the WDFW trawl survey and the REEF surveys.

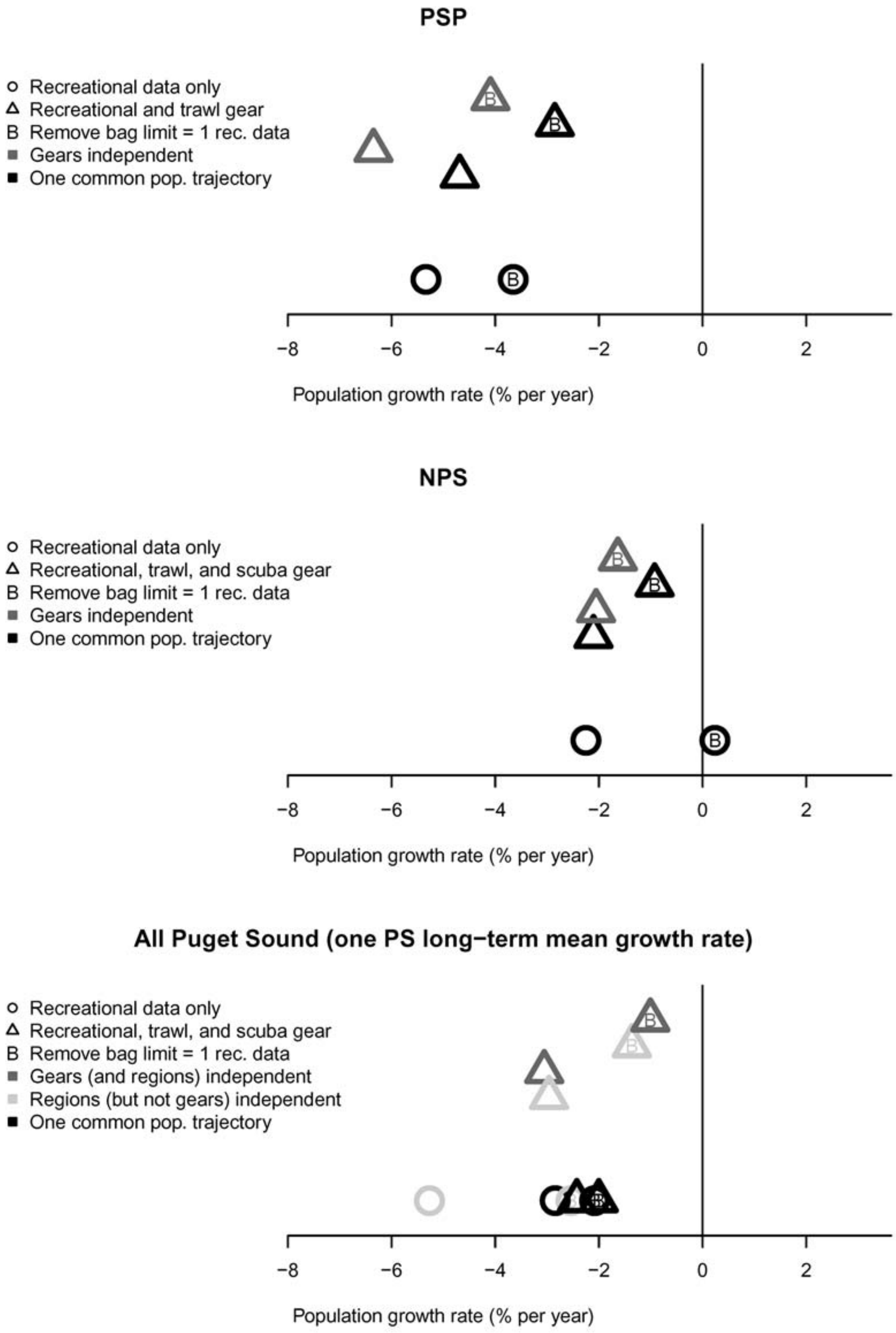


Figure 36. Estimates of rate of population growth (or decline if negative) for 1965–2007 using recreational, trawl, and REEF survey data. The colors (black and two shades of gray) and symbols denote different model assumptions (shown in legend). The height on the y-axis expresses the subjective assessment of the support for the assumptions behind each model. See Long-term Mean Population Growth Estimates subsection text for a discussion of the assumptions and which ones are supported by the data.

The recreational data since 2000 is from a fishery with a one fish bag limit on rockfish. In addition to the one fish bag limit, other regulations have been added incrementally: restriction of the season and rules against discarding undesirable rockfish. After the one fish bag limit was imposed, the trend in the rockfish per angler trip decreased from increasing to flat in the north and from flat to decreasing in the south. Arguments can be made that these data should be excluded from the analysis. The estimates marked with B show the effect of excluding these data from the analysis. As would be expected, the trend estimates increase.

Lastly, estimates were run with and without WDFW trawl survey data and REEF dive survey data in order to show how the estimates change with the inclusion of other data sources. However, there is no reason to believe these data are uninformative or invalid, thus they should be included in the analysis. If it is believed they are sampling substantially different segments of the rockfish community, then they can be included using the “gears are independent” assumption (dark gray shaded symbols).

Formal model selection approaches will not be helpful in resolving which assumptions are best because they cannot give information on whether the one fish bag limit data, trawl data, or REEF data should be excluded. Model selection can be used to look at the support for using one population process versus different processes for regions and gears. This type of analysis was used to make an argument against the one population process assumption for the “all Puget Sound” analysis.

Estimated Model Fits

Figure 37 and Figure 38 show the estimated trajectories with the rescaled data. When there are multiple data sources for a single population trajectory, the model estimates the best scaling (i.e., how to move the data up or down on the y-axis) to fit a shared population trajectory. In particular, note that recreational data with different bag limits are assumed to measure the same population trajectory, but have a different scaling.

The BRT confronted a number of issues pertaining to the species composition data. The issues and how they were handled are detailed in Appendix D.

Size Data for Each DPS

The BRT examined length frequency data for two general reasons. Size data provide some insight about the degree to which populations of the petitioned species were the result of rare (even single) recruitment events versus multiple, less episodic events. The former may indicate that Puget Sound represents a sink population that is part of a larger DPS, while the latter is more suggestive of a self-sustaining population. Second, length frequency data provide information about the degree to which large size classes have been removed from the populations.

The BRT analyzed size data available from recreationally caught fish archived in files obtained from WDFW. Data were combined from three data files (Palsson unpubl. data). Data

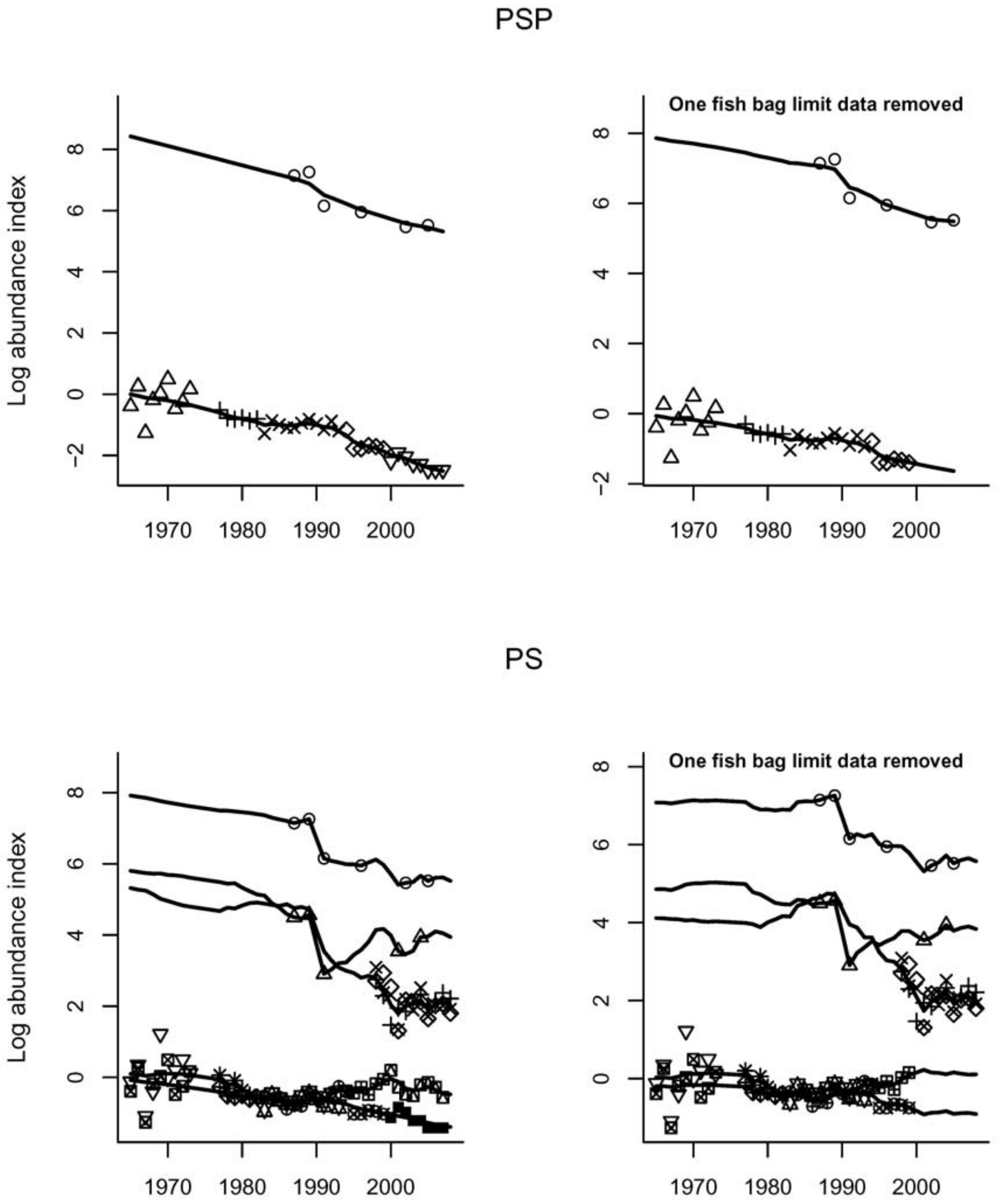


Figure 37. The model estimates for total rockfish trajectories measured by each data source for the analysis where different data sources (denoted by different lines) are allowed to be measuring independent realizations of the population process. Mathematically, each gear *i* is modeled as $log(X_{t,i}) = a + log(X_{t-1,i}) + e_{t,i}$; $log(Y_{t,i}) = log(X_{t,i}) + g_{t,i}$ trajectory, where a is the shared mean population growth term (same across data sources), $e_{t,i}$ are the independent process error terms drawn from a normal distribution with mean 0 and variance σ_i, and $g_{t,i}$ are the observation errors for data source *i*. Each line is a different *Xt* modeling the data from a different gear/location type and the points around the lines show the raw data. The goal of the analysis is to find the shared *a* that is most consistent with all the data. The analyses with (left-hand graphs) and without (right-hand graphs) the one fish bag limit data are shown.

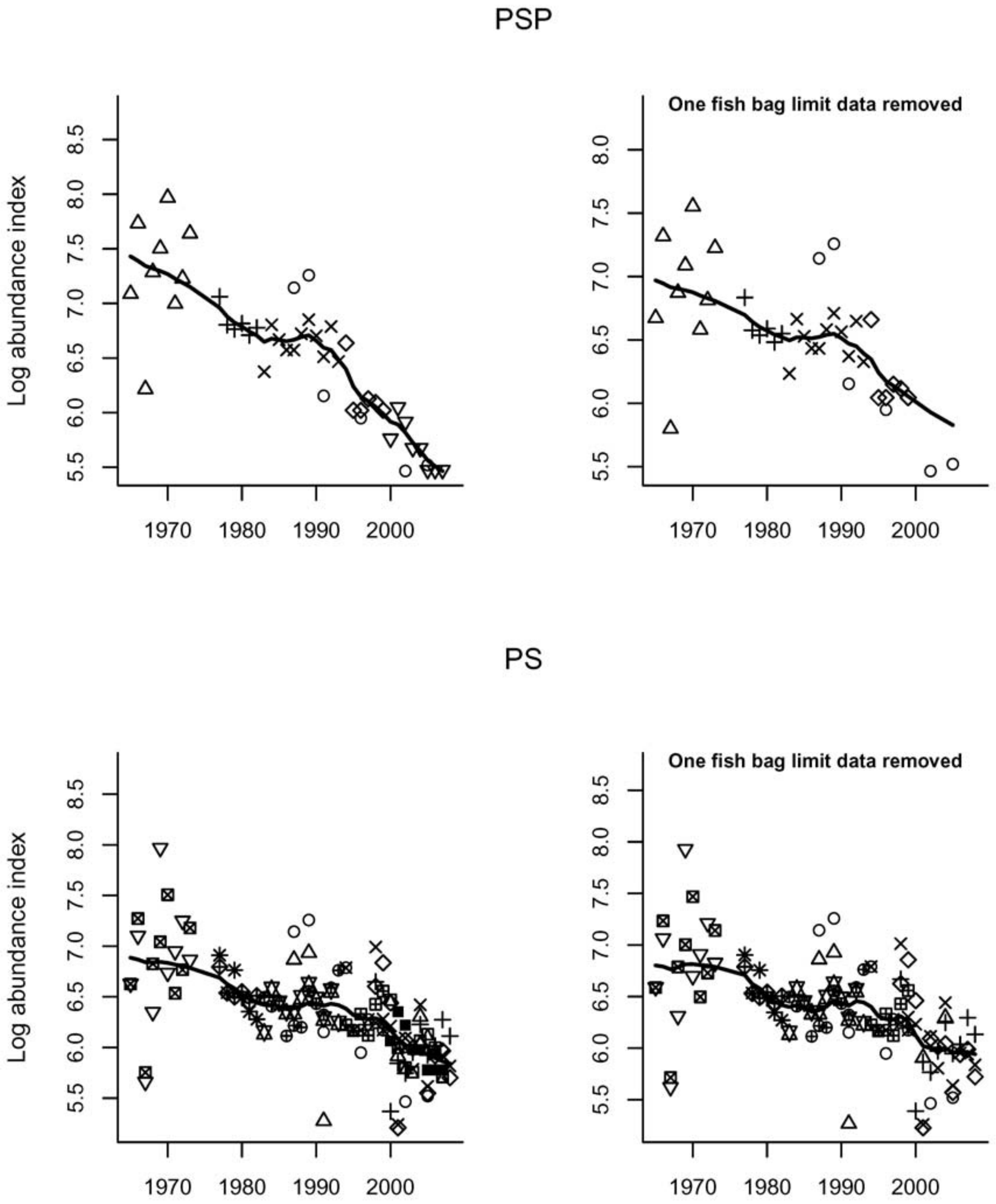


Figure 38. The model estimates for total rockfish trajectories measured by each data source for the analysis where different data sources are forced to be measuring the same population process (the line in the graph). Mathematically, all the data from each gear *i* are modeled as $log(X_t) = a + log(X_{t-1}) + e_t$; $log(Y_{t,i}) = log(X_t) + g_{t,i}$ trajectory, where *a* is the mean population growth term for the single population process, e_t is the independent process error term drawn from a normal distribution with mean 0 and variance σ_i, and $g_{t,i}$ are the observation errors for data source *i*. The goal of the analysis is to find the population trajectory that is most consistent with all the data. The analyses with (left-hand graphs) and without (right-hand graphs) the one fish bag limit data are shown.

were restricted to fish caught inside the Strait of Juan de Fuca, Georgia Basin, or PSP (punch card areas 5–13). Fish potentially caught on the coast (punch card areas 1–4) were excluded.

Size data were also available from WDFW trawl surveys conducted from 1987 to 2008. Of the five petitioned species, only redstripe rockfish (n = 3) were caught in the 1980s, canary rockfish were only caught in 2007, and bocaccio were never caught. In addition, there was a clear difference in gear selectivity between the recreational data and the trawl data, with smaller fish more common in trawls. Due to this limited applicability for examining temporal trends, we excluded trawl data from the comparisons.

Size data (presumed to be fork length for all individuals) were binned by 5 cm size classes, then plotted by species for each decade. An arbitrary cutoff size at which about 30% of the fish were larger than the rest of the sample in the 1970s (the earliest available decade for size records) was plotted for comparison with subsequent decades. Although populations in the 1970s probably did not comprise unfished size structures, they were used as the baseline for examining the availability of older fish. The 30% cutoff simply provided a metric for comparison, with healthy populations expected to include a diverse age/size structure comparable to the unfished population. Because these data were primarily derived by opportunistic creel censuses and not by a systematic sampling program, there are potential biases for many aspects. Sampling effort was not evenly distributed across time or spatial areas. Thus the size frequency histograms presented here can only serve as a general indication of trends over time, with the assumption that the examined fish were representative of size distributions within the DPS as a whole.

Bocaccio

Size frequency distributions for bocaccio in the 1970s indicate a wide range of sizes (Figure 14), with recreationally caught individuals from 25 to 85 cm. Although the distribution is clearly bimodal, some individuals in every 5 cm class are represented. This broad size distribution suggests a spread of ages, with some successful recruitment over multiple years. A similar range of sizes is also evident in the 1980s. These patterns are more likely to result from a self-sustaining population within the Puget Sound/Georgia Basin DPS rather than sporadic immigration from coastal populations. The temporal trend in size distributions for bocaccio also suggests size truncation of the population, with larger fish becoming less common over time. By the decade of the 2000s, no bocaccio data were available, so the BRT was not able to determine whether the size truncation continued in this decade.

Canary Rockfish

Canary rockfish exhibited a similar broad spread of sizes in the 1970s (Figure 14). However, by the 2000s there were far fewer size classes represented and no fish greater than 55 cm were recorded in the recreational data. Although some of this truncation may be a function of the overall lower number of sampled fish, the data in general suggest few older fish remain in the population.

Yelloweye Rockfish

Recreationally caught yelloweye rockfish in the 1970s spanned a broad range of sizes (Figure 14). By the decade of the 2000s, there was some evidence of fewer older fish in the population. However, overall numbers of fish in the database were also much lower, making it difficult to determine whether clear size truncation occurred.

Greenstriped Rockfish

Greenstriped rockfish have a relatively small maximum size. Although common in the recreational catch data for the 1970s and 1980s, they are represented by few individuals in the 1990s and 2000s. Size distributions do not suggest size truncation over this time period. Low numbers in the catch may be a function of decreasing bag limits over time and the likelihood of recreational fishermen discarding this less desired species.

Redstripe Rockfish

Similar to greenstriped, redstripe rockfish have a small maximum size and are less desirable to recreational fishermen. Large numbers of redstripe were retained by fishermen in the 1980s, but very few were available in the database for the 1990s and 2000s. There was no evidence of size truncation in this species over time, but too few fish were measured in the later decades to provide a meaningful analysis.

Although the recreational fisheries data have sampling limitations and inherent biases, they are the only source of information available for historical size distributions of the petitioned species. Fisheries impacts were likely occurring before the 1970s, when the available data series begins. The suggestion of size truncation in bocaccio, canary, and yelloweye rockfish is likely conservative. As bag limits were reduced from 15 to 10 (NPS) and 5 (PSP) in 1983, to 5 (NPS) and 3 (PSP) in 1994, and to 1 in both NPS and PSP in 2000, fishermen would be expected to select for larger fish and high-grading was likely. Thus if larger fish were available in the population at comparable proportions to the 1970s, the recreational catch might be expected to exhibit larger rather than smaller fish. For these three species, we discuss in the next subsection how the reduced proportion of older fish in the population limits reproduction to smaller, younger females, potentially leading to a host of associated maternal effects, such as reduced relative fecundity, reduced temporal span in parturition timing, and possible reduced larval quality. The absence of older fish may, therefore, decrease the resilience of the population and increase recovery time.

Threats Assessment for Petitioned Species of Rockfish

Rockfish populations in Puget Sound are potentially threatened by a number of factors that increase mortality, reduce productivity, degrade or destroy habitat, reduce water quality, or alter ecological interactions. The BRT was asked to perform a quantitative threats assessment for each DPS by scoring the severity of current threats to the five rockfish DPSs (Table 25). Severity of threat scores was defined as: 1–very low, 2–low, 3–moderate, 4–high, and 5–very high. Insufficient data to score the threat severity were indicated by U for unknown. Threats that are not applicable to the area were indicated by NA Threats were arranged within the four statutory listing factors, as described in the table heading.

The BRT created a list of the potential threats to bocaccio, canary, greenstriped, redstripe, and yelloweye rockfish in Puget Sound. Risks to marine life in Puget Sound have been documented repeatedly and in detail (e.g., Snover et al. 2005, Ruckelshaus and McClure 2007, Palsson et al. 2009), and we refer readers to these documents for a more thorough description of these threats. Following this summary of threats, the BRT reported the results of the BRT analysis of the severity of threats to each of the petitioned species DPS.

Overutilization

In Appendix F, the BRT considers the history of fisheries and fishery removals in Puget Sound. There is little doubt that overfishing played a major role in the declines of rockfish in Puget Sound (Palsson et al. 2009). For example, comparison of rockfish densities and sizes in

Table 25. Sample worksheet used by BRT in scoring the severity of current threats to the five rockfish DPSs. Threats are arranged within the four statutory listing factors: 1) present or threatened destruction, modification, or curtailment of its habitat or range; 2) overutilization for commercial, recreational, scientific, or educational purposes; 3) disease or predation; and 4) other natural or man-made factors affecting its continued existence.

Species	**Nearshore habitat loss**	**Dissolved oxygen**	**Chemical contamination**	**Nutrients**	**Commercial harvest**	**Recreational harvest**	**Disease**	**Predation**	**Competition**	**Derelict fishing gear**	**Nonindigenous species**	**Climate**	**Hatchery practices**
Bocaccio													
Yelloweye													
Canary													
Redstripe													
Greenstriped													
ESA listing factor	Habitat modification				Overutilization		Disease or predation		Other				

no-take marine protected areas to fished areas shows that the increased fishing mortality experienced by fish outside marine protected areas results in lower abundance and smaller-sized fish outside versus inside marine protected areas (Palsson et al. 2009). While fishery regulations are markedly different now than they were historically, the effects of fishing are long lasting and may constitute an ongoing threat. In particular, fishing can have dramatic impacts on the size or age structure of the population, with effects that can influence ongoing productivity. Notably, when the size and age of females declines, this negatively impacts reproductive success. The BRT considered the evidence for maternal effects on reproductive success, as well as the possibility that such effects occur in the petitioned species.

Maternal effects on reproductive success can influence the fundamental assumptions underlying stock assessment and associated fisheries management models. Put simply, the basic assumption is that all females, after adjusting for difference in biomass, are equivalent in their likelihood of producing surviving progeny. Metrics of spawning stock biomass (the weight of all mature females) or lifetime egg production (expected number of total eggs produced after incorporating adult mortality schedules) are used to estimate how many of a population's females can be removed without severely reducing the stock's reproductive capacity. Under this basic assumption, the number of progeny produced per unit weight of female biomass is constant, the seasonal timing of spawning is equivalent for all females, and all eggs or larvae have a similar likelihood of survival. Recent studies of several teleosts, including rockfishes, indicate that all of these traits can vary with female age or size. Because even minor levels of fishing can remove a disproportionate number of older or larger fish, violation of the basic assumption of reproductive equivalence can result in overestimates of the capacity of a stock to maintain a desired level of abundance.

Maternal effects in rockfishes are evident in all of the traits noted above. Larger or older females have a higher weight-specific fecundity (number of larvae per gram of female weight) in black rockfish (Bobko and Berkeley 2004), blue rockfish (*Sebastes mystinus*), yellowtail rockfish (Sogard et al. 2008), widow rockfish (Boehlert et al. 1982) and chilipepper rockfish (*S. goodie*) (Sogard unpubl. data). A particularly striking and consistent maternal effect in rockfishes relates to the timing of parturition. Because most rockfish females release larvae on only one day each year (with a few exceptions in SPS populations), the timing of parturition can be crucial in terms of matching favorable oceanographic conditions for larvae. Larger or older females release larvae earlier in the season compared to smaller or younger females in black rockfish, blue rockfish, yellowtail rockfish, kelp rockfish (*S. atrovierns*), and darkblotched rockfish (*S. crameri*) (Nichol and Pikitch 1994, Sogard et al. 2008).

Maternal effects on larval quality have been documented for black rockfish, blue rockfish, gopher rockfish (*S. carnatus*), and yellowtail rockfish (Berkeley et al. 2004, Sogard et al. 2008). The mechanism across species is the size of the oil globule at parturition, which provides the developing larva with energy insurance against the risks of starvation (Berkeley et al. 2004, Fisher et al. 2007), and in black rockfish enhances early growth rates (Berkeley et al. 2004). An additional maternal effect in black rockfish indicates that older females are more successful in completing recruitment of progeny from primary oocyte to fully developed larva (Bobko and Berkeley 2004). This effect is relevant to estimates of fecundity, since estimates of prefertilized eggs will provide a valid estimate of the final batch of released larvae for older females but will greatly overestimate the final fecundity of younger females.

Although the maternal traits examined thus far in rockfishes have been consistent in direction, with older and larger females producing proportionately greater numbers of larvae, producing higher quality larvae, and releasing them earlier in the season than younger and smaller females, not all rockfishes examined have exhibited maternal effects in all traits examined. For the species examined by Sogard et al. (2008), maternal effects were stronger in winter spawning species of the subgenus *Sebastosomus* than in spring spawning species of the subgenus *Pteropodus*.

There have been no direct studies of maternal effects for any of the *Sebastes* species listed in the current petition. The five species belong to five different subgenera, with bocaccio in *Sebastodes*, canary rockfish in *Rosicola*, yelloweye rockfish in *Sebastopyr*, greenstriped rockfish in *Hispanicus*, and redstripe rockfish in *Allosebastes* (Li et al. 2007, their Table 1). Spawning appears to occur primarily in winter for bocaccio and canary rockfish, in spring for redstripe rockfish, and across a broad span of months from winter to summer in yelloweye and greenstriped rockfish (Love et al. 2002). Predicting the form or strength of maternal effects based on phylogenetic relationships or timing of spawning is thus difficult for these five species. However, the generality of maternal effects in *Sebastes* suggests that some level of age or size influence on reproduction is likely.

Exploited species typically exhibit a reduction in the proportion of older and larger fish in the fished population. This age truncation effect has been widely demonstrated for *Sebastes* populations all along the west coast (Mason 1998, Harvey et al. 2006), even for species not currently categorized as overfished by the Pacific Fishery Management Council. Over time, removal of older fish leads to a shift to earlier ages and sizes at maturation. This effect may be a result of phenotypic plasticity and therefore reversible if exploitation is reduced, but there is some evidence of evolutionary selection toward younger ages at maturity (Law 2007). Under either scenario, age truncation leads to increased dependence on younger females for reproduction. Shifts in the age of maturity have not been examined in rockfishes. The importance of the maternal effect on larval quality to population productivity depends greatly on the maturity schedule (O'Farrell and Botsford 2006).

In a broad span of species, there is evidence that age or size truncation is associated with increased variability in recruitment, for example, Icelandic cod (*Gadus morhua*) (Marteinsdottir and Thorarinsson 1998), striped bass (*Morone saxatilis*) (Secor 2000), Baltic cod (*Gadus morhua callarias*) (Wieland et al. 2000), and a broad suite of California Current species (Hsieh et al. 2006). For long-lived species, reproduction over a span of many years is considered a bet-hedging strategy that has a buffering effect at the population level, increasing the likelihood of some successful reproduction over a period of variable environmental conditions (Longhurst 2002). When reproductive effort is limited to younger ages, this buffering capacity is lost and populations more closely follow short-term fluctuations in the environment (Hsieh 2006).

The importance of maternal effects on extinction risk in rockfishes will depend on how severely the population's size and age structure have been truncated. Risk will increase as the proportion of reproduction contributed solely by younger females increases.

Habitat Destruction and Modification

Physical habitat

As presented earlier, adult bocaccio, canary, and yelloweye rockfish are typically associated with rocky habitats. Palsson et al. (2009) report that such habitat is extremely limited in Puget Sound, with only 10 km^2 of such habitat in PSP (i.e., south of Admiralty Inlet), and 207 km^2 in NPS. Palsson et al. (2009) note that this habitat can be degraded by construction of bridges, sewer lines and other structures, deployment of cables and pipelines, and by burying from dredge spoils and natural subtidal slope failures.

Biogenic habitat

The human population in the greater Puget Sound region has increased rapidly over the last two decades. In 2005 the Puget Sound basin housed approximately 4.4 million people, a 25% increase from 1991. Although estimates vary depending on the area encompassed, according to the Washington Office of Management, the population is expected to grow to 4.7–6.1 million residents by 2025 (Ruckelshaus and McClure 2007). Freshwater, marine, nearshore, and upland habitats throughout the greater Puget Sound region have been affected by a variety of human activities, including agriculture, heavy industry, timber harvest, and the development of seaports and residential property. The extent of some of these habitats has markedly declined over the last century. Hutchinson (1988) indicated that overall losses since European settlement by area of intertidal habitat were 58% for greater Puget Sound and 18% for the Strait of Georgia. Four river deltas (the Duwamish, Lummi, Puyallup, and Samish) have lost more than 92% of their intertidal marshes (Simenstad et al. 1982, Schmitt et al. 1994). At least 76% of the wetlands around greater Puget Sound have been eliminated, especially in urbanized estuaries. Substantial declines of mudflats and sand flats have also occurred in the deltas of these estuaries (Levings and Thom 1994).

More recent estimates suggest that more than 80% of all tidal wetlands have been converted to human-dominated land uses (Collins and Sheikh 2005). Furthermore, approximately 30% of the Puget Sound shoreline has been modified by humans, most intensely in heavily populated regions. Nearly 52% of central Puget Sound and about 35% of the shorelines of Whidbey Island, Hood Canal, and SPS have been modified (Nearshore Habitat Program 2001).

Eelgrass, kelp, and other submerged vegetation may provide important rockfish habitat, particularly for juveniles (Love et al. 1991). In 2006 there were about 20,234 hectares of eelgrass in Puget Sound, with about one-third of this in Padilla and Samish bays. Monitoring of eelgrass began in 2000, and although coverage declined until 2004, since that time it has remained unchanged over all of Puget Sound. However, localized declines have occurred, with local losses in Hood Canal ranging from 1–22% per year (the BRT). Kelp cover is highly variable and has shown long-term declines in some regions, while kelp beds have increased in areas where artificial substrate provides additional kelp habitat (Palsson et al. 2009).

Nonindigenous species are an emerging threat to biogenic habitat in Puget Sound. *Sargassum muiticum* is an introduced brown alga that is now common throughout much of the sound. The degree to which *S. muiticum* influences native macroalgae, eelgrass, or rockfish is not presently understood. Several species of nonindigenous tunicates have been indentified in Puget Sound. For example, *Ciona savignyo* was initially seen in one location in 2004, but within 2 years spread to 86% of sites surveyed in Hood Canal (the BRT). The exact impact of invasive tunicates on rockfish or their habitats is unknown, but results in other regions (e.g., Levin et al. 2002) suggest the potential for introduced invertebrates to have widespread impacts on rocky reef fish populations.

Water quality

Over the last century, human activities have introduced a variety of toxins into Puget Sound at levels that may affect rockfish populations or the prey that support them. Several urban embayments in Puget Sound have high levels of heavy metals and organic compounds. About 32% of the sediments in the sound are considered to be moderately or highly contaminated. Organisms that live in or eat these sediments are themselves consumed, thus transferring contaminants up the food web and to a wider area.

Not surprisingly, contaminants such as polychlorinated biphenyls (PCBs), chlorinated pesticides (e.g., DDT), and polybrominated diphenyl ethers (PBDEs) appear in rockfish collected in urban areas. However, while the highest levels of contamination occur in urban areas, toxins can be found in the tissues of animals in all regions of Puget Sound (the BRT). Indeed, rockfish collected in rural areas of the San Juan Islands revealed high levels of mercury and hydrocarbons (West et al. 2001).

Although risks from contaminants can affect all life history stages of rockfish, few studies have investigated the effects of toxins on rockfish ecology or physiology. Contaminants may influence growth rates of rockfish. For example, Palsson et al. (2009) describe a case in which male rockfish have lower growth rates than females—an unusual pattern for rockfish since males typically grow faster than females. The explanation may be that male rockfish tend to accumulate PCBs while the female's body burden does not increase with time since they lower their toxin level when they release eggs. Thus the observed difference in growth rate may result from the higher contaminant concentration in males versus females.

Rockfish may also experience reproductive dysfunction as a result of contaminant exposure. Although no studies have shown an effect on rockfish, other fish in Puget Sound that have been studied do show a substantial impact. For instance in English sole (*Parophrys vetulus*), reproductive function is reduced in animals from contaminated areas, and this effectively decreases the productivity of the species (Landahl et al. 1997).

As noted, rockfish rely to some degree on pelagic prey and thus may experience greater exposure to persistent bioaccumulative toxics across a greater spatial range (not just urban areas) than the discussion above suggests. Pelagic prey such as Pacific herring in Puget Sound have unusually high body burdens of toxins that can biomagnify in their predators. Long life span and residency in Puget Sound, both characteristics of the petitioned rockfish species, increase the risk of exposure. In addition, environmental levels of legacy toxins such as PCBs were probably higher in Puget Sound's pelagic species in the 1970s and 1980s, the period when the petitioned species declined.

The full effect of contaminants on rockfish remains unknown, but there is clearly a potential for impact. Historically, rockfish were captured in great numbers in areas that are now subject to high levels of contaminants (compare PSAT 2007 and Palsson et al. 2009). In addition, Palsson et al. (2009) suggest that urban embayments have become de facto no-take zones. Thus in these contaminated areas, we might expect to find relatively high densities of fish exposed to high levels of toxins. Such a scenario has the potential to greatly limit recovery of depleted rockfish populations.

In addition to chemical contamination, water quality in Puget Sound is also influenced by sewage, animal waste, and nutrient inputs. The Washington Department of Ecology has been monitoring water quality in Puget Sound for several decades. Monitoring includes fecal coliform, nitrogen, ammonium, and DO. Of 39 sites sampled in 2005, 8 were classified as highest concern and 10 were classified as high concern. DO has been an increasing concern. Hood Canal has seen persistent and increasing areas of low DO since the mid-1990s. Typically, rockfish move out of areas with DO less than 2 mg/L; however, when low DO waters were upwelled to the surface in 2003, about 26% of the rockfish population were killed (Palsson et al. 2009). In addition to Hood Canal, Palsson et al. (2009) report that periods of low DO are becoming more widespread in waters south of the Tacoma Narrows.

Predation

Prominent members of the Puget Sound/Georgia Basin food web are described in Appendix C. Here we highlight several predatory species or trophic groups that may significantly influence rockfish population dynamics.

Rockfish are important prey items of lingcod (Beaudreau and Essington 2007). Lingcod populations have been low in Puget Sound, but are increasing in recent years (Palsson et al. 2009). Ruckelshaus et al. (2009) examined the potential effect of predation by lingcod on rockfish recovery. Their models indicate that even very small increases in predation mortality within marine protected areas (MPAs) (i.e., 1.2%) are sufficient to negate the benefit of zero fishing pressure that occurs within MPAs.

Predation by pinnipeds may be locally significant. Four pinniped species are found in the waters of Washington State: harbor seals, California sea lions (*Zalophus californianus*), Steller sea lions (*Eumetopias jubatus*), and northern elephant seals (*Mirounga angustirostris*). Harbor seal populations have increased from hundreds during the 1970s to more than 10,000 at present (Jeffries et al. 2003). The harbor seal is the only pinniped species that breeds in Washington waters, and is the only pinniped with known haul-out sites in the San Juan Islands (Jeffries et al. 2000). Harbor seals are considered a threat to local fisheries in many areas (Olesiuk et al. 1990, Bjorge et al. 2002) and concerns have arisen about their impact on fisheries in Washington, Oregon, and California, where consumption by California sea lions and harbor seals are estimated to be almost half of what is harvested in commercial fisheries (NMFS 1997). In Puget Sound, harbor seals are considered opportunistic feeders that consume seasonally and locally abundant prey (Olesiuk et al. 1990, London et al. 2001).

About 2,000 Stellar sea lions occur seasonally in Washington waters, with dozens found in Puget Sound, particularly in the San Juan Islands (Palsson et al. 2009). About 8% of the stellar sea lion diet are rockfish (Lance and Jeffries 2007). Though not abundant, their large size and aggregated distribution suggest that their local impact could be nontrivial.

Fifteen species of marine birds breed along the Washington coast; seven which historically breed in the San Juan Islands/Puget Sound area (Speich and Wahl 1989). The predominant breeding marine birds in the San Juan Islands are pigeon guillemots (*Cepphus columba*), double-crested cormorants (*Phalacrocorax auritus*), pelagic cormorants (*Phalacrocorax pelagicus*), and members of the western gull and glaucous-winged gull complex (*Larus occidentalis* and *L. glaucescens*) (Speich and Wahl 1989). The first three species are locally abundant. Whether or not these avian predators have an impact on rockfish populations is unknown.

Disease

Rockfish are susceptible to diseases and parasites (Love et al. 2002), but their impact on the petitioned species is not known. Palsson et al. (2009) suggest that stress associated with poor water quality may exacerbate the incidence and severity of naturally occurring diseases to the point of directly or indirectly decreasing survivorship of the petitioned species.

Competition

Rockfishes are known to compete for resources (Larson 1980). Harvey et al. (2006) documented the decline of bocaccio in the California Current and used bioenergetic models to suggest that recovery of coastal populations of bocaccio may be inhibited by their more common congeners. In Puget Sound, more abundant species such as copper and quillback rockfish may interact with juvenile bocaccio, canary, or yelloweye rockfish and limit the ability of these petitioned species to recover from perturbations. However, evidence documenting competition in Puget Sound is generally lacking.

Release of Propagated Fish

Chinook and coho (*Oncorhynchus kisutch*) salmon consume larval and juvenile rockfish and they also share prey with small size classes of rockfish (Buckley 1997); thus large releases of hatchery salmon have the potential to influence the population dynamics of the petitioned species. Total hatchery releases in Puget Sound have mirrored those in the California Current region (Naish et al. 2007); hatchery releases of delayed release Chinook and coho salmon into Puget Sound averaged 21.2 million fish annually from 1983 to 2000. Present annual releases are now approximately 14.7 million (Palsson et al. 2009).

Lingcod have been identified as a suitable species for enhancement via hatcheries under the Puget Sound Recreational Fishery Enhancement Fund. A collaborative effort by the Washington SCUBA Alliance, Northwest Indian Fisheries Commission, Squaxin Island Tribe, and NOAA resulted in a small-scale release of 3-year-old lingcod in SPS in 2001. Additional small-scale releases (<100 fish) are planned in the near future. Long-term (subject to funding), the annual release of approximately 9,000 lingcod into the southern portion of Puget Sound is planned (Lee et al. 2008, Palsson et al. 2009). As described above, lingcod may be important predators of rockfish. Because lingcod exhibit limited movement (Tolimieri et al. 2009), large hatchery releases of lingcod have the potential to have a major local impact on rockfish populations.

Bycatch

Rockfish are unintentionally captured as part of fishing activities targeting other species. Although fishers may return these fish to the water, the mortality rate of these fish is extremely high (Parker et al. 2006). Although there are some methods available that could lower the mortality rates of discarded rockfish (summarized by Palsson et al. 2009), application of these methods in the Puget Sound fishery would be difficult (Palsson et al. 2009). WDFW considers bycatch of rockfish to be a “high impact stressor” on rockfish populations (Palsson et al. 2009).

Derelict Fishing Gear

Palsson et al. (2009) report that more than 3,600 pieces of abandoned fishing gear (especially gill nets) have been located in Puget Sound. About 35% of this derelict gear has been removed. Derelict nets continue fishing and are known to kill rockfish. While the total impact of this abandoned gear has not been fully enumerated, WDFW has concluded that derelict gear is likely to moderately affect local populations of rockfish (Palsson et al. 2009).

Climate

As discussed earlier and in Appendix E, patterns of circulation and productivity in Puget Sound are fundamentally influenced by climate conditions. Briefly, changes in the timing of freshwater input affect stratification and mixing in the sound, while changes in wind pattern influence the amount of biologically important upwelled water that enters the Strait of Juan de Fuca from the coast (Snover et al. 2005). Direct studies on the effect of climate variability on rockfish are rare, but all the studies performed to date suggest that climate plays an extremely important role in population dynamics. Tolimieri and Levin (2005) examined the effects of climate variability on bocaccio recruitment. They found that the dynamics of bocaccio populations were governed by rare recruitment events, and that these rare events resulted when specific climate conditions occurred at different times in their early life history. The coincidence of such climate patterns only occurred 15% of the time.

Harvey (2005) created a generic bioenergetic model for rockfish, arguing that productivity of rockfish is highly influenced by climate conditions such that El Niño-like conditions generally lowered growth rates and increased generation time. The negative effect of the warm water conditions associated with El Niño appear to be common across rockfishes (Moser et al. 2000). Field and Ralston (2005) noted that recruitment of all species of rockfish appeared to be correlated at large scales and hypothesized that such synchrony was the result of large-scale climate forcing. Exactly how climate influences the petitioned species in Puget Sound is unknown; however, given the general importance of climate to the sound and to rockfish, it is likely that climate strongly influences the dynamics of the petitioned species.

Overall Risk Determination

The BRT's analysis of overall risk to the species or DPS used the categories of "high risk" of extinction, "moderate risk" of extinction, or "not at risk" of extinction. Table 26 describes the qualitative reference levels of extinction risk associated with these terms. The overall extinction risk determination reflected informed professional judgment by each BRT member. This assessment was guided by the results of the risk matrix analysis, integrating information about demographic risks with expectations about likely interactions with threats and other factors.

To allow individuals to express uncertainty in determining the overall level of extinction risk facing the species, the BRT adopted the "likelihood point" (FEMAT) method. See Table 27 for an example worksheet. This method has been used in all status review updates for anadromous Pacific salmonids since 1999, as well as in reviews of Puget Sound rockfishes (Stout et al. 2001a), Pacific herring (Stout et al. 2001b, Gustafson et al. 2006), Pacific hake, walleye pollock, Pacific cod (Gustafson et al. 2000), and black abalone (VanBlaricom et al. 2009).

Table 26. Description of reference levels for the BRT's assessment of extinction risk.

Qualitative "reference levels" of relative extinction risk	
↑ Continuum of decreasing relative risk of extinction	Moderate risk: A species or DPS is at moderate risk of extinction if it exhibits a trajectory indicating that it is more likely than not to be at a high level of extinction risk (see description of "High risk" below). A species or DPS may be at moderate risk of extinction due to projected threats or declining trends in abundance, productivity, spatial structure, or diversity. The appropriate time horizon for evaluating whether a species or DPS is more likely than not to be at high risk depends on various case- and species-specific factors. For example, the time horizon may reflect certain life history characteristics (e.g., long generation time or late age-at-maturity) and may also reflect the time frame or rate over which identified threats are likely to impact the biological status of the species or DPS (e.g., the rate of disease spread). The appropriate time horizon is not limited to the period that status can be quantitatively modeled or predicted within predetermined limits of statistical confidence. Please explain the time scale over which the BRT has confidence in evaluating moderate risk.
	High risk: A species or DPS with a high risk of extinction is at or near a level of abundance, productivity, spatial structure, and/or diversity that place its persistence in question. The demographics of a species or DPS at such a high level of risk may be highly uncertain and strongly influenced by stochastic or depensatory processes. Similarly, a species or DPS may be at high risk of extinction if it faces clear and present threats (e.g., confinement to a small geographic area; imminent destruction, modification, or curtailment of its habitat; or disease epidemic) that are likely to create such imminent demographic risks.
Extinct	A species or DPS is extinct when there is no longer a living representative.

Table 27. Example worksheet used for the evaluation of the overall level of extinction risk for the various Puget Sound rockfish DPSs using the "likelihood point" method (FEMAT 1993).

	Overall extinction risk category[a]		
	Not at risk	**Moderate risk**	**High risk**
Number of likelihood points[b]			
	Comments:		

---

[a] These evaluations do not consider protective efforts and therefore are not recommendations regarding Endangered Species Act listing status.

[b] Each Biological Review Team member distributes 10 likelihood points among the three overall extinction risk categories. Placement of all 10 points in a given risk category reflect 100% certainty that level of risk reflects the true level of extinction risk for the species. Distributing points between risk categories reflects uncertainty in whether a given category reflects the true species status.

Conclusions Regarding Risk Status for Each of the Five DPSs of Puget Sound Rockfish

Bocaccio

Evaluation of Demographic Risks

Abundance

BRT scores for abundance of the bocaccio DPS ranged from 4 to 5 with a mean score of 4.78 (±0.15 SD) and a modal score of 5. A score of 4 represents high risk and a score of 5 represents very high risk. Seven of the nine BRT members scored this category as a 5, very high risk. In this context, very high risk means that current trends and levels of abundance by themselves indicate danger of extinction in the near future.

Several BRT members commented that there are few good data available to adequately judge bocaccio abundance trends. Comments on the abundance criterion included consideration that: 1) there were historical catch data reflecting consistent former abundance in portions of the bocaccio DPS; 2) compared with former abundance, the bocaccio DPS has been at all time low abundance levels for the past several years, exhibiting a disturbing trend in abundance of 0; 3) recent Canadian COSEWIC abundance data for bocaccio, as indicated by catch records, are low in all or nearly all spawning populations relative to earlier periods; and 4) low DO events in Puget Sound affected historic range.

Growth rate/productivity

BRT scores for growth rate and productivity of the bocaccio DPS ranged from 4 to 5 with a mean score of 4.78 (±0.15 SE) and a modal score of 5. BRT members scored this category as 5, very high risk. In this context, very high risk means that population productivity (growth rate) by itself indicates danger of extinction in the near future.

Many BRT members felt that there was insufficient data to adequately score this category with any certainty. However, several BRT members noted that low abundance in the bocaccio DPS is likely resulting in reduced productivity. Tolimieri and Levin (2005) found that the bocaccio population growth rate, in the absence of harvest, is around 1.01, indicating a very low intrinsic growth rate for this species. Other studies suggest that populations are not capable of supporting continuous harvest. Demographically, this species demonstrates some of the highest recruitment variability among rockfish species, with many years of failed recruitment being the norm (Tolimieri and Levin 2005). High fecundity and episodic recruitment events, largely correlated with environmental conditions, mean that bocaccio populations do not follow consistent growth trajectories. Sporadic recruitment drives population structure. The BRT noted no positive indications for population growth rate and productivity.

Spatial structure and connectivity

BRT scores for spatial structure and connectivity of the bocaccio DPS ranged from 3 to 4 with a mean score of 3.56 (±0.18 SE) and a modal score of 4. BRT members scored this category as 4. A score of 4 represents high risk, which in this context means that population spatial structure and connectivity contribute significantly to long-term risk of extinction and are likely to contribute to short-term risk of extinction in the foreseeable future.

Comments on spatial structure and connectivity criteria included concerns that: 1) apart from an isolated historical population in the southern portion of this DPS in SPS, other populations do not appear to be viable; 2) the loss of former populations has likely resulted in a contraction of the bocaccio DPS range; 3) there is the potential loss of habitat due to hypoxia issues in SPS; 4) juvenile recruitment depends on the availability of specific types of macroalgae (kelp), which is also decreasing in some portions of the DPS; and 5) size data suggests a cohort population structure that differs from coastal populations and thus provides some evidence of that this DPS is only weakly connected to California Current bocaccio. However, one BRT member thought that this DPS may consist of a vagrant population seeded by coastal populations.

Diversity

BRT scores for diversity of the bocaccio DPS ranged from 3 to 4 with a mean score of 3.11 (±0.26 SE) and a modal score of 3. A score of 3 represents moderate risk which, in this context, means that diversity contributes significantly to long-term risk of extinction, but does not in itself constitute a danger of extinction in the near future.

Several BRT members commented that the apparent uniformity in life history traits and low genetic diversity across the entire range of the biological species made it difficult to assign a risk score to the diversity category. Comments on the diversity criterion included concerns related to: 1) the unique habitats in the Puget Sound ecosystem, when compared to the coast, which may have led to unique adaptations to conditions at the northern extent of the species' range; 2) the potential loss of diversity in the bocaccio DPS due to contraction of effective population size and a truncated age structure due to harvest selection; and 3) variable ocean conditions (exacerbated by climate change) that may lead to a mismatch with current diversity traits. The BRT noted no positive signs pertinent to the diversity parameter for this DPS.

Recent events

For recent events, the BRT's scores ranged from double minus to single minus (– – to –) with a mode of single minus (–). These scores reflect an assessment that recent events, considered collectively, are likely to have an overall negative impact on long-term viability of the bocaccio DPS. The recent drop in abundance of the bocaccio DPS, coupled with the probable disruption of metapopulation structure, may make it more difficult for the bocaccio DPS to rebuild.

Qualitative Threats Assessment

The results of the BRT's analysis of the severity of threats to the bocaccio DPS are presented in Table 28. Shown are the median threat scores with the SD about the median. The BRT ranked low DO and recreational and commercial harvest as the most serious threats to persistence of the bocaccio DPS. In some categories, some portion of the BRT felt that insufficient data were available to score the threat severity (thereby marking the threat severity as unknown).

Overall Risk Summary

Bocaccio appear to have declined in frequency in PSP, relative to other species, from the 1970s to the present. From 1975 to 1979, bocaccio were reported as an average of 4.63% of the catch. From 1980 to 1989, they were 0.24% of the rockfish identified, and from 1996 to 2007, bocaccio have not been observed out of the 2,238 rockfish identified in the dockside surveys of the recreational catches. In a sample this large, the probability of observing at least 1 bocaccio would be 99.5% assuming it was at the same frequency (0.24%) as in the 1980s. In conclusion, there is strong support in the data for a decline in the frequency of bocaccio relative to other species in PSP. We do know from other data sources (scuba surveys) that although rare, bocaccio rockfish were present in PSP as recently as 2001. In NPS, bocaccio have always been rare in the surveys of the recreational fishery. In the Strait of Georgia, bocaccio have been documented in some inlets, but records are sparse, isolated, and often based on anecdotal reports (COSEWIC 2002).

As previously stated, size frequency distributions for bocaccio in the 1970s indicate a wide range of sizes, with recreationally caught individuals from 25 to 85 cm. Although the distribution is clearly bimodal, some individuals in every 5 cm class are represented. This broad size distribution suggests a spread of ages, with some successful recruitment over many years. A similar range of sizes is also evident in the 1980s. These patterns are more likely to result from a self-sustaining population within the Puget Sound/Georgia Basin DPS rather than sporadic immigration from coastal populations. The temporal trend in size distributions for bocaccio also suggests size truncation of the population, with larger fish becoming less common over time. By the 2000s, no bocaccio data were available, so the BRT was not able to determine whether the size truncation continued in this decade.

Overall, the BRT was very concerned about the downward trend in bocaccio abundance, and a large majority concluded that this trend was, by itself, sufficient to indicate that the Puget Sound/Georgia Basin bocaccio DPS was in danger of extinction in the near future. The BRT was also concerned that bocaccio as a species have a very low intrinsic rate of population growth, even in the absence of harvest or other threats that may limit productivity, and the size distribution of bocaccio in Puget Sound appeared to be trending toward smaller, less productive fish.

Bocaccio are also characterized by highly variable recruitment that is largely driven by environmental conditions which occur only infrequently (Tolimieri and Levin 2005). Even in the absence of continued exploitation, the BRT was therefore concerned that Puget Sound/Georgia Basin bocaccio were at risk due to their low abundance and low intrinsic

Table 28. Results of qualitative ranking by the Puget Sound rockfish BRT of severity of threats for five DPSs. The median (with standard deviation) is shown for each threat type. Threats were scored as: 1–very low, 2–low, 3–moderate, 4–high, and 5–very high. Members not voting mark severity of threat as “unknown.”

		Habitat Modification				**Fisheries**		
DPS		**Nearshore**	**Dissolved oxygen**	**Contaminant**	**Nutrients**	**Commercial**	**Recreational**	**Disease**
Bocaccio	Median	3	4	3.5	3	4	5	Unknown
	SD	0.707107	1.30247	0.744024	1	0.64087	0.755929	
Yelloweye	Median	3	3	3	3	4	4	Unknown
	SD	0.755929	1.246423	1.035098	1	1.30247	0.517549	
Canary	Median	3	4	3.5	3	4	4	Unknown
	SD	0.707107	1.30247	0.744024	1	1.06066	0.517549	
Redstripe	Median	2	3.5	3	3	2.5	2.5	Unknown
	SD	0.834523	1.28174	1.125992	1	1.164965	1.164965	
Greenstriped	Median	2	3	3	3	2.5	2.5	Unknown
	SD	1.139626	1.296538	1.307323	1.069045	1.51174	1.899376	

DPS (table continues horizontally)			**Other**				
		Predation	**Competition**	**Derelict gear**	**Invasives**	**Climate**	**Hatchery**
Bocaccio	Median	3	3	2.5	3.5	3.5	4
	SD	0.894427	1.414214	1.21106	0.957427	1.264911	0.408248
Yelloweye	Median	3	3.5	3.5	3.5	4	4
	SD	0.752773	1.47196	0.816497	0.957427	1.032796	0.408248
Canary	Median	1.5	3	2.5	3.5	2	2
	SD	0.816497	1.414214	1.21106	0.957427	1.032796	1.032796
Redstripe	Median	1.5	3	2.5	3.5	2	2.5
	SD	0.816497	1.414214	1.21106	0.957427	1.169045	1.048809
Greenstriped	Median	1.5	3	2.5	3.5	2	2
	SD	0.979759	0.921485	0.969312	1.359062	1.194626	1.540314

population growth rate. In addition, the BRT noted that because the Puget Sound/Georgia Basin bocaccio DPS is largely isolated from the rest of the species, it appeared unlikely that dispersal from coastal populations, which themselves are highly depressed, would be sufficient to maintain the abundance of the DPS. Threats to this DPS include areas of low DO within their range, the potential for continued losses as bycatch in recreational and commercial harvest, and the reduction of kelp habitat necessary for juvenile recruitment. The BRT's conclusions regarding the overall risk to the Georgia Basin bocaccio DPS were weighted heavily to high risk (59/90) with substantially less support for moderate risk (29/90) and almost no support for not at risk (2/90).

Although there have been no confirmed observations of bocaccio in Puget Sound/Georgia Basin for approximately 7 years, the BRT concluded that there was no compelling reason to believe that the DPS has been extirpated. In particular, although it has disappeared from the recreational catch, the recreational fishery does not provide a complete sampling of the Puget Sound/Georgia Basin area. Additionally, existing fishery regulations limit potential observations from bycatch in the set net fishery, where bocaccio were reliably observed through the 1980s. Given the lack of an intensive effort to completely enumerate bocaccio and the long life-span of the species, the BRT concluded that it is likely that the DPS still exists at a very low abundance and would be observed with a sufficiently intensive observation program.

Significant Portion of its Range Question

The BRT concluded that the bocaccio DPS is at high risk of extinction throughout all of its range; in effect answering the question in the affirmative as to whether the bocaccio DPS is at risk throughout a significant portion of its range.

Canary Rockfish

Evaluation of Demographic Risks

Abundance

BRT scores for abundance of the canary rockfish DPS ranged from 3 to 5 with a mean score of 4 (±0.288 SE) and a modal score of 3. Seven of the nine BRT members scored this as 5, very high risk. In this context, high risk means that current trends and levels of abundance contribute significantly to long-term risk of extinction and are likely to contribute to short-term risk of extinction in the foreseeable future. Very high risk means that current trends and levels of abundance by themselves indicate danger of extinction in the near future.

Several BRT members commented that there are few good data available to adequately judge canary rockfish abundance trends. Catch records are a poor substitute for fishery-independent data, leading to high levels of uncertainty. Comments on the abundance criterion included consideration that: 1) no core population or subpopulation is at normal levels of abundance anywhere in the DPS; 2) the DPS has been at all time low abundance levels for the past several years, exhibiting a disturbing trend in abundance, which is declining at a faster rate than other rockfish populations; 3) recent 10-year abundance in the DPS (as indicated by catch and scuba survey records) is low in all or nearly all spawning populations relative to earlier periods; and 4) it formerly comprised one of the top three species found in the WDFW recreational catch data, which is no longer the case.

Growth rate/productivity

BRT scores for growth rate and productivity of the canary rockfish DPS ranged from 3 to 5 with a mean score of 4.11 (±0.20 SE) and a modal score of 4. Six of the nine BRT members scored this category as 4, high risk. In this context, high risk means that population productivity (growth rate) contributes significantly to the long-term risk of extinction and is likely to contribute to short-term risk of extinction in the foreseeable future.

Many BRT members felt that there was insufficient data to adequately score this category with any certainty. However, several BRT members noted that low abundance in the canary rockfish DPS is likely resulting in reduced productivity. Life history traits would suggest intrinsic slow growth rate and low rates of productivity for this species, specifically its age at maturity (9 years) and its maximum age (84 years). Other BRT members noted that long generation time for canary rockfish means they have very low rates of productivity (Love et al. 2002). Although commercial and recreational fishing have been curtailed, this was believed to have depressed populations to a threshold beyond which optimal productivity might be unattainable. The BRT noted no positive indications for population growth rate and productivity for this DPS.

Spatial structure and connectivity

BRT scores for spatial structure and connectivity of the canary rockfish DPS ranged from 2 to 4 with a mean score of 2.89 (±0.20 SE) and a modal score of 3. Six of the nine BRT members scored this category as 3, moderate risk. In this context, moderate risk means that population spatial structure and connectivity contribute significantly to long-term risk of extinction, but do not by themselves constitute a danger of extinction in the near future.

Comments on spatial structure and connectivity criteria included concerns that: 1) SPS populations are no longer viable; 2) the loss of either the NPS or SPS populations could result in a contraction of the canary rockfish range within this DPS; 3) there is little known about population structure or lack of structure in this DPS; 4) although adults are known to move into other areas, there does not appear to be a strong refugial population anywhere in this DPS; 5) several historically large populations in the canary rockfish DPS may have been lost, including an area of historic distribution in SPS, which has declined due to low DO events; and 6) low abundance may result in disconnection among historically connected populations across this DPS, as reflected in their current patchy distribution. Positive signs for spatial structure and connectivity include considerations that adults are capable of migrating hundreds of kilometers.

Diversity

BRT scores for diversity of the canary rockfish DPS ranged from 2 to 4 with a mean score of 3 (±0.26 SE) and a modal score of 3. Five of the nine BRT members scored this category as a 3, moderate risk. In this context, moderate risk means that diversity contributes significantly to long-term risk of extinction, but does not in itself constitute a danger of extinction in the near future.

Several BRT members commented that the apparent uniformity in life history traits and low genetic diversity across the entire range of the biological species made it difficult to assign a risk score to the diversity category. Comments on the diversity criterion included concerns related to: 1) the unique ecological features of Puget Sound, which may have resulted in unique adaptations; 2) a truncated age structure and loss of large spawning females, perhaps as a result of size-selective harvest; and 3) variable ocean conditions (exacerbated by climate change) in the DPS that may lead to a mismatch with current diversity traits. Other comments on diversity noted that there is little evidence that diversity is critical for rockfish species in general, and that there is a paucity of data supporting high genetic diversity for this DPS, whereas data from coastal populations reflect only a moderate level of genetic diversity.

Recent events

For recent events, the BRT's scores ranged from double minus to single minus (– – to –) with a mode of single minus (–). These scores reflect an assessment that recent events, considered collectively, are likely to have an overall negative impact on long-term viability of the canary rockfish DPS. The recent drop in abundance of the canary rockfish DPS, coupled with the probable disruption of metapopulation structure, may make it more difficult for the canary rockfish DPS to recover.

Qualitative Threats Assessment

The results of the BRT's analysis of the severity of threats to the canary rockfish DPS are presented in Table 28. Shown are the median threat scores with the SD about the median threat scores. The BRT ranked effects of commercial and recreational harvests as the most serious threats to persistence of the canary rockfish DPS. Loss of nearshore habitat, low levels of DO, chemical contamination, and high nutrient loading were also ranked in the top four threats in the canary rockfish DPS. In some categories, some portion of the BRT felt that insufficient data was available to score the threat severity (thereby marking the threat severity as unknown).

Overall Risk Summary

The BRT was concerned with what appears to be a steep decline in the abundance of canary rockfish in Puget Sound/Georgia Basin. Canary rockfish have become less frequent in the catch data since 1965. In PSP, canary rockfish occurred at frequencies above 2% in the 1960s and 1970s, but by the late 1990s had declined to about 0.76%. In NPS, the frequency of canary rockfish exceeded 6% in the 1960s and declined to 0.56% in the 1990s. Based on this decline in frequency, combined with the overall decline in rockfish abundance in Puget Sound, the BRT concluded that the current trend in abundance contributes significantly to the extinction risk of the DPS.

The BRT was also concerned that the low intrinsic productivity combined with continuing threats from bycatch in commercial and recreational harvest, loss of near shore habitat, chemical contamination, and areas of low DO increase the extinction risk of this species. The BRT was also concerned about downward trends in the size of canary rockfish in Puget Sound. As previously stated, canary rockfish exhibited a broad spread of sizes in the 1970s. However, by the 2000s there were far fewer size classes represented and no fish greater than 55 cm were recorded in the recreational data. Although some of this truncation may be a function of the overall lower number of sampled fish, the data in general suggest few older fish remain in the population.

The BRT noted that this species is more mobile that many other rockfish species, which may help preserve genetic diversity by increasing connectivity among breeding populations. However, the BRT was concerned about the lack of specific information on canary rockfish population structure within the Puget Sound/Georgia Basin area, and noted that there does not appear to be a stronghold for canary rockfish anywhere within the range of the DPS. The BRT's conclusions regarding the overall risk to the Puget Sound/Georgia Basin canary rockfish DPS were heavily weighted toward moderate risk (50/90), with minority support for high risk (22/90) and not at risk (18/90).

Significant Portion of its Range Question

The BRT concluded that the canary rockfish DPS is at moderate risk of extinction throughout all of its range; in effect answering the question in the affirmative as to whether the canary rockfish DPS is at risk throughout a significant portion of its range.

Yelloweye Rockfish

Evaluation of Demographic Risks

Abundance

BRT scores for abundance of the yelloweye rockfish DPS ranged from 3 to 5 with a mean score of 3.67 (±0.26 SE) and a modal score of 3. A score of 4 represents high risk. In this context, high risk means that current trends and levels of abundance contribute significantly to long-term risk of extinction and are likely to contribute to short-term risk of extinction in the foreseeable future.

Several BRT members commented that there are few good data available to adequately judge yelloweye rockfish abundance trends. Catch records are a poor substitute for fishery-independent data, leading to high levels of uncertainty. Comments on the abundance criterion included consideration that: 1) large declines in NPS, but effects of changing harvest regulations may mask the magnitude of the decline; 2) Wallace (2002) documents large historical populations in the Strait of Georgia; and 3) Palsson et al. (2009) estimate approximately 3,000 individuals, although recent 10-year abundance in the yelloweye rockfish DPS, as indicated by catch and trawl records, is low in all or nearly all spawning populations relative to earlier periods. Additionally, some BRT members noted that if yelloweye rockfish in PSP are distinct from those in the Strait of Georgia, it is possible that the trends in abundance understate the degree to which they are at risk.

Growth rate/productivity

BRT scores for growth rate and productivity of the yelloweye rockfish DPS ranged from 3 to 5 with a mean score of 4.11 (±0.26 SE) and a modal score of 4. Four BRT members scored this category as 4, high risk, while three members scored this as 5, very high risk. In this context, high risk means that population productivity (growth rate) contributes significantly to the long-term risk of extinction and is likely to contribute to short-term risk of extinction in the foreseeable future. Very high risk means that population productivity (growth rate) by itself indicates danger of extinction in the near future.

Many BRT members felt that there was insufficient data to adequately score this category with any certainty. However several BRT members noted that: 1) long generations times (e.g., 50% age at maturity is 15–20 years) reflect intrinsic low productivity for this species; 2) larger, older females are most productive, but these individuals are reduced in abundance; and 3) low productivity in the yelloweye rockfish DPS reflects the overall decrease in productivity for all rockfish species in this region. The BRT noted no positive indications for population growth rate and productivity.

Spatial structure and connectivity

BRT scores for spatial structure and connectivity of the yelloweye rockfish DPS ranged from 2 to 4 with a mean score of 3.11 (±0.20 SE) and a modal score of 3. Six BRT members scored this category as 3, moderate risk. In this context, moderate risk means that population spatial structure and connectivity contribute significantly to long-term risk of extinction, but do not by themselves constitute a danger of extinction in the near future.

Comments on spatial structure and connectivity criteria included concerns that: 1) SPS populations are no longer viable, 2) the loss of these populations may eventually result in a contraction of the yelloweye rockfish DPS, 3) there is no evidence of spatially structured populations in the DPS, and 4) although larval dispersal through currents may increase connectivity, adult movement is limited. The BRT noted no positive signs for spatial structure and connectivity.

Diversity

BRT scores for diversity of the yelloweye rockfish DPS ranged from 2 to 4 with a mean score of 3.11 (±0.26 SE) and a modal score of 3. A score of 3 represents moderate risk. In this context, moderate risk means that diversity contributes significantly to long-term risk of extinction, but does not in itself constitute a danger of extinction in the near future.

Several BRT members commented that the apparent uniformity in life history traits and low genetic diversity across the entire range of the biological species made it difficult to assign a risk score to the diversity category. Comments on the diversity criterion included concerns related to: 1) the apparent loss of population structure in Canadian waters; 2) the truncation of size and age structure, particularly the loss of older and larger fish, may reduce the viability of offspring; and 3) selective harvest may lead to shifts in phenotypic traits, for example, size at age. The BRT noted no positive signs for diversity.

Recent events

For recent events, the BRT's scores ranged from double minus to double plus (– – to + +) with a mode of neutral. These scores reflect an assessment that recent events, considered collectively, are likely to have an overall negative impact on long-term viability of the yelloweye rockfish DPS. Recent harvest restrictions imposed by WDFW and the treaty tribes were viewed as having no impact. However, the potential COSEWIC listing in Canadian waters was viewed as having a potential positive impact. The effects of these recent positive and negative events are difficult to estimate; most members indicated that the net effect is likely to be neutral.

Qualitative Threats Assessment

The results of the BRT's analysis of the severity of threats to the yelloweye rockfish DPS are presented in Table 28. Shown are the median threat scores and the SD about the scores. The BRT ranked effects of commercial and recreational harvests as the most serious threats to persistence of the yelloweye rockfish DPS. Loss of nearshore habitat, low levels of DO, chemical contamination, and high nutrient loading were also ranked in the top four threats in the yelloweye rockfish DPS. In some categories, some portion of the BRT felt that insufficient data was available to score the threat severity (thereby marking the threat severity as unknown).

Overall Risk Summary

The frequency of yelloweye rockfish in PSP does not show a consistent trend, with percent frequencies less than 1 in the 1960s and 1980s and about 3% in the 1970s and 1990s. In NPS, however, the frequency of yelloweye rockfish decreased from a high of more than 3% in the 1970s to a frequency of 0.65% in the most recent samples. Based on this decline in frequency in NPS, combined with the overall decline in rockfish abundance in Puget Sound, the BRT concluded that the current trend in abundance contributes significantly to the extinction risk of the DPS.

As with bocaccio and canary rockfish, the BRT was also concerned that low intrinsic productivity combined with continuing threats from bycatch in commercial and recreational harvest, loss of near shore habitat, chemical contamination, and areas of low DO increase the extinction risk of this species. As previously stated, recreationally caught yelloweye rockfish in the 1970s spanned a broad range of sizes. By the 2000s, there was some evidence of fewer older fish in the population. However, overall numbers of fish in the database were also much lower, making it difficult to determine if clear size truncation occurred. The BRT's conclusions regarding the overall risk to the Puget Sound/Georgia Basin canary rockfish DPS were heavily weighted toward moderate risk (53/90), with minority support for high risk (21/90) and not at risk (16/90).

Significant Portion of its Range Question

The BRT concluded that the yelloweye rockfish DPS is at moderate risk of extinction throughout all of its range; in effect answering the question in the affirmative as to whether the yelloweye DPS is at risk throughout a significant portion of its range.

Greenstriped Rockfish

Evaluation of Demographic Risks

Abundance

BRT scores for abundance of the greenstriped rockfish DPS ranged from 2 to 4 with a mean score of 2.78 (±0.28 SE) and a modal score of 2. A score of 3 represents moderate risk. In this context, moderate risk means that diversity contributes significantly to long-term risk of extinction, but does not in itself constitute a danger of extinction in the near future.

Several BRT members commented that there are few good data available to adequately judge greenstriped rockfish abundance trends. Comments on the abundance criterion included consideration that: 1) abundance may be relatively low, but a constant biomass persists; 2) the effects of fishing pressure are unknown, however commercial trawling in Puget Sound has ceased; and 3) absolute abundance, whether current or historical, remains unknown.

Growth rate/productivity

BRT scores for growth rate and productivity of the greenstriped rockfish DPS ranged from 2 to 4 with a mean score of 2.78 (±0.22 SE) and a modal score of 3. Five BRT members scored this category as 3, moderate risk. In this context, moderate risk means that population productivity (growth rate) contributes significantly to long-term risk of extinction, but does not in itself constitute a danger of extinction in the near future.

Many BRT members felt that there was insufficient data to adequately score this category with any certainty. However several BRT members noted that: 1) low abundance in the DPS is likely resulting in reduced productivity; 2) this species tends to be relatively productive when compared to other rockfish species, with a 50% maturity at 7–19 years; and 3) although it is not usually a targeted species, it remains susceptible to discarding. Positive indications for population growth rate and productivity included considerations that this is not highly valued by recreational fishers.

Spatial structure and connectivity

BRT scores for spatial structure and connectivity of the greenstriped rockfish DPS ranged from 2 to 3 with a mean score of 2.33 (±0.17 SE) and a modal score of 2. Six BRT members scored this category as 2, low risk. In this context, low risk means that it is unlikely that diversity contributes significantly to risk of extinction by itself, but some concern that it may, in combination with other factors.

Comments on spatial structure and connectivity criteria included concerns that: 1) this species tends to be a habitat generalist and uses a commonly available habitat in this DPS; 2) although its distribution in this DPS tends to be patchy, its wide distribution provides evidence of high connectivity; 3) adult movement is believed to be low, but its dispersal period is larval; and 4) it is not reliant on the less frequent rocky habitat in this DPS. Most of these aspects were viewed as positive signs for spatial structure and connectivity for this DPS.

Diversity

BRT scores for diversity of the greenstriped rockfish DPS ranged from 1 to 3 with a mean score of 2.22 (±0.22 SE) and a modal score of 2. A score of 2 represents low risk. In this context, low risk means that it is unlikely that diversity contributes significantly to risk of extinction by itself, but some concern that it may, in combination with other factors.

Several BRT members commented that the apparent uniformity in life history traits and low genetic diversity across the entire range of the biological species made it difficult to assign a risk score to the diversity category. Comments on the diversity criterion included concerns related to: 1) the absence of relevant genetic and life history data from individuals sampled within this DPS and 2) the unique ecological aspects of PSP, discussed above, that might lead to local adaptations.

Recent events

For recent events, the BRT's scores consisted of a single minus (–). These scores reflect an assessment that recent events, considered collectively, are likely to have an overall negative impact on long-term viability of the greenstriped rockfish DPS. BRT members noted that there were no longer recent threats due to harvest, but increased pollution, low DO events, and invasive species (jellyfishes) may have posed a threat. The effects of these recent events are difficult to estimate; most members indicated that the net effect is likely to be negative.

Qualitative Threats Assessment

The results of the BRT's analysis of the severity of threats to the greenstriped rockfish DPS are presented in Table 28. Shown are the median threat scores with the SD about the median threat scores. The BRT ranked low DO events as the most serious threat to persistence of the greenstriped rockfish DPS. Contamination, nutrient loading, and commercial harvesting and bycatch were also ranked in the top four threats in the greenstriped rockfish DPS. In some categories, some portion of the BRT felt that insufficient data was available to score the threat severity (thereby marking the threat severity as unknown).

Overall Risk Summary

Greenstriped rockfish do not occur in the recreational catch data from NPS and occur very infrequently in the PSP recreational catch data, presumably due to the low value attached to this species. Bag limits imposed in 1983 were further reduced in 1994 and 2000. Since greenstriped rockfish are smaller than other species, the bag limit may lead to discarding and thus underrepresentation of greenstriped rockfish in the recreational catch. Greenstriped rockfish appear in a low frequency in the WDFW fishery-independent trawl survey, but they were caught in the most recent years of the WDFW trawl survey in PSP (2002 and 2005). Thus although greenstriped rockfish have been almost entirely absent from the recreational catch from 1999 to 2007, they are still present in PSP.

The BRT was concerned about the lack of information on the abundance trends of greenstriped rockfish, but noted that PSP has large areas of the unconsolidated habitat that is used by this species, and that they have somewhat higher intrinsic productivity than other rockfish species. The BRT noted that the species is not preferred by recreational anglers, and may therefore be less susceptible to overharvest. Because this species is also more of a habitat generalist than many other rockfish, the BRT was less concerned about risks from habitat loss or reduced diversity. Size distributions do not suggest any size truncation since the 1970s. The BRT did note that areas of low DO are a potential risk factor. The BRT conclusions regarding the overall risk to the DPS were weighted toward not at risk (53/90), with moderate risk receiving minority support (29/90) and high risk receiving very little support (8/90).

Significant Portion of its Range Question

The BRT concluded that the greenstriped rockfish DPS is not at risk of extinction throughout all of its range; in effect answering the question in the negative as to whether the greenstriped rockfish DPS is at risk throughout a significant portion of its range.

Redstripe Rockfish

Evaluation of Demographic Risks

Abundance

BRT scores for abundance of the redstripe rockfish DPS ranged from 2 to 4 with a mean score of 2.56 (±0.24 SE) and a modal score of 2. A score of 2 represents low risk. In this context, low risk means that it is unlikely that diversity contributes significantly to risk of extinction by itself, but some concern that it may, in combination with other factors.

Several BRT members commented that there are few good data available to adequately judge redstripe rockfish abundance trends. Comments on the abundance criterion included consideration that: 1) although abundance may be relatively low, it remains fairly consistent over time; 2) this species displays a patchy distribution, but is periodically caught in large numbers in WDFW trawls (Palsson et al. 2009); 3) declines in the recreational catch data from Puget Sound are likely due to discarding, as the decline coincides with reduced bag limits and this species is less desirable; 4) COSEWIC reported that from 1996 to 2001 this species represented 7% of the bottom trawl in the outer coast; and 5) its absolute abundance remains unknown, but it appears to be highly abundant in certain areas.

Growth rate/productivity

BRT scores for growth rate and productivity of the redstripe rockfish DPS ranged from 2 to 4 with a mean score of 2.78 (±0.22 SE) and a modal score of 3. Five BRT members scored this category as 3, moderate risk. In this context, moderate risk means that population productivity (growth rate) contributes significantly to long-term risk of extinction, but does not in itself constitute a danger of extinction in the near future.

Many BRT members felt that there was insufficient data to adequately score this category with any certainty. However, several BRT members noted: 1) this species generally has a higher growth rate, smaller size, shorter generation times, and earlier maturity than other rockfishes and

2) mortality due to discarding may decrease productivity, but this species is not targeted. These were viewed as positive indications for population growth rate and productivity.

Spatial structure and connectivity

BRT scores for spatial structure and connectivity of the redstripe rockfish DPS ranged from 2 to 3 with a mean score of 2.22 (±0.15 SE) and a modal score of 2. Seven BRT members scored this category as 2, low risk. In this context, low risk means that it is unlikely that diversity contributes significantly to risk of extinction by itself, but some concern that it may, in combination with other factors.

Comments on spatial structure and connectivity criteria included: 1) there is little evidence of change from its historical state; 2) it is found in WDFW trawls throughout Puget Sound (Palsson et al. 2009); 3) there is no data as to whether underwater sills actually impede movement and little information on movement for this DPS; 4) this species is found on the coast and in the Strait of Juan de Fuca; 5) although adults are not known to move great distances, the larval phase is believed to comprise the dispersal period; 6) this is a habitat generalist, although it is not ubiquitous in the DPS; and 7) no genetic data on population structure are available. Generally, these comments were viewed as positive signs for spatial structure and connectivity.

Diversity

BRT scores for diversity of the redstripe rockfish DPS ranged from 1 to 3 with a mean score of 2.22 (±0.22 SE) and a modal score of 2. A score of 2 represents low risk. In this context, low risk means that it is unlikely that diversity contributes significantly to risk of extinction by itself, but some concern that it may, in combination with other factors.

Several BRT members commented that the apparent uniformity in life history traits and low genetic diversity across the entire range of the biological species made it difficult to assign a risk score to the diversity category. Comments on the diversity criterion included concerns related to: 1) the absence of data related to change in traits for this DPS; 2) as a deepwater species, little is known about its diversity; 3) Puget Sound represents a unique ecosystem, although local adaptation is not known for this species; and 4) there is no genetic data for this DPS, but some other rockfish species in the sound display some degree of genetic differentiation.

Recent events

For recent events, the BRT's scores consisted of single minus (–). These scores reflect an assessment that recent events, considered collectively, are likely to have an overall negative impact on long-term viability of the redstripe rockfish DPS. Harvest was mentioned as a past threat, although harvest has been eliminated in recent years. Recent pollution events were also cited. The effects of these recent positive and negative events are difficult to estimate; most members indicated that the net effect is likely to be negative.

Qualitative Threats Assessment

The results of the BRT's analysis of the severity of threats to the redstripe rockfish DPS are presented in Table 28. Shown are the median threat scores together with the SD about the median threat scores. The BRT ranked low DO events, chemical contaminants, and nutrient loading as the most serious threat to persistence of the redstripe rockfish DPS. Overharvesting and bycatch were also ranked in the top four threats in the redstripe rockfish DPS. In some categories, some portion of the BRT felt that insufficient data was available to score the threat severity (thereby marking the threat severity as unknown).

Overall Risk Summary

Redstripe rockfish do not occur in the catch data from NPS. In PSP, however, redstripe rockfish appeared frequently in the recreational catch (between 1 and 14%) during 1980 to 1985. Previous to that, from 1965 to 1979, redstripe rockfish appeared much less frequently (<1%). After 1985 the frequency of redstripe rockfish declined in the recreational data, and since 1996, it does not appear in the catch data. A bag limit imposed in 1983 was further reduced in 1994 and 2000. Since redstripe rockfish are smaller than other species, bag limits may lead to discarding and thus underrepresentation of redstripe rockfish in the recreational catch.

In the 1980s and 1990s, redstripe rockfish appeared at low frequency (<1.5%) in the WDFW trawl survey. The frequency increased dramatically in 2002 and 2005, with redstripe rockfish making up 39 and 48% of the individuals caught, respectively. The BRT concluded these high estimates may be statistical outliers, however, not necessarily indicative of an actual increase in abundance in recent years. The biomass of redstripe rockfish in the Puget Sound trawls was significantly higher in 2008 than in 1995, indicating a potential increase in abundance. The BRT also noted that the presence of redstripe rockfish in the WDFW trawl survey indicates that redstripe rockfish are present in the sound but no longer being recorded in the dockside surveys of the recreational catch, for undetermined reasons.

Overall, the BRT was concerned that the total abundance and trends in abundance for restripe rockfish were not well-known, but concluded that the available data indicated that the species was at least locally abundant within Puget Sound. The BRT also found that the species has a shorter generation time and higher intrinsic rate of productivity than many other rockfish species. The BRT noted that this species is not preferred by recreational anglers, and may therefore be less susceptible to overharvest. Because this species is also more of a habitat generalist than many other rockfish, the BRT was less concerned about risks from habitat loss or reduced diversity. The BRT did note that areas of low DO and chemical contamination are potential risk factors for redstripe rockfish. There was no evidence of size truncation in this species over time, but too few fish were measured in the later decades to provide a meaningful analysis. The BRT conclusions regarding the overall risk the DPS were weighted toward not at risk (52/90), with moderate risk receiving minority support (29/90) and high risk receiving little support (9/90).

Significant Portion of its Range Question

The BRT concluded that the redstripe rockfish DPS is not at risk of extinction throughout all of its range; in effect answering the question in the negative as to whether the redstripe rockfish DPS is at risk throughout a significant portion of its range.

References

Ainley, D. G., D. W. Anderson, and P. R. Kelly. 1981. Feeding ecology of marine cormorants in southwestern North America. Condor 83:120–131.

Ainley, D. G., W. J. Sydman, R. Parrish, and W. Lenarz. 1993. Oceanic factors influencing distribution of young rockfish (*Sebastes*) in central California: A predator's perspective. Calif. Coop. Ocean. Fish. Investig. Rep. 34:133–139.

Altheit, J., and E. Hagen. 1997. Long-term climate forcing of European herring sardine populations. Fish. Oceanogr. 6(2):130–139.

Allen, M. J. 1982. Functional structure of soft-bottom fish communities of the southern California shelf. Doctoral dissertation. Scripps Institute of Oceanography, Univ. California, San Diego.

Allen, M. J., and G. B. Smith. 1988. Atlas and zoogeography of common fishes in the Bering Sea and northeastern Pacific. U.S. Dept. Commer., NOAA Tech. Rep. NMFS 66.

Anderson, F. E. 1968. Seaward terminus of the Vashon continental glacier in the Strait of Juan de Fuca. Mar. Geol. 6(6):419–438.

Andrews, A. H., E. E. Cordes, M. M. Mahoney, K. Munk, K. H. Coale, G. M. Cailliet, and J. Heifetz. 2002. Age, growth, and radiometric age validation of a deep-sea, habitat-forming gorgonian (*Primnoa resedaeformis*) from the Gulf of Alaska. Hydrobiologia 471:101–110.

Antonelis, G. A., and C. H. Fiscus. 1980. The pinnipeds of the California Current. Calif. Coop. Ocean. Fish. Investig. Rep. 21:68–78.

Avise, J. C., J. Arnold, R. M. Ball, E. Bermingham, T. Lamb, J. E. Neigel, C. A. Reeb, and N. C. Saunders. 1987. Intraspecific phylogeography: The mitochondrial DNA bridge between population genetics and systematics. Annu. Rev. Ecol. Syst. 18:489–522.

Babson, A. L., M. Kawase, and P. MacCready. 2006. Seasonal and interannual variability in the circulation of Puget Sound, Washington: A box model study. Atmos. Ocean 44:29–45.

Bailey, A., H. Berry, A. Bookheim, and D. Stevens. 1998. Probability-based estimation of nearshore characteristics. *In* Puget Sound Research '98 proceedings: Washington State Convention and Trade Center, Seattle, Washington, March 12 and 13, 1998, p. 580–588. Puget Sound Water Quality Action Team, Olympia, WA.

Bargmann, G. G. 1977. The recreational hook and line fishery for marine fish in Puget Sound, 1968–1973. WDFW Progress Rep. 33. Washington Dept. Fish and Wildlife, Olympia.

Barker, M. W. 1979. Population and fishery dynamics of recreationally exploited marine bottomfish of northern Puget Sound. Doctoral dissertation. Univ. Washington, Seattle, WA.

Barss, W. H. 1989. Maturity and reproductive cycle for 35 species from the family Scorpaenidae found off Oregon. Rep. 89-7. Oregon Dept. Fish and Game, Portland.

Baumgartner, T. R., A. Soutar, and V. Ferreira-Bartrina. 1992. Reconstruction of the history of Pacific sardine and northern anchovy populations over the past two millennia from sediments of the Santa Barbara basin, CA. Calif. Coop. Ocean. Fish. Investig. Rep. 33:24–40.

Beaudreau, A. H., and T. E. Essington. 2007. Spatial, temporal, and ontogenetic patterns of predation on rockfishes by lingcod. Trans. Am. Fish. Soc. 136:1438–1452.

Begg, G. A., J. A. Hare, and D. D. Sheehan. 1999. The role of life history parameters as indicators of stock structure. Fish. Res. 43:141–163.

Berkeley, S. A., C. Chapman, and S. M. Sogard. 2004. Maternal age as a determinant of larval growth and survival in a marine fish, *Sebastes melanops*. Ecology 85:1258–1264.

Bernardi, G., L. Findley, and A. Rocha-Olivares. 2003. Vicariance and dispersal across Baja California in disjunct marine fish populations. Evolution 57:1599–1609.

Bjorge, A., T. Bekkby, V. Bakkestuen, and E. Framstad. 2002. Interactions between harbour seals, *Phoca vitulina*, and fisheries in complex coastal waters explored by combined geographic information system (GIS) and energetics modeling. ICES J. Mar. Sci.: Journal du Conseil 59:29.

Blaylock, R. B., L. Margolis, and J. C. Holmes. 1998. Zoogeography of the parasites of Pacific halibut (*Hippoglossus stenolepis*) in the northeast Pacific. Can. J. Zool. 76:2262–2273.

Bobko, S. J., and S. A. Berkeley. 2004. Maturity, ovarian cycle, fecundity, and age-specific parturition of black rockfish (*Sebastes melanops*). Fish. Bull. 102:418–429.

Bocking, R. C. 1997. Mighty river: A portrait of the Fraser. Douglas & McIntyre Inc., Vancouver, BC.

Boehlert, G. W. 1980. Size composition, age composition, and growth of canary rockfish, *Sebastes pinniger*, and splitnose rockfish, *S. diploproa*, from the 1977 rockfish survey. Mar. Fish. Rev. 42:57–63.

Boehlert, G. W., W. H. Barss, and P. B. Lamberson. 1982. Fecundity of the widow rockfish, *Sebastes entomelas*, off the coast of Oregon. Fish. Bull. 80:881–884.

Boehlert, G. W., and R. F. Kappenman. 1980. Variation of growth with latitude in two species of rockfish (*Sebastes pinniger* and *S. diploproa*) from the northeast Pacific Ocean. Mar. Ecol. Prog. Ser. 3:1–10.

Bollens, S. M., B. W. Frost, and T. S. Lin. 1992. Recruitment, growth, and diel vertical migration of *Euphausia pacifica* in a temperate fjord. Mar. Biol. 114:219–228.

Bond, G., W. Broecker, S. Johnson, J. McManus, L. Labeyrie, J. Jouzel, and G. Bonani. 1993. Correlation between climate records from North Atlantic sediments and Greenland ice. Nature 365:143–147.

Bourne, N. F., and K. K. Chew. 1994. The present and future for molluscan shellfish resources in the Strait of Georgia-Puget Sound-Juan de Fuca Strait areas. *In* R. C. H. Wilson, R. J. Beamish, F. Aitkins, and J. Bell (eds.), Review of the marine environment and biota of Strait of Georgia, Puget Sound, and Juan de Fuca Strait: Proceedings of the BC/Washington Symposium on the Marine Environment, January13 and 14, 1994, p. 205–217. Can. Tech. Rep. Fish. Aquat. Sci.

Briggs, J. C. 1974. Marine zoogeography. McGraw-Hill, New York.

Buckley, R. M. 1997. Substrate associated recruitment of juvenile *Sebastes* in artificial reef and natural habitats in Puget Sound and the San Juan Archipelago, Washington. Tech. Rep. RAD97-06, 320. Wash. Dept. Fish and Wildlife, Olympia.

Buckley, R. M. 1967. 1965 bottomfish sport fishery. Washington Dept. Fisheries Supplemental Progress Rep. Washington Dept. Fisheries, Olympia.

Buckley, R. M. 1968. 1966 bottomfish sport fishery occurring in Washington marine punch card areas 2 through 12. Washington Dept. Fisheries Supplemental Progress Rep. Washington Dept. Fisheries, Olympia.

Buckley, R. M. 1970. 1967 bottomfish sport fishery. Washington Dept. Fisheries Supplemental Progress Rep. Washington Dept. Fisheries, Olympia.

Buonaccorsi, V. P., C. A. Kimbrell, E. A. Lynn, and R. D. Vetter. 2002. Population structure of copper rockfish (*Sebastes caurinus*) reflects postglacial colonization and contemporary patterns of larval dispersal. Can. J. Fish. Aquat. Sci. 59:1374–1384.

Buonaccorsi, V. P., C. A. Kimbrell, E. A. Lynn, and R. D. Vetter. 2005. Limited realized dispersal and introgressive hybridization influence genetic structure and conservation strategies for brown rockfish, *Sebastes auriculatus*. Conserv. Genet. 6:697–713.

Buonaccorsi, V. P., M. Westerman, J. Stannard, C. Kimbrell, E. Lynn, and R. D. Vetter. 2004. Molecular genetic structure suggests limited larval dispersal in grass rockfish, *Sebastes rastrelliger*. Mar. Biol. 145:779–788.

Burford, M. O., and G. Bernardi. 2008. Incipient speciation within a subgenus of rockfish (*Sebastomus*) provides evidence of recent radiations within an ancient species flock. Mar. Biol. 154(4):701–717.

Burns, R. 1985. The shape and form of Puget Sound. Univ. Washington, Washington Sea Grant Program, Seattle.

Burr, J. C. 1999. Microsatellite analysis of population structure of quillback rockfish (*Sebastes maliger*) from Puget Sound to Alaska. Master's thesis. Univ. Puget Sound, Tacoma, WA.

Cailliet, G. M., E. J. Burton, J. M. Cope, and L. A. Kerr (eds). 2000. Biological characteristics of nearshore fishes of California: A review of existing knowledge. Final report and Excel data matrix, Pacific States Marine Fisheries Commission. California Dept. Fish and Game, Sacramento.

Calambokidis, J., and R. W. Baird. 1994. Status of marine mammals in the Strait of Georgia, Puget Sound, and the Juan de Fuca Strait and potential human impacts. Can. Tech. Rep. Fish. Aquat. Sci. 1948:282–300.

Cannon, G. A. 1983. An overview of circulation in the Puget Sound estuarine system. U.S. Dept. Commer., NOAA Tech. Memo. ERL-PMEL-48.

Cannon, G. A. 1990. Variations in the onset of bottom-water intrusion over the entrance sill of a fjord. Estuaries 13(1):31–42.

Carlson, H. R., and R. R. Straty. 1981. Habitat and nursery grounds of Pacific rockfish, *Sebastes* spp., in rocky coastal areas of southeastern Alaska. Mar. Fish. Rev. 43(7):13–19.

Carr, M. H. 1983. Spatial and temporal patterns of recruitment of young-of-the-year rockfishes (genus *Sebastes*) into a central California kelp forest. Master's thesis. San Francisco State Univ., Moss Landing Marine Laboratories, Moss Landing, CA.

Casillas E., L. Crockett, Y. deReynier, J. Glock, M. Helvey, B. Meyer, C. Schmitt, M. Yoklavich, A. Bailey, B. Chao, B. Johnson, and T. Pepperell. 1998. Essential fish habitat West Coast groundfish appendix, National Marine Fisheries Service, Seattle, WA.

Caughley, G., and A. R. E. Sinclair. 1994. Wildlife management and ecology. Blackwell Science, Oxford, UK.

Chen, L. 1971. Systematics, variation, distribution, and biology of rockfishes of the subgenus *Sebastomus* (Pisces, Scorpaenidae, *Sebastes*). Bull. Scripps Inst. Oceanogr., Univ. Calif. 18:1–107.

Chester, A. J., D. M. Damkaer, D. B. Dey, G. A. Heron, and J. D. Larrance. 1980. Plankton of the Strait of Juan de Fuca, 1976–1977. Interagency Energy-Environment R and D Program Rep. EPA-600/7-80-032. U.S. Environmental Protection Agency, Office of Environmental Engineering and Technology, Washington, DC.

Collias, E., N. McGary, and C. A. Barnes. 1974. Atlas of physical and chemical properties of Puget Sound and its surrounding approaches. WSG-74-1. Univ. Washington, Dept. Oceanography, Seattle.

Collins, B. D., and A. J. Sheikh. 2005. Historical reconstruction, classification, and change analysis of Puget Sound tidal marshes. Final project rep. to Washington Dept. Natural Resources, Aquatic Resources Division, Olympia.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2002. COSEWIC assessment and status report on the bocaccio *Sebastes paucispinis* in Canada. COSEWIC, Ottawa, ON.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). In press. COSEWIC assessment and status report on the canary rockfish *Sebastes pinniger* in Canada, COSEWIC, Ottawa, ON.

Coombs, C. I. 1979. Reef fishes near Depoe Bay, Oregon: Movement and the recreational fishery. Master's thesis. Oregon State Univ., Fisheries and Wildlife, Corvallis.

Cope, J. M. 2002. Phylodemography of the blue rockfish (*Sebastes mystinus*) from California to Washington. Master's thesis. San Francisco State Univ., Moss Landing Marine Laboratories, Moss Landing, CA.

Cope, J. M. 2004. Population genetics and phylogeography of the blue rockfish (*Sebastes mystinus*) from Washington to California. Can. J. Fish. Aquat. Sci. 61(3):332–342.

Crean, P. B., T. S. Murty, and J. Stronach. 1988. Numerical simulation of oceanographic processes in the waters between Vancouver Island and the mainland. Oceanogr. Mar. Biol. Ann. Rev. 26:11–143.

DeLacy, A. C., C. R. Hitz, and R. L. Dryfoos. 1964. Maturation, gestation, and birth of rockfish (Sebastodes) from Washington and adjacent waters. Fish. Res. Papers 2:51–67. Washington Dept. Fisheries, Olympia.

DeLacy, A. C., B. S. Miller, and S. F. Borton. 1972. Checklist of Puget Sound fishes. Publication WSG 72-3. Univ. Washington, Washington Sea Grant Program, Seattle.

DeMott, G. E. 1983. Movement of tagged lingcod and rockfishes off Depoe Bay, Oregon. Master's thesis. Oregon State Univ., Corvallis.

Dennis, B., P. L. Munholland, and J. M. Scott. 1991. Estimation of growth and extinction parameters for endangered species. Ecol. Monogr. 61:115–143.

Dennis, B., J. M. Ponciano, S. R. Lele, M. L. Taper, and D. F. Staples. 2006. Estimating density dependence, process noise, and observation error. Ecol. Monogr. 76:323–341.

DFO (Department of Fisheries and Oceans Canada). 2008. [Untitled data.] DFO Canada, Pacific Region Regional Data Services Unit, Vancouver, BC.

Dethier, M. N. 1990. A marine and estuarine habitat classification system for Washington state. Washington Dept. Natural Resources, Washington Natural Heritage Program, Olympia.

Dethier, M. N. 2006. Native shellfish in nearshore ecosystems of Puget Sound. Puget Sound Nearshore Partnership Rep. 2006-04. U.S. Army Corps of Engineers, Seattle District, Seattle, WA. Online at http://www.pugetsoundnearshore.org [accessed 3 May 2010].

Downing, J. 1983. The coast of Puget Sound: Its processes and development. Univ. Washington, Washington Sea Grant Program, Seattle.

Dumbauld, B. R. 1985. The distributional ecology of zooplankton in East Passage and the Main Basin of Puget Sound, Washington. Master's thesis. Univ. Washington, Seattle.

Ebbesmeyer, C. C., and C. A. Barnes. 1980. Control of a fjord basin's dynamics by tidal mixing in embracing sill zones. Estuar. Coast. Mar. Sci. 11:311–330.

Ebbesmeyer, C. C., C. A. Coomes, J. M. Cox, J. M. Helseth, L. R. Hinchey, G. A. Cannon, and C. A. Barnes. 1984. Synthesis of current measurements in Puget Sound, Washington. Vol. 3. Circulation in Puget Sound: An interpretation based on historical records of currents. U.S. Dept. Commer., NOAA Tech. Memo. NOS-OMS-5.

Ebbesmeyer, C. C., R. J. Stewart, and S. Albertson. 1998. Circulation in southern Puget Sound's finger inlets: Hammersley, Totten, Budd, Eld, and Case inlets. *In* Puget Sound Research '98 proceedings: Washington State Convention and Trade Center, Seattle, Washington, March 12 and 13, 1998, p. 239–258. Puget Sound Water Quality Action Team, Olympia, WA.

Ebbesmeyer, C. C., and R. M. Strickland. 1995. Oyster condition and climate: Evidence from Willapa Bay. Publication WSG-MR-95-02. Univ. Washington, Washington Sea Grant Program, Seattle.

Eigenmann, C. H. 1891. The spawning season of San Diego fishes. Am. Nat. 25:578–579.

Ekman, S. 1953. Zoogeography of the sea. Sidgwick and Jackson Ltd., London.

Embery, S. S., and E. L. Inkpen. 1998. Water quality assessment of the Puget Sound Basin, Washington, nutrient transportation in rivers, 1980–93. U.S. Geological Survey, Water Resour. Investig. Rep. 97-4270.

Engie, K., and T. Klinger. 2007. Modeling passive dispersal through a large estuarine system to evaluate marine reserve network connections. Estuar. Coast. 30:201–213.

Feder, H. M., C. H. Turner, and C. Limbaugh. 1974. Observations on fishes associated with kelp beds in Southern California. Fish Bull. 160:144.

FEMAT (Forest Ecosystem Management Assessment Team). 1993. Forest ecosystem management: An ecological, economic, and social assessment. U.S. Forest Service, Bureau of Land Management. U.S. Fish and Wildlife Service, National Oceanic and Atmospheric Administration, Environmental Protection Administration, and National Park Service, Portland, OR.

Field, J. C., E. J. Dick, D. Pearsons, and A. D. MacCall. 2009. Status of bocaccio, *Sebastes paucispinis*, in the Conception, Monterey, and Eureka INPFC areas for 2009. Pacific Fishery Management Council, Portland, OR.

Field, J. C., and S. Ralston. 2005. Spatial variability in rockfish (*Sebastes* spp.) recruitment events in the California Current system. Can. J. Fish. Aquat. Sci. 62:2199–2210.

Finlayson, D. 2006. The geomorphology of Puget Sound beaches. Puget Sound Nearshore Partnership Rep. 2006-02. Univ. Washington, Washington Sea Grant Program, Seattle. Online at http://pugetsoundnearshore.org [accessed 3 May 2010].

Fisher, R., S. M. Sogard, and S. A. Berkeley. 2007. Trade-offs between size and energy reserves reflect alternative strategies for optimizing larval survival potential in rockfish. Mar. Ecol. Prog. Ser. 344:257–270.

Ford, J. K. B., G. M. Ellis, L. G. Barrett-Lennard, A. B. Morton, R. S. Palm, and K. C. Balcomb. 1998. Dietary specialization in two sympatric populations of killer whales (*Orcinus orca*) in coastal British Columbia and adjacent waters. Can. J. Zool. 76:1456–1471.

Foreman, M. G. G., W. Callendar, A. MacFadyen, B. M. Hickey, R. E. Thomson, and E. Di Lorenzo. 2008. Modeling the generation of the Juan de Fuca eddy. J. Geophys. Res. 113:1–18. Online at http://ocean3d.org/manu/papers/PDFs/Foreman_2008_JGR.pdf [accessed 3 May 2010].

Francis, R. C., S. R. Hare, A. B. Hollowed, and W. S. Wooster. 1998. Effects of interdecadal climate variability on the oceanic ecosystems of the NE Pacific. Fish. Oceanogr. 7:1–21.

Fresh, K. L. 2007. Juvenile Pacific salmon in Puget Sound. Puget Sound Nearshore Partnership Rep. No. 2006-06. U.S. Army Corps. of Engineers, Seattle District, Seattle, WA.

Gaines, S. D., and J. Roughgarden. 1987. Fish in offshore kelp forests affect recruitment to intertidal barnacle populations. Science 235:479–481.

Garrison, K. J., and B. S. Miller. 1982. Review of the early life history of Puget Sound fishes. Univ. Washington, Fisheries Research Institute, Seattle.

Gascon, D., and R. A. Miller. 1981. Colonization by nearshore fish on small artificial reefs in Barkley Sound, British Columbia. Can. J. Zool. 59:1635–1646.

Gilbert-Horvath, E. A., R. J. Larson, and J. C. Garza. 2006. Temporal recruitment patterns and gene flow in kelp rockfish *(Sebastes atrovirens*). Mol. Ecol. 15:3801–3815.

Giles, S. L., and J. R. Cordell. 1998. Zooplankton composition and abundance in Budd Inlet, Washington. *In* Puget Sound Research ’98 proceedings: Washington State Convention and Trade Center, Seattle, Washington, March 12 and 13, 1998, p. 634–642. Puget Sound Water Quality Action Team, Olympia, WA.

Gilpin, M. E., and M. E. Soulé. 1986. Minimum viable populations: Processes of species extinction. *In* M. E. Soule (ed.), Conservation biology: The science of scarcity and diversity, p. 19–34. Sinauer Associates, Sunderland, MA.

Gomez, U. D., E. A. Hoffman, W. R. Ardren, and M. A. Banks. 2003. Microsatellite markers for the heavily exploited canary (*Sebastes pinniger*) and other rockfish species. Mol. Ecol. 3:387–389.

Gomez-Uchida, D., and M. A. Banks. 2005. Microsatellite analyses of special genetic structure in darkblotched rockfish (*Sebastes crameri*): Is pooling samples safe? Can. J. Fish. Aquat. Sci. 62:1874–1886.

Good, T. P., R. S. Waples, and P. Adams (eds.). 2005. Updated status of federally listed ESUs of West Coast salmon and steelhead. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-66.

Gowan, R. E. 1983. Population dynamics and exploitation rates of rockfish (*Sebastes* spp.) in central Puget Sound, Washington. Doctoral dissertation. Univ. Washington, Seattle.

Graham, W. M., J. G. Field, and D. C. Potts. 1992. Persistent "upwelling shadows" and their influence on zooplankton distributions. Mar. Biol. 144:561–570.

Grant, W. S., I. Z. Chang, T. Kobayashi, and G. Stahl. 1987. Lack of genetic stock discretion in Pacific cod (*Gadus macrocephalus*). Can. J. Fish. Aquat. Sci. 44:490–498.

Graumlich, L. J., and L. B. Brubaker. 1986. Reconstruction of annual temperature (1950–1979) for Longmire, Washington, derived from tree rings. Quat. Res. 25:223–234.

Guillemot, P. J., R. J. Larson, and W. H. Lenarz. 1985. Seasonal cycles of fat and gonad volume in five species of northern California rockfish (Scorpaenidae: *Sebastes*). Fish. Bull. 83:299–311.

Gunderson, D. R., P. Callahan, and B. Goiney. 1980. Maturation and fecundity of four species of *Sebastes*. Mar. Fish. Rev. 42:74–79.

Gunderson, D. R., A. M. Parma, R. Hilborn, J. M. Cope, D. L. Fluharty, M. L. Miller, R. D. Vetter, S. S. Heppell, and H. G. Greene. 2008. The challenge of managing nearshore rocky reef resources. Fisheries 33:172–179.

Gunderson, L. H., and R. D. Vetter. 2006. Temperate rocky reef fish. *In* J. P. Kritzer and P. F. Sale, Marine Metapopulations, p. 69–118. Elsevier, Amsterdam.

Gustafson R. G., W. H. Lenarz, B. B. McCain, C. C. Schmitt, W. S. Grant, T. L. Builder, and R. D. Methot. 2000. Status review of Pacific hake, Pacific cod, and walleye pollock from Puget Sound, Washington. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-44.

Gustafson R. G., J. Drake, M. J. Ford, J. M. Myers, E. E. Holmes, and R. S. Waples. 2006. Status review of Cherry Point Pacific herring (*Clupea pallasii*) and updated status review of the Georgia Basin Pacific herring distinct population segment under the Endangered Species Act. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-76.

Hamel, O. S. 2007. Status and future prospects for darkblotched rockfish resource in waters off Washington, Oregon, and California as assessed in 2007. Pacific Fishery Management Council, Portland, OR.

Hard, J. J., J. M. Myers, M. J. Ford, R. G. Cope, G. R. Pess, R. S. Waples, G. A. Winans, B. A. Berejikian, F. W. Waknitz, P. B. Adams, P. A. Bisson, D. E. Campton, and R. R. Reisenbichler. 2007. Status review of Puget Sound steelhead (*Oncorhynchus mykiss*). U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-81.

Hare, S. R., and N. J. Mantua. 2000. Empirical evidence for North Pacific regime shifts in 1977 and 1989. Prog. Oceanogr. 47:103–146.

Harrison, P. J., D. L. Mackas, B. W. Frost, R. W. Macdonald, and E. A. Crecelius. 1994. An assessment of nutrients , plankton, and some pollutants in the water column of the Juan de Fuca Strait, Strait of Georgia, and Puget Sound, and their transboundary transport. Can. Tech. Rep. Fish. Aquat. Sci. 1948:138–172.

Hart, J. L. 1973. Pacific fishes of Canada. Bull. Fish. Res. Board Can. 180.

Hartmann, A. R. 1987. Movement of scorpionfishes (Scorpaenidae: *Sebastes* and *Scorpaena*) in the southern California Bight. Calif. Dept. Fish Game Bull. 73:68–79.

Harvey, C. J. 2005. Effects of El Niño events on energy demand and egg production of rockfish (Scorpaenidae: *Sebastes*): A bioenergetics approach. Fish. Bull. 103:71–83.

Harvey, C. J., N. Tolimieri, and P. S. Levin. 2006. Changes in body size, abundance, and energy allocation in rockfish assemblages of the Northeast Pacific. Ecol. Appl. 16:1502–1515.

Haw, F., and R. Buckley. 1971. Saltwater fishing in Washington. Stanley N. Jones, Seattle.

Hedgpeth, J. W. 1957. Marine biogeography. *In* J. W. Hedgpeth (ed.), Treatise on marine ecology and paleoecology, p. 359–382. Geol. Soc. Am. Bull. 67(1).

Hess, J. Unpubl. data. Rockfish molecular genetic data. (Available from J. Hess, Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112.)

Heyomoto, H., E. K. Holmberg, and G. S. DiDonato. 1959. Research report on the Washington trawl fishery, 1957–1959. Washington Dept. Fisheries, Olympia.

Hinrichsen, R. A., and E. E. Holmes. 2009. Using multivariate state-space models to study spatial structure and dynamics. *In* R. S. Cantrell, C. Cosner, and S. Ruan (eds.), Spatial ecology. CRC/Chapman Hall, New York.

Hitz, C. R. 1962. Seasons of birth of rockfish (*Sebastodes*) in Oregon coastal waters. Trans. Am. Fish. Soc. 91:231–233.

Holbrook, J. R., R. D. Muench, D. G. Kachel, and C. Wright. 1980. Circulation in the Strait of Juan de Fuca: Recent oceanographic observations in the eastern basin. NOAA Tech. Rep. ERL-PMEL 33.

Holmberg, E. K, D. Day, N. Pasquale, and B. Pattie. 1967. Research report on the Washington trawl fishery 1962–64. Washington Dept. Fisheries, Research Division, Olympia.

Holmberg, E. K., G. S. DiDonato, and N. Pasquale. 1961. Research report on the Washington trawl fishery, 1960–1961. Washington Dept. Fisheries, Olympia.

Holmes, E. E. 2001. Estimating risks in declining populations with poor data. Proc. Natl. Acad. Sci. USA. 98:5072–5077.

Holmes, E. E., and W. Fagan. 2002. Validating population viability analysis for corrupted data sets. Ecology 83:2379–2386.

Holmes, E. E., J. L. Sabo, S. V. Viscido, and W. Fagan. 2007. A statistical approach to quasi-extinction forecasting. Ecol. Lett. 10:1182–1198.

Hsieh, C. H., C. S. Reiss, J. R. Hunter, J. R. Beddington, R. M. May, and G. Sugihara. 2006. Fishing elevates variability in the abundance of exploited species. Nature 443:859–862.

Hyde, J. R. 2007. The origin, evolution, and diversification of rockfishes of the genus *Sebastes* (Cuvier): Insights into speciation and biogeography of temperate reef fishes. Univ. California, San Diego.

Hyde, J. R.,C. A. Kimbrell, J. E. Budrick, E. A. Lynn, and R. D. Vetter. 2008. Cryptic speciation in the vermilion rockfish (*Sebastes miniatus*) and the role of bathymetry in the speciation process. Mol. Ecol. 17:1122–1136.

Hyde, J. R., and R. D. Vetter. 2007. The origin, evolution, and diversification of rockfishes of the genus *Sebastes* (Cuvier). Mol. Phylogenet. Evol. 44:790–811.

Hutchinson, I. 1988. The biogeography of the coastal wetlands of the Puget Trough: Deltaic form, environment, and marsh community structure. J. Biogeogr. 15:729–745.

Imbrie, J., J. D. Hays, D. G. Martinson, A. McIntyre, A. C. Mix, J. J. Morley, N. G. Pisias, W. L. Prell, and N. J. Shackleton. 1984. The orbital theory of pleistocene climate: Support from a revised chronology of the marine 180 record. *In* A. L. Berger, (ed.), Milankovitch and Climate, Part 1, p. 269–305. D. Reidel, Norwell, MA.

Iwamoto, E., M. J. Ford, and R. G. Gustafson. 2004. Genetic population structure of Pacific hake, *Merluccius productus*, in the Pacific Northwest. Environ. Biol. Fishes 69:187–199.

Ives, A. R., B. Dennis, K. L. Cottingham, and S. R. Carpenter. 2003. Estimating community stability and ecological interactions from time series data. Ecol. Monogr. 73:301–330.

Jeffries, S. J., P. J. Gearin, H. R. Huber, D. L. Saul, and D. A. Pruett. 2000. Atlas of seal and sea lion haul out sites in Washington. Washington Dept. Fish and Wildlife, Wildlife Science Division, Olympia.

Jeffries, S., H. Huber, J. Calambokidis, and J. Laake. 2003. Trends and status of harbor seals in Washington State: 1978–1999. J. Wildl. Manag. 67:207–218.

Johns, G. C., and J. C. Avise. 1998. Tests for ancient species flocks based on molecular phylogenetic appraisals of *Sebastes* rockfishes and other marine fishes. Evolution 52(4):1135–1146.

Johansson, M. L., M. A. Banks, K. D. Glunt, H. M. Hassel-Finnegan, and V. P. Buonaccorsi. 2008. Influence of habitat discontinuity, geographical distance, and oceanography on fine-scale population genetic structure of copper rockfish (*Sebastes caurinus*). Mol. Ecol. 17:3051–3061. Online at http://marineresearch.oregonstate.edu/genetics/PDFs/Johansson_etal2008.pdf [accessed 3 May 2010].

Johannessen, S. C., G. Potentier., C. A. Wright, D. Masson, and R. W. Macdonald. 2008. Water column organic carbon in a Pacific marginal sea (Strait of Georgia, Canada). Mar. Environ. Res. 66(Suppl. 1):49–61.

Johnson, D. W. 2006. Predation, habitat complexity, and variation in density-dependent mortality of temperate reef fishes. Ecology 87:1179–1188.

Johnson, K. A. 1997. Rockfish (*Sebastes* spp.) recruitment to soft bottom habitats in Monterey Bay, CA. Master's thesis. California State Univ., Stanislaus/Moss Landing Marine Laboratories, Stanislaus, CA.

Johnson, S. W., M. L. Murphy, and D. J. Csepp. 2003. Distribution, habitat, and behavior of rockfishes, *Sebastes* spp., in nearshore waters of southeastern Alaska: Observations from a remotely operated vehicle. Environ. Biol. Fishes 66:259–270.

Kincaid, T. 1919. An annotated list of the Puget Sound fishes. Washington Dept. Fisheries, Olympia.

Kozloff, E. N. 1987. Marine invertebrates of the Pacific Northwest. University of Washington Press, Seattle.

Krahn, M. M., M. J. Ford, W. F. Perrin, P. R. Wade, R. P. Angliss, M. B. Hanson, B. L. Taylor, G. M. Ylitalo, M. E. Dahlheim, J. E. Stein, and R. S. Waples. 2004. 2004 Status review of southern resident killer whales (*Orcinus orca*) under the Endangered Species Act. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-62.

Krahn, M. M., P. R. Wade, S. T. Kalinowski, M. E. Dahlheim, B. L. Taylor, M. B. Hanson, G. M. Ylitalo, R. P. Angliss, J. E. Stein, R. W. Waples. 2002. Status review of Southern Resident killer whales (*Orcinus orca*) under the Endangered Species Act. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-54.

Krieger, K. J., and B. L. Wing. 2002. Megafauna associations with deepwater corals (*Primnoa* spp.) in the Gulf of Alaska. Hydrobiologia 471(1):83–90.

Kriete, B. 2007. Orcas in Puget Sound. Puget Sound Nearshore Partnership Rep. 2007-01. Published by U.S. Army Corps of Engineers, Seattle District, Seattle, WA. Online at www.pugetsoundnearshore.org [accessed 3 May 2010].

Krigsman, L. M. 2000. A review of larval duration for Pacific coast temperate reef fishes, including kelp rockfish, *Sebastes atrovirens*. Senior thesis. Univ. California Santa Cruz.

Kritzer, J. P., and P. F. Sale. 2004. Metapopulation ecology in the sea: From Levis' model to marine ecology and fisheries science. Fisheries 5:131–140.

Lance, M. M., and S. J. Jeffries. 2007. Temporal and spatial variability of harbor seal diet in the San Juan archipelago. Contract Rep. Washington Dept. Fish and Wildlife, Olympia.

Landahl, J. T., L. L. Johnson, J. E. Stein, T. K. Collier, and U. Varanasi. 1997. Approaches for determining effects of pollution on fish populations of Puget Sound. Trans. Am. Fish. Soc. 126:519–535.

Larson, R. J. 1980. Competition, habitat selection, and the bathymetric segregation of two rockfish (*Sebastes*) species. Ecol. Monogr. 50:221–239.

Larson, R. J., W. H. Lenarz, and S. Ralston. 1994. The distribution of pelagic juvenile rockfish of the genus *Sebastes* in the upwelling region off central California. Calif. Coop. Ocean. Fish. Investig. Rep. 35:175–219.

Law, R. 2007. Fisheries-induced evolution: Present status and future directions. Mar. Ecol. Prog. Ser. 335:271–277.

Lea, R. N., R. D. McAllister, and D. A. VenTresca. 1999. Biological aspects of nearshore rockfishes of the genus *Sebastes* from central California. Fish. Bull. 177:1–109.

LeClair, L. L., S. F. Young, and J. B. Shaklee. 2006. Allozyme and microsatellite DNA analyses of lingcod from Puget Sound, Washington, and adjoining waters. Trans. Am. Fish. Soc. 135:1631–1643.

Lee, J., W. Palsson, C. Muns, M. Racine, B. Berejikian, M. Rust, T. Wright, and K. Massee. 2008. A multilateral research program to investigate culture-based rebuilding using lingcod (*Ophiodon elongatus*) as a model species. Proposal to the Puget Sound Recreational Fishery Enhancement

Fund. (Available from J. Lee, Washington Dept. Fish and Wildlife, 600 Capitol Way N., Olympia, WA 98501.)

Lemberg, N. A., M. F. O'Toole, D. E. Pentilla, and K. C. Stick. 1997. WDFW 1996 forage fish stock status report. Washington Dept. Fish and Wildlife, Fisheries Management Division, Olympia.

Lenarz, W. H., and T. W. Echeverria. 1991. Sexual dimorphism in *Sebastes*. Environ. Biol. Fishes 30:71–80.

Levin, P. S., J. A. Coyer, R. Petrik, and T. P. Good. 2002. Community-wide effects of nonindigenous species on temperate reefs. Ecology 83:3182–3193.

Levings, C. D., and R. M. Thom. 1994. Habitat changes in Georgia Basin: Implications for resource management and restoration. *In* R. C. H. Wilson, R. J. Beamish, F. Aitkens, and J. Bell (eds.), Review of the marine environment and biota of Strait of Georgia, Puget Sound, and Juan de Fuca Strait, p. 300–351. Proceedings of the British Columbia/Washington Symposium on the Marine Environment. Can. Tech. Rep. Fish. Aquat. Sci. 1948.

Li, Z., A. Gray, M. Love, A. Goto, and A. Gharrett. 2007. Are the subgenera of *Sebastes* monophyletic? *In* J. Heifetz and coeditors (eds.), Biology, assessment, and management of North Pacific rockfishes, p. 185–206. Univ. Alaska Fairbanks, Alaska Sea Grant Program, Fairbanks.

Lie, U. 1968. A quantitative study of benthic infauna in Puget Sound, Washington, USA, in 1963–1964 (with a section on polychaetes). Fiskidir. Skr. Ser. Havunders. 14:229–556.

Lie, U. 1974. Distribution and structure of benthic assemblages in Puget Sound, Washington, USA. Mar. Biol. 26:203–223.

Lindley, S. T. 2003. Estimation of population growth and extinction parameters from noisy data. Ecol. Appl. 13:806–813.

Liston, J., J. Peters, and J. A. Stern. 1960. Parasites in summer-caught Pacific rockfishes. Rep. 352. U.S. Fish and Wildlife Service, Washington, DC.

Llansó, R., S. Aasen, and K. Weltch. 1998. Distribution and structure of benthic communities in Puget Sound 1989–1993. Marine Sediment Monitoring Program II. Washington Dept. Ecology, Olympia.

Lochead, J. K., and K. L. Yamanaka. 2007. Summary report for the inshore rockfish (*Sebastes* spp.) longline survey conducted in statistical areas 14 to 20, 28, and 29, from 11 August to 6 September 2005. Can. Tech. Rep. Fish. Aquat. Sci. 2690.

London, J. M., M. M. Lance, and S. Jeffries. 2001. Observations of harbor seal predation on Hood Canal salmonids from 1998 to 2000. PSMFC Contract 02-15. Final report on studies of expanding pinniped populations to NOAA. Washington Dept. Fish and Wildlife, Olympia.

Longhurst, A. 2002. Murphy's law revisited: Longevity as a factor in recruitment to fish populations. Fish. Res. 56:125–131.

Longhurst, A. R. 2006. Ecological geography of the sea. 2nd edition. Elsevier Academic Press, Amsterdam.

Love, M. S. 1978. Aspects of the life history of the olive rockfish (*Sebastes serranoides*). Doctoral dissertation. Univ. California Santa Barbara.

Love, M. S., M. H. Carr, and L. J. Haldorson. 1991. The ecology of substrate-associated juveniles of the genus *Sebastes*. Environ. Biol. Fishes 30:225–243.

Love, M. S., P. Morris, M. McCrae, and R. Collins. 1990. Life history aspects of 19 rockfish species (Scorpaenidae: *Sebastes*) from the southern California Bight. U.S. Dept. Commer., NOAA Tech. Rep. NMFS-87.

Love, M. S., and M. Moser. 1983. A checklist of parasites of California, Oregon, and Washington marine and estuarine fishes. U.S. Dept. Commer., NOAA Tech. Rep. NMFS SSRF-777.

Love, M. S., D. M. Schroeder, and W. Lenarz. 2005. Distribution of bocaccio (*Sebastes paucispinis*) and cow cod (*Sebastes levis*) around oil platforms and natural outcrops off California with implications for larval production. Bull. Mar. Sci. 77:397–408.

Love, M. S., D. M. Schroeder, W. Lenarz, A. MacCall, A. S. Bull, and L. Thorsteinson. 2006. Potential use of offshore marine structures in rebuilding an overfished rockfish species, bocaccio (*Sebastes paucispinis*). Fish. Bull. 104:383–390.

Love, M. S., L. Thorsteinson, C. W. Mecklenburg, and T. A. Mecklenburg. 2005. Resource inventory of marine and estuarine fishes of the west coast and Alaska: A checklist of northeast Pacific and Arctic Ocean species from Baja California to the Alaska-Yukon border. OCS Study MMS 2005-030. U.S. Geological Survey, Biological Resources Division, Seattle, WA.

Love, M. S., and M. M. Yoklavich. 2008. Habitat characteristics of juvenile cow cod, *Sebastes levis* (Scorpaenidae), in Southern California. Environ. Biol. Fishes 82:195–202.

Love, M. S., M. M. Yoklavich, and L. Thorsteinson. 2002. The rockfishes of the Northeast Pacific. University of California Press, Berkeley.

Love, M. S., and A. York. 2005. A comparison of the fish assemblages associated with an oil/gas pipeline and adjacent seafloor in the Santa Barbara Channel, Southern California Bight. Bull. Mar. Sci. 77:101–117.

Lyubimova, T. G. 1965. Main stages in the life cycle of the rockfish *Sebastodes alutus* (Gilbert) in the Gulf of Alaska. Trudy VNIRO 49:85–111.

MacCall, A. D. 2002. Use of known-biomass production models to determine productivity of West Coast groundfish stocks. N. Am. J. Fish. Manag. 22:272–279.

MacCall, A. D. 2003. Status of bocaccio off California in 2003. Pacific Fishery Management Council, Portland, OR.

MacCall, A. D. 2007. Status of bocaccio off California in 2007. Pacific Fishery Management Council, Portland, OR.

MacCall, A. D., and X. He. 2002. Status review of the southern stock of bocaccio (*Sebastes paucispinis*). Revised October 2002. Southwest Fisheries Science Center, Santa Cruz Laboratory, CA. Online at http://www.nmfs.noaa.gov/pr/pdfs/statusreviews/bocaccio.pdf [accessed 3 May 2010].

MacGregor, J. S. 1970. Fecundity, multiple spawning, and description of the gonads in *Sebastodes*. Special Scientific Rep. Fisheries 596. U.S. Fish and Wildlife Service, Washington, DC.

Mackas, D. L., and P. J. Harrison. 1997. Nitrogenous nutrient sources and sinks in the Juan de Fuca Strait/Strait of Georgia/Puget Sound estuarine system: Assessing the potential for eutrophication. Estuar. Coast. Shelf Sci. 44:1–21.

Mahaffy, M., D. Nysewander, K. Vermeer, T. Whal, and P. Whitehead. 1994. Status, trends, and potential threats related to birds in the Strait of Georgia, Puget Sound, and Juan de Fuca Strait. Symposium on the Marine Environment organized by the Canadian Wildlife Service, British Columbia, and the U.S. Fish and Wildlife Service, Washington. Can. Tech. Rep. Fish. Aquat. Sci. 1994.

Mantua, N. J., S. R. Hare, Y. Zhang, J. M. Wallace, and R. C. Francis. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Bull. Am. Meteorol. Soc. 78:1069–1079.

Marteinsdottir, G., and K. Thorarinsson. 1998. Improving the stock-recruitment relationship in Icelandic cod (*Gadus morhua*) by including age diversity of spawners. Can. J. Fish. Aquat. Sci. 55:1372–1377.

Martin, J. C., L. C. Lacko, and K. L. Yamanaka. 2006. A pilot study using a remotely operated vehicle (ROV) to observe inshore rockfish (*Sebastes* spp.) in the southern Strait of Georgia, March 3–11, 2005. Can. Tech. Rep. Fish. Aquat. Sci. 2663.

Mason, J. E. 1998. Declining rockfish lengths in the Monterey Bay, California, recreational fishery, 1959–94. Mar. Fish. Rev. 60:15–28.

Masson, D. 2002. Deep water renewal in the Strait of Georgia. Estuar. Coast. Shelf Sci. 54:115–126.

Masson, D., and P. F. Cummins. 2000. Fortnightly modulation of the estuarine circulation in Juan de Fuca Strait. J. Mar. Res. 58:439–463.

Matala, A. P., A. K. Gray, and A. J. Gharrett. 2004. Microsatellite variation indicates population genetics structure of bocaccio. N. Am. J. Fish. Manag. 24:1189–1202.

Matala, A. P., A. K. Gray, A. J. Gharrett, and M. S. Love. 2004a. Microsatellite variation indicates population genetic structure of bocaccio. N. Am. J. Fish. Manag. 24:1189–1202.

Matala, A. P., A. K. Gray, J. Heifetz, and A. J. Gharrett. 2004b. Population structure of Alaskan shortraker rockfish, *Sebastes borealis*, inferred from microsatellite variation. Environ. Biol. Fishes 68:201–210.

Matarese, A. C., A. W. Kendall Jr., D. M. Blood, and B. M. Vinter. 1989. Laboratory guide to early life history stages of northeast Pacific fishes. U.S. Dept. Commer., NOAA Tech. Rep. NMFS-80.

Mathews, S. B., and M. W. Barker. 1983. Movements of rockfish (*Sebastes*) in northern Puget Sound, Washington. Fish. Bull. 82:916–922.

Matsuura, H., and G. A. Cannon. 1997. Wind effects on subtidal currents in Puget Sound. J. Oceanogr. 53:53–66.

McElhany, P., M. H. Ruckelshaus, M. J. Ford, T. C. Wainwright, and E. P. Bjorkstedt. 2000. Viable salmonid populations and the recovery of evolutionarily significant units. U. S. Dept. Commer., NOAA Tech. Memo NMFS-NWFSC-42. Online at http://www.nwfsc.noaa.gov/assets/25/5561_06162004_143739_tm42.pdf. [accessed 3 May 2010].

Merkel, T. J. 1957. Food habits of the king salmon *Oncorhynchus tshawytscha*. Calif. Fish Game 43:249–270.

Methot, R. D., and J. J. Stewart. 2005. Status of the U.S. canary rockfish resource in 2005. *In* Status of the Pacific Coast groundfish fishery through 2005, Stock assessment and fishery evaluation: Stock assessments and rebuilding analyses. Pacific Fishery Management Council, Portland, OR.

Miller, B. S., and S. F. Borton. 1980. Geographical distribution of Puget Sound fishes: Maps and data source sheets. Univ. Washington, Fisheries Research Institute, Seattle.

Miller, D. J., and J. J. Geibel. 1973. Summary of blue rockfish and lingcod life histories; a reef ecology study; and giant kelp, *Macrocystis pyrifera*, experiments in Monterey Bay, California. Fish. Bull. 158:1–137.

Miller, D. J., and R. N. Lea. 1972. Guide to the coastal marine fishes of California. Fish. Bull. 157:1–249.

Miller, J. A., and A. L. Shanks. 2004. Evidence for limited larval dispersal in black rockfish (*Sebastes melanops*): Implications for population structure and marine-reserve design. Can. J. Fish. Aquat. Sci. 61:1723–1735.

Morejohn, G. V., J. T. Harvey, and L. T. Krasnow. 1978. The importance of *Loligo opalescens* in the food web of marine vertebrates in Monterey Bay, California. *In* C. W. Recksiek and H. W. Frey (eds.), Biological, oceanographic, and acoustic aspects of the market squid, *Loligo opalescens* Berry, p. 67–98. Calif. Dept. Fish Game Bull. 169.

Moser, H. G. 1967. Reproduction and development of *Sebastodes paucispinis* and comparison with other rockfishes off southern California. Copeia 4:773–797.

Moser, H. G. 1996a. The early life stages of fishes in the California current region, Vol. 33. National Marine Fisheries Service, La Jolla, CA.

Moser, H. G. 1996b. Scorpaenidae: Scorpionfishes and rockfishes. *In* H. G. Moser (ed.), The early life stages of fishes in the California current region, p. 733–795. Allen Press, Lawrence, KS.

Moser, H. G., and G. W. Boehlert. 1991. Ecology of pelagic larvae and juveniles of the genus *Sebastes*. Environ. Biol. Fishes 30:203–224.

Moser, H. G., R. L. Charter, W. Watson, D. A. Ambrose, J. L. Butler, J. Charter, and E. M. Sandknop. 2000. Abundance and distribution of rockfish (*Sebastes*) larvae in the southern California Bight in relation to environmental conditions and fishery exploitation. Calif. Coop. Ocean. Fish. Investig. Rep. 41:132–147.

Mote, P. W., A. F. Hamlet, M. P. Clark, and D. P. Lettenmaier. 2005. Declining mountain snowpack in western North America. Bull. Amer. Meteorol. Soc. 86:39-49.

Moulton, L. L. 1977. An ecological analysis of fishes inhabiting the rocky nearshore regions of northern Puget Sound, Washington. University of Washington Press, Seattle.

Mumford, T. F. 2007. Kelp and eelgrass in Puget Sound. Puget Sound Nearshore Partnership Rep. 2007-05. U.S. Army Corps of Engineers, Seattle District, Seattle, WA. Online at http://www.pugetsoundnearshore.org [accessed 3 May 2010].

Munk, K. 2001. Maximum ages of groundfishes in waters off Alaska and British Columbia and consideration of age determination. Alsk. Fish. Res. Bull. 8:12–21.

Musick, J. A. 1999. Criteria to define extinction risk in marine fishes. Fisheries 24:6–14.

Musick, J. A., S. A. Berkeley, G. M. Cailliet, M. Camhi, G. Huntsman, N. Nammack, and M. L. Warren Jr. 2000. Protection of marine fish stocks at risk of extinction. Fisheries 25(3):6–8.

Naish, K. A., J. E. Taylor III, P. S. Levin, T. P. Quinn, J. R. Winton, D. Huppert, and R. Hilborn. 2007. An evaluation of the effects of conservation and fishery enhancement hatcheries on wild populations of salmon. Adv. Mar. Biol. 53:61–194.

Narum, S. R., V. P. Buonaccorsi, C. A. Kimbrell, and R. D. Vetter. 2004. Genetic divergence between gopher rockfish (*Sebastes carnatus*) and black and yellow rockfish (*Sebastes chrysomelas*). Copeia 4:926–931.

Nearshore Habitat Program. 2001. The Washington state shore zone inventory. Washington Dept. Natural Resources, Olympia.

Nelson, J. S., E. J. Crossman, H. Espinosa-Pérez, L. T. Findley, C. R. Gilbert, R. N. Lea, and J. D. Williams. 2004. Common and scientific names of fishes from the United States, Canada, and Mexico. Special Publication 29. American Fisheries Society, Bethesda, MD.

Nelson, K., and M. Soulé. 1987. Genetical conservation of exploited fishes. *In* N. Ryman and F. Utter (eds.), Population genetics and fishery management, p. 345–368. University of Washington Press, Seattle.

Nichol, D. G., and E. K. Pikitch. 1994. Reproduction of darkblotched rockfish off the Oregon coast. Trans. Am. Fish. Soc. 123(4):469–481.

Nichols, F. H. 1988. Long-term changes in a deep Puget Sound benthic community: Local or basin-wide? Proceedings, First Annual Meeting on Puget Sound Research, Puget Sound Water Quality Authority, Seattle 1:65–71.

NMFS (National Marine Fisheries Service). 1997. Investigation of scientific information on the impacts of California sea lions and Pacific harbor seals on salmonids and on the coastal ecosystems of Washington, Oregon, and California. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-28.

NMFS (National Marine Fisheries Service). 2000. Endangered and threatened species: Puget Sound populations of Pacific hake, Pacific cod, and walleye pollock. Federal Register (Docket No. 001103310-0310-01; 24 November 2000) 65(227):70514–70521.

NMFS (National Marine Fisheries Service). 2001. Endangered and threatened species: Puget Sound populations of copper rockfish, quillback rockfish, brown rockfish, and Pacific herring. Federal Register (Docket No. 010312061–1061–01; 3 April 2001) 66(64):17659–17668.

NMFS (National Marine Fisheries Service). 2002. Endangered and threatened wildlife and plants; 12-month finding on a petition to list bocaccio as threatened. Federal Register (19 November 2002) 67(223):69704–69708.

NMFS (National Marine Fisheries Service). 2003. Endangered and threatened species; Final endangered status for a distinct population segment of smalltooth sawfish (*Pristis pectinata*) in the United States. Federal Register (Docket No. 000303059–3034–03; 1 April 2003) 68(62):15674–15680.

Nysewander, D. R., J. R. Evenson, B. L. Murphie, and T. A. Cyra. 2005. Report of marine bird and marine mammal component, Puget Sound Ambient Monitoring Program, for July 1992 to December 1999 period. Washington Dept. Fish and Wildlife, Olympia.

O'Connell, V. M. 1987. Reproductive seasons for some *Sebastes* species in southeastern Alaska. Information Leaflet 263. Alaska Dept. Fish and Game, Division of Commercial Fisheries, Juneau.

O'Connell, V. M., and D. W. Carlisle. 1993. Habitat-specific density of adult yelloweye rockfish *Sebastes ruberrimus* in the eastern Gulf of Alaska. Fish. Bull. 91:304–309.

O'Farrell, M., and L. W. Botsford. 2006. The fisheries management implications of maternal-age-dependent larval survival. Can. J. Fish. Aquat. Sci. 63:2249–2258.

Ohman, M. D. 1990. The demographic benefits of diel vertical migration by zooplankton. Ecol. Monogr. 60:257–281.

Olesiuk, P. F., M. A. Bigg, G. M. Ellis, S. J. Crockford, and R. J. Wigen. 1990. An assessment of the feeding habits of harbour seals (*Phoca vitulina*) in the Strait of Georgia, British Columbia, based on scat analysis. Can. Tech. Rep. Fish. Aquat. Sci. 1370.

O'Reilly, P. T., M. F. Canino, K. M. Bailey, and P. Bentzen. 2004. Inverse relationship between F_{ST} and microsatellite polymorphism in the marine fish, walleye pollock (*Theragra chalcogramma*): Implications for resolving weak population structure. Mol. Ecol. 13:1799–1814.

Owen, R. W. 1980. Eddies of the California Current system: Physical and ecological characteristics. *In* D. M. Power (ed.), The California Islands: Proceedings of a multidisciplinary symposium, Santa Barbara Museum of Natural History, p. 237–263. Santa Barbara, CA.

Pacunski, R. E., and W. A. Palsson. 1998. The distribution and abundance of nearshore rocky reef habitats and fishes in Puget Sound. *In* Puget Sound Research '98 proceedings: Washington State Convention and Trade Center, Seattle, Washington, March 12 and 13, 1998, p. 545–554. Puget Sound Water Quality Action Team, Olympia, WA.

Pacunski, R. E., W. A. Palsson, H. G. Greene, and D. Gunderson. 2008. Conducting visual surveys with a small ROV in shallow water. *In* J. R. Reynolds and H. G. Greene (eds.), Marine habitat mapping technology for Alaska, p. 109–128. Univ. Alaska Fairbanks, Alaska Sea Grant Program, Fairbanks.

Palsson, W. A. 1988. Bottomfish catch and effort statistics from boat-based recreational fisheries in Puget Sound, 1970–1985 (revised). Progress Rep. 261, Washington Dept. Fisheries, Olympia.

Palsson, W. A. Unpubl. data. Three data files provided in July 2008. (Available from W. A. Palsson, WDFW, 600 Capitol Way N., Olympia, WA 98501.)

Palsson W. A., J. C. Hoeman, G. G. Bargmann, and D. E. Day. 1997. 1995 status of Puget Sound bottomfish stocks (revised). Washington Dept. Fish and Wildlife, Olympia.

Palsson, W. A., T.-S. Tsou, G. G. Bargmann, R. M. Buckley, J. E. West, M. L. Mills, Y. W. Cheng, and R. E. Pacunski. 2009. The biology and assessment of rockfishes in Puget Sound. FPT 09-04. Washington Dept. Fish and Wildlife, Olympia. Online at http://wdfw.wa.gov/publications/00926/wdfw00926.pdf [accessed 16 September 2010].

Palumbi, S. R. 1994. Genetic divergence, reproductive isolation, and marine speciation. Annu. Rev. Ecol. Syst. 25:547–572.

Parker, S. J., H. I. McElderry, P. S. Rankin, and R. W. Hannah. 2006. Buoyancy regulation and barotrauma in two species of nearshore rockfish. Trans. Am. Fish. Soc. 135:1213–1223.

Pedchenko, A. P. 2005. The role of interannual environmental variations in geographic range of spawning and feeding concentrations of redfish *Sebastes mentella* in the Irminger Sea. ICES J. Mar. Sci. 62:1501–1510.

Pedersen, M. G., and G. G. Bargmann. 1986. 1984 supplement for the groundfish management plan for Washington’s inside waters. Progress Rep. 247. Washington Dept. Fisheries, Olympia.

Pedersen, M., and G. DiDonato. 1982. Groundfish management plan for Washington’s inside waters. Progress Rep. 170. Washington Dept. Fisheries, Olympia.

Peden, A. E., and D. E. Wilson. 1976. Distribution of intertidal and subtidal fishes of northern British Columbia and southeastern Alaska. Syesis 9:221–248.

Pentilla, D. 2007. Marine forage fishes in Puget Sound. Puget Sound Nearshore Partnership Rep. 2007-03. U.S. Army Corps of Engineers, Seattle District, Seattle, WA. Online at http://www.pugetsoundnearshore.org/technical_papers/marine_fish.pdf [accessed 7 June 2010].

Phillips, J. B. 1960. Canary rockfish. *In* California ocean fisheries resources to the year 1960, p. 39. Calif. Dept. Fish and Game, Sacramento.

Phillips, J. B. 1964. Life history studies on 10 species of rockfish (Genus *Sebastodes*). Fish Bull. 126:1–70.

Pinnix, W. D. 1999. Climate and coho: A Puget Sound perspective. Master’s thesis. Univ. Washington, School of Aquatic and Fishery Sciences, Seattle.

PMFC (Pacific Marine Fisheries Commission). 1979. Data series, groundfish section. Pacific Marine Fisheries Commission, Portland, OR.

PSAT (Puget Sound Action Team). 2007. State of the sound 2007. Publication PSAT:07-01. Puget Sound Action Team, Olympia, WA.

PSWQA (Puget Sound Water Quality Authority). 1987. Puget Sound environmental atlas. Puget Sound Estuary Program, Olympia, WA.

PSWQA (Puget Sound Water Quality Authority). 1988. Committee on research. Final report. Puget Sound Water Quality Authority, Seattle, WA.

PSWQAT (Puget Sound Water Quality Action Team). 2000. 2000 Puget Sound update: Seventh report of the Puget Sound Ambient Monitoring Program. Puget Sound Water Quality Action Team, Olympia, WA.

Ralston, S., and J. N. Ianelli. 1998. When lengths are better than ages: The complex case of bocaccio. Rep. AK-SG-98-01. Univ. Alaska Fairbanks, Alaska Sea Grant Program, Fairbanks.

Reddingius, J. 1971. Gambling for existence. A discussion of some theoretical problems in animal population ecology. Acta Biotheoretica 20(Suppl. Primum):1–208.

REEF (Reef Environmental Education Foundation). 2008. Reef Environmental Education Foundation. Online at www.reef.org [accessed 3 May 2010].

Reilly, P. N., D. Wilson-Vandenberg, R. N. Lea, C. Wilson, and M. Sullivan. 1994. Recreational angler’s guide to the common nearshore fishes of northern and central California. Marine resources leaflet. California Dept. Fish and Game, Sacramento.

Reum, J. C. P. 2006. Spatial and temporal variation in the Puget Sound food web. Master's thesis. Univ. Washington, School of Aquatic and Fishery Sciences, Seattle.

Rice, C. A. 2007. Evaluating the biological condition of Puget Sound. Doctoral dissertation. Univ. Washington, School of Aquatic and Fishery Sciences, Seattle.

Richards, L. J. 1986. Depth and habitat distributions of three species of rockfish (*Sebastes*) in British Columbia: Observations from the submersible PISCES IV. Environ. Biol. Fishes 17:13–21.

Richards, L. J., J. Paul, A. J. Cass, L. Fitzpatrick, R. van den Broek, and C. Lauridsen. 1985. Scuba survey of rockfish assemblages in the Strait of Georgia, July to October 1984. Can. Data Rep. Fish. Aquat. Sci. 545. Dept. Fisheries and Oceans Canada, Fisheries Research Branch, Pacific Biological Station, Nanaimo, BC.

Richardson, S. L., and W. A. Laroche. 1979. Development and occurrence of larvae and juveniles of the rockfishes *Sebastes crameri, Sebastes pinniger*, and *Sebastes helvomaculatus* (Family Scorpaenidae) off Oregon. Fish. Bull. 77:1–46.

Roberts, D. A. 1979. Food habits as an ecological partitioning mechanism in the nearshore rockfishes (*Sebastes*) of Carmel Bay, California. Master's thesis. San Francisco State Univ., Moss Landing Marine Laboratories, Moss Landing, CA.

Rocha-Olivares, A., R. A. Leal-Navarro, C. Kimbrell, E. A. Lynn, and R. D. Vetter. 2003. Microsatellite variation in the Mexican rockfish *Sebastes macdonaldi*. Scientia Marina 67:451–460.

Rocha-Olivares, A., and R. D. Vetter. 1999. Effects of oceanographic circulation on the gene flow, genetic structure, and phylogeography of the rosethorn rockfish (*Sebastes helvomaculatus*). Can. J. Fish. Aquat. Sci. 56:803–813.

Rosenthal, R. J., L. Haldorson, L. J. Field, V. Moran-O'Connell, and M. G. LaRiviere. 1982. Inshore and shallow offshore bottomfish resources in the southeastern Gulf of Alaska, Alaska Coastal Research, Sitka. Alaska Dept. Fish and Game, Juneau.

Rosenthal, R. J., V. Moran-O'Connell, and M. C. Murphy. 1988. Feeding ecology of 10 species of rockfishes (Scorpaenidae) from the Gulf of Alaska. Calif. Fish Game 74:16–37.

Ruckelshaus, M., T. Essington, and P. S. Levin. 2009. How science can inform ecosystem-based management in the sea: Examples from Puget Sound. *In* K. L. McLeod and H. M. Leslie (eds.), Ecosystem-based management for the oceans: Applying resilience thinking, p. 392. Island Press, Washington, DC.

Ruckelshaus, M. H., and M. McClure (coordinators, prepared in cooperation with the Sound Science collaborative team). 2007. Sound Science: Synthesizing ecological and socioeconomic information about the Puget Sound ecosystem. Northwest Fisheries Science Center, Seattle, WA.

Ryman, N., P. E. Jorde, and L. Laikre. 1995. Supportive breeding and variance effective population size. Conserv. Biol. 9:1619–1628.

Ryman, N., and L. Laikre. 1991. Effects of supportive breeding on the genetically effective populations size. Conserv. Biol. 5:325–329.

Schmitt, C., S. Quinnell, M. Rickey, and M. Stanley. 1991. Groundfish statistics from commercial fisheries in Puget Sound, 1970–1988. Prog. Rep. 285. Washington Dept. Fisheries, Olympia.

Schmitt, C., J. Schweigert, and T. P. Quinn. 1994. Anthropogenic influences on fish populations of the Georgia Basin. *In* R. C. H. Wilson, R. J. Beamish, F. Aitkens, and J. Bell, (eds.), Review of the marine environment and biota of Strait of Georgia, Puget Sound, and Juan de Fuca Strait, p. 218–252. Can. Tech. Rep. Fish. Aquat. Sci. 1948.

Secor, D. H. 2000. Longevity and resilience of Chesapeake Bay striped bass. ICES J. Mar. Sci. 57:808–815.

Seeb, L. W. 1998. Gene flow and introgression within and among three species of rockfishes, *Sebastes auriculatus, S. caurinus*, and *S. maliger*. J. Hered. 89(5):393–403.

Seeb, L. W., and D. R. Gunderson. 1988. Genetic variation and population structure of Pacific ocean perch (*Sebastes alutus*). Can. J. Fish Aquat. Sci. 45:78–88.

Sekino, M., N. Takagi, M. Hara, and H. Takahashi. 2001. Analysis of microsatellite DNA polymorphisms in rockfish *Sebastes thompsoni* and application to population genetic studies. Mar. Biotechnol. 3:45–52.

Shaw, F. R. 1999. Life history of four species of rockfish (genus *Sebastes*). Doctoral dissertation, Univ. Washington, School of Aquatic and Fishery Sciences, Seattle.

Shaw, F. R., and D. R. Gunderson. 2006. Life history traits of the greenstriped rockfish, *Sebastes elongatus*. California Fish Game 92:1–23.

Shipman, H. 2004. Coastal bluffs and sea cliffs on Puget Sound, Washington. U.S. Geological Survey Professional Pap. 1693, p. 81–94. Online at http://pubs.usgs.gov/pp/pp1693/ [accessed 4 May 2010].

Shumway, R., and D. Stoffer. 2006. Time series analysis and its applications. 2nd edition. Springer-Verlag, NY.

Simenstad, C. A., K. L. Fresh, and E. O. Salo. 1982. The role of Puget Sound and Washington coastal estuaries in the life history of Pacific salmon: An unappreciated function. *In* V. S. Kennedy (ed.), Estuarine comparisons, p. 343–364. Academic Press, New York.

Singer, M. M. 1982. Food habit and activity patterns of juvenile rockfishes (*Sebastes*) in a central California kelp forest. Master's thesis. San Jose State University, San Jose, CA.

Small, M. P., J. L. Loxterman, A. E. Frye, J. F. Von Bargen, C. Bowman, and S. Young. 2005. Temporal and spatial genetic structure among some Pacific herring populations in Puget Sound and the southern Strait of Georgia. Trans. Am. Fish. Soc. 134:1329–1341.

Smith, R. T. 1936. Report on the Puget Sound otter trawl investigations. Biological Rep. 36B. Washington Dept. Fisheries, Olympia.

Snover, A. K., P. W. Mote, L. W. Binder, A. F. Hamlet, and N. J. Mantua. 2005. Uncertain future: Climate change and its effects on Puget Sound. A report for the Puget Sound Action Team by the Climate Impacts Group (Center for Science in the Earth System, Joint Institute for the Study of the Atmosphere and Oceans), Univ. Washington, Seattle.

Sogard, S. M. Unpubl. data. Maternal effects data. (Available from S. Sogard, Southwest Fisheries Science Center, 110 Shaffer Road, Santa Cruz, CA 95060.)

Sogard, S. M., S. A. Berkeley, and R. Fisher. 2008. Maternal effects in rockfishes *Sebastes* spp.: A comparison among species. Mar. Ecol. Prog. Ser. 360:227–236.

Speich, S., and T. R. Wahl. 1989. Catalog of Washington marine bird colonies. U.S. Fish Wildl. Serv. Biol. Rep. 88(6):1–510.

Stahl-Johnson, K. L. 1985. Descriptive characteristics of reared *Sebastes caurinus* and *S. auriculatus* larvae. *In* A. W. Kendall Jr. and J. B. Marliave (eds.), Descriptions of early life history stages of selected fishes: From the 3rd international symposium on the early life history of fishes and 8th annual larval fish conference, p. 65–76. Can. Tech. Rep. Fish Aquat. Sci. 1359.

Starr, R. M. 1998. Design principles for rockfish reserves on the U.S. West Coast. *In* M. M. Yoklavich (ed.), Marine harvest refugia for West Coast rockfish: A workshop, p. 50–63. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-SWFSC-255.

Starr, R. M., J. N. Heine, J. M. Felton, and G. M. Cailliet. 2002. Movements of bocaccio (*Sebastes paucispinis*) and greenspotted (*S. chlorostictus*) rockfishes in a Monterey submarine canyon: Implications for the design of marine reserves. Fish. Bull. 100:324–337.

STAT (Stock Assessment Team). 1999. Status of the canary rockfish resource off Oregon and Washington in 1999. National Marine Fisheries Service, Newport, OR.

Staubitz, W. W., G. C. Bortleson, S. D. Semans, A. J. Tesoriero, and R. W. Black. 1997. Water-quality assessment of the Puget Sound basin–Environmental setting and its implications for water quality and aquatic biota. Water Resources Investigations Rep. 97-4013. U.S. Geological Survey, Tacoma, WA.

Stevens, D. E., and L. W. Miller. 1983. Effects of river flow on abundance of young Chinook salmon, American shad, longfin smelt, and delta smelt in the Sacramento-San Joaquin river system. N. Am. J. Fish. Manag. 3:425–437.

Stewart, I. J. 2007. Status of the U.S. canary rockfish resource in 2007. Pacific Fishery Management Council, Portland, OR.

Stout, H. A., R. G. Gustafson, W. H. Lenarz, B. B. McCain, D. M. VanDoornik, T. L. Builder, and R. D. Methot. 2001b. Status review of Pacific herring in Puget Sound, Washington. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-45.

Stout, H. A., B. B. McCain, R. D. Vetter, T. L. Builder, W. H. Lenarz, L. L. Johnson, and R. D. Methot. 2001a. Status review of copper rockfish (*Sebastes caurinus*), quillback rockfish (*S. maliger*), and brown rockfish (*S. auriculatus*) in Puget Sound, Washington. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-46.

Strickland, R. M. 1983. The fertile fjord: Plankton in Puget Sound. Puget Sound Books, Washington Sea Grant Program, Seattle, WA.

Sumida, B. Y., H. G. Moser, and E. H. Ahlstrom. 1985. Descriptions of larvae of California yellowtail, *Seriola lalandi*, and three other carangids from the eastern tropical Pacific: *Chloroscombrus orqueta, Caranx caballu*s, and *Caranx sexfasciatus*. Calif. Coop. Ocean. Fish. Investig. Rep. 26:139–159.

Swain, D. P. 1999. Changes in the distribution of Atlantic cod (*Gadus morhua*) in the southern Gulf of St. Lawrence: Effects of environmental change or change in environmental preferences? Fish. Oceanogr. 8:1–17.

Taylor, C. A. 2004. Patterns of early staged pelagic dispersal and gene flow in rockfish species from the southern California Bight. Univ. California, Scripps Institute of Oceanography, San Diego.

Thom, R. M, T. L. Parkwell, D. K. Shreffler, and K. B. MacDonald. 1994. Shoreline armoring effects on coastal ecology and biological resources in Puget Sound. Coastal erosion management studies, Vol. 7. Shorelands and Coastal Zone Management Program. Washington Dept. Ecology, Olympia,WA.

Thompson, G. G. 1991. Determining minimum viable populations under the Endangered Species Act. U.S. Dept. Commer., NOAA Tech. Memo. NMFS F/NWC-198.

Thomson, R. E. 1994. Physical oceanography of the Strait of Georgia-Puget Sound-Juan de Fuca Strait System. *In* R. C. Wilson et al. (eds.), Review of marine environment and biota of the Georgia-Puget Sound-Juan de Fuca Strait, p. 36–98. Proceedings of the BC/Washington Symposium on the Marine Environment, January 13 and 14, 1994. Can. Tech. Rep. Fish. Aquat. Sci. 1948.

Thorson, R. M. 1980. Ice-sheet glaciation of the Puget Lowland, Washington, during the Vashon Stade (late Pleistocene). Quat. Res. 13:303–321.

Tissot, B. N., M. A. Hixon, and D. L. Stein. 2007. Habitat-based submersible assessment of macro-invertebrate and groundfish assemblages at Heceta Bank, Oregon from 1988 to 1990. J. Exp. Mar. Biol. Ecol. 352:50–64.

Tolimieri, N., K. Andrews, G. Williams, and P. S. Levin. 2009. Home range size and patterns of space use for lingcod, copper rockfish, and quillback rockfish in Puget Sound in relation to diel and tidal cycles. Mar. Ecol. Prog. Ser. 380:229–243.

Tolimieri, N., and P. S. Levin. 2005. The roles of fishing and climate in the population dynamics of bocaccio rockfish. Ecol. Appl. 15:458–468.

Tully, J. P., and A. J. Dodimead. 1957. Properties of the water in the Strait of Georgia, British Columbia, and influencing factors. J. Fish. Board Can. 14:241–319.

Turgeon, D. D., J. F. Quinn Jr., A. E. Bogan, E. V. Coan, F. G. Hochberg, W. G. Lyons, P. M. Mikkelsen, R. J. Neves, C. F. E. Roper, G. Rosenberg, B. Roth, A. Scheltema, F. G. Thompson, M. Vecchione, and J. D. Williams. 1998. Common and scientific names of aquatic invertebrates from the United States and Canada: Mollusks. Second edition. Special Publication 26. American Fisheries Society, Bethesda, MD.

U.S. Census Bureau. 2003. July 1, 2003 population data for Olympia, WA, and Shelton, WA. Online at http://www.census.gov/popest/cities/tables/SUB-EST2008-04-53.xls [accessed 8 June 2010].

U.S. Fish Commission. 1900. Bulletin of the U.S. Fish Commission, Washington, DC.

USFWS-NMFS (U.S. Fish and Wildlife Service and National Marine Fisheries Service). 1996. Policy regarding the recognition of distinct vertebrate population segments under the Endangered Species Act. Federal Register (7 February 1996) 61(26):4722–4725.

Utter, F. M., and H. O. Hodgins. 1971. Biochemical polymorphism in the Pacific hake (*Merluccius productus*). Cons. Perm. Int. Explor. Mer. Rapp. P.-V. Reun. 161:87–89.

Valentine, J. W. 1966. Numerical analysis of marine molluscan ranges on the extratropical northeastern Pacific shelf. Limnol. Oceanogr. 11:198–211.

VanBlaricom, G., M. Neuman, J. A. Butler, A. DeVogelaere, R. Gustafson, C. Mobley, D. Richards, S. Rumsey, and B. Taylor. 2009. Status review report for black abalone (*Haliotis cracherodii* Leach, 1814). National Marine Fisheries Service Southwest Region, Long Beach, CA. Online at http://swr.ucsd.edu/bfrp/BASR_Report_Final_8_Jan_2009-ver4.pdf [accessed 15 September 2008].

Vetter, R. D., and E. A. Lynn. 1997. Bathymetric demography, enzyme activity patterns, and bioenergetics of deep-living scorpaenid fishes (genera *Sebastes* and *Sebatolobus*): Paradigms revisited. Mar. Ecol. Prog. Ser. 155:173–188.

Wahl, T. R., B. Tweit, and S. G. Mlodinow. 2005. Birds of Washington: Status and distribution. Oregon State University Press, Corvallis.

Wainwright, T. C., and R. G. Kope. 1999. Short communication: Methods of extinction risk assessment developed for U.S. West Coast salmon. ICES J. Mar. Sci. 56:444–448.

Waldron, K. D. 1968. Early larvae of the canary rockfish, *Sebastodes pinniger*. J. Fish. Res. Board Can. 25:801–803.

Waldichuck, M. 1957. Physical oceanography of the Strait of Georgia, British Columbia. J. Fish. Res. Board Can. 14:321–486.

Wallace, F. R. 2002. Status of the yelloweye rockfish resource in 2001 for northern California and Oregon waters. *In* Appendix to the status of the Pacific Coast groundfish fishery through 2001 and acceptable biological catches for 2002 (Stock assessment and fishery evaluation). Pacific Fishery Management Council, Portland, OR.

Wallace, J. R. 2007. Update to the status of yelloweye rockfish (*Sebastes ruberrimus*) off the U.S. West Coast in 2007. Pacific Fishery Management Council, Portland, OR.

Walton, J. M. 1979. Puget Sound artificial reef study. Tech. Rep. 50. Washington Dept. Fisheries, Olympia.

Waples, R. S. 1998. Separating the wheat from the chaff: Patterns of genetic differentiation in high gene flow species. J. Hered. 89:438–450.

Waples, R. S., and C. Do. 1994. Genetic risk associated with supplementation of Pacific salmonids: Captive broodstock programs. Can. J. Fish. Aquat. Sci. 51(Suppl. 1):310–329.

Ware, D. M., and G. A. McFarlane. 1989. Fisheries production domains in the northeast Pacific Ocean. *In* R. J. Beamish and G. A. McFarlane (eds.), Effects of ocean variability on recruitment and an evaluation of parameters used in stock assessment models, p. 990–998. Can. Spec. Pub. Fish. Aquat. Sci. 168.

Warner, R. R., and P. L. Chesson. 1985. Coexistence mediated by recruitment fluctuations: A field guide to the storage effect. Am. Nat. 125:769–787.

WDF (Washington Department of Fisheries). 1964. Annual Reports, Washington Dept. Fisheries, Olympia.

WDF (Washington Department of Fisheries). 1975–86. Washington state sport catch reports. Washington Dept. Fisheries, Olympia.

WDOE (Washington Department of Ecology). 1998. Sediment quality values refinement. Washington Dept. Ecology, Olympia. Online at http://www.ecy.wa.gov/biblio/0609094.html [accessed 15 July 2010].

WDOE (Washington Department of Ecology). 1999. Sediment quality in Puget Sound. Washington Dept. Ecology, Olympia. Online at http://www.ecy.wa.gov/biblio/99347.html [accessed 15 July 2010].

Washington, P. M., R. Gowan, and D. H. Ito. 1978. A biological report on eight species of rockfish (*Sebastes* spp.) from Puget Sound, Washington. Northwest and Alaska Fisheries Center Processed Report. National Marine Fisheries Service, Seattle.

West, J. E. 1997. Protection and restoration of marine life in the inland waters of Washington state. Puget Sound/Georgia Basin Environmental Rep. 6. Puget Sound Water Quality Action Team, Olympia, WA.

West, J. E., S. M. O'Neill, G. Lippert, and S. Quinnell. 2001. Toxic contaminants in marine and anadromous fish from Puget Sound, Washington: Results of the Puget Sound Ambient Monitoring Program fish component, 1989–1999. Washington Dept. Fish and Wildlife, Olympia.

Westrheim, S. J. 1975. Reproduction, maturation, and identification of larvae of some *Sebastes* (Scorpaenidae) species in the northeast Pacific Ocean. J. Fish. Res. Board Can. 32:2399–2411.

Westrheim, S. J., and W. R. Harling. 1975. Age-length relationships for 26 scorpaenids in the northeast Pacific Ocean. Tech. Rep. 565. Dept. Fisheries and Oceans Canada, Fisheries and Marine Service Research Division, Nanaimo, BC.

Wieland, K., A. Jarre-Teichmann, and K. Horbowa. 2000. Changes in the timing of spawning of Baltic cod: Possible causes and implications for recruitment. ICES J. Mar. Sci. 57:452–464.

Williams, E. H., and S. Ralston. 2002. Distribution and co-occurrence of rockfishes (family: Sebastidae) over trawlable shelf and slope habitats of California and southern Oregon. Fish. Bull. 100:836–855.

Williams, E. H., S. Ralston, A. D. MacCall, D. Woodbury, and D. E. Pearson. 1999. Stock assessment of the canary rockfish resource in the waters off southern Oregon and California in 1999. *In* Status of the Pacific Coast groundfish fishery through 1999 and recommended acceptable biological catches for 2000 appendix: Stock assessments. Pacific Fishery Management Council, Portland, OR.

Wimberger, P. In prep. Microsatellite data. (Available from P. Wimberger, Univ. Puget Sound, 1500 N. Warner, Tacoma, WA 98416.)

Wing, S. R., L. W. Botsford, S. V. Ralston, and J. L. Largier. 1998. Meroplanktonic distribution and circulation in a coastal retention zone of the northern California upwelling system. Limnol. Oceanogr. 43:1710–1721.

Winter, D. F., K. Banse, and G. C. Anderson. 1975. The dynamics of phytoplankton blooms in Puget Sound, a fjord in the northwestern United States. Mar. Biol. 29:139–176.

Wishard, L. N., F. M. Utter, and D. R. Gunderson. 1980. Stock separation of five rockfish species using naturally occurring biochemical genetic markers. Mar. Fish. Rev. 42:64–73.

Withler, R. Unpubl. data. Yelloweye rockfish genetic differences. (Available from R. Withler, Dept. Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, BC V9T 6N7.)

Withler, R. E., T. D. Beacham, A. D. Schulze, L. J. Richards, and K. M. Miller. 2001. Co-existing populations of Pacific ocean perch, *Sebastes alutus*, in Queen Charlotte Sound, British Columbia. Mar. Biol. 139:1–12.

Wourms, J. P. 1991. Reproduction and development of *Sebastes* in the context of the evolution of piscine viviparity. Environ. Biol. Fishes 30:111–126.

Wyllie-Echeverria, T. 1987. Thirty-four species of California rockfishes: Maturity and seasonality of reproduction. Fish. Bull. 85:229–250.

Yamanaka, K. L., and A. R. Kronlund. 1997. Inshore rockfish stock assessment for the west coast of Canada in 1996 and recommended yields for 1997. Can. Tech. Rep. Fish. Aquat. Sci. 2175.

Yamanaka, K. L., L. Lacko, J. Lochead, J. Martin, R. Haigh, C. Grandin, and K. West. 2004. Stock assessment framework for inshore rockfish. Research Document 2004/068. Canadian Science Advisory Secretariat, Ottawa, ON.

Yamanaka, K. L., L. C. Lacko, R. Withler, C. Grandin, J. K. Lochead, J. C. Martin, N. Olsen, and S. S. Wallace. 2006. A review of yelloweye rockfish *Sebastes ruberrimus* along the Pacific coast of Canada: Biology, distribution, and abundance trends. Research Document 2006/076. Canadian Science Advisory Secretariat, Ottawa, ON.

Yang, Z., and T. Khangaonkar. 2008. Modeling the hydrodynamics of Puget Sound using a three-dimensional unstructured finite volume coastal ocean model. *In* M. L. Spaulding (ed.), Proceedings of the 10th International Conference on Estuarine and Coastal Modeling. American Society of Civil Engineers, Newport, RI.

Yoklavich, M. M., H. G. Greene, G. M. Cailliet, D. E. Sullivan, R. N. Lea, and M. S. Love. 2000. Habitat associations of deepwater rockfishes in a submarine canyon: An example of a natural refuge. Fish. Bull. 98:625–641.

Yoklavich, M. M., V. Loeb, M. Nishimoto, and B. Daly. 1996. Nearshore assemblages of larval rockfishes and their physical environment off central California during an extended El Nino event, 1991–1993. Fish. Bull. 94:766–782.

Appendix A: Technical Comments and Reviews

Public Comments

Public comments were received from the Western States Petroleum Association, Mr. Sam Wright, the Washington Department of Fish and Wildlife, and the King County Department of Natural Resources and Parks. The comments are reproduced below.

Western States Petroleum Association Letter

June 22, 2009

Chief, Protected Resources Division
Northwest Region
National Marine Fisheries Service
1201 NE Lloyd Blvd., Suite 1100
Portland, Oregon 97232

Re: Proposed Listing of Puget Sound Rockfish

To Whom It May Concern:

The Western States Petroleum Association ("WSPA") appreciates the opportunity to provide comments on the proposed listing of three species of Puget Sound rockfish—Boccaccio, yelloweye, and canary, under the Endangered Species Act ("ESA"). *See* 74 Fed. Reg. 18516 (April 29, 2009). WSPA is a nonprofit trade association that represents companies that account for the bulk of petroleum exploration, production, refining, transportation, and marketing in the western states. WSPA represents a range of companies that operate in various capacities in and around Puget Sound, and are significant contributors to the local and regional economies.

It is of primary importance to WSPA members that they operate in a safe, secure, efficient, and environmentally responsible manner in Puget Sound and in the other regional and national locations in which they operate. Members have committed significant resources and developed technological sophistication in order to achieve this goal.

While WSPA supports the appropriate protection of sensitive species under the ESA, it also believes that species listings must be properly supported by science, and reflect an accurate understanding of the risks and available conservation programs. To this end, this letter sets out WSPA's comments concerning the proposed listings and provides information intended to inform final determinations.

Scientific Foundation for Proposed Listings

As an initial matter, the proposed rule sets out in some detail the gaps and inadequacies associated with the underlying data, raising questions about the defensibility of the scientific foundation for the proposed listings. While ESA conclusions, including those about listings, can be based on less than conclusive scientific evidence, there must be evidence upon which to base the conclusions. *See National Ass'n of Home Builders v. Norton*, 340 F.3d 835, 847 (9th Cir. 2003) citing *Bennett v. Spear*, 520 U.S. 154, 176 (1997) ("The obvious purpose of the requirement that each agency 'use the best scientific and commercial evidence available' is to ensure that the ESA not be implemented haphazardly, on the basis of *speculation or surmise*."). Given the identified gaps in the proposed listing rule, it does not seem certain here that the threshold for listing has been met.

For example, in the abundance trends analysis, quantitative estimates of trends in abundance were not generated for the petitioned species since the low sampling of catches in many years provided insufficient yearly estimates. *See* 74 Fed. Reg. 18531. Due to such data gaps, the listing rule appears to be based an inferences and extrapolations. NMFS itself states that due to a lack of systematic sampling targeting rockfishes, absolute estimates of population size of the proposed species "cannot be generated with any accuracy." *Id.* For current abundance, results were extrapolated from a video survey to estimate the population size of common rockfish species and then the percent frequency of the petitioned species in the recreational catch (with its attendant data limitations) were applied. *Id.* For abundance trends, the overall trend in rockfishes, which was heavily influenced by common rockfish species, were used to make inferences about the magnitude of trend in the petitioned species. *Id.*

Given the considerable uncertainties associated with abundance estimation, and the admitted lack of accurate estimates of population sizes for the proposed species, it appears premature to propose the rockfish species for listing at this time. Statements contained in the proposed rule suggest that NMFS does not possess a reasonable basis to conclude that listing is warranted at this time. At most, available information may suggest a need for monitoring of the proposed species to determine current population sizes. Furthermore, listing these species at this stage will make it difficult, if not impossible, to establish accurate delisting and recovery criteria.

Role of Environmental Contaminants in Factors for Species Decline

Regarding the effects of environmental contaminants on rockfish status, WSPA encourages NMFS to insure its conclusions clearly and specifically reflect the best available science, and include appropriate qualifiers. The proposed rule states that few studies have investigated the effects of toxins on rockfish ecology or physiology, that "no studies have shown an effect on rockfish" reproduction, and that the full effect of contaminants on rockfish in the Georgia Basin remains unknown. *See* 74 Fed. Reg. 18533. There does not appear to be any conclusive evidence that water quality is a limiting factor impacting the status of the species.

Moreover, information contained in the proposed rule should be augmented to reflect current regulatory mechanisms that address environmental contaminants. For example, the use of DDT has been prohibited by federal law and is no longer actively used in the Puget Sound region. In addition, the use of PCBs is limited to existing equipment that was manufactured in the past, and such equipment is subject to stringent monitoring, reporting, cleanup, and disposal requirements under various federal laws, including RCRA and CERCLA. The proposed rule should be revised to reflect the import of these and other various federal and state environmental laws that limit rockfish exposure to environmental contaminants.

Existing Regulatory Programs

As noted in the proposed rule, the ESA requires the Secretary of Commerce to take into account efforts being made to protect a species that has been proposed for listing. The rationale behind this requirement is that if sufficiently protective regulatory requirements exist, it is then redundant and undesirable to overlay additional ESA regulation. *See* NMFS and FWS, Policy for Evaluating Conservation Efforts, 68 Fed. Reg. 15113 (2003); *Natural Resources Defense Council v. U.S. Dept. of the Interior,* 113 F.3d 1121, n.1 (9th Cir.1997).

With regard to the rockfish species proposed for listing, it is unclear whether existing regulatory protections have been given full credit, and thus whether the case has been made for an additional regulatory overlay. For example, the proposed listing rule identifies overfishing as the essential cause of rockfish declines, and explains the fairly recent increases in protective regulations that may address this factor for decline. While NMFS suggests that fishing regulations have not yet conclusively demonstrated their effectiveness, it is not clear why these regulations that directly target the key causal factor have been discounted in determining that a listing is necessary. In particular, it would seem prudent for NMFS to engage in a more detailed analysis of the adequacy of Washington fishing regulations. Perhaps through discussions with Washington Department of Fish and Wildlife, NMFS could develop an agreement with the state to further restrict fishing, or enhance regulatory implementation and enforcement, in manner that makes listing of the species unnecessary.

Aside from state fishing regulations, NMFS takes a pessimistic view of the potential impact of the Puget Sound Partnership on the basis that it “does not presently have a track record to support a conclusion that the control or reduction of pollutants into Puget Sound is reasonably foreseeable.” *See* 74 Fed. Reg. 18537. It is difficult to reconcile this conclusion with the guidance of the agency’s own Policy for Evaluating Conservation Efforts. *See* 68 Fed. Reg. 15114-115 (2003). The Puget Sound Partnership seems to be effectively discounted despite its legislative mandate, significant funding, and its focus on Puget Sound, including the key problem of stormwater runoff: “It is not possible to draw conclusions about Partnership efforts and how they may reduce pollution and contamination or other threats to rockfish populations.” *Id.* To make a rational case for listing, existing measures such as these deserve a more sustained and detailed analysis.

Critical Habitat Designation

Information has been requested about the potential economic impacts and impacts on national security of a rockfish critical habitat designation. There is no indication that the activities of WSPA members (including its marine shipping activities) negatively impact or adversely modify any rockfish PCEs that might exist in Puget Sound. Marine vessel operations in Puget Sound are highly regulated, and closely scrutinized. Puget Sound possesses the lowest commercial vessel oil spill rate in the nation. There have been no documented drift grounding oil spill incidents in

Puget Sound in over several million monitored vessel transits. Thus, even if critical habitat was determinable for the rockfish proposed for listing—which seems unlikely given the lack of good information presented in support of listing—there is no causal relationship between marine shipping and rockfish to justify mandatory restrictions in the context of a section 7 consultation.

If, however, restrictions on vessel movements were imposed as a result of a rockfish critical habitat designation, the economic and national security implications would be significant. Vessel movements and shipping lane operations in general implicate important national security considerations and international agreements. Any material limitations on shipping movements would have significant impacts on the regional economy. Such impacts would need to be carefully balanced against the benefits of any wide-ranging critical habitat designation.

Summary

In summary, the proposed rule identifies a number of uncertainties regarding rockfish population size that call into question the basis for species listing at this time. NMFS is required to base its listing decisions on the best available scientific and commercial information. Available information, according to NMFS, is lacking regarding overall rockfish population sizes. By extension, it would seem difficult, if not impossible, to conclude the species warrant listing when their overall numbers are still in question.

WSPA supports responsible management of natural resources in Puget Sound. A number of State, Federal and local environmental initiatives are underway to address environmental concerns. Many of these programs have been in place for a number of years, and effectively address factors that are thought to have contributed to species decline. WSPA urges NMFS to analyze the regulatory programs in detail and, if necessary, work with WDFW to further strengthen fishing regulations in a manner that avoids the need to list these species. Doing so will validate the efforts of groups working to protect Puget Sound, and it will help foster a climate of regulatory certainty in the business community.

Thank you for the opportunity to provide comments concerning the development of the proposed Puget Sound rockfish listing. Please feel free to contact me if you have any questions regarding these comments.

Sincerely,
/s/ Frank E. Holmes,
Manager, Northwest Region

copy: WSPA Environmental Committee
Jim Lynch, K&L Gates LLP

Mr. Sam Wright Letter

To: Chief, Protected Resources Division, Northwest Region, National Marine Fisheries Service, 1201 NE Lloyd Blvd., Suite 1100, Portland, OR 97232

From: Sam Wright, 1522 Evanston Ct. NE, Olympia, WA 98506 (360-943-4424, sam.wright@att.net)

Subject: **Proposed Endangered, Threatened, and Not Warranted Status for Distinct Population Segments of Rockfish in Puget Sound**

The subject at hand represents a first-rate professional work product and everyone involved should be commended for their efforts. There are only a few problems that need to be resolved.

The most serious deficiency is failure to evaluate potential adverse impacts to low abundance rockfish populations due to depensation, especially the subset of depensatory mortality factors commonly known as Allee effects. The subject was presented in a general way in the April 2007 petition, but I have to admit that I did not realize a specific problem until very recently. Last November, David Jennings, a certified marine fish identifier and underwater surveyor, presented a report to the Washington Fish and Wildlife Commission about a 2008 assessment of fish populations in the area between Neah Bay and Tatoosh Island. In that report, he stated that, in ten days of surveys, he detected a total of two tiger rockfish, three China rockfish, and two canary rockfish. No yelloweye rockfish were observed. All of these four species are brightly colored and have small home ranges in common.

I immediately knew what the specific problem was for low abundance rockfish populations with small home ranges. It is the most fundamental of all possible Allee effects—failure of individual mature fish to find mature mates of the opposite sex. With abundance levels this low, there is really no alternative explanation unless mature fish routinely move far outside their home ranges to specifically seek mature mates. I then checked the NGO REEF (www.reef.org) database for the same four species in Washington waters of the Georgia Basin. This showed the same consistent low abundance picture for all four species during recent years. You can never have the infrequent successful recruitment event if most of the mature fish cannot even find mates. It is a special (and rare) resource conservation problem where every single fish matters and you cannot allow additional fishing mortality for any reason. If the BRT team had been aware of this problem, they may well have cast their majority vote for Endangered instead of Threatened for canary rockfish and yelloweye rockfish.

I also realized that the April 2007 petition should have included tiger rockfish and China rockfish. I encourage the National Marine Fisheries Service to consider initiating a "supplemental" status review of these two species in the Georgia Basin. This is a very opportune time to conduct such a review since over 90% of the work has already been done and would not have to be repeated at some time in the future in response to a new ESA Petition. This additional status review would complete the coverage for Puget Sound rockfish species. There are no additional species with the combination of long-term persistence in the area, low abundance, and small home ranges.

The only other serious problem is in your discussion of bycatch, where the language seems to indicate that the most serious concern is with the lingcod fishery. This is incorrect. By a wide margin, the highest bycatch mortality for rockfish occurs in the Puget Sound recreational fishery for "blackmouth." These are immature resident ESA-listed Puget Sound Chinook salmon and form the backbone of the Puget Sound salmon fishery since returning mature Chinook and coho salmon have reduced or ceased feeding and are much harder to catch. Blackmouth are found right near the bottom, especially during the five month period from November through March. Immature Chinook are much more associated with the bottom than other species of Pacific salmon and this is why Chinook always predominate in the salmon bycatch in winter bottom trawl fisheries off both Washington and Alaska—even though they are by far the least abundant of the five Pacific salmon species.

The Puget Sound blackmouth fishery is very different than the summer ocean salmon fishery that some of the BRT team members may be familiar with. In addition to fishing close to the bottom, there is widespread use of down riggers and electronic fish finders. This allows anglers to place their terminal gear at precisely the same depth as the fish and also allows them to fish effectively throughout the entire tidal cycle. Beginning in 2007, fishing opportunity was significantly expanded by providing new selective fisheries for adipose marked Chinook. This also increased the bycatch mortality for rockfish since it is impossible [to] fish for blackmouth without encountering rockfish. Additional opportunities were provided in 2008 and additional increases are scheduled for 2009. This means that there have already been three successive incremental increases in bycatch mortality for rockfish in 2007, 2008, and 2009.

The other problem is that targeted fishing for rockfish is allowed every time fishing is allowed for salmon and/or lingcod. People still fish for rockfish with a one fish daily bag limit because they fish for boat limits, not individual limits, and high grading is a common practice. Thus the increases in salmon fishing opportunities have produced three incremental increases in targeted fishing for rockfish in 2007, 2008, and 2009. The obvious solution, and the only one that protects each individual rockfish, is to confine all recreational fishing for both salmon and marine fish to waters inside the 20 fathom line. The equally obvious benefit to this is that, due to the additional protection provided to ESA-listed Puget Sound Chinook, a year around selective fishery could be justified for Chinook.

The elimination of deepwater fishing with down rigger gear would also benefit the ESA-listed Puget Sound Chinook resource. When you fish in deep water with down rigger gear, it is often necessary to tighten the fishing line release mechanism in order to counter the drag effects from strong currents and/or snagged vegetation. Small Chinook (less than the minimum size limit) are then unable to trip the fishing line release mechanism. They remain undetected until the down rigger is retrieved. By this time, they have been dragged to exhaustion and will either be dead or die within six hours due to a build-up of excessive lactic acid in the body.

A final point concerns your discussion of releases of propagated fish, where the numbers given for salmon are incorrect. The correct numbers for Chinook salmon are 45.6 million subyearlings and 2.6 million yearlings. Ecological interactions with hatchery Chinook are discussed on pages 9 and 10 of the April 2007 petition.

Canary rockfish from NGO REEF (www.reef.org) database, minimum of 1 fish

2001	Dabob Bay	15 surveys, fish seen in 1, density 1
2001	Vashon Island	16 surveys, fish seen in 2, density 2
2001	West Seattle area	28 surveys, fish seen in 1, density 1
2002	Kitsap Peninsula, Port Gamble–Gig Harbor, includes Poulsbo and Bremerton	8 surveys, fish seen in 1, density 2
2003	Dabob Bay	57 surveys, fish seen in 6, density 1.3
2003	Quatsap Pt. and Misery Pt., Potlatch State Park	63 surveys, fish seen in 1, density 3
2004	Dabob Bay	19 surveys, fish seen in 1, density 2
2004	Quatsap Pt. and Misery Pt., Potlatch State Park	72 surveys, fish seen in 2, density 1
2004	Vashon Island	29 surveys, fish seen in 1, density 1
2005	Dabob Bay	13 surveys, fish seen in 6, density 1.3
2005	West Seattle area	44 surveys, fish seen in 1, density 2
2006	Dabob Bay	38 surveys, fish seen in 1, density 1
2006	Quatsap Pt. and Misery Pt., Potlatch State Park	99 surveys, fish seen in 4, density 2
2007	Quatsap Pt. and Misery Pt., Potlatch State Park	135 surveys, fish seen in 3, density 2
2007	Whidbey Island	150 surveys, fish seen in 2, density 2
2007	Tacoma area	207 surveys, fish seen in 3, density 1
2008	Dabob Bay	44 surveys, fish seen in 6, density 1.5

China rockfish from NGO REEF (www.reef.org) database, minimum of 1 fish

1998	Bainbridge Island	20 surveys, fish seen in 1, density 1
1999	San Juan Is. (including Henry)	1 survey, fish seen in 1, density 2
1999	Hood Head–Dungeness Bay	31 surveys, fish seen in 1, density 3
2000	Hood Head–Dungeness Bay	18 surveys, fish seen in 1, density 2
2001	Vashon Island	16 surveys, fish seen in 2, density 1
2001	Tacoma area	56 surveys, fish seen in 2, density 1
2002	Hood Head–Dungeness Bay	15 surveys, fish seen in 1, density 3
2003	Vashon Island	17 surveys, fish seen in 2, density 2
2004	Port Susan and Possession Sound	21 surveys, fish seen in 2, density 1
2005	Orcas Island	33 surveys, fish seen in 1, density 2
2006	Orcas Island	95 surveys, fish seen in 3, density 2.3
2006	Quatsap Pt. and Misery Pt., Potlatch State Park	99 surveys, fish seen in 1, density 3
2007	Port Susan and Possession Sound	21 surveys, fish seen in 1, density 3
2007	Bainbridge Island	15 surveys, fish seen in 1, density 2

Tiger rockfish from NGO REEF (www.reef.org) database, minimum of 1 fish

1998	Orcas Island	3 surveys, fish seen in 2, density 1.5
1998	Lopez Island	14 surveys, fish seen in 1, density 1
1999	Edmonds	46 surveys, fish seen in 1, density 2
2000	Orcas Island	3 surveys, fish seen in 1, density 2
2001	Orcas Island	9 surveys, fish seen in 1, density 1
2001	Tacoma area	56 surveys, fish seen in 1, density 1
2001	Kitsap Peninsula, Port Gamble–Gig Harbor (includes Poulsbo and Bremerton)	18 surveys, fish seen in 1, density 2
2002	Orcas Island	8 surveys, fish seen in 2, density 2
2002	San Juan Is. (including Henry)	33 surveys, fish seen in 1, density 1
2004	Orcas Island	32 surveys, fish seen in 7, density 1.7
2004	San Juan Is. (including Henry)	22 surveys, fish seen in 2, density 1.5
2005	Orcas Island	33 surveys, fish seen in 2, density 1
2005	Shaw Island	1 survey, fish seen in 1, density 1
2005	Quatsap Pt. and Misery Pt., Potlatch State Park	36 surveys, fish seen in 2, density 2
2006	Orcas Island	95 surveys, fish seen in 6, density 2
2006	Shaw Island	9 surveys, fish seen in 4, density 1
2006	Stuart Island and Speiden Island (including Jones and Flattop)	3 surveys, fish seen in 1, density 1
2007	Orcas Island	37 surveys, fish seen in 6, density 1.5
2008	Orcas Island	26 surveys, fish seen in 1, density 1
2008	Whidbey Island	157 surveys, fish seen in 1, density 1
2008	Dungeness Bay–Kydaka Pt.	40 surveys, fish seen in 3, density 1

Yelloweye rockfish from NGO REEF (www.reef.org) database, minimum of 1 fish

1998	Edmonds	53 surveys, fish seen in 1, density 1
2001	Vashon Island	16 surveys, fish seen in 2, density 2
2002	Edmonds	102 surveys, fish seen in 1, density 1
2003	Dabob Bay	57 surveys, fish seen in 3, density 1.7
2004	Orcas Island	32 surveys, fish seen in 2, density 1
2004	Dabob Bay	19 surveys, fish seen in 1, density 2
2004	Quatsap Pt. and Misery Pt., Potlatch State Park	72 surveys, fish seen in 3, density 1.3
2004	Whidbey Island	72 surveys, fish seen in 1, density 1
2005	Dabob Bay	13 surveys, fish seen in 2, density 1
2006	Orcas Island	95 surveys, fish seen in 4, density 2
2006	Whidbey Island	58 surveys, fish seen in 2, density 1.5
2006	Edmonds	11 surveys, fish seen in 1, density 1
2007	Orcas Island	37 surveys, fish seen in 2, density 1.5
2007	Cypress Island	21 surveys, fish seen in 2, density 1
2007	Dabob Bay	51 surveys, fish seen in 1, density 1
2007	Whidbey Island	150 surveys, fish seen in 4, density 1.8
2008	Decatur	7 surveys, fish seen in 1, density 1
2008	Whidbey Island	157 surveys, fish seen in 1, density 1
2008	Port Susan and Possession Sound	11 surveys, fish seen in 1, density 1
2008	Dungeness Bay–Kydaka Pt.	40 surveys, fish seen in 1, density 2

June Washington Department of Fish and Wildlife Letter

June 22, 2009

Garth Griffin
Chief, Protected Resources Division
National Marine Fisheries Service
1201 NE Lloyd Boulevard
Suite 1100
Portland, Oregon 97232

Dear Mr. Griffin:

After analysis of the April 23rd 2009 federal register notice (74 FR 18516) and associated status report (NMFS 2008), the Washington Department of Fish & Wildlife (WDFW) concurs with the not warranted status for greenstriped rockfish (*Sebastes elongatus*) and redstripe rockfish (*S. proriger*). We also agree with the proposed threatened listings of Georgia Basin DPS canary rockfish (*S. pinniger*) and Georgia Basin DPS yelloweye (*S. ruberrimus*). However we question the proposed endangered listing of bocaccio (*S. paucispinis*) and request you consider listing this species as threatened. We request this change for bocaccio due to lack of information regarding the species in Puget Sound and to be consistent with our own evaluation of the stock status of this species, Palsson et al. (*DRAFT* 2009). The WDFW appreciates the opportunity to elaborate and comment upon six areas in the Federal Register notice (FRN): 1) DPS conclusions, 2) trends in abundance, 3) overutilization for commercial and recreational purposes, 4) present or threatened destruction, modification, or curtailment of habitat, 5) inadequacy of existing regulatory mechanisms, and 6) efforts to protect rockfish in Puget Sound. We will limit our comments to the three species that are proposed for listing—bocaccio, canary rockfish, and yelloweye rockfish.

DPS Conclusions

Two vexing questions exist regarding the proposed rockfish DPSs: 1) do sufficient data exist for the determination of the appropriate DPS for bocaccio, canary, and yelloweye rockfish; and 2) can assumptions be made from other species where data exist.

1) Do sufficient data exist?

Given the specifics outlined in the petition to list bocaccio, canary rockfish, and yelloweye rockfish in Puget Sound, the Biological Review Team (BRT) developed an appropriate set of possible DPS scenarios. These scenarios fall into two categories: 1) DPSs at varying geographic scales within Puget Sound and Georgia Basin differentiated from coastal DPS(s) (Scenarios 1–3) and 2) a single DPS inclusive of Puget Sound, Georgia Basin, and Washington Coast (Scenario 4). The BRT review determined there was a lack of appropriate information, especially population genetic data, to adequately evaluate population structure for these three petitioned rockfish species, stating "it is not possible to make broad statements about the patterns of radiation and divergence" among rockfish species. More specifically, known population differentiation patterns within rockfish species do not appear to fall consistently within phylogenetic clades, ecological groups, or among species occurring within similar oceanographic features. However, we emphasize the importance of the single-DPS hypothesis for the protection and recovery of these species, and urge that the hypothesis be further vetted prior to the final listing decision. We further urge NMFS to renew attempts to locate existing tissue for genetic analysis, confer with regional management and academic authorities, and conduct a thorough literature search prior to making a final listing decision.

2) Can assumptions be made from other species?

Genetic data from five rockfish populations within Puget Sound, Georgia Basin, or Queen Charlotte Islands exists: the three *Pteropodus* species considered by NMFS in 2001 (copper, brown, and quillback rockfish; all within Puget Sound), Pacific ocean perch (Queen Charlotte Islands), and yelloweye rockfish (Georgia Basin). Based on genetic analyses, each species showed differentiation between populations within the restricted waters of Puget Sound, Georgia Basin, or Queen Charlotte Islands and outer coast populations. With the exception of the *Pteropodus* species, these species are not closely related and do not share similar life histories or distributions. However, their occurrence in isolated waters, such as Puget Sound, and the differentiation of these isolated populations from other populations do suggest that the physical environment within Puget Sound and Georgia Basin may restrict gene flow in and out of the Puget Sound/Georgia Basin areas. There is, however, information from other life history research that suggests other modes of distribution and dispersal exist among rockfish occurring in Puget Sound. Eleven of the 28 species of rockfish recorded in Puget Sound have only been observed five times or less until 1980. The BRT presumes that all rockfish within Puget Sound form an inland DPS implying these rare records each constitute a unique DPS. It is more likely that these species stray into Puget Sound from coastal waters. Recent occurrence patterns of vermilion rockfish, which were not known from Puget Sound prior to 1980 (Miller and Borton 1980), demonstrate that intrusions from coastal waters dynamically influence species compositions. Yellowtail rockfish appear to only occur as juveniles in the San Juan Islands with subsequent dispersal of adults to coastal waters (Barker 1979). More recent observations of rockfish recruitment confirm that postlarval copper, quillback, and brown rockfish are self-sustaining populations within Puget Sound Proper, but that black and yellowtail rockfish may recruit to Puget Sound Proper as yearlings from adjacent northern waters. Additionally, whether bocaccio and canary rockfish constitute self-sustaining populations may be questionable. Their early life stages have not been confirmed in Puget Sound (Garrison and Miller 1982) and their documented occurrence in Puget Sound Proper is restricted to less than 24 locations, compared to hundreds of records for copper, quillback, and brown rockfish (Washington 1977, Miller and Borton 1980). Evidence that the species occur as self-sustaining populations within Puget Sound is based upon multiple size classes. The occurrence of multiple size classes could equally be explained by success and sporadic recruitment events from coastal waters. Within these hypotheses, assumptions, and patterns is a lack of data to resolve them. The WDFW supports further research and monitoring to remedy this data gap. Recognizing the lack of direct data, the WDFW agrees with the BRT’s selection of Scenario 3 for the Georgia Basin DPS as most likely for bocaccio, canary, and yelloweye rockfish. That yelloweye rockfish, a demersal species as an adult, shows isolation between British Columbian inland and coastal populations is strong evidence that precautionary approaches are warranted, and we believe Scenario 3 to be the most precautionary DPS designation.

Trends in Abundance

The WDFW concurs with the general population trend analyses for the three proposed species. These patterns generally follow those of Palsson et al. (*DRAFT* 2009) that canary, yelloweye, and bocaccio rockfish were generally more common in early time series of species compositions and that catch rates and relative abundances of rockfish have declined. The WDFW cautions that early species identifications may reflect the difficulty of identifying rockfish by lay observers or untrained samplers. One new piece of information shows promising evidence that yelloweye rockfish are not rare. In a recent region-wide survey of shallow and deepwater rocky habitats in the San Juan Islands, yelloweye rockfish were observed in 7% of 207 ROV transects (WDFW, unpublished data). These data are being processed and will result in population estimates for yelloweye rockfish in this region. The use of the ROV has been successful in Puget Sound and offers a great potential to assess and monitor shallow and deepwater species in inland marine waters (Pacunski et al. 2008).

The WDFW requests two corrections in the FRN. There is a significant misspelling regarding bocaccio found on page 18521. The statement that "89%" of the recreational rockfish catch in the late 1970s consisted of bocaccio should read as 8–9%. This statement was attributed to Palsson et al. (2008) but these authors did not make this statement. The draft BRT report by Drake et al. (2008) should be credited with this statement that was drawn from dated Washington Department of Fisheries (WDF) Sport Catch Reports.

Overutilization for Commercial, Recreational, Scientific, or Educational Purposes

The WDFW concurs with the conclusion that overutilization for commercial and recreational purposes is the most severe threat to petitioned rockfish in the Georgia Basin (74 FR 18534). The WDFW acknowledges that past fisheries have contributed to the decline of bocaccio, canary, and yelloweye rockfish. In recognition of the impact fishing has had on the proposed species, the WDFW has taken action to reduce fishing pressure on these three rockfish and other rockfish species in Puget Sound. From 1982 to 2001, the WDFW reduced the daily bag limit to one rockfish (for Puget Sound and the Strait of Juan de Fuca east of Slip Point) with the regulation of no retention for canary and yelloweye rockfish in recreational rockfish fisheries. The fishing season is scheduled from May 1 to September 30 for marine areas 5, 6, 7, and 9; only during the lingcod and salmon fishing season in marine areas 8, 10, 11, and 13; and is closed year-round in marine area 12. According to the WDFW's current catch records, very little landings of any of the three rockfish species proposed for listing occur in state managed fisheries in Puget Sound. Current harvest levels of these three species in Puget Sound are very low.

Present or Threatened Destruction, Modification, or Curtailment of Habitat or Range

The BRT identified habitat destruction as a threat to petitioned rockfish (71 FR 18533). In particular, loss of rocky habitat, loss of eelgrass and kelp, introduction of nonnative species that modify habitat, and degradation of water quality were identified as specific threats to rockfish habitat in the Georgia Basin. Palsson et al. (*DRAFT* 2009) does not indicate that loss of rocky habitat has occurred. However, the habitat may be degraded due to the presence of derelict fishing gear or impaired water quality. The impact of hypoxia as a risk to the petitioned rockfish in southern Puget Sound may be overstated in that historical documented occurrences of canary, bocaccio, and yelloweye rockfish do not correspond to areas of poor water quality in southern Puget Sound. It is unclear if these species utilized these habitats prior to their degradation. Furthermore, these species have not been observed during recent massive fish kills in southern Hood Canal (Palsson et al. 2008).

The FRN adequately characterizes what is known and not known regarding the impact or threat of toxic contaminants on the proposed rockfish species. The WDFW agrees with the reasonable conclusions regarding the potential for health impacts on these species using what is known regarding exposure of closely related rockfish. In addition, the WDFW agrees with the reasonable conclusions regarding potential reproductive impacts on rockfish using results from nonrockfish species. In particular, the FRN recognizes that urban areas have become *de facto* no-take zones for some species of rockfish (e.g., *S. maliger*, *S. caurinus*, and *S. auriculatus*), and where greatest exposure to toxics occurs. If reproductive potential of recovering populations is concentrated in urban areas, the FRN reasonably concludes that toxics could impede recovery. However, it should be noted that although other rockfish species are common in the WDFW's toxics-monitoring surveys of Puget Sound urban waters, none of the three species proposed have ever been recorded in our toxics-monitoring surveys in urban waters.

The previous paragraph describes potential exposure patterns for benthic feeding rockfish in urban areas, however the FRN review indicates that all three petitioned species appear to rely to some degree on pelagic prey. If pelagic prey dominate the diet of a petitioned species, it may experience greater exposure to persistent bioaccumulative toxics (PBTs) across a greater spatial range (not just urban areas). Pelagic prey such as Pacific herring in Puget Sound have unusually high body burdens of PBTs (West et al. 2008); these PBTs biomagnify in their predators (e.g., Chinook salmon, see O'Neill and West 2009). Long life span and residency in Puget Sound, both characteristics of the three petitioned rockfish species, increase the risk of exposure. In addition, environmental levels of legacy PBTs such as polychlorinated biphenyls were probably higher in Puget Sound's pelagic species in the 1970s and 80s (West and O'Neill 2007), the period when the petitioned species declined. If petitioned species consume herring or similar pelagic prey, we believe that PBT contamination may have played a role in their decline, and is a risk factor for their recovery.

Inadequacy of Existing Regulatory Mechanisms

The WDFW is currently assessing and addressing limiting factors to Puget Sound rockfish, including fishing impacts, in the "Puget Sound Rockfish Conservation Plan" (WDFW, *DRAFT* 2009) through the State Environmental Protection Act (SEPA) process, scheduled for completion in December 2009. The WDFW encourages the National Marine Fisheries Service (NMFS) to review the plan after adoption, to inform their listing decision prior to making a final determination on the status of these three rockfish species.

Efforts Being Made to Protect Rockfish Habitat in Puget Sound and the Georgia Basin

In the FRN, pages 18537–38, a number of habitat protection actions are identified. However, this section omits habitat protection programs that are undertaken by the state regulatory agencies. The statutory owner of aquatic lands is the Department of Natural Resources. This agency has a number of strategies to protect seafloor habitats and has created a system of aquatic reserves. The WDFW has a systematic protection process to preserve the habitat of fish and wildlife species as implemented through the Hydraulic Permit Approval (HPA) process (see http://wdfw.wa.gov/hab/phslist.htm) and the Priority Habitats and Species (PHS) Program (see http://wdfw.wa.gov/habitat/permits_regs.html). The impacts of proposed construction projects in marine waters on rockfish and other species are evaluated through these programs and offer a conservation framework for habitat management. Additionally, WDFW has implemented a system of marine reserves that include habitats of the proposed species.

Summary Recommendations

- The WDFW concurs with the proposed not warranted status for greenstriped and redstripe rockfish and the proposal to list canary and yelloweye rockfish as threatened in the Puget Sound/Georgia Basin DPS.
- The WDFW strongly recommends that NMFS consider revaluating the proposed endangered status of bocaccio rockfish and recommend a threatened listing.
- Recognizing the lack of data, the WDFW agrees with the BRT's selection of Scenario 3 Georgia Basin DPS as most likely for bocaccio, canary rockfish, and yelloweye rockfish. Clarification of the DPS boundaries for each species would fulfill the most important information gap. Incorrect specification of the boundaries could negate any recovery efforts and increase risk to each of the stocks. Suggested research would focus on genetic studies, stable isotope studies, tagging, or a combination.
- The WDFW requests two corrections in the FRN. The statement that "89%" of the recreational rockfish catch in the late 1970s consisted of bocaccio should read as 8–9% and be attributed to the draft BRT report by Drake et al. (2008).
- The WDFW agrees with the BRT's identification of habitat degradation as a threat to petitioned rockfish (71 FR 18533). The WDFW agrees with the FRN conclusions regarding the potential of contaminant impacts on the health and reproduction of rockfish species as a risk factor. However, it should be noted that although some rockfish species are common in the WDFW's toxics-monitoring surveys of Puget Sound urban waters, canary, yelloweye, or bocaccio rockfish have never been recorded in our toxics-monitoring surveys.
- The WDFW concurs that historic fishing levels have contributed to the current low abundance levels of the proposed species. Decreasing and eliminating limiting factors upon rockfish are underway through measures proposed in the WDFW "Puget Sound Rockfish Conservation Plan." The WDFW intends to complete the conservation plan by 2009.
- Habitat protection actions on the part of state regulatory agencies are omitted in the FRN, including protection of seafloor habitats and establishment of aquatic reserves through the Department of Natural Resources, and protection of habitat for fish and wildlife species implemented through the Hydraulic Permit Approval (HPA) process and Priority Habitats and Species (PHS) program through the WDFW.

The WDFW is strongly committed to protecting and enhancing rockfish populations. We look forward to the opportunity to develop and/or comment on the proposed protective regulations and critical habitat designations in the event bocaccio, canary rockfish, and/or yelloweye rockfish are listed. The WDFW will continue to assist NMFS staff if additional data is requested during the review process. The WDFW would be happy to provide a copy of the Puget Sound Rockfish Conservation Plan upon approval December 2009.

Please feel free to contact Wayne Palsson, Groundfish Research Scientist (425-379-2313, Wayne.Palsson@dfw.wa.gov); Greg Bargmann, Marine Ecosystem Manager (360-902-2825, Gregory.Bargmann@dfw.wa.gov); or Mitch Dennis, WDFW ESA Response Unit Biologist (360-902-2654, Mitchell.Dennis@dfw.wa.gov) with any questions. Thank you for the opportunity to comment on the proposed listing of Georgia Basin DPSs for bocaccio, canary rockfish, and yelloweye rockfish.

Sincerely,

/s/ Philip Anderson
Interim Director

cc: Jim Scott, WDFW
Jo Wadsworth, WDFW
Craig Burley, WDFW
Greg Bargmann, WDFW
Craig Busack, WDFW
Mitch Dennis, WDFW
Wayne Palsson, WDFW
Ken Warheit, WDFW
Jim West, WDFW
Amilee Wilson. WDFW

Literature Cited

Barker, M. W. 1979. Population and fishery dynamics of recreationally exploited marine bottomfish of northern Puget Sound. Doctoral dissertation. Univ. Washington, Seattle.

Drake et al. 2008. Draft preliminary scientific conclusions of the review of the status of 5 species of rockfish: Bocaccio (*Sebastes paucispinis*), canary rockfish (*Sebastes pinniger*), yelloweye rockfish (*Sebastes ruberrimus*), greenstriped rockfish (*Sebastes elongatus*) and redstripe rockfish (*Sebastes proriger*) in Puget Sound, Washington. NWFSC, Seattle.

Garrison, K. J., and B. S. Miller. 1982. Review of the early life history of Puget Sound fishes. Univ. Washington, School of Fisheries Research Institute, Seattle.

Miller, B. S., and S. F. Borton. 1980. Geographical distribution of Puget Sound fishes: Maps and data source sheets. Univ. Washington, School of Fisheries Research Institute, Seattle.

National Marine Fisheries Service. 2001. Status review of copper rockfish (*Sebastes caurinus*), quillback rockfish (*S. maliger*), and brown rockfish (*S. auriculatus*) in Puget Sound, Washington. NOAA Technical Memorandum NMFS-NWFSC-46. NWFSC, Seattle.

O'Neill, S. M., and J. E. West. 2009. Marine distribution, life history traits, and the accumulation of polychlorinated biphenyls in Chinook salmon from Puget Sound, Washington. Transactions of the American Fisheries Society 138(3):616–632.

Pacunski, R. E., W. A. Palsson, H. G. Greene, and D. R. Gunderson. 2008. Conducting visual surveys with a small ROV in shallow water. *In* J. R. Reynolds and H. G. Greene (eds.), Marine habitat mapping technology for Alaska, p. 109–128. Alaska Sea Grant Program, AK-SG-08-03.

Palsson, W. A., R. E. Pacunski, T. R. Parra, and J. Beam. 2008. The effects of hypoxia on marine fish populations in southern Hood Canal, Washington. *In* K. D. McLaughlin (ed.), Mitigating natural disasters in fisheries ecosystems, p. 255–280. American Fisheries Society, Symposium 64, Bethesda, MD.

Palsson, W. A., T. S. Tsou, G. G. Bargmann, R. M. Buckley, J. E. West, M. L. Mills, Y. K. Cheng, and R. E. Pacunski. 2009. DRAFT—The Biology and assessment of rockfish in Puget Sound. Washington Dept. Fish and Wildlife, Olympia.

Washington, P. M. 1977. Recreationally important marine fishes of Puget Sound, Washington. NOAA/NMFS Northwest and Alaska Fisheries Center Processed Report.

WDFW. 2009. DRAFT—WDFW Puget Sound Rockfish Conservation Plan. Washington Dept. Fish and Wildlife, Olympia.

West, J. E., and S. M. O’Neill. 2007. Thirty years of persistent bioaccumulative toxics in Puget Sound: Time trends of PCBs and PBDE flame retardants in three fish species. Online at http://www.engr.washington.edu/epp/psgb/2007psgb/2007proceedings/papers/12E_West.pdf.

West, J. E., S. M. O’Neill, and G. M. Ylitalo. 2008. Spatial extent, magnitude, and patterns of persistent organochlorine pollutants in Pacific herring (*Clupea pallasii*) populations in the Puget Sound (USA) and Strait of Georgia (Canada). Science of the Total Environment 394(2–3):369–378.

December Washington Department of Fish and Wildlife Letter

December 14, 2009

Ms. Donna Darm
Assistant Regional Administrator
Protected Resources Division
National Marine Fisheries Service
7600 Sand Point Way N.E.
Seattle, Washington 98115

Dear Ms. Darm:

The Washington Department of Fish and Wildlife (Department) provided comments in our letter of June 22, 2009, on the proposed listing of bocaccio, canary, and yelloweye rockfishes in Puget Sound. In that letter, we agreed with the Biological Review Team's (BRT) designation of a distinct population segment for bocaccio east of Port Angeles, but requested that bocaccio be considered threatened and not endangered as proposed by the National Oceanic and Atmospheric Administration (NOAA).

New analysis conducted by NOAA has recently come to light that raises substantive questions about the BRT's conclusions (and ours) on the population structure of bocaccio along the Pacific Coast and Puget Sound. In addition, the further examination and clarification of information casts further doubt on whether bocaccio is a viable population in Puget Sound.

We now suggest that bocaccio be considered a Species of Concern rather than a threatened or endangered species under the terms of the Endangered Species Act. It is our understanding that a previous status review identified a southern and a northern distinct population segment (DPS), and that the southern DPS was classified as a Species of Concern after the completion of a status review (67 FR69704 November 18, 2002). We believe that extension of the Species of Concern to the northern DPS is appropriate given the lack of scientific information on bocaccio in Puget Sound and the protective measures that will be put in place for all rockfish in Puget Sound.

In our letter of June 22, 2009, the Department agreed with the BRT's selection of Scenario 3 for the Georgia Basin distinct population segment (DPS) as the most likely DPS for bocaccio, canary, and yelloweye rockfish. We came to this conclusion in the same manner as the BRT. Lacking sufficient genetic data for these three species in Puget Sound, we used: 1) published data for these species in areas outside Puget Sound and 2) comparative data from other species both within and outside the Georgia Basin (including Puget Sound). Given the paucity of genetic data, especially for populations within Puget Sound, we agreed with the BRT that Scenario 3 was the most precautionary DPS designation. The Department still adheres to this opinion as it relates to the canary and yelloweye rockfish. However, we are now concerned that the comparative approach used to select a Georgia Basin DPS for bocaccio is wanting, especially in light of NOAA's August 2009 reanalysis of the Matala et al. (2004)[1] data (Field et al. 2009).[2]

The Department supported a Georgia Basin DPS for bocaccio if the species demonstrated a propensity for spatial structuring of its populations. Matala et al. (2004) provided data and analyses that suggested spatial structuring for bocaccio, and the existence of at least three population-groups (Queen Charlotte Island; Vancouver Island to north of Point Conception, California; and south of Point Conception, including Baja California), with boundaries defined by oceanographic features.

However, Field et al. (2009) presented a reanalysis of the Matala et al. (2004) data and showed, using a Bayesian clustering method (program STRUCTURE), that the bocaccio populations studied by Matala et al. (2004) were not geographically structured, and from a genetic perspective the populations appears to be panmictic or unstructured.[3] Wishard et al. (1980) also showed no spatial structuring for chilipepper rockfish, a close relative of bocaccio.

If bocaccio is not spatially structured, it would be one of the few North Pacific *Sebastes* species whose populations do not respond structurally to geographic distances or oceanographic features (Berntson and Moran 2009).[4] Another of these species is the Mexican rockfish, with populations on either side of Baja California, and shows no spatial structuring (Bernardi et al. 2003).[5] The Gulf of California is an inland water body with oceanographic features distinct from the outer Pacific coast. The Mexican rockfish situation parallels that of bocaccio but contrasts with Scenario 3 established by the BRT for bocaccio.

The BRT also used length frequency data to support the conclusion of a bocaccio DPS in the Georgia Basin. The BRT inferred that bocaccio was a viable population in the DPS based upon the presence of multiple modes in the length frequency distributions compiled from measurements of fish caught in the recreational fishery. In the draft Predecisional Document (BRT, December 3, 2008) the BRT states:

> "In particular, examination of the available size frequency data (discussed below) indicated the existence of multiple year classes spread out over the available time series, a pattern which does not appear to be consistent with a single rare recruitment event from the coastal population. These data also revealed the presence of individuals large enough to be sexually mature (Figure 14). Finally,

---

[1] Matala, A. P., A. K. Gray, A. J. Gharrett, and M. S. Love. 2004. Microsatellite variation indicates population genetic structure of bocaccio. N. Am. J. Fish. Manag. 24:1189–1202.

[2] Field, J. C., E. J. Dick, D. Pearson, and A. D. MacCall. 2009. Status of bocaccio, *Sebastes paucispinis*, in the Conception, Monterey, and Eureka INPFC areas for 2009. Post-STAR Panel, pre-SSC review draft. [Disclaimer on document: This information is distributed solely for the purpose of predissemination peer review under applicable information quality guidelines. It has not been formally disseminated by NOAA Fisheries. It does not represent and should not be construed to represent any agency determination or policy].

[3] The STRUCTURE analysis was conducted by D. E. Pearse, FED/SWFSC, and was cited as a personal communication.

[4] Berntson, E. A., and P. Moran. 2009. The utility and limitations of genetic data for stock identification and management of North Pacific rockfish (*Sebastes* spp.). Rev. Fish Biol. Fish. 19:233–247.

[5] Bernardi, G., L. Findley, and A. Rocha-Olivares. 2003. Vicariance and dispersal across Baja California in disjunct marine fish populations. Evolution 57:1599–1609.

> the BRT noted that the 1999 year class, which dominated coastal bocaccio populations, was not apparent in the size frequency data in Puget Sound/Georgia Basin. The BRT interpreted this as evidence that the coastal and Puget Sound-Georgia Strait populations were not highly connected, and thus consisted of two discrete units." (Page 47)

The BRT also noted:

> "Size data suggests a cohort population structure that differs from coastal populations, and thus provides some evidence that this DPS is only weakly connected to California Current bocaccio. However, one BRT member thought that this DPS may consist of a vagrant population seeded by coastal populations." (Page 85)

and,

> "Size frequency distributions for bocaccio in the 1970s indicate a wide range of sizes, with recreationally caught individuals from 25 to 85 cm. Although the distribution is clearly bimodal, some individuals in every 5 cm class are represented. This broad size distribution suggests a spread of ages, with some successful recruitment over many years. A similar range of sizes is also evident in the 1980s. These patterns are more likely to result from a self-sustaining population within the Puget Sound/Georgia Basin DPS rather than sporadic immigration from coastal populations. The temporal trend in size distributions for bocaccio also suggests size truncation of the population, with larger fish becoming less common over time. By the decade of the 2000s, no bocaccio data were available, so the BRT was not able to determine if the size truncation continued in this decade." (Page 87)

We disagree with the BRT that the continuity of length frequency observations among 5-cm size classes supports the conclusion that successful recruitment is occurring in Puget Sound and that the presence of sexually mature individuals and many size (age) classes supports a viable population in Puget Sound. While mature individuals have been present in Puget Sound, multiple size classes could still result from sporadic, but not rare, recruitment from the coastal population. The BRT chose to group the small number of observations into decadal compilations of size frequencies. However, when individual years are plotted, the continuity among size ranges is not obvious. When the size data are pooled, the size ranges appear to be continuous which would be suggestive of continuous recruitment (Figure 1). Alternatively, when examining the individual years, though the data are limited, there is no continuity in size classes; and the growth of an individual cohort is suggested between 1980 and 1982 and to 1985 (Figures 2 to 7). The growth between one year and the next may confuse the interpretation of a pooled length frequency distribution when, in fact, the continuity is caused by growth of a strong cohort over time. One point to note is that the below data are primarily from the Marine Recreational Fisheries Statistical Survey. The data used by the BRT appears to include these data plus the data from our Biological Data System (BDS). In some years, the BDS data may have included the MRFSS data series and were augmented by occasional sampling by Department samplers. The use of the two data sets may be duplicative.

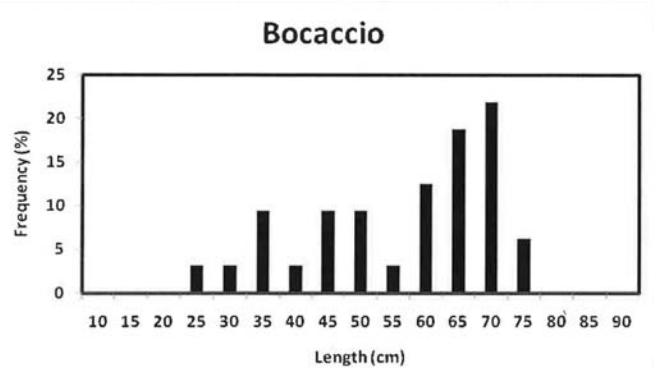


Figure 1. Pooled length frequency observations of bocaccio from trained samplers in Puget Sound, 1980–1998.

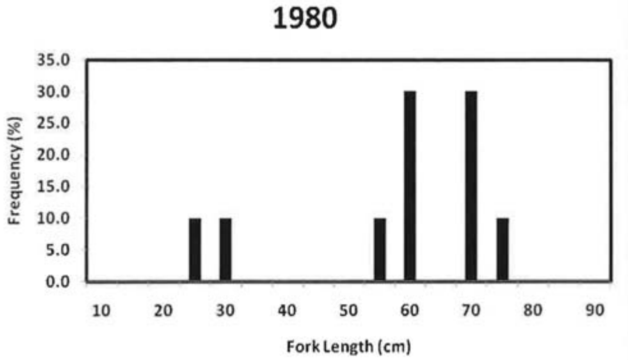


Figure 2. Individual year, 1980 length frequency observations of bocaccio from trained samplers in Puget Sound.

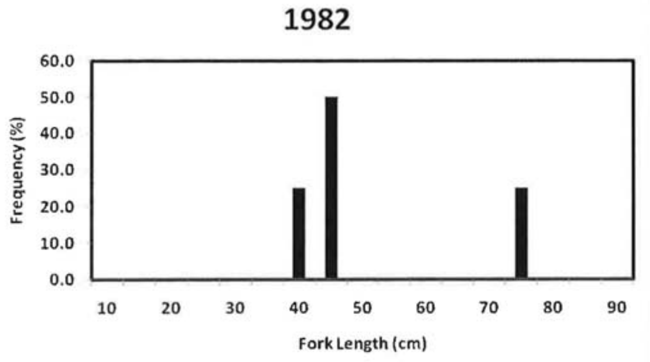


Figure 3. Individual year, 1982 length frequency observations of bocaccio from trained samplers in Puget Sound.

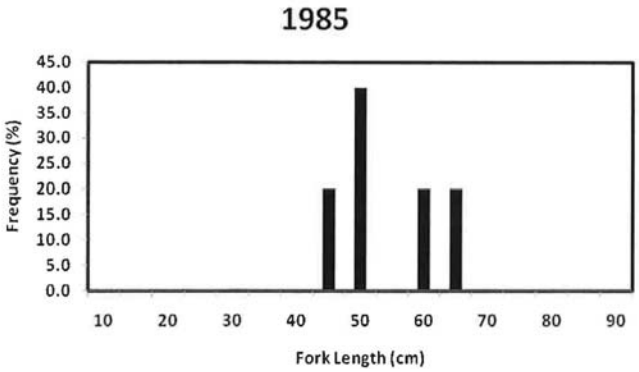


Figure 4. Individual year, 1985 length frequency observations of bocaccio from trained samplers in Puget Sound.

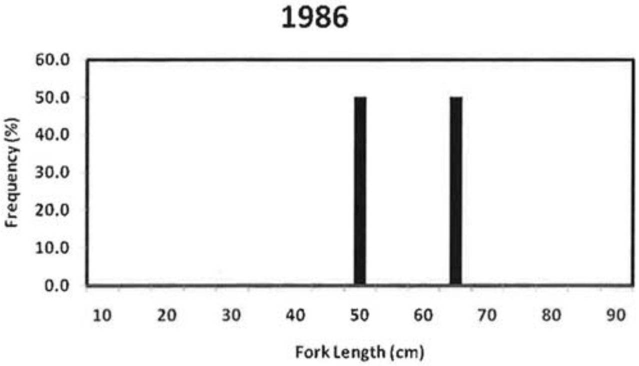


Figure 5. Individual year, 1986 length frequency observations of bocaccio from trained samplers in Puget Sound.

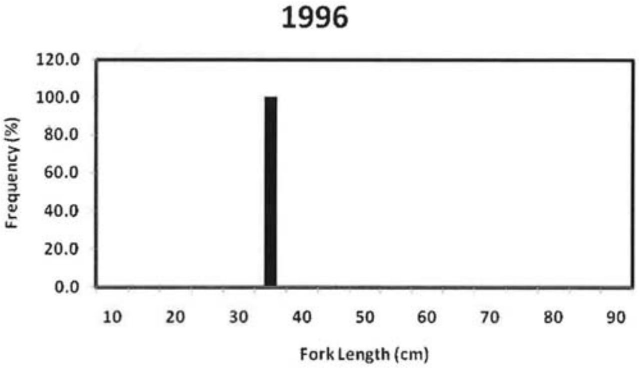


Figure 6. Individual year, 1996 length frequency observations of bocaccio from trained samplers in Puget Sound.

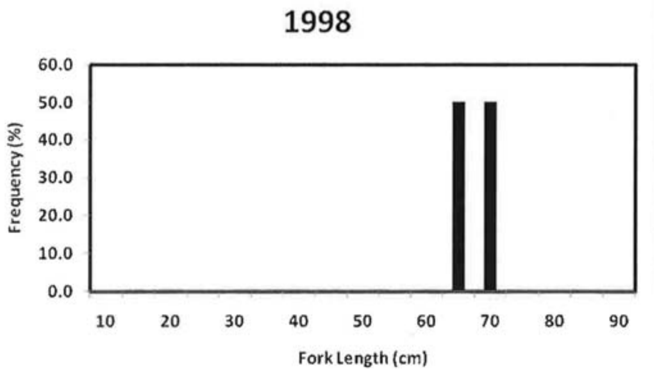


Figure 7. Individual year, 1998 length frequency observations of bocaccio from trained samplers in Puget Sound.

Further evidence of a Georgia Basin DPS, the BRT states, is that the 1999 year class that was evident on the California coast should have been evident in Puget Sound if bocaccio on the coast were a source for bocaccio in Puget Sound:

> "Finally, the BRT noted that the 1999 year class which dominated coastal bocaccio populations was not apparent in the size frequency data in Puget Sound/Georgia Basin. The BRT interpreted this as evidence that the coastal and Puget Sound-Georgia Strait populations were not highly connected, and thus consisted of two discrete units." (Page 47)

We do not agree with this conclusion. The documented 1999 strong year class was evident in the southern portion of the California Current system.[6] The presence of a strong year class in northern portions of their range has not been documented. Also not documented is the relationship between coastal recruitment events and possible recruitment into Puget Sound given dependencies such as climate, ocean currents, and fish behavior. In all, we feel the reliance on length frequency information and the analysis does not provide any support for the conclusion that there is a viable population of bocaccio in Puget Sound.

The absence of larvae or postsettlement of bocaccio larvae in Puget Sound is consistent with a conclusion that a viable population of bocaccio does not exist in the Georgia Basin. Early juvenile stages of juvenile bocaccio are commonly observed in nearshore waters of California,[7] yet despite SCUBA, beach seine, bottom trawl, and many other surveys, early juvenile stages of bocaccio have not been detected in Puget Sound as summarized by Garrison and Miller[8] in at least 14 major studies including groundfish conducted in Puget Sound since 1977. Since 1987, the Department has conducted 4,000 bottom trawl, dive, and drop camera surveys and has not detected juvenile or adult bocaccio. We stated this view in our letter of June 22, that there is no

---

[6] MacCall, A. D. 2008. Status of bocaccio off California in 2007. Pacific Fishery Management Council Status of Stocks Document. Portland, OR.

[7] Love, M. S., J. E. Caselle, and K. Herbinson. 1998. Declines in nearshore rockfish recruitment and populations in the southern California Bight as measured by impingement rates in coastal electrical power generating stations. Fish. Bull. 96:492–501.

[8] Garrison, K. J., and B. S. Miller. 1982. Review of the early life history of Puget Sound fishes. Rep. FRI-UW-8216. University of Washington, Fisheries Research Institute, Seattle.

direct evidence that young-of-the-year (YOY) bocaccio have been detected in Puget Sound, and this corroborates the lack of a viable population of bocaccio in Puget Sound.

The ambiguity of population structure information and the lack of evidence for self-sustaining populations of bocaccio demonstrate the need to reconsider the listing of this species as endangered. We believe that NOAA's Species of Concern program is an appropriate alternative for highlighting the concerns and research needs for bocaccio. As noted by NOAA, "Species of Concern" are those species about which NOAA's National Marine Fisheries Service (NMFS) has some concerns regarding status and threats, but for which insufficient information is available to indicate a need to list the species under the Endangered Species Act (ESA). We wish to draw proactive attention and conservation action to these species. It is our understanding that bocaccio has already been identified as a Species of Concern in the southern part of their range.

The Department is currently considering strong management measures to reduce directed and unintentional fishing and other impacts on rockfish. A Puget Sound Rockfish Conservation Plan is outlining strong precautionary measures for restoration of rockfishes in Puget Sound. Companion regulations eliminating recreational rockfish harvest and prohibiting bottomfishing in depths of 120 feet and greater are being considered for adoption by the Fish and Wildlife Commission in February 2010.

We believe that bocaccio as a Species of Concern, and the strong conservation measures for rockfish will protect bocaccio in Puget Sound and provide for research to establish stock status and structure.

Sincerely,

/s/ Philip Anderson
Director

cc: Garth Griffin, NOAA Protected Resources Division
Jim Scott, Assistant Director, Fish Program

King County Department of Natural Resources and Parks Letter

From: King County Department of Natural Resources and Parks
Director's Office
King Street Center
201 South Jackson Street, Suite 700
Seattle, WA 98104-3855

June 22, 2009

Chief
Protected Resources Division, Northwest Region
National Marine Fisheries Service
1201 NE Lloyd Boulevard, Suite 1100
Portland, OR 97232

To Whom It May Concern:

I am pleased to provide King County Department of Natural Resources and Parks' formal comments on the April 23, 2009 proposal by the National Marine Fisheries Service (NMFS) to list several Distinct Population Segments (DPSs) of rockfish in the Puget Sound under the federal Endangered Species Act (ESA).

Under the direction of former King County Executive Ron Sims and current King County Executive Kurt Triplett, King County has been a leader in natural resource conservation efforts in King County and in the Puget Sound region. As a general purpose local government, King County implements a range of policies, programs and projects intended to perform the day-to-day functions of government while protecting and restoring our natural heritage. While fulfilling these responsibilities, we remain committed to the protection of species, restoration of habitat, and maintaining and improving environmental quality.

King County Programs Relevant to Rockfish Management

King County has great interest in the need to list and recover these fish given the range of our current and planned activities that will protect and restore Puget Sound. We believe the implementation of these programs will contribute to improving the health of rockfish populations. They include efforts to treat wastewater, reduce combined sewer overflows (CSOs), remediate contaminated sediments, and manage stormwater. They also include management of land use in the saltwater shoreline area around Vashon Island and the management of stormwater in unincorporated King County that eventually reaches Puget Sound via rivers and streams. These program areas are addressed in brief in the following paragraphs.

Wastewater Treatment

King County provides regional wastewater treatment services for about 1.5 million residents. As part of providing these services, King County currently operates four treatment plants, two reclaimed water facilities, four CSO treatment facilities, and several CSO outfalls. In addition, we are currently constructing a fifth treatment plant, the Brightwater Treatment Plant, in southern Snohomish County. This plant will provide a very high level of treatment and incorporate the production of reclaimed water, lessening the eventual flow of treated wastewater into the Puget Sound. The plant is anticipated to come on line in 2011 at a cost of about $1.8 billion, and its expedited implementation will be a key factor in the region's ability to maintain and improve water quality as the human population continues to grow.

King County has been implementing a CSO reduction program since 1988 to eliminate and or minimize the discharge of untreated wastewater during heavy rain. This program has encompassed several large projects to control overflows, and includes development of a long-term CSO control plan. As part of the wastewater system, King County also operates a strong pretreatment program to address toxic discharges from industries, and has piloted several take-back programs that prevent toxics from entering the wastewater treatment system in the first place.

King County is also committed to effective and targeted sediment cleanup activities in the lower Duwamish, Elliott Bay, and any other locations where we share responsibility for such cleanup. Given that rockfish can accumulate high concentrations of toxics due to their position in the food web, cleanup of contaminated sediments is likely to have positive effects on the species proposed for listing. In conjunction with other parties, we have initiated several cleanup activities and are proceeding to do more.

We believe all of these activities—investments in state of the art wastewater infrastructure, combined sewer overflow projects, and sediment cleanup projects—will provide a significant net benefit to rockfish through the water quality improvements they will likely provide. It is possible that some temporary effects on a small amount of habitat may occur during construction of some CSO facilities. We believe that through the use of best management practices these effects will be short in duration and that no permanent habitat alteration will result. In sum, the Brightwater project will eventually reduce the amount of treated effluent that is released to Puget Sound by recycling water into uses formerly requiring potable water taken from our rivers and aquifers.

Should a recovery planning process result from this listing proposal, it will be important to develop management strategies that facilitate—rather than hinder—the implementation of these projects. Moreover, these cleanup activities are and will continue to be challenged by unanticipated financial pressures. For example, state toxics control funding targeted for such activities has recently been reduced due to competing pressures for this funding. Regional ratepayers bear the significant costs of these activities, including the $1.8 billion Brightwater Treatment Plant capital investment. For this reason, it will be important to proceed expeditiously but strategically, targeting actions and resources based on careful application of the best available science.

Stormwater Management

King County has provided effective programs to manage stormwater runoff caused by land development for more than 20 years. The goal of these programs is to protect people and natural resources from damage caused by uncontrolled runoff and pollutants in stormwater. As surface water runoff, or stormwater, flows across the landscape, it typically picks up various pollutants, including pesticides, fertilizers, pet wastes, oils and metals from vehicles, and many other chemicals. These pollutants can disrupt ecosystem processes and also threaten public health. Runoff can also cause erosion, create higher peak flows and velocities in streams and rivers in winter and, because of reduced infiltration, create lower, often slower flows in summer.

Through the implementation of King County's Stormwater Management Program (SWMP) as required by the NPDES Phase I Municipal Stormwater Permit, the County is taking numerous steps that protect habitat and preserve and improve water quality. The SWMP describes the actions the County is taking to avoid, reduce, and repair damages caused by the quantity and quality of stormwater runoff. These include: reviewing development plans for stormwater controls, inspecting construction sites for erosion and sediment controls, building and retrofitting stormwater control structures, inspecting businesses for stormwater pollutant source control, preventing illicit discharges and illegal dumping, and mandating pollution-preventing controls on typical operations and maintenance activities. Development and implementation of the SWMP has brought about a new level of internal King County coordination on activities and issues related to stormwater with the goal of improving water quality in the Puget Sound region. More information regarding the SWMP can be found at http:www.kingcounty.gov/environment/wlr/stormwaterprogram.aspx.

Saltwater Shoreline Land Use Management

King County develops and implements comprehensive land use plans and regulations to manage land uses along freshwater and saltwater shorelines. Beginning in the 1970s, under direction of the Washington Shoreline Management Act (SMA), King County's Shoreline Master Program (SMP) has protected the marine shorelines along Vashon Island and the larger rivers and lakes covered by the SMA. In the 1980s King County expanded these efforts with its first Comprehensive Plan that directed growth to urban areas of the county and limited the nature and intensity of development in rural areas and where there were significant environmental resources. In the 1990s King County adopted additional regulations to specifically protect environmentally sensitive areas, such as wetlands and streams not covered by the SMA. These regulations have been updated on a regular basis, with a major update taking effect in January 2005. King County is also in the process of updating its 30-year-old SMP and expects to adopt it in 2010. Detailed information about the application of these regulations in saltwater shoreline areas can be found at these web pages:

- King County's Comprehensive Plan:
  http:www.kingcounty.gov/property/permits/codes/growth/CompPlan.aspx
- King County's current CAO:
  http:www.kingcounty.gov/property/permits/codes/CAO.aspx
- King County's current SMP:
  http:www.kingcounty.gov/shorelines

Concerns Regarding Elements of the Listing Proposal Document

We encourage greater clarity in the characterization of impacts on rockfish relative to what is presented in the Federal Register notice, given the importance of grounding potential future recovery strategies on a strong technical foundation. For example, we believe the characterization of nutrient issues and dissolved oxygen problems in Puget Sound is exceedingly broad and likely to be misinterpreted. It is clear that dissolved oxygen problems occur in certain parts of Puget Sound in certain times of the year. The extent, causes, and locations of these nutrient problems, and appropriate management actions to address them, are currently being actively investigated by the Washington Department of Ecology through a range of studies, supported by the Puget Sound Partnership. We believe it is important to highlight the variability of these problems across Puget Sound, rather than infer that they accrue uniformly. Given the variability of dissolved oxygen problems and the potentially high cost of control strategies, it is highly likely that successful control strategies will require careful targeting of activities where they will be effective.

The notice also states that in-water construction of major infrastructure projects such as sewers is presumed to be a threat to rockfish habitat. We suggest that the final listing decision document make distinctions between the potential for habitat disturbance during time-limited construction activities of any kind, and the ongoing presence and operation of essential public infrastructure which, when in operation, often has no effect on rockfish use of habitat areas.

We would also encourage the presentation of additional detail regarding the level of scientific consensus on the emerging topics of reproductive dysfunction and other sublethal affects as a result of contaminant exposure. While King County and other entities are working to better understand these effects, there is much that is unknown in this area of study. In light of the current level of uncertainty, we encourage NMFS to ensure that attribution of impacts on rockfish from contaminant exposure be based on scientifically demonstrated evidence, and to provide perspective on where advances in the science would improve our understanding of the potential for such impacts on rockfish.

Finally, we encourage specific attention during this listing decision process to the effects of climate change on the health of the rockfish populations at issue. Numerous recent studies and reports have alluded to present and future habitat and species impacts in Puget Sound from climate change. We suggest that the listing decision process incorporate direct characterization and consideration of climate change effects on rockfish.

King County Data Relevant to the Listing Proposal

King County has gathered data and completed studies that may be of interest in regards to the listing proposal, relating to the abundance, distribution, and habitat for rockfish in Puget Sound. We wish to make you aware of this information in the event that it may be useful in NMFS' decision processes. Such data is presented in several King County documents, including these two that we have enclosed on a CD:

- Summary report of data from trawl surveys in Elliot Bay and the Duwamish River (from the contaminated sediment cleanup activities), which may be helpful in defining critical habitat.
- Marine Habitat Report, prepared in support of the Wastewater Treatment Division's Habitat Conservation Plan and the Brightwater Outfall Siting Survey.

These two reports, in addition to several other reports relating in varying degrees to rockfish and their habitat in proximity to wastewater system activities in saltwater, can also be found at http://green.kingcounty.gov/marine/Reports.aspx. Reports found under the heading “Brightwater Marine Outfall Studies” are likely to be the most relevant to this process.

Comments Regarding Recovery Planning

Finally, while it is premature to address the specifics of recovery planning for rockfish pending the outcome of NMFS’ listing decision process, I do encourage NMFS to build on relevant regional and local habitat protection and restoration efforts that could contribute to rockfish recovery should a listing take place. I point specifically to the Puget Sound Partnership’s 2020 Action Agenda and the watershed-based salmon recovery plans. The Action Agenda likely encompasses many activities that would be important to rockfish recovery, and it represents a degree of regional and local consensus around these activities that should serve as a foundation for recovery efforts. The salmon plans similarly provide some foundation for rockfish recovery planning, from the actions they contain that could contribute to improved water quality and shoreline habitat conditions to the notion that local communities can play an important supporting role in developing and implementing recovery strategies.

The prospect of a rockfish listing under the ESA is yet another reminder that there is much work to be done in the Puget Sound region to sustain the natural resources that are integral to Pacific Northwest culture and quality of life. I extend my thanks for the opportunity to comment on this listing proposal. I look forward to hearing your agency’s conclusions about the need to afford these fish the protections of the ESA. Please feel free to contact me at (206) 296-6500 if there are questions about these comments or if additional information regarding any of the programs described here would be helpful to you.

Sincerely,

/s/ Theresa Jennings
Director

cc: The Honorable Kurt Triplett, King County Executive
Barry Thom, Acting Regional Administrator, NOAA National Marine Fisheries Service
Isabel Tinoco, Natural Resources Director, Muckleshoot Indian Tribe
Terry Williams, Natural Resources Director, Tulalip Tribes
Joe Anderson, Fisheries Director, Puyallup Tribe
Rob Purser, Fisheries Director, Suquamish Tribe
David Dicks, Executive Director, Puget Sound Partnership
Phil Anderson, Interim Director, Washington Department of Fish and Wildlife
Peter Goldmark, Washington Commissioner of Public Lands
The Honorable Dow Constantine, Chair, King County Council
The Honorable Larry Phillips, King County Councilmember

External Peer Reviews

Peer review was solicited from experts in rockfish biology and conservation biology. Six individuals agreed to provide reviews, although we only actually received four reviews. Reviewers were: Dr. Leah Gerber, Arizona State University, Tempe; Dr. Donald Gunderson, University of Washington, Seattle; Dr. Milton Love, University of California, Santa Barbara; and Dr. J. Wilson White, University of California, Davis. Reviews are provided below (in no particular order and not associated with a particular reviewer). Page references are to an earlier draft of this status review

Reviewer 1

Six factors are listed as considerations by NMFS in listing decisions. How do these differ from the five factors specified in the ESA? In general the narrative that goes with each of the six factors considered by NMFS is very general and not specific to rockfish. Maybe this is because data are lacking, but it could be condensed and focused on including key information (or mention that there are no data in each category). For example, describe trend data that are available.

Page 52 and beyond: should "absolute numbers" be "absolute abundance?" Also, how can one say anything about extinction risk without having an idea of abundance (even with wide CIs)?

Page 56: It sounds like "expert opinion" was used to rank demographic risk. This could be strengthened if a bit more attention is given to the methods in ranking criteria. Social scientists worry about things like uncertainty in how various metrics are ranked. This is not my field, but I have been scrutinized in similar endeavors. Ben Halpern and Carrie Kappell have some published approaches, and I am sure a look at the social science literature could strengthen this approach.

I am skeptical about applying a trend analysis to "total rockfish" (i.e., applying analysis to combined species). Given the paucity of data, I can see why this approach was employed, but it seems like it could be misleading if the relative trends are different among species (which seems likely).

Figure 33 legend indicates that different colors were used to show which data were treated as separate pops, but I am only seeing one color. The legend also is a little unclear (some typos), so it's hard to figure out what the figures represent. I think the figure is showing trends for combined data, which has merit because it confirms that these populations seem to be declining. But I am still hesitant about performing any kind of extinction risk analysis for combined species data for the reason mentioned above.

I realize that a lot of creative work went into these analyses, and they are really impressive given that there are so few data. The analyses certainly provide a strong basis for taking management action for these species (e.g., listing under the ESA). When you start developing a recovery plan and criteria, you could consider a more general approach that does not rely on quantitative analyses that are potentially flawed due to sparse data. A general approach would set recovery criteria and objectives independent of data in hand, and then specify that species should be listed until data are available to show recovery (i.e., a precautionary approach). It might be worthwhile to consider the recently developed white abalone recovery plan: http://www.nmfs.noaa.gov/pr/pdfs/recovery/whiteabalone.pdf.

Reviewer 2

Dear Dr. Levin,

As you requested, I have reviewed the draft ESA status review of Puget Sound rockfish. Overall, I found the status review to be soundly reasoned and to employ the best available statistical techniques and scientific interpretation to the available data on these species. I must agree with the Biological Review Team (BRT) that the data available for this type of evaluation are sorely lacking, especially in terms of genetic evidence for evaluating the DPS determinations and in terms of the abundance data available for examining population trends and extinction risk. However, it appears that the BRT has been careful in extrapolating from the available data to make conservative inferences regarding the five species in question.

At your request, I paid special attention to the evaluation of extinction risk in my review. There are two potential difficulties with this analysis. First is that abundance data for the individual species are not sufficient for independent analysis, particularly for species that historically made up a small proportion of the overall rockfish fishery, and for species that have had catch restrictions imposed and thus have no recent fishery-dependent data. The remedy for this difficulty proposed by the BRT is to analyze the long-term trend in overall rockfish abundance, recognizing that this trend is driven primarily by more abundant species but could serve as an estimate of the trend in the rarer petitioned species. Clearly this is quite a striking assumption, and any number of factors could produce violations of the assumption. However, this approach should produce a conservative estimate of the trend in the petitioned species (i.e., the actual trend is probably more negative than that identified here). Changes in gear and switches in the targeted species should tend to prolong high catch levels in a multispecies time series, so an observed decline in overall catch probably reflects steeper declines in the actual abundance of individual fishes. Furthermore, in the petitioned species for which data were available, the proportion of the overall catch appears to have declined in recent years. Provided that this does not reflect a change in the species-specific targeting of the recreational fisheries (which seems unlikely), this suggests that the multispecies data would again be an optimistic estimate of the rate of decline. One caveat should be that the overall rockfish trend should not necessarily be representative of species that are completely closed to fishing, such as canary rockfish since 2002. The BRT notes that there was not a trend for declining canary rockfish abundance since 2002 in the REEF surveys; has there been any evidence for a temporal increase in those surveys?

The second difficulty in the extinction risk analysis is the presence of multiple data sources that should have different error structures and different relationships to the overall mean abundance. The state-space model approach taken by the BRT is an excellent solution to the problem, and they appear to have chosen appropriate specifications for the model. The model fits to the data appear quite good (although considering the number of potential parameters in the model, a good fit is to be expected). My largest concern with this modeling approach is that it assumes a temporally stationary population growth rate (parameter a). This presumes that the overall rockfish "population" is either declining to extinction ($a < 0$) or rising to a non-zero steady state equilibrium (a > 0). The model is therefore constrained to identify an overall negative or positive trend in the data, and cannot represent behavior such as a decline to a minimum followed by subsequent increase. This assumption is probably reasonable for the current state of the Puget Sound rockfish community. However, if some sort of intervention were to change the demographics in the study region, such as a large-scale change in fishing regulations or environmental mitigation in response to ESA classification, this same analysis would be inappropriate for the analysis of future data sets. Rather than identifying a deterministic change in recent abundances, this type of model would fit positive observation and process error terms to those recent years. To deal with that situation, future analyses would require a temporally variable parameter a, or a three parameter model that includes an intrinsic growth parameter and an exploitation parameter. I add this comment not necessarily as a criticism of the current approach (after all, there is pretty convincing evidence for a long-term decline in Figure 36 and Figure 37, even without the model fits), but rather as a clarification that should be made for future investigators who may desire to revisit this analysis in the future.

In addition to these major comments, I had a number of specific comments that I itemize below.

Page 16: “myctophids” is misspelled.

Page 27, second paragraph: Probably better to say that eelgrass and seaweed habitat support most “species” in the sound, rather than most “populations.”

Page 38: This is a very nice explanation of the benefits of mitochondria1 DNA evidence. I recommend clarifying at some point in this discussion that microsatellites are nuclear markers.

Page 41: With respect to the comparison with other rockfish species in Puget Sound, this seems like a very reasonable approach for making inferences regarding the genetic structure of the petitioned species. I would add that, given the apparent level of development and swimming abilities of rockfish larvae and postlarvae, it is probably reasonable to err on the side of shorter rather than longer larval dispersal distances.

Page 42: It is not clear what should be made of the comparison with the nonrockfish species in the sound. Are there reasons, based on spawning behavior, spawning season, or larval life history, that the petitioned rockfish species should be more or less like any of the nonrockfish species mentioned here?

Page 45: “were” not “where.”

Page 69: Summary of methods: Rephrase as “... using a maximum likelihood approach to fit ....”

Page 70: Ward et al. 2008 and Shumway and Stoffer 2006 are missing from the references.

Page 70: To be clear, R is constant with time, and D represents fixed factors, not random variates, correct?

Page 73: What sort of model selection was used to compare the one vs. multiple population process models?

Page 76: It is reasonable to point out the importance of ontogenetic changes in fecundity, but there is no reason that those variations cannot be included in a calculation of LEP (lifetime egg production), and LEP can then be used in the standard way (comparison to a biological reference point or to the slope of the stock-recruit curve). It is correct that variation in the relationship between biomass and fecundity would invalidate the use of SSB (standing stock biomass). On the same point, is the issue of the seasonal timing of reproduction relevant to Puget Sound populations? I am only familiar with that type of argument being used in open coast populations for which the timing of spawning relative to upwelling transitions, etc. is very important.

Page 76: On the topic of LEP, I was somewhat surprised that extinction risk analysis did not incorporate some of the traditional approaches to evaluating population persistence, such as a comparison of LEP to the compensation ratio. Since the relative value of those two measures is a fundamental measure of the long-term persistence of a population, that comparison would be very useful. Are estimates of these values not available for the petitioned species?

Overall, I found this status review to be a sensible and well-reasoned analysis, given the limited data available.

Reviewer 3

I found this to be a comprehensive review of the status of the rockfish stocks in question. This was a difficult undertaking, since the review team had very little data to work with.

However, the lack of genetic studies pertinent to the species of concern led the team to generalize from what is known about other rockfish, notably the more well-studied copper, quillback, and brown rockfish. All three of these species are known to mate and spawn in Puget Sound, and to be highly restricted in their migrations as adults. Recent genetic analyses suggest that many of their larvae may drift no more than a few tens of kilometers after parturition. This is probably not the case for bocaccio or canary rockfish, and a different model is more appropriate.

Bocaccio and canary rockfish probably have a life history that is more similar to species like yellowtail or splitnose rockfish. Both have large populations in offshore waters and Puget Sound is likely a sink for larvae that drift in. While splitnose larvae are commonly found in drifting kelp mats, adults are rare throughout most of Puget Sound Proper. Most yellowtail rockfish in Puget Sound are immature, migrating to the ocean once they reach sexual maturity (see Mathews and Barker 1983, Gunderson and Vetter 2006). I am not aware of any reported mating or spawning of splitnose or yellowtail rockfish in either Puget Sound Proper or the San Juan Islands.

Without further genetic study and documentation of both mating and spawning in Puget Sound, there is no reason to suppose that the bocaccio and canary rockfish there constitute a population segment that is distinct from the ocean population. Populations within Puget Sound are more likely to be sink populations that exist only through sporadic recruitment of larvae from ocean sources.

Despite the lack of genetic analyses for yelloweye rockfish in Puget Sound Proper, the Canadian work cited (Yamanaka et al. 2006) is consistent with the existence of distinct population segments in the ocean and protected waters. However, we still have no way of knowing if the yellowtail population in Puget Sound constitutes a population segment that is distinct from fish in the Strait of Georgia. If the yellowtail in Puget Sound constitute a DPS, the teams assessment probably understates the degree to which they are at risk.

The team's analysis indicates that yelloweye rockfish were once plentiful in greater Puget Sound (Kincaid 1919). This is consistent with Yamanaka et al. 2006, who cited an 1886 report of "plentiful…large red rock cod" in the Strait of Georgia, the most abundant and highly prized being "the red cod or snapper." A century of commercial and recreational fishing on this highly prized species has taken an enormous toll on the yellowtail rockfish population, yet the review team is unable to determine the true magnitude of the decline given data that goes no further back than the 1980s. This is the "sliding baseline" phenomenon in one of its clearest manifestations.

Rather than rely on recreational catch data of uncertain reliability or bottom trawl surveys that don't target the rocky reefs inhabited by yelloweye rockfish, it would be better to estimate current population distribution and numbers directly, using ROV/camera surveys of known statistical validity. The technology for such surveys is capable of giving reliable results (Gunderson et al. 2008, Pacunski et al. 2008), and has already been employed successfully by WDFW (Palsson et al. 2008). Historic abundances could be estimated indirectly using maps of rocky habitat in the appropriate depth range and inferring the densities (number per square meter) that once occurred there. These inferences could be made using some combination of known current densities in unfished areas and anecdotal information provided by fishermen who were active in the 1950s.

[Editor's note: References for Reviewer 3's citations are as follows.]

Gunderson, D. R., A. M. Parma, R. Hilborn, J. M. Cope, D. L. Fluharty, M. L. Miller, R. D. Vetter, S. S. Heppell, and H. G. Greene. 2008. The challenge of managing nearshore rocky reef resources. Fisheries 33:172–179.

Gunderson, L. H., and R. D. Vetter. 2006. Temperate rocky reef fish. *In* J. P. Kritzer and P. F. Sale, Marine Metapopulations, p. 69–118. Elsevier, Amsterdam.

Kincaid, T. 1919. An annotated list of the Puget Sound fishes. State of Washington, Dept. Fisheries, Olympia.

Matthews, S. B., and M. W. Barker. 1983. Movements of rockfish (Sebastes) in northern Puget Sound, Washington. Fish. Bull. 82:916–922.

Pacunski, R. W., W. A. Palsson, H. G. Greene, and D. Gunderson. 2008. Conducting visual surveys with a small ROV in shallow water. *In* J. R. Reynolds and H. G. Green (eds.), Marine habitat mapping technology for Alaska. Univ. Alaska Fairbanks, Alaska Sea Grant Program.

Palsson, W. A., T.-S. Tsou, G. G. Barbman, R. M. Buckley, J. E. West, M. L. Mills, Y. W. Cheng, and R. E. Pacunski. 2008. The biology and assessment of rockfishes in Puget Sound. Washington Dept. Fish and Wildlife, Olympia.

Yamanaka, K. L., L. C. Lacko, R. Withler, C. Grandin, J. K. Lochead, J. C. Martin, N. Olsen, and S. S. Wallace. 2006. A review of yelloweye rockfish *Sebastes ruberrimus* along the Pacific coast of

Canada: Biology, distribution, and abundance trends. Research doc. 2006/076. *In* Canadian Science Advisory Secretariat, 2006.

Reviewer 4

I have gone over the draft ESA status review of Puget Sound rockfishes.

I was impressed with the thought that has gone into the process leading to the document and I think I would have come to the same conclusions.

Really, given the shortage of data on some of these species, this was the best work that one could have expected.

Appendix B: Responses to Comments and Reviews

Responses to Peer Reviews

External Reviewer 1

Comment 1

Should “absolute numbers” be “absolute abundance?”

Response

We altered the text to read absolute abundance.

Comment 2

How can one say anything about extinction risk without having an idea of abundance (even with wide CI’s [confidence intervals])?

Response

Quantitative criteria for listing species do not always rely on “risk of hitting 0 numbers.” Another criteria used is the rate of decline and an observed or projected severe decline. Examples include the International Union for the Conservation of Nature Red List risk criteria and the Alaska Fisheries Science Center listing criteria. Severe declines, 80–99%, are considered reason for high conservation concern; if such declines persist, extinction is certain. If no accurate numbers are available, one must rely on the information available, such as how often the species is observed, to form an expert opinion concerning whether the species is sparse, rare, or extremely rare.

Comment 3

It sounds like “expert opinion” was used to rank demographic risk. This could be strengthened if a bit more attention is given to the methods in ranking criteria. Social scientists worry about things like uncertainty in how various metrics are ranked. This is not my field, but I have been scrutinized in similar endeavors. Ben Halpern and Carrie Kappell have some published approaches, and I am sure a look at the social science literature could strengthen this approach.

Response

We used standard, established, and peer-reviewed methods employed by NMFS for other status reviews including salmonids (*Oncorhynchus* spp.), Pacific hake (*Merluccius productus*), walleye pollock (*Theragra chalcogramma*), Pacific cod (*Gadus macrocephalus*), Pacific herring (*Clupea pallasii*), black abalone (*Haliotis cracherodi*), and copper (*Sebastes caurinus*), quillback (*S. maliger*). and brown (*S. auriculatus*) rockfishes.

Comment 4

I am skeptical about applying a trend analysis to "total rockfish" (i.e., applying analysis to combined species). Given the paucity of data, I can see why this approach was employed, but it seems like it could be misleading if the relative trends are different among species (which seems likely).

Response

This and a similar comment by External Reviewer 2, are a misinterpretation of the approach we used. Importantly, we did not make the assumption that the total trend is an estimate of the trend in the rarer species. The logic is as follows:

N_rare(t) = (N_rare(t) / N_total(t)) × N_total(t)

If N_rare(t)/N_total(t) is constant, then the trend in N_total = the trend in N_rare.

If N_rare(t)/N_total(t) has been going down, then the rare species is going down faster than the total.

If N_rare(t)/N_total(t) has been going up, then the rare species is not going down as fast as the total.

The analysis consisted of:

1. Evaluating the trend in the total rockfish abundance using all available data and multiple ways of looking at the data
2. Evaluating the evidence that the prevalence of each rare species has been going up relative to the total (has N_rare/N_total been increasing)

We have edited the text in several places to clarify this.

Comment 5

Figure 33 [earlier draft] legend indicates that different colors were used to show which data were treated as separate populations, but I am only seeing one color. The legend also is a little unclear (some typos), so it's hard to figure out what the figures represent. I think the figure is showing trends for combined data, which has merit because it confirms that these populations seem to be declining. But I am still hesitant about performing any kind of extinction risk analysis for combined species data for the reason mentioned above.

Response

We updated the figure and text. The new legend reads as follows:

Figure 33 [earlier draft]. The different colors in the bottom panel show which data were treated as separate (but not independent) population processes. Specifically, data from the trawl survey may be sampled from a different segment of the total rockfish assemblage (age or size) than the recreational data. Thus the trawl data are treated as an independent trajectory but with the same long-term growth rate. Each process has the same long-term population growth rate (parameter a) because over the long term one segment of a population cannot have a different trend than another segment of the population. But over the short term, different population segments can certainly have different trajectories. Modeling the trawl data as its own process also allows that this segment of the population could have different process variance than the segment of the population sampled by recreational gear.

External Reviewer 2

Comment 1

I paid special attention to the evaluation of extinction risk in my review. There are two potential difficulties with this analysis. First is that abundance data for the individual species are not sufficient for independent analysis, particularly for species that historically made up a small proportion of the overall rockfish fishery, and for species that have had catch restrictions imposed and thus have no recent fishery-dependent data. The remedy for this difficulty proposed by the BRT is to analyze the long-term trend in overall rockfish abundance, recognizing that this trend is driven primarily by more abundant species but could serve as an estimate of the trend in the rarer petitioned species. Clearly this is quite a striking assumption, and any number of factors could produce violations of the assumption.

Response

As described above for External Reviewer 1, this is a misinterpretation of the methods.

In addition to clarifying the methods, we added the following text [earlier draft]:

Results—Looking at all the data available to us, we found no evidence that the petitioned species make up an increasing fraction of the total rockfish pool over time. Instead, for some species, we found evidence that the species are a smaller percentage of the "total rockfish" over time. Thus we found no evidence to suggest that the petitioned species have increased or been stable while the total rockfish abundance has declined. Instead the evidence points to some species declining faster than the total abundance.

Discussion—Because time series data on the petitioned species were not available, we could not do a direct quantitative analysis on these species. Instead we were forced to use data on total rockfish trends and trends in the species composition of the total rockfish assemblage. We recognize that the trend in total rockfish does not equal the trend in the petitioned species. However, this does not mean we had no information on trends in the petitioned species. Total rockfish abundance has declined and some of the petitioned species have become a smaller proportion of the total rockfish assemblage. This allows us to use the trends in total rockfish as an upper bound on the trends for the petitioned species. This was the approach taken in the analysis.

Comment 2

This approach should produce a conservative estimate of the trend in the petitioned species (i.e., the actual trend is probably more negative than that identified here). Changes in gear and switches in the targeted species should tend to prolong high catch levels in a multispecies time series, so an observed decline in overall catch probably reflects steeper declines in the actual abundance of individual fishes.

Response

This is a good point that we added to the text.

Comment 3

Furthermore, in the petitioned species for which data were available, the proportion of the overall catch appears to have declined in recent years. Provided that this does not reflect a change in the species-specific targeting of the recreational fisheries (which seems unlikely), this suggests that the multispecies data would again be an optimistic estimate of the rate of decline. One caveat should be that the overall rockfish trend should not necessarily be representative of species that are completely closed to fishing, such as canary rockfish since 2002. The BRT notes that there was not a trend for declining canary rockfish abundance since 2002 in the REEF (Reef Environmental Education Foundation) surveys; has there been any evidence for a temporal increase in those surveys?

Response

Several good points here, which we incorporated into the trend discussion.

Comment 4

The second difficulty in the extinction risk analysis is the presence of multiple data sources that should have different error structures and different relationships to the overall mean abundance. The state-space model approach taken by the BRT is an excellent solution to the problem, and they appear to have chosen appropriate specifications for the model. The model fits to the data appear quite good (although considering the number of potential parameters in the model, a good fit is to be expected). My largest concern with this modeling approach is that it assumes a temporally stationary population growth rate (parameter a). This presumes that the overall rockfish “population” is either declining to extinction ($a < 0$) or rising to a non-zero steady state equilibrium ($a > 0$). The model is therefore constrained to indentify an overall negative or positive trend in the data, and cannot represent behavior such as a decline to a minimum followed by subsequent increase.

Response

Given our data constraints, our risk metric was a measure of the long-term trends. Our parameter a is effectively the average population growth rate over the entire data set. The analysis does allow that there have been periods of positive population growth, but we use the long-term average population growth for forecasting and risk assessment. Although current rates of decline may be less (or more) than the long-term average, a negative long-term population growth means the current population is well below the levels seen 30–50 years ago.

Comment 5

This assumption [from the above comment] is probably reasonable for the current state of the Puget Sound rockfish community. However, if some sort of intervention were to change the demographics in the study region, such as a large scale change in fishing regulations or environmental mitigation in response to ESA classification, this same analysis would be inappropriate for the analysis of future data sets.

Response

This is a very hard question to address with variable data, and we agree with the basic premise of the question. Importantly, however, the forecasting used for petition analyses asks "if trends over the last 30 years continue …," and as this reviewer notes, one goal of ESA protection would be to ensure that past trends do not continue.

Comment 6

Rather than identifying a deterministic change in recent abundances, this type of model would fit positive observation and process error terms to those recent years. To deal with that situation, future analyses would require a temporally variable parameter a or a three parameter model that includes an intrinsic growth parameter and an exploitation parameter. I add this comment not necessarily as a criticism of the current approach (after all, there is pretty convincing evidence for a long-term decline in Figures 36 and 37, even without the model fits), but rather as a clarification that should be made for future investigators who may desire to revisit this analysis in the future.

Response

Agreed.

Comment 7

"Myctophids" is misspelled.

Response

Corrected.

Comment 8

Probably better to say that eelgrass and seaweed habitat support most "species" in the sound, rather than most "populations."

Response

Done.

Comment 9

This is a very nice explanation of the benefits of mitochondrial DNA evidence. I recommend clarifying at some point in this discussion that microsatellites are nuclear markers.

Response

Done.

Comment 10

With respect to the comparison with other rockfish species in Puget Sound, this seems like a very reasonable approach for making inferences regarding the genetic structure of the petitioned species. I would add that, given the apparent level of development and swimming abilities of rockfish larvae and postlarvae, it is probably reasonable to err on the side of shorter rather than longer larval dispersal distances.

Response

Agreed.

Comment 11

It is not clear what should be made of the comparison with the nonrockfish species in the sound. Are there reasons, based on spawning behavior, spawning season, or larval life history, that the petitioned rockfish species should be more or less like any of the nonrockfish species mentioned here?

Response

We added text to clarify this.

Comment 12

"Were" not "where."

Response

Fixed.

Comment 13

Rephrase as "using a maximum likelihood approach to fit."

Response

Done.

Comment 14

Ward et al. 2008 and Shumway and Stoffer 2006 are missing from the references.

Response

Fixed.

Comment 15

It is reasonable to point out the importance of ontogenetic changes in fecundity, but there is no reason that those variations cannot be included in a calculation of LEP, and LEP can then be used in the standard way (comparison to a biological reference point or to the slope of the stock-recruit curve). It is correct that variation in the relationship between biomass and fecundity would invalidate the use of SSB. On the same point, is the issue of the seasonal timing of reproduction relevant to Puget Sound populations? I am only familiar with that type of argument being used in open coast populations for which the timing of spawning relative to upwelling transitions, etc., is very important.

Response

We agree with the statement that calculation of LEP can be adjusted to account for ontogenetic changes in fecundity, and this is mentioned in the text.

The purpose of pointing out the importance of maternal effects here is to state that rockfish populations seem particularly sensitive to such age class truncation. We are therefore concerned not only with population decline, but also the modification of population composition.

Comment 16

On the topic of LEP, I was somewhat surprised that extinction risk analysis did not incorporate some of the traditional approaches to evaluating population persistence, such as a comparison of LEP to the compensation ratio. Since the relative value of those two measures is a fundamental measure of the long-term persistence of a population, that comparison would be very useful. Are estimates of these values not available for the petitioned species?

Response

The reviewer is correct that the necessary data were not available to the BRT.

External Reviewer 3

Comment 1

I found this to be a comprehensive review of the status of the rockfish stocks in question. This was a difficult undertaking, since the review team had very little data to work with.

However, the lack of genetic studies pertinent to the species of concern led the team to generalize from what is known about other rockfish, notably the more well-studied copper, quillback, and brown rockfish. All three of these species are known to mate and spawn in Puget Sound and to be highly restricted in their migrations as adults. Recent genetic analyses suggest that many of their larvae may drift no more than a few tens of kilometers after parturition. This is probably not the case for bocaccio (*Sebastes paucispinis*) or canary rockfish (*S. pinniger*), and a different model is more appropriate.

Response

We agree that copper, quillback, and brown rockfish may have shorter larval lives than bocaccio and canary rockfish. However, all species are subject to hydrological restrictions that certainly have a large effect on dispersal distance.

Comment 2

Bocaccio and canary rockfish probably have a life history that is more similar to species like yellowtail (*S. flavidus*) or splitnose (*S. diploproa*) rockfish. Both have large populations in offshore waters and Puget Sound is likely a sink for larvae that drift in. While splitnose larvae are commonly found in drifting kelp mats, adults are rare throughout most of Puget Sound Proper. Most yellowtail rockfish in Puget Sound are immature, migrating to the ocean once they reach sexual maturity (see Barker and Mathews 1983, Gunderson and Vetter 2006). I am not aware of any reported mating or spawning of splitnose or yellowtail rockfish in either Puget Sound Proper or the San Juan Islands.

Without further genetic study and documentation of both mating and spawning in Puget Sound, there is no reason to suppose that the bocaccio and canary rockfish there constitute a population segment that is distinct from the ocean population. Populations within Puget Sound are more likely to be sink populations that exist only through sporadic recruitment of larvae from ocean sources.

Response

The basic premise of this comment seems to be that Puget Sound represents a sink population. That is, there is no spawning of bocaccio or canary rockfish in the sound. This is certainly a valid hypothesis and did gain a minority of support in the BRT's DPS deliberations. However, the reviewer offers no direct evidence of this hypothesis for bocaccio and canary rockfish.

In the absence of direct evidence of population structure, the BRT reasoned that if Puget Sound was a sink population that is seeded with larvae from coastal populations then the age structure of Puget Sound and coastal populations should be similar. As the BRT report notes, this does not appear to be the case. In revision, the BRT expanded and clarified this analysis. In particular, the analyses shows the existence of strong year classes in Puget Sound that were absent along the coast, as well as strong coastal year classes that are missing from Puget Sound.

External Reviewer 4

Comment 1

I have gone over the draft ESA status review of Puget Sound rockfishes.

I was impressed with the thought that has gone into the process leading to the document and I think I would have come to the same conclusions.

Really, given the shortage of data on some of these species, this was the best work that one could have expected.

Response

No response needed.

Responses to Public Comments

Western States Petroleum Association

Comment 1

WSPA criticized the scientific foundations of the proposed listings.

Response

The comments of WSPA suggest that they did not fully understand the logic and rigor of the approach adopted by the BRT. As discussed above, the document has been edited to increase clarity.

As previously discussed, quantitative criteria for listing species do not always rely on “risk of hitting 0 numbers.” Another criteria used is the rate of decline and an observed or projected severe decline. The time to extinction (or functional extinction) depends on the current numbers but not whether extinction occurs.

Comment 2

WSPA also commented on the role of environmental contaminants as a factor in the species decline.

Response

We agree with WSPA that there is not conclusive evidence suggesting that water quality is a limiting factor affecting the specific species addressed by the BRT. Instead, the BRT relied on the rich body of literature that suggests that various contaminants can affect the health of many fish species. Given the impacts of contaminants on the fish species that have been investigated (including limited work on rockfish), the BRT concluded that there is a clear potential for impact. This conclusion has also been echoed by the Washington Department of Fish and Wildlife (WDFW).

Sam Wright

Comment 1

The most serious deficiency is failure to evaluate potential adverse impacts to low abundance rockfish populations due to depensation, especially the subset of depensatory mortality factors commonly known as Allee effects.

Response

Allee effects are included in the general discussion of extinction risk. This has been clarified in revision.

Comment 2

The only other serious problem is in your discussion of bycatch, where the language seems to indicate that the most serious concern is with the lingcod fishery. This is incorrect. By a wide margin, the highest bycatch mortality for rockfish occurs in the Puget Sound recreational fishery for “blackmouth.”

Response

The reference to lingcod (*Ophiodon elongatus*) has been removed and the statement regarding bycatch is now more general. The statement now reads, “Rockfish are unintentionally captured as part of fishing activities targeting other species.” This paragraph concludes by stating that bycatch of rockfish is thought to be a high impact stressor.

Comment 3

A final point concerns your discussion of releases of propagated fish, where the numbers given for salmon are incorrect. The correct numbers for Chinook salmon are 45.6 million subyearlings and 2.6 million yearlings. Ecological interactions with hatchery Chinook are discussed on pages 9 and 10 of the April 2007 petition.

Response

The figures in the BRT report now mirror those provided by WDFW, and state that hatchery releases of Chinook salmon and coho salmon (*Oncorhynchus kisutch*) averaged 21.2 million from 1983 to 2000 and have declined to around 14 million in recent years.

WDFW (22 June 2009 Letter)

Comment 1

Do sufficient data exist?

Given the specifics outlined in the petition to list bocaccio, canary rockfish, and yelloweye rockfish (*S. ruberrimus*) in Puget Sound, the BRT developed an appropriate set of possible DPS scenarios. These scenarios fall into two categories: 1) DPSs at varying geographic scales within Puget Sound and Georgia Basin differentiated from coastal DPS(s) (Scenarios 1–3) and 2) a single DPS inclusive of Puget Sound, Georgia Basin, and Washington Coast (Scenario 4). The BRT review determined there was a lack of appropriate information, especially population genetic data, to adequately evaluate population structure for these three petitioned rockfish species stating, “it is not possible to make broad statements about the patterns of radiation and divergence” among rockfish species. More specifically, known population differentiation patterns within rockfish species do not appear to fall consistently within phylogenetic clades, ecological groups, or among species occurring within similar oceanographic features. However, we emphasize the importance of the single-DPS hypothesis for the protection and recovery of these species, and urge that the hypothesis be further vetted prior to the final listing decision. We further urge NMFS to renew attempts to locate existing tissue for genetic analysis, confer with regional management and academic authorities, and conduct a thorough literature search prior to making a final listing decision.

Response

We agree with WDFW that the lack of genetic data on the petitioned species is a limitation. However, given the unique environment and the restricted circulation of Puget Sound, patterns of population structure of the petitioned species in other regions, and patterns of population of other species in Puget Sound led to the DPS determinations of the BRT. Importantly, the results of the DPS determination process highlighted that the lack of data produced some uncertainties, and we agree with WDFW that additional data would reduce this uncertainty.

Comment 2

Can assumptions be made from other species?

Genetic data from five rockfish populations within Puget Sound, Georgia Basin, or Queen Charlotte Islands exists: the three *Pteropodus* species considered by NMFS in 2001 (copper, brown, and quillback rockfish; all within Puget Sound), Pacific ocean perch (*S. alutus*) (Queen Charlotte Islands), and yelloweye rockfish (Georgia Basin). Based on genetic analyses, each species showed differentiation between populations within the restricted waters of Puget

Sound, Georgia Basin, or Queen Charlotte Islands and outer coast populations. With the exception of the *Pteropodus* species, these species are not closely related and do not share similar life histories or distributions. However, their occurrence in isolated waters, such as Puget Sound, and the differentiation of these isolated populations from other populations do suggest that the physical environment within Puget Sound and George Basin may restrict gene flow in and out of the Puget Sound/Georgia Basin areas. There is, however, information from other life history research that suggests other modes of distribution and dispersal exist among rockfish occurring in Puget Sound. Eleven of the 28 species of rockfish recorded in Puget Sound have only been observed 5 times or less until 1980. The BRT presumes that all rockfish within Puget Sound form an inland DPS implying these rare records each constitute a unique DPS. It is more likely that these species stray into Puget Sound from coastal waters. Recent occurrence patterns of vermilion rockfish (*Sebastes miniatus*), which were not known from Puget Sound prior to 1980 (Miller and Borton 1980), demonstrate that intrusions from coastal waters dynamically influence species compositions. Yellowtail rockfish appear to only occur as juveniles in the San Juan Islands with subsequent dispersal of adults to coastal waters (Barker 1979). More recent observations of rockfish recruitment confirm that postlarval copper, quillback, and brown rockfish are self-sustaining populations within Puget Sound Proper but that black (*S. melanops*) and yellowtail rockfish may recruit to Puget Sound Proper as yearlings from adjacent northern waters. Additionally, whether bocaccio and canary rockfish constitute self-sustaining populations may be questionable. Their early life stages have not been confirmed in Puget Sound (Garrison and Miller 1982) and their documented occurrence in Puget Sound Proper is restricted to less than 24 locations compared to hundreds of records for copper, quillback, and brown rockfish (Washington 1977, Miller and Borton 1980). Evidence that the species occur as self-sustaining populations within Puget Sound is based upon multiple size classes. The occurrence of multiple size classes could equally be explained by success and sporadic recruitment events from coastal waters. Within these hypotheses, assumptions, and patterns is a lack of data to resolve them. The WDFW supports further research and monitoring to remedy this data gap. Recognizing the lack of direct data, the WDFW agrees with the BRT's selection of Scenario 3 for the Georgia Basin DPS as most likely for bocaccio, canary, and yelloweye rockfish. That yelloweye rockfish, a demersal species as an adult, shows isolation between British Columbian inland and coastal populations is strong evidence that precautionary approaches are warranted, and we believe Scenario 3 to be the most precautionary DPS designation.

Response

While agreeing with the BRT's selection of DPS, WDFW raises a number of concerns, which we address here (and above).

The rare, transient occurrence of a fish in Puget Sound would not constitute grounds for creating a DPS, since this would not satisfy the requirements that the population be discrete and significant. Similarly, the presence of only juveniles in the sound would also not satisfy DPS requirements.

We agree that the presence of multiple age classes could indicate several intrusions of larvae from coastal waters; however, as we noted above, the strong year classes of bocaccio in

Puget Sound do not appear to coincide with the strong coastal year classes. The BRT considered this strong support for independence of coastal and Puget Sound populations.

Comment 3

The WDFW concurs with the general population trend analyses for the three proposed species. These patterns generally follow those of Palsson et al. (2009) that canary, yelloweye, and bocaccio rockfish were generally more common in early time series of species compositions and that catch rates and relative abundances of rockfish have declined. WDFW cautions that early species identifications may reflect the difficulty of identifying rockfish by lay observers or untrained samplers.

Response

The concern about species identifications has been noted in the BRT report.

Comment 4

The WDFW requests two corrections in the FRN (Federal Register notice). There is a significant misspelling regarding bocaccio found on page 18521. The statement that "89%" of the recreational rockfish catch in the late 1970s consisted of bocaccio should read as 8–9%. This statement was attributed to Palsson et al. (2008) but these authors did not make this statement. The draft BRT report by Drake et al. (2008) should be credited with this statement that was drawn from dated Washington Department of Fisheries (WDF) Sport Catch Reports.

Response

This was an error in the FRN, but not the BRT report.

Comment 5

The WDFW concurs with the conclusion that overutilization for commercial and recreational purposes is the most severe threat to petitioned rockfish in the Georgia Basin (74 FR 18534). The WDFW acknowledges that past fisheries have contributed to the decline of bocaccio, canary, and yelloweye rockfish.

Response

Noted.

Comment 6

The BRT identified habitat destruction as a threat to petitioned rockfish (71 FR 18533). In particular, loss of rocky habitat, loss of eelgrass and kelp, introduction of nonnative species that modify habitat, and degradation of water quality were identified as specific threats to rockfish habitat in the Georgia Basin. Palsson et al. (2009) does not indicate that loss of rocky habitat has occurred. However, habitat may be degraded due to the presence of derelict fishing gear or impaired water quality. The impact of hypoxia as a risk to the petitioned rockfish in southern Puget Sound may be overstated in that historically documented occurrences of canary, bocaccio, and yelloweye rockfish do not correspond to areas of poor water quality in southern Puget Sound. It is unclear if these species utilized these habitats prior to their degradation. Furthermore, these species have not been observed during recent massive fish kills in southern Hood Canal (Palsson et al. 2008).

Response

The BRT report does not state that there has been loss of rocky habitat, but does note that it can be degraded by construction of bridges, sewer lines and other structures, deployment of cables and pipelines, and by burying from dredge spoils and natural subtidal slope failures.

Comment 7

The FRN adequately characterizes what is known and not known regarding the impact or threat of toxic contaminants on the proposed rockfish species. The WDFW agrees with the reasonable conclusions regarding the potential for health impacts on these species using what is known regarding exposure of closely related rockfish. In addition, the WDFW agrees with the reasonable conclusions regarding potential reproductive impacts on rockfish using results from nonrockfish species.

Response

Noted.

Comment 8

The previous paragraph describes potential exposure patterns for benthic feeding rockfish in urban areas; however, the FRN review indicates that all three petitioned species appear to rely to some degree on pelagic prey. If pelagic prey dominate the diet of a petitioned species, it may experience greater exposure to persistent bioaccumulative toxics (PBTs), across a greater spatial range (not just urban areas). Pelagic prey such as Pacific herring in Puget Sound have unusually high body burdens of PBTs (West et al. 2008); these PBTs biomagnify in their predators (e.g., Chinook salmon [*Oncorhynchus tshawytscha*], see O'Neill and West 2009). Long life span and residency in Puget Sound, both characteristics of the three petitioned rockfish species, increase the risk of exposure. In addition, environmental levels of legacy PBTs such as polychlorinated biphenyls were probably higher in Puget Sound's pelagic species in the 1970s and 1980s (West and O'Neill 2007), the period when the petitioned species declined. If petitioned species consume herring or similar pelagic prey, we believe that PBT contamination may have played a role in their decline, and is a risk factor for their recovery.

Response

This is now mentioned in the BRT report.

WDFW (14 December 2009 Letter)

Comment 1

The WDFW provided a discussion of genetic and size frequency information as the basis for a suggestion to reconsider the BRT's selection of a Puget Sound/Georgia Basin DPS for bocaccio.

Response

The BRT generally agrees with the crux of the WDFW comments; there appears to be little genetic structure in bocaccio along the coast and differences in age structure between coastal and Puget Sound populations are difficult to interpret.

Given this uncertainty, WDFW concludes that the Species of Concern program is appropriate for bocaccio.

Based on the earlier DPS designations for other Puget Sound rockfishes, the BRT assumed that, in the absence of information indicating otherwise, the petition species were likely to have DPS in inland marine waters distinct from coastal populations. Thus the BRT evaluation consisted of evaluating evidence that supported or contradicted this starting point. After considering the limited evidence, the BRT considered the available evidence insufficient to refute the hypothesis of an inland DPS. However, in agreement with WDFW, the BRT noted there was uncertainty in this conclusion, and this was reflected in the DPS voting—a significant minority of the votes were cast for a coastal DPS.

Comment 2

The WDFW presented the Field et al. (2009) reanalysis of the Matala et al. (2004) data to revise the conclusion that bocaccio exhibit genetic structure among coastal populations.

Response

The BRT agrees that bocaccio show markedly lower population structure along coastal populations compared to several other rockfish species. There are examples of a number of species, however, that show structure between Puget Sound or Georgia Basin and the outer Washington Coast, but little structure along the coast (Pacific ocean perch, copper, quillback, and brown rockfish, as well as herring and hake). There remain no data addressing potential genetic differentiation between Puget Sound and coastal populations.

While Field et al. do provide a reanalysis of Matala et al., the BRT notes that the basic conclusion of Matala et al. remains—there is little genetic structure in coastal populations of bocaccio, and this information was available to the BRT during its deliberations.

The BRT also notes that Field et al. state: "Thus, although the failure to identify clear evidence of population genetic structure among bocaccio populations in the Canadian/northern U.S. region and the southern/central California region suggests that some migratory connectivity exists, the apparent differences in growth rates, size (and presumably age) at maturity, and longevity suggest that some level of demographic independence is likely." As a result, Field et al. continue to distinguish a northern and southern stock.

Comment 3

The WDFW argued that length frequency data do not support the conclusion that successful recruitment is occurring in Puget Sound and that the presence of mature individuals and many size (age) classes supports a viable population in Puget Sound.

Response

We agree with WDFW that interpretation of the length frequency data is ambiguous. The critical point for DPS determination for the BRT related to how this uncertain information was used. The limited information on bocaccio available to the BRT and in the WDFW letter provides uncertain evidence that in some cases supports the hypothesis that Puget Sound and coastal populations are discrete, while in other instances it contradicts the hypothesis. Importantly, however, while the BRT recognized that there is some evidence supporting a coastal DPS, on balance, the BRT did not consider this strong enough to refute the starting assumption of an inland DPS.

Comment 4

The WDFW concluded that the absence of documented postsettlement juveniles or larvae in scuba and seine surveys suggested there is no viable population of bocaccio in Puget Sound.

Response

The absence of postsettlement bocaccio in surveys is difficult to interpret, and the BRT does not consider this evidence of a lack of evidence for a viable population of bocaccio in Puget Sound. The WDFW surveys were conducted after the bocaccio population was already very low. Given the extremely episodic nature of bocaccio recruitment and their apparently very low population size, the probability of seeing a juvenile bocaccio is extremely low. Thus it is difficult to know what the absence of postsettlement bocaccio in recent surveys really indicates.

Comment 5

The WDFW argued that the population strong 1999 year class of bocaccio was present in California, but not documented in northern portions of their range. Also not documented is the relationship between coastal recruitment and recruitment in Puget Sound.

Response

The WDFW is correct in noting that the BRT used the bocaccio stock assessment to conclude that 1999 was a strong coastal year class, and that the stock assessment is performed on the California portion of the stock. Thus we agree that it could be problematic to conclude that the 1999 year class was strong in the portion of the population off the coast of Washington and British Columbia. The report was revised to more clearly state that the stock assessment focused on the California stock.

However, given that strong year classes in several species of rockfish are coherent at scales up to 1,000 km (Field and Ralston 2005), and that the 1999 year class was strong for a number of northern rockfish (e.g. Hamel 2007, Stewart 2007), the BRT opted to leave this analysis in the report. In addition, the BRT augmented the original analysis to include an examination of the coherence of other year classes. Overall, there appears to be little correspondence between age structure inside and outside of Puget Sound. The BRT considers this suggestive (though not conclusive) of an inland DPS.

Appendix C: Marine Species in Greater Puget Sound

Primary Producers

The major classes of primary producers in Puget Sound are phytoplankton, sediment-associated microalgae, and rooted or attached algae and vascular plants in the sound, freshwater, and on land (Ruckelshaus and McClure 2007). Phytoplankton production in Puget Sound occurs in nearshore and offshore marine waters. Pelagic phytoplankton in Puget Sound is mainly composed of two major groups, diatoms and dinoflagellates, with diatoms accounting for most of the biomass (Strickland 1983). Some single-celled algae or diatoms adhere to benthic substrates or are motile within sediments.

Algal productivity in the open waters of the central basin of Puget Sound Proper (PSP) is dominated by intense but patchy blooms of microalgae beginning in late April or May, with a series of intermittent blooms through the summer and perhaps another intense bloom in the fall (Strickland 1983). Annual primary productivity in the Main Basin of the sound is about 465 g C/m^2. This high productivity is due to intensive upward transport of nitrate by the estuarine mechanism and tidal mixing. Chlorophyll concentrations rarely exceed 15 µg/L. There is frequently more chlorophyll below the photic zone than within it. Winter et al. (1975) concluded that phytoplankton growth was limited by a combination of factors, including vertical advection and turbulence, light, sinking, and occasional rapid horizontal advection of the phytoplankton from the area by sustained winds. Summer winds from the northwest would be expected to transport phytoplankton to the south end of Puget Sound, which could exacerbate the anthropogenic effects that are already evident in some of these inlets and bays (Harrison et al. 1994).

When estuarine and marine macrophytes die or senesce (or terrestrial plant material is washed in), they are colonized by microbes, including bacteria, protists, and fungi that break down and transform the organic matter into detritus that can be reused by producers (Ruckelshaus and McClure 2007). Detritus also encompasses molts from crustaceans and other animals, fecal pellets, and other animal-related sources. This consumer pathway is a very important trophic pathway in the nearshore areas and deep benthic habitats of Puget Sound (Mumford 2007).

Zooplankton

The abundance and distribution of zooplankton in greater Puget Sound is generally not well understood. Vertical migration on both daily and seasonal cycles dominates the vertical distribution of most large zooplankton species, which are observed near the surface at night and at depths approaching 200 m during the day (Strickland 1983). A few field surveys have been conducted in selected inlets and waterways, but reports on sound-wide surveys are lacking. In general, the most numerically abundant zooplankton throughout the greater Puget Sound region are the calanoid copepods, especially *Pseudocalanus* spp. (Chester et al. 1980, Dumbauld 1985, Ohman 1990, Giles and Cordell 1998). Giles and Cordell (1998) reported that crustaceans (primarily calanoid copepods) were most abundant in Budd Inlet in South Puget Sound, although larvae of larvaceans, cnidarians, and polychaetes in varying numbers were also abundant during the year. In a similar study, conducted at two locations in the Main Basin (a site near downtown Seattle and a cluster of sites in the East Passage near Seattle covering a variety of depths from 12 to 220 m), Dumbauld (1985) found that calanoid copepods, cyclopoid copepods, and two species of larvaceans were dominant numerically. Dominant copepods at deeper sites were *Pseudocalanus* spp. and *Corycaeus anglicus*. A larvacean, *Oikopleura dioica*, was also relatively common at the shallow sites. Similarly, calanoid copepods were the most abundant zooplankton in the Strait of Juan de Fuca (Chester et al. 1980), including *Pseudocalanus* spp., *Acartia longiremis*, and a cyclopoid copepod, *Oithona similis*.

It is likely that zooplankton assemblages vary both seasonally and annually. Ohman (1990) reported evidence of depth-specific differences. In studies conducted in Dabob Bay off Hood Canal, Ohman (1990) compared the abundance of certain zooplankton species at a shallow and a deep site. Ohman (1990) found one species of copepod (*Pseudocalanus newmani)* that was common at both sites, whereas species (e.g., *Euchaeta elongata* and *Euphausia pacifica*) that prey upon *P. newmani* were abundant at the deep site, but virtually absent from the shallow site. Bollens et al. (1992b) reported an example of seasonal variability. In Dabob Bay, *E. pacifica* larvae were abundant in the spring and absent in the winter, and juveniles and adults were most abundant in the summer and early fall, with their numbers declining in the winter (Bollens et al. 1992b).

Benthic Invertebrates

A few sound-wide surveys of abundance and distribution of benthic invertebrates have been performed (Lie 1974, Llansó et al. 1998). A common finding among these surveys is that certain species prefer specific sediment types. For example, in areas with predominantly sandy sediments, *Axinopsida serricata* (lenticular axinopsid, a bivalve) and *Prionospio jubata* (a polychaete) are among the most common species. In muddy clay areas of mean to average depth, *Amphiodia urtica-periercta* (an echinoderm) and *Eudorella pacifica* (a cumacean) are among the most common species. In areas with mixed mud and sand, *Axinopsida serricata* and *Aphelochaeta* sp. (a polychaete) are commonly found. And lastly, in deep muddy, clayey areas, predominant species tend to be the Charlotte macoma (*Macoma carlottensis*, a bivalve) and *Pectinaria californiensis* (a polychaete). In general, areas with sandy sediments tend to have the most species (Llansó et al. 1998) but the lowest biomass (Lie 1974). Areas with mixed sediments tend to have the highest biomass (Lie 1974).

As with zooplankton, assemblages of benthic invertebrates vary seasonally and annually. Lie (1968) reported seasonal variations in the abundance of species, with the maxima taking place during July-August and the minima occurring in January-February. However, there were no significant variations in the number of species during different seasons. Nichols (1988) examined annual variation at three PSP sites in the Main Basin: two deep sites (200–250 m) and one shallow site (35 m). For one of the deep sites, he reported that the Charlotte macoma generally dominated the benthic community from 1963 through the mid-1970s. Subsequently, these species were largely replaced by *A. serricata, E. pacifica, P. californiensis, Ampharete acutifrons* (a polychaete), and *Euphiomedes producta* (an ostracod). A similar dominance by *P. californiensis* and *A. acutifrons* was reported for the other deep site over approximately the same time period.

Several macroinvertebrate species that are widely distributed in greater Puget Sound are of high ecological, economic, cultural, and recreational value (Dethier 2006). Among crustaceans, Dungeness crab (*Cancer magister*) and several species of shrimp (e.g., sidestripe [*Pandalopsis dispar*] and pink [*Pandalus borealis*]) are the most commonly harvested invertebrate species (Bourne and Chew 1994). The nonindigenous Pacific oyster (*Crassostrea gigas*) accounts for approximately 90% of the landings of bivalves. Other abundant bivalves are the Pacific littleneck clam (*Protothaca staminea*), Pacific geoduck (*Panopea abrupta*), Pacific gaper (*Tresus nuttalii*), and the nonindigenous Japanese littleneck clam (*Tapes philippinarum*) and softshell clam (*Mya arenaria*) (Kozloff 1987, Turgeon et al. 1998).

Fish

More than 200 species of fish have been recorded in the Georgia Basin and greater Puget Sound (Schmitt et al. 1994, Palsson et al. 1997). Marine species are generally categorized as forage fish, bottomfish, and other nongame fishes. Many are, or have been, considered important commercial species, including Pacific herring (*Clupea pallasii*), spiny dogfish (*Squalus acanthias*), Pacific hake (*Merluccius productus*), Pacific cod (*Gadus macrocephalus*), walleye pollock (*Theragra chalcogramma*), lingcod (*Ophiodon elongatus*), rockfish (*Sebastes* spp.), and English sole (*Parophrys vetulus*).

Forage fishes are small, schooling fishes that are key prey items for larger fish and wildlife in a marine food web (Pentilla 2007). Forage fish are valuable indicators of the health and productivity of the marine environment, and in turn are reliant upon a variety of shallow nearshore and estuarine habitats (Lemberg et al. 1997). The major forage fish species in nearshore waters of Puget Sound include Pacific herring, surf smelt (*Hypomesus pretiosus*), and sand lance (*Ammodytes hexapterus*), all three of which lay eggs in shallow, intertidal vegetated or sand and gravel beach habitats (Pentilla 2007). Pacific herring stocks in the sound have recently undergone federal listing reviews (Stout et al. 2001a, Gustafson et al. 2006).

Bottomfish live in marine waters and spend their lives near or on the bottom. Species commonly found in Puget Sound include the true cods (Pacific cod, walleye pollock, and Pacific hake), lingcod, flatfish, and rockfish (Palsson et al. 1997). Populations of several stocks, particularly Pacific cod and hake, are at historic lows in the sound (Gustafson et al. 2000). More than 20 species of rockfish inhabit Puget Sound (West 1997), with copper (*Sebastes caurinus*), quillback (*S. maliger*), and brown rockfish (*S. auriculatus*) considered three of the most common species (Palsson et al. 2009). These three species have also recently undergone a status review for federal listing (Stout et al. 2001b). The spiny dogfish is a slow-growing, long-lived shark species found throughout Georgia Basin and Puget Sound (Schmitt et al. 1994, Palsson et al. 1997). English sole is the dominant member of the flatfish community in Puget Sound and stocks are considered relatively healthy throughout most of the sound (Palsson et al. 1997). However, significant declines have been recorded in localized embayments, such as Bellingham and Discovery bays, and high levels of toxic contaminants have been measured in the tissues of individuals collected from urban embayments (West et al. 2001).

Other bottomfish species found throughout greater Puget Sound include skates (longnose skate [*Raja rhina*] and big skate [*R. binoculata*]), spotted ratfish (*Hydrolagus colliei*), sablefish (*Anoplopoma fimbria*), greenlings (kelp greenling [*Hexagrammos decagrammus*] and whitespotted greenling [*H. stelleri*]), sculpins (e.g., cabezon [*Scorpaenichthys marmoratus*], Pacific staghorn sculpin [*Leptocottus armatus*], and roughback sculpin [*Chitonotus pugetensis*]), surfperches (e.g., pile perch [*Rhacochilus vacca*] and striped seaperch [*Embiotoca lateralis*]), wolf-eel (*Anarrhichthys ocellatus*), and flatfishes (Pacific halibut [*Hippoglossus stenolepis*], Pacific sanddab [*Citharichthys sordidus*], butter sole [*Pleuronectes isolepis*], rock sole [*Pleuronectes bilineatus*], Dover sole [*Microstomus pacificus*], starry flounder [*Platichthys stellatus*], and sand sole [*Psettichthys melanostictus*]) (DeLacy et al. 1972, Nelson et al. 2004). Additional fish species that are less known, but widely distributed in greater Puget Sound, include plainfin midshipman (*Porichthys notatus*), eelpouts (e.g., blackbelly eelpout [*Lycodopsis pacifica*]), pricklebacks (e.g., snake prickleback, [*Lumpenus sagitta*]), gunnels (e.g., penpoint gunnel [*Apodichthys flavidus*]), bay goby (*Lepidogobius lepidus*), and poachers (e.g., sturgeon poacher [*Podothecus acipenserinus*]) (DeLacy et al. 1972, Robins et al. 1991).

Several species of Pacific salmon use greater Puget Sound during some portion of their life cycle. These include Chinook (*Oncorhynchus tshawytscha*), coho (*O. kisutch*), chum (*O. keta*), pink (*O. gorbuscha*), and sockeye salmon (*O. nerka*). Anadromous steelhead (*O. mykiss*) and cutthroat trout (*O. clarki*) also reside in greater Puget Sound habitats. All juvenile salmon move along the shallows of estuaries and nearshore areas during their outmigration to the sea, and may be found in these habitats throughout the year depending on species, stock, and life history stage (Fresh 2007).

Birds and Mammals

About 66,000 marine birds breed in or near greater Puget Sound, with about 70% of them breeding on Protection Island, located just outside of the northern entrance to the sound (Wahl et al. 2005, Buchanan 2007). The most abundant species are rhinoceros auklet (*Cerorhinca monocerata*), glaucous-winged gull (*Larus glaucescens*), pigeon guillemot (*Cepphus columba*), cormorants (*Phalacrocorax* spp.), marbled murrelet (*Brachyramphus marmoratus*), and Canada goose (*Branta canadensis*). Examples of less abundant species include common murre (*Uria aalge*) and tufted puffin (*Fratercula cirrhata*). A number of additional bird species use greater Puget Sound during the winter months. Dabbling ducks, including American widgeon (*Anas americana*), mallard (*A. platyrhynchos*) and northern pintail (*A. acuta*), are the most common, followed by geese and swans, such as trumpeter swan (*Cygnus buccinator*), tundra swan (*C. columbianus*), and Canada goose (Mahaffy et al. 1994). The surf scoter (*Melanitta perspicillata*) is one of the more abundant diving ducks in Puget Sound and a conspicuous member of the waterfowl community in open marine waters of western Washington (Buchanan 2006).

Populations of rhinoceros auklet and pigeon guillemot appear to be stable, whereas populations of glaucous-winged gull have increased slightly in recent years, especially in urban areas (Mahaffy et al. 1994). Accurate estimates of current populations of marbled murrelets and Canada geese are not available, but the population of marbled murrelets has been greatly reduced and this species has been listed as threatened. Thirty years ago, year-round resident Canada geese were rare, but current anecdotal evidence from observations in waterfront parks suggests that their population is growing rapidly. The common murre and tufted puffin populations have declined drastically during the last two decades. Surveys have also documented a 58% reduction in density indices of all three scoter species (combined) from 1978–1979 to the mid-1990s (Nysewander et al. 2005). Human activity affects the taxonomic composition of marine bird assemblages across greater Puget Sound, and such changes can be detected at a variety of spatial scales with simple measures of taxonomic composition and urbanization (Rice 2007).

Nine primary marine mammal species occur in greater Puget Sound including (listed in order of abundance): harbor seal (*Phoca vitulina*), California sea lion (*Zalophus californianus*), Steller sea lion (*Eumetopias jubatus*), northern elephant seal (*Mirounga angustirostris*), harbor porpoise (*Phocoena phocoena*), Dall's porpoise (*Phocoenoides dalli*), killer whale (*Orcinus orca*), gray whale (*Eschrichtius robustus*), and minke whale (*Balaenoptera acutorostrata*) (Calambokidis and Baird 1994).

Harbor seals are year-round residents and their abundance has been increasing in greater Puget Sound since the late 1970s (Jeffries et al. 2000, Jeffries et al. 2003). California sea lions, primarily males, reside in greater Puget Sound between late summer and late spring, and spend the remainder of the year at their breeding grounds in Southern California and Baja California. Populations of the remaining species are quite low in greater Puget Sound. Steller sea lions and elephant seals are transitory residents that are occasionally seen in Puget Sound. The Steller sea lion is currently listed as threatened in the United States whereas the elephant seal is considered abundant in the eastern North Pacific.

Although harbor porpoises are also abundant in the eastern North Pacific and were common in greater Puget Sound 50 or more years ago, they are now rarely seen in the sound (Calambokidis and Baird 1994). Low numbers of Dall's porpoise are observed in greater Puget Sound throughout the year, but little is known about their population size; they are also abundant in the North Pacific. Resident and transient populations of killer whales are occasionally observed in small pods of 3 to 40 individuals throughout Puget Sound (Kriete 2007). Southern residents feed primarily on salmon and other fish, whereas transients feed primarily on marine mammals. Southern residents are primarily found in North Puget Sound and the size of this group has been estimated at 70–100 individuals since the 1970s. The southern resident population declined 20% from 1996 to 2001 (Krahn et al. 2004) and was listed in 2005 under the U.S. Endangered Species Act. The causes of this decline likely include a combination of factors, including exposure to chemical contaminants, reduced availability of prey resources, and increased human activities (Krahn et al. 2004). Minke whales are also primarily observed in this same northern area, but their population size is unknown. Gray whales migrate past the Georgia Basin en route to or from their feeding or breeding grounds; a few of them enter greater Puget Sound during spring through fall to feed.

Appendix D: Issues Pertaining to the Species Composition Data

Washington State Sport Catch Reports 1975–1986

The data from these reports total bottomfish catch by hook and line by punch card area. The data are presented by species and include all five petitioned rockfish species (*Sebastes* spp.). The report does not include catch by divers or shore and pier anglers. No information is provided on the methods by which the numbers were derived, however, we assume that data are derived from punch card catches, as data later than 1980 are adjusted downward to account for statistical bias from methodology (as is done in other reports working with punch card data). No distinction is made between bottomfish specific versus bottomfish catches incidental to the salmon (*Oncorhynchus* spp.) fishery. In many years, some punch card areas are listed with only two or three rockfish species with no listing for "other rockfishes," whereas the same areas have many more species in later surveys. This suggests that data were recorded on species idiosyncratically and inconsistently. The large amount of variability in the frequency data suggests the same. Note that harvest numbers of some species (e.g., bocaccio [*S. paucispinis*] and canary [*S. pinniger*] rockfish) are much higher than in any subsequent published reports.

Bargmann 1977 and Buckley 1967, 1968, 1970

These reports summarize bottomfish specific and incidental (salmon angler) catch of bottomfish in catch areas 4–12 by month in 1965–1973 using punch card data. Total catch estimates are derived from formulas used to estimate bottomfish angler effort and catch from the more thorough sampling done for the salmon fishery. The data cover only hook-and-line catch and do not cover dock, jetty, or shore anglers. The species data show many of the same patterns seen in the Washington State Sport Catch Reports, which suggests that species reporting was not being done in a consistent fashion from year to year or punch card area to area. Indeed, the authors note that positive identification of individual rockfish species is spotty in some areas and often noted as "rockfish." However, the "rockfish" category was not consistently reported every year. The reports include all five species in the petition, although this varies greatly between years and catch record areas.

Palsson 1988

This publication is a comprehensive summary of catch data from 1970 to 1985 and includes three of the five petitioned species (except greenstriped [*S. elongatus*] and redstripe [*S. proriger*] rockfish, which were presumably pooled into misc/unidentified rockfish). The publication includes data previously published by Bargmann (1977). The Estimation Procedures section of the publication reviews the many limitations of Puget Sound data, including relatively low sampling percentages (as compared to coastal fisheries), large increments of unidentified rockfish, and dependence of total catch estimates on expansion factors from the recreational salmon fishery. As in previous publications, the estimates do not include catch by divers, shore, and pier anglers. Catch estimates since 1981 for catch areas 5–13 were adjusted downward by multiplying 0.833 following previously established punch card methodology to correct for the assumed bias of 20% in the punch card samples. Species composition data reported from Washington Department of Fish and Wildlife (WDFW) dockside samplers were modified using species compositions from the Marine Recreational Fisheries Statistical Survey (MRFSS) sampling data, when available, because these were considered more reliable. The corrections involved identifications pooled over 6 years of survey data. These species composition correction factors are not included in the document.

Palsson et al. 2009

This publication is a comprehensive review of the history, data sources, research, management, trends, and conservation efforts associated with rockfish resources in Puget Sound. Recreational rockfish catch by species (including all petitioned species except bocaccio) is presented from 2004 to 2007 in terms of pounds of fish harvested or released in two major management regions (North Puget South and South Puget Sound). The text provides a summary of species composition information that highlights the range of reliable species composition information for recreational species, and includes some discussion of MRFSS data collection procedures (see below), with graphs of MRFSS species composition by North Puget Sound and South Puget Sound management regions (Palsson et al. 2009, their Figure 6.9 and Figure 6.10); the five petitioned species are presumably pooled into the “other rockfish” category.

Species composition estimates from commercial fisheries are presented by Palsson et al. (2009, their Table 6.1 and Table 6.2). This includes the 1970–1986 observations described in Pedersen and Bargmann (1986) and used in Schmitt et al. (1991). The tables also include subsequent observations from 1988, 1989, 1991, and 1993, when the last commercial rockfish compositions were taken. Information on the sample sizes and distribution of these samples is not given.

MRFSS

This is a federal survey occurring in Washington State in 1980–86, 1989, and 1996–2002 that used telephone and creel surveys to estimate statewide catch and effort for boat and shore-based recreational fisheries, including harvest by scuba divers. It also estimated released and discarded catch, and entails extensive training of samplers in marine species identification. The MRFSS survey catch estimates for bottomfish are notably different than the estimates of the WDFW survey that were derived using salmon fishery data. This may be associated with the collection of fewer interviews and difficulties in apportioning harvest by coast and Puget Sound. We have not yet been able to review these data extensively.

WDFW Trawl Survey Data, Palsson et al. 2009

These data provide catch records, biological data, and trawl effort and location from annual surveys throughout Puget Sound from 1987 to 2008 (>1,500 trawls). The data include records for four species of the petitioned species (no bocaccio), including biological records (length/weight information) for canary (n = 25), greenstriped (n = 481), redstripe (n = 484), and yelloweye (*S. ruberrimus*) (n = 10) rockfish. Effort is distributed unevenly at various levels over all geographic areas over time. This complicates temporal density and abundance trend estimation of some species. In addition, the sample sizes are low relative to the infrequent and clumped occurrence of the petitioned species. This leads to high sensitivity to outliers. Specifically, the high redstripe rockfish estimates in recent years are driven by outlier trawls (single trawl samples with high numbers of redstripe rockfish).

Schmitt et al. 1991

This source contains commercially trawled species weight by area for bocaccio, yelloweye, and canary rockfish for 1970 to 1987. However, note that all numbers are based on a single percent composition estimate made in one year (Pedersen and Bargmann 1986) that was then applied to all the “rockfish” category of landings 1970–1987.

Appendix E: Geological and Climatic History of Puget Sound

The greater Puget Sound basin falls within the Puget Lowland, a portion of a low lying area extending from the lower Fraser River valley southward to the Willamette Lowland (Burns 1985). In the distant past, the Puget Lowland was drained by numerous small rivers that flowed northward from the Cascade and Olympic mountains and emptied into an earlier configuration of the Strait of Juan de Fuca. During the Pleistocene, massive Piedmont glaciers as much as 1,100 meters thick moved southward from the Coast Mountains of British Columbia and carved out the Strait of Juan de Fuca and greater Puget Sound. Deepest basins were created in North Puget Sound in and around the San Juan Islands. About 15,000 years ago, the southern tongue of the last glacier receded rapidly, leaving the lowland covered with glacial deposits and glacial lakes and revealing the Puget Sound basin (Burns 1985). The large glacially formed troughs of Puget Sound were initially occupied by proglacial lakes that drained southward (Thorson 1980). Almost two dozen deltas were developed in these lakes as the result of streams flowing from the melting ice margins.

Important changes have occurred in the Puget Sound region in the past century and the next several decades will likely see even greater changes (Mote et al. 2005). Glaciers in the Cascade and Olympic mountains have been retreating since the 1850s. Since the late 1800s, Pacific Northwest temperatures rose faster than the global average. Puget Sound waters have warmed substantially, especially in the period since the early 1970s, when the sea surface temperature at Race Rocks in the Strait of Juan de Fuca began a prolonged warming trend that continues through the present (Ruckelshaus and McClure 2007).

Considerable evidence indicates that climate in the greater Puget Sound region is cyclical, with maxima (warm, dry periods) and minima (cold, wet periods) occurring at decadal intervals. For example, the Pacific Northwest Index indicates that since 1893 there have been about five temperature minima and four maxima (Ebbesmeyer and Strickland 1995). Three minima occurred between 1893 and 1920, one between the mid-1940s and 1960, and one between the mid-1960s and mid-1970s. Two maxima occurred between the early 1920s and the early 1940s, and two more occurred between the late 1970s and 1997.

Mantua et al. (1997) and Hare and Mantua (2000) evaluated relationships between interdecadal climate variability and fluctuations in the abundance and distribution of marine biota. The Pacific decadal oscillation (PDO) shows predominantly warmer periods between 1925 and 1946 and following 1977 and a cooler phase between 1947 and 1976 (Figure E-1). For Washington State, warmer periods are characterized by increased flow of relatively warm, humid air and less than normal precipitation, and the cool phase corresponded to a cool and wet climate. Mantua et al. (1997) reported connections between the PDO and indicators of populations of Alaska sockeye (*Oncorhynchus nerka*) and pink salmon (*O. gorbuscha*) and Washington-Oregon-California coho (*O. kisutch*) and Chinook salmon (*O. tshawytscha*), although the coho

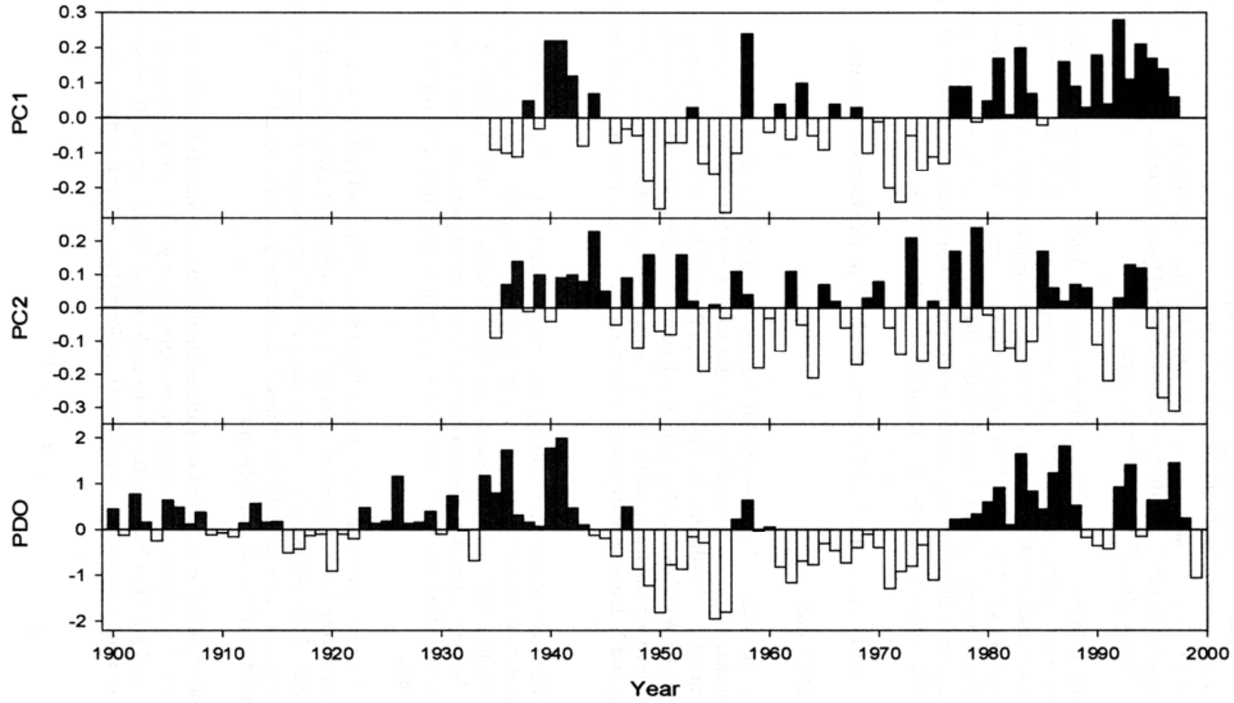


Figure E-1. First (PC1) and second (PC2) principal components analysis of climate variables for Puget Sound (Pinnix 1999) along with the PDO (Mantua 1997) for years 1900–2000. PC1 captures decadal scale variability and resembles the PDO; PC2 captures interannual scale variability. (Reprinted from Stout et al. 2001a.)

and Chinook populations were highest during the negative epochs. Hare and Mantua (2000) found evidence for major ecological and climate changes during the warm period following 1977 (Figure E-1). They also found weak evidence for a shift to a cooler regime following 1989. In particular they noted that a number of ecological parameters were correlated with this decadal-scale climate variability. These included annual catches of Alaska coho and sockeye salmon, annual catches of Washington and Oregon coho and Chinook salmon, zooplankton biomass in the California Current, and the Oyster Condition Index for oysters in Willapa Bay, Washington (Hare and Mantua 2000).

Proxies of climatic variation have been used to reconstruct temperature fluctuations in the Pacific Northwest. Graumlich and Brubaker (1986) reported correlations between annual growth records for larch (*Larix* spp.) and hemlock (*Tsuga heterophylla*) trees located near Mt. Rainier and temperature and snow depth. A regression model was used to reconstruct temperatures from 1590 to 1913. Their major findings were that temperatures prior to 1900 were approximately 1°C lower than those of the 1900s, and that only the temperature pattern in the late 1600s resembled that of the 1900s.

As a consequence of regional warming in the 20th century, springtime snow pack has decreased markedly at many sites in Puget Sound, and the timing of river and stream flow has shifted with significant reductions in snowmelt runoff in May-July, reduced summer stream flows, and increased runoff in late winter and early spring (Ruckelshaus and McClure 2007). Projections for the consequences of future global warming in the Puget Sound region include continued rise of air and marine water temperatures, altered river and stream flows, increased winter runoff with decreased water stored as snow pack, increased river flooding, and continued sea level rise (Ruckelshaus and McClure 2007). Related consequences to Puget Sound will likely consist of changes to water quality, circulation patterns, biological productivity, habitat distributions, populations of sensitive species, rates of harmful algal blooms, surface wind patterns, and coastal upwelling regimes.

Appendix F: Rockfish Historic Data Summary and Synthesis

In general, historic and more recent reports confirm that the five petitioned species of rockfish are present in Puget Sound, although in different habitats or with various levels of susceptibility to particular types of sampling or fishing gear. Adult greenstriped (*Sebastes elongatus*) and redstripe rockfish (*S. proriger*) are found in deepwater habitats over cobble or mud bottoms or in the water column; consequently, they are more prevalent in trawl catches where this gear is utilized. Conversely, canary rockfish (*S. pinniger*), bocaccio (*S. paucispinis*) and yelloweye rockfish (*S. ruberrimus*) are generally associated with steep sidewalls or rocky untrawlable bottom, and are therefore more often observed by divers or caught in the recreational hook-and-line fishery. There is also some indication that individual species may be more abundant or prevalent in particular subregions of Puget Sound.

The earliest accounts of Puget Sound's fish fauna are rarely quantitative, but do provide anecdotal accounts of species' relative abundance and reported locations of occurrence. Alternate common names often used in historic accounts for four of the five petitioned rockfish species are as follows:

Common name	Other common name
Bocaccio	Rock salmon
Canary rockfish	Orange rockfish
Greenstriped rockfish	Olive-banded rock cod
Yelloweye rockfish	Red rockfish, red snapper, rasphead rockfish

Before European colonization of the region, native people harvested rockfish for consumption, although it was not an intensive fishery and little detailed information documents or differentiates harvest of particular species. Coast Salish people in the San Juan archipelago regarded rockfish primarily as something that would be line fished for immediate consumption.[6] In contrast, salmon (*Oncorhynchus* spp.) and halibut (*Hippoglossus stenolepis*) were fished intensively in the islands for drying and trade. Places that were famous for rockfish include Deception Island (Deception Pass), Turn Point on Stuart Island, Iceberg Point on Lopez Island, and Point Disney and Point Hammond on Waldron Island.

There are few reliable data sets that document rockfish consumption by native people in an archaeological context; most of this information is in the gray literature.[7] Very few archaeological sites in this area have been excavated and only very recently have archaeologists begun to identify fish bones systematically. More than 7,000 fish remains from Watmough Bight, Lopez Island, were reviewed for the University of Washington Burke Museum of Natural

---

[6] R. Barsh, Center for the Study of Coastal Salish Environments, Anacortes, WA. Pers. commun., June 2007.
[7] See footnote 6.

History and Culture and the U.S. Bureau of Land Management, and 2,450 of those bones were identified to at least the family level. Only four rockfish (family Scorpaenidae) bones were identified, while nearly 10% of the assemblage were greenlings (family Hexagrammidae). Watmough was a summer salmon fishing camp, and not surprisingly, the midden consisted mainly of salmon remains from large-scale cleaning, splitting, and drying operations.

Reviews of British Columbia and Washington fisheries at the turn of the century focused on "useful" saltwater fishes such as halibut and sturgeon (*Acipenser* spp.), which figured prominently in the catch at the time (U.S. Fish Commission 1900). Rockfishes are not mentioned explicitly in these reports and are assumed to represent what the authors termed "a reserve stock [of saltwater species], which will be drawn upon more and more with the increase of local population." Almost two decades later, however, Kincaid (1919) acknowledged that the family Scorpaenidae constituted "one of the most important and valuable groups of fishes found on the Pacific Coast." He produced an annotated list of Puget Sound fishes that documented 13 species of rockfish that were known to inhabit Puget Sound, including two of the petitioned species: the "orange rockfish" (*Sebastes pinniger*) that was "abundant in deep water," and the "red rockfish or red snapper" (*S. ruberrimus*), the largest of this group, "common in deep water" and "brought to market in considerable quantities."

Smith (1936) provided one of the first scientific reports on Puget Sound commercial fisheries focused on the fleet of otter trawlers, which targeted flatfish landed for market in Seattle. The fishery occurred primarily over relatively soft bottom areas, with 12 important fishing grounds identified in greater Puget Sound based on relative productivity. Seven rockfish species were indicated as being taken by this fishery, including three of the petitioned species: orange rockfish, red snapper, and olive-banded rock cod.

Haw and Buckley's (1971) text on saltwater fishing in Washington marine waters, including Puget Sound, was designed to popularize recreational sport (hook-and-line) fishing in the region to the general public. Increased recreational utilization of salmon and marine fish resources was needed to promote recognition of the needs of this fishery in management decisions that were historically driven by commercial fishery interests. Fishing locations and habitat preferences were indicated for three species of rockfish: canary, yelloweye, and bocaccio. Canary rockfish were found at depths of more than 45 m and were not restricted to rocky bottom areas. This species occurred in certain locations as far south as Pt. Defiance and was taken in good numbers at Tacoma Narrows, but was considered more abundant in the San Juan Islands, North Puget Sound (NPS), and Strait of Juan de Fuca. Rockfish were found at depths greater than 45 m on rocky bottoms and primarily occurred in NPS, the strait, and the outer coast. Finally, bocaccio were frequently caught in the Tacoma Narrows.

Buckley's retrospective assessment of rockfish distribution and abundance in the 1960s is that the strong tidal currents and rocky, high vertical relief walls at Tacoma Narrows essentially represented a microcosm of marine fish found in the Neah Bay area. He noted that the Tacoma Narrows likely had almost "virgin assemblages" of bottomfish that received little fishing pressure except from occasional experienced recreational anglers and a small boat commercial fishery for lingcod (*Ophiodon elongatus*). The bottom habitat in the central Tacoma Narrows was difficult to fish because of the mass of cables and concrete remains from the Tacoma Narrows Bridge collapse in 1940. The recreational harvest of rockfish in Puget Sound and other inland marine waters increased when recreational fishing for these species was popularized and electronic depth sounders enhanced the ability of anglers to locate productive fishing locations. Buckley noted that the Washington Department of Fish and Wildlife worked with the media to teach the public to target bottomfish. In the Tacoma Narrows, rockfish resources declined once the mature assemblages of fish were removed. Buckley believed this was the result of a lack of a regular source of natural recruitment.

Two documents (DeLacy et al. 1972, Miller and Borton 1980) compiled all available data on Puget Sound fish species distributions and relative number of occurrences since 1971–1973 from the literature (including some records noted above), fish collections, unpublished log records, and other sources. These documents list 27 representatives of the Scorpaenidae family, including all 5 species considered in this status review (total records indicated in parentheses): greenstriped rockfish (54), most records occur in Hood Canal, although also collected near Seattle primarily associated with otter trawls; bocaccio (110), most records occur from the 1970s in Tacoma Narrows and Appletree Cove (near Kingston) associated with sport catch; canary rockfish (114), most records occur from the 1960s and 1970s in Tacoma Narrows, Hood Canal, San Juan Islands, Bellingham, and Appletree Cove associated with sport catch; redstripe rockfish (26), most records are from Hood Canal sport catch, although a few were also taken in central Puget Sound/Seattle; and yelloweye rockfish (113), most records occur from the early 1970s in the San Juan Islands (Sucia Island) and Bellingham Bay associated with the sport catch.

Some research was conducted by several graduate students at the University of Washington School of Fisheries (Moulton 1977, Barker 1979, Gowan 1983) on the ecology and recreational exploitation of rockfish in Puget Sound during the 1970s and 1980s. Moulton (1977) developed scuba methods for surveying fish populations in the rocky nearshore region of NPS (San Juan Islands) to estimate changes in biomass, density, and depth distribution for these species. Of the five species of interest, only yelloweye rockfish were observed in the nearshore scuba surveys.

Barker (1979) and Gowan (1983) focused on the most frequently encountered recreational rockfish species: copper (*Sebastes caurinus*), quillback (*S. maliger*), brown (*S. auriculatus*), black (*S. melanops*), and yellowtail (*S. flavidus*) rockfish. Barker's work, conducted in the San Juan Islands, mentions none of the rockfish species being reviewed. Gowan collected rockfish specimens for age and growth analysis throughout Puget Sound from 1973 to 1976 by hook and line (>1,100 specimens) and commercial landings at processors (<200 specimens). Although the majority of these species were represented by the more common species noted above, Gowan's (1983) records also include size-at-age records for canary rockfish (n = 10, 303–401 mm total length [TL]), yelloweye rockfish (n = 26, 430–707 mm TL), and bocaccio (n = 23, 550–730 mm TL). Results of a subsequent creel census around Bainbridge Island during 1976–1977 yielded an additional 446 rockfish specimens, although only a single yelloweye rockfish specimen was enumerated from this effort.

Walton (1979) surveyed eight artificial reef (tire reefs) habitats and other structures with scuba for density and biomass of fish species from 1975 to 1978 near Edmonds, Washington (central Puget Sound). Over the course of the 213 survey dives, 20,239 fish were observed, including 5,139 rockfish comprising seven species. Bocaccio (n = 10, 0.2% of rockfish, 2% frequency of occurrence) and greenstriped rockfish (n = 26, 0.5% of rockfish, 5% frequency of occurrence) were the only two petitioned species observed during this study. Bocaccio were observed in a school of black rockfish swimming in the water column near a breakwater, whereas greenstriped rockfish were usually associated with cobble and rubble habitat or a concrete outfall block.

Reum's (2006) work used otter trawls at four depths (20–160 m) along the Main Basin of Puget Sound during 2004–2005 to describe seasonal and depth-related variation in feeding relationships of fish communities. Three of the rockfish species of interest were collected: greenstriped, redstripe, and yelloweye. Greenstriped rockfish were encountered at 0.544 kg/km (3.977 individuals 1,000 m^{-2}) during the summer at 80 m depth. Redstripe rockfish were found at 0.055 kg/km (0.389 individuals 1,000 m^{-2}) during the fall at 160 m depth and at 0.343 kg/km (3.398 individuals 1,000 m^{-2}) during the summer at 80 m depth. Yelloweye rockfish were found during the winter at 0.944 kg/km (0.853 individuals 1,000 m^{-2}) at 160 m depth and during the summer at 1.093 kg/km (1.879 individuals 1,000 m^{-2}) at 80 m depth and 2.365 kg/km (1.027 individuals 1000 m^{-2}) at 160 m depth.

Supplemental Fishery-independent Data

Besides the historical studies described above, there are several sources of fishery-independent data that have been collected for more extended periods of time. Most of these studies utilized a bottom trawl to collect demersal fishes over the past 25 years. Because of the affinity of canary rockfish, yelloweye rockfish, and bocaccio for untrawlable habitat, trawls are ineffective at sampling abundance of these species. However, information about presence or absence was considered valuable by the BRT when it was considered with the quantitative information provided in the body of the status review.

Unpublished data from the logbooks of University of Washington research vessels were recently summarized,[8] consisting primarily of otter trawls conducted from 1948 to 1978 throughout Puget Sound. All five of the petitioned rockfish species occur in the species list of this effort. Of the more than 1,000 trawls (n = 1,063) for which there was deemed sufficient documentation, the relative occurrence, percent frequency of occurrence, and total number individuals, respectively, of each species was as follows: greenstriped (8, 0.75%, 22), bocaccio (3, 0.28%, 3), canary (3, 0.28%, 3), redstripe (4, 0.38%, 5), and yelloweye rockfish (3, 0.28%, 4). Additional analysis of spatial and temporal patterns of occurrence is warranted; for example, all records of greenstriped rockfish occurred before 1959, with centers of abundance in Hood Canal and the Main Basin.

The Puget Sound Ambient Monitoring Program is a multiagency effort to monitor the health of the sound and assess the status and trends of chemical contamination in fish and macroinvertebrates (http://acwi.gov/monitoring/conference/98proceedings/Papers/52-REDM.html). During the period 1989–2001, marine or anadromous fish species were collected by trawl from more than 100 stations from Puget Sound and southern Georgia Basin, with special

---

[8] T. Essington, Univ. Washington, Seattle. Pers. commun., 7 May 2008.

focus on highly contaminated urban embayments. Samples from these trawls have included greenstriped (n = 14), redstripe (n = 17), and yelloweye rockfish (n = 4).[9]

Fishery-dependent Data

Palsson et al. (2009) provide a comprehensive overview of the management history, catch statistics, and fishery landing trends of rockfishes in Puget Sound. Below, we highlight aspects of this report that have direct bearing on the five petitioned rockfish species. We supplement it with additional information to provide additional context for the analyses present in the body of our status review.

Management History

The history of management of Puget Sound rockfish lends insight into the trajectory of rockfish landings in Puget Sound and the transition of the fishery from commercial to recreational. Regulation and management of this fishery from the onset has been based on rockfish as a group, and until very recently has not differentiated between different species and their life history, behavior, or ecology. Rockfish were harvested at relatively low levels by a small Puget Sound trawl fishery from perhaps the 1880s to the 1960s (Holmberg et al. 1967, Palsson et al. 2009). Trawl fisherman did not specifically target rockfish populations, which were marketed seasonally, considered scattered throughout Puget Sound, and principally comprised of copper, quillback, and orange (canary) species (Holmberg et al. 1967). In fact, management of rockfish in the sound received little attention until the 1970s, when Puget Sound fisheries were expanded and publicized to reduce social and economic stress from 1) displacement of Washington-based vessels from Canadian waters with Canada's extended jurisdiction over marine waters and 2) the reduction in salmon fishing opportunities by nontreaty fisheries from the 1974 Boldt decision (Palsson et al. 2009).

By the 1980s rockfish were recognized as an important recreational and commercial species in Puget Sound and were actively managed to favor recreational fisheries in South Puget Sound (SPS). Comprehensive groundfish plans were written by WDFW (Pedersen and DiDonato 1982, Pedersen and Bargmann 1986) and summarized what was then known about some of the most prominent groundfish species, including bocaccio, canary, and yelloweye rockfish. These plans emerged as a response to diminished catch trends, competition between user groups, and growth in the recreational fishery. The first bag limit reductions were instituted in 1983 and bottom trawling was banned south of Admiralty Inlet in 1984. By the 1990s signs of rockfish population decline were evident, more bag limit reductions were put in place, and a variety of commercial gears (trawl roller gear, bottomfish jig, and troll gear) were banned in NPS. By 2000 recreational rockfish bag limits were reduced to one fish in Puget Sound, commercial gear limits were expanded, and catch prohibitions instituted for yelloweye and canary rockfish throughout Washington's inside waters (Pedchenko 2005, Palsson et al. 2009).

---

[9] J. West, Washington Dept. Fish and Wildlife, Olympia. Pers. commun., 2 May 2008.

Landings Trends

Commercial rockfish landings have been documented since the 1920s by WDFW in the form of tax receipts or landing tickets (Palsson et al. 2009), whereas recreational landings have been estimated by dockside surveys since 1965 (Buckley 1967). Recreational harvests have typically exceeded commercial catch in each region and year since combined landings have been estimated. These trends are described in Palsson et al. (2009) and briefly summarized here. In general, annual rockfish landings remained under 20,000 lb before the 1940s, rose during World War II when harvests peaked at more than 375,000 lb, then fluctuated between 50,000 and 220,000 lb until 1970 (Palsson et al. 2009). After 1970 the total rockfish harvest generally mirrored fishing effort. Harvests gradually increased after 1970 when recreational fishing effort increased and this catch was incorporated into total landings estimates. By the mid-1970s total rockfish harvest had increased to more than 300,000 lb per year and peaked at nearly 900,000 lb in 1980. Annual harvest fluctuated between 48,000 lb and 300,000 lb between 1981 and 1991, declined below 30,000 lb during the 1990s, and reached a low of approximately 2,600 lb in 2003.

Harvest Details and Data Shortcomings

As the nature of the rockfish harvest has changed through time, so has the availability of particular types of biological information for later analysis. Some of the earliest reported commercial landings in Puget Sound from 1935 to 1964 are published in annual fishery reports (WDF 1964), although they share the common weakness that precise catch location and effort is not indicated, and these landings estimates are likely dominated by rockfish caught on the outer coast or in Canadian waters.

In the Puget Sound commercial fishery, bottom trawling accounted for the majority of recorded annual harvest of rockfish, averaging 84% of the total catch since 1955 (Palsson et al. 2009). Commercial fishing effort (e.g., hours trawling) is not available before 1955 (Holmberg et al. 1967, PMFC 1979, Schmitt et al. 1991). Furthermore, rockfish have never been distinguished by species in the commercial fishery, likely due to difficulties in differentiating between the many similar species and the irrelevance of this information to processors and the market. Rather, rockfish are considered as a group that includes all commercially retained red and black rockfish except Pacific ocean perch (*S. alutus*). As a result, there are no historic landing trends of individual rockfish species and no size data. Because commercial harvest only includes landed catch, the amount of rockfish bycatch that was discarded is unknown, but thought to be small relative to the landed portion.

After 1970 commercial groundfish catch, effort, and value statistics are documented in Puget Sound by subregion, but there are still very few discrete estimates of rockfish catch composition or size (Schmitt et al. 1991). For example, although Schmitt et al. (1991) provide 1970–1988 catch information on three of the petitioned species—bocaccio, yelloweye, and canary rockfish—these numbers were derived from percent composition estimates made in 1984 (derived from Pedersen and Bargmann 1986) that were later applied to “all rockfish” landings. The rare species composition estimates that do exist show that some gears were selective on particular species in some areas. For example, the 1984 percent species composition estimates show that approximately 70% of the rockfish catch (by weight) were represented by bocaccio in the set net fishery of the Main Basin and SPS regions and 20% by yelloweye rockfish in the San

Juan region. Set lines were similarly effective for catching bocaccio in Hood Canal (30% of rockfish catch by weight) and SPS (50%), and for yelloweye rockfish in Juan de Fuca (50%) and Hood Canal (30%). Rockfish species composition estimates made in 1988, 1989, 1990, 1991, and 1992 and 1993–2003 (Palsson et al. 2009) showed similar trends by commercial gear type.

Historical estimates of recreational catch present a number of challenges to interpretation because of relatively low or unequal sampling effort in time and space, large increments of unidentified and possibly misidentified rockfish, dependence on the recreational salmon fishery, and lack of diver, shore, and pier angler data. Estimates of rockfish recreational harvest by boat-based anglers were begun in 1965 (Buckley 1967, 1968, 1970, Bargmann 1977), but subsequent documents (e.g., Palsson 1988, Palsson et al. 2009) do not use data before 1970 because of the previously mentioned shortcomings. The recreational data does provide some of the only historical information on rockfish species composition and size in Puget Sound, although there are some disagreements in the reported data. As an example, sport catches published from 1975–1986 by WDF (1975–1986) show that bocaccio were harvested primarily from SPS (PCA 13) at rates of greater than 1,000 fish per year^{-1} from 1976–1982, including more than 7,500 bocaccio caught in 1977.

In comparison, the estimated catch of bocaccio presented by Palsson (1988) during the same years exceeds 1,000 bocaccio year^{-1} in only 1977 (1,128 fish). These differences are attributed to unpublished algorithms Palsson (1988) used to correct species composition data collected before 1980 using “reliable” Marine Recreational Fisheries Statistical Survey (MRFSS) estimates. WDFW rockfish species composition and catch data have been considered reliable since 2004 (Palsson et al. 2009); bocaccio are not noted as part of the recreational catch in these years.

Rockfish size data from Puget Sound are rare, even when compared to the notably infrequent species composition data. Of the data that exist, most have been collected via recreational creel surveys conducted by WDFW or the federal MRFSS since 1980. However, there are a handful of records reaching into the mid-1970s.

Other Fishery Details

Individual reports provide further insight into how the commercial fishery evolved and declined over time guided by market demand, technological advances, and management actions (Heyamoto et al. 1959, Holmberg et al. 1961, Holmberg et al. 1967). Geographically, the trawl fishery was often divided into two distinct groups: an ocean or outside fishery that included the Washington coast and waters off Vancouver Island, and a local or inside Puget Sound fishery that included catches of everything inside of a line extending north of Cape Flattery (PMFC catch area 4A, Washington statistical area 18) (Heyamoto et al. 1959). Catches from the outside fishery predominated and the bulk of all Washington trawl landings were made up of 10 major species (groups): Petrale sole (*Eopsetta jordani*), English sole (*Parophrys vetulus*), Dover sole (*Microstomus pacificus*), rock sole (*Lepidopsetta bilineata*), starry flounder (*Platichthys stellatus*), Pacific cod (*Gadus macrocephalus*), lingcod, sablefish (*Anoplopoma fimbria*), rockfish, and Pacific ocean perch. The principal species comprising the rockfish catch in the outer coast included bocaccio, canary, yellowtail, flag (*Sebastes rubrivinctus*), and splitnose (*S. diploproa*) (Holmberg et al. 1961).

The inside Puget Sound trawl fishery from 1955 to 1964 was exploited by about 50 vessels designed for a variety of fishing strategies (gill net, set net, purse seine, etc.). Most trawl fishing inside Puget Sound occurred in the winter and early spring when fishermen were not harvesting salmon or halibut; consequently rockfish demand was greatest, prices were higher, and the targeted effort likely increased when fresh fish such as salmon and halibut were scarce (Holmberg et al. 1961). The principal species taken by the trawl fishery during these years were Pacific cod, English sole, and starry flounder (Table F-1). Trawl fisherman did not specifically target rockfish, which were principally comprised of copper, quillback, and orange rockfish (Holmberg et al. 1967). Rockfish populations were considered "scattered throughout Puget Sound," and annual landings averaged less than 100,000 lb, a level considered rather insignificant (Holmberg et al. 1967, their Table 30). In fact, Puget Sound rockfish catches generally increased from 1955 to 1959, but catch rates remained below 20 lb/hr in most years, almost five times lower than the next most productive coastal region, leading the authors to conjecture that "this is all the inside waters are capable of producing" (Heyamoto et al. 1959).

Table F-1. Average annual landings by the Puget Sound trawl fishery from 1944 to 1964 (data from Holmberg et al. 1967).

Species group	**Average annual landings (lb)**	**Years**	**Price/lb**	**Comments**
Petrale sole			$0.10	Not abundant in Puget Sound
English sole	2,000,000	1945–1964		
Dover sole	<50,000	1951–1964	$0.065	Catches down by 1964
Rock sole				Not abundant in Puget Sound
Starry flounder	350,000	1944–1964		
Pacific cod	>3,000,000	1955–1964		
Lingcod (trawl)	>75,000	1955–1964		225,000 lb/yr by troll
Sablefish				Not abundant in Puget Sound
Rockfish	<100,000	1955–1964	$0.05	
Pacific ocean perch				Not abundant in Puget Sound
Small sole, walleye pollock, skate, hake			$0.03	Mink food

Recent NOAA Technical Memorandums

published by the

Northwest Fisheries Science Center

NOAA Technical Memorandum NMFS-NWFSC-

107 **Lian, C.E. 2010.** West Coast limited entry groundfish trawl cost earnings survey protocols and results for 2004. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-107, 35 p. NTIS number PB2011-102712.

106 **Harvey, C.J., K.K. Bartz, J. Davies, T.B. Francis, T.P. Good, A.D. Guerry, B. Hanson, K.K. Holsman, J. Miller, M.L. Plummer, J.C.P. Reum, L.D. Rhodes, C.A. Rice, J.F. Samhouri, G.D. Williams, N. Yoder, P.S. Levin, and M.H. Ruckelshaus. 2010.** A mass-balance model for evaluating food web structure and community-scale indicators in the central basin of Puget Sound. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-106, 180 p. NTIS number PB2011-102711.

105 **Gustafson, R.G., M.J. Ford, D. Teel, and J.S. Drake. 2010.** Status review of eulachon (*Thaleichthys pacificus*) in Washington, Oregon, and California. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-105, 360 p. NTIS number PB2011-102710.

104 **Horne, P.J., I.C. Kaplan, K.N. Marshall, P.S. Levin, C.J. Harvey, A.J. Hermann, and E.A. Fulton. 2010.** Design and parameterization of a spatially explicit ecosystem model of the central California Current. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-104, 140 p. NTIS number PB2010-110533.

103 **Dufault, A.M., K. Marshall, and I.C. Kaplan. 2009.** A synthesis of diets and trophic overlap of marine species in the California Current. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-103, 81 p. NTIS number PB2010-110532.

102 **Reppond, K.D. 2009.** Biochemistry of red king crab (*Paralithodes camtschaticus*) from different locations in Alaskan waters. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-102, 16 p. NTIS number PB2010-110531.

101 **Sands, N.J., K. Rawson, K.P. Currens, W.H. Graeber, M.H. Ruckelshaus, R.R. Fuerstenberg, and J.B. Scott. 2009.** Determination of independent populations and viability criteria for the Hood Canal summer chum salmon evolutionarily significant unit. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-101, 58 p. NTIS number PB2010-110530.

100 **Linbo, T.L. 2009.** Zebrafish *(Danio rerio)* husbandry and colony maintenance at the Northwest Fisheries Science Center. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-100, 62 p. NTIS number PB2009-113299.

Most NOAA Technical Memorandums NMFS-NWFSC are available online at the Northwest Fisheries Science Center web site (http://www.nwfsc.noaa.gov).