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

Biological Review Team
Northwest Fisheries Science Center
National Marine Fisheries Service
2725 Montlake Blvd. E.
Seattle, WA 98112-2097

Date
December 2, 2008

Table of Contents

TABLE OF FIGURES

SUMMARY

This report describes the preliminary conclusions of the National Marine Fisheries Service's (NMFS) Biological Review Team (BRT) on the status of five 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 under the U.S. Endangered Species Act (ESA).

The BRT has determined that populations of each of the 5 species in either Puget Sound Proper (inland marine waters south or 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 NMFS-U.S. Fish and Wildlife Service (USFWS) interagency policy on vertebrate populations (USFWS-NMFS 1996). 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 yelloweye rockfish, canary rockfish, and bocaccio, and a Puget Sound Proper DPS for redstripe rockfish and greenstriped 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 redstripe rockfish and greenstriped rockfish are the same as the previously identified DPS boundaries for copper, quillback and brown rockfish (Stout et al. 2001). All of the DPS designations were characterized by considerable uncertainty 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 threat to persistence of each DPS. Variability in ocean conditions and by-catch 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 redstripe and greenstriped rockfish are not at risk of extinction throughout all of their range.

INTRODUCTION

On April 9, 2007, 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 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 FR 56986; October 5, 2007). On October 29, 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 October 5, 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 petitions might support the identification of DPSs that might 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.

The Puget Sound rockfish Biological Review Team (BRT)[1]– consisting of scientists from the Northwest Fisheries Science Center and the Southwest Fisheries Science Center– was formed by NMFS, 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 which was received from the Northwest Region in draft form on May 19, 2008. In that memo the BRT was asked to consider whether the petitioned species meet the criteria for being considered DPS as defined by the joint NOAA-FWS Distinct Population Segment (DPS) Policy (61 FR 4722; February 7, 1996). If DPS 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

[1] The BRT for Puget Sound rockfish consisted of the following: Dr. Ewann Berntson, Dr. Jason Cope, Dr. Jonathan Drake (co-chair), Dr. Rick Gustafson, Dr. Eli Holmes, Dr. Phillip Levin (co-chair), Dr. Nick Tolimieri, Dr. Robin Waples, (NMFS, Northwest Fisheries Science Center) and Dr. Susan Sogard (NMFS, Southwest Fisheries Science Center)

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 risk 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 manmade factors affecting its continued existence.

This document is a preliminary report of the conclusions of BRT on the status of the five petitioned rockfish species from Puget Sound, Washington. A final report is being prepared and will be available at a later time.

THE “SPECIES” QUESTION

As amended in 1978, the ESA allows listing of “distinct population segments” of vertebrates as well as named species and subspecies. Guidance on what constitutes a “distinct population segment” is provided by the joint NMFS-U.S. Fish and Wildlife Service (USFWS) interagency policy on vertebrate populations (USFWS-NMFS 1996). 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 DPS in marine fish, NMFS has placed the emphasis on biological information in defining DPS and has considered political boundaries only at the implementation of ESA listings. Therefore, the BRT focused only on biological information in identifying DPS 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 sections.

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 are usually also strongly influenced by environmental factors over the life time 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) have emphasized 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, there is evidence from the study of the developmental energetics that 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, which is 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 & Chesson 1985, Tolimieri & Levin 2005). Recruitment is generally poor because larval survival and settlement are dependent upon the vagaries of climate, the abundance of predators, oceanic currents and chance events. Being long-lived allows adult population to persist through many years of poor reproduction until one good recruitment year occurs.

Bocaccio (*Sebastes paucispinis*) 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 third group 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 and sand (Love et al. 1991). Several weeks after settlement fish move to deeper waters in the range of 18-30 m where they are found on rocky reefs (Feder et al. 1974, Carr 1983, Johnson 2006, Love & 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 & 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 into 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 three years for both males and females, although males (32 cm) are somewhat smaller than females (36 cm). Fifty percent of males are mature by age three (42 cm), and all are mature by seven years (55 cm). Fifty percent of females are mature by their fourth year (48 cm), and all are mature by eight years of age (60 cm) (Wyllie Echeverria 1987). Off of southern California 50% of males are mature at 35 cm and all are reproductive at 42 cm. Fifty percent of females are reproductive at 36 cm and all are mature at 44 cm. Off Oregon bocaccio mature at larger sizes with females beginning to mature at 54 cm and all 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 of north 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 prior to 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 45 years (Ralston & 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 two 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 half of the adult bocaccio stayed within areas around 200-400 ha the majority of the 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 prior to returning. Some individuals remained at fairly constant depths while other changed depth by as much as 100m, generally moving more shallow 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, sablefish, anchovies, lanternfishes but also squid (Love et al. 2002). King salmon, terns and harbor seals are known predators on smaller bocaccio (Love et al. 2002).

Fishery

Bocaccio historically were targeted heavily both in recreational and commercial fisheries from the Canadian border down into Mexico. Catches of bocaccio are attributed to set nets, trawls, and hook-and-line gears. The largest captures are mainly south of Cape Mendocino down into the southern Californian 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 population increase has been detected due mostly to a very strong recruitment event in 1999.

Canary Rockfish (Sebastes pinniger) 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 & Lea 1972, Hart 1973, Cailliet et al. 2000, Love et al. 2002). In Canadian waters (B.C.), 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 the intertidal, in surface waters, and occasionally to as deep as 838 m (Love et al. 2002). Larger fishes tend to inhabit deeper waters with the mean size of fishes increasing in the 55 – 90 m depth range and remaining stable thereafter (Methot & 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 from 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 & 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 and then move into sandy areas at night (Love et al. 2002). Juveniles remain on rocky reefs in shallower areas for as much as three years prior to moving to deeper waters (Boehlert 1980, Methot & Stewart 2005). Fish move deeper as they increase in size (Vetter & Lynn 1997), and adults are found on the rocky shelf 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 is 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 are mature by 9 years (44 cm). All females 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 the waters off of Vancouver Island, 50% of females are mature at 41 cm and males at 48 cm (Westrheim 1975).

Females produce between 260,000 and 1,900,000 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 with geographically (Gunderson et al. 1980, Love et al. 2002).

Fertilization occurs as early as September off of central California (Lea et al. 1999) but peaks in December (Phillips 1960, Phillips 1964, Wyllie Echeverria 1987). Parturition occurs between January and April and peaks in April (Phillips 1960). Off of 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 & 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 & Laroche 1979, Stahl-Johnson 1985).

Estimates of larval duration range from 1-2 months (Moser 1996a) to 3-4 months (Krigsman 2000, Love et al. 2002). Juveniles settle at approximately 18.5 mm SL (Richardson & Laroche 1979, Moser 1996b).

Females grow larger and more quickly than do males (Lenarz & Echeverria 1991, STAT 1999), although growth does not appear to vary with latitude (Boehlert & Kappenman 1980). A 58 cm female is approximately 20 years of age; a male of the same age is about 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 & Stewart 2005).

Migrations and Movements

Fish tend to move to deeper water as they grow larger (Vetter & Lynn 1997). In terms of alongshore movements they are reported as being both transient (DeMott 1983, Casillas et al. 1998) and resident (Gascon & Miller 1981). Demott (1983) tagged 348 fishes off of Oregon between 1978 and 1982. Of the 23 recaptures, twelve fish moved over 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 from 160-210 m in the late winter to 100-170 m in the late summer (COSEWIC in press).

Trophic Interactions

Canary rockfish larvae and planktivores feeding primarily on nauplii, and other invertebrate eggs and copepods (Moser & 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 & Roughgarden 1987, Love et al. 1991). They are diurnal feeders (Singer 1982). Predators on juvenile rockfish include other fishes, especially rockfishes, lingcod, cabezon and salmon, as well as birds and porpoise (Miller & Geibel 1973, Morejohn et al. 1978, Roberts 1979, Ainley et al. 1981, Love et al. 1991).

Adult canary rockfish are planktivores/carnivores consuming euphasiids and other crustacean, small fishes like shortbelly rockfish Sebastes jordanii, mytophids and stomiatiods (Cailliet et al. 2000, Love et al. 2002). Canary rockfish predators include yelloweye rockfish, lingcod, salmon, sharks, dolphin, seals (Merkel 1957, Morejohn et al. 1978, Antonelis Jr. & Fiscus 1980, Rosenthal et al. 1982) and possibly river otters (Stevens & Miller 1983).

Canary rockfish can be 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 & Moser 1983).

Fishery

Canary rockfish supported an important commercial fishery off California for over 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 pre-fishing levels (Stewart 2007). Though canary rockfish have been declared overfished off the west coast of the United States, the population has demonstrated increases since the 1990s.

Yelloweye Rockfish (Sebastes ruberrimus) General Biology

Geographical Distribution and Habitat

Yelloweye rockfish range along the US and Canadian west coast, with individuals recorded from northern Baja California to the Aleutian Islands. The major portion of the abundance is found central California to Alaska and they are rare in Puget Sound (Love et al. 2002). Yelloweye rockfish use a broad depth range throughout their life history, with individuals recorded 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 between 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, Love et al. 1991, O'Connell and Carlisle 1993, Richards 1986). 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 rockfishes associations with deepwater corals demonstrated an association of some rockfishes to their habitats (Andrews et al. 2002, Krieger and Wing 2002). Yelloweye rockfish can be 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 the months of 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 as one moves from south to north in their range (DeLacy et al. 1964, Hitz 1962, Lea et al. 1999, O’Connell 1987, Westrheim 1975). Larvae are extruded after a typical gestation period of a couple 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 fertilized eggs during the winter to summer months, giving birth 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 1996), settling at around 25 mm (Love et al. 2002). Female yelloweye rockfish can produce from 1.2 to 2.7 million eggs over a reproductive season, with a mean eggs per gram body weight of 300 (Hart 1973, MacGregor 1970). 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 400 to 500 mm and ages of 15 to 20 (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 690 mm for males and females (Rosenthal et al. 1982). A study in British Columbia (Westrheim and Harling 1975) estimated this parameter at 676 and 659 for males and females, respectively (Yamanaka et al. 2006). A study in California also noted males obtaining a mean size greater females (Lea et al. 1999). Maximum size is reported as 910 mm (Love et al. 2005) and maximum age at 118 (Munk 2001). Natural mortality rates has been estimated from 0.02 to 0.046 (Wallace 2007, Yamanaka and Kronlund 1997).

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 (Coombs 1979, DeMott 1983, Love 1978).

Trophic Interactions

Yelloweye rockfish are opportunistic feeders, targeting different food sources at during different phases of their life history. The early life stages following typical rockfish predator-prey relationships. Because adult yelloweye rockfish obtain such large sizes, they are able to handle much larger prey, including smaller yelloweye, and are preyed upon less frequently (Rosenthal et al. 1982), though predation of killer whales on yelloweye rockfish has been reported (Ford et al. 1998). Typical pray of adult yelloweye rockfish include sand lance, 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 (Sebastes elongatus) General Biology

Geographical Distribution and Habitat

Greenstriped rockfish is a typically wide-ranging North Pacific rockfish, with individuals recorded from central Baja California to the Aleutian Islands (Shaw 1999). The major portion of the abundance is found British Columbia down to northern Baja California (Love et al. 2002). Greenstriped rockfish are also found in the southern Puget Sound region (Palsson et al. pers. comm.). Greenstriped rockfish also span a broad depth range, with individuals recorded 12 to 495 m. Juvenile are often found in shallower depths, making an ontogenetic shift to deeper waters. Adults are most commonly found between 150 to 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 sea-floor bottom, but may occur in large numbers.

Reproduction

Greenstriped rockfish are internally fertilized and store sperm for several months until fertilization occurs, commonly between the months of 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 a couple months, peaking in June for areas around Oregon to Alaska (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 some evidence of multiple spawning have 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 150 mm and 5 years of age, with 50% maturity occurring at 230 mm and 7-10 years (Shaw and Gunderson 2006, Wyllie Echeverria 1987). 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 375 mm in British Columbia (Westrheim and Harling 1975) and 300 and 375 for males and females, respectively, from California to Washington (Shaw and Gunderson 2006). Maximum sizes obtained are 430 mm (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 has been reported as 54 years (K. Munk, pers. comm.). Natural mortality rates (M) 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 (Moser and Boehlert 1991, Sumida et al. 1985). 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 porpoise (Ainley et al. 1993, Love et al. 1991, Morejohn et al. 1978). 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 (Antonelis Jr. and Fiscus 1980, Merkel 1957, Morejohn et al. 1978).

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 bigger sizes (Love et al. 2002). They are also frequently taken, but not targeted, in recreational fisheries, and often discarded.

Redstripe Rockfish (Sebastes proriger) General Biology

Geographical Distribution and Habitat

Redstripe rockfish are wide ranging, with reports of individuals from southern Baja California to the Aleutian Islands (Love et al. 2002), including the Puget Sound. Redstripe rockfish 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. Juvenile settle in shallower depths and move to deeper habitat as adults. Adult redstripe rockfish are most commonly found between 150 to 275 m.

Redstripe rockfish are most commonly found on a variety of substrates, from hard, high-relief reefs to and 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 sea-floor bottom (Love et al. 2002).

Reproduction

Redstripe rockfish are internally fertilized and store sperm for several months until fertilization. Fertilization occurs between the months of April and May in areas north of California (O'Connell 1987, Shaw 1999, Wyllie Echeverria 1987). Larvae are extruded after a typical gestation period of a couple months, peaking in July for British Columbia (Westrheim 1975) and from June in Oregon (Shaw 1999, Wyllie Echeverria 1987). Redstripe rockfish spawn once (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 for redstripe rockfish is 210 to 220 mm (Shaw 1999). Size at 50% maturity was recorded in the 1970s to be 280 and 290 mm (Westrheim 1975) for males and females, respectively, differing for samples collected in the 1990s (243 and 262 mm 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 410 to 420 mm in British Columbia, while males reach mean asymptotic mean size at 330 and 340 mm (Westrheim and Harling 1975). Individual redstripe rockfish taken from California to Washington were estimated to reach a mean asymptotic size of 295 to 383 for males and females respectively (Shaw 1999). Maximum sizes obtained are 510 mm (Shaw 1999). Maximum age has been reported at 40 years (T. Laidig, pers. comm.). 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. Redstripe rockfish adults are generally considered to be site-attached.

Trophic Interactions

Redstripe rockfish are active and opportunistic feeders, and show feeding habits similar to the greenstriped rockfish. Larvae are diurnal, with nauplii, eggs, and copepods representing important food sources (Moser and Boehlert 1991, Sumida et al. 1985). Siphonophores and chaetognaths commonly prey on redstripe rockfish 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 are preyed upon by birds, nearshore fishes, salmon, and porpoise (Ainley et al. 1993, Love et al. 1991, Morejohn et al. 1978). 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 (Antonelis Jr. and Fiscus 1980, Merkel 1957, Morejohn et al. 1978).

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 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' (Burford and Bernardi 2008, Johns and Avise 1998) 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) receive 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 created conditions that retain larvae rather than distribute them (Graham et al. 1992, Owen 1980, Wing et al. 1998). Larger barriers to dispersal have also been identified in many rockfishes (Cope 2004, Matala et al. 2004, Williams and Ralston 2002), potentially dividing the coast up 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 (Hyde et al. 2008, Narum et al. 2004).

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 found strong separation between coastal and inland populations (Buonaccorsi et al. 2002). This separation may be maintained through a very low exchange of water (Ebbsmeyer et al. 1984), thus promoting the isolation of Puget Sound populations from coastal conspecifics.

The 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 of the criteria 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 (USFWS-NMFS 1996) 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 of unique species' assemblages (Ekman 1953, Hedgpeth 1957, Briggs 1974, Allen and Smith 1988). These province boundaries are usually coincident with changes in the physical environment such as temperature and major oceanographic currents. Similarly 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. Along the coastline of the boreal eastern Pacific, which extends roughly from Point Conception, California to the eastern Bering Sea, numerous schemes have been proposed for grouping the faunas into zones or provinces.

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 from fishes, respectively, and found the coastal region from Puget Sound to Sitka, Alaska to be a "gray zone" or transition zone that could be classified as part of either of two provinces: Aleutian or Oregonian (see Figure 1, Figure 2, and Figure 3). The southern boundary of the Oregonian Province is generally recognized as Point Conception, California and the northern boundary of the Aleutian Province is similarly recognized as Nunivak 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, Alaska. Briggs (1974) placed strong emphasis on the distribution of littoral mollusks (due to the more thorough treatment this group has received) 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 area. Valentine (1966) erected the term Columbian Sub-province 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, Alaska, off northern Vancouver Island, or off Cape Flattery, Washington (Peden and Wilson 1976, Allen and Smith 1988). Chen (1971) found that of the more than 50 or more rockfish species belonging to the genus *Sebastes* occurring 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 over 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. 2269) found a breakpoint between zoogeographic zones “in the vicinity of the Queen Charlotte Islands.”

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

This section 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 section, along with Appendices C (Geological and climate history of Puget Sound) and D (Marine species in Greater Puget Sound) 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 rockfish species are also found throughout the extensive inland waterway that also encompasses the Strait of Georgia in Canada, a brief description of this larger system is also presented.

Greater Puget Sound is a fjord-like estuary located in northwest Washington State and covers an area of about 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 Strait of Georgia and Strait of Juan de Fuca (Burns 1985). This extensive system (the Georgia-Fuca system) is 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). It 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 forcing 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 define 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 upon 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, 2) Main Basin, 3) Whidbey Basin, 4) South Puget Sound, and 5) Hood Canal (Figure 4) When considered DPS designations for the petitioned species the Main Basin, Whidbey Basin, South Puget Sound and Hood Canal are collectively referred to as "Puget Sound Proper" 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 (NMFS 2007). Tidal currents dominate the circulation, and typically a two-layered pattern of estuarine circulation is superimposed on the tides (Ebbesmeyer et al. 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 the 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 (NOAA, 1984).

Large tidal exchanges combined with 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 the greater Puget Sound, largely due to the flux of oceanic water into the basin (Harrison et al. 1994).

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 /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 (NOAA Technical Memorandum NMFS-NWFSC-44). 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 over 4,000 km of shorelines, ranging from rocky sea cliffs to coastal bluffs and river deltas. Most of Puget Sound's shorelines are coastal bluffs, which are composed of erodable gravel, sand, and clay deposited by glaciers over 15,000 years ago (Downing 1983; Shipman 2004). Extensive development of coastal bluffs along the Sound 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 shorelines, 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, sub tidal soft sediments, eelgrass beds, and open water/pelagic habitats (Dethier 1990, Levings and Thom 1994, NMFS 2007). The shallow nearshore areas of Puget Sound contain vegetated eelgrass and seaweed habitats that support most marine fish and invertebrate populations 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 South Sound (Nearshore Habitat Program 2001, Mumford 2007). Other major habitats include sub aerial and intertidal wetlands (176 km^2), and mudflats and sand flats (246 km^2). In pelagic areas, the euphotic zone extends to about 20m in the relatively clear regions of Northern Puget Sound, and to 10m in the more turbid waters of the South Sound. 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 (*Sebastes* spp.). Approximately 95% of the rocky reef habitat in greater Puget Sound is located in North Puget Sound (Palsson et al. 2008).

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

Northern Puget Sound

<u>Bathymetry and geomorphology</u>. Northern Puget Sound encompasses southern Georgia Strait 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 the North Sound is the Strait of Juan de Fuca, which is 160 km long and 22 km wide at its western end to over 40 km at its eastern end (Thomson 1994). Other notable geographic features include Admiralty Inlet, the San Juan Islands, and the southern part of the Georgia Strait.

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). Sub tidal depths range from 20 to 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 from 120 to 180 m in depth (PSWQA 1987).

The vast majority (approximately 93%) of the rocky-reef habitat in greater Puget Sound is located in the Northern Puget Sound region. Pacunski and Palsson (1998) estimated that about 200 km² of shallow (<39 m MLLW) rocky-reef habitat was present in Northern Puget Sound, whereas only about 14 km² was found in the remaining Puget Sound basins.

<u>Sediment characteristics</u>. 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 North Sound and gradually becomes finer towards the mouth (Anderson 1968). Many of the bays and sounds in the eastern portion of the North Sound have sub tidal 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 sub tidal surface sediments among the San Juan Islands consist 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).

<u>Currents and tidal activity</u>. 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, the circulation in the Strait consists of seaward surface flow of diluted seawater (<30.0psu) in the upper layer and an inshore flow of saline oceanic water (>33.0 psu) at depth (Thomson 1994, Collias et al. 1974). Exceptions include an easterly flow of surface

waters near the shoreline between Port Angeles and Dungeness Spit (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^{o} and 11^{o}C, although occasionally surface temperatures reach as high as 14^{o}C (WDOE 1999). In the eastern portion of North Sound, temperature and salinity vary from north to south, with the waters in the Strait of Georgia being slightly warmer than the waters near Admiralty Inlet. Waters near Admiralty Inlet also tended to have higher salinities than waters to the north (WDOE 1999). Dissolved oxygen levels vary seasonally, with lowest levels of about 4 mg/L at depth during the summer months, and highest levels of about 8 mg/L near the surface during the winter. However, in a study conducted between 1996 and 1997, WDOE reported dissolved oxygen (DO) levels in the southern end of Discovery Bay below 3.0 mg/l (PSQAT 2000).

Macro vegetation. 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 Puget Sound proper Basins (Mumford 2007). Nevertheless, both areas each have approximately 50% of the total kelp resource. Most species of kelp 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).

Urban, industrial, and agricultural development. The North Puget Sound Basin is bordered primarily by rural areas with a few localized industrial developments (PSWQA 1988). About 71% of the area draining into North Puget Sound is forested, 6% is urbanized, and 15% is used for agriculture (NMFS 2007). Among the five greater Puget Sound basins, this basin is used most heavily for agriculture. The main human population in this area centers around Bellingham (71,289), Port Angeles (18,397), Anacortes (14,557), and Port Townsend (8,334) (US Census Bureau, 2003 population census). About 10% of the total amount of wastes discharged from point-sources into greater Puget Sound comes 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 originates from rivers carrying runoff from areas of agricultural and forest production (Embrey and Inkpen 1998). The Washington Department of Natural

Resources (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 such water bodies as 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 sub-basins: 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, 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. Sub tidal 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 also found in the bays and inlets bordering this basin.

Currents and tidal activity. About 30% of the freshwater flow into the Main Basin is derived 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 the 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 about 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/cm²/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 mid-depth when the basin is cooler than 9.7°C. However, the strongest oceanic currents move toward the bottom of the basin, during warmer, dryer periods when waters are warmer than 9.7°C.

Water quality. Water temperature, salinity, and concentration of dissolved oxygen in waters of the Main Basin are routinely measured by the 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 about 30 psu in summer and fall, but decrease to about 29 psu during the rainier 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 mid-basin has consistently higher temperatures and lower salinity relative to the Northern Puget Sound region (WDOE 1999). Dissolved oxygen 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, summer-time highs reach 13-14 mg/L at the surface.

Macro vegetation. 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 (2003 census) (US Census Bureau 2003). Approximately 70% of the drainage area in this basin is forested, 23% is urbanized, and 4% is used for agriculture (Staubitz et al. 1997). About 80% of the total amount of waste discharged from point-sources into greater Puget Sound comes from urban and industrial sources in this region (PSWQA 1988). Moreover, about 16% of the waste entering greater Puget Sound, 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 Camano Island and receives freshwater from the Stillaguamish River at the northern end and from the Snohomish River (the second largest of greater Puget Sound's rivers) at southeastern corner. Port Susan also contains a deep area (120 m) near Camano Head. The deepest section of the basin is located near its southern boundary in Possession Sound (220 m).

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 is the next most common sediment type covering 25.6 ± 18.9% of the intertidal area (Bailey et al. 1998). Similarly, sub tidal 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 largely 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 northward toward Deception Pass. Approximately 60% of the water from the Skagit River flows through Deception Pass, and this water flows directly into the Strait of Juan de Fuca (Ebbesmeyer et al. 1984). Current speeds through Deception Pass are among the highest in Puget Sound; a westward surface current speed of 37.37 cm/sec, and an eastward bottom current of 5.92 cm/sec were reported by PSWQA (1987). Currents through Saratoga Passage tend to move at moderate rates in a southerly direction (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 being warmer in summer (generally 10-13^{o}C) and cooler in winter (generally 7-10^{o}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 from 10-15 psu. However, salinities in deeper areas often parallel those of the Main Basin (WDOE 1999).

Concentrations of dissolved oxygen in the waters of the Whidbey Basin are routinely measured by the 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 run-off had the highest concentrations of dissolved oxygen. 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).

Macro vegetation. 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, agricultural, and 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 from 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). The WDNR (Nearshore Habitat Program 2001) estimated that 36% of the shoreline in this area has been modified by human activities.

Southern Puget Sound

Bathymetry and geomorphology. The Southern Basin 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 of this basin is 37 m, and the deepest area (190 m) is located east of McNeil Island, just south of the sill (45 m) at Tacoma Narrows (Burns 1985). The largest river entering the basin is the Nisqually River which enters just south of Anderson Island.

Sediment characteristics. A wide assortment of sediments are 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 as follows: mud, 38.3 ± 29.3%; sand, 21.7 ± 23.9%; mixed fine, 22.9 ± 16.1%; and gravel, 11.1 ± 4.9%. Sub tidal 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 largely to the shallowness of Squaxin Passage (Ebbesmeyer et al. 1998). These current patterns are characterized by flows of high salinity waters from Budd and Eld inlets into the south end of Case Inlet, and from Totten and Hammersley inlets into the north end of Case Inlet. Flows of freshwater into the north and sound ends of Case Inlet originate from surface water runoff and the Nisqually River, respectively.

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 from 27-29 psu, and, although surface temperatures reach 14-15^{o}C in summer, the temperatures of subsurface waters generally range from 10-13^{o}C in summer and 8-10^{o}C in winter (WDOE 1999). Dissolved oxygen levels generally range from 6.5 to 9.5 mg/L. Salinity in the inlets tends to be similar to those of the major channels, whereas temperatures and dissolved oxygen levels in the inlets are frequently much higher in summer. Two of the principal inlets, Carr and Case inlets, have surface salinities ranging from 28-30 psu in the inlet mouths and main bodies, but lower salinities ranging from 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 from 15-19^{o}C and dissolved oxygen values of 10-15 mg/L. Temperature of subsurface water tends to be elevated in the summer (14-15^{o}C); however, temperatures are similar to those of the main channels in other seasons of the year (WDOE 1999).

Macro vegetation. Among the five basins of greater Puget Sound, the Southern 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) being 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 South Sound Basin are found in the western portions of Pierce County. These communities include west Tacoma, University Place, Steilacoom, and Fircrest, with a combined population of about 100,000. Other urban centers in the South Sound Basin include Olympia with a population of 43,963 and Shelton with a population of 8,442 (U.S. Census Bureau 2003). Important point sources of wastes include sewage treatment facilities in these 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 non-point sources (Embrey and Inkpen 1998). The 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, being 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 of Hood Canal (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 sub-basins (200 and 180 m, respectively), whereas other areas are relatively shallow, <40 m for The Great Bend and 50-100 m at the Hood Canal entrance (Collias et al. 1974).

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 sub tidal 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 1984).

Water quality. Portions of Hood Canal are stratified, with marked differences temperature and dissolved oxygen between the entrance and the Great Bend. Water temperature, salinity, and concentration of dissolved oxygen in Hood Canal are routinely measured by the 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 dissolved oxygen values are often markedly different between the two sites.

Macro vegetation. 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-around residences (PSWQA 1988). A small amount of waste is generated by forestry practices and agriculture. Nutrients (as inorganic nitrogen) from non-point sources in this basin represent only 3% of the total flowing into greater Puget Sound annually (Embrey and Inkpen 1998). The 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 from 0^oC to 5^oC in January and 12^oC to 22^oC in July, and 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) and 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 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).

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). The rate of flow in the Fraser River 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 run-off 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 off 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 counter-clockwise direction (Waldichuck 1957). Tides, winds, and freshwater run-off 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 of Georgia. The upper, brackish water layer in the Strait of Georgia is influenced by large freshwater run-off and salinity in this layer varies from 5 to 25 psu. Deep, high-salinity (33.5 to 34 psu), oceanic water enters the Strait of Georgia 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 is a southerly outflow of low-salinity surface water through the 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 the 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 run-off peaks near the time of peak salinity of inflowing source water, the salinity of the deepwater in the Strait of Georgia undergoes only a small seasonal change in salinity (Waldichuck 1957).

Genetic Differentiation

The 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 that are not found in the cell nucleus. Mitochondrial DNA differs from nuclear DNA (nDNA) in two ways. One way 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. A second way is that 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 markers 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, the rockfish radiation appears to have been relatively abrupt, with pulses of diversification occurring approximately 9-8 MYA and 8-6 MYA, resulting in poor resolution of internal phylogenetic nodes (Hyde & Vetter 2007). A great deal of diversity exists among species, with frequent exceptions to otherwise general patterns or expectations. More effort will therefore need 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 inhabit geographically isolated areas, such as Puget Sound, tend to be genetically differentiated from other populations.

Bocaccio (*Sebastes paucispinis*)

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 the outer coast. Wishard et al. (1980) examined allozyme variation in nine coastal sampling locations ranging from Baja California to southern Oregon, with sample sizes ranging from $n = 12$ to over 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 seven microsatellite loci in samples ($n = 30$-67) from eight 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 breeding population. A large-scale pattern of isolation by distance was not observed in the data. 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. The authors 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.

Canary rockfish (*Sebastes pinniger*)

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 PGM 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 (*Sebastes ruberrimus*)

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 Georgia Strait 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 vs. 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 (R. Withler, personal communication July 2008). Preliminary analysis of these new samples shows that these patterns remain consistent: all the 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 the Gordon Channel. Whether a similar pattern occurs in the south is not know, 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 (*Sebastes elongatus*)

Very little genetic information is available for greenstriped rockfish. A preliminary study of mitochondrial DNA control region sequences (J. Hess, unpublished 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 species: most haplotypes shared by more than one individual were found in all populations sampled, and the only significant pair wise comparison was Washington coast vs. California. However, sample sizes were low (12-40 individuals), so power to detect differences was also low. Furthermore, because no samples were available from Puget Sound proper, this preliminary study provided no information about the relationship between greenstriped rockfish in Puget Sound and the Pacific coast.

Redstripe rockfish (*Sebastes proriger*)

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 discussion above, essential 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 was sufficiently similar to species that have been subject to genetic analysis that did include samples from Puget Sound that patterns of variation from these "surrogate species" should be considered when evaluating potential DPS for the less studied petitioned species.

Despite the lack of genetic studies targeting the five species named in the current petition, some information is available for other rockfish species found in Puget Sound. Copper (*Sebastes caurinus*), brown (*S. auriculatus*), and quillback (*S. maliger*) rockfish are three closely related species that were the subject of a previous Biological Review Team, the results of which can be found in Stout et al. (2001). 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 (see 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 of 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 brown, quillback and copper rockfish and yelloweye rockfish, a study of Pacific ocean perch (*S. alutus*) 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 non-rockfish species have been studied in- and outside of Puget Sound, including Pacific hake (*Merluccius productus*), Pacific cod (*Gadus macrocephalus*), walleye pollock (*Theragra chalcogramma*), lingcod (*Ophiodon elongatus*), and 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 species 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 southern Puget Sound) (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 both 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 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

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. DPS's have been designated for portions of the range of Pacific hake (*Merluccius productus*), Pacific cod (*Gadus macrocephalus*), walleye pollock (*Theragra* *chalcogramma*) (NMFS 2000), copper rockfish (*Sebastes caurinus*), quillback rockfish *(S. maliger*), brown rockfish (*S. auriculatus*) (NMFS 2001), bocaccio (*S. paucispinis*) (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 the 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 (Puget Sound Proper DPS, Northern Puget Sound DPS, and coastal DPS) and two of brown rockfish (Puget Sound Proper DPS and coastal DPS) were identified. Some of these marine fish 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. 2001b).

Of particular interest to the current BRT, the previous BRT assembled to consider Puget Sound populations of copper rockfish (*S. caurinus*), quillback rockfish (*S. maliger*), and brown rockfish (*S. auriculatus*) (Stout et al. 2001) faced similar questions to the current petition regarding the DPS designation for rockfish found in inland marine waters of Washington state. With regard to discreteness, Stout et al. (2001) 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 and the environmental features of Puget Sound. With regard to significance, Stout et al. (2001) 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. were unanimous in their decision for a Puget Sound proper DPS for copper rockfish, distinct from a North Puget Sound 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 Puget Sound proper specimens, but microsatellite data from Wimberger (in prep) and Buonaccorsi et al. (in prep) showed large differences among populations from within Puget Sound proper and populations found outside Puget Sound proper. 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 found within Puget Sound proper). Wimberger found significant divergence between both Central Puget Sound and Admiralty Inlet populations, and all populations found outside of Puget Sound proper. Equal divergence was found among Puget Sound proper populations compared with San Juan, Gulf Island, and coastal populations as well.

Buonaccorsi et al. (in prep, subsequently published as Buonaccorsi et al. 2002) used a different set of microsatellite loci to compare populations from Puget Sound proper, 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 Puget Sound proper and the Canadian Gulf

Islands. Buonaccorsi et al. also identified private alleles in Puget Sound proper, further evidence for isolation of Puget Sound proper populations from other neighboring regions. In addition to genetic information, Stout et al. pointed out that copper rockfish are live-bearing and have internal fertilization, a short pelagic larval stage, and high habitat fidelity. All of these traits, combined with the physical isolation of Puget Sound proper, could lead to reproductive isolation of the Puget Sound proper DPS.

Stout et al. (2001) were somewhat divided regarding the appropriate DPS for quillback rockfish, but 66% of the BRT supported a Puget Sound proper DPS, as distinct from a North Puget Sound 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 Puget Sound proper, 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 Puget Sound proper and the San Juan Islands. When the Puget Sound proper 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 Puget Sound proper and the San Juan Islands. The San Juan Island population was more similar to Sitka, Alaska, than it was to Puget Sound proper. 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 Puget Sound proper DPS was appropriate for quillback rockfish as well.

Brown rockfish have a distribution that is very different from copper and quillback rockfishes, as they are found in Puget Sound proper but only rarely occur in North Puget Sound, Georgia Basin, or the Washington and Oregon coastline (Stout et al. 2001). The large disconnect between Puget Sound proper and coastal populations of brown rockfish suggested to the previous BRT that the Puget Sound proper population might be a remnant population in an ecologically unique habitat. Genetic data available at the time supported a divergence between Puget Sound proper and California populations (Seeb 1998). Stout et al. noted that a microsatellite study was underway which would also compare coastal and Puget Sound populations (subsequently published, Buonaccorsi et al. 2005). Buonaccorsi et al. sample three sites within Puget Sound Proper, and compared them to coastal populations ranging from California to Mexico. They found significant divergence among the populations, and even between two of the Puget Sound proper populations. Puget Sound proper populations exhibited extremely low genetic divergence compared to coastal samples, which suggested to the authors a potential founder effect combined with reproductive isolation, and/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 President Clinton’s Forest Plan (Forest Ecosystem Management: An Ecological, Economic, and Social Assessment Report of the Forest Ecosystem Management

Assessment Team [FEMAT, http://www.or.blm.gov/ForestPlan/ NWFPTitl.htm]). This method has also been used in all recent status review updates for federally listed Pacific salmon and steelhead (*Oncorhynchus mykiss*) ESUs (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 ten "likelihood" points among a number of proposed DPS scenarios, reflecting their 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 Puget Sound proper, he or she could assign all 10 points to that scenario. A member with less certainty about DPS boundaries could split their points among two, three, or even more DPS scenarios. Ultimately each BRT member distributed their 10 "likelihood points" amongst these 4 possible DPS scenarios. With nine 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 4 possible DPS scenarios that could incorporate the petitioned Puget Sound rockfish species:

1. DPS Scenario 1 (Puget Sound Proper) is a Puget Sound Proper DPS identical to the Puget Sound Proper DPS defined by Stout et al. (2001) for copper, quillback and brown rockfish. This scenario posits a DPS consisting of the members of the species in questions inhabiting the waters south or east of Admiralty Inlet. This is the DPS structure that was identified in the petition.

2. DPS Scenario 2 (Greater Puget Sound) hypothesisizes a DPS that includes Puget Sound Proper and Northern Puget Sound (which includes the San Juan and Canadian Gulf Islands).

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 (Coastal DPS) consists of a coastal DPS, whose northern and southern terminus were not defined, but which also includes the region described in DPS Scenario 3.

Factors considered in common to all species

Based on the earlier DPS designations for copper rockfish, quillback rockfish and brown rockfish (Stout et al. 2001), the BRT generally assumed that in the absence of information indicating otherwise, the five petition species where likely to have DPS in inland marine waters distinct from coastal populations. The reasoning for this is that the ecological and environmental factors considered by Stout et al. (2001) and reviewed in earlier sections of this report – including the relatively site-attached nature of rockfish, the unique features of the Georgia Basin /Puget Sound 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. (2001). The BRT also noted that relatively large genetic differences have been found between inner (Puget Sound and/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 might have a substantial affect on dispersal and connectivity. The BRT therefore concluded that, in the absence of other information, rockfish of all species that inhabit the Georgia Basin and/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 in this document and in Appendix B, Puget Sound-Georgia Strait 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 some 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 – Georgia Strait region substantially different than the rest of the California Large Marine Ecosystem.

Below, we discuss 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.

I. 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 (Puget Sound Proper; 15 pts).

Discreteness of the DPS

As discussed above, no published studies have compared genetic characteristics of bocaccio from Puget Sound and outer coastal areas, but studies of coastal populations have found modest levels of differentiation over large geographic distances. Compared to some other rockfishes, bocaccio appear to have greater potential to move long distances (see life-history summary above), suggesting that a DPS for bocaccio could encompass a greater area than DPS for more sedentary species such as copper rockfish, quillback rockfish, and brown rockfish.

As was discussed above, the BRT generally assumed that all rockfish are likely to have at least one DPS in inland marine waters. However, for bocaccio, a DPS that included the coastal populations (Scenario 4) received some support as well. Under this scenario, the BRT considered the hypothesis that Puget Sound bocaccio are simply either the result of a rare recruitment event and were never a viable population distinct from the coastal populations, or are regularly connected to coastal populations by dispersal. However, on balance the BRT determined that the available information provided more support for the presence of an inland DPS. In particular, examination of the available size frequency data (discussed below) indicated the existance 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, 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. The BRT also considered whether bocaccio were likely to have a Puget Sound Proper DPS, distinct from other areas in the Georgia Basin (Scenario 1). However, in the absence of any direct data indicating genetic differentiation between bocaccio from Puget Sound Proper and areas to the north and considering the relatively high potential for movement of this species, the BRT concluded that a Puget Sound/Georgia Basin DPS was more likely.

Significance of the DPS

In addition to the factors considered in common to all rockfish species discussed above, the BRT noted that Puget Sound-Georgia Strait 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 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.

II. Yelloweye rockfish

DPS Scenario 3 (Puget Sound/Georgia Basin) received the most support (49 pts), followed by DPS Scenario 1 (Puget Sound Proper; 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 Georgia Strait.

Discreteness of the DPS

In addition to the general consideration in common to all rockfish species summarized above, members of the BRT used a 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 (unpublished data) report on genetic differences in this species between samples from inland marine waters and the outer coast, although the samples did not include the Georgia Basin. Their samples, collected from interior waters between Vancouver Island and the mainland British Columbia, formed a discrete genetic cluster that differed consistently from coastal samples The BRT took this is reasonable evidence suggesting that yelloweye rockfish from the Georgia Basin are also likely to be genetically differentiated from coastal population.

In addition, two aspects of the life history of yelloweye rockfish discussed earlier favor genetic and potentially demographic isolation. First, as both adults and juveniles yelloweye rockfish are tightly associated with rocky substrata (or invertebrates associated with hard substrate). Such habitat is infrequent and patchy in its distribution in North Puget Sound and the Georgia strait, and is very rare in Puget Sound inside Admiralty Inlet. Secondly, adult 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 – Georgia Strait 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 Puget Sound Proper might be genetically distinct from the rest of the region, the BRT relied on historic distributional information and the habitat availability in its assessment. In particular, the BRT felt the historical abundance of yelloweye rockfish was greater in North Puget Sound (Appendix A, and Palsson et al. 2008), and this was the result of the lack of appropriate rocky habitat in Puget Sound Proper (Palsson et al 2008). Thus, even if Puget Sound Proper supported, at times, a semi-discrete 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 Georgia Strait where rockier habitat is available and yelloweye rockfish are currently found.

Significance of the DPS

(See Above "Factors in considered in common to all species".)

Relationship to other DPS

The BRT concluded that Puget Sound/Georgia Basin yellowtail rockfish are a DPS distinct from coastal yellowtail rockfish populations. The coastal populations of yellowtail 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 if coastal populations of yellowtail rockfish consist of a single versus multiple additional DPS.

III. 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 (Puget Sound Proper; 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 northern Puget Sound 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 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 the relatively high potential for movement in this species. However, due to this high movement potential, a separation of Puget Sound Proper from the Georgia Strait also seemed unlikely to the BRT. Examination of historical records of abundance and distribution revealed large populations of canary rockfish in South Puget Sound (Appendix A). While abundant in South Sound, the BRT felt that 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 "Factors in considered in common to all species")

Relationship to other DPS

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 if coastal populations of canary rockfish consist of a single versus multiple additional DPS.

IV. Redstripe rockfish

DPS Scenario 1 (Puget Sound Proper) 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/sand habitat that characterized much of Puget Sound Proper. 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. 2001) to make DPS conclusions. In particular, the BRT found no compelling information to suggest that populations of redstripe rockfish in Puget Sound Proper 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. (2001), the BRT concluded that Puget Sound Proper 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 Puget Sound Proper (Appendix A).

Relationship to other DPS

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

V. Greenstriped rockfish

DPS Scenario 1 (Puget Sound Proper) 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 Puget Sound Proper. Compared to other rockfish species, greenstriped rockfish tend to occur in the mud/sand habitat that characterized much of Puget Sound Proper. 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. 2001) to make DPS conclusions. In particular, the BRT found no compelling information to suggest that populations of greenstriped rockfish in Puget Sound Proper 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 also 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 Puget Sound proper 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 North Puget Sound 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. (2001), the BRT concluded that Puget Sound Proper is an ecologically unique environment distinct from other parts of Georgia Basin. In addition, the BRT noted that historical records (Appendix A) indicated a long-standing presence of this species in Puget Sound Proper.

Relationship to other DPS

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

Western Boundary of the Puget Sound/Georgia Basin canary rockfish, Bocaccio, and yelloweye 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 of 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: 1) the Sekiu River and 2) the Victoria Sill (Figure 15). The Sekiu River is used as the western boundary in the WDFW assessment of rockfishes (Palsson et al., 2008). 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 15). This sill is a significant oceanographic feature in the Strait of Juan de Fuca. The deep water in the Juan de Fuca Strait extends to a depth of about 100m 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 & Cummins, 2000), nitrogen (Mackas & 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 & Klinger, 2007, Paul Chittaro, NWFSC, unpublished data).

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 3 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.

THE “EXTINCTION RISK” QUESTION

APPROACHES TO THE DETERMINATION OF EXTINCTION RISK

The "Extinction Risk" Question

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 numbers 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 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 number of individuals in a population is important in assessing two aspects of extinction risk. First, population sizes 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 the theory of minimum viable populations (MVP) (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 numbers, 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 Georgia Basin/Puget Sound 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- 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, by use of different survey methods for a species, and, for harvest data, by the imposition of harvest regulations. The BRT took several approaches to utilize the best available data in order to estimate the abundance trends, and 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 questions 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 non-native 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 have 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, 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 (Francis et al. 1998, Mantua et al. 1997) in the North Pacific, and Atlantic herring (Alheit and Hagen 1997) and Atlantic cod (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. Secondly, length-frequency data 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 section on threats.

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 is 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” as a method 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. 2001b), Pacific herring (Stout et al. 2001a; Gustafson et al. 2006), and black abalone (Butler et al. 2008).

In this 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 are 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 sections, data were available that allowed an estimate in the trend in abundance of rockfishes, and this information was considered by the BRT.

After reviewing all relevant biological information for the species, each BRT member assigned a risk score (see below) 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 sub-population might be at a high level of extinction risk because of high risk to spatial structure/connectivity, even if it exhibited low risk for the 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***. Unlikely that this factor contributes significantly to risk of extinction, either by itself or in combination with other factors.

2. ***Low Risk***. Unlikely that this factor contributes significantly to risk of extinction by itself, but some concern that it may, in combination with other factors.

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:

++ (double plus):	expect a strong improvement in status of the DPS;
+ (single plus):	expect some improvement in status;
0 :	neutral effect on status;
- (single minus):	expect some decline in status;
-- (double minus):	expect strong decline in status.

Data Reviewed by the BRT

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

Recreational fishery data

The main data available on Puget Sound rockfish trends are from surveys of recreational anglers conducted by Washington Department of Fish and Wildlife (WDFW) (Bargmann 1977; Buckley 1967, 1968, 1970; Palsson 1988; Palsson et al. 2008). 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. 2008). The data are reported both for the targeted catch (targeting bottomfish) and the incidental catch (targeting salmon). For the trend analyses here only the data from the fishery targeting bottomfish were used. The data for Puget Sound Proper (punch card areas 8-13, Figure 16), north Puget Sound (punch card areas -Figure 16), and all Puget Sound (punch card areas 5-13 - Figure 16) are plotted in Figure 17. The raw numbers are given Table 4, Table 5, and Table 6. Note that all sources analyze the same raw data (the WDFW creel survey data), but different adjustments have been made to the data.

Department of Fisheries and Oceans (Canada) 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 (angler trips) and catch data (total rockfish) that we were able to obtain included both salmon-targeted 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. (2008). In particular, during 1994 to 2003, the total catch was still estimated using salmon fishery data, yet restrictions on the salmon fishery lead to limited information from the salmon fishery. In addition, the bag limit on rockfish was lowered from 15 fish in 1983 to 1 rockfish per trip in both the north Puget Sound and Puget Sound Proper in 2000. Reductions in bag limits both 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 dataset and a scaling parameter to adjust the mean for each period is estimated.

Commercial data

Commercial data with effort information is available from records on the bottom trawl fishery operating until 1988 (PMFC 1979; Holmberg 1967; Schmitt et al. 1991). Effort data (hours trawled) are available from 1955 (Table 7). While other commercial fisheries have been operated in Puget Sound, there was no effort information available. Data for other gears were 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. (2008). These trawl surveys cover 1987-2000, are depth stratified and done in twelve regions (Table 8). The sampling is somewhat episodic with some regions sampled infrequently, only once, or only at the beginning or the end of the survey (Table 8). Four main regions, Central Sound, Georgia Basin (US waters), Hood Canal, and the South Sound 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 south Puget Sound 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 18, Figure 19, see also Figure 20). 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 9.

REEF dive surveys

Another data source included in the trend analysis is sightings of rockfish by recreational scuba divers throughout the 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 database was used to determine presence/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 the categorical levels to numerical levels. The data for 'all rockfish' in the REEF database are shown in Table 9.

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 A). 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 thirteen 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 which 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" (*Sebastes pinniger*), "red snapper" (*S. ruberrimus*), 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 over 150’ 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, and Strait of Juan de Fuca. Rockfish were found at depths over 150’ on rocky bottoms, and primarily occurred in north Puget Sound, 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. Twenty-seven representative of the family Scorpaenidae are listed in these documents, including all five 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 1970’s in Tacoma Narrows and Appletree Cove (near Kingston) associated with sport catch; canary rockfish (114): most records occur from the 1960-70’s 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 Sound/Seattle; yelloweye rockfish (113): most records occur from the early 1970’s in the San Juan Islands (Sucia Island) and Bellingham Bay associated with the sport catch.

Summary of previous assessments

The WDFW conducted an extensive review of the current status of all Puget Sound rockfishes (Palsson et al. 2008). This review included a review of historic patterns of abundance, results of WDFW surveys, ecosystem stressors and a qualitative risk assessment. Palsson et al. note a precipitous decline in several species of rockfish, including bocaccio, yelloweye rockfish and canary rockfish. They concluded 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 dissolved oxygen, 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). Their evaluation was based on the American Fisheries Society’s (AFS) Criteria for Marine Fish Stocks. This method is makes use of 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 to be 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 rockfish were depleted in both Northern and Southern Puget Sound. Canary rockfish were also considered depleted in Northern and Southern Puget Sound. Greenstriped rockfish and redstripe rockfish were both considered to be healthy. Bocaccio were concluded to have a precautionary status. The precautionary status of bocaccio was the result of a lack of information for bocaccio as well as their increased rarity in Southern Puget Sound.

An evaluation on the status of yelloweye rockfish was prepared for the Canadian Committee on the Status of Endangered Wildlife in Canada (COSEWIC). COSEWIC concludes 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 indicates 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 1/3 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 concluded to be threatened.

Coastal populations of yelloweye rockfish, canary rockfish and bocaccio are considered “overfished” by the Pacific Fisheries 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 has been collected as part of WDFW’s monitoring of the recreational fisheries and for a limited number of years for the commercial fisheries. Data prior to 1975 are available from Bargmann (1977) and Buckley (1967, 1968, 1970). From 1975-1986, 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, specifically see Table 7.5 of Palsson et al (2008), which summarizes the species identification data. Likewise, specifically see Table 6.1 in Palsson et al (2008) which summarizes the data from the commercial fisheries.

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 noise in the early data, especially from the Buckley and Bargmann reports, is suggestive of low sample size. The noise 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 of less desirable (smaller) species.

Despite the limitations, the recreational data in particular show some patterns. The three most common species during 1965-2007 in the North Puget Sound (black rockfish, copper rockfish and quillback rockfish) and Puget Sound Proper (brown rockfish, copper rockfish, and quillback rockfish) increased in proportion from 1980 through 1990 and currently comprise approximately 90% of the recreational catch (Figure 21). Four of the five petitioned species (boccacio, canary rockfish, greenstriped rockfish, and yelloweye rockfish) became progressively less frequent in the recreational catch during the same time period (Figure 21). However, during 1988 to 1993, declines were not seen in the commercial gear that catch bocaccio (set line and set net in south Puget Sound), canary rockfish (bottom trawl and set line in north Puget Sound) and yelloweye rockfish (multiple gear types in north Puget Sound). 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 was infrequently recorded in the recreational catch data reported by Buckley and Bargmann for Puget Sound Proper from the mid-1960s into the early 1970s (Table 10). However, bocaccio were reported up to 8-9% of the catch in the late-1970s from the Washington State Sport Catch Reports (WDF 1975-86) (see generally Figure 22 and Figure 23). The majority of the catch (66%) during 1975-1986 was from punch card area 13 (as reported in the WA 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 to the 1980s to the 1990s. From 1975-1979, bocaccio were reported as an average of 4.63% of the catch (sample size unknown; reference WA State Sport Catch Reports). In 1980-1989, they were 0.24% of the 8430 rockfish identified (Palsson et al. 2008). From 1996 to 2007, bocaccio have not been observed out of the 2238 rockfish identified in the dockside surveys of the recreational catches (Palsson et al. 2008). 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. Also, (as expected as a result of their habitat preferences) bocaccio have not been observed in the WDFW fisheries independent trawl surveys (specifically see Table 7.5 in Palsson et al. 2008).

In conclusion, there is strong support in the data for a decline in the frequency of bocaccio relative to other species in Puget Sound Proper (Figure 22 and Figure 23). The magnitude of the decline cannot be ascertained since we have no estimates of its current frequency. We do know that although rare, bocaccio rockfish were present in Puget Sound Proper into the current decade. In the WDFW size surveys, bocaccio have been recorded in 1994, 1996, 1997, 1998, (punch card areas 5, 6, and 7). The latest record in the size database is 1999 when four fish were recorded (3 from punch card area 13 and one from punch card area 11). There is one 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 the Puget Sound Proper.

In North Puget Sound, bocaccio have always been rare in the surveys of the recreational fishery (Table 11 and Table 12). 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 not identified to species until 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 Puget Sound Proper and 2-5% in north Puget Sound). Like bocaccio, canary rockfish appear to have become less frequent in the catch data since 1965 (Table 13 (recreational data), Table 14 (recreational data), Table 15 (commercial data) and Figure 24 and Figure 25). From 1980-1989, they were reported at a frequency of 1.1% (sample size 8430) and 1.4% (sample size 3910) in south and north Puget Sound respectively. From 1996-2001, they were reported at a frequency of 0.73% (sample size 550) and 0.56% (sample size 1718) in south and north Puget Sound respectively. The decadal trends along with 95% confidence intervals for the data with sample sizes are shown in Figure 24. Note the early data do not report sample size (number of individuals identified) thus the 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 non-random reporting of species in the catch in the 1960s and early 1970s. The tables from Buckley and Bargmann (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 and thus no frequency data are available from the recreational fishery since then. Canary rockfish have not been observed in the WDFW fisheries independent trawl surveys (see specifically Table 7.5 in Palsson et al. (2008). In the REEF scuba data REEF (2008), canary rockfish were not observed in the first three years of the survey, 1998-2000, when the number of dives was 100-130 per year. Since 2001, however, the number of dives per year has increased substantially, to 400-1000 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 26 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 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 suggests that catch estimates may be unreliable due to poor species identification and changing bag limits (COSEWIC in press). Recent long-line surveys throughout the Strait of Georgia collected ten canary rockfish individuals from two shallow sets in statistical areas 16 and 17. All were adults (mean size 529 cm) in post-spawning condition Lochead and Yamanaka (2007). They have also been documented in Georgia Strait 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 Puget Sound Proper and 2-5% in north Puget Sound). The frequency of yelloweye rockfish in Puget Sound Proper appears to have increased from a frequency of 0.34% (sample size 8430) in 1980-1989 to a frequency of 2.7% (sample size 550) in 1996-2001 (Figure 27 and Table 16). There were three 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 North Puget Sound, in contrast, the frequency of yelloweye rockfish decreased between the 1980s and 1990s in the catch surveys (Table 17 (recreational data) and Table 18 (commercial data)). From 1980-1989, they were reported at a frequency of 1.9% (sample size 3910), and from 1996-2001, they were reported at a frequency of 0.65% (sample size 1718). Since 2002, fishing for yelloweye rockfish is prohibited and thus no frequency data are available since 2002 from the recreational fishery.

The decadal trends along with 95% confidence intervals for the data with sample sizes are shown in Figure 28. Note the early data do not report sample size (number of individuals identified) thus the 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 non-random reporting in the 1960s and early 1970s. The tables from Buckley and Bargmann (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 the WDFW fisheries independent trawl surveys (Table 16) in Puget Sound Proper, and in north Puget Sound, 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 the REEF scuba survey data, yelloweye rockfish have been sighted consistently throughout the Puget Sound (north and south) since 2001 at an average frequency of 0.5% of dives in the south reporting a sighting of yelloweye rockfish and 2% of dives in the north reporting a sighting. There is no evidence of a decline in the probability of sightings during dives (Table 19).

In the Strait of Georgia, yelloweye rockfish are common in the recent recreational catches; the proportion of yelloweye rockfish in the 2006 and 2005 recreational catch (DFO Canada 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 small proportion of the rockfish observed in the few fisheries independent surveys that are available. 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, (see specifically Table 10 in Yamanaka et al. (2004)), 439 rockfish were observed of which 1 (0.2%) was a yelloweye rockfish. Another ROV survey in 2004 in the southern Strait of Georgia, identified 105 rockfish species of which 5 (4.8%) were yelloweye rockfish.

There appears to be limited information on population trends yelloweye rockfish in the Strait of Georgia. Data from the recreational creel survey conducted by Department of Fisheries and Oceans Canada is of limited value because species composition information and groundfish-targeted effort is lacking; salmon-targeted and groundfish-targets 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 long-line 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 North Puget Sound and occur very infrequently in the Puget Sound Proper recreational catch data and the WDFW trawl survey (greenstriped occurred in 143 of 1555 (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 29 and Figure 30). This suggests that greenstriped rockfish were not being consistently recorded during dockside identifications during the 1960/1970s. From 1975 to 1980 (WDF 1975-86), greenstriped rockfish were recorded at a 1-2% frequency in Puget Sound Proper (Figure 29, Table 20 (PSP) and Table 21 (NPS)). After 1980, the frequency of greenstriped rockfish declined in the recreational data and since 1996 it 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 under-representation of greenstriped rockfish in the recreational catch. Greenstriped rockfish appear in a low frequency in the WDFW fisheries independent trawl survey (Table 20), and they were caught in the most recent years of the WDFW trawl survey in Puget Sound Proper (in both 2002 and 2005). However the high variance in the data makes detecting any patterns difficult. Simple ANOVA models with Region (Hood Canal, Central Sound, South Sound, 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 1999-2007, they are still present in Puget Sound Proper.

Greenstriped rockfish also do not appear in the 2006 and 2005 species composition data from the recreational catch in the Strait of Georgia (DFO Canada creel survey data). However they have appeared in other fishery-independent surveys such as long-line, jig and ROV surveys (see specifically Table 4 in Yamanaka et al. (2004)). In statistical area 13, they were 1.5% of the rockfish caught in a long-line survey (Lochead and Yamanaka, 2007). In the 2005 ROV survey in 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 North Puget Sound. In Puget Sound Proper, however, redstripe rockfish appeared frequently in the recreational catch (between 1-14%) during 1980 to 1985 (Figure 31 and Figure 32, Table 22). Previous to that, from 1965 to 1979, redstripe rockfish appeared much less frequently (< 1%) (See Buckley and Bargmann references and Washington State Sport Catch Reports). It is not known if redstripe rockfish were being consistently recorded during dockside identifications in the 1960/1970s, but its absence suggests that it may not have been. 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 was imposed in 1983 and the bag limit was further reduced in 1994 and 2000. Since redstripe rockfish are smaller than other species, bag limits may lead to discarding and thus under-representation 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 23), however in 2002 and 2005, redstripe rockfish comprised 39 and 48% of the individuals caught, respectively. Examination of the individual trawl samples however indicates that this was caused by outlier trawl samples in each of those years and 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, Central Sound, South Sound, 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 s.e.) 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 rockfish are present in Puget Sound but are no longer being recorded in the dockside surveys of the recreational catch, for undetermined reasons.

Redstripe rockfish do appear in the 2006 and 2005 species composition data from DFO Canada for the Strait of Georgia statistical areas 13-20, 28-29. They comprised 0.08% and 0.1% of the rockfish catch, respectively. They have appeared in other fishery-independent surveys such as charter and jig surveys (see specifically Table 4 in Yamanaka et al. (2004)) although these surveys included area 12 and it is unclear if redstripe rockfish were collected farther south. Redstripe rockfish did not appear in the 2004 long-line 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. (2008) 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 Puget Sound Proper as about 40,683 and in Northern Puget Sound as 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 <10,000 in Georgia Basin and <1000 in Puget Sound Proper.

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; Lindley 2003; Holmes and Fagan 2002; Holmes et al. 2007; Dennis et al. 2006) 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 2 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) form ca. 90% of the "total rockfish" in the different data sources used in the trend analysis. The goal of the trend analysis is to determine the 1965-2008 trend in "total rockfish" (i.e., what the actual population rate of decline has been from 1965-2008). This analysis does not make any 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 the low sampling of the catches in many years, particularly early years, provides insufficient yearly estimates for the petitioned species.

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 catch per unit effort data is problematic. The main problems can be summarized are 1) The trend in the total catch will be dominated by the most abundant species, and the signal from infrequent species is lost, 2) Catch-per-unit effort data from fisheries are strongly influenced by targeting and by changes in the efficiency of gear and fish-locating technology. Switching of the 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 change, 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.

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 if 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.

Problem 1 cannot be addressed by changes in the analysis (or data used). It should be kept in mind that the estimated trends are the 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, evidence for changes in the frequency of the petitioned species in the recreational catch, WDFW trawl surveys and REEF dive surveys was examined. 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, from 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.

Methods

Summary of the methods

The basic concept involves using a maximum-likelihood 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 the WDFW trawl data and the REEF dive surveys. For this analysis, it is allowed that these data sources might be sampling a different segment of the population (e.g. 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 a) rockfish per angler trip data for different time periods with different bag limits within one DPS, b) rockfish per angler trip data for different time periods with different bag limits within multiple DPSs, and c) 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). The stochastic Gompertz equation written in log-space is

$$X_t = a + bX_{t-1} + E_t \qquad (1)$$

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 auto-regressive, 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 AR(1) process as

$$\mathbf{Y}_t = \mathbf{D} + X_t + \boldsymbol{\varepsilon}_t \qquad (2)$$

where $\mathbf{Y}_t$ is an $n \times 1$ vector of the n observed time series (Ward et al. 2008), 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 R. The $n \times 1$ vector **D** represents bias in observation errors, and the off-diagonal elements of R represent the spatial correlation between the observation errors for the *n* observed time series. **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 **R** and **D** matrices are:

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

Model fitting and parameter estimation

Equations 1 and 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 ($\mathbf{Y}_1$, $\mathbf{Y}_2$,... $\mathbf{Y}_T$) from a set of n data sources, the goal is to estimate the trend parameter a and process variance σ^2 that describe the 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).

How is this different than just fitting a line through the log data?

Fitting a line through the data means that one is 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 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 very 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 × forecast length for the model with both variance sources.

Data used for trend analyses

The data used for each analysis are shown in Figure 33 and Figure 34. The different analyses were

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

PS-R Puget Sound (Puget Sound Proper plus north Puget Sound 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 the WDFW trawl data from Puget Sound Proper (south Puget Sound)

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

Note that when data from different survey types are combined the multivariate AR(1) model is used to all different data sources to be monitoring 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 color. 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 the BRT examined. Since the frequency of the petitioned species declined in frequency, the BRT concluded that the decline of the petitioned species must have been greater than the 70% observed in the total rockfish. Figure 35 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 of 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 north Puget Sound) = x × abundance' while 'scuba sightings per dive in south Puget Sound = y × abundance' and $x \neq y$.

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 the north and south Puget Sound should be highly correlated. This assumption is unsupported by the data as evidenced by the different trends in the north and south (the upper and middle panels), and by the separation of North and South Puget Sound into separate DPS's 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, north or south Puget Sound, 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.

The recreational data since 2000 is from a fishery with a 1 bag limit on rockfish. In addition to the 1 bag limit, other regulations have been added incrementally: restriction of the season and rules against discarding undesirable rockfish. After the 1 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 the WDFW trawl survey data and the REEF dive survey data in order to show how the estimates change with the inclusion of other data sources. However, there is not 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 (red symbols).

Formal model selection approaches will not be helpful in resolving which assumptions are best because they cannot give information on whether the 1 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 36 and Figure 37 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 the 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 the were handled are detailed in Appendix D.

Size Data for Each DPS

The BRT examined length-frequency data for two general reasons. 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. Secondly, length-frequency data provides 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 data files obtained from WDFW. Data were combined from three data files provided by Wayne Palsson in July, 2008. Data were restricted to fish caught inside the Strait of Juan de Fuca, the Georgia Basin, or Puget Sound proper (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) was 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 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 we were not able to determine if the size truncation continued in this decade.

Canary - 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 > 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 - 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 if clear size truncation occurred.

Greenstriped - 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 any 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 discarding of this less desired species by recreational fishermen.

Redstripe - 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 'historic' 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 rockfish, and yelloweye rockfish is likely conservative. As bag limits were reduced from 15 to 10 (North Sound) and 5 (South Sound) in 1983, to 5 (North Sound) and 3 (South Sound) in 1994, and to 1 in both North and South Sound 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 below (threats) 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 5 rockfish DPS's (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 "n/a". Threats were arranged within the four statutory listing factors: 1) the present or threatened destruction, modification, or curtailment of its habitat or range; 2) over utilization for commercial, recreational, scientific, or educational purposes; 3) disease or predation; and 4) other natural or manmade factors affecting its continued existence.

The BRT created a list of the potential threats to bocaccio, canary rockfish rockfish, greenstriped rockfish, redstripe rockfish 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, Team 2007, Palsson et al. 2008), 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

Elsewhere in this report, the BRT considers the history of fisheries and fishery removals in Puget Sound (Appendix A). There is little doubt that overfishing played a major role in the declines of rockfish in Puget Sound (Palsson et al. 2008). For example, comparison of rockfish densities and sizes in no-take marine protected areas to fished areas shows that the increased fishing mortality experienced by fish outside of marine protected areas results in lower abundance and smaller-sized fish outside versus inside marine protected areas (Palsson et al. 2008). 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 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 (SSB, the weight of all mature females) or lifetime egg production (LEP, expected number of total eggs produced after incorporating adult mortality schedules) are used to estimate how many of the 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 g of female weight) in black rockfish (Bobko and Berkeley 2004), blue rockfish, yellowtail rockfish (Sogard et al. 2008), widow rockfish (Boehlert et al. 1982) and chilipepper rockfish (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 southern 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, and darkblotched rockfish (Sogard et al. 2008, Nichol and Pikitch 1994). Maternal effects on larval quality have been documented for black rockfish, blue rockfish, gopher rockfish, 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 pre-fertilized 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/larger females producing proportionately greater numbers of larvae, producing higher quality larvae, and releasing them earlier in the season than younger/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 (see specifically Table 1 in Li et al. (2007)). 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/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, e.g. Icelandic cod (Marteinsdottir & Thorarinsson 1998, striped bass (Secor 2000), Baltic cod (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 has 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 rockfish and yelloweye rockfish are typically associated with rocky habitats. Palsson et al. (2008) report that such habitat is extremely limited in Puget Sound, with only 10 km^2 of such habitat in Puget Sound Proper (i.e., south of Admiralty Inlet), and 207 km^2 in Northern Puget Sound. Palsson et al. note that this habitat is threatened by construction of bridges, sewer lines and other structures, deployment of cables and pipelines, and by burying from dredge spoils and natural sub tidal 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 State Office of Management, the population is expected to grow to 4.7 - 6.1 million residents by 2025 (Sound Science 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 sea ports 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 greater 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 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 the central Puget Sound and about 35% of the shorelines of Whidbey Island, Hood Canal and South Puget Sound 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 1/3 of this in Padilla an Samish bays. Monitoring of eelgrass began in 2000, and although coverage declined until 2004, since that time it has remained unchanged over all Puget Sound. However, localized declines have occurred, with local losses in Hood Canal ranging from 1-22 percent per year (Team 2007). 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. 2008).

Non-indigenous 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 *Sargassum* influences native macroalgae, eel grass or rockfish themselves is not presently understood. Several species of non-indigenous tunicates have been indentified in Puget Sound. For example, *Ciona savignyo* was initial seen in one location in 2004, but within 2 years spread to 86% of sites surveyed in Hood Canal (Team 2007). 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 the Sound have high levels of heavy metals and organic compounds. About 32% of the sediments in Puget Sound are considered to be moderately or highly contaminated. Organisms that live in or eat these sediments are consumed this transferring contaminants up the food web and to a wider area.

Not surprisingly, contaminants such as polychlorinated biphenyls (PCBs) and chlorinated pesticides (e.g. DDT), and polybromnated diphenyl ethers (PBDEs) appear in rockfish collected in urban areas. However, while highest levels of contamination occur in urban areas, toxins can be found in the tissues of animals in all regions of the sound (Team 2007). Indeed, rockfish collected in rural areas of the San Juan Islands revealed high levels mercury and hydrocarbons (West et al. 2002).

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. Contaminant may influence growth rates of rockfish. For example, Palsson et al (2008) 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 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, reproductive function is reduced in animals from contaminated areas, and this effectively decreases the productivity of the species (Landahl et al. 1997).

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 Palsson et al. 2008 and Puget Sound Action Team 2007). In addition Palsson et al. 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 dissolved oxygen. In 2005, Of the 39 sites sampled, 8 were classified as highest concern, and 10 were classified as high concern. Dissolved oxygen (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 was killed (Palsson et al. 2008). In addition to Hood Canal, Palsson et al. report that periods of low DO are becoming more widespread in waters south of Tacoma Narrows.

Predation

Prominent members of the Puget Sound/Georgia Basin foodweb 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). Populations of lingcod have been low in Puget sound, but are increasing in recent years (Palsson et al. 2008). 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 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 the state of Washington: the harbor seal, the California sea lion (*Zalophus californianus*), the Steller sea lion, and the northern elephant seal (*Mirounga angustirostris*). Harbor seal populations have increased from in the 100s 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 2000 Stellar sea lions (*Eumetopiasjubatus*) occur seasonally in Washington waters, with dozens found in Puget Sound, particularly in the San Juan Islands (Palsson et al. 2008). About 8% of stellar sea lion diet is rockfish (Lance and Jeffries 2007). Though not abundant, their large size and aggregated distribution suggest that their local impact on could be non-trivial.

Fifteen species of marine birds breed along the Washington coast; seven of these have historically been found breeding 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, double-crested cormorants (*Phalacrocorax auritus*), pelagic cormorants (*Phalacrocorax pelagicus*), and members of the western gull/glaucous-winged gull complex (*Larus occidentalis/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. (2008) 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 rockfish and quillback rockfish may interact with juvenile bocaccio, canary rockfish 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 salmon consume larval and juvenile rockfish, and they also share prey with small size classes of rockfish (Buckley 1997), and 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), with about 2 million fish released in the early 1970s, reaching a peak of over 8 million in the early 1990s. Present annual releases are now around 4 million (Palsson et al. 2008).

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 three-year-old lingcod in South Puget Sound in 2001. Additional small-scale releases (< 100 fish) are planned in the near future. Long-term (and subject to funding), the annual release of ca. 9000 lingcod into the southern portion of Puget Sound is planned (Lee 2008, Wayne Palsson, pers. comm.). As described above, lingcod may be important predators of rockfish. Because lingcod exhibit limited movement (Tolimieri et al. in press), large hatchery releases of lingcod have the potential to have a large local impact on rockfish populations.

Bycatch

Rockfish are unintentionally captured as part of fishing activities targeting other species (e.g. lingcod). 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. 2008), application of these methods in the Puget Sound fishery would be difficult (Palsson et al. 2008). Washington Department of Fish and Wildlife consider bycatch of rockfish to be a “high impact stressor” on rockfish populations (Palsson et al. 2008).

Derelict Fishing Gear

Palsson et al. (2008) report that there are more than 3600 pieces of abandoned fishing gear (especially gillnets) 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. 2008).

Climate

As discussed earlier and in Appendix B, 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 places an extremely important role in population dynamics. Tolimeri and Levin (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 high influenced by climate conditions such that El Nino-like conditions generally lowered growth rates and increased generation time. The negative effect of the warm water conditions associated with El Nino appear to be common across rockfishes (Moser et al. 2000). Field and Ralston (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 Puget 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 used the categories of "high risk" of extinction; at "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" method, often referred to as the "FEMAT" method because it is a variation of a method used by scientific teams evaluating options under the Northwest Forest Plan (Forest Ecosystem Management: An Ecological, Economic, and Social Assessment Report of the Forest Ecosystem Management Assessment Team (FEMAT), 1993). (See Table 27 for an example worksheet). In this approach, each BRT member distributes ten likelihood points among the three species extinction risk categories, reflecting their opinion of how likely that category correctly reflects the true species status. Thus, if a member were certain that the species was in the "not at risk" category, he or she could assign all ten points to that category. A reviewer with less certainty about the species' status could split the points among two or even three categories. 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. 2001b), Pacific herring (Stout et al. 2001a; Gustafson et al. 2006), Pacific hake, walleye pollock, Pacific cod (Gustafson et al. 2000), and black abalone (Butler et al. 2008).

Conclusions regarding risk status for each of the 5 DPSs of Puget Sound rockfish

I. 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." 7 of the 9 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, is low in all or nearly all spawning populations relative to earlier periods 4). Low dissolved oxygen event in Puget Sound that 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. A score of 5 represents "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. Tolimeri and Levin (2005) found that 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 did not note any 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–high risk. 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 southern Puget Sound other populations do not appear to be viable; 2) The loss of former populations has likely resulted in a contraction of the bocaccio DPS's range; 3) The potential loss of habitat due to hypoxia issues in south sound; 4) Juvenile recruitment depends on the availability of specific types of macro algae (kelp), which is also decreasing in some portions of the DPS. 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." 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 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; 3) Variable ocean conditions (exacerbated by climate change) that may lead to a mismatch with current diversity traits. The BRT did not note any 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 the bocaccio DPS are presented in Table 28. Presented in the table are the median threat scores with the standard deviation (SD) about the median. The BRT ranked low dissolved oxygen, recreational and commercial harvest as the most serious threat to persistence of the bocaccio 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

Bocaccio appear to have declined in frequency in Puget Sound Proper, relative to other species, from the 1970s to the present. From 1975-1979, bocaccio were reported as an average of 4.63% of the catch. From 1980-1989, they were 0.24% of the rockfish identified, and from 1996 to 2007, bocaccio have not been observed out of the 2238 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 Puget Sound Proper. We do know from other data sources (scuba surveys) that although rare, bocaccio rockfish were present in Puget Sound Proper as recently as 2001. In North Puget Sound, 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).

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.

Overall, the BRT was very concerned about downward trend in bocaccio abundance, and a large majority of the BRT concluded that this trend was, by itself, sufficient to indicate that the Georgia Basin/Puget Sound 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 sizes. 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 GBPS bocaccio were at risk due to their low abundance and low intrinsic population growth rate. In addition, the BRT noted that because the GBPS 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 dissolved oxygen within their range, the potential for continued losses as by-catch in recreational and commercial harvest, the reduction of kelp habitat necessary for juvenile recruitment. The BRT's conclusions regarding the overall risk to the Geogia 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).

The BRT considered the possibility that bocaccio have been extirpated from the Puget Sound/Georgia Basin DPS, since there have been no confirmed observations in Georgia Basin-Puget Sound for ca. 7 years. Despite the lack of observations, the BRT concluded that it is plausible that DPS still exists at a very low abundance. In particular, currently there is no systematic sampling program that would consistently detect rare, rock-dwelling species. Additionally, existing fishery regulations limit potential observations that might emerge from bycatch in the setnet fishery, where bocaccio were reliably observed through the 1980s. Given the lack of any intensive effort to enumerate bocaccio, the BRT concluded that the lack of recent observations of this rare species does not necessarily indicate that the DPS has been extirpated.

“Significant Portion of its Range” Question

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

II. 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. 7 of the 9 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 fisheries independent data, leading to high levels of uncertainty. Comments on the abundance criterion included consideration that: 1) No "core population" or sub-population 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; 4). It formerly comprised one of the top 3 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. 6 of the 9 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 has been curtailed, this was felt to have depressed populations to a threshold beyond which optimal productivity might be unattainable. The BRT did not note any 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. 6 of the 9 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) South Puget Sound populations are no longer viable; 2) The loss of either the North or South Puget Sound 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 South Puget Sound which has declined due to low dissolved oxygen events; 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. 5 of the 9 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; 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 the canary rockfish DPS are presented in Table 28. Presented in the table are the median threat scores with the standard deviation (SD) about the median threat scores. The BRT ranked effects of commercial and recreational harvests the most serious threat to persistence of the canary rockfish DPS. Loss of nearshore habitat, low levels of dissolved oxygen, 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 about 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 Puget Sound Proper canary rockfish occurred at frequencies above 2% in the 1960s and 1970s, but by the late 1990s had declined to about 0.76%. In North Puget Sound, 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 by-catch in commercial and recreational harvest, loss of near shore habitat, chemical contamination, and areas of low dissolved oxygen, increase the extinction risk of this species. The BRT was also concerned about downward trends in the size of the canary rockfish in Puget Sound. 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 > 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 Georgia Basin/Puget Sound 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 Georgia Basin/Puget Sound 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 and 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.”

III. 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 fisheries independent data, leading to high levels of uncertainty. Comments on the abundance criterion included consideration that: 1) large declines in North Puget Sound, 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; 3) Palsson et al. (2008) estimates approximately 3000 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.

Growth Rate/Productivity

BRT scores for growth rate and productivity of the yelloweye rockfish DPS ranged from 3 to 5with a mean score of 4.11 (± 0.26 SE) and a modal score of 4. 4 BRT members scored this category as 4 - high risk, while 3 BRT 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; 3. Low productivity in the yelloweye rockfish DPS reflects the overall decrease in productivity for all rockfish species in this region. The BRT did not note any 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. 6 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) South Puget Sound populations are no longer viable; 2) The loss of these populations may eventually result in a contraction of the yelloweye rockfish DPS; 3) No evidence of spatially structured populations in the DPS.; 4) Although larval dispersal through currents may increase connectivity, adult movement is limited. The BRT did not note any 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; 3) Selective harvest may lead to shifts in phenotypic traits, e.g. size at age. The BRT did not note any 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. The 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 the yelloweye rockfish DPS are presented in Table 28. Presented in the table are the median threat scores and the standard deviation (SD) about the scores. The BRT ranked effects of commercial and recreational harvests the most serious threat to persistence of the yelloweye rockfish DPS. Loss of nearshore habitat, low levels of dissolved oxygen, 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 Puget Sound Proper 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 North Puget Sound, however, the frequency of yelloweye rockfish decreased from a high of > 3% in the 1970s to a frequency of 0.65% in the most recent samples. Based on this decline in frequency in North Sound, 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. Like bocaccio and canary rockfish, the BRT was also concerned that the low intrinsic productivity combined with continuing threats from by-catch in commercial and recreational harvest, loss of near shore habitat, chemical contamination, and areas of low dissolved oxygen, increase the extinction risk of this species. 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 Georgia Basin/Puget Sound 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 and in effect answering the question in the affirmative as to "whether the yelloweye DPS is at risk throughout a significant portion of its range."

IV. 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 is unknown, however commercial trawling in Puget Sound has ceased; 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. 5 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; 4. 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. 6 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; 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; 2.The unique ecological aspects of Puget Sound Proper, 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 dissolved oxygen 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 the greenstriped rockfish DPS are presented inTable 28. Presented in the table are the median threat scores with the standard deviation (SD) about the median threat scores. The BRT ranked low dissolved oxygen events as the most serious threat to persistence of the greenstriped rockfish DPS. Contamination, nutrient loading and commercial harvesting and by-catch 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 North Puget Sound and occur very infrequently in the Puget Sound Proper recreational catch data, presumably due to the low value attached to this species. 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 under-representation of greenstriped rockfish in the recreational catch. Greenstriped rockfish appear in a low frequency in the WDFW fisheries independent trawl survey, but they were caught in the most recent years of the WDFW trawl survey in Puget Sound Proper (in both 2002 and 2005). Thus although greenstriped rockfish have been almost entirely absent from the recreational catch from 1999-2007, they are still present in Puget Sound Proper. The BRT was concerned about the lack of information on the abundance trends of greenstriped rockfish, but noted that Puget Sound Proper has large areas of the unconsolidated habitat that are used by this species, and that this species has somewhat higher intrinsic productivity than 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. Size distributions do not suggest any size truncation since the 1970s. The BRT did note that areas of low dissolved oxygen are a potential risk factor. The BRT conclusions regarding the overall risk 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 and 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.”

V. 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 2008); 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 1996-2001 this species represented 7% of the bottom trawl in the outer coast; 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 4with a mean score of 2.78 (± 0.22 SE) and a modal score of 3. 5 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; 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. 7 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 through Puget Sound (Palsson 2008); 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; 6. No genetic data on population structure is 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 deep water species, little is known about its diversity; 3. Puget Sound represents a unique ecosystem, although local adaptation is not known for this species; 4. There is no genetic data for this DPS, but some other rockfish species in Puget 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 the redstripe rockfish DPS are presented in Table 28. Presented in the table are the median threat scores together with the standard deviation (SD) about the median threat scores. The BRT ranked low dissolved oxygen events, chemical contaminants, and nutrient loading as the most serious threat to persistence of the redstripe rockfish DPS. Overharvesting and by-catch 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 North Puget Sound. In Puget Sound Proper, however, redstripe rockfish appeared frequently in the recreational catch (between 1-14%) 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 was imposed in 1983 and the bag limit was further reduced in 1994 and 2000. Since redstripe rockfish are smaller than other species, bag limits may lead to discarding and thus under-representation 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. The frequency increased dramatically in 2002 and 2005, with redstripe rockfish making up 39 and 48% of the individuals caught. The BRT concluded these high estimates may be statistical outliers, however, and are not necessarily indicative of an actual increase in abundance in recent years. However, 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 Puget Sound but are 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 this species were not well known, but concluded that the available data indicated that the species was at least locally abundant with in Puget Sound. The BRT also noted that this 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 dissolved oxygen and chemical contamination are potential risk factors for this species. 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 and 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.”

Appendix A - Rockfish Historic Data Summary and Synthesis

In general, both historic and more recent reports confirm that the five petitioned species are present in Puget Sound, although in different habitats and/or with various levels of susceptibility to particular types of sampling or fishing gear. Adult greenstriped and redstripe rockfish are found in deep water 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, bocaccio and yelloweye rockfish 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 sub regions 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 are noted in Table 29.

Before European colonization of the region's native people harvested rockfish for consumption, although it was not an intensive fishery and there is little detailed information that documents or differentiates harvest of particular species. Coast Salish people in the San Juan archipelago regarded rockfish primarily as something you would line-fish for immediate consumption (pers. comm. Russell Barsh, Director of the Center for the Study of Coastal Salish Environments). In contrast, salmon and halibut 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, 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 (R. Barsh, pers comm.). Very few archaeological sites in this area have been excavated and only very recently have archaeologists begun to identify fish bones systematically. Kopperl (2004) reviewed over 7,000 fish remains from Watmough Bight, Lopez Island, for the UW Burke Museum and Bureau of Land Management and was able to identify 2,450 of those bones at least to the Family level. Only four rockfish (family Scorpaenidae) bones were identified, while nearly 10 percent 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 the fisheries from British Columbia and Washington at the turn of the century focused on “useful” saltwater fishes such as halibut and sturgeon, which figured prominently in the catch at the time (U.S. Fisheries 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, Trevor 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 thirteen 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 which targeted flatfish landed for market in Seattle. The fishery occurred primarily over relatively soft-bottom areas, with twelve 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” (*Sebastes pinniger*), “red snapper” (*S. ruberrimus*), 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. 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 over 150’ 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, and Strait of Juan de Fuca. Rockfish were found at depths over 150’ on rocky bottoms, and primarily occurred in north Puget Sound, the Strait, and the outer coast. Finally, bocaccio were frequently caught in the Tacoma Narrows. In person, Buckley’s retrospective assessment of rockfish distribution and abundance in the 1960’s 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 WDFW worked with the media to teach the public to target bottomfish. In the Tacoma Narrows the rockfish resources declined once the mature assemblages of fish were removed. Buckley felt 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. Twenty-seven representative of the family Scorpaenidae are listed in these documents, including all five 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 1970’s in Tacoma Narrows and Appletree Cove (near Kingston) associated with sport catch; canary rockfish (114): most records occur from the 1960-70’s 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 Sound/Seattle; yelloweye rockfish (113): most records occur from the early 1970’s in the San Juan Islands (Sucia Island) and Bellingham Bay associated with the sport catch.

Some research was conducted on the ecology and recreational exploitation of rockfish in Puget Sound during the 1970’s and 1980’s by several graduate students at the University of Washington’s School of Fisheries (Moulton 1977, Barker 1979, Gowan 1983). Moulton (1977) developed SCUBA methods for surveying fish populations in the rocky nearshore region of northern Puget Sound (San Juan Islands) to estimate changes in biomass, density, and depth distribution for these species. Of the five species of interest, only one yelloweye rockfish was observed in the nearshore SCUBA surveys. Barker (1979) and Gowan (1983) focused on the most frequently-encountered recreational rockfish species: Copper, quillback, brown, black, and yellowtail rockfish. Barker’s work, conducted in the San Juan Islands, does not mention any of the rockfish species being reviewed. Gowan collected rockfish specimens for age and growth analysis throughout Puget Sound from 1973-76 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 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 1975-1978 near

Edmonds, WA (Central Puget Sound). Over the course of the 213 survey dives 20,239 fishes were observed, including 5139 rockfishes 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 / rubble habitat or a concrete outfall block.

Reum's (2006) UW thesis used otter trawls at four depths (20-160 m) along the Central 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: *Sebastes elongatus*, *S. proriger*, and *S. ruberrimus*. *Sebastes elongatus* was encountered at 0.544 kg/km (3.977 individuals $1000m^{-2}$) during the summer at 80-m depth. *Sebastes proriger* was found at 0.055 kg/km (0.389 individuals $1000m^{-2}$) during the fall at 160-m depth and at 0.343 kg/km (3.398 individuals $1000m^{-2}$) during the summer at 80-m depth. *Sebastes ruberrimus* was found during the winter at 0.944 kg/km (0.853 individuals $1000m^{-2}$) at 160-m depth, and during the summer at 1.093 kg/km (1.879 individuals $1000m^{-2}$) at 80-m depth and 2.365 kg/km (1.027 individuals $1000m^{-2}$) at 160-m depth.

Supplemental fishery-independent data

Besides the historic 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 /absence was considered valuable by the BRT when it was considered with the quantitative information provided in the body of the status review.

Tim Essington (University of WA, personal communication) recently summarized unpublished data from the logbooks of University of Washington research vessels, 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 1000 trawls (n=1063) for which there was deemed sufficient documentation, the relative occurrence, % 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 S. elongatus occurred before 1959, with centers of abundance in Hood Canal and the Central basin of Puget Sound.

The Puget Sound Ambient Monitoring Program (PSAMP) is a multi-agency effort to monitor the health of Puget Sound and assess the status and trends of chemical contamination in Puget Sound fish and macro-invertebrates (http://wdfw.wa.gov/fish/psamp/). In the period covering 1989 through 2001 marine or anadromous fish species were collected by trawl from over 100 stations from Puget Sound and southern Georgia Basin, with special focus on highly contaminated urban embayments. Samples from these trawls have included greenstriped (n=14), redstripe (n=17), and yelloweye rockfish (n=4) (J. West, WDFW, Personal communication, 5/2/08).

Fishery dependent data

Palsson et al. (2008) 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 this with additional information to provide additional context for the analyses present in the body of the 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 has always 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 1880's to the 1960's (Holmberg et al. 1967; Palsson et al. 2008). Trawl fisherman did not specifically target rockfish populations, which were marketed seasonally, considered "scattered throughout Puget Sound", and principally comprised of copper (*S. caurinus*), quillback (*S. maliger*), and orange (*S. pinniger*) rockfish species (Holmberg et al. 1967). In fact, management of rockfish in Puget Sound received little attention until the 1970's, 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 non-treaty fisheries from the 1974 Boldt decision (Palsson et al. 2008). By the 1980's, rockfish were recognized as an important recreational and commercial species in Puget Sound and were actively managed to favor recreational fisheries in South Sound. 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 1990's 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 North Sound. 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 (Palsson et al. 2008)(Pedchenko 2005).

Landings trends.

Commercial rockfish landings have been documented since the 1920's by WDFW in the form of tax receipts or landing tickets (Palsson et al. 2008), 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. (2008) and briefly summarized here. In general, annual rockfish landings remained under 20,000 lbs before the 1940's, rose during World War II when harvests peaked at over 375,000 lbs, then fluctuated between 50,000 and 220,000 lbs until 1970 (Palsson et al. 2008). After 1970 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-1970's total rockfish harvest had increased to over 300,000 lbs per year and peaked at almost 900,000 lbs in 1980. Annual harvest fluctuated between 48,000 lbs and 300,000 lbs between 1981 and 1991, declined below 30,000 lbs during the 1990's, and reached a low of approximately 2,600 lbs 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 (Washington State 1964) although they share the common weakness that precise catch location and effort is not indicated, and these landings estimates are probably dominated by rockfish caught on the outer coast or in Canada. 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. 2008). Commercial fishing effort (e.g., hours trawling) is not available before 1955 (Holmberg et al. 1967, Schmitt et al. 1991, PMFC 1979 unpublished data series). 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 the processors and market. Rather, rockfish are considered as a group which includes all commercially retained red and black rockfish except Pacific Ocean perch (*Sebastes alutus*). As a result, there are no historic landing trends of individual rockfish species and there are no size data. Because commercial harvest only includes landed catch, the amount of rockfish bycatch that was discarded is unknown, but it is thought to be small relative to the landed portion.

After 1970, commercial groundfish catch, effort, and value statistics are documented in Puget Sound by sub region, 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) was represented by bocaccio in the set net fishery of the Central and South Sound 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 South Sound (50%), and for yelloweye rockfish in Juan de Fuca (50%) and Hood Canal (30%). Rockfish species composition estimates made in 1988, 1989, 1990, 1991-2, and 1993-2003 (Palsson et al. 2008) showed similar trends by commercial gear type.

Historic 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; Bargman 1977), but subsequent documents (e.g., Palsson 1987; Palsson et al. 2008) do not use data before 1970 because of the previously mentioned shortcomings. The recreational data does provide some of the only historic 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 Washington Department of Fisheries (1975-1986) show that bocaccio were harvested primarily from south Puget Sound (PCA 13) at rates of greater than 1000 fish year^{-1} from 1976-1982, including more than 7500 bocaccio caught in 1977. In comparison, the estimated catch of bocaccio presented by Palsson (1987) during the same years exceeds 1000 bocaccio year^{-1} in only 1977 (1128 fish). These differences are attributed to (unpublished) algorithms Palsson (1987) used to correct species composition data collected before 1980 using “reliable” MRFSS estimates. WDFW rockfish species composition and catch data has been considered reliable since 2004 (Palsson et al 2008); 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 has been collected via recreational creel surveys conducted by Washington Department of Fish and Wildlife (WDFW) or the federal Marine Recreational Fisheries Statistical Survey (MRFSS) since 1980. However, there are a handful of records reaching into the mid-1970’s.

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 "outside" or ocean fishery which included the Washington coast and waters off Vancouver Island, and a local or "inside" Puget Sound fishery which 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 ten major species (groups): Petrale sole, English sole, Dover sole, rock sole, starry flounder, Pacific cod, lingcod, sablefish, rockfish, and Pacific Ocean perch. The principal species comprising the rockfish catch in the outer coast included *S. brevispinis*, *S. pinniger*, *S. flavidus*, *S. rubrivinctu*s, and *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 (gillnet, 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 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 30). Trawl fisherman did not specifically target rockfish, which were principally comprised of copper (*S. caurinus*), quillback (*S. maliger*), and orange (*S. pinniger*) 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, Table 30). In fact, Puget Sound rockfish catches generally increased from 1955-1959, but catch rates remained below 20-lb/hr in most years, almost 5 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).

Appendix B - 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 m thick, moved southward from the Coast Mountains of British Columbia and carved out the Strait of Juan de Fuca and greater Puget Sound. The 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 large 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 very 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 continued through the present (Sound Science 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 (PNI) 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 PDO shows predominantly warmer periods between 1925 and 1946 and following 1977, and a cooler phase between 1947 and 1976 (Figure 38). For Washington State, warmer periods are characterized by increased flow of relatively warm-humid air and less than normal precipitation, and the cool phase correspond to a cool-wet climate. Mantua et al. (1997) reported connections between the PDO and indicators of populations of Alaskan sockeye and pink salmon and Washington-Oregon-California coho and Chinook salmon, although the coho 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 38). 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 Alaskan coho and sockeye salmon, annual catches of Washington and Oregon coho and Chinook salmon, biomass of zooplankton 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 and hemlock trees located near Mt. Rainier and temperature and snow depth. A regression model was used to reconstruct temperatures from 1590 to 1913, and their major findings were that temperatures prior to 1900 were approximately 1^{o}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, spring time 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 (Sound Science 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, increase of winter runoff with decrease in water stored as snow pack, increased river flooding, and continued sea level rise (NMFS 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 C - Marine Species in Greater Puget Sound

Primary producers

The major classes of primary producers in Puget Sound are phytoplankton, sediment-associated micro algae, and rooted or attached algae and vascular plants in the Sound, freshwater, and on land (NMFS 2007). Phytoplankton production in Puget Sound occurs in both 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 is dominated by intense but patchy blooms of micro algae beginning in late April or May, with a series of intermittent bloom through the summer, and perhaps another intense bloom in the fall (Strickland 1983). Annual primary productivity in the central 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 ⊙g/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 the 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 used again by producers (NMFS 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. (Giles and Cordell 1998, Dumbauld 1985, Chester et al.

1980, Ohman 1990). 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 by Dumbauld (1985) 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 found that calanoid copepods and cyclopoid copepods, and two species of larvaceans were dominant numerically. Dominant copepods at deeper sites were *Pseudocalanus* spp. and *Corycaeus anglicus*. The larvacean, *Oikopleura dioica*, was also relatively common at the shallow sites. Similarly, the most abundant zooplankton in the Strait of Juan de Fuca were reported by Chester et al. (1980) to be calanoid copepods, including *Pseudocalanus* spp. and *Acartia longiremis*, and the cyclopoid copepod, *Oithona similis*.

It is likely that zooplankton assemblages vary both seasonally and annually. Evidence of depth-specific differences was reported by Ohman (1990). In studies conducted in Dabob Bay near Hood Canal, Ohman (1999) compared the abundance of certain zooplankton species at a shallow and deep site. Ohman (1999) 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. An example of seasonal variability was reported by Bollens et al. (1992b). 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, among the most common species are *Axinopsida serricata* (a bivalve) and *Prionospio jubata* (a polychaete). In muddy-clay areas of mean to average depth, *Amphiodia urtica-periercta* (a 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 *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 both 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 to February. However, there were no significant variations in the number of species during different seasons. Annual variation was examined by Nichols (1988) at three Puget

Sound proper 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 *M. carlottensis* generally dominated the benthic community from 1963 through the mid-1970s. Subsequently, these species were largely replaced by *A. serricata*, *E. pacifica*, *P. californensis*, *Ampharete acutifrons* (a polychaete), and *Euphiomedes producta* (an ostracod). A similar dominance by *P. californensis* and *A. acutifrons* was reported for the other deep site over approximately the same time period.

Several macro invertebrate species 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 non-indigenous 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 non-indigenous Japanese littleneck clam (*Tapes philippinarum*) and softshell clam (*Mya arenaria*) (Kozloff 1987, Turgeon et al. 1988).

Fish

Over 200 species of fish have been recorded in the Georgia Basin and greater Puget Sound (Schmitt et al. 1994, Palsson et al. 1997). The marine species are generally categorized as forage fish, bottomfish, and other non-game fishes. Many are, or have been, considered important commercial species, including Pacific herring (*Clupea pallasi*), 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 (*Pleuronectes vetulus*).

Forage fishes are small, schooling fishes that are key prey items for larger predatory fish and wildlife in a marine food web (Pentilla 2007). Forage fish are a valuable indicator 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-gravel beach habitats (Pentilla 2007). Pacific herring stocks in Puget Sound have recently undergone federal listing reviews (Stout et al. 2001; Gustafson et al. 2006).

Bottomfish live in marine waters and spend their lives near or on the bottom; bottomfish species commonly found in Puget Sound include the true cods (Pacific cod, walleye pollock, and Pacific hake), lingcod, flatfish, and rockfish (Palsson 1997). Populations of several stocks, particularly Pacific cod and hake, are at historic lows in Puget 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. 2008). These three rockfish species have also recently undergone a status review for federal listing (Stout et al. 2001). The spiny dogfish is a slow-growing long-lived species of shark found throughout the Georgia Basin and Puget Sound (Schmitt et al. 1994, Palsson 1997). English sole are the dominant member of the flatfish community in Puget Sound and stocks are considered relatively healthy throughout most of Puget Sound (Palsson 1997). However, significant declines have been recorded in localized embayments, such as Bellingham Bay and Discovery Bay, and high levels of toxic contaminants have been measured in the tissues of individuals collected from urban embayments (West et al. 2001).

Other species of bottomfish species found throughout greater Puget Sound include skates (*Raja rhina* and *R. binoculata*), spotted ratfish (*Hydrolagus cooliei*), sablefish (*Anoplopoma fimbria*), greenlings (*Hexagrammos decagrammus* and *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, Robins et al. 1991). 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 clarki*) also reside in greater Puget Sound habitats. All juvenile salmon move along the shallows of estuaries and nearshore areas during their out migration 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 the Canada goose (*Branta canadensis*). Examples of less abundant species include common murre (*Uria aalge*) and tufted puffins (*Fratercula cirrhata*). A number of additional bird species use greater Puget Sound during the winter months. Dabbling ducks, including American wigeon (*Anas americana*), mallard ducks (*A. platyrhynchos*) and northern pintail (*A. acuta*), are the most common, followed by geese and swans, such as trumpeter swans (*Cygnus columbianus*), tundra swans (*C. columbianus*), and Canada geese (*Branta canadensis*) (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 2007).

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 murrelet and the Canada goose are not available, but the population of marbled murrelet 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-1990's (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 1970's (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 U.S. 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 whale are occasionally observed in small pods of 3 to 40 individuals throughout Puget Sound (Kriete 2007). Southern residents feed primarily on salmon and other fishes, whereas transient feed primarily on marine mammals. Southern residents are primarily found in Northern Puget Sound and size of this group has been estimated at between 70-100 individuals since the 1970's. The southern resident population declined 20% from 1996 to 2001 (Krahn et al. 2004) and was listed under the endangered species act in 2005. The causes of this decline are likely to 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 the 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 species of rockfish in the petition. The report does not include catch by divers or shore/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 >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 vs. bottomfish catches incidental to salmon fishery. In many years, some punch card areas are listed with only 2 or 3 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 in idiosyncratically and inconsistently. The large amount of noise in the frequency data suggests the same. Note that harvest numbers of some species (e.g., bocaccio and canary 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 1965-73 using punch card data. The 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 shows 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, W. A. (1988)

This publication is a comprehensive summary of catch data from 1970-1985 and includes all the petitioned species (except greenstriped and redstripe rockfish, which were presumably pooled into misc/unidentified rockfish). The publication includes data previously published by Bargmann (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 WDFW dockside samplers were modified using species compositions from the MRFSS sampling data, when available, because these were considered more reliable. The corrections involved identifications pooled over six years of survey data. These species composition correction factors are not included in the document.

Palsson, W.A., T. Tsou, G.G. Bargmann, R.M. Buckley, J.E. West, M.L. Mills, Y.W. Cheng, and R.E. Pacunski. Draft document (2008).

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 2004-2007 in terms of pounds of fish harvested or released in two major management regions (north and south Puget Sound). The text provides a summary of species composition information that highlights range of reliable species composition information for recreational species, and also includes some discussion of MRFSS data collection procedures (see below), with graphs of MRFSS species composition by north and south Puget Sound management regions (See specifically Figures 6.9 and 6.10 in Palsson et al (2008)); the five petitioned species are presumably pooled into "other rockfish" category.

Species composition estimates from commercial fisheries are presented by Palsson et al (2008) (Specifically see Tables 6.1 and 6.2 in Palsson (2008)). 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.

Marine Recreational Fisheries Statistical Survey (MRFSS)

This is a federal survey occurring in Washington State from 1980-86, 1989, and 1996-2002 that used telephone and creel surveys to estimate state-wide 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/Puget Sound. We have not yet been able to review these data extensively for the BRT.

WDFW trawl survey data. Palsson et al. (2008)

These data provide catch records, biological data, and trawl effort/location from annual surveys throughout Puget Sound from 1987-2008 (>1500 trawls). The data includes records for four species of the petitioned species (no bocaccio), including biological records (length/weight info) for canary rockfish (n=25), greenstriped (n=481), redstripe (n=484), and Yelloweye (n= 10) rockfish. Effort is distributed unevenly at various levels over all geographic areas over time. This complicates temporal density/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, C., S. Quinnell, M. Rickey, and M. Stanley (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 from 1970-87.

CITATIONS

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., Sydman, W.J., Parrish, R., and Lenarz, W. 1993. Oceanic factors influencing distribution of young rockfish (*Sebastes*) in central California: a predator's perspective. CalCOFI 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. Ph.D., Mar. Biol., Scripps Institute of Oceanography, University of 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-NWFSC-66.

Andrews, A.H., Cordes, E.E., Mahoney, M.M., Munk, K., Coale, K.H., Cailliet, G.M., and Heifetz, J. 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, Jr., G. A., and C. H. Fiscus. 1980. The pinnipeds of the California Current. CalCOFI 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, AL, M Kawase, and P MacCready. 2006. Seasonal and interannual variability in the circulation of Puget Sound, Washington: A box model study. Atmosphere-Ocean 44:29-45.

Bargmann, G. G. 1977. The recreational hook and line fishery for marine fish in Puget Sound, 1968-1973. Technical report, WDFW Progress Report No. 33.

Barker, M. W. 1979. Population and fishery dynamics of recreationally exploited marine bottomfish of northern Puget Sound. PhD Dissertation. University of Washington, Seattle, WA. 146 pp.

Barss, W. H. 1989. Maturity and reproductive cycle for 35 species from the family Scorpaenidae found off Oregon. Report No. 89-7, Oregon Department of Fish and Game, Portland, OR.

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, California. 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. Transactions of the American Fisheries Society 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.

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 Journal of Marine Science: 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*). Fishery Bulletin, U.S. 102:418-429.

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. Fishery Bulletin, U.S. 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. Marine Ecology Progress Series 3:1-10

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.

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

Buchanan, J.B. 2006. Nearshore Birds in Puget Sound. Puget Sound Nearshore Partnership Report No. 2006-05. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington. Available at www.pugetsoundnearshore.org

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. Wash. Dept. Fish and Wildlife Technical Report No. RAD97-06, 320.

Buckley, R. M. 1967. 1965 bottomfish sport fishery. Technical report, Washington Dept. Fisheries Supplemental Progress Report.

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

Buckley, R. M. 1970. 1967 bottomfish sport fishery. Technical report, WA Dept Fisheries Supplemental Progress Report.

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

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

Burns, R. 1985. The shape and form of Puget Sound. Washington Sea Grant Program, University of Washington Press, Seattle, WA, 100 p.

Butler, J., A. DeVogelaere, R. Gustafson, C. Mobley, M. Neuman, D. Richards, S. Rumsey, B. Taylor, G. VanBlaricom. 2008. Status review report for black abalone (*Haliotis cracherodii* Leach, 1814), DRAFT – 4 January 2008. NOAA Tech. Memo. NMFS-SWR-##. Online at http://swr.nmfs.noaa.gov/media/BASR_Report_Draft_11_January_2008.pdf [accessed July 2008].

Burr, J. C. 1999. Microsatellite analysis of population structure of quillback rockfish (*Sebastes maliger*) from Puget Sound to Alaska. Senior thesis, University of Puget Sound

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. , Vol. Final Report and Excel Data Matrix, Pacific States Marine Fisheries Commission. California Department of Fish and Game

Cannon, GA. 1990. Variations in the Onset of Bottom-Water Intrusion Over the Entrance Sill of a Fjord Estuaries Vol. 13, No. 1, p. 31-42.

Carlson, H.R., and Straty, R.R. 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 of Arts, San Francisco State University/Moss Landing Marine Laboratories

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, Washington.

Caughley, G. 1994. Directions in conservation biology. J. Anim. Ecol. 63:215-244.

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

Clemens, W.A. and G.V. Wilby. 1961. Fishes of the Pacific coast of Canada. Bull. Fish. Res. Board. Can. 68: 443.

Collins, B. D. and A. J. Sheikh. 2005. Historical reconstruction, classification, and change analysis of Puget Sound tidal marshes. Final project report to Washington

Department of Natural Resources Aquatic Resources Division, Olympia, WA 98504-7027.
.
COSEWIC (Committee On The Status Of Endangered Wildlife In Canada). 2002. COSEWIC assessment and status report on the Bocaccio *Sebastes paucispinis* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vii + 43 p.

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, Committee on the Status of Endangered Wildlife in Canada, Ottawa

Coombs, C. I. 1979. Reef fishes near Depoe Bay, Oregon: movement and the recreational fishery. Master of Science, Fisheries and Wildlife, Oregon State University.

Cope, J. M. 2002. Phylodemography of the blue rockfish (*Sebastes mystinus*) from California to Washington. M.S., Moss Landing Marine Laboratories/ San Francisco State University.

Cope, J. M. 2004. Population genetics and phylogeography of the blue rockfish (*Sebastes mystinus*) from Washington to California. Canadian Journal of Fisheries and Aquatic Sciences 61(3): 332-342.

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

DeMott, G.E. 1983. Movement of tagged lingcod and rockfishes off Depoe Bay, Oregon. Master of Science, Oregon State University.

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. Ecological Monographs 76:323–341.

DFO (Department of Fisheries and Oceans Canada). 2008. Fisheries and Oceans Canada, Pacific region regional data services unit.

Delacy, A.C., B.S. Miller, and S.F. Borton. 1972. Checklist of Puget Sound fishes. Washington Sea Grant Program Publication WSG 72-3, 43 p.

Dethier, M.N. 2006. Native Shellfish in Nearshore Ecosystems of Puget Sound. Puget Sound Nearshore Partnership Report No. 2006-04. Published by Seattle District, U.S.Army Corps of Engineers, Seattle, Washington. Online at www.pugetsoundnearshore.org

Downing, J. 1983. The coast of Puget Sound: Its processes and development. Washington SeaGrant, University of Washington Press, Seattle, Washington.

Dulvy, N. K., Y. Sadovy, and J. D. Reynolds. 2003. Extinction vulnerability in marine populations. Fish. 4:25–64.

Dulvy, N. K., J. R. Ellis, N. B. Goodwin, A. Grant, J. D. Reynolds, and S. Jennings. 2004. Methods of assessing extinction risk in marine fishes. Fish. 5:255–276.

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.

Ebbsmeyer, C.C., Cannon, G.A., and C.A. Barnes. 1984. Synthesis of current measurements in Puget Sound, Washington. NOAA Tech. Memo. NOS OMS 5.

Eigenmann, C.H. 1891. The spawning season of San Diego fishes. Am. Nat.: 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. US Geol. 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. Estuaries and Coasts*,* 30, 201-213.

Essington, T. 2008 University of Washington. Seattle, WA, Personal communication, May 7, 2008.

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

FEMAT (Forest Ecosystem Management Assessment Team). 1993. Forest ecosystem management: An ecological, economic, and social assessment. USDA Forest Service, BLM, USFWS, NOAA, EPA, and National Park Service, Portland, Oregon.

Field, J. C. and S. Ralston. 2005. Spatial variability in rockfish (*Sebastes* spp.) recruitment events in the California Current System. Canadian Journal of Fisheries and Aquatic Sciences 62:2199-2210.

Finlayson, D. 2006. The geomorphology of Puget Sound beaches. Puget Sound Nearshore Partnership Report No. 2006-02. Published by Washington Sea Grant Program, University of Washington, Seattle, Washington. Available at http://pugetsoundnearshore.org.

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. Marine Ecology Progress Series 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.

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., F. D. Cardwell, and R. R. Koons. 1981. Food habits of Pacific salmon, baitfish, and their potential competitors and predators in marine waters of Washington, August 1978 to September 1979. Wash. Dept. Fish. Prog. Rep. No. 145.

Fresh, K.L. 2006. Juvenile Pacific Salmon in Puget Sound. Puget Sound Nearshore Partnership Report No. 2006-06. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington. Available at www.pugetsoundnearshore.org.

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. of Washington School of Fisheries Research Institute, Seattle, WA, 729 p.

Gascon D.,and R.A. Miller. 1981. Colonization by nearshore fish on small artificial reefs in Barkley Sound, British Columbia. Canadian Journal of Zoology 59:1635-1646

Gilpin, M.E., and M.E. Soule. 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. Molecular Ecology Notes 3:387-389.

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. of Commerce, NOAA Tech. Memo., NMFS-NWFSC-66, 598 p.

Gowan, R. E. 1983. Population dynamics and exploitation rates of rockfish (Sebastes spp.) in Central Puget Sound, Washington. PhD Dissertation. University of Washington. Seattle, WA. 90 pp.

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*). Canadian Journal of Fisheries and Aquatic Sciences 44:490-498.

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

Gunderson, D. R., P. Callahan, and B. Goiney. 1980. Maturation and fecundity of four species of *Sebastes*. Marine Fisheries Review 42:74-79.

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, 182 p.

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, 117 p.

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. Fisheries Research Board of Canada Bulletin 180.

Hartmann, A.R. 1987. Movement of scorpionfishes (Scorpaenidae: *Sebastes* and *Scorpaena*) in the Southern California Bight. California Department of Fish and Game 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. Fishery Bulletin 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. Ecological Applications 16:1502-1515.

Haw, F. and R. Buckley. 1971. Saltwater fishing in Washington. Stanley N. Jones, Seattle. 192 pp**.**

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

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

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

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

Holmberg, E. K, D. Day, N. Pasquale, and B. Pattie. 1967. Research report on the Washington trawl fishery 1962-64. Technical report, Washington Department of Fisheries, Research Division, unpublished report.

Holmes, E. E. 2001. Estimating risks in declining populations with poor data. Proc. Natl. Acad. Sci. 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. Ecology Letters 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

Hutchings, J. A. 2000. Collapse and recovery of marine fishes. Nature 406:882–885.

Hutchings, J. A. 2001a. Conservation biology of marine fishes: Perceptions and caveats regarding assignment of extinction risk. Can. J. Fish. Aquat. Sci. 58:108–121.

Hutchings, J. A. 2001b. Influence of population decline, fishing, and spawner variability on the recovery of marine fishes. J. Fish Biol. 59 (Suppl. A):306–322.

Hutchings, J. A., and J. D. Reynolds. 2004. Marine fish population collapses: Consequences for recovery and extinction risk. BioScience 54:297–309.

Hyde, J. R., and R. D. Vetter. 2007. The origin, evolution, and diversification of rockfishes of the genus *Sebastes* (Cuvier). Molecular Phylogenetics and Evolution 44:790-811.

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. Molecular Ecology 17: 1122-1136.

Ihssen, P. E., H. E. Booke, J. M. Casselmann, J. M. McGlade, N. R. Payne, and F. M. Utter. 1981. Stock identification: materials and methods. Can. J. Fish. Aquat. Sci. 38:1838-1855.

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 ^{18}O record. In A. L. Berger, (ed.), Milankovitch and Climate, Part 1, p. 269_305. D. Reidel, Norwell, MA.

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 Department of Fish and Wildlife, Wildlife Science Division, Olympia. 139 pp.

Jeffries, S., H. Huber, J. Calambokidis, and J. Laake. 2003. Trends and status of harbor seals in Washington State: 1978-1999. Journal of Wildlife Management 67:207-218.

Johns, G.C., and Avise, J.C. 1998. Tests for ancient species flocks based on molecular phylogenetic appraisals of *Sebastes* rockfishes and other marine fishes. Evol. 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*). Molecular Ecology online.

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). Marine Environmental Research.

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. M.S. Marine Science, California State University, Stanislaus/Moss Landing Marine Laboratories, Stanislaus.

Johnson SW, Murphy ML, Csepp DJ (2003) Distribution, habitat, and behavior of rockfishes, *Sebastes* spp., in nearshore waters of southeastern Alaska: observations from a remotely operated vehicle. Environmental Biology of Fishes 66:259-270.

Kincaid, T. 1919. An annotated list of the Puget Sound fishes. State of Washington, Department of Fisheries publication. 51 pp.

Kopperl, R. E. and V. Butler. 2001. Faunal Analysis: Fish Remains. /In /Vashon Island Archaeology: A View from Burton Acres Shell Midden. Julie K. Stein and Laura S. Phillips, eds. Pp. 105–118. Burke Museum of Natural History and Culture Research Report, 8. Seattle: University of Washington Press.

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. NMFSNWFSC-62, 73 p.

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 Report No. 2007-01. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington. Available at www.pugetsoundnearshore.org.

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

Kritzer, J. P., and P. F. Sale. 2004. Metapopulation ecology in the sea: From Levis' model to marine ecology and fisheries science. Fish. 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 Report. Washington Department of Fish and Wildlife.

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. Transactions of the American Fisheries Society 126:519-535.

Larson, R. J. 1980. Competition, Habitat Selection, and the Bathymetric Segregation of 2 Rockfish (*Sebastes*) Species. Ecological Monographs 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. CalCOFI Rep. 35: 175-219.

Law, R. 2007. Fisheries-induced evolution: present status and future directions. Marine Ecology Progress Series 335:271-277.

Lea, R.N., McAllister, R.D., 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., Young, S.F., and J. B. Shaklee. 2006. Allozyme and microsatellite DNA analyses of lingcod from Puget Sound, Washington, and adjoining waters. Transactions of the American Fisheries Society 135:1631-1643.

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

Lenarz W.H., and T.W. Echeverria. 1991. Sexual dimorphism in *Sebastes*. Environmental Biology of Fishes 30:71-80

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

Li, Z., A. Gray, M. Love, A. Goto, and A. Gharrett. 2007. Are the subgenera of *Sebastes* monophyletic? Pages 185-206 in J. Heifetz, and coeditors, editors. Biology, assessment, and management of North Pacific rockfishes. Alaska Sea Grant, University of Alaska, Fairbanks.

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. Report No. 352, U. S. Fish and Wildlife Service, Washington D.C.

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 August 11 to September 6, 2005. Technical report, Canadian Technical Report 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. Washington Department of Fish and Wildlife, PSMFC Contract No. 02-15. Final Report on Studies of Expanding Pinniped Populations to NOAA, Olympia. 20.

Longhurst, A. 2002. Murphy's law revisited: longevity as a factor in recruitment to fish populations. Fisheries Research 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*). Doctor of Philosophy, Biological Science, University of California at Santa Barbara, 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. NOAA Tech. Rep. NMFS 87, U.S. Dept. Commer.

Love, M.S. and M. Moser. 1983. A checklist of parasites of California, Oregon, and Washington marine and estuarine fishes, NOAA Technical Report NMFS SSRF-777

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*). Fishery Bulletin 104:383-390

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. Bulletin of Marine Science 77:397-408

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 boarder. OCS Study MMS 2005-030, U.S. Department of the Interior, U.S. Geological Survey, Biological Resources Division, Seattle, WA.

Love, M.S., and M. Yoklavich. 2008. Habitat characteristics of juvenile cow cod, *Sebastes levis* (Scorpaenidae), in Southern California. Environmental Biology of 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, California.

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. Bulletin of Marine Science 77:101-117

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

Mace, G. M., and E. J. Hudson. 1999. Attitudes toward sustainability and extinction. Cons. Biol. 13:242–246.

MacCall, A.D. 2002. Use of Known-Biomass Production Models to Determine Productivity of West Coast Groundfish Stocks. North American Journal of Fisheries Management [N Am J Fish Manage] 22:272-279

MacCall, A.D. and He, X. 2002. Status Review of the Southern Stock of Bocaccio (*Sebastes paucispinis*). Revised October, 2002. Santa Cruz Laboratory, Southerwest Fisheries Science Center, National Marine Fisheries Service. Available at http://www.nmfs.noaa.gov/pr/pdfs/statusreviews/bocaccio.pdf.

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

MacCall, A. D. 2007. Status of bocaccio off California in 2007. Pacific Fishery Management Council 7700 NE Ambassador Place, Suite 101, Portland, OR 97220-1384, Portland, OR, 67p.

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. Estuarine, Coastal And Shelf Science, 44, 1-21.

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. NMFS-NWFSC-42. Online at http://www.nwfsc.noaa.gov/assets/25/ 5561_06162004_143739_tm42.pdf.

MacGregor, J. S. 1970. Fecundity, multiple spawning, and description of the gonads in *Sebastodes*. Special Scientific Report-- Fisheries 596, United States Fish and Wildlife Service, Washington, D. C.

Marteinsdottir, G., and K. Thorarinsson. 1998. Improving the stock-recruitment relationship in Icelandic cod (*Gadus morhua*) by including age diversity of spawners. Canadian Journal of Fisheries and Aquatic Sciences 55:1372-1377.

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. Meteorological Soc. 78:1069–1079.

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. Technical report, Canadian Technical Report Fish. Aquat. Sci. 2663.

Mason, J. E. 1998. Declining rockfish lengths in the Monterey Bay, California, recreational fishery, 1959-94. Marine Fisheries Review 60:15-28.

Masson, D. 2002. Deep water renewal in the Strait of Georgia. Estuarine, Coastal and Shelf Science (2002) 54, 115–126.

Masson, D., and P.F. Cummins. 2000. Fortnightly modulation of the estuarine circulation in Juan de Fuca Strait. Journal of Marine Research, 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. Management 24: 1189-1202.

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. NOAA Tech. Report NMFS 80, U. S. Dept. of Comm.

Matsuda, H., T. Yahara, and Y. Ouzami. 1997. Is tuna critically endangered? Extinction risk of a large and over-exploited population. Ecol. Res. 12:345–356.

Matsuura, H and GA Cannon 1997. Wind Effects on Sub-Tidal Currents in Puget Sound. Journal of Oceanography, 53:53-66.

Mecklenburg, C.W., Mecklenburg, T.A. and Thorsteinson, L.K. 2002. Fishes of Alaska. American Fisheries Society, Bethesda, MD.

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, National Marine Fisheries Service, Seattle WA.

Miller, B.S., and S.F. Borton. 1980. Geographical distribution of Puget Sound fishes: Maps and data source sheets. Univ. of Washington Fisheries Research Institute, 3 vols.

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

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 Bulletin:137.

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.

Mitson, R. B. 1995. Underwater noise of research vessels: Review and recommendations. ICES Co-op. Res. Rep. 209:1–61.

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.

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. 1996. 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. Oceanic Fish. Invest. Rep 41:132-147.

Moulton, L. L. 1977. An ecological analysis of fishes inhabiting the rocky nearshore regions of northern Puget Sound, Washington School of Fisheries, University of Washington: 181 pp

Mumford, T.F. 2007. Kelp and Eelgrass in Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-05. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington. Available at www.pugetsoundnearshore.org.

Munk, K. 2001. Maximum ages of groundfishes in waters off Alaska and British Columbia and consideration of age determination. Alaska 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 p.

Naish, K. A., J. E. Taylor 3rd, 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 State Department of Natural Resources, Olympia, WA.

Nei, M., and F. Tajima. 1981. Genetic drift and estimation of effective population size. Genetics 98:625–640.

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

Nichol, D. G., and E. K. Pikitch. 1994. Reproduction of darkblotched rockfish off the Oregon coast. Transactions of the American Fisheries Society 123(4):469-481.

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). 1999a. Listing endangered and threatened species and designating critical habitat: petition to list eighteen species of marine fishes in Puget Sound, Washington. Federal Register (Docket No. 990614161-9161-01; 21 June 1999) 64(118):33037–33040.

NMFS (National Marine Fisheries Service). 2000. Endangered and threatened species: Puget Sound populations of Pacific hake, Pacific cod, and walleye pollock. (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.

NMFS (National Marine Fisheries Service). 2004. Listing endangered and threatened species and designating critical habitat: Petitions to list the Cherry Point stock of Pacific herring as an endangered or threatened species. Federal Register (Docket No. 040511147–4147–01; 10 August 2004) 69(153):48455–48460.

NMFS (National Marine Fisheries Service) (2007) Sound Science: Synthesizing ecological and socioeconomic information about the Puget Sound ecosystem. Ruckelshaus MH, McClure MM (coordinators); prepared in cooperation with the Sound Science collaborative team. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration (NMFS), Northwest Fisheries Science Center. Seattle, Washington. 93 p.

O'Connell, V., 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'Connell, V. M. 1987. Reproductive seasons for some *Sebastes* species in southeastern Alaska.

O'Farrell, M., and L. W. Botsford. 2006. The fisheries management implications of maternal-age-dependent larval survival. Canadian Journal of Fisheries and Aquatic Sciences 63:2249-2258.

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. Rept. 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. Molecular Ecology 13:1799-1814

Owen, R. W. 1980. Eddies of the California current system: physical and ecological characteristics. In The California Islands: Proceedings of a Multidisciplinary Symposium, Santa Barbara, p. 237-263.

PMFC (Pacific Marine Fisheries Commission). 1979. Data series, groundfish section. unpublished data and graphs. Technical report, Pacific Marine Fisheries Commission.

Palsson, W. A. 1987. Bottomfish catch and effort statistics from boat-based recreational fisheries in Puget Sound, 1970-1985. Olympia, WA; State of Washington, Dept. of Fisheries, Marine Fish Program, Report no. 261.

Palsson, W.A. 1988. Bottomfish catch and effort statistics from boat-based recreational fisheries in Puget Sound, 1970-1985 (revised). Technical report, Washington Department of Fisheries Progress Report No. 261.

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 Department of Fish and Wildlife, Olympia WA.

Palumbi, S. R. 1994. Genetic divergence, reproductive isolation, and marine speciation. Ann. 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. Transactions of the American Fisheries Society 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 Journal of Marine Science, 62: p.p. 1501-1510.

Pedersen, M.G., and G. G. Bargmann. 1986. 1984 supplement for the groundfish management plan for Washington's inside waters. Technical report, Washington State Department of Fisheries Progress Report No. 247.

Pedersen, M. and G. DiDonato. 1982. Groundfish management plan for Washington's inside waters. State of Washington, Dept. of Fisheries, Progress Report No. 170.

Peden, A. E., and D. E. Wilson. 1976. Distribution of intertidal and sub tidal fishes of northern British Columbia and southeastern Alaska. Syesis 9:221–248.

Phillips, J.B. 1960. Canary rockfish. In: California ocean fisheries resources to the year 1960. California Department of Fish and Game, p 39.

Phillips, J.B. 1964. Life history studies on ten species of rockfish (Genus Sebastodes). Fish Bulletin 126:1-70.

Powles, H., M. J. Bradford, R. G. Bradford, W. G. Doubleday, S. Innes, and C. D. Levings. 2000. Assessing and protecting endangered marine species. ICES J. Mar. Sci. 57:669–676.

PSAT (Puget Sound Action Team). 2007. State of the Sound 2007. Puget Sound Action Team, Olympia, WA. Publication No. PSAT:07-01.

Ralston S, and J.N. Ianelli. 1998. When lengths are better than ages: The complex case of bocaccio. Report No. Alaska Sea Grant Program Report No. AK-SG-98-01, University of Alaska, Fairbanks.

REEF (Reef Environmental Education Foundation). 2008. Reef environmental education foundation. Online at www.reef.org [accessed 24 June 2008].

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.

Reum, J. C. P. 2006. Spatial and temporal variation in the Puget Sound food web. MS Thesis, University of Washington, Seattle, WA.

Rice, C. A. 2007. Evaluating the biological condition of Puget Sound. Ph.D. University of Washington, School of Aquatic and Fisheries Sciences. 270 pp.

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, Department of Fisheries and Oceans, Fisheries Research Branch, Pacific Biological Station, British Columbia.

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. Fishery Bulletin 77:1-46.

Roberts, D.A. 1979. Food Habits as an ecological partitioning mechanism in the nearshore rockfishes (*Sebastes*) of Carmel Bay, California. Master of Arts, San Francisco State University/Moss Landing Marine Laboratories

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.

Rosenthal, R.J., V. Moran-O'Connell, and M.C. Murphy. 1988. Feeding ecology of ten species of rockfishes (Scorpaenidae) from the Gulf of Alaska. California Department of Fish and Game 74:16-37

Ruckelshaus, M. H. and M. McClure. 2007. Sound Science: Synthesizing ecological and socioeconomic information about the Puget Sound ecosystem. U.S Department of Commerce, NOAA, Northwest Fisheries Science Center. Seattle, WA.

Ryman, N., and L. Laikre. 1991. Effects of supportive breeding on the genetically effective populations size. Conserv. Biol. 5:325-329.

Ryman, N., Jorde, P.E., and Laikre, L. 1995. Supportive breeding and variance effective population size. Conservation Biology, **9**: 1619-1628.

Sabo, J. 2005. Stochasticity, predator-prey dynamics and trigger harvest of non-native predators. Ecology 86:2329–2343.

Schmitt, C. C., S. J. Jeffries, and P. J. Gearin. 1995. Pinniped predation on marine fish in Puget Sound. In E. Robichaud (ed.), Puget Sound Research '95 proceedings, p. 630–637. Puget Sound Water Quality Authority, Bellevue, WA.

Schmitt, C., S. Quinnell, M. Rickey, and M. Stanley. 1991. Groundfish statistics from commercial fisheries in Puget Sound, 1970-1988. Wash. Dept. Fisheries Prog. Rep. No. 285.

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 Journal of Marine Science 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*. Journal of Heredity 89(5):393-403.

Shaw, F. R. 1999. Life history of four species of rockfish (Genus *Sebastes*). Ph.D. dissertation, School of Fisheries, University of Washington, Seattle.

Shaw, F. R., and D. R. Gunderson. 2006. Life history traits of the greenstriped rockfish, *Sebastes elongatus*. Department of Fish and Game 1: 1-23.

Shepard, M. P., and J. C. Stevenson. 1956. Abundance, distribution and commercial exploitation of the fisheries resources of Canada's west coast. Transactions of the Ninth British Columbia Natural Resources Conference, February 22-24, 1956, Victoria, B. C. FRB 453

Shipman, H. 2004. Coastal bluffs and sea cliffs on Puget Sound, Washington. U.S. Geological Survey Professional Paper 1693, pp. 81-94.

Short, J. W., S. D. Rice, R. A. Heintz, M. G. Carls, and A. Moles. 2003. Long-term effects of crude oil on developing fish: Lessons from the Exxon Valdez oil spill. Energy Sources. 25:509–517.

Singer, M.M. 1982. Food habit and activity patterns of juvenile rockfishes (*Sebastes*) in a central California kelp forest. Master of Arts, San Jose State University

Smedbol, R. K., A. McPherson, M. M. Hansen, and E. Kenchington. 2002. Myths and moderation in marine 'metapopulations'? Fish. 3:20–35.

Smedbol, R. K., and J. S. Wroblewski. 2002. Metapopulation theory and northern cod population structure: Interdependency of subpopulations in recovery of a groundfish population. Fish. Res. 55:161–174.

Smith, R. T. 1936. Report on the Puget Sound Otter Trawl Investigations. Biological Report No. 36B. Department of Fisheries, State of Washington.

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, University of Washington, Seattle.

Sogard, S. M., S. A. Berkeley, and R. Fisher. 2008. Maternal effects in rockfishes *Sebastes* spp.: a comparison among species. Marine Ecology Progress Series 360:227-236.

Sotka, E.E., J.A. Hempelmann, and C.H. Biermann. 2005. Genetic evidence of postglacial population expansion in Puget Sound rockfish (*Sebastes emphaeus*). Marine Biotechnology 7:223-230.

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* Kendall Jr. AW, Marliave JB (eds) Descriptions of early life history stages of selected fishes: from the 3rd international symposium on the early life history of fishes & 8th annual larval fish conference, Vol 1359, Nanaimo, p 65-76.

Starr, R.M. 1998. Design principles for rockfish reserves on the U. S. West Coast. In: Yoklavich MM (ed) Marine Harvest Refugia For West Coast Rockfish: A Workshop. U.S. Dept. Comm., p 50-63.

Starr, R.M., J.N. Heine JN, 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. Fishery Bulletin [Fish Bull] 100:324-337

STAT (1999) Status of the canary rockfish resource off Oregon and Washington in 1999, National Marine Fisheries Service, Newport

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. Journal of Fisheries Management 3:425-437

Stewart, I.J. 2007. Status of bocaccio off California in 2007. Pacific Fishery Management Council 7700 NE Ambassador Place, Suite 101, Portland, OR 97220-1384, Portland, OR, 362p.

Stout, H.A., R.G. Gustafson, W.H. Lenarz, B.B. McCain, D.M. VanDoornik, T.L. Builder, and R.D. Methot. 2001. Status review of Pacific herring in Puget Sound, Washington. U.S. Dept. Commerce. 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. 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.

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 caballus*, and *Caranx sexfasciatus*. CalCOFI 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.

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, Volume 7. Shorelands and Coastal Zone Management Program, WDOE, Olympia,WA.

Thompson, G.G. 1991. Determining minimum viable populations under the Endangered Species Act. NOAA Tech. Memo. NMFS F/NWC-198, 78 p.

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 of Georgia-Puget Sound-Juan de Fuca Strait, p36-98. Proceedings of the BC/Washington Symposium on the Marine Environment, January 13 & 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. Journal of Experimental Marine Biology and Ecology 352:50-64.

Tolimieri, N. and P. S. Levin. 2005. The roles of fishing and climate in the population dynamics of bocaccio rockfish. Ecological Applications 15:458-468.

Tolimieri, N., K. Andrews, G. Williams, and P.S. Levin. (in press) 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. Marine Ecology Progress Series

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.

United States Fish and Wildlife Service, and National Marine Fisheries Service (USFWS-NMFS). 1996. Policy regarding the recognition of distinct vertebrate population segments under the Endangered Species Act. Federal Register (7 February 1996) 61(26):4722-4725.

United States Fish Commission. 1900. Bulletin of the United States Fish Commission.

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. Marine Ecology Progress Series 155:173-188.

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*. Journal of the Fisheries Research Board of Canada 25:801-803.

Waldichuck, M. 1957. Physical oceanography of the Strait of Georgia, British Columbia. J. Fish. Res. Board Can. 14:321-486.

Walton, J.M. 1979. Puget Sound artificial reef study. State of Washington, Dept of Fisheries, Technical report no. 50. 130 pp.

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.

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. 1991a. Definition of "species" under the Endangered Species Act: Application to Pacific salmon. U.S. Dept. Commer., NOAA Tech. Memo. NMFS, F/NWC-194.

Waples, R. S. 1991b. Pacific salmon, *Oncorhynchus* spp., and the definition of "species" under the Endangered Species Act. Mar. Fish. Rev. 53(3):11–22.

Waples, R. S. 1995. Evolutionary significant units and the conservation of biological diversity under the Endangered Species Act. Am. Soc. Fish. Symp. 17:8–27.

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.

Warner, R. R., and P. L. Chesson. 1985. Coexistence mediated by recruitment fluctuations - a field guide to the storage effect. Am. Naturalist 125:769-787.

WDF (Washington Department of Fisheries). 1975-86. Washington state sport catch reports. Technical report, Washington Dept. of Fisheries.

Washington State Department of Fisheries Annual Reports. 1964.

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.

Weir, B. S. 1996. Genetic data analysis II. Sinauer Associates Inc., Sunderland, MA

West, J. E., S. M. O'Neill, G. R. Lippert, and S. R. Quinnell. 2002. Toxic contaminants in marine and anadromous fish from Puget Sound, Washington: Results from the Puget Sound Ambient Monitoring Program Fish Component, 1989-1999. Washington Department of Fish and Wildlife, FTP01-14, Olympia, WA.

Westrheim, S.J. 1975. Reproduction, maturation, and identification of larvae of some *Sebastes* (Scorpaenidae) species in the northeast Pacific Ocean. J. Fish. Res. Bd. Canada 32: 2399-2411.

Westrheim, S. J. 1975. Reproduction, maturation, and identification of larvae of some *Sebastes* (Scorpaenidae) species in the northeast Pacific Ocean. J. Fish. Res. Bd. Canada 32: 2399-2411.

Westrheim, S. J., and W. R. Harling. 1975. Age-length relationships for 26 scorpaenids in the northeast Pacific Ocean. Technical Report 565, Fisheries and Marine Service Research Division, Nanaimo, British Columbia.

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 Journal of Marine Science 57:452-464.

Williams, E. H., and S. Ralston. 2002. Distribution and co-occurrence of rockfishes (family: Sebastidae) over trawl able 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, Oregon, p 75

Wing, S. R., Botsford, L. W., Ralston, S. V., 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.

Wishard, L.N., F.M. Utter, and D.R. Gunderson. 1980. Stock separation of five rockfish species using naturally occurring biochemical genetic markers. Marine Fisheries Review 42:64-73.

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. Marine Biology 139:1-12.

Wourms, J. P. 1991. Reproduction and development of *Sebastes* in the context of the evolution of piscine viviparity. Environm. Biol. Fishes 30:111-126.

Wright, S. 1978. Evolution and the genetics of populations. Vol. 4. Variability within and among natural populations. University of Chicago Press, Chicago.

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. 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.

Yang, Z and T. Khangaonkar. 2008. Modeling the Hydrodynamics of Puget Sound using a Three-dimensional Unstructured Finite Volume Coastal Ocean Model. Proceedings of the 10th International Conference on Estuarine and Coastal Modeling, edited by M. L. Spaulding, 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 deep-water 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.

TABLES

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

Pattern of population structure	Species	Source
No population structure detected	chilipepper rockfish	Wishard et al. (1980)
	Mexican rockfish	Bernardi et al. (2003); Rocha-Olivares et al. (200
	kelp rockfish	Gilbert-Horvath et al. (2006)
Isolation by distance	darkblotched rockfish	Gomez-Uchida & Banks (2005)
	canary rockfish	Wishard et al. (1980)
	goldeye rockfish	Sekino et al. (2001)
	Pacific ocean perch	Wishard et al. (1980); Seeb & Gunderson (1988)
	copper rockfish	Seeb et al. (1998); Buonaccorsi et al. (2002)
	quillback rockfish	Seeb et al. (1998)
	brown rockfish	Seeb et al. (1998); Buonaccorsi et al. (2005)
	kelp rockfish	Taylor (2004)
	grass rockfish	Buonaccorsi et al. (2004)
Genetic differentiation, but not consistent with isolation by distance	shortraker rockfish	Matala et al. (2004b)
	quillback rockfish	Burr (1999)
Influence of oceanographic features	Pacific ocean perch	Withler et al. (2001)
	blue rockfish	Cope (2004)
	grass rockfish	Buonaccorsi et al. (2004)
	vermilion rockfish	Hyde (2007)
	rosethorn rockfish	Rocha-Olivares & 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)

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

Differentiation Found	Common Name	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 2 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 & Hodgins 1971

Table 3 Sample worksheet for evaluating potential DPS(s) of Puget Sound rockfishes using the "likelihood point" method (FEMAT 1993)Table 1. 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 ten 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 ten likelihood points among the six DPS scenarios. Placement of all ten 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

Table 4 Total rockfish CPUE data from the recreational bottomfish for 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. Data from Bargmann (1977) and Buckley (1967, 1968, 1970).

Year	Buckley and Bargmann	Palsson et al. (2008)	Palsson (1988)
1965	0.77		
1966	1.34		
1967	0.29		
1968	0.8		
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 5 The total rockfish CPUE data from the recreational bottomfish-specific fishery for the Puget Sound Proper (south Puget Sound). 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. (2008)
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		0.5
1987		0.5
1988		0.58
1989		0.66
1990		0.57
1991		0.47
1992		0.62
1993		0.45
1994		0.5
1995		0.27
1996		0.27
1997		0.3
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

Table 6 The total rockfish CPUE data from the recreational bottomfish-specific fishery for the North Puget Sound. For Palsson et al. (2008) data are the total catch divided by the total trips in areas 5-7. For Buckley (1967, 1968, 1970) and Bargmann (1977), the 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. (2008)
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
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		0.9
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		0.3
2005		0.32
2006		0.28
2007		0.21

Table 7 The total rockfish CPUE from the commercial bottom trawl data for the whole Puget Sound, including Strait of Juan de Fuca. These data are estimates of pounds (× 1000) 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	4.3		
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		13.4	
1981		6.47	
1982		5.55	
1983		5.72	
1984		6.59	
1985		5.34	
1986		4.92	
1987		0.94	
1988		3.31	

Table 8 Washington Department of Fish and Wildlife Trawl survey sampling effort by region depth and year. HC=Hood Canal, ,SS=South Puget Sound, WI=Whidbey Basin, CS= Central Puget Sound, GB=US Strait of Georgia, GC=BC Strait of Georgia ,JE=East US Juan de Fuca, CJ=East BC Juan de Fuca, SJ=US San Juan Archipelago, DB=Discovery Bay, WJ=West US Juan De Fuca, CA=BC Haro Strait and Boundary Pass. Depth is given in fathoms.

0-20 fm	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 fm	CJ	CS	DB	GB	GC	HC	JE	JF	JW	SJ	SS	WI
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

41-60 fm	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 fm	CJ	CS	DB	GB	GC	HC	JE	JF	JW	SJ	SS	WI
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

>121 fm	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												

Table 9 The total rockfish CPUE from the WDFW trawl survey (Palsson et al., 2008) and the REEF dive surveys (REEF, 2008). The WDFW trawl survey is reported as an estimate of abundance in north and south Puget Sound (Puget Sound Proper). The estimate for south Puget Sound is an order of magnitude larger than the estimate for north Puget Sound, which is contrary to our assumptions about the 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 the south and north Puget Sound. Most of these dives occurred in south Puget Sound.

Year	WDFW Trawl Survey (south Puget Sound)	WDFW Trawl Survey (north Puget Sound)	REEF (2008) (south Puget Sound)	REEF (2008) (north Puget Sound)
1987	1265.2	89.9		
1988				
1989	1419.0	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

Table 10 The species frequency data for bocaccio in Puget Sound Proper. Data 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. (2008). Reported sample sizes (fish identified) are given in parentheses if available.

Year	WA Sport Catch Rpts	Palsson et al. (2008)	Buckley and Bargmann
1965			0 (NA)
1966			0.41 (NA)
1967			1.01 (NA)
1968			0 (NA)
1969			0 (NA)
1970			1.51 (NA)
1971			3.12 (NA)
1972			0 (NA)
1973			0 (NA)
1974			
1975	1.38 (NA)		
1976	2.5 (NA)		
1977	9.35 (NA)		
1978	8.03 (NA)		
1979	1.89 (NA)		
1980	1.11 (NA)	0.58 (1460)	
1981	0.37 (NA)	0 (1027)	
1982	1.15 (NA)	0.44 (965)	
1983	0.63 (NA)	0 (937)	
1984	0.01 (NA)	0 (985)	
1985	0 (NA)	0.41 (1292)	
1986	0.24 (NA)	0.3 (760)	
1987			
1988			
1989		0 (1004)	
1990			
1991			
1992			
1993			
1994			
1995			
1996		0 (185)	
1997		0 (85)	
1998		0 (133)	
1999		0 (74)	
2000		0 (47)	
2001		0 (26)	
2002		0 (85)	
2003		0 (367)	
2004		0 (322)	
2005		0 (335)	
2006		0 (296)	
2007		0 (283)	

Table 11 The species frequency data for bocaccio in North Puget Sound. Data 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. (2008). Reported sample sizes (fish identified) are given in parentheses if available.

Year	WA Sport Catch Rpts	Palsson et al. (2008)	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 (NA)		
1976	0.06 (NA)		
1977	0.08 (NA)		
1978	0.11 (NA)		
1979	0.32 (NA)		
1980	1.01 (NA)	0.2 (1121)	
1981	0.29 (NA)	0 (434)	
1982	0 (NA)	0 (404)	
1983	0 (NA)	0 (321)	
1984	0.18 (NA)	0 (318)	
1985	0 (NA)	0 (360)	
1986	0.15 (NA)	0 (519)	
1987			
1988			
1989		0 (433)	
1990			
1991			
1992			
1993			
1994			
1995			
1996		0.2 (578)	
1997		0 (223)	
1998		0 (496)	
1999		0 (200)	
2000		0 (162)	
2001		0 (59)	
2002		0 (91)	
2003		0 (715)	
2004		0 (613)	
2005		0 (490)	
2006		0 (513)	
2007		0 (275)	

Table 12 The species frequency data from the commercial catch data for bocaccio rockfish in Puget Sound Proper. 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. (2008), but the original identifications appear to have been done in a single year. The 1988, 1989, 1990, 1991, and 1993 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. (2008)). 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
1983-84	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

Table 13 The species frequency data for canary rockfish in Puget Sound Proper. These 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. (2008). 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 Rpts	Palsson et al. (2008)	Buckley and Bargmann
1965			0.53 (NA)
1966			0.18 (NA)
1967			0.84 (NA)
1968			3.75 (NA)
1969			6.9 (NA)
1970			0.36 (NA)
1971			0 (NA)
1972			2 (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 (1460)	
1981	0.84 (NA)	0.54 (1027)	
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 (1292)	
1986	1.81 (NA)	1.11 (760)	
1987			
1988			
1989		0.7 (1004)	
1990			
1991			
1992			
1993			
1994			
1995			
1996		0 (185)	
1997		0 (85)	
1998		0 (133)	
1999		0 (74)	
2000		8.5 (47)	
2001		0 (26)	

Table 14 The species frequency data for canary rockfish in North Puget Sound. These 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. (2008). 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 Rpts	Palsson et al. (2008)	Buckley and Bargmann
1965			0 (NA)
1966			12.42 (NA)
1967			1.6 (NA)
1968			10.29 (NA)
1969			7.73 (NA)
1970			0 (NA)
1971			0 (NA)
1972			13.21 (NA)
1973			51.9 (NA)
1974			
1975	6.94 (NA)		
1976	5.23 (NA)		
1977	5.41 (NA)		
1978	3 (NA)		
1979	1.17 (NA)		
1980	2.05 (NA)	1.5 (1121)	
1981	1.43 (NA)	1.8 (434)	
1982	1.27 (NA)	1.71 (404)	
1983	1.61 (NA)	2.21 (321)	
1984	1.54 (NA)	1.3 (318)	
1985	1.88 (NA)	1.9 (360)	
1986	1.87 (NA)	1 (519)	
1987			
1988			
1989		0 (433)	
1990			
1991			
1992			
1993			
1994			
1995			
1996		0.3 (578)	
1997		0.4 (223)	
1998		0.6 (496)	
1999		1 (200)	
2000		1.2 (162)	
2001		0 (59)	

Table 15 The species frequency data from the commercial catch data for canary rockfish in north Puget Sound. The 1970-1987 data point is from accumulated data over this period. Reference is Palsson et al. (2008, 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
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

Table 16 The species frequency data for yelloweye rockfish in Puget Sound Proper. The recreational fishery data are calculated from dockside surveys in punch card areas 8-13. The 1980-2007 data are in Palsson et al. (2008, Table 7.5). Since 2002, no catch of yelloweye rockfish is allowed in the recreational fishery thus no frequency data are available. Note that 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 Rpts	Palsson et al. (2008)	WDFW Trawl Survey	Buckley and Bargmann
1965				0.99 (NA)
1966				0.88 (NA)
1967				0 (NA)
1968				0.44 (NA)
1969				2.43 (NA)
1970				0 (NA)
1971				1.32 (NA)
1972				18.6 (NA)
1973				2.14 (NA)
1974				
1975	0.59 (NA)			
1976	0.71 (NA)			
1977	0.84 (NA)			
1978	0.66 (NA)			
1979	0 (NA)			
1980	1.44 (NA)	0.47 (1460)		
1981	0.29 (NA)	0.86 (1027)		
1982	0.62 (NA)	0.44 (965)		
1983	0.66 (NA)	0.11 (937)		
1984	0.43 (NA)	0 (985)		
1985	0.86 (NA)	0.31 (1292)		
1986	1.32 (NA)	0.1 (760)		
1987			0 (NA)	
1988				
1989		0.3 (1004)	0 (NA)	
1990				
1991			0 (NA)	
1992				
1993				
1994				
1995				
1996		5.92 (185)	2.22 (NA)	
1997		1.2 (85)		
1998		2.3 (133)		
1999		0 (74)		
2000		0 (47)		
2001		0 (26)		
2002		NA (85)	0 (NA)	
2003		NA (367)		
2004		NA (322)		

2005	NA (335)	0.2 (NA)

Table 17 The species frequency data for yelloweye rockfish in north Puget Sound 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. (2008, Table 7.5). Since 2002, no catch of yelloweye rockfish is allowed in the recreational fishery thus no frequency data are available. Note that redstripe rockfish have been removed from the original data when calculating species frequencies.

Year	WA Sport Catch Rpts	Palsson et al. (2008)	WDFW Trawl Survey	Buckley and Bargmann
1965				0.41 (NA)
1966				1.33 (NA)
1967				0 (NA)
1968				1.51 (NA)
1969				0.44 (NA)
1970				17.12 (NA)
1971				0 (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 (NA)			
1980	5.53 (NA)	1.5 (1121)		
1981	0.94 (NA)	1.6 (434)		
1982	5.14 (NA)	1.71 (404)		
1983	2.73 (NA)	4.02 (321)		
1984	1.61 (NA)	1.6 (318)		
1985	2.73 (NA)	2.5 (360)		
1986	2.26 (NA)	0.8 (519)		
1987			0 (NA)	
1988				
1989		3 (433)	0 (NA)	
1990				
1991			0 (NA)	
1992				
1993				
1994				
1995				
1996		0.9 (578)		
1997		0.4 (223)		
1998		0 (496)		
1999		1.5 (200)		
2000		0 (162)		
2001		3.4 (59)	0 (NA)	
2002		NA (91)		
2003		NA (715)		
2004		NA (613)	1.37 (NA)	

Table 18 The species frequency data from the commercial catch data for yelloweye rockfish in north Puget Sound. The 1970-1987 data point is from accumulated data over this period. Reference is Palsson et al. (2008, 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
1983-84	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

Table 19 The 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 are given in parentheses.

Year	South Puget Sound	North Puget Sound
1998	1.05 (95)	0 (27)
1999	0 (95)	0 (8)
2000	0 (93)	0 (15)
2001	0.53 (379)	0 (33)
2002	0.27 (376)	0 (74)
2003	0.71 (421)	0 (51)
2004	1.07 (469)	3.03 (66)
2005	0.47 (428)	0 (54)
2006	0.49 (608)	2.56 (156)
2007	0.6 (826)	2.44 (164)
2008	0 (383)	1.89 (53)

Table 20 The species frequency data for greenstriped rockfish in Puget Sound Proper. These 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. (2008, Table 7.5).

Year	WA Sport Catch Rpts	Palsson et al. (2008)	WDFW Trawl Survey	Buckley and Bargmann
1965				0 (NA)
1966				0.35 (NA)
1967				0.18 (NA)
1968				0 (NA)
1969				8.78 (NA)
1970				0 (NA)
1971				0 (NA)
1972				0 (NA)
1973				0 (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 (1460)		
1981	0.14 (NA)	0.54 (1027)		
1982	1.15 (NA)	0.89 (965)		
1983	0.15 (NA)	2.3 (937)		
1984	0.25 (NA)	0.21 (985)		
1985	0 (NA)	0.21 (1292)		
1986	0 (NA)	0 (760)		
1987			0 (NA)	
1988				
1989		0.4 (1004)	0 (NA)	
1990				
1991			0.09 (NA)	
1992				
1993				
1994				
1995				
1996		0.5 (185)	0.31 (NA)	
1997		0 (85)		
1998		1.5 (133)		
1999		0 (74)		
2000		0 (47)		
2001		0 (26)		
2002		0 (85)	0.68 (NA)	
2003		0.3 (367)		
2004		0 (322)		
2005		0 (335)	0.52 (NA)	
2006		0 (296)		
2007		0 (283)		

Table 21 The species frequency data for greenstriped rockfish in north Puget Sound. These 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. (2008, Table 7.5).

Year	WA Sport Catch Rpts	Palsson et al. (2008)	WDFW Trawl Survey	Buckley and Bargmann
1965				0 (NA)
1966				0 (NA)
1967				0 (NA)
1968				3 (NA)
1969				0 (NA)
1970				0 (NA)
1971				0 (NA)
1972				0 (NA)
1973				0 (NA)
1974				
1975	0 (NA)			
1976	0 (NA)			
1977	0 (NA)			
1978	0 (NA)			
1979	0.05 (NA)			
1980	0.07 (NA)	0 (1121)		
1981	0 (NA)	0 (434)		
1982	0 (NA)	0 (404)		
1983	0 (NA)	0 (321)		
1984	0 (NA)	0 (318)		
1985	0 (NA)	0 (360)		
1986	0 (NA)	0 (519)		
1987			0 (NA)	
1988				
1989		0 (433)	0 (NA)	
1990				
1991			0 (NA)	
1992				
1993				
1994				
1995				
1996		0 (578)		
1997		0 (223)		
1998		0 (496)		
1999		0 (200)		
2000		0 (162)		
2001		0 (59)	0 (NA)	
2002		0 (91)		
2003		0 (715)		
2004		0 (613)	0.78 (NA)	
2005		0 (490)		
2006		0 (513)		
2007		0.4 (275)		

Table 22 The species frequency data for redstripe rockfish in Puget Sound Proper. These 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. (2008, Table 7.5).

Year	WA Sport Catch Rpts	Palsson et al. (2008)	WDFW Trawl Survey	Buckley and Bargmann
1965				0 (NA)
1966				0 (NA)
1967				0 (NA)
1968				1.05 (NA)
1969				1.03 (NA)
1970				0.24 (NA)
1971				0 (NA)
1972				0 (NA)
1973				0 (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)	14.2 (1460)		
1981	0.75 (NA)	7.5 (1027)		
1982	4.19 (NA)	9.8 (965)		
1983	9.53 (NA)	8.1 (937)		
1984	0.25 (NA)	4.2 (985)		
1985	0.16 (NA)	3 (1292)		
1986	0 (NA)	0.8 (760)		
1987			0.06 (NA)	
1988				
1989		0.6 (1004)	0.06 (NA)	
1990				
1991			1.43 (NA)	
1992				
1993				
1994				
1995				
1996		0 (185)	1.39 (NA)	
1997		0 (85)		
1998		0 (133)		
1999		0 (74)		
2000		0 (47)		
2001		0 (26)		
2002		0 (85)	39.11 (NA)	
2003		0 (367)		
2004		0 (322)		
2005		0 (335)	48.37 (NA)	
2006		0 (296)		
2007		0 (283)		

Table 23 The species frequency data for redstripe rockfish in north Puget Sound. These 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. (2008, Table 7.5).

Year	WA Sport Catch Rpts	Palsson et al. (2008)	WDFW Trawl Survey	Buckley and Bargmann
1965				0 (NA)
1966				0 (NA)
1967				0 (NA)
1968				0.46 (NA)
1969				0 (NA)
1970				0 (NA)
1971				0 (NA)
1972				0 (NA)
1973				0 (NA)
1974				
1975	0 (NA)			
1976	0 (NA)			
1977	0 (NA)			
1978	0 (NA)			
1979	0 (NA)			
1980	0.07 (NA)	0.1 (1121)		
1981	0 (NA)	0 (434)		
1982	0.43 (NA)	0 (404)		
1983	0.27 (NA)	0 (321)		
1984	0.09 (NA)	0 (318)		
1985	0 (NA)	0 (360)		
1986	0 (NA)	0.4 (519)		
1987			3.64 (NA)	
1988				
1989		0 (433)	0.41 (NA)	
1990				
1991			6.63 (NA)	
1992				
1993				
1994				
1995				
1996		0 (578)		
1997		0 (223)		
1998		0 (496)		
1999		0 (200)		
2000		0 (162)		
2001		0 (59)	3.61 (NA)	
2002		0 (91)		
2003		0 (715)		
2004		0 (613)	52.59 (NA)	
2005		0.2 (490)		
2006		0 (513)		
2007		0 (275)		

Table 24 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[1] Comments:	
Growth Rate/Productivity[1] Comments:	
Spatial Structure and Connectivity[1] Comments:	
Diversity[1] Comments:	
Recent Events[2]	

[1] Rate overall risk to the DPS on 5-point scale (1–very low risk; 2–low risk; 3–moderate risk; 4–high risk; 5–very high risk).
[2] Rate recent events from double plus (++) strong benefit to double minus (– –) strong detriment.

Table 25 Sample worksheet used by BRT in scoring the severity of current threats to the 5 rockfish DPSs. Threats are arranged within the four statutory listing factors: 1) the 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 manmade factors affecting its continued existence.

Species	Nearshore habitat loss	Dissolved Oxygen	Chemical contamination	Nutrients	Commercial harvest	Recreational harvest	Disease	Predation	Competition	Derelict Fishing Gear	Non-indigenous species	Climate	Hatchery Practices
Bocaccio													
Yelloweye													
Canary													
Redstripe													
Greenstriped													
ESA listing factor	Habitat modification				Overutilization		Disease or predation		Other				

Table 26 Description of reference levels for the Biological Review Team's assessment of the species' or Distinct Population Segment's (DPS) extinction risk.

Qualitative "Reference Levels" of Relative Extinction Risk	
↑ Continuum of decreasing relative risk of extinction	(1) 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/DPS may be at moderate risk of extinction due to projected threats and/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 timeframe 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.
	(2) 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/DPS at such a high level of risk may be highly uncertain and strongly influenced by stochastic and/or depensatory processes. Similarly, a species/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 DPS using the "likelihood point" method (FEMAT 1993)

	Overall Extinction Risk Category [1]		
	Not at risk	**Moderate Risk**	**High Risk**
Number of likelihood points[2]			

***Comments*:**

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

[2] Each Biological Review Team member distributes ten likelihood points among the three overall extinction risk categories. Placement of all ten 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.

Table 28 Results of qualitative ranking by the Puget Sound rockfish BRT of severity of threats for 5 DPSs of Puget Sound rockfish. 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".

Threat type		Habitat Modification				Fisheries		
		Nearshore	DO	Contaminant	Nutrients	Comm.	Rec.	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	

Threat type				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

Table 29 Historically used common names of the five petitioned rockfish species.

Scientific name	Common name	Other Common names
Sebastes pinniger	canary rockfish	Orange rockfish
Sebastes ruberrimus	yelloweye rockfish	Red rockfish Red snapper Rasphead rockfish
Sebastes elongatus	greenstriped rockfish	Olive banded rock cod
Sebastes paucispinis	Bocaccio	Rock salmon
Sebastes proriger	redstripe rockfish	

Table 30 Average landings by the Puget Sound trawl fishery from 1955-1964 (data from Holmberg et al. 1967)

Species group	Puget Sound – Ave. Annual Landings (lb)	Years of data	Price/lb	Comments
Petrale sole			$0.10	Not abundant in PS
English sole	2,000,000	1945-64		
Dover sole	<50,000	1951-64	$0.065	Catches down by 1964
Rock sole				Not abundant in PS
Starry flounder	350,000	1944-64		
Pacific cod	>3,000,000	1955-64		
Lingcod (trawl)	>75,000	1955-64		*225,000 lb/yr by troll
Sablefish				Not abundant in PS
Rockfish	<100,000	1955-64	$0.05	
Pacific Ocean perch				Not abundant in PS
Small sole, walleye pollack, skate, hake			$0.03	Mink food

FIGURES

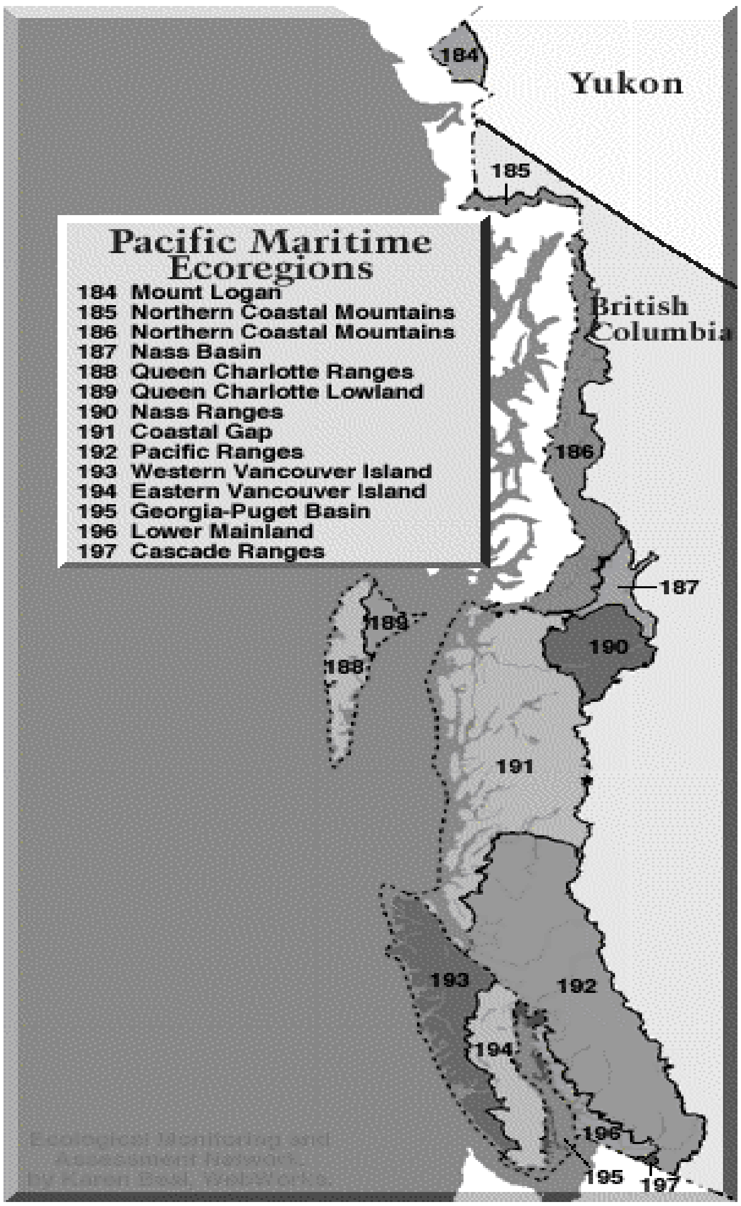


Figure 1 Ecoregions in the Pacific Maritime Ecozone of British Columbia. (Map retrieved from online source: http://www.ec.gc.ca/soer-ree/English/Framework/NarDesc/pacmar_e.cfm)

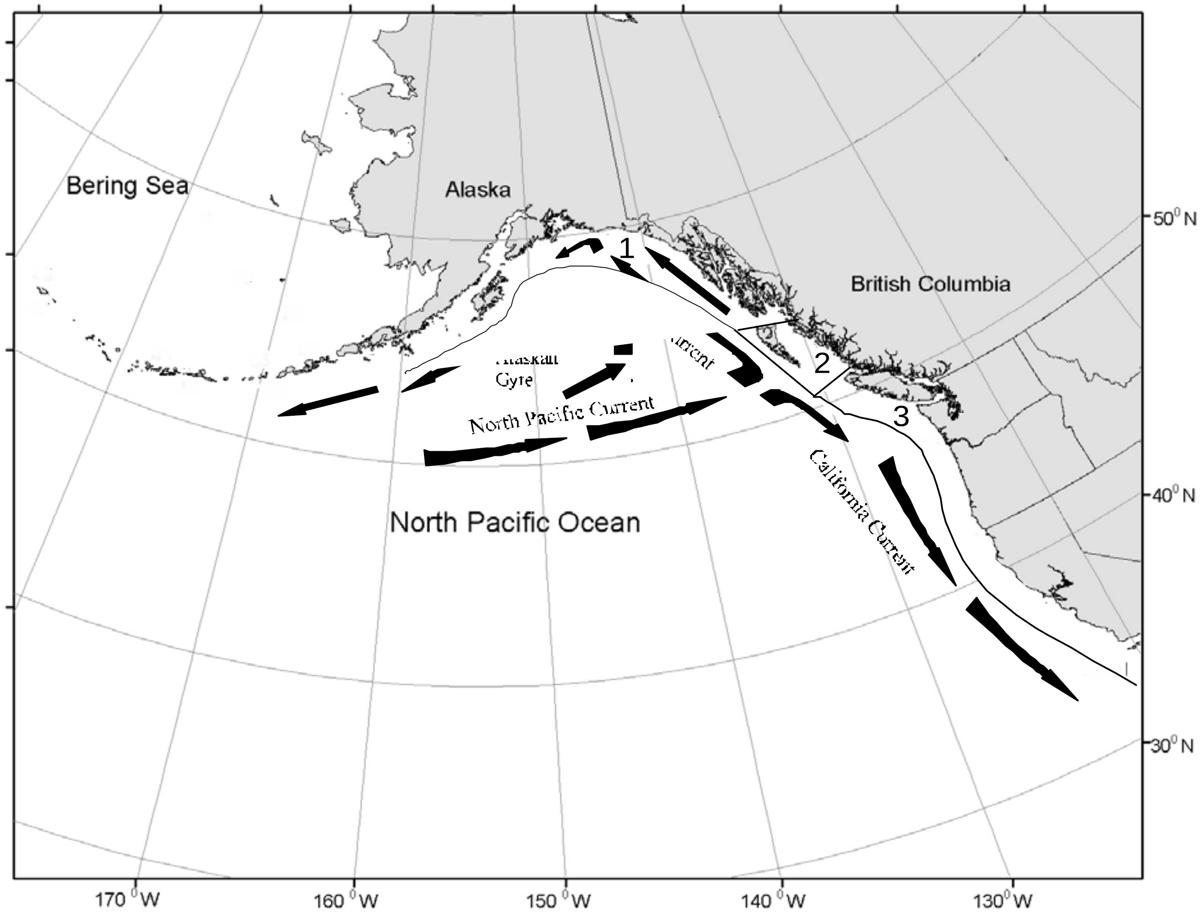


Figure 2 Approximate locations of oceanographic currents, Oceanic Domainsc(Ware and McFarlane 1989), and Coastal Provinces (Longhurst 2006), in the Northeast Pacific. 1 - Alaska Coastal Down welling Province, 2 - Transition Zone, and 3 - California Current Province. (From Stout et al. (2001))

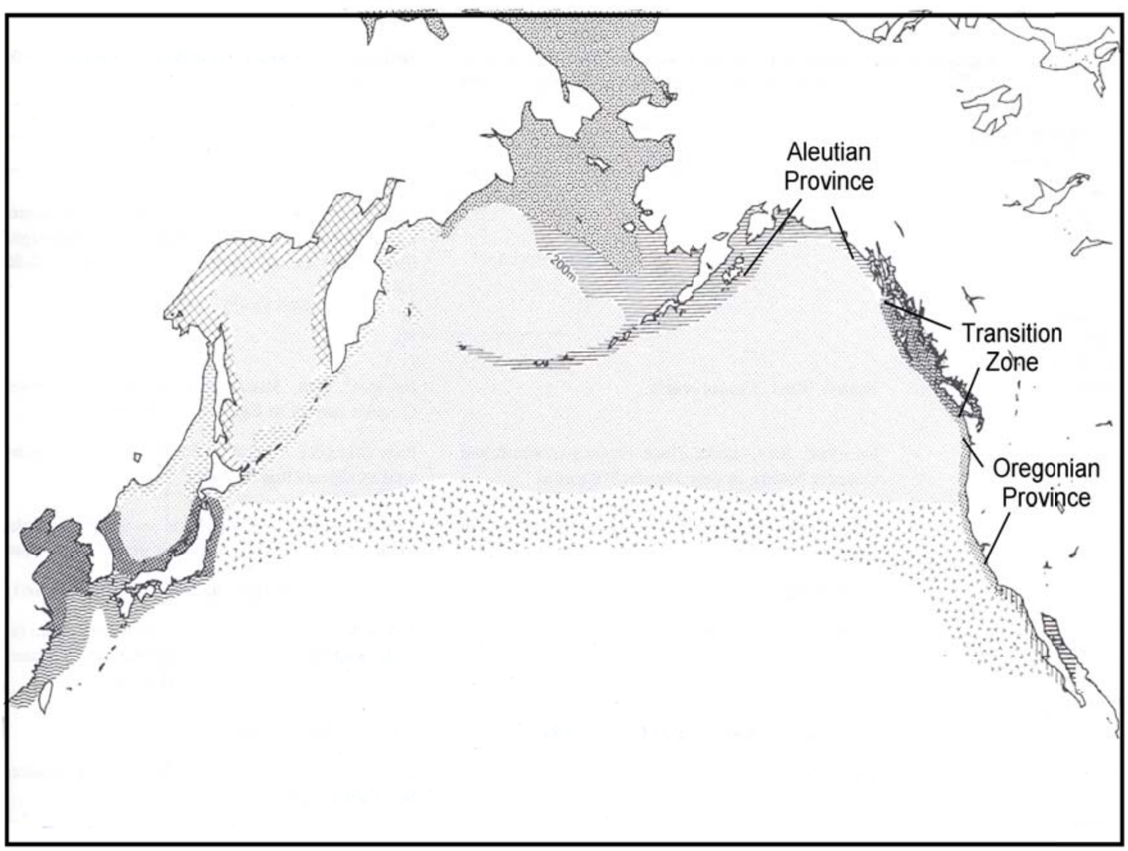


Figure 3 Marine zoogeographic provinces of the North Pacific Ocean. (Modified after Allen and Smith (1988) in Stout et al. (2001)).

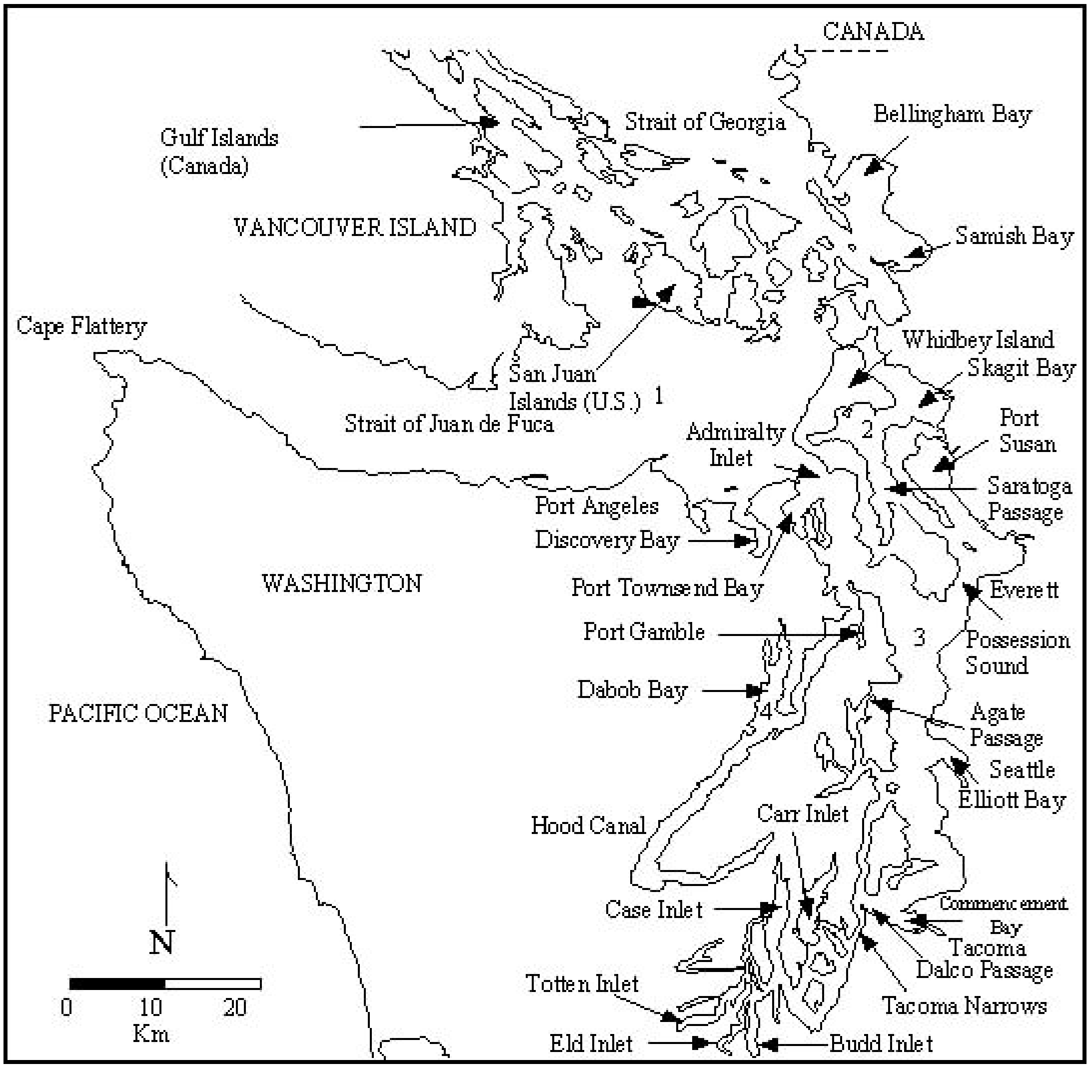


Figure 4 Regional water masses and sub areas of greater Puget Sound: 1. Northern Puget Sound 2. Whidbey Basin 3. Main Basin 4. Hood Canal and 5. Southern Puget Sound (From Stout et al. 2001).

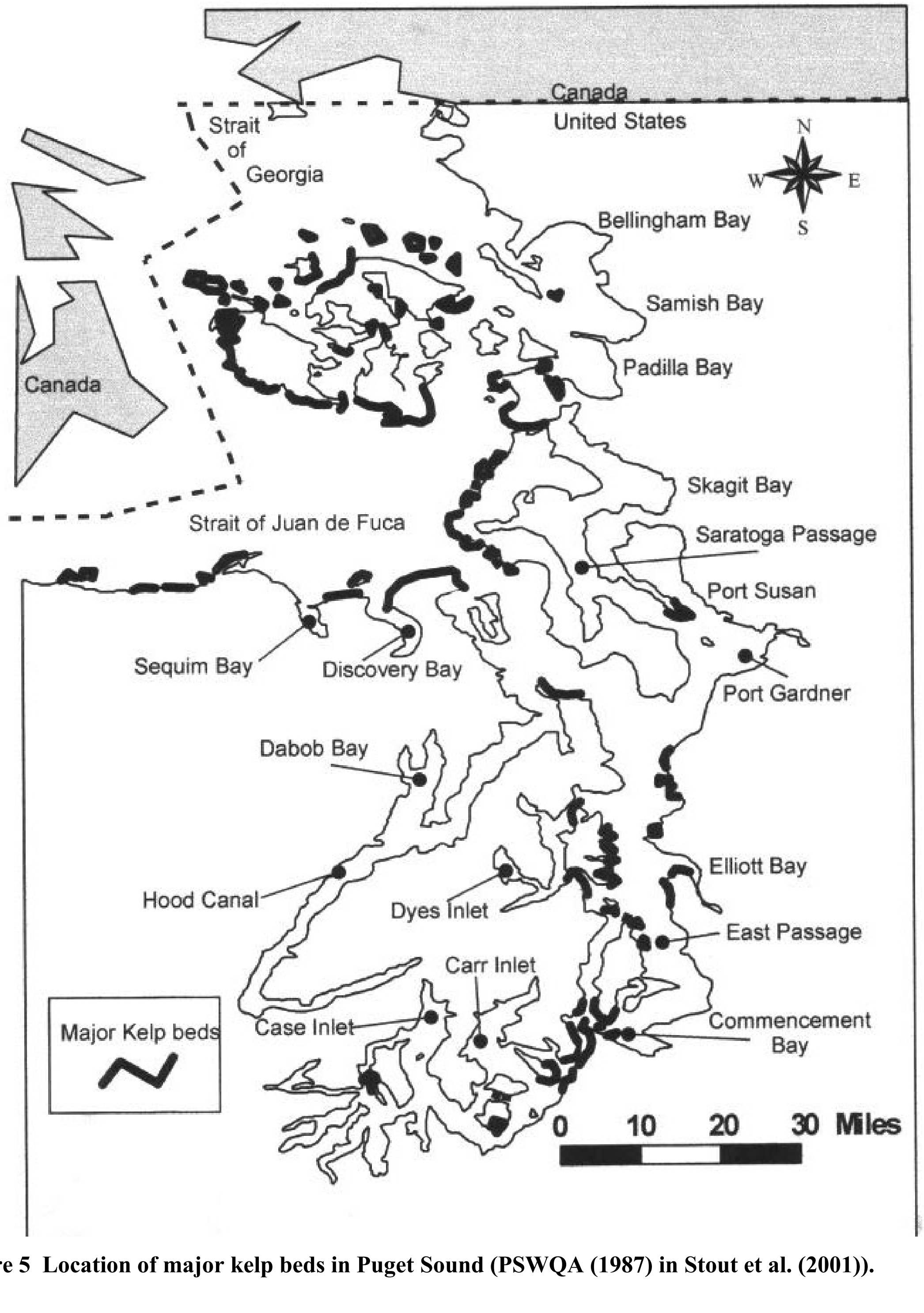


Figure 5 Location of major kelp beds in Puget Sound (PSWQA (1987) in Stout et al. (2001)).

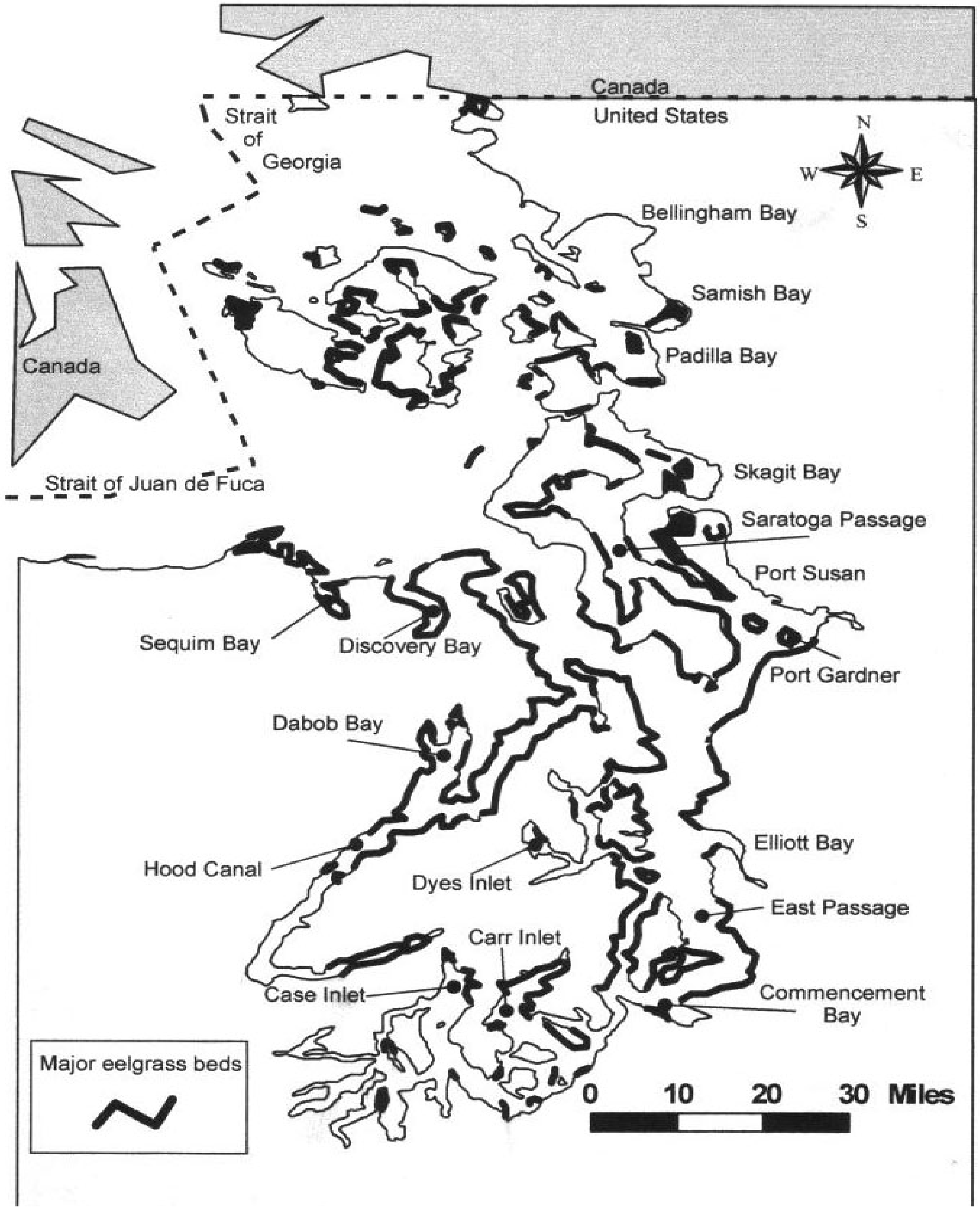


Figure 6 Locations of major eel grass beds in Puget Sound (PSWQA (1987) in Stout et al. (2001)).

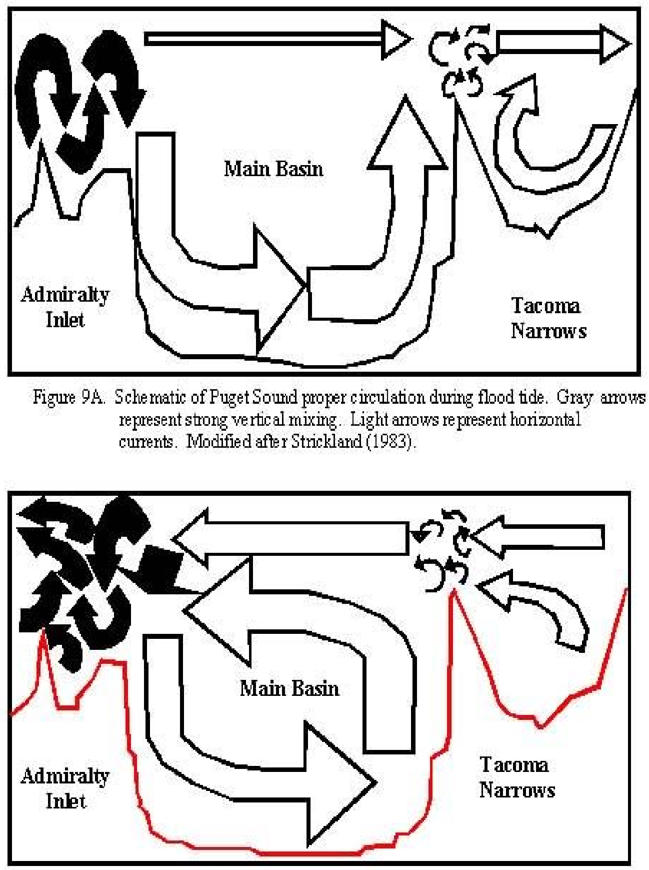


Figure 7 Schematic of circulation in Puget Sound proper during ebb tide (lower diagram) and flood tide (upper diagram). (Modified after Strickland (1983) in Stout et al. (2001)).

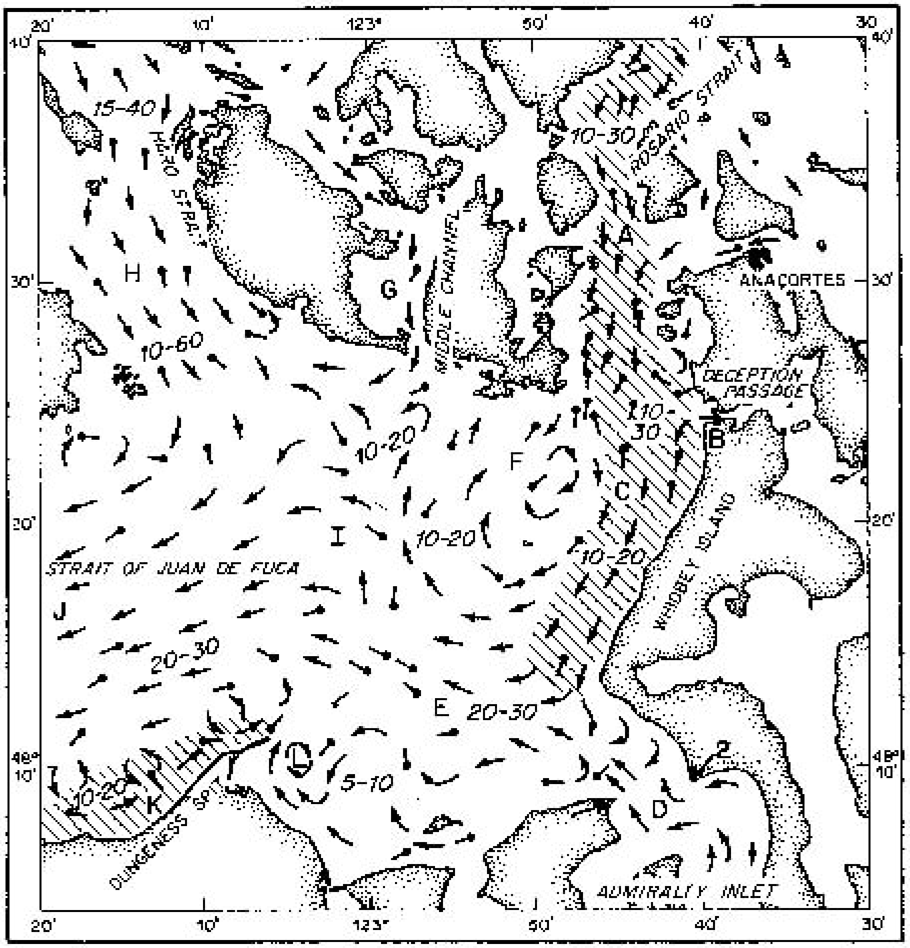


Figure 8 Plan view of net circulation in upper layer (30m) of the eastern end of the Strait of Juan de Fuca in North Puget Sound (Ebbesmeyer et al. (1984) in Stout et al. (2001)).

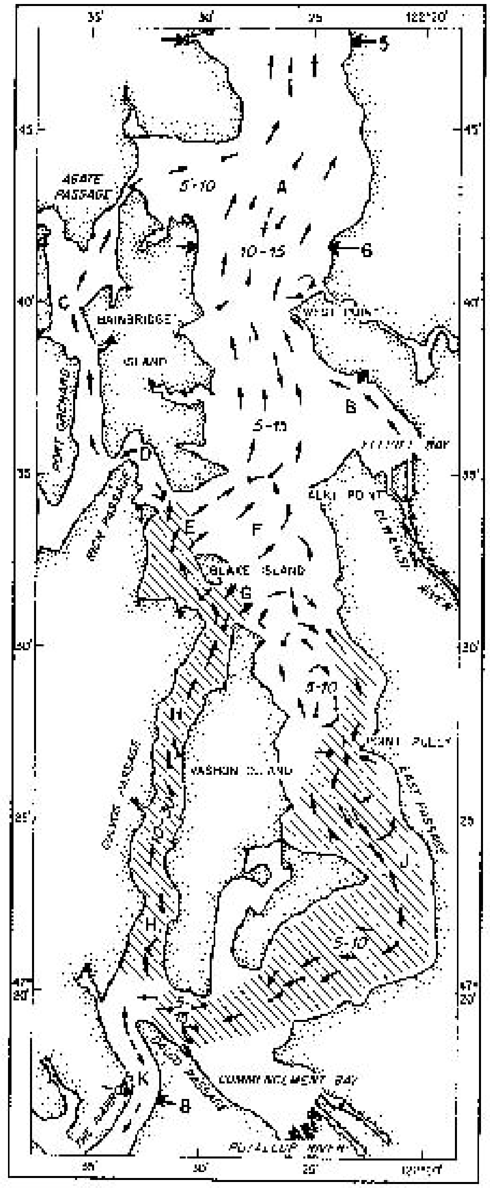


Figure 9 Plan view of the net circulation in upper layer (30m) of the Main Basin of Puget Sound Proper (Ebbesmeyer et al. (1984) in Stout et al. (2001)).

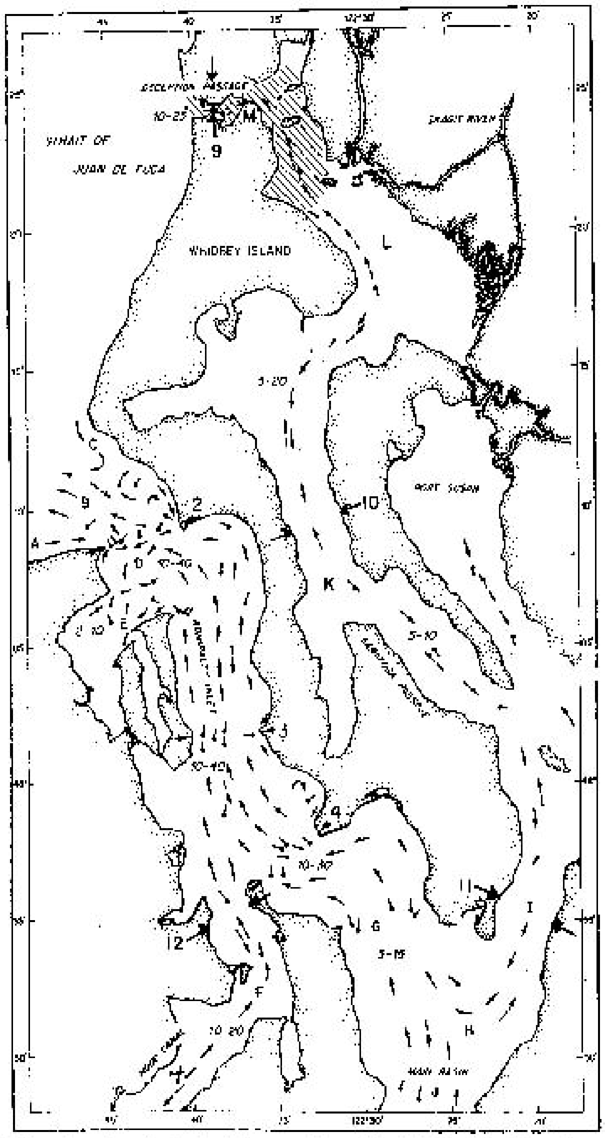


Figure 10 Plan view of net circulation in upper layer (30m) of Admiralty Inlet and Whidbey Basin in Puget Sound Proper (Ebbesmeyer et al (1984) in Stout et al. (2001)).

Figure 11 Geographic locations in the Strait of Georgia and southern B.C. considered in this manuscript (From Stout et al. 2001).

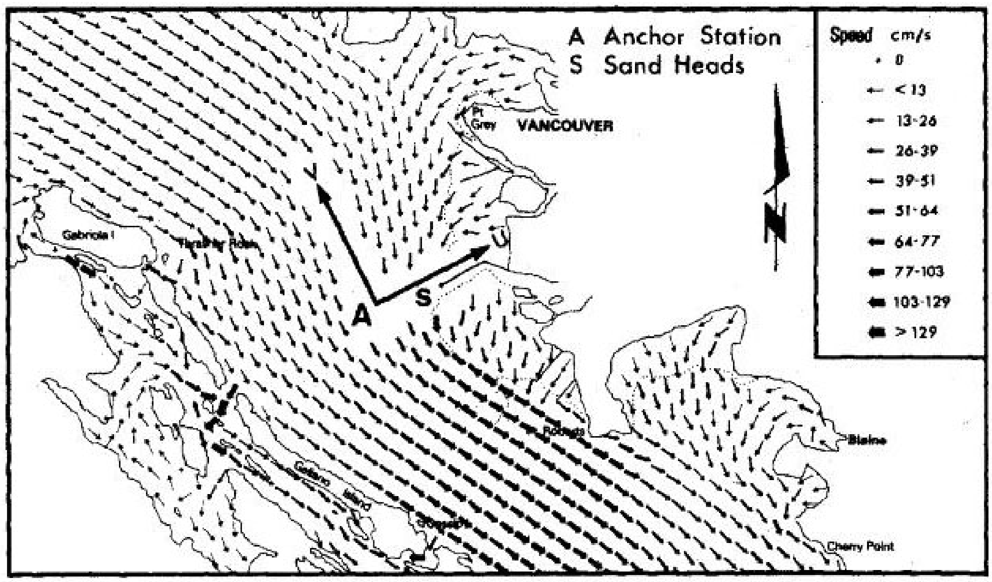


Figure 12 – Representative ebb velocity vectors in the general vicinity of the Fraser River mouth in the Strait of Georgia (Crean et al. (1988) in Stout et al. (2001)).

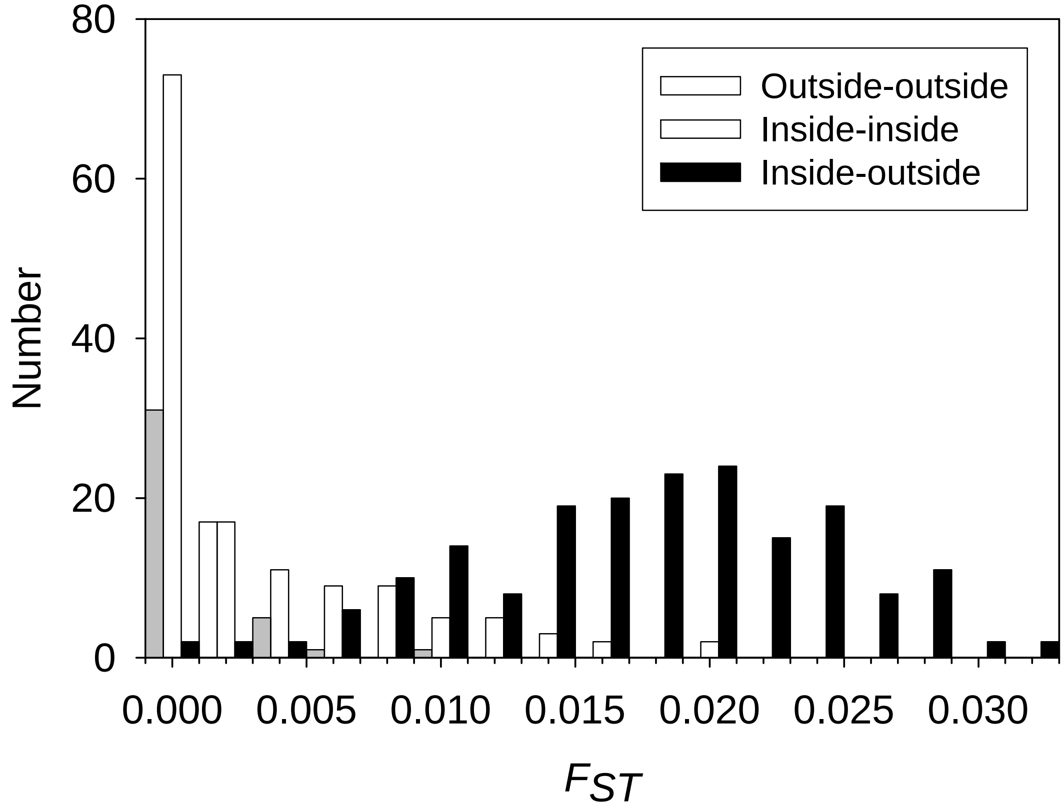
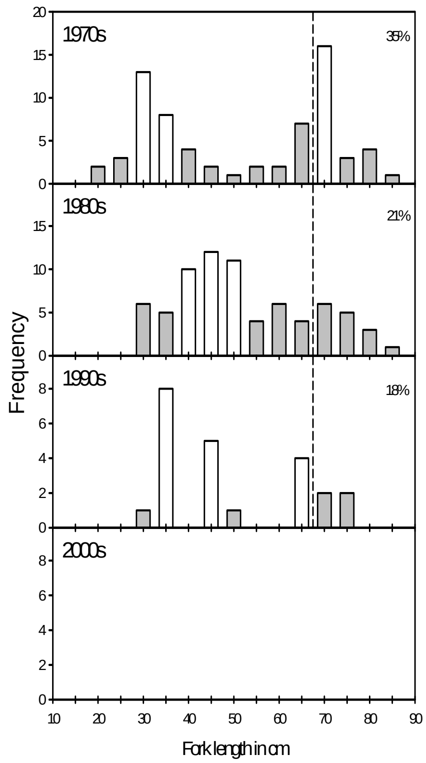
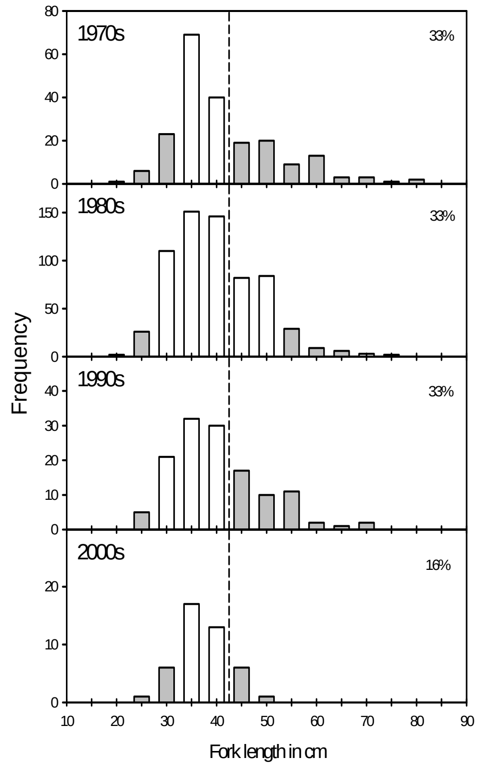


Figure 13 Distribution of pair wise F_{ST} values for 28 samples of yelloweye rockfish collected from coastal populations ('outside') or the Strait of Georgia and Queen Charlotte Strait ('inside'). Based on Yamanaka et al. (2006) and unpublished data (R. Withler, pers. Comm.).

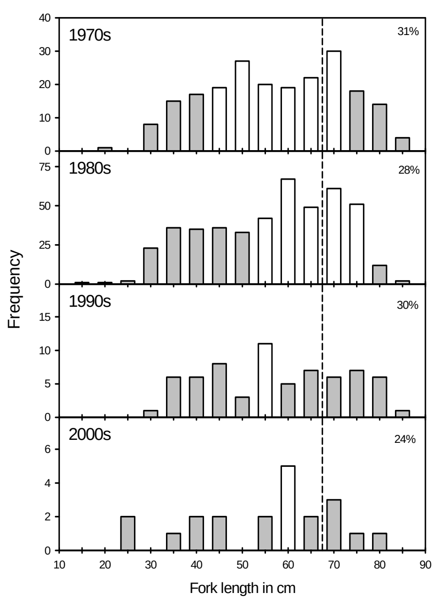
Bocaccio



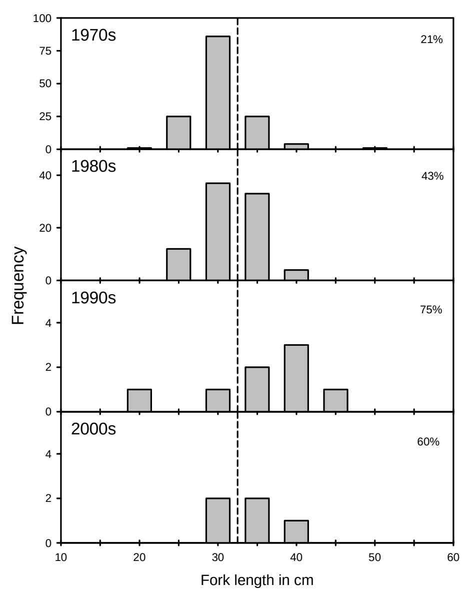
Canary



Yelloweye



Greenstriped



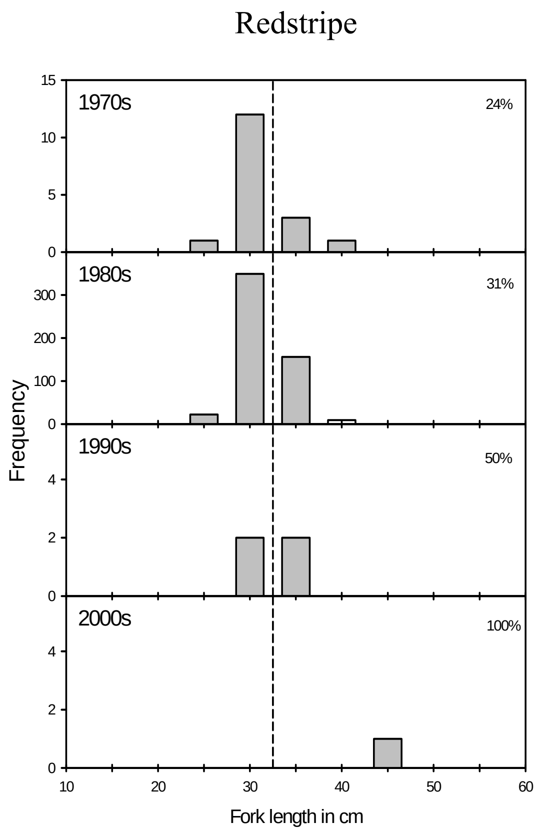


Figure 14 Length frequency distributions of the 5 petitioned species over time. Sizes binned in 5cm classes and within decades. All data are from recreational fisheries records of WDFW. Vertical lines depict the size at which about 30% of the population was comprised of fish larger than the rest of the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

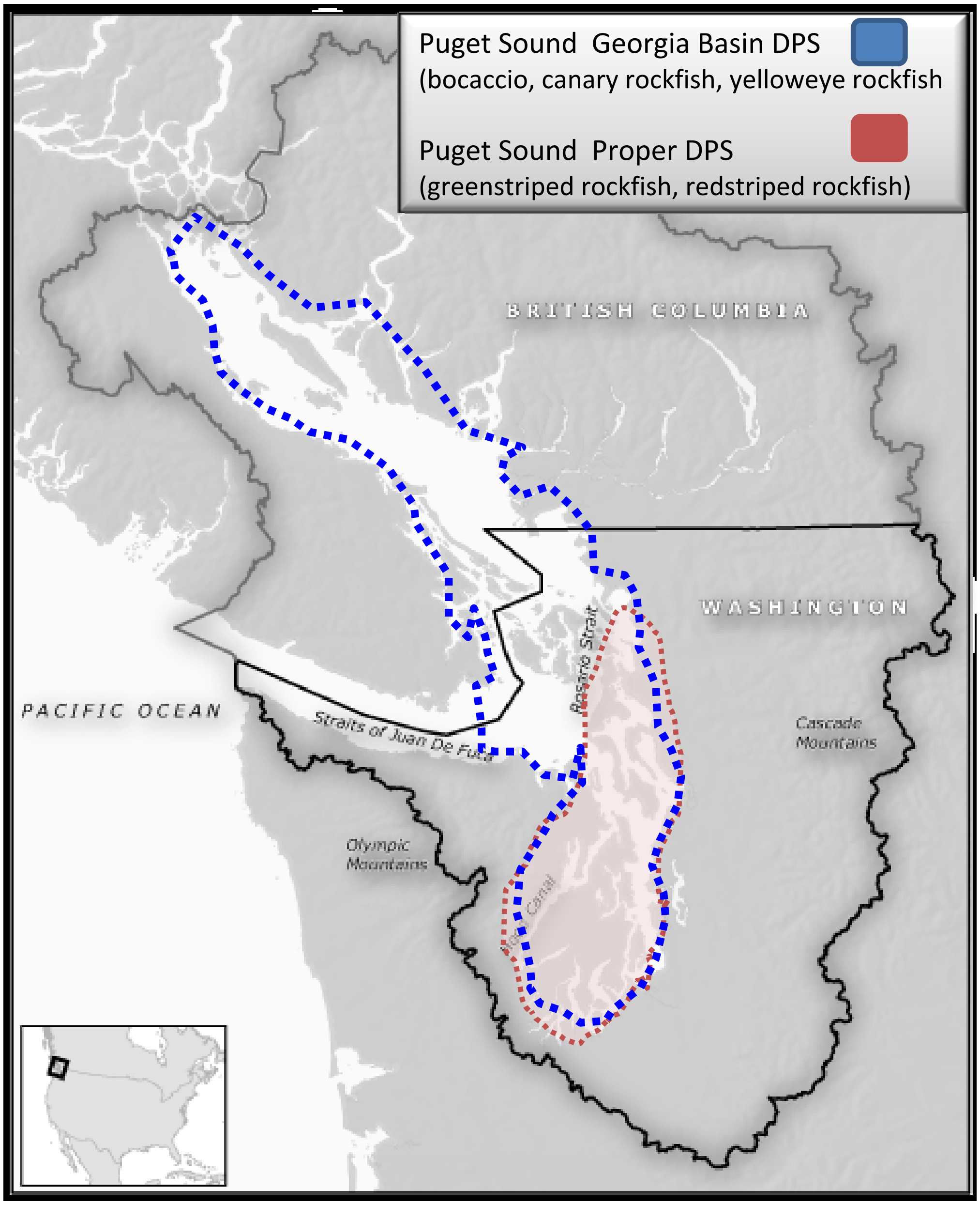


Figure 15. Map depicting the approximate DPS boundaries for the Georgia Basin/Puget Sound and Puget Sound Proper DPSs. Figure is for purposes of illustration only and should not be used to identify precise boundaries.

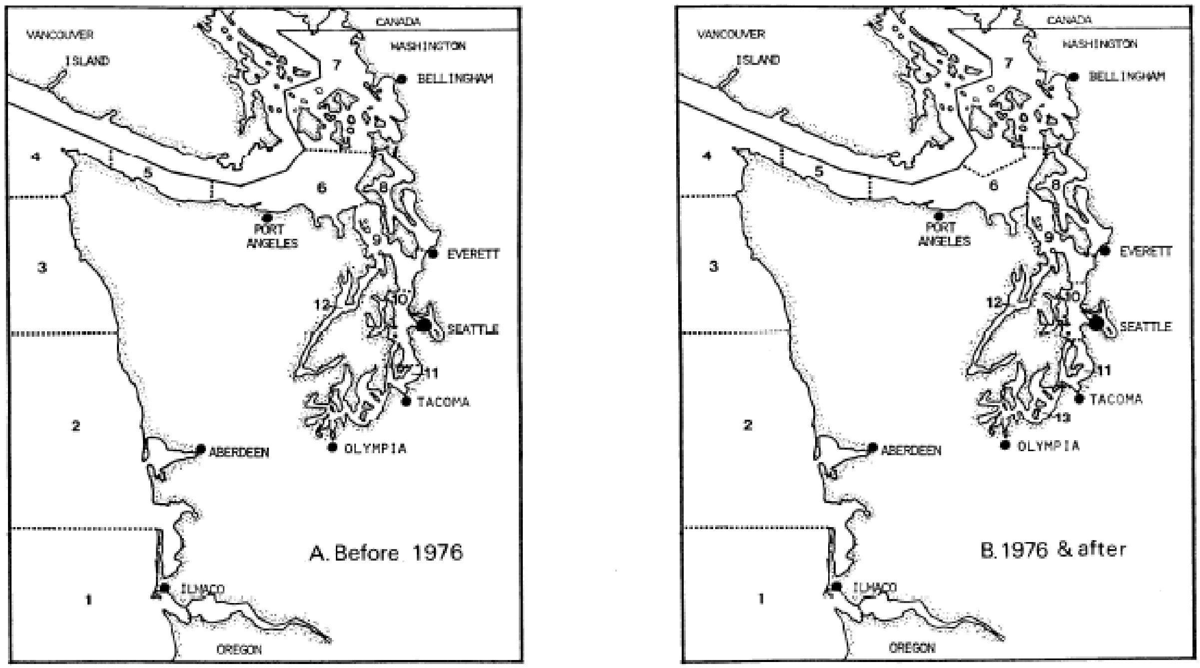


Figure 16 Punch card areas for WDFW recreational data. Puget Sound Proper (Areas 8-13) and North Puget Sound (Areas 5-7) are used in this analysis (From Palsson (1988)).

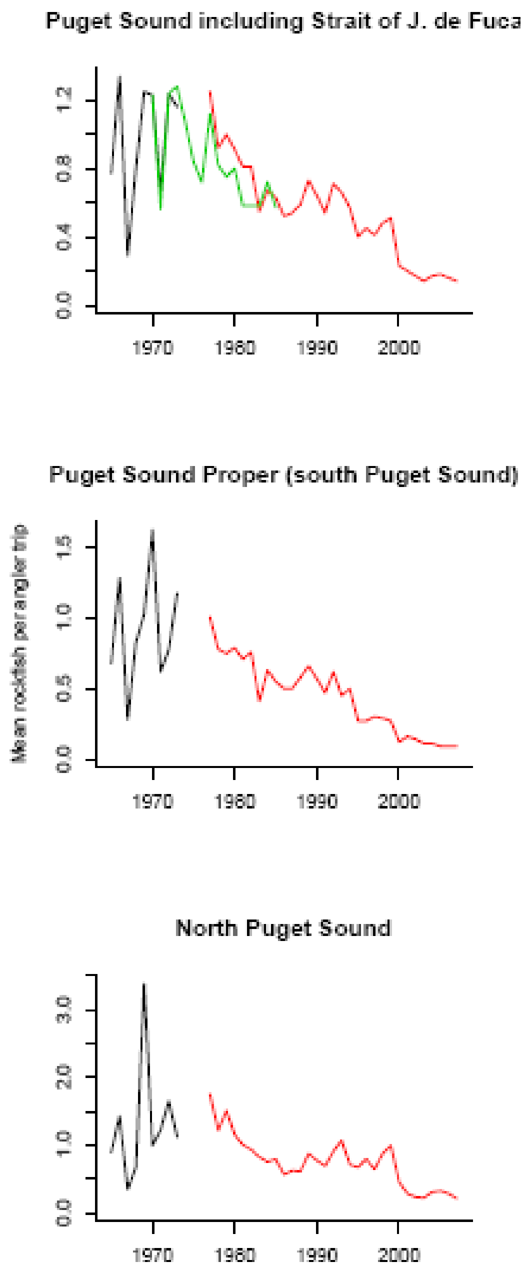
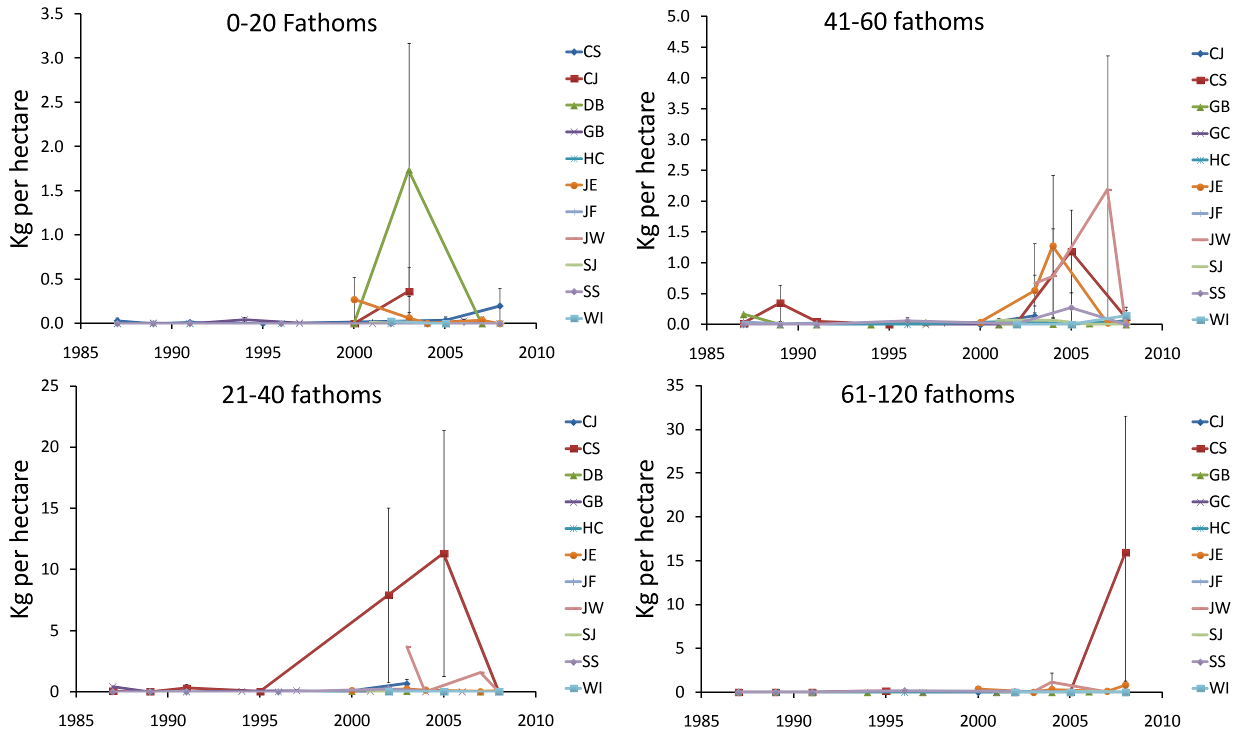


Figure 17 Rockfish per angler trip for bottomfish specific recreational fishery. Black line refers to data from Buckley and Bargmann. Green refers to Palsson (1988). Red refers to Palsson (2008).

Greenstiped rockfish



Redstripe rockfish

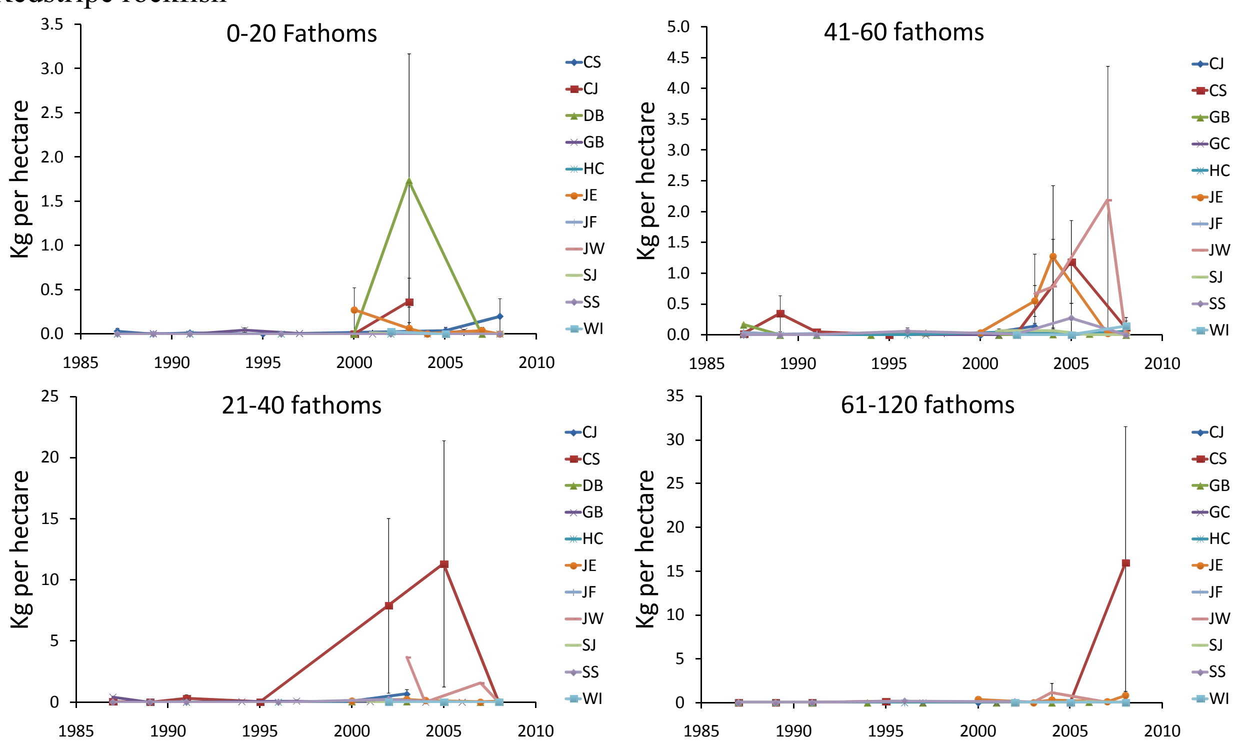


Figure 18 Greenstriped rockfish (upper graph) and redstripe rockfish (lower graph) hauls by depth zone in kilograms per hectare.

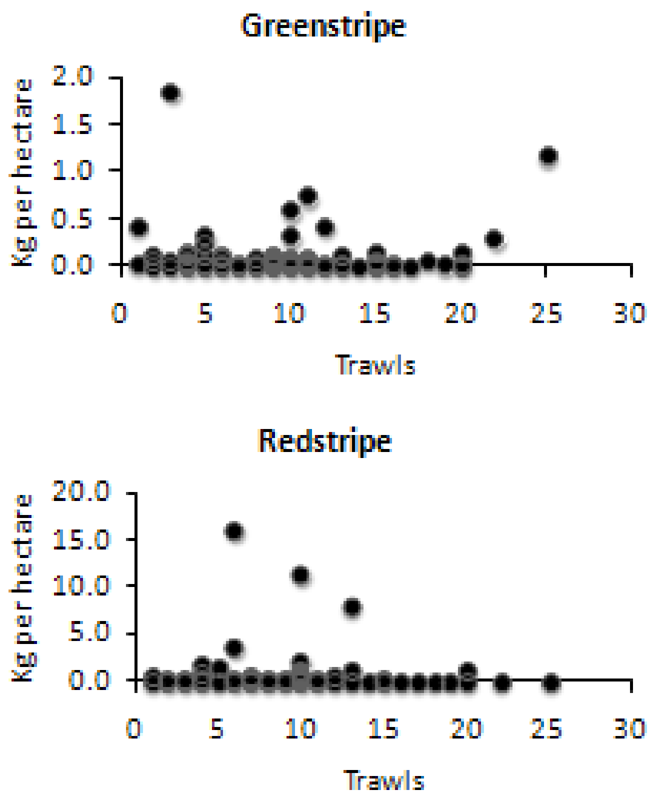
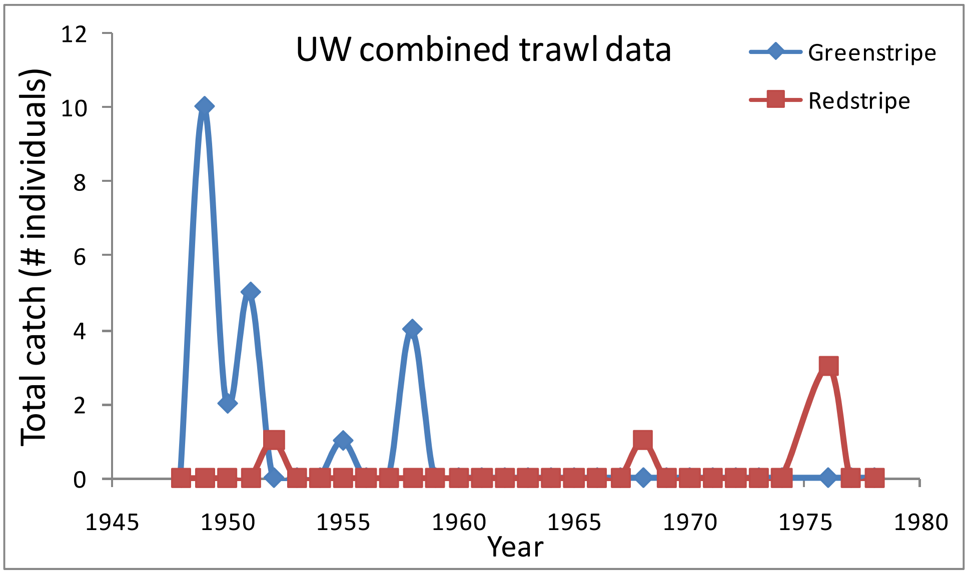


Figure 19 Hauls (kg/hectare) as a function of the number of WDFW trawls for greenstriped rockfish (upper graph) and redstripe rockfish (lower graph)



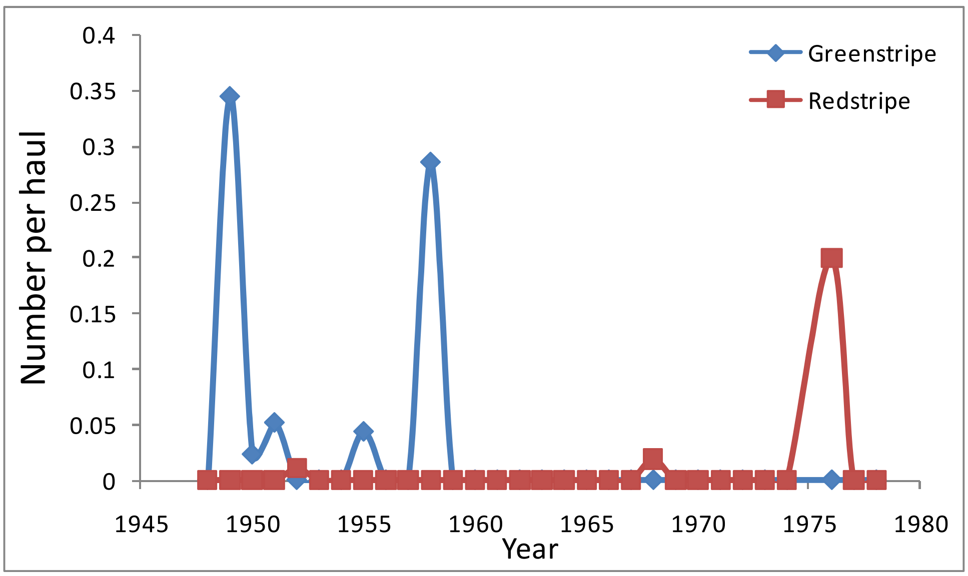


Figure 20 Total catch (# of individual fish) from University of Washington combined trawl data over time.

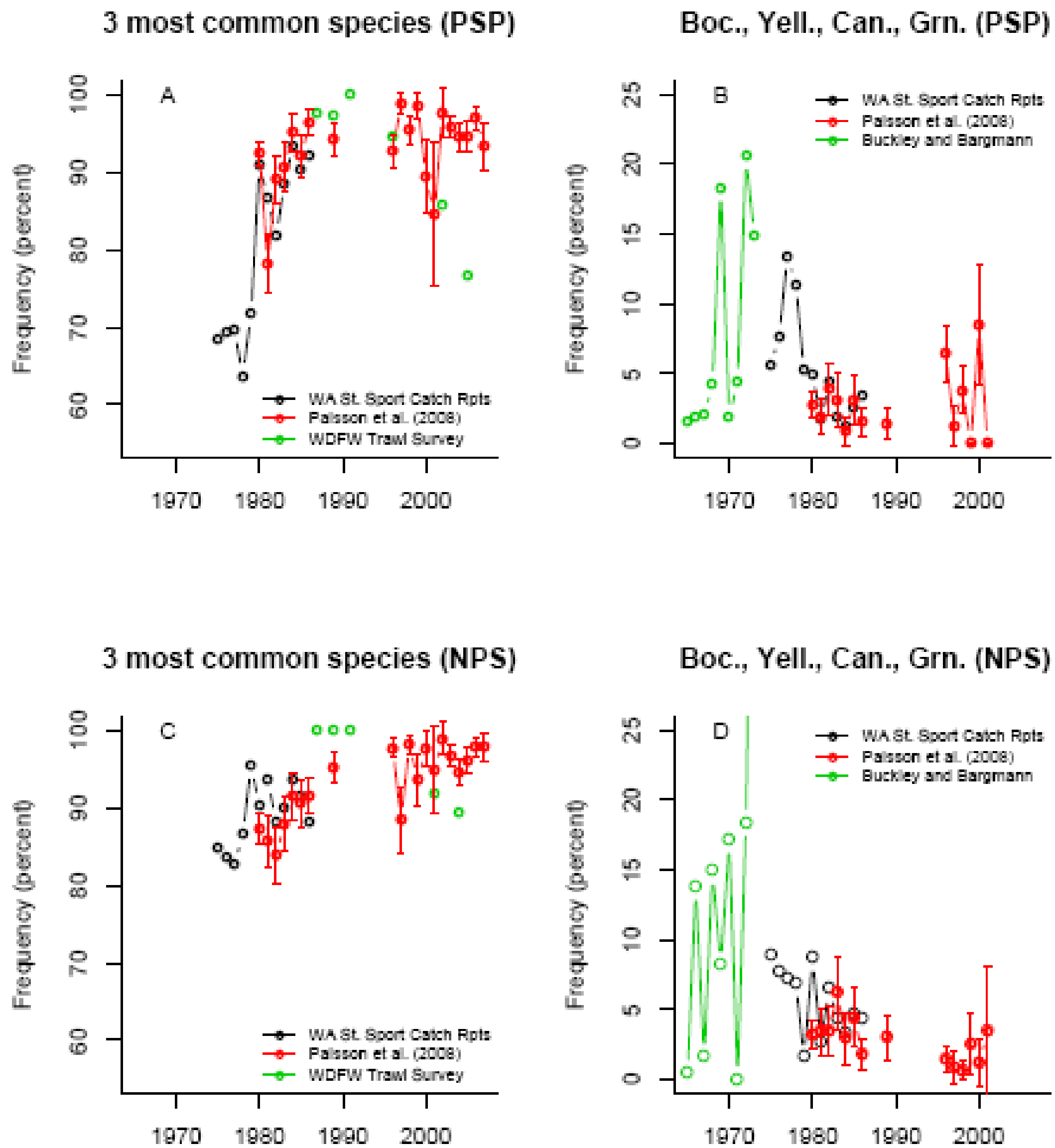


Figure 21 Species frequency data from recreational bottomfish fisheries in Puget Sound Proper and North Puget Sound. See text for details on the data sources. Approximate 95% confidence intervals were calculated for the frequencies reported in Palsson et al. (2008) using the normal approximation ˆp ± zα/2 pˆ(1 − pˆ)/n and sample sizes, n provided by citetPalsson08. Redstripe rockfish has been removed from the datasets when calculated changes in frequencies because of concerns that discarding and highly aggregation led to large biases in the recreational and WDFS trawl data, respectively.

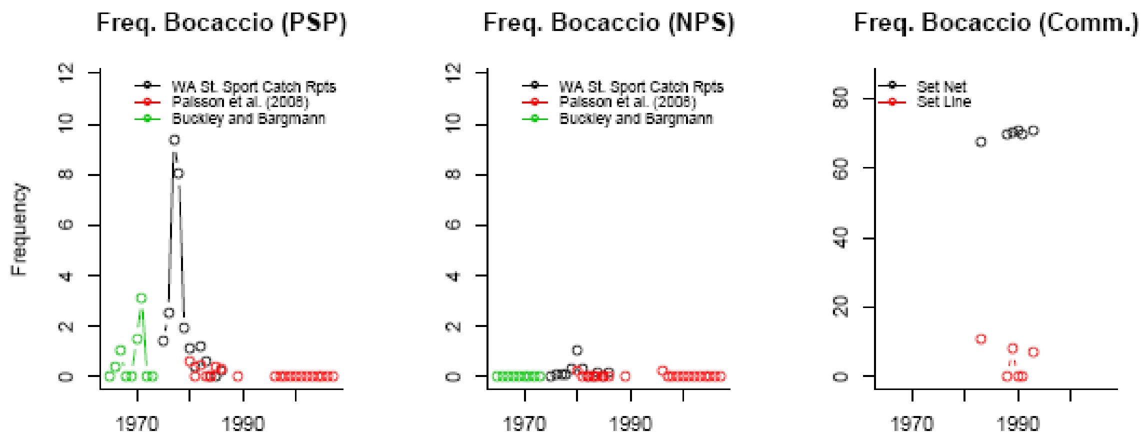


Figure 22 Frequency estimates (% total catch) for Bocaccio in the recreational catch in Puget Sound Proper (PSP) and north Puget Sound (NPS), and commercial catch in Puget Sound Proper (Comm). Bocaccio do not appear in commercial catch records in NPS.

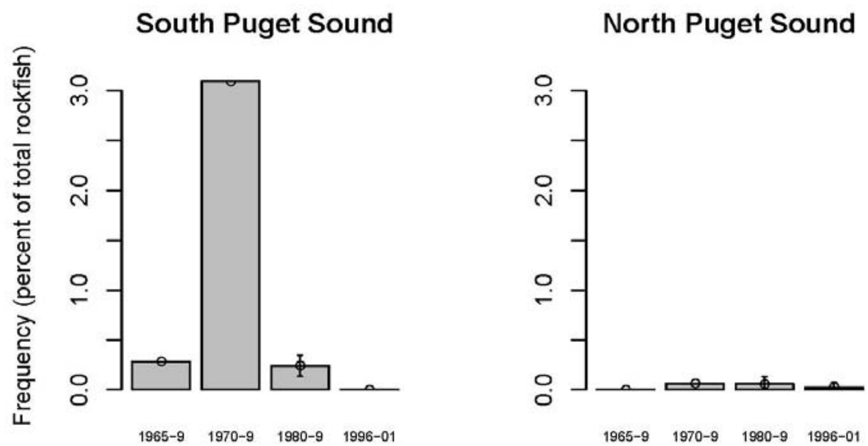


Figure 23 Frequency (% total catch) for Bocaccio in recreational catch in Puget Sound Proper and north Puget Sound averaged across decades.

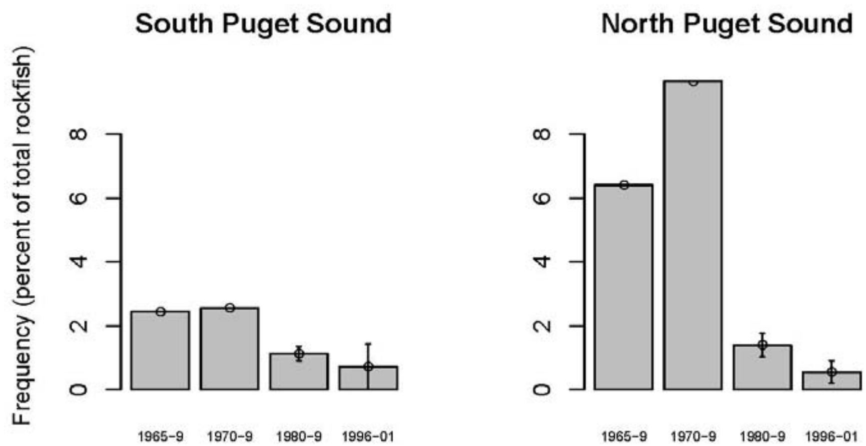


Figure 24 Frequency (% total catch) for canary rockfish in recreational catch in Puget Sound Proper and north Puget Sound averaged across decades.

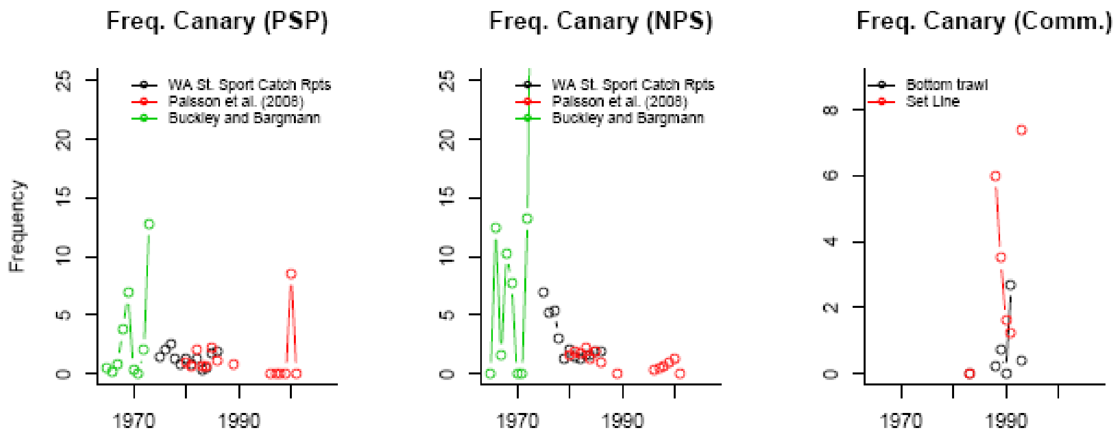


Figure 25 Frequency estimates (% total catch) for canary rockfish in recreational catch in Puget Sound Proper (PSP) and north Puget Sound (NPS), and in commercial catch from north Puget Sound (Comm). It does not appear in commercial catch in PSP. The outlier point (1973 in NPS) for the Buckley and Bargmann data is at 52%.

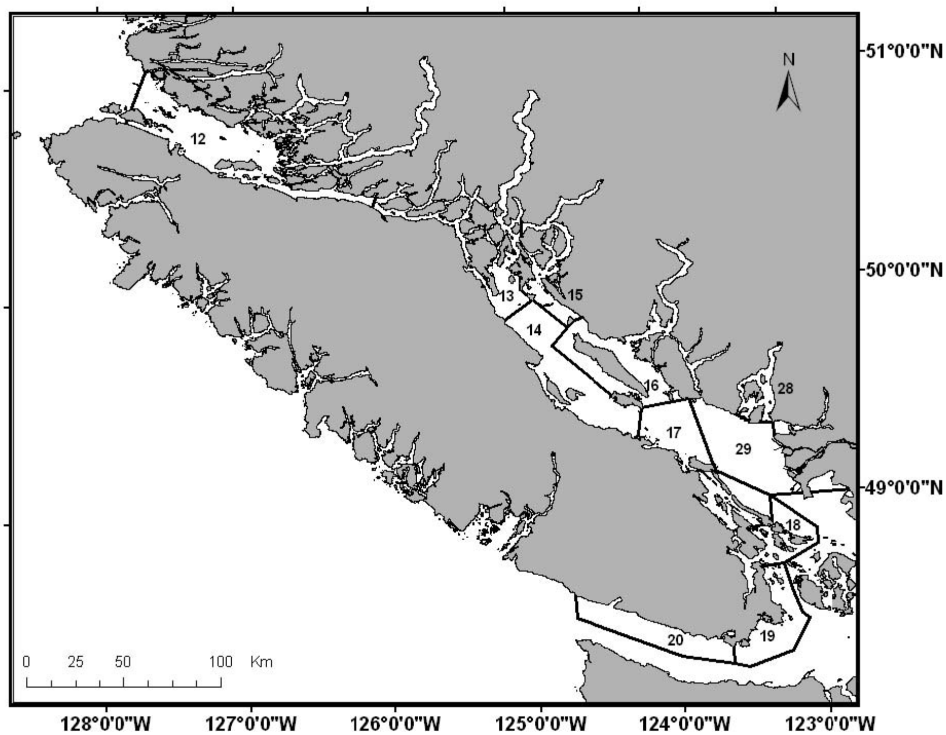


Figure 26 Statistical reporting areas divided into nos. 12-20 and 28-29, as used by the Department of Fisheries and Oceans Canada (From COSEWIC (2002)).

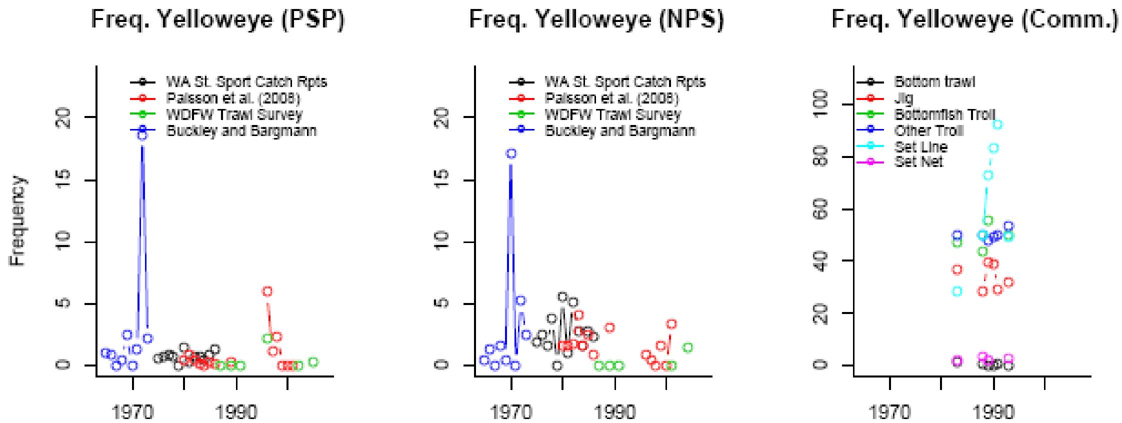


Figure 27 Frequency estimates (% total catch) for yelloweye rockfish in recreational catch in Puget Sound Proper (PSP), north Puget Sound (NPS), and commercial catch from NPS. They do not appear in commercial catch in PSP.

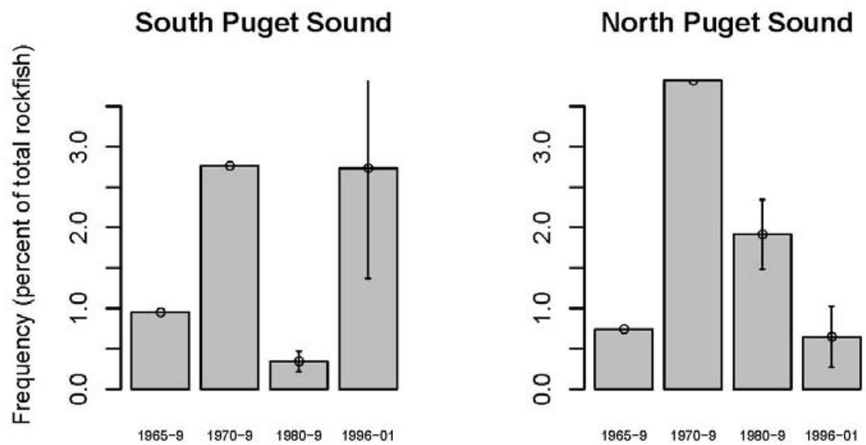


Figure 28 Frequency (% total catch) for yelloweye rockfish in the recreational catch in Puget Sound Proper and north Puget Sound averaged across decades.

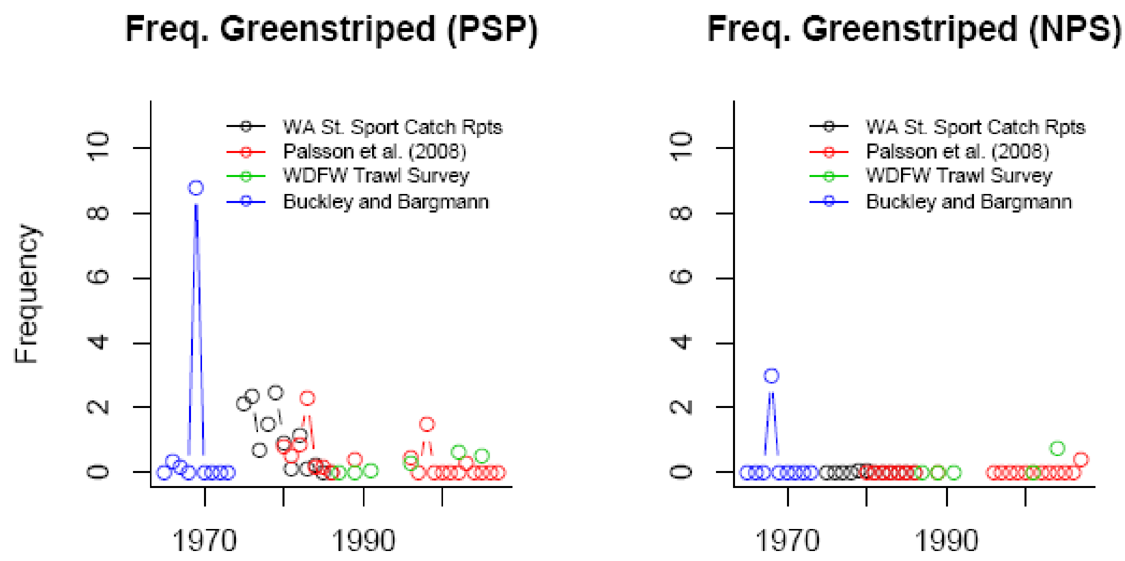


Figure 29 Frequency estimates (% total catch) for greenstriped rockfish in the recreational catch. They are not recorded in the commercial catch.

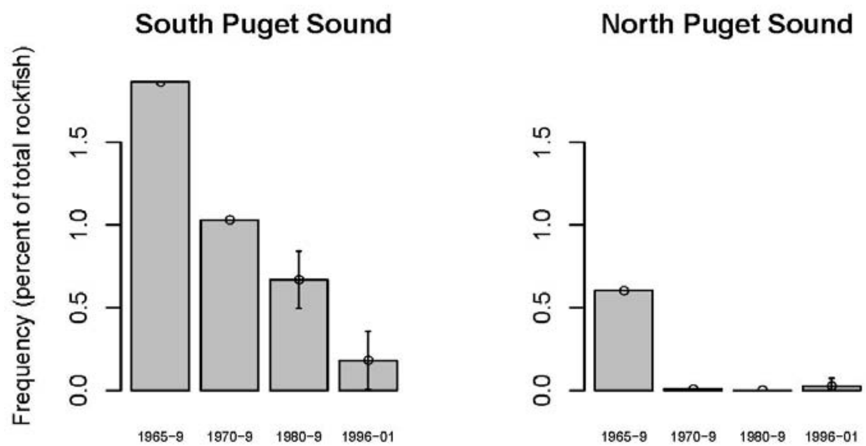


Figure 30 Frequency (% total catch) for greenstriped rockfish in the recreational catch in Puget Sound Proper and north Puget Sound averaged across decades.

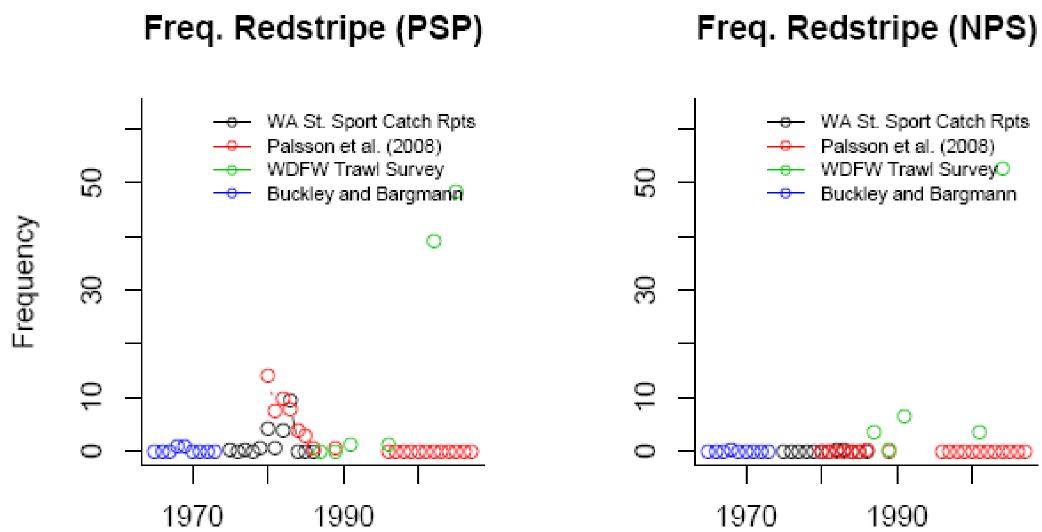


Figure 31 Frequency estimate (% of catch) for redstripe rockfish.

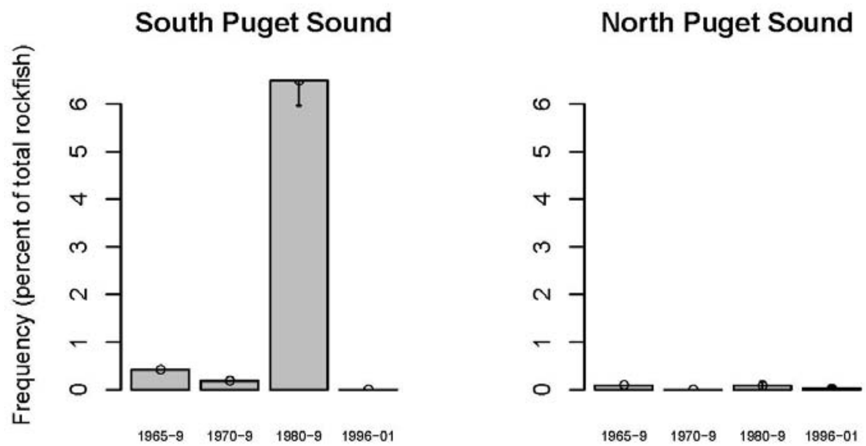
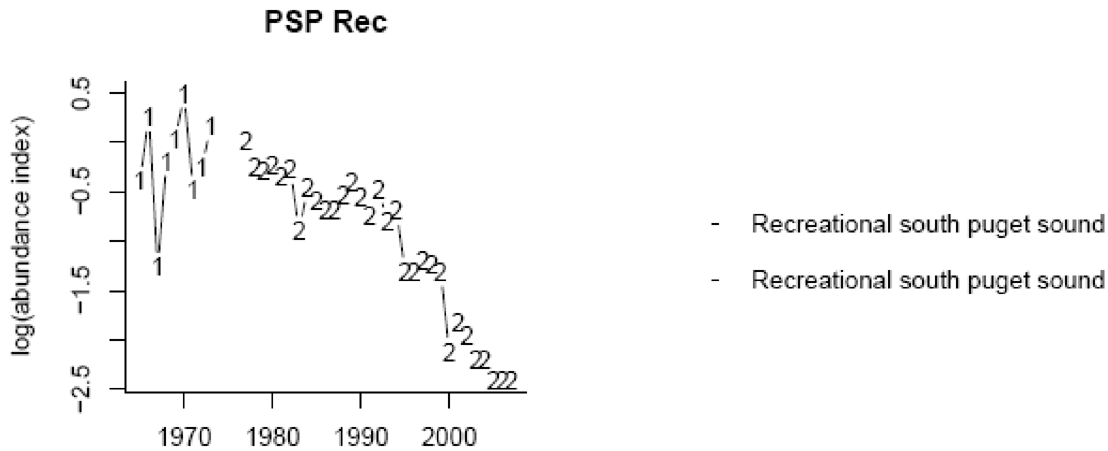


Figure 32 Frequency (% total catch) for redstripe rockfish in the recreational catch in Puget Sound Proper and north Puget Sound averaged across decades.



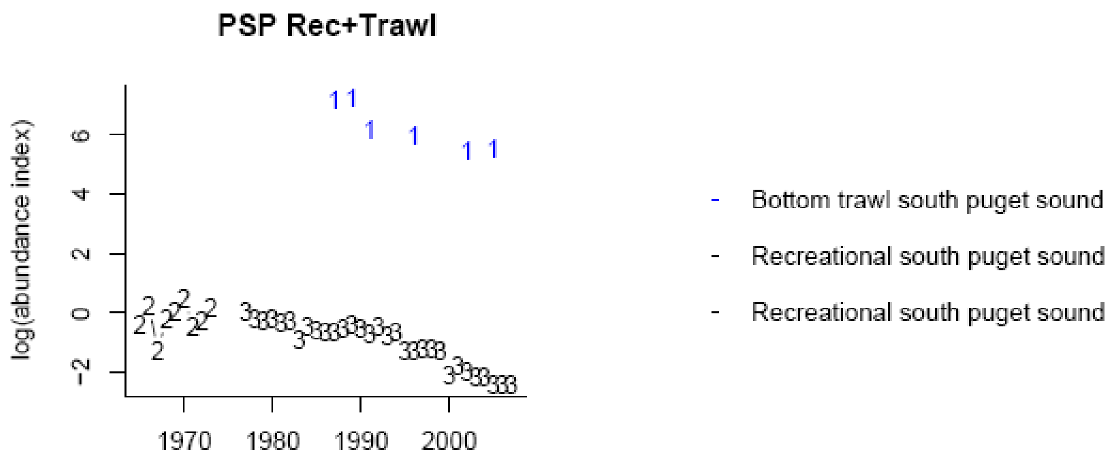


Figure 33 Data used for two Puget Sound Proper analyses. The different colors show which data were treated as separate (but not independent) population processes. Data from the trawl survey may be sampling a different segment of the total rockfish assemblage (age or size). Each process has the same long-term population growth rate (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.

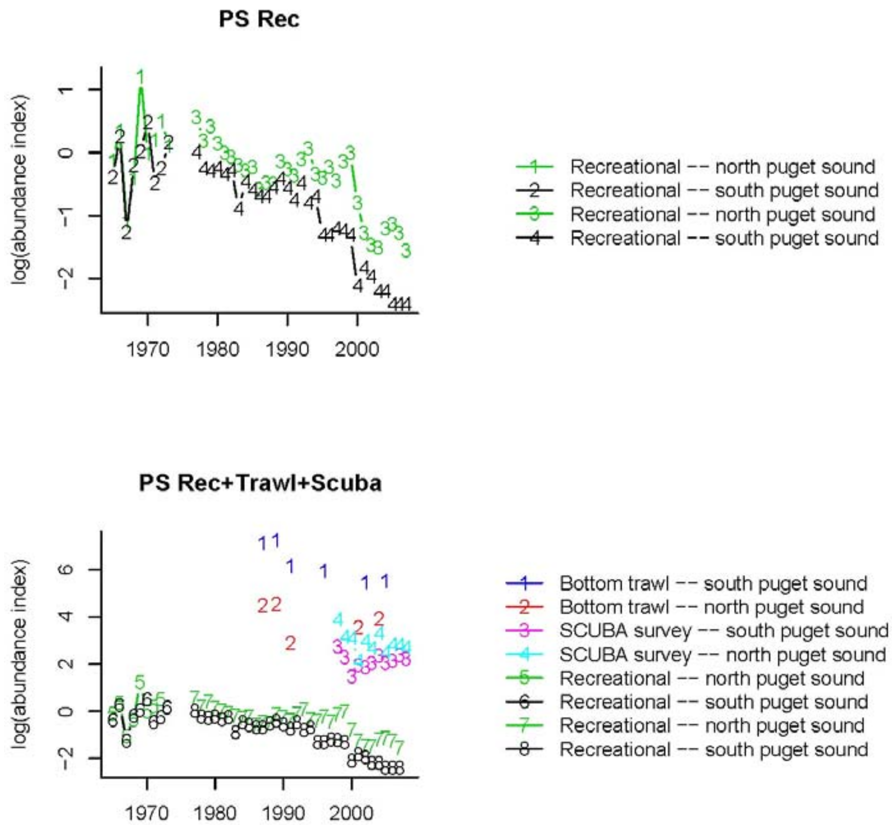


Figure 34 Data used for two Puget Sound (north plus south) analyses. Different colors show which data were treated as separate (but not independent) population processes. See comments on previous figure.

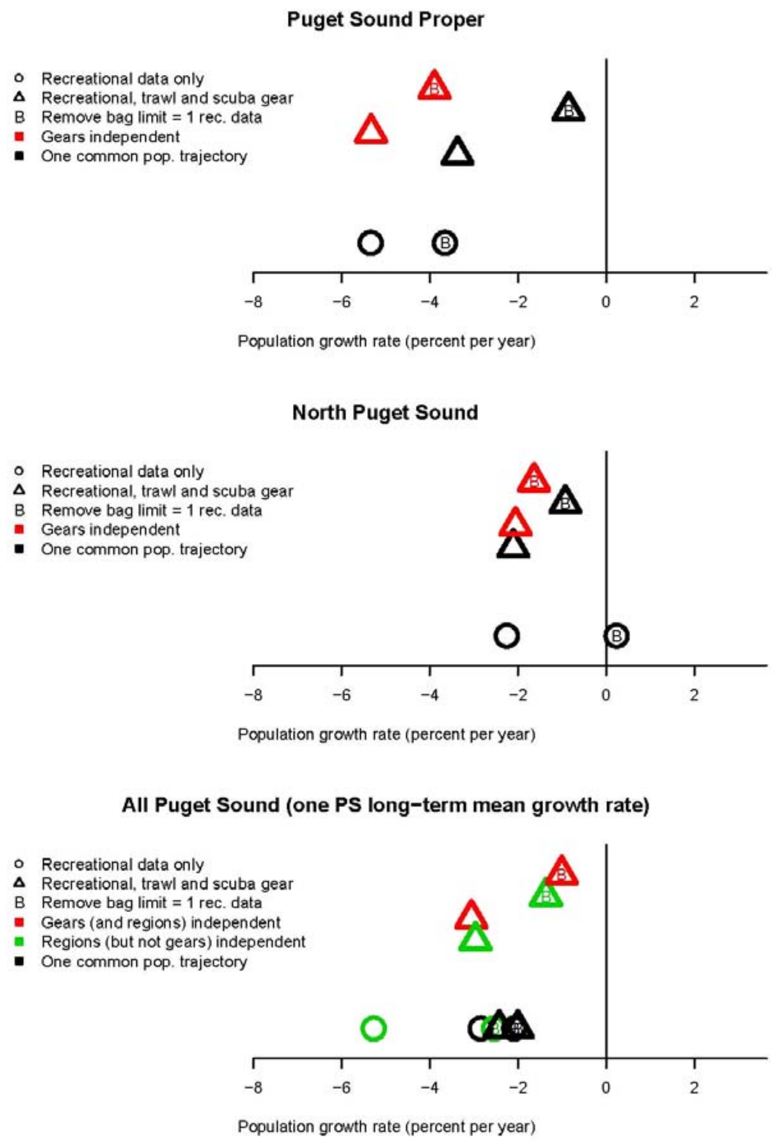


Figure 35 Estimates of rate of population growth (or decline if negative) for 1965-2007 using recreational, trawl and REEF survey data. Colors and symbols denote different model assumptions. The height on the y-axis expresses the subjective assessment of the support for the assumptions behind each model. See text for a discussion of the assumptions and which are supported by the data.

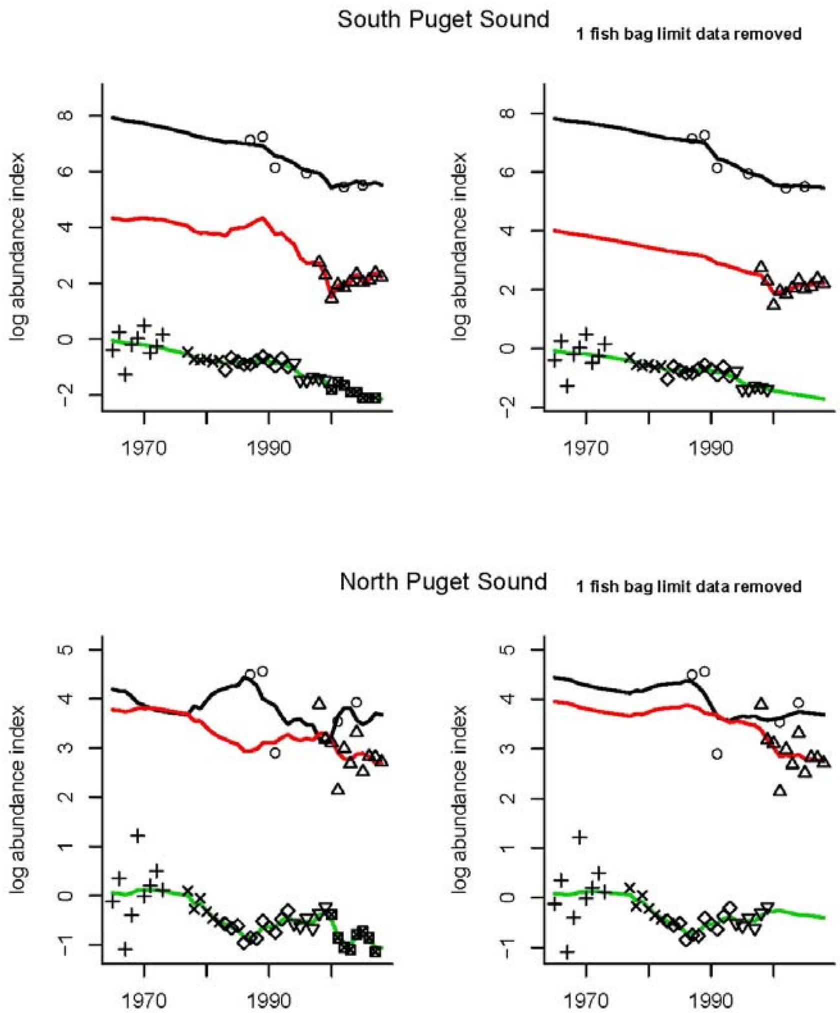


Figure 36 The model estimates for 'total rockfish' trajectories measured by each data source for the analysis where different data sources are allowed to be measuring independent realizations of the population process. Mathematically, each gear *i* is modeled as $log(X_{t,i}) = a + log(X_{t-1,i}) + e_{t,i}$; $log(Y_{t,i}) = log(X_{t,i}) + g_{t,i}$ trajectory, where a is the shared mean population growth term (same across data sources), $e_{t,i}$ are the independent process error terms which are drawn from a normal with mean 0 and variance σ_i, and $g_{t,i}$ are the observations errors data source *i*. The goal of the analysis is to find the shared a that is most consistent with all the data. The analyses with and without the 1 fish bag limit data are shown.

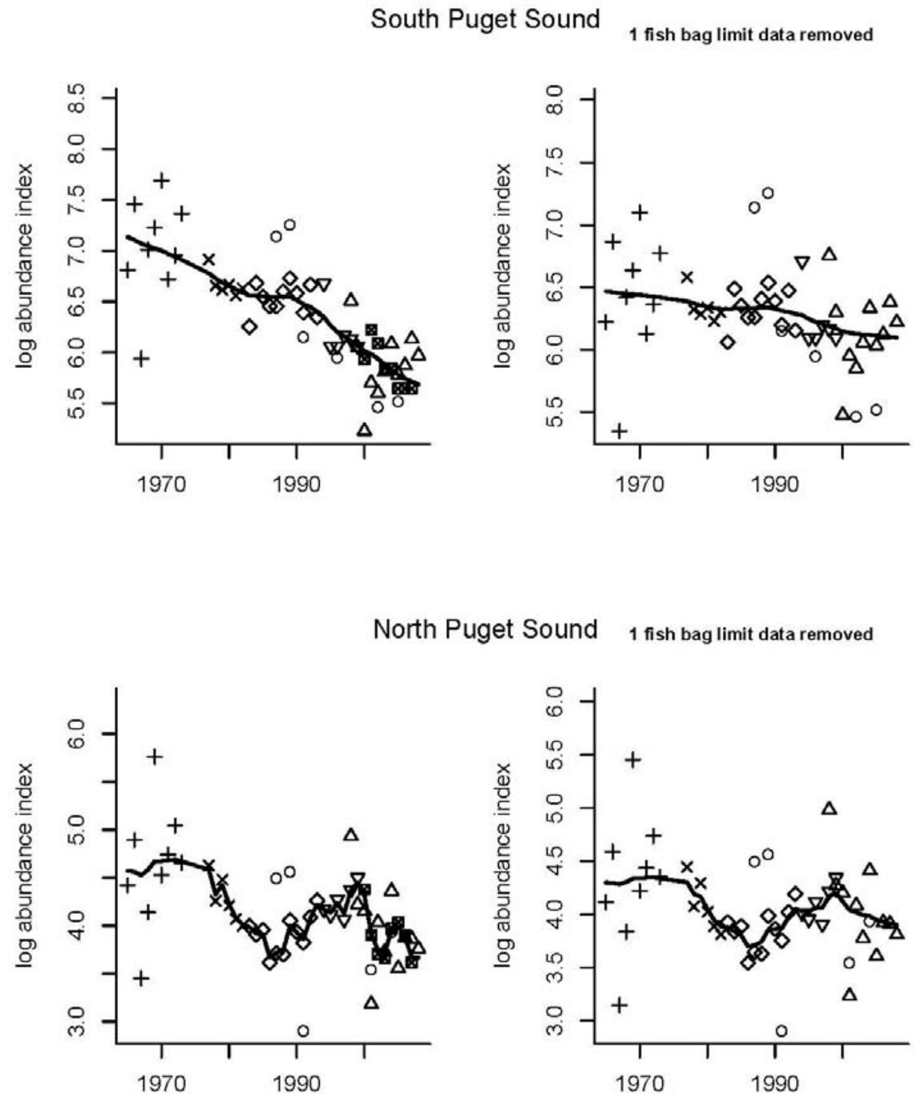


Figure 37 The model estimates for 'total rockfish' trajectories measured by each data source for the analysis where different data sources are forced to be measuring the same population process. Each gear *i* is modeled as $log(X_{t,i}) = a + log(X_{t-1,i}) + e_{t,i}$; $log(Y_{t,i}) = log(X_{t,i}) + g_{t,i}$ trajectory, where a is the shared mean population growth term (same across data sources), $e_{t,i}$ are the independent process error terms which are drawn from a normal with mean 0 and variance σ_i, and $g_{t,i}$ are the observations errors 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 and without the 1 fish bag limit data are shown.

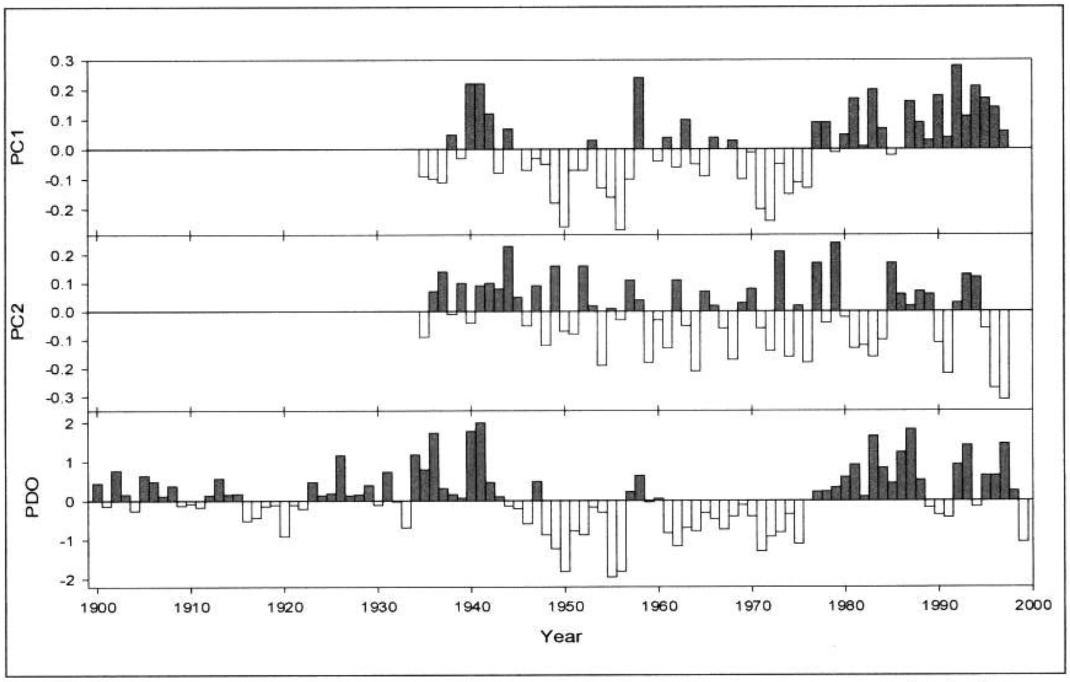


Figure 38 First (PC1) and second (PC2) principal components analysis of climate variables for Puget Sound (Pinnix 1999) along with the Pacific Decadal Oscillation (PD0) (Mantua 1997). PC1 captures decadal scale variability; resembles the PDO. PC2 captures interannual scale variability.