Yelloweye rockfish (*Sebastes ruberrimus*), canary rockfish (*Sebastes pinniger*), and bocaccio (*Sebastes paucispinis*) of the Puget Sound/Georgia Basin

5-Year Review:
Summary and Evaluation

NOAA's National Marine Fisheries Service
West Coast Region

Office of Protected Resources
Seattle, Washington

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5-Year Review: Yelloweye Rockfish, Canary Rockfish, and Bocaccio of the Puget Sound/Georgia Basin

Cover image of adult yelloweye rockfish in Hood Canal in 2015, courtesy of the Washington Department of Fish and Wildlife.

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5-YEAR REVIEW

Species reviewed: Yelloweye rockfish (*Sebastes ruberrimus*), canary rockfish (*Sebastes pinniger*), and bocaccio (*Sebastes paucispinis*) of the Puget Sound/Georgia Basin

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5-YEAR REVIEW
Yelloweye rockfish (*Sebastes ruberrimus*), canary rockfish (*Sebastes pinniger*), and bocaccio (*Sebastes paucispinis*) of the Puget Sound/Georgia Basin

1 General Information

1.1 Reviewers

Lynne Barre
Laurie Beale

1.2 Methodology Used to Complete the Review

The National Marine Fisheries Service (NMFS) of the National Oceanic and Atmospheric Administration (NOAA) initiated a 5-year review of Puget Sound/Georgia Basin DPSs of yelloweye rockfish, canary rockfish, and bocaccio (listed rockfish) in February 2015. NMFS solicited information from the public through a Federal Register (FR) Notice (80 Fed. Reg. 6695, February 6, 2015). To complete the review, we collected, evaluated, and incorporated all information on the species that has become available since April 2010, the date of the listing, including the 2014 final critical habitat designation. Thus, the review is based upon the best scientific and commercial data available. We include relevant recent research on rockfish from within the range of the DPSs, along the Pacific coast, and on other species of rockfish with similar life history (i.e., quillback rockfish, *Sebastes maliger*) as these findings provide insight on listed rockfish condition and threats and inform their status within the Puget Sound/Georgia Basin.

1.3 Background

1.3.1 Federal Register Notice Citation Announcing Initiation of This Review

The notice announcing the initiation of this 5-year review and requesting information from the public was published February 6, 2015 (80 Fed. Reg. 6695), Endangered and Threatened Species; Initiation of 5-Year Reviews for 32 Listed Species of Pacific Salmon and Steelhead, Puget Sound Rockfishes, and Eulachon.

1.3.2 Listing History

On April 9, 2007, NMFS received a petition from Mr. Sam Wright (Olympia, Washington) to list “distinct population segments (DPSs)” of five rockfishes in Puget Sound, as endangered or threatened species under the Endangered Species Act (ESA) and to designate critical habitat. NMFS found that this petition did not present substantial scientific or commercial information to suggest that the petitioned actions may be warranted (72 Fed. Reg. 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 reconsideration of the decision not to initiate a review of the species' status. NMFS considered the supplemental information as a new petition and concluded that there was enough information in this new petition to warrant conducting status reviews of these rockfishes. The status review was initiated on March 17, 2008 (73 Fed. Reg. 14195).

The Biological Review Team completed the status review in December 2009 (Drake et al. 2010). The BRT determined that yelloweye rockfish (*Sebastes ruberrimus*), canary rockfish (*Sebastes pinniger*), and bocaccio (*Sebastes paucispinis*) are DPSs. Section 3 of the ESA defines "species" as including "any subspecies of fish or wildlife or plants, and any distinct population segment of any species of vertebrate fish or wildlife which interbreeds when mature." Under the DPS policy (61 FR 4722), a population segment is considered a DPS if it is both discrete from other populations within its taxon and significant to its taxon. According to the policy, quantitative measures of genetic or morphological discontinuity can be used to provide evidence for discreteness. Because there was a lack of genetic data for yelloweye rockfish, canary rockfish, and bocaccio, the BRT based their DPS recommendations, in part, on NMFS' 2001 status review of copper, quillback, and brown rockfish (Stout et al. 2001), which concluded there were DPSs of these rockfish in Puget Sound Proper based on genetic information (Drake et al., 2010). The review determined that the Puget Sound/Georgia Basin DPS of bocaccio is at high risk of extinction throughout all of its range and that the Puget Sound/Georgia Basin DPSs of yelloweye rockfish and canary rockfish are at moderate risk of extinction throughout all of their range (Drake et al. 2010). On April 28, 2010, NMFS published a final rule listing the Puget Sound/Georgia Basin DPSs of yelloweye rockfish and canary rockfish as threatened, and bocaccio rockfish as endangered under the ESA.

Federal Register Notice: 75 Fed. Reg. 22276, April 28, 2010 - Endangered and Threatened Wildlife and Plants: Threatened Status for the Puget Sound/Georgia Basin Distinct Population Segments of Yelloweye and Canary Rockfish and Endangered Status for the Puget Sound/Georgia Basin Distinct Population Segment of Bocaccio Rockfish.
Date listed: Effective July 27, 2010

Table 1. Listed Species and ESA Classification of DPSs under 75 Federal Register 22276.

Entity Listed	Classification
Puget Sound/Georgia Basin bocaccio	Endangered
Puget Sound/Georgia Basin canary rockfish	Threatened
Puget Sound/Georgia Basin yelloweye rockfish	Threatened

1.3.3 Associated Rulemakings

Critical Habitat Designation: 79 Fed. Reg. 68041, November 1, 2014 - Endangered and Threatened Species; Designation of Critical Habitat for the Puget Sound/Georgia Basin Distinct Population Segments of Yelloweye Rockfish, Canary Rockfish, and Bocaccio.

1.3.4 Review History

There are no prior reviews for these species.

1.3.5 Species' Recovery Priority Number at Start of 5-year Review

On June 15, 1990, NMFS issued guidelines (55 Fed. Reg. 24296) for assigning listing and recovery priorities. For recovery plan development, implementation, and resource allocation, we assess three criteria to determine a species' recovery priority number from 1 (high) to 12 (low): (1) magnitude of threat; (2) recovery potential; and (3) conflict with development projects or other economic activity. NMFS re-evaluated the recovery priority numbers for listed species as part of the FY2013-FY2014 ESA Biennial Report to Congress (NMFS 2015a).

The Puget Sound/Georgia Basin DPS of bocaccio have a recovery Priority Number of three based on criteria in the Recovery Priority Guidelines (55 Fed. Reg. 24296, June 15, 1990), which describes a high magnitude of threats, moderate recovery potential, and the potential for economic conflicts while implementing recovery actions. The Puget Sound/Georgia Basin DPS of yelloweye rockfish and canary rockfish have a Priority Number of seven, which describes a moderate magnitude of threats, moderate recovery potential, and the potential for economic conflicts while implementing recovery actions. Regardless of a species' recovery priority number, NMFS remains committed to continued efforts to recovery all ESA-listed species under our authority.

1.3.6 Recovery Plan or Outline

We initiated recovery planning for listed rockfish in 2013 with the appointment of a Recovery Team made up of scientists from the University of Washington, Washington Department of Fish and Wildlife (WDFW), Northwest Indian Fisheries Commission, and NOAA's West Coast Regional Office and Northwest Fisheries Science Center. No recovery outline was published, but the draft plan was released for peer review and review by the government of Canada, the state of Washington, and the Puget Sound treaty tribes in early 2015. The draft recovery plan is anticipated to be released for public review and comment in 2016.

2 Review Analysis

2.1 Application of the 1996 Distinct Population Segment (DPS) Policy

2.1.1 Is the species under review a vertebrate?

DPS Name	Yes	No
Puget Sound/Georgia Basin bocaccio	X	
Puget Sound/Georgia Basin canary rockfish	X	
Puget Sound/Georgia Basin yelloweye rockfish	X	

2.1.2 Is the species under review listed as a DPS?

DPS Name	Yes	No
Puget Sound/Georgia Basin bocaccio	X	
Puget Sound/Georgia Basin canary rockfish	X	
Puget Sound/Georgia Basin yelloweye rockfish	X	

2.1.3 Was the DPS listed prior to 1996?

DPS Name	Yes	No
Puget Sound/Georgia Basin bocaccio		X
Puget Sound/Georgia Basin canary rockfish		X
Puget Sound/Georgia Basin yelloweye rockfish		X

2.1.4 Is there relevant new information for this species regarding the application of the DPS policy?

DPS Name	Yes	No
Puget Sound/Georgia Basin bocaccio		X
Puget Sound/Georgia Basin canary rockfish	X	
Puget Sound/Georgia Basin yelloweye rockfish	X	

A recent study has resulted in new genetic information for listed rockfish of the Puget Sound/Georgia Basin. This new information is covered in Subsection 2.3.1.3, Genetics, Genetic Variation, or Trends in Genetic Variation, of this review. In summary, new genetic information largely confirms the DPS structure of yelloweye rockfish of the Puget Sound/Georgia Basin, with some slight modifications to the northern geographic boundaries that define the DPS. New genetic information indicates that canary rockfish of the Puget Sound/Georgia basin are not discrete from coastal fish, and therefore are not a DPS. There is some new genetic information for bocaccio, but it is not sufficient to result in a recommended change to the DPS at this time.

2.2 Recovery Criteria

2.2.1 Does the species have a final, approved recovery plan containing objective, measurable criteria?

DPS Name	Yes	No
Puget Sound/Georgia Basin bocaccio		X
Puget Sound/Georgia Basin canary rockfish		X
Puget Sound/Georgia Basin yelloweye rockfish		X

2.3 Updated Information and Current Species' Status

2.3.1 Biology and Habitat

Where possible, we describe updated information for the Puget Sound/Georgia Basin within particular biogeographic basins termed the San Juan/Strait of Juan de Fuca, the Whidbey Basin, the Main (or Central) Basin, South Sound, Hood Canal, and Canadian waters of Georgia Strait (Downing 1983; Burns 1985) (Figure 1). Puget Sound and Georgia Basin make up the southern arm of an inland sea located on the Pacific Coast of North America and are connected to the Pacific Ocean by the Strait of Juan de Fuca. Puget Sound is a fjord-like estuary covering 2,331.8 square miles (6,039.3 sq. km). Puget Sound has 14 major river systems and its benthic areas consist of a series of interconnected basins separated by relatively shallow sills, which are bathymetric shallow areas. The sills largely define the boundaries between the basins (except where the Whidbey Basin meets the Main Basin) and contribute to relatively fast water currents during portions of the tidal cycle. The sills, in combination with bathymetry, freshwater input, and tidal exchange influence environmental conditions such as the movement and exchange of biota from one region to the next and water temperatures and water quality, and they also restrict water exchange (Ebbesmeyer et al. 1984; Burns 1985; Rice 2007). In addition, each basin differs in biological condition; depth profiles and contours; subtidal benthic and intertidal habitats; and shoreline composition and condition (Downing 1983; Ebbesmeyer et al. 1984; Burns 1985; Rice 2007; Drake et al. 2010; Green et al. 2015).

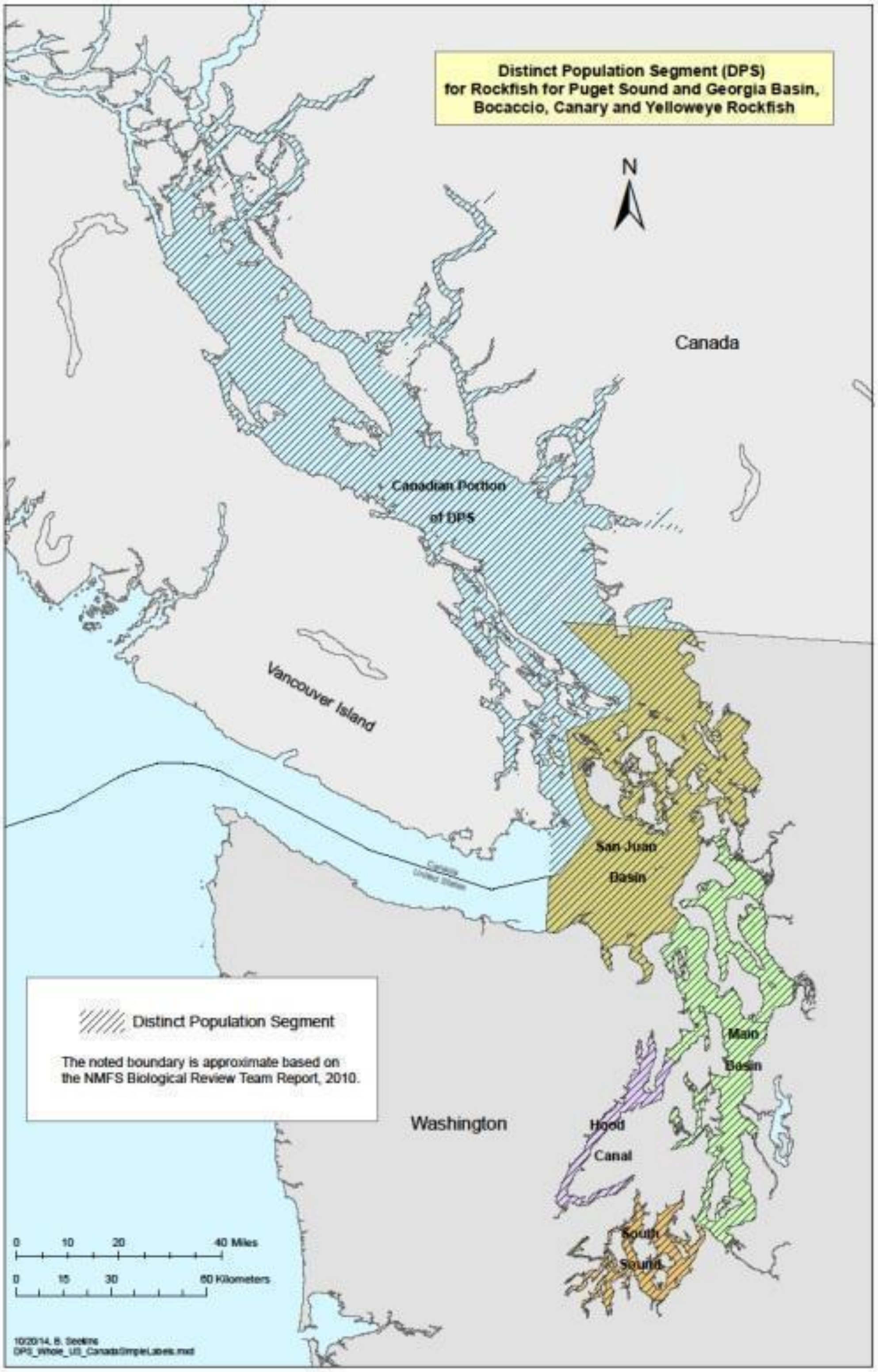


Figure 1. Distinct population segment area with five biogeographic basins shown.

2.3.1.1 New Information on the Species' Biology and Life History

The best available science on the listed species' biology and life history were summarized in the status review in subsections entitled bocaccio general biology, canary rockfish biology, and yelloweye rockfish general biology, as well as the general rockfish life history subsection (Drake et al. 2010).

2.3.1.2 Abundance, Population Trends (e.g., increasing, decreasing, stable), demographic features (e.g., age structure, sex ratio, family size, birth rate, age at mortality, mortality rate, etc.), or Demographic Trends

Abundance

There are no estimates of historic (pre-fishery) nor present-day abundance or biomass of yelloweye rockfish, canary rockfish, or bocaccio across the full DPSs area. In 2013, the WDFW published abundance estimates from a remotely operated vehicle (ROV) survey conducted in 2008 in the San Juan Island area (Pacunski et al. 2013). This survey was conducted exclusively within rocky habitats and represents the best available abundance estimates to date for one basin of the DPS because of their survey area, number of transects, and stratification methods. The survey produced estimates of 47,407 (25 percent variance) yelloweye rockfish, 1,697 (100 percent variance) canary rockfish, and 4,606 (100 percent variance) bocaccio in the San Juan area. The WDFW has completed ROV surveys in the San Juan area in 2010 and elsewhere in 2012/2013, but the results of these surveys have not been published. The 2012/2013 study was conducted to assess a number of species and habitats and was not designed to determine rockfish abundance with any precision.

In Canada, yelloweye rockfish biomass is estimated to be 12 percent of the unfished stock size on the inside waters of Vancouver Island (Fisheries and Oceans Canada 2011). The median estimate of bocaccio biomass is 3.5 percent of its unfished stock size (though this included Canadian waters outside of the DPSs area (Stanley et al. 2012). There are no such estimates for canary rockfish in Canadian waters of the DPS.

Estimates of Rockfish Trends in Puget Sound

We conducted a new assessment of rockfish population trends following similar methodology used in the 2010 rockfish Biological Review Team (BRT) report (Drake et al. 2010). In this new analysis we estimate the population trajectory (year-to-year variation) and population growth rate for all rockfish species using data from the recreational fishery survey data, REEF scuba diver surveys, and the WDFW trawl survey (see Appendix A for a description of these data sources). These surveys contain information on the common rockfish species but insufficient observations of the listed species for direct analysis. Therefore, we make inferences about listed rockfish by evaluating evidence that they have increased or decreased as a proportion of the assemblage. For example, if the frequency of a species decreases, we infer that it has decreased faster than the estimated trend for total rockfish. Each time-series was updated by extending the time-series from 2007 (end date of original analysis) to 2014 (data available at time of the analysis).

This analysis considers the trends in greater spatial detail than found in Drake et al. (2010). The 2010 analysis divided the United States waters into North Puget Sound (NPS, MCAs 5 to 7) and Puget Sound Proper (PSP, MCAs 8 to 13) (Figure 2), and the time-series were averaged for these areas prior to analysis. Here, we use separate time-series for each of the nine Washington State Marine Catch Areas (MCAs) within Greater Puget Sound (GPS, 5 to 13) and model population trends for total rockfish at three spatial resolutions: by MCA, and by NSP vs. PSP and GPS. Finally, MCA 5 and much of MCA 6 were included in the 2010 BRT analysis but were later considered to be outside the DPS for the three listed rockfish. Therefore, we also determine whether excluding data from areas 5 and 6 affects the estimate of population growth rate for total rockfish.

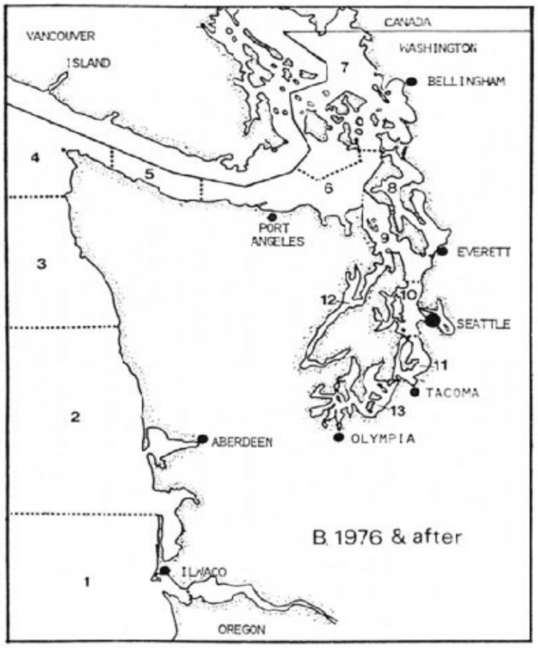


Figure 2. Marine Conservation Areas (MCAs, or Punch Card Areas) for WDFW recreational catch data. Data from North Puget Sound (5 to 7) and Puget Sound Proper (8 to 13) are used in the analyses. (Reprinted from Palsson 1988.)

Long-term Trends in Total Rockfish Abundance

We fit a series of Multivariate Autoregressive State Space (MARSS) models (Appendix A) (Ives et al. 2003; Holmes et al. 2014) to estimate the long-term growth rate (*u*) for total rockfish in Puget Sound and to investigate the effect of different assumptions about space (area). We conducted three separate modeling exercises to test hypotheses about the spatial structure of the rockfish trajectories and to estimate the growth rate *u*. The separate exercises included different combinations of the available data: (a) recreational fishery survey; (b) recreational fishery survey and REEF scuba survey; and (c) recreational fishery, REEF, and trawl surveys. We tested three primary hypotheses about the spatial structure of the rockfish trajectories (i.e., number of state processes, year-to-year variation in abundance) for each of the three data combinations (Drake et al. 2010):

1) Different rockfish trajectories by Marine Catch Area
2) Different rockfish trajectories by Region: North Puget Sound vs. Puget Sound Proper
3) One overall trajectory for Greater Puget Sound

For each main hypothesis, we tested different levels of model complexity. We allowed the growth rate to be different or equal across MCAs or Basins/Regions and to be equal or different across gear types. We set the level of process variation to be different for each MCA, region, or gear, but allowed it to be correlated or independent. In the models that include more than one gear type (cases b and c), we treated gear types as separate trajectories or combined them. For all models, we estimated independent observational variance by MCA and gear type. For data from the recreational fishery survey, we treated different regulatory periods as separate observational time-series within MCA, Region, or for GPS. See Tables A7-A14 for further detail of tested models.

We compared models using Akiake's Information Criterion (corrected for small sample size, AICc) (Burnham and Anderson 1998; Ward et al. 2010; Hampton et al. 2013). Within each data combination (Rec, Rec+REEF, Rec+REEF+Trawl), we considered the best-fit model to be the one with a delta AICc less than 2.0 and the fewest total parameters.

Results

The data suggest that total rockfish declined at a rate of 3.1 to 3.8 percent per year from 1977 to 2014 (u's from the best-fit models were between -0.031 and -0.038) or a 69 to 76 percent total decline over that period (Table 2, Figure 3, Appendix A). We did not find evidence for sub-populations with different population growth rates. Best-fit models regardless of data combination included one overall population growth rate (u_{GPS}) for all of Puget Sound (Table 2, Figure 3). However, there was some evidence for temporal independence between NSP and PSP in the trajectories for the recreational data. Best-fit models regardless of the data combination included separate trajectories (but one u) for the recreational survey data north and south of Admiralty Inlet (NPS vs. PSP, Appendix A). Nevertheless, the trajectories were not entirely independent. The best-fit models also included process covariance between the recreational trajectories in NPS and PSP. For the recreational data, NPS had higher CPUE and higher processes variance (more variable population size) than did PSP even though their rate of decrease (u) as similar.

There was some evidence that REEF trajectories ($u = 0.041$) differed from Recreational and Trawl ones. For both the Rec + REEF and Rec + REEF + Trawl data combination, candidate models with delta AICs< 2.0 included models with separate u's for REEF data (Appendix A, Figure A13, Table A10, A13. However, these models included more parameters than did the best-fit ones. Nevertheless, the REEF data appear to sample a different assemblage than the recreational survey and trawl survey.

Removing MCAs 5 and 6 from the best-fit models did not substantially change the estimates of the decline in total rockfish abundance (Table 2).

The three listed species declined as a proportion of the assemblage in both the recreational (Figures A9 through A11) and REEF surveys (Figure A12). Therefore, growth rate (*u*) for the listed species was likely lower (more negative) than that for total rockfish.

Table 2. Estimates of total rockfish growth rate for the best-fit models from three different data combinations (recreational fishery survey [Rec], Rec + REEF scuba survey, Rec +REEF + WDFW trawl survey for Marine Conservation Areas 5 to 13, MCAs 6 to 13 and MCAs 7 to 13). Area 5 is entirely outside the DPS for ESA-listed rockfish. Part of area 6 is outside the DPS. For the models including trawl data, Juan de Fuca East was removed from the MCA 6 to 13 models, and Juan de Fuca East and West were removed from the MCA 7 to 13 models.

Data combination	Growth rate (*u*) MCAs 5-13	Growth rate (*u*) MCAs 6-13	Growth rate (*u*) MCAs 7-13
Recreational	-0.038 ± 0.008 s.e.	-0.040 ± 0.010 s.e.	-0.040 ± 0.015 s.e.
Rec + REEF	-0.031 ± 0.010 s.e.	-0.030 ± 0.014 s.e.	-0.030 ± 0.011 s.e.
Rec + REEF + Trawl	-0.031 ± 0.011 s.e.	-0.030 ± 0.014 s.e.	-0.030 ± 0.009 s.e.

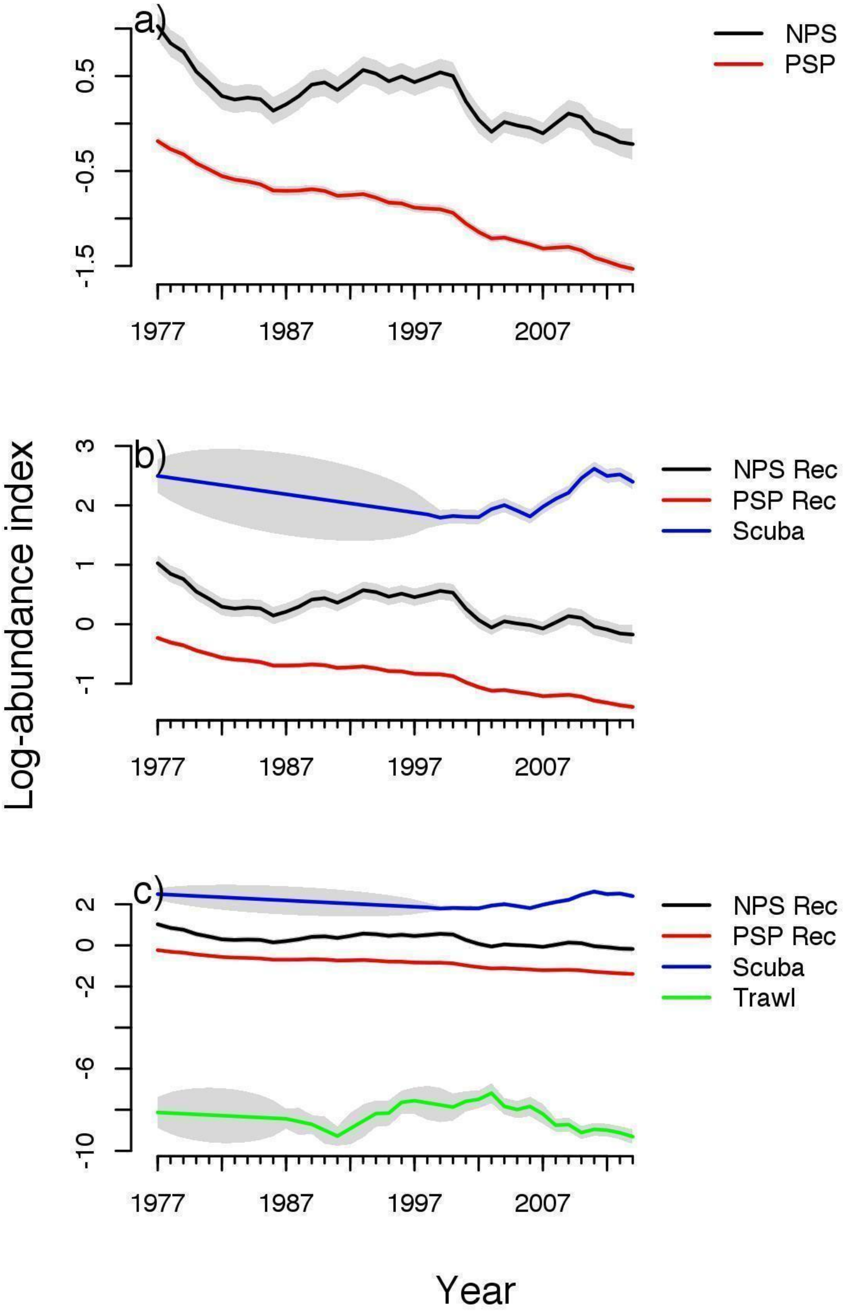


Figure 3. Results of MARSS trend analysis for total rockfishes in Puget Sound a) Recreational (Rec) data: one growth rate *u*, two trajectories (or states; NPS, PSP), *u* = -0.038 ± 0.008 s.e., b) Rec + REEF data: one *u*, three trajectories, *u* = -0.031± 0.010, and c) Rec + REEF + trawl data: one *u*, four trajectories, *u* = -0.031± 0.011. Log abundance index is log (CPUE) from each time-series. Grey envelopes indicate 95 percent confidence intervals. Note, declines are not obvious in the lower pane because of large differences in scale.

Analysis of Growth Rate by Recreational Regulatory Period

The preceding analyses all estimate one *u*, one long-term population growth rate across the entire time-series. However, a number of regulatory changes have occurred through time. Here, we estimate a time-varying *u* and *a* to examine changes in population growth rate with each regulatory change, and more specifically, to determine if there is any evidence of more recent recovery over the final portion of the time-series.

We estimate a different population growth rate *u* for each of the regulatory periods within the recreational survey data (Williams et al. 2010). Key regulatory changes were the imposition of 10/5 (NPS/PSP) bag limit in 1983, a reduction of 5/3 bag limit in 1994, a one fish per bag for all Puget Sound in 2000 (Palsson et al. 2009), and the imposition of a 120-foot (36.6 m) maximum depth for bottom fishing in 2010. However, we shifted the 2010 boundary to the 2007-2008 boundary because we received the new download of data for 2008 through 2014 and discovered some differences in the estimation procedures. A yelloweye rockfish and canary rockfish retention ban was imposed for non-tribal fisheries in 2002 and 2003, respectively (Palsson et al. 2009), but is not included in the present analysis.

Results

The analysis shows changes in *u* (the slope of the log abundance index) with each regulatory change (Table 3, Figure 4a). Most importantly CPUE has tended to decrease in all periods with the exception of 1983 through 1993. Thus, there is no evidence of recent recovery of total rockfish from the recreational fishery survey data alone with *u* = -0.04 for 2008 through 2014.

Including the REEF scuba survey does suggest some recent recovery in CPUE for total rockfishes (Table 3, Figure 4b). In this case, the overall trajectories were similar, but there was positive slope from 2008 through 2014 suggesting some recovery for total rockfishes.

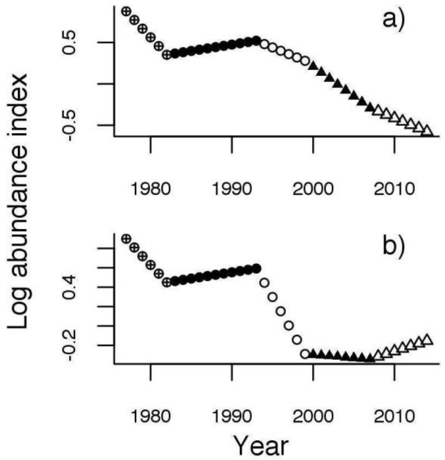


Figure 4. Log-abundance index for a) Greater Puget Sound estimated using the recreational fishery survey data, and b) for Greater Puget Sound

estimated using the recreational fishery survey data and the REEF scuba survey data. Symbols indicate different regulatory periods as described in the text.

These results should be interpreted with some caution, however. Both the recreational bottom fish fishery in these years and the REEF scuba survey generally are limited to shallow water (less than ~120 feet [36.6 m]). Adult listed rockfish are not typically found at these depths and recent data may not reflect trends in the listed species. Additionally, fisher behavior such as avoidance (of listed species) may also have affected the CPUE.

Table 3. Slope and standard error by regulatory time-series.

	Recreational Data		Rec + REEF Data	
Year	Slope (u)	Standard Error	Slope (u)	Standard Error
1977-1982	-0.1051	0.0332	-0.09	0.04
1983-1993	0.0154	0.0132	0.01	0.01
1994-1999	-0.0404	0.0339	-0.15	0.03
2000-2007	-0.0712	0.0214	-0.01	0.02
2008-2014	-0.0409	0.0463	0.03	0.02

Demographics and Rates of Maturity

WDFW's ROV survey (Pacunski et al. 2013) provided general size information for yelloweye rockfish in the San Juan area. Precise measurements were not attainable, but observed fish were all reported to be less than 7.9 inches (20 cm) long, indicating that much of the yelloweye rockfish population consisted of juvenile fish (in 2008).

Size frequency information was collected during the NOAA rockfish genetics study (described in Subsection 2.3.1.3, Genetics, Genetic Variation, or Trends in Genetic Variation), which was initiated in 2014 to gain genetic data to better delineate the population structure for the three listed species. Both yelloweye rockfish and canary rockfish show some evidence of recent recruitment within the last 10 years (Figure 5). For example, most of the canary rockfish were 13.8 inches (35 cm) fork length (FL) or less making them 4 to 6 years old (based on von Bertalanffy growth parameters from Lea et al. 1999; note, these growth parameters are for central California). The survey caught nine yelloweye rockfish that were less than 15.8 inches (40 cm) in FL. At 13.8 inches (35 cm) FL, these fish would be approximately 7 to 10 years of age (using the von Bertalanffy growth parameters from Love et al. 2002). The WDFW scientists observed a strong rockfish recruitment event in 2006 (Lowry et al. 2013). Thus, the data suggest some recent replenishment of local populations of yelloweye rockfish and canary rockfish, although the extent is not known. In addition, several observations of young-of-year (YOY) yelloweye rockfish and canary rockfish in Puget Sound have been documented by local recreational divers, the Seattle Aquarium and WDFW (NMFS, unpublished database).

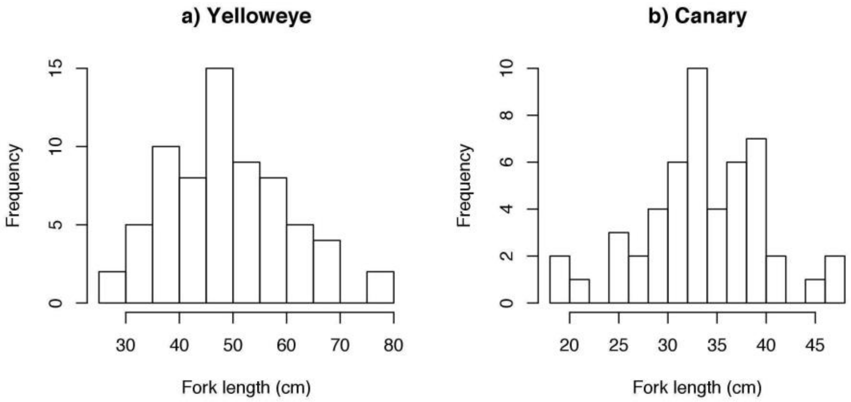


Figure 5. Size frequency of (a) yelloweye rockfish and (b) canary rockfish in Puget Sound (MCAs ~5-13) from the NOAA rockfish genetics study.

Growth Rates in Puget Sound

There is evidence of varied growth rates of quillback rockfish across regions of the Salish Sea. West et al. (2014) found that their largest asymptotic size occurred in the Strait of Juan de Fuca, followed by smaller asymptotic sizes at earlier ages in inland waters. Adult quillback rockfish in Puget Sound were roughly 3.9 inches (10 cm) smaller than adults sampled nearer to the Pacific Ocean and their growth appeared to slow at an earlier age (West et al. 2014). The reasons for reduced growth rates are not known, but environmental conditions (such as contaminants, salinity, temperature) and fishing pressure may individually or collectively explain the differing growth rates (West et al. 2014). Such data have not been collected for yelloweye rockfish, canary rockfish, and bocaccio, but given the similar life history it is possible that similar growth differences also occur within fish in Puget Sound proper.

2.3.1.3 Genetics, Genetic Variation, or Trends in Genetic Variation (e.g., loss of genetic variation, genetic drift, inbreeding, etc.)

In 2014 and 2015, NMFS, WDFW, several local recreational fishing charters, and Puget Sound Anglers partnered to gather new genetic information for yelloweye rockfish, canary rockfish, and bocaccio from the Pacific Coast and waters of the Puget Sound/Georgia Basin DPSs. The primary objective of this research was to determine whether differences exist in the genetic structure of the species' populations between the inland basins of the DPSs area and the outer coast.

This study was initiated because the lack of genetic and demographic data for these species in the Puget Sound region created uncertainty in NOAA's Biological Review Team recommendation that yelloweye rockfish, canary rockfish, and bocaccio of the Puget Sound/Georgia Basin were each a DPS (Drake et al. 2010). Therefore, collection of genetic data was identified as a research priority at the initiation of recovery planning.

Methods

Over the course of 74 fishing trips, biological samples were gathered from listed rockfish using hook-and-line recreational fishing methods in Puget Sound and the Strait of the Juan de Fuca. Additional samples were gathered from archived samples from Fisheries and Oceans Canada and the Northwest Fisheries Science Center's West Coast bottom trawl groundfish survey (Table 4). After each fish was caught, they were measured for length and weight, the gender and location of catch was recorded, a small clip of the caudal fin was removed, an external marker was inserted into their dorsal musculature, and finally they were released at depth using a Seaqualizer ® descending device. The descending device was used in order to get rockfish with expanded swim bladders back down to the bottom and increase their likelihood of survival. Fin clips were stored in ethanol at sampling and prepared for Restriction site associated DNA (RAD) sequencing (Davey and Blaxter 2010).

Table 4. Number of fin clip samples from each region used in the genetics analysis (as of November 2015). Numbers in parentheses are additional samples to be analyzed.

	Yelloweye	Canary	Bocaccio
Southeast Alaska	1	0	0
British Columbia, CAN	25	0	1 (2)
U.S. West Coast	16 (45)	18	8 (4)
Strait of Juan de Fuca	18 (1)	22	0
San Juan Islands	25 (3)	23 (2)	0
Hood Canal	16	0	0
Central Puget Sound	3 (2)	17 (8)	2 (1)
South Puget Sound	0	0	0

Genetic Analysis

We used genomic data to understand population structure and admixture (Luikart et al. 2003). Current sequencing technologies allow the generation of thousands of markers across the entire genome of organisms. Thousands of genetic loci were used to examine the population structure among the samples collected.

DNA was extracted from fin tissue, and then samples were barcoded for individual identification, pooled, and sequenced on the Illumina HiSeq™. Hundreds of thousands of sequence reads were identified to individuals. Data were quality filtered and processed to identify polymorphic sites—single nucleotide polymorphisms (SNPs) as described by Catchen and colleagues (2013). From this, a matrix of genotypes at thousands of locations in the genome were generated for each species.

Population genetic approaches were used to examine the full set of genotyped SNPs to examine population structure within each species. Population structure was examined using three methods: principal components analysis, calculation of F_{ST} among geographic groups, and a population genetic based model clustering analysis (STRUCTURE) (Pritchard et al. 2010). These parallel approaches were used to evaluate *a priori* hypotheses about population structure according to known possible boundaries (e.g., population structure exists between populations separated by the Victoria sill), and to identify the possible numbers of populations within the samples sequenced (Lamichhaney et al. 2012; Vincent et al. 2013).

Results

The results of the new genetic information were reviewed by NOAA's Puget Sound/Georgia Basin rockfish BRT on November 13, 2015. The results of the BRT review and recommendations are documented in a December 9, 2015 memo to Chris Yates of the Protected Resources Division (Ford 2015), summarized below (and included as Appendix B)

Yelloweye Rockfish

Several different analytical methods indicated significant genetic differentiation between the inland and coastal samples at a level consistent with the limited data that were available at the time of the 2010 status review. The BRT concluded that these new data are consistent with and further support the existence of a population of Puget Sound/Georgia Basin yelloweye rockfish that is discrete from coastal populations (Ford 2015).

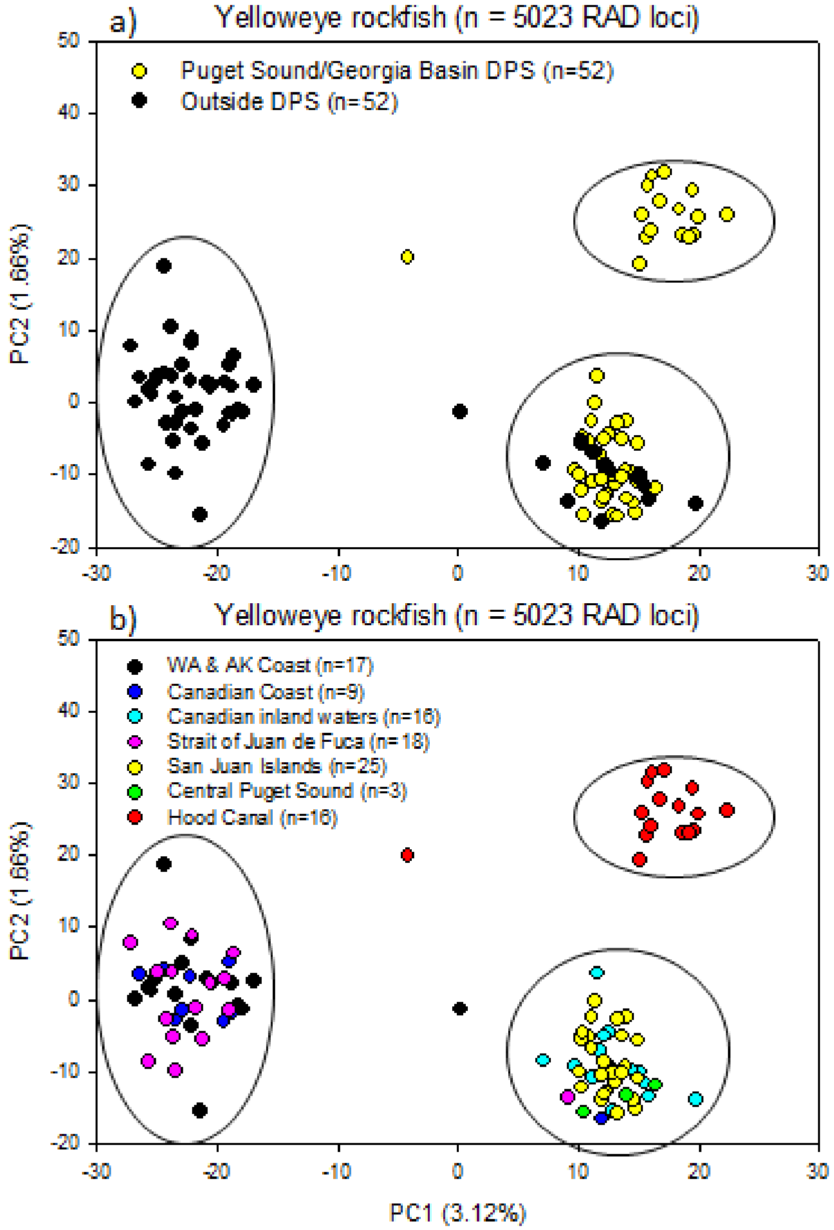


Figure 6. Three distinct clusters of yelloweye rockfish based on a principal components analysis of the genetic variation between individuals a) inside and outside the DPS and b) among specific regions (Andrews et al. in prep).

Three distinct clusters of individuals were identified and supported with three analytical methods. Results from the principal components analysis are shown in Figure 6. One cluster includes yelloweye rockfish consisting of only individuals from the outer coast, one cluster includes yelloweye rockfish consisting of only individuals from within the DPS, and one cluster includes individuals from both within and outside the DPS (Figure 6a). A closer look at the lower right cluster reveals that yelloweye rockfish from inland Canadian waters make up the majority of the “Outside DPS” individuals (cyan blue dots in Figure 6b). The yelloweye rockfish from inland Canadian waters that group with the rest of Puget Sound yelloweye extend as far north as the Johnstone Strait, which was not included in the original DPS listing as identified in Drake et al. (2010). The BRT also reviewed new microsatellite data from Fisheries and Oceans Canada (Yamanaka et al. 2006; COSEWIC 2008; Yamanaka et al. unpublished) that indicated a genetic difference between populations in this same area. In addition, yelloweye rockfish from Hood Canal were genetically differentiated from other Puget Sound/Georgia Basin fish (cluster in the upper right of Figure 6b), indicating a previously unknown degree of population differentiation within the DPS. STRUCTURE analysis also suggests that there are three populations represented in the data. Pairwise F_{ST} calculated between collections in each of these three groups were significantly different from zero, also confirming population differentiation between Puget Sound/Georgia Basin fish and those collected from coastal waters.

Canary Rockfish

The same analytical methods were used to analyze canary rockfish. These analyses indicated a lack of genetic differentiation between coastal and Puget Sound/Georgia Basin samples, as seen in the lack of distinct clusters in the principal components analysis (Figure 7). F_{ST} values, a metric of population differentiation, among groups was not significantly different from zero, and STRUCTURE analysis did not provide evidence supporting population structure in the data. These analyses all suggest there is no evidence of genetic differentiation of canary rockfish across the boundaries of the DPS.

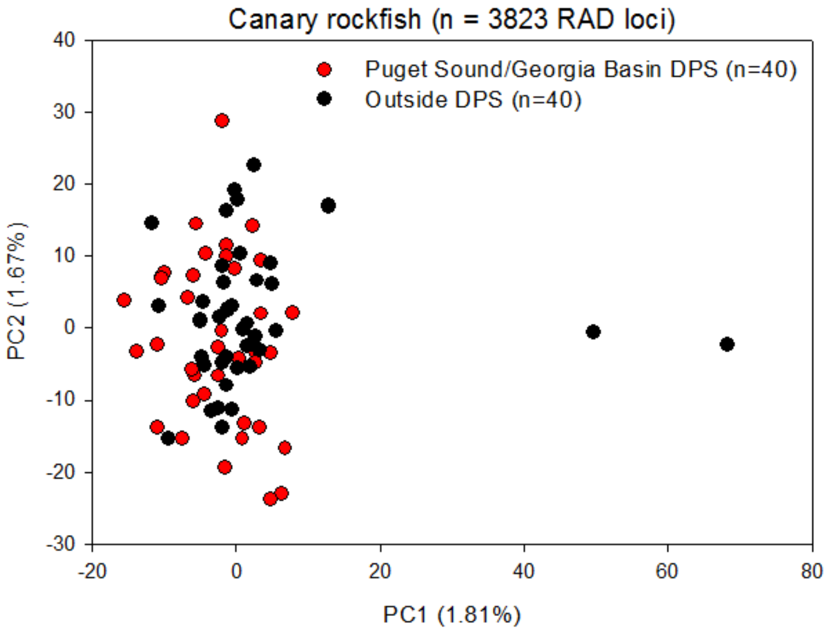


Figure 7. No distinct genetic structure observed in canary rockfish based on a principal components analysis of the genetic variation between individuals inside and outside the DPS (Andrews et al. in prep).

The BRT noted that the very large number of loci provided considerable power to detect differentiation among sample groups and concluded that the lack of such differentiation indicated that it was unlikely the Puget Sound/Georgia Basin samples were discrete from coastal areas (Ford 2015). The BRT discussed the possibility that other factors, such as oceanography and ecological differences among locations, might be sufficient to indicate a discrete population, but concluded that the lack of genetic differentiation indicated sufficient dispersal that discreteness as a result of environmental factors was not plausible.

Bocaccio

The genetic analysis for bocaccio included only two samples from within the DPS area (Figure 8). There were insufficient new data on bocaccio to update the prior status review determination that bocaccio of the Puget Sound/Georgia Basin are distinct from coastal populations (Ford 2015).

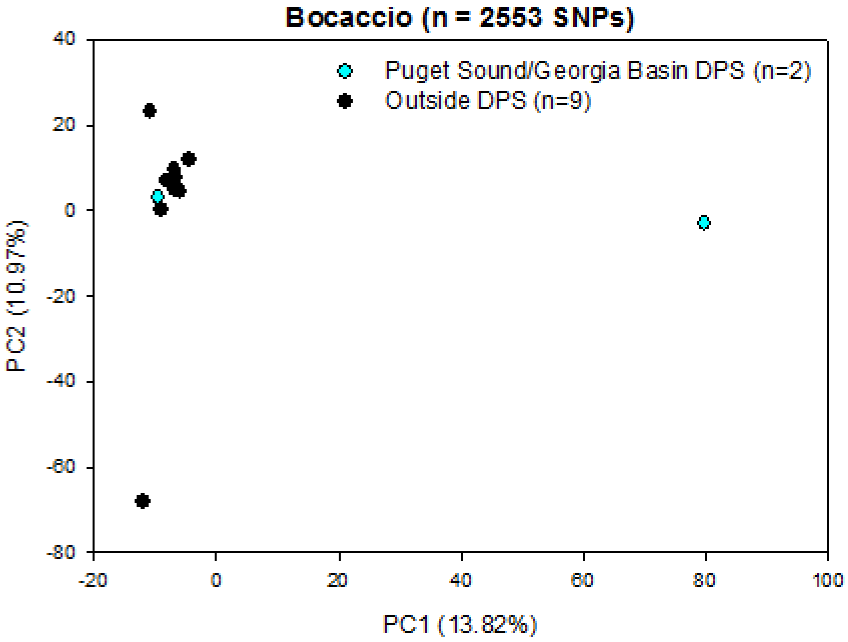


Figure 8. Insufficient sample size to determine genetic structure of bocaccio based on a principal components analysis of the genetic variation between individuals inside and outside the DPS (Andrews et al. in prep.).

The BRT noted that bocaccio have a propensity for greater adult movement than more benthic rockfish species, similar to the case for canary rockfish. There was some discussion that the lack of genetic differentiation between coastal and Puget Sound/Georgia Basin canary rockfish might suggest a similar lack of genetic differentiation for bocaccio because of similarities in the life history of the two species. However, the BRT concluded that the new information was not sufficient to change the conclusions of the previous BRT documented in Drake et al. (2010).

2.3.1.4 Taxonomic Classification or Changes in Nomenclature

There have been no changes to the taxonomic classification as recognized by the scientific community.

2.3.1.5 Spatial Distribution, Trends in Spatial Distribution (e.g., increasingly fragmented, increased numbers of corridors, etc.), or Historic Range (e.g., corrections to the historical range, change in distribution of the species within its historic range, etc.)

ROV Survey

In 2014, NMFS and the WDFW partnered to conduct a 2-year ROV survey in Puget Sound in order to provide habitat association and condition, presence/absence, and density information for listed rockfishes by: 1) observing specific known historical habitats and likely habitats of rare rockfishes; and 2) documenting habitat characteristics of these areas, including the occurrence of anthropogenic disturbances such as derelict fishing gear. Ultimately, the ROV survey will enable population estimates for yelloweye rockfish, canary rockfish, and bocaccio, as well as inform recovery planning actions.

The study design was guided by researchers at NOAA’s Alaska Fisheries Science Center, who developed a Maximum Entropy (MaxEnt) model that assigns a probability of listed rockfish occurrence to gridded cell locations throughout the Puget Sound based on water depth, bottom complexity, current speed, and slope (Elith et al. 2011). Model outputs for all three listed rockfish species were then merged, using the highest probability of occurrence for any species as the preferred value, to generate occurrence probability strata for the whole of the survey area. The WDFW then used frequency histograms to separate the 483 target sites into 60 percent high, 20 percent medium, and 20 percent low probability (Figure 9) in order to more effectively survey the available habitat. The survey has thus far resulted in sightings of 1 bocaccio, 6 canary rockfish, and 34 yelloweye rockfish. At the conclusion of the project the data will be used to develop a new habitat suitability model and to identify index sites for future repeat surveys as identified in the draft recovery plan.

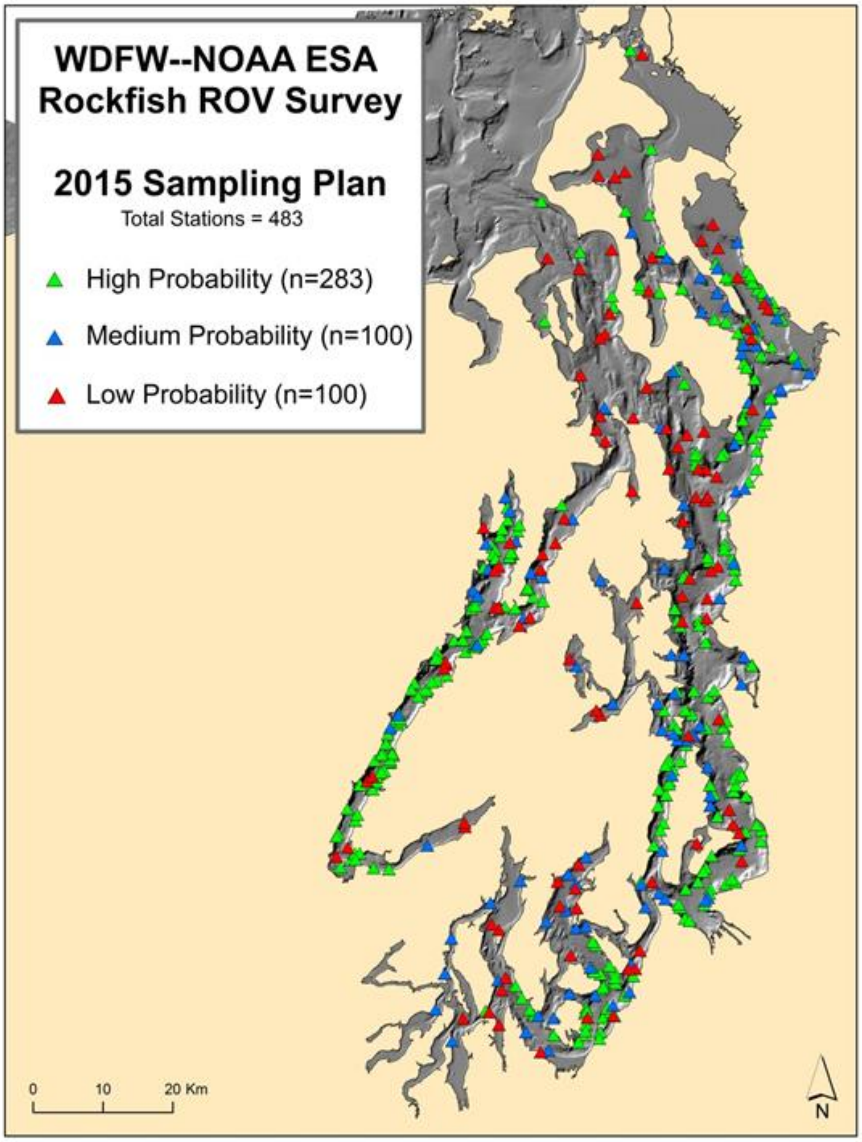


Figure 9. 2015 Rockfish ROV survey target sites.

As a result of the hook-and-line sampling and ROV surveys there is additional information on the precise locations of each species. This new location information assists in understanding contemporary rockfish habitat usage, but does not provide any insights on trends in spatial distributions or assist in understanding their historic range because of the lack of historical comparison data.

Larval Rockfish Study

In 2011 the Northwest Fisheries Science Center sampled larval rockfish at 79 sites across Puget Sound over 7 months (April to October) (Greene and Godersky 2012). The 79 sites were across the major biogeographic basins in Puget Sound. Additional sampling for larval fish was conducted at six Puget Sound Dredged Material Management Program sediment disposal sites from April 2011 through February 2012. The six disposal sites were located in deep water (range 95 to 564 feet [29 to 172 m]) and at least 0.62 miles (1 km) from any shoreline, while index sites were located in subtidal areas along shorelines at 16.4 to 131 feet (5 to 40 m) depth.

Larval fish were processed in the lab using a dissecting microscope and identified to the most detailed taxonomic level possible. Rockfish species are difficult to distinguish during the larval phase (Love et al. 2002). One listed species that can be readily identified visually at early larval stages are boccacio, because of the pronounced size and distinct pigmentation of larval pectoral fins (Matarese et al. 2011). Among the 495 rockfish identified, none were identified as boccacio. The samples provided a broad sampling of temporal and spatial patterns and provided sound conclusions on overall patterns of abundance (Figure 10).

Rockfish ichthyoplankton were commonly seen in surface waters of the sediment disposal sites. Their relative abundance (percent of total catch composed of rockfish) tended to increase over the sampling period, peaking in August or September 2011. However, when looking at actual densities, larval rockfish appeared to occur in two peaks (early spring, late summer) that coincide with the main primary production peaks in Puget Sound. Both measures indicated that rockfish ichthyoplankton essentially disappeared from the surface waters by the beginning of November. Densities also tended to be lower in the more northerly basins, compared to Central and South Sound, and rockfish larvae were practically nonexistent at the Bellingham Bay site.

The data showed some variability across oceanographic basins. Densities at disposal sites were two to ten times greater than those at index sites, which was likely the result of biological and physical differences between deepwater disposal sites and nearshore index sites. Because 2011 appeared to be a relatively cool year for which peak productivity was substantially delayed, the temporal pattern Greene and Godersky (2012) observed might be expected to shift earlier in average or warmer years. The larval rockfish abundance patterns seen likely reflect a combination of water circulation and residence time, larval movements into nearshore habitats (Palsson et al. 2009), and spatiotemporal variation in spawning among multiple species (Greene and Godersky 2012).

As part of recovery planning, a monitoring project is currently being developed to record observations of listed juvenile rockfish and their habitat around Puget Sound. Because there is little information about juvenile rockfish and their habitat, this program will contribute to the existing base of knowledge on temporal and spatial population trends, associations with habitat features, and associations with oceanic and climatic variables.

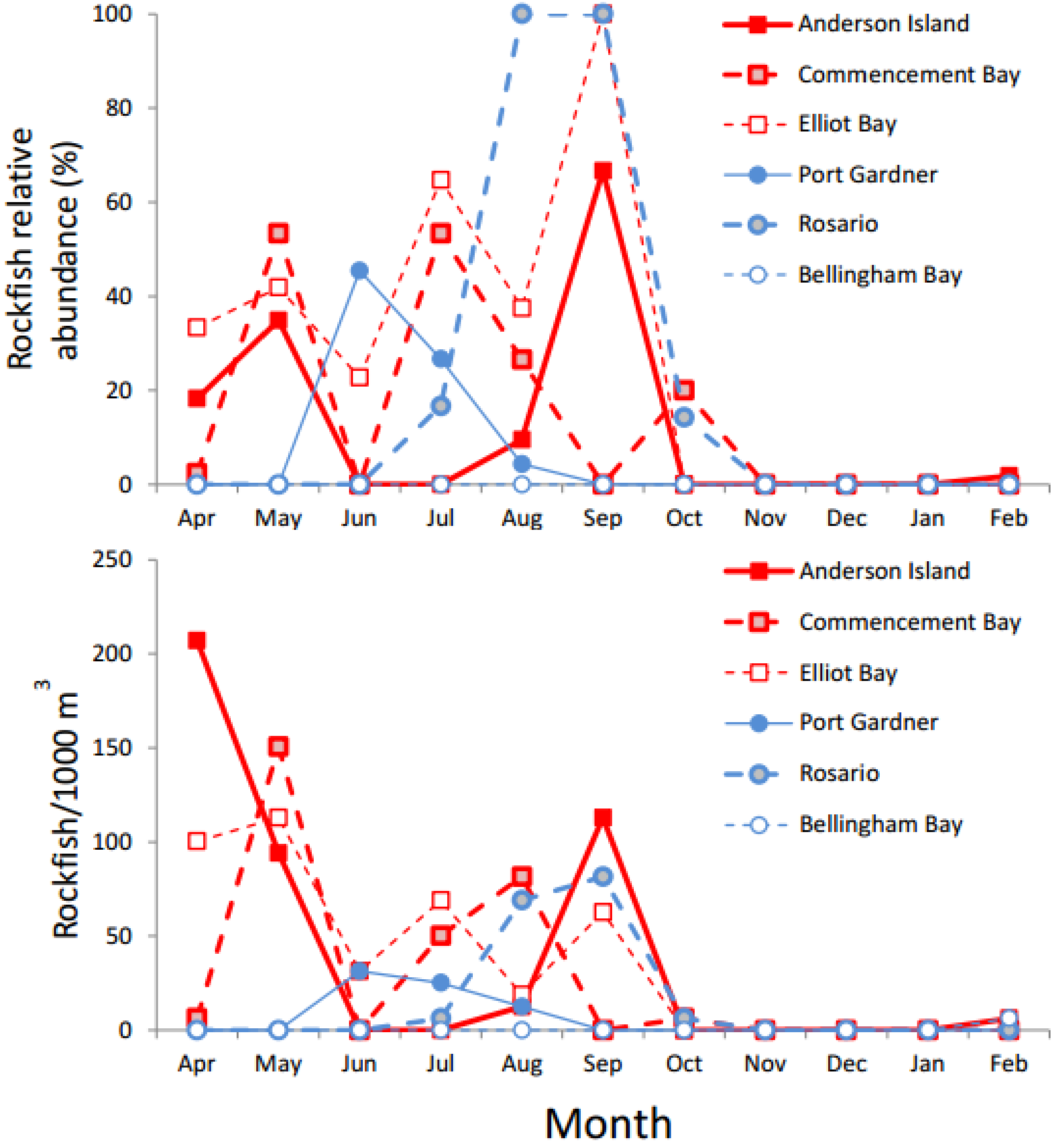


Figure 10. Relative abundance (percent of all specimens identified as rockfish) and density (rockfish larvae/1000 m^3) at the six sediment disposal sites from April 2011 through February 2012.

2.3.1.6 Habitat or Ecosystem Conditions (e.g., amount, distribution, and suitability of the habitat or ecosystem)

We summarize the known changes and new observations of the habitats of yelloweye rockfish, canary rockfish, and bocaccio in the Puget Sound/Georgia Basin in three general habitat types. They include the benthic environment (the sea floor), pelagic environment (the water column), and the nearshore (from extreme high water to 90 feet [27.4 m] deep). We then discuss the observed and potential consequences of climate change and ocean acidification.

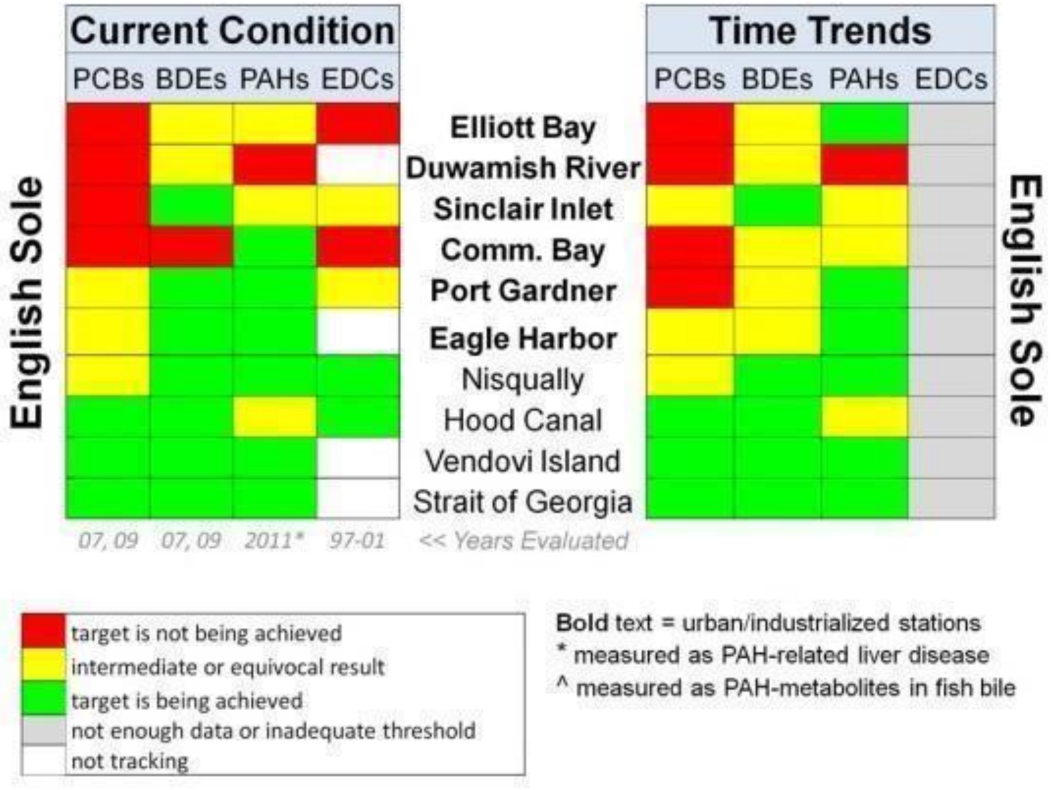
Benthic Environments

Sediment and Water Quality

Marine sediment can act as a repository by burying contaminants or it can be a source of contaminant exposure for benthic food webs. Rockfish health may be affected by sediment quality because most adult rockfish spend much of their lives on or near the benthic environment, eat invertebrates and fish that may have contaminant loads derived from contaminated sediments, and are long lived. The most contaminated sediments are centered near major urban areas in Puget Sound where industrial and domestic activities are concentrated. Organisms that live in or ingest these sediments transfer persistent toxicants up the food web to higher-level predators like rockfish, and to wider geographic areas though dispersal of both primary consumers and their predators.

In the past 5 years, there have been no new data regarding contaminant levels in yelloweye rockfish, canary rockfish, or bocaccio in the Puget Sound/Georgia Basin. However, the Washington Department of Fish and Wildlife's Puget Sound Assessment and Monitoring Program (PSAMP) has documented contaminant levels in English sole (*Parophrys vetulus*), a common bottom dwelling flatfish in Puget Sound, for decades. PSAMP uses three generalized classes of contaminants in Puget Sound: (1) persistent bioaccumulative toxics (PBTs) such as polychlorinated biphenyls (PCBs) and polybrominated diphenylethers (PBDEs), (2) polycyclic aromatic hydrocarbons (PAHs), and (3) endocrine disrupting compounds (EDCs). Fat-bonding, or lipophilic, contaminants, such as PCBs and PBDEs, can be taken up and retained by plankton, or attach to particles and settle into the bottom sediments. PBTs retained by plankton are rapidly assimilated into the food web and accumulated by pelagic consumers such as zooplankton and forage fish, and then amplified throughout the food web to higher trophic level predators like demersal rockfish (PSAT 2007). West et al. (2011) found that contaminant levels in English sole

> "*.... from four urban locations failed to meet recovery targets (or showed uncertain results) for current conditions for most of the PCBs, PBDEs, PAHs and EDCs.... English sole from two urban locations (Port Gardner and Eagle Harbor), and for non-urban locations met recovery goals or exhibited intermediate results. English sole from most urban locations showed no declining trend in PCBs and PBDEs (failed target), while most non-urban locations showed no increasing trend (met target). PAHs appear to be declining in English sole from three (and possibly five) urban locations and were low and stable in non-urban locations*" (see Figure 11).



English Sole

	Current Condition				Time Trends			
	PCBs	BDEs	PAHs	EDCs	PCBs	BDEs	PAHs	EDCs
Elliott Bay	🟥	🟨	🟨	🟥	🟥	🟨	🟩	▨
Duwamish River	🟥	🟨	🟥	⬜	🟥	🟨	🟥	▨
Sinclair Inlet	🟥	🟩	🟨	🟨	🟨	🟩	🟨	▨
Comm. Bay	🟥	🟥	🟩	🟥	🟥	🟨	🟨	▨
Port Gardner	🟨	🟩	🟩	🟨	🟥	🟨	🟩	▨
Eagle Harbor	🟨	🟩	🟩	⬜	🟨	🟨	🟩	▨
Nisqually	🟨	🟩	🟩	🟩	🟨	🟩	🟩	▨
Hood Canal	🟩	🟩	🟨	🟩	🟩	🟩	🟨	▨
Vendovi Island	🟩	🟩	🟩	⬜	🟩	🟩	🟩	▨
Strait of Georgia	🟩	🟩	🟩	⬜	🟩	🟩	🟩	▨
<< Years Evaluated	07, 09	07, 09	2011*	97-01				

English Sole

🟥	target is not being achieved
🟨	intermediate or equivocal result
🟩	target is being achieved
▨	not enough data or inadequate threshold
⬜	not tracking

Bold text = urban/industrialized stations
* measured as PAH-related liver disease
^ measured as PAH-metabolites in fish bile

Figure 11. Summary of current conditions and long-term time trends in contaminants for English sole in various regions of the greater Puget Sound, Washington. (Adapted from West et al. 2011.)

Rockfish occupy similar environments to English sole, but in contrast are a higher trophic level predator species and thus have been shown to have higher concentrations of PBTs (PSAT 2007). Trophic-level effects were evident in PCB concentrations in English sole (62 ng/g), quillback rockfish (121 ng/g), and lingcod, *Ophiodon elongates*, (270 ng/g) sampled from Elliot Bay, where English sole feed at a lower trophic level than quillback rockfish and lingcod (West and O’Neill 2012).

There are no studies to date that define precise adverse health effect thresholds for specific toxicants in any rockfish species; however, it is likely that PCBs pose a risk to rockfish health and fitness (Palsson et al. 2009). The threshold for PCBs in wild juvenile salmonids is 2.4 µg PCBs per g lipid, above which fish would be expected to exhibit some adverse health effects (e.g., altered thyroid activity, disease susceptibility, reproductive impairment, or mortality) (Meador et al. 2002). Adult male quillback rockfish sampled from Elliot Bay had higher PCB concentrations than this threshold (West and O’Neill 2012). West and O’Neill (2012) also found some male rockfish from Elliot Bay have lower growth rates than females, whereas non-urban male and female rockfish had similar growth rates and had PCB concentrations below the

Meador et al. (2002) threshold. The differences in growth rate may result from higher contaminant concentrations (West and O'Neill 2012). Contaminant-induced immunotoxicity (e.g., increased disease susceptibility) has been observed in several fish and wildlife species (Collier and Varanasi 1991; Johnson et al. 2002; and Arkoosh et al. 2010).

Finally, progress is being made in the cleaning and containment of the 31 Superfund sites in Puget Sound (Sanga 2015), of which at least 11 leaked contaminants into marine waters. Advances in the control of point-source pollution have also taken place. Environmental levels of many organochlorine residues (e.g., PCBs, dioxins, furans, organochlorine pesticides, and chlorophenols) have declined significantly during the past several decades (Gray and Tuominen 2001; Mearns 2001; Grant and Ross 2002; EVS Environmental Consultants 2003). O'Neill et al. (2011) proposed that the reductions they saw in English sole PCB concentrations in Sinclair Inlet were likely due to reduced PCB input (e.g., from contaminated sediment removal, enhanced wastewater treatment, and stormwater outfall retrofits). Despite these improvements, the presence of some chemicals (e.g., PCBs and DDE) in coastal habitats and wildlife has stabilized since the early 1990s and is not expected to decline further for decades (Calambokidis et al. 1999; Grant and Ross 2002) and environmental levels of many emerging contaminants, which are typically poorly regulated, are likely increasing.

Derelict Fishing Gear

Derelict fishing gear has been documented throughout Puget Sound and impacts numerous species and their benthic habitat (Good et al. 2010). Rockfish are thought to be among the most impacted species of fish from derelict fishing nets because nets typically are lost or accumulate in areas of rock and/or high benthic complexity that are also attractive to rockfish. Derelict fishing net removal has continued for the past 5 years largely because of two infusions of financial support. In 2009 the Northwest Straits Foundation was awarded 4.6 million dollars through the American Recovery and Reinvestment Act to support the removal of derelict fishing gear in Puget Sound. This funding resulted in a total of 2,493 nets removed, restoring an estimated 232 acres of marine habitat.

Legislation passed in 2012 (SB 5661) mandated the reporting of lost gear to the Washington Department of Fish and Wildlife (WDFW) within 24 hours of the loss. In 2013, the Washington State Legislature appropriated 3.5 million dollars to support further removal of shallow water derelict nets and the vast majority of these nets were removed by summer of 2015. Thus far, a total of 5,660 nets and 3,800 shellfish pots have been removed, improving the habitat conditions of 813 acres (see www.derelictgear.org).

Most derelict nets have been removed by divers with surface supplied air and supported by a dive vessel that can mechanically lift the nets from the surface onto the boat. All of the derelict nets removed have been from waters 105 feet (32 m) or shallower because of diver safety protocols. Nets that have been found to extend below 105 feet (32 m) are cut off and only the shallow portion of the net is removed. Several hundred derelict nets have been documented in waters deeper than 100 feet (30.5 m) deep (NRC 2014) (Figure 12). Sidescan sonar and drop camera surveys on the west side of San Juan Island conducted in 2011 identified numerous likely deepwater nets, and it is probable that further deepwater surveys would reveal additional deepwater nets (NRC 2011).

Because habitats deeper than 100 feet (30.5 m) are most readily used by adult yelloweye rockfish, canary rockfish, and bocaccio, there is an unknown but potentially significant impact from deepwater derelict gear on rockfish habitats within Puget Sound. Removal methodology for deepwater nets has been identified (NRC 2013) and subsequent testing of deepwater net removal by ROV has occurred recently. In 2013 and 2014, WDFW and NWSI applied for funding to test removal methods and begin removing deepwater derelict gear to benefit listed rockfish under NOAA’s Species Recovery Grants to States program. Neither project proposal was funded.

In 2013 NOAA funded an assessment of methods to prevent the loss of gillnets in Puget Sound salmon fisheries. The assessment included best practices to prevent net loss, actions that may require changes to contemporary fishing methods, and actions that would require changes to existing practices as well as applied research (Gibson 2013).

In addition to derelict nets, approximately 12,000 crab pots are lost annually (Antonelis et al. 2011), resulting in perhaps over 60,000 lost crab pots over the past 5 years. The loss of recreational shrimp pots was recently assessed - in 2012 and 2013, an estimated 1,340 pots were lost by recreational fishermen and the trap loss rate estimated for the recreational fishery is 2.33 percent of all traps fished (NRC 2014). Only two rockfish have been documented in removed derelict crab pots (K. Antonelis, electronic mail, NRC, December 10, 2013), but derelict shrimp pots appear to continue to “fish” and trap juvenile rockfish (NRC 2014). The number of juvenile rockfish potentially entrapped in derelict shrimp pots has not been estimated.

The effects to the benthic environment from derelict pots has not been assessed, but they appear to attract rockfish because they introduce additional structure to the sea floor.

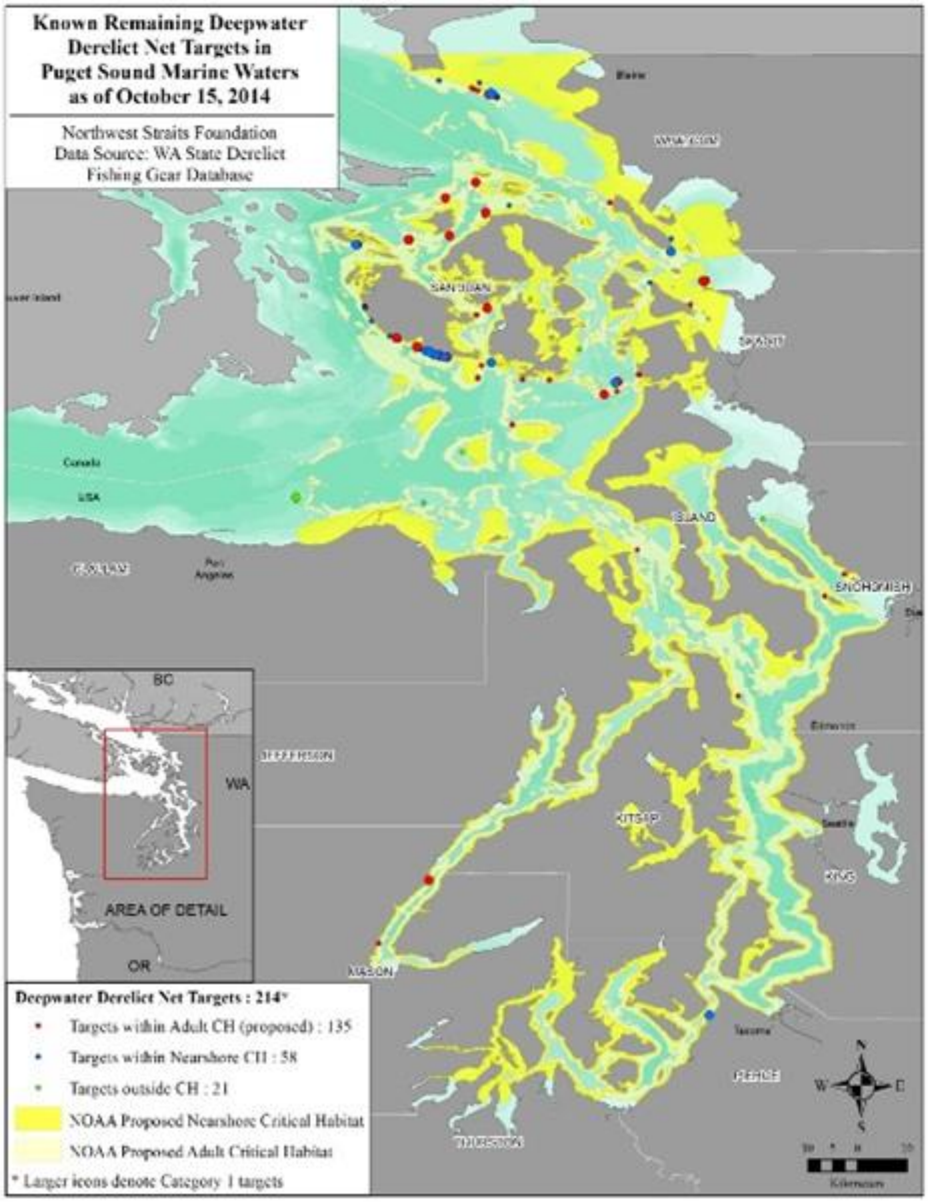


Figure 12. Location of remaining deepwater (>100 feet [30.5 m]) derelict net targets in Puget Sound as of October 2014.

Invasive and Non-indigenous Species

Invasive or non-indigenous species (NIS) are an emerging threat to biogenic habitat in Puget Sound. The effects of NIS are generally poorly understood but could pose a threat to listed rockfish habitats. In general terms, NIS may alter community dynamics, remove or degrade habitat, and are more likely to colonize stressed habitats (Bax et al. 2003; Occhipinti-Ambrogi and Savini 2003). A recent assessment of three tunicate species of concern (*S. clava*, *D. vexillum*, and *C. savignyi*) that are relatively new to the region suggests that their effects may not be as consequential as previously thought; however, their distributions and effects may not have reached full potential. The authors of the assessment therefore recommend these tunicate species remain a high priority for monitoring (Cordell et al. 2012).

Pelagic Environment

The pelagic environment is utilized by larval rockfish in the weeks to months after their birth, and by juvenile and adult canary rockfish and bocaccio because of their propensity to occasionally suspend within the water column. The suitability of the pelagic environment is influenced by species compositions and exposure to prey and predators, water quality, and other factors. We summarize several new studies of the pelagic environment of Puget Sound that have relevance to listed rockfish and their prey.

Species Compositions

An assessment of species compositions within the pelagic environment of Puget Sound reveals significant change over the past 40 years (Greene et al. 2015):

> *"...the historically dominant forage fishes (Pacific herring and surf smelt) have declined in surface waters in 2 sub-basins (Central and South Puget Sound) by up to 2 orders of magnitude. However, 2 other species (Pacific sand lance and three-spine stickleback) increased in all 4 sub-basins. Consequently, species composition diverged among sub-basins over the last 40 yr. In addition, jelly - fish-dominated catches increased 3- to 9-fold in Central and South Puget Sound, and abundance positively tracked human population density across all basins."*

The increase of jellyfish populations in Puget Sound may be attributed to their tolerance to impacted habitat conditions (Parsons and Lalli 2002; Purcell et al. 2007; Richardson et al. 2009; Rice et al. 2012; Greene et al. 2015). Because of their increased numbers they have become a competitor with rockfish for zooplankton prey (Brodeur et al. 2008, 2014) and potentially a predator consuming early life stages of forage fish and ichthyoplankton (Purcell and Arai 2001) such as larval rockfish.

Dissolved Oxygen

Portions of southern Hood Canal have episodic periods of low dissolved oxygen (DO) that have been found to kill rockfish and other fish. Rockfish move out of areas with DO less than 2 mg/l; however, in one instance when low DO waters were quickly upwelled to the surface in 2003, about 26 percent of the local rockfish population was killed (Palsson et al. 2009). The NOAA Coastal Hypoxia Research Program funded a study by the Pacific Northwest National Laboratory to collect and assess sediment cores from Hood Canal. The cores were dated and assessed for historical oxygen conditions in the Canal. The sediment cores revealed hypoxia occurred in Hood Canal before European settlement (Brandenberger et al. 2011). A subsequent report by the Environmental Protection Agency and Washington State Department of Ecology reported that there is "*...no compelling evidence that humans have caused decreasing trends in dissolved* *oxygen in Hood Canal*" (Cope and Roberts 2012). Though low DO events in Hood Canal are likely a natural occurrence, they nonetheless affect habitat suitability for listed rockfish.

Anthropogenic Noise and Vessel Traffic

Regionally, vessel traffic within Admiralty Inlet is high and is increasing (Bassett et al. 2012). Cargo ships, tugs, and passenger vessels all contribute to elevated noise levels (approximately 120 decibels or greater) (Basset et al. 2012) and may affect rockfish. A recent study of coral reef fish larvae found that noise traffic may have a disruptive effect on larvae orientation and settlement (Holles et al. 2013), which are important to finding appropriate habitat for many marine fishes, including rockfish.

There are few published studies that assess mortality from vessel traffic on fishes, but studies thus far indicate that ichthyoplankton, which could include rockfish, may be susceptible to mortality because they are unable to swim away from traffic and thus may be harmed by propellers and turbulence (Bickel et al. 2011). One study found low overall mortality from traffic, but that larvae loss was size dependent and that smaller larvae were more susceptible to mortality (Kilgore et al. 2001).

Nearshore Habitat

The nearshore is generally defined as habitats contiguous with the shoreline from extreme high water out to a depth no greater than 98 feet (30 m) relative to mean lower low water. This area generally coincides with the maximum depth of the photic zone and can contain physical or biological features essential to the conservation of many fish and invertebrate species, including juvenile canary rockfish and bocaccio. Approximately 27 percent of Puget Sound's shoreline has been modified by armoring (Simenstad et al. 2010). Nearshore 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 (Drake et al. 2010).

The alteration of Puget Sound shorelines has been found to impact a variety of marine life, ranging from invertebrate fauna (Sobocinski 2003) to surf smelt egg viability (Rice 2006), but consequences of the alteration of Puget Sound shorelines on rockfish habitat such as kelp are less understood. Some areas around Puget Sound have shown a large decrease in kelp. Areas with floating and submerged kelp (families *Chordaceae, Alariaceae*, *Lessoniacea, Costariaceae,* and *Laminaricea*) support the highest densities of most juvenile rockfish species (Matthews 1989; Halderson and Richards 1987; Carr 1983; Hayden-Spear 2006). Kelp habitat provides structure for feeding, predation refuge, and reduced currents that enable energy conservation for juveniles.

The Puget Sound Restoration Fund (PSRF), the Northwest Straits Commission, and others are currently working to restore kelp coverage at select locations in Puget Sound by developing a comprehensive restoration plan, including piloting restoration projects and monitoring. In April 2015, the PSRF was awarded a 1.5 million dollar grant from the Paul G. Allen Ocean Challenge to cultivate macroalgae at one site in Hood Canal. The goal of the 5-year study is to assess the impact of kelp restoration for extracting dissolved carbon dioxide and other excess nutrients in the water to mitigate for ocean acidification and eutrophication in Puget Sound. If successful, the restoration of kelp in Puget Sound could assist in protecting shellfish and other sensitive species from ocean acidification, which would benefit listed rockfish not only by protecting prey resources but also by supplementing habitat for juvenile life stages. Additionally, the PSRF maintains a citizen science program, named KELP WATCH, to help monitor kelp coverage in Puget Sound. Help the Kelp is a similar organization in Canada that is helping to document and restore kelp coverage in the Salish Sea. In January 2015, the Northwest Straits Commission launched the Salish Sea International Kelp Alliance to help protect and restore kelp in Washington and British Columbia. Their goals are to monitor changes in local kelp populations, foster awareness about the ecological and cultural importance of kelp, promote citizen science contributions to regional research, and provide a forum for exchanging relevant information and ideas.

Recently, the WDFW compiled information from their Hydraulic Project Approval permits from 2005 through 2014 and found that, in 2014, the amount of removed armoring along Puget Sound shorelines was greater than the amount of new armoring (Dunagan 2015) (Figure 13). This data only takes into account projects that applied for and received permits; it does not account for unpermitted projects. Nevertheless, this is a positive achievement for Puget Sound and benefits listed rockfish.

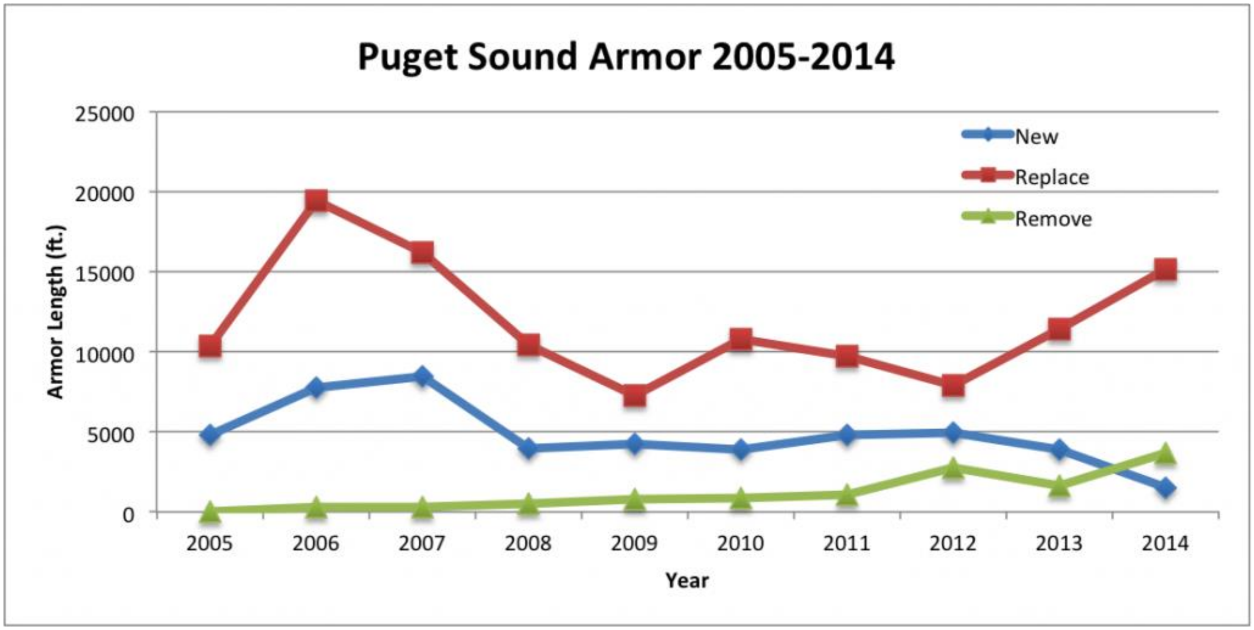


Figure 13. New, replaced, and removed Puget Sound armoring (2005-2014). (Source: Dunagan 2015)

Climate Change

Climate change can affect the benthic, pelagic, and nearshore environments of rockfish. In November 2015, the Climate Impacts Group at the University of Washington released "State of

Knowledge: Climate Change in Puget Sound" (Mauger et al. 2015). The report summarizes how climate change will likely affect the Puget Sound region by altering climate-related factors that shape the local environment. These key factors include temperature, precipitation, heavy rainfall, sea level, and ocean acidification (Mauger et al. 2015). The changes in these factors have implications for changes in freshwater resources, sediment transport, and ecosystems, and consequences for marine waters, coastal and marine ecosystems, water quality, water circulation, species distributions, and timing of biological events (Mauger et al. 2015). It is still unknown to what extent climate change or ocean acidification will affect listed rockfish.

Temperature

In all but six of the years from 1980 through 2014 the Puget Sound region warmed. In the 21st century, warming is projected to be at least double that experienced in the 20th century, and could be nearly 10 times greater. By the 2050s the average year in the Puget Sound region is projected to be 4.2° F (range: +2.9° to +5.4°) warmer under a low greenhouse gas scenario (Mauger et al. 2015). Increased temperature may be a driver of many changes in the Puget Sound ecosystem, including, but not limited to, introduction or elimination of some invasive species and diseases, increased cases and duration of harmful algal blooms, sea level rise, decreased primary production, increased stratification, and hypoxia.

Sea Level

Although rates vary by location, over the last century sea levels rose at many areas along the shorelines of Puget Sound. Sea levels are projected to continue to rise over the next century, with a wide range of possible future amounts, depending on the rate of global emissions (Mauger et al. 2015).

Species Distributions

Many species will exhibit changes, expansion, or contraction in their geographic ranges as a result of climate change (Mauger et al. 2015). Temperature, atmospheric pressure, ocean circulation, and other factors affect growth, survival, and density of rockfishes. Long-term warming could result in northerly shifts for rockfish distribution in addition to decreased larval survival and decreased maximum size and fecundity (PFMC 2011).

Water Circulation in Puget Sound

Future changes in circulation within Puget Sound are unclear, though the timing and the amount of river flows may affect the ability of Puget Sound's surface and deep waters to mix and potentially alter the dispersal of larval rockfish and distribution of nutrients. Ocean upwelling may also change but projections are not conclusive (Mauger et al. 2015).

Ocean Acidification

Because of the absorption of excess CO_2, the chemistry of the ocean along the Washington coast has already changed. The pH of the Northeast Pacific Ocean surface waters decreased by 0.1, which corresponds with a 26 percent increase in H+ concentration since the pre-industrial era and a decrease of 0.027 from 1991 to 2006. The pH of Washington's waters is projected to continue to decrease by 0.14 to 0.32 by 2100, which corresponds to an increase in H+ concentration of 32 to 109 percent (Mauger et al. 2015). These decreases in pH result in a decrease in CO_3^{2-}, which is essential for the biology and survival of a wide range of marine organisms, including important rockfish prey.

Ocean acidification is expected to adversely affect calcification for a number of marine organisms, which could alter trophic functions and the distribution of prey for a variety of marine life (Feely et al. 2010), including listed rockfish. For example, coccolithophores, some of the most abundant primary producers, will be affected and are vulnerable to dissolution (Feely et al. 2010). Fertilization rates, early development, and larval size are negatively affected by high CO_2 concentrations in a number of groups, such as sea urchins, some mollusks, and copepods (Fabry et al. 2008), which are important prey items for larval and juvenile rockfish (Love et al. 1991; Love et al. 2002).

There have been few studies on the direct effects of ocean acidification on rockfish, though Hamilton et al. (2014) found that ocean acidification affected rockfish behavior in juvenile splitnose rockfish (*Sebastes diploproa*), causing what the researchers termed "anxiety." In other fishes, there is evidence that ocean acidification could have serious consequences on behavior and sensory functions important to recruitment, settlement, prey and predator detection, and overall survival (e.g., Munday et al. 2009; Chung et al. 2014).

With funding from the Washington State Legislature and Federal investments from NOAA and the U.S. Integrated Ocean Observing System (US IOOS), the Washington Ocean Acidification Center (WOAC) has developed an expanded ocean acidification monitoring network that focuses on marine species as well as physical and chemical properties of marine waters along the Washington coast and in Puget Sound. The monitoring includes high-priority plankton species to assess effects to their shells as well as pH, pCO2, total alkalinity, dissolved inorganic carbon, oxygen, nutrients, chlorophyll, salinity, and temperature. In addition, they have been able to maintain and support three research buoys, several monitoring cruises, and improve sensor quality at nearshore, shellfish, and basin sites (Figure 14).

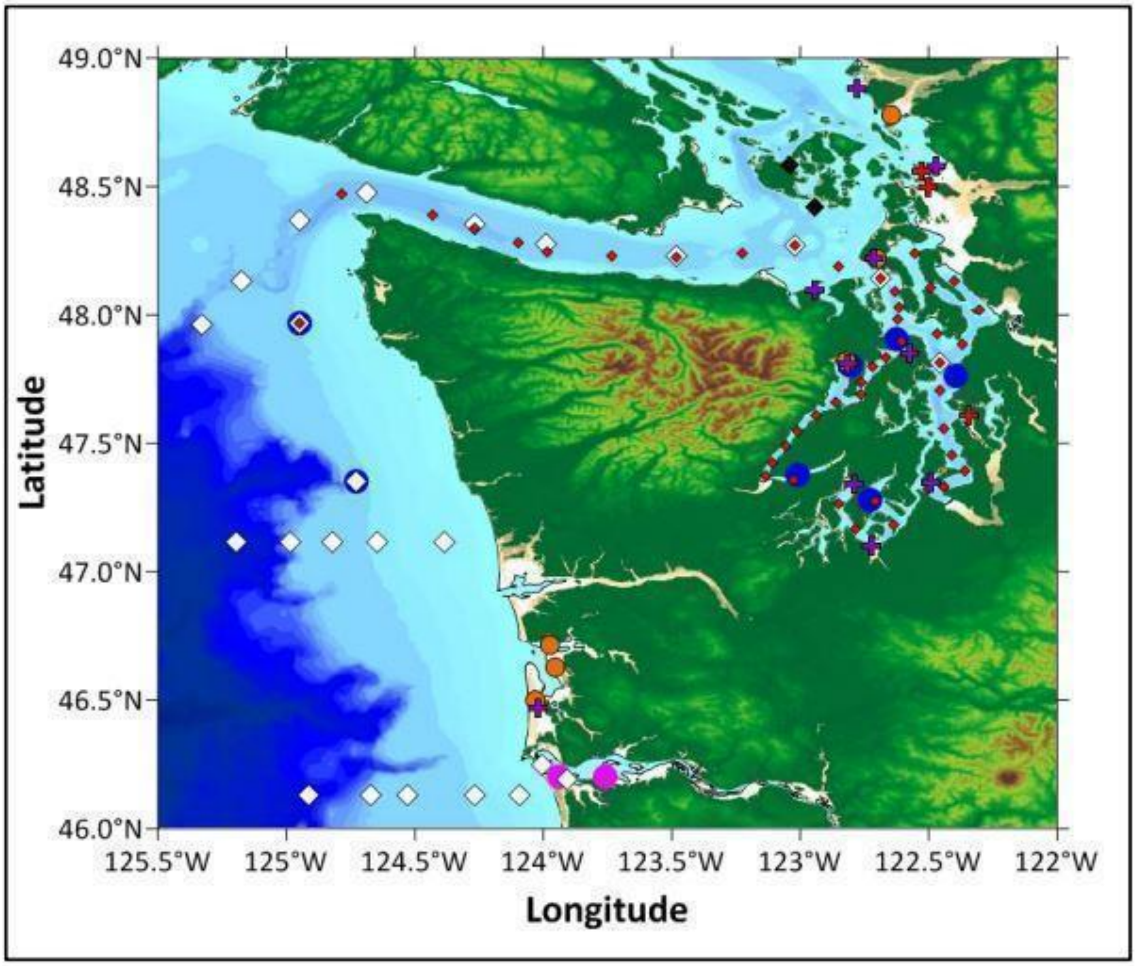


Figure 14. WOAC monitoring network. White, red, and black diamonds are ship cruise stations; blue dots are OA buoys (or soon to be); pink dots are OA moorings; orange dots are shellfish grower sites; and crosses are nearshore monitoring stations, including those of WA DNR (purple). (Excerpted from WOAC Integrated Monitoring for Ocean Acidification in Washington's Waters science information sheet 2015.)

2.3.1.7 Other: Critical Habitat

Critical habitat was designated in 2014 for each of the listed rockfish under section 4(a)(3)(A) of the ESA (79 Fed. Reg. 68041, November 13, 2014). The specific areas designated for canary rockfish and bocaccio are the same and include approximately 1,083.11 square miles (1,743.10 sq. km) of deepwater (< 98.4 feet [30 m]) and nearshore (> 98.4 feet [30 m]) marine habitat in Puget Sound. The specific areas designated for yelloweye rockfish include 438.45 square miles (705.62 sq. km) of deepwater marine habitat in Puget Sound, all of which overlap with areas designated for canary rockfish and bocaccio. Section 3(5)(A) of the ESA defines critical habitat as "(i) the specific areas within the geographical area occupied by the species, at the time it is listed . . . on which are found those physical or biological features (I) essential to the conservation of the species and (II) which may require special management considerations or protection; and (ii) specific areas outside the geographical area occupied by the species at the time it is listed . . . upon a determination by the Secretary that such areas are essential for the conservation of the species."

Critical habitat is not designated in areas outside of United States jurisdiction; therefore, although waters in Canada are part of the DPSs' ranges for all three species, critical habitat was not designated in that area. We also excluded 13 of the 14 Department of Defense Restricted Areas, Operating Areas, and Danger Zones, and waters adjacent to tribal lands from the critical habitat designation (Figure 15).

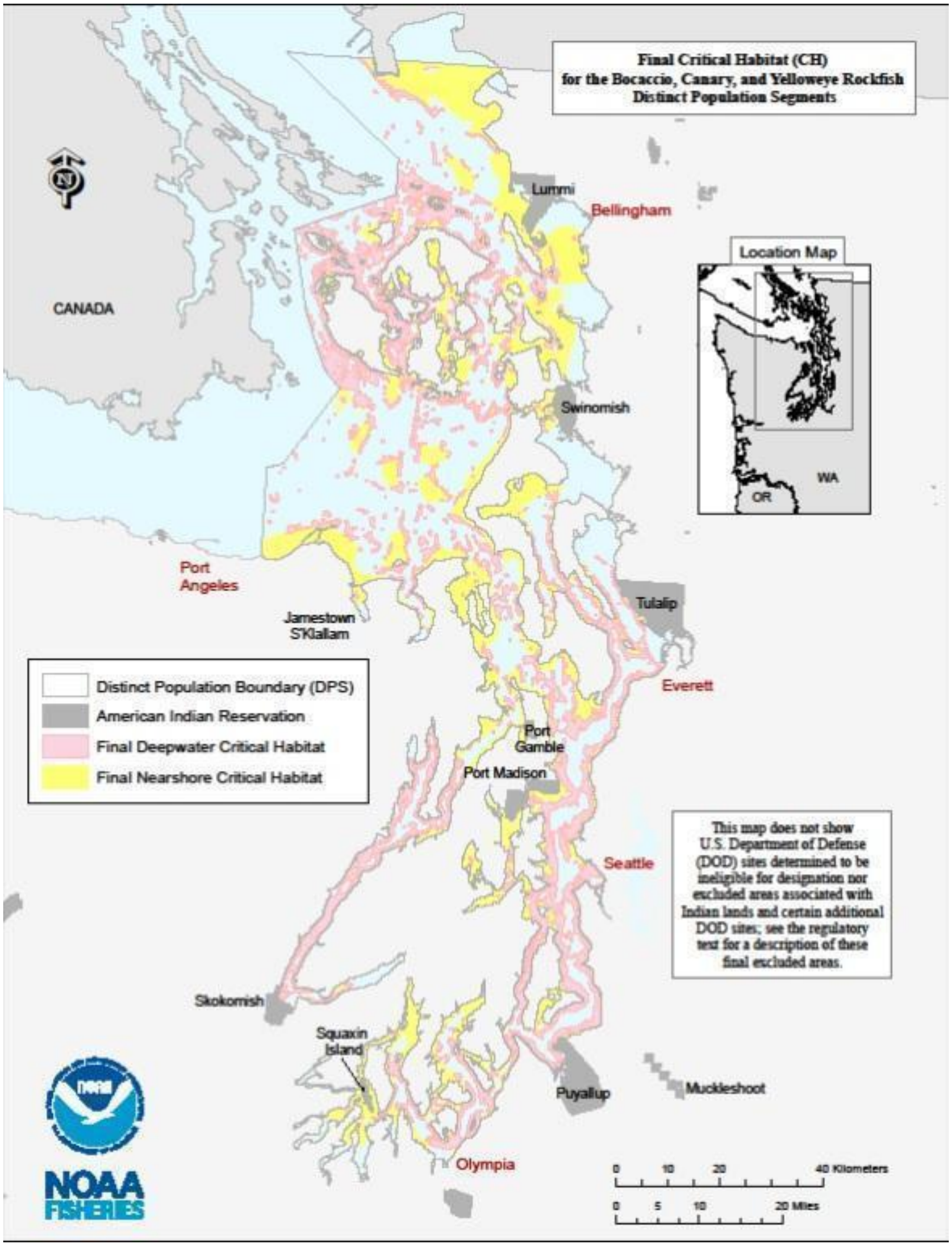


Figure 15. Critical Habitat for yelloweye rockfish, canary rockfish, and bocaccio.

Physical and Biological Features Essential for Conservation

Based on the best available scientific information regarding natural history and habitat needs, we developed a list of physical and biological features essential to the conservation of adult and juvenile yelloweye rockfish, canary rockfish, and bocaccio (Table 5), and relevant to determining whether proposed specific areas are consistent with the above regulations and the ESA section (3)(5)(A) definition of "critical habitat."

Table 5. Physical and biological features and management considerations of subadult and adult habitat for yelloweye rockfish, canary rockfish, and bocaccio, prior to exclusions.

DPS Basin	Nearshore sq. mi. (for juvenile bocaccio only)	Deepwater sq. mi. (for adult and juvenile yelloweye rockfish and adult bocaccio)	Physical or Biological Features		Activities
San Juan/ Strait of Juan de Fuca	349.4	203.6	Deepwater sites <30 meters) that support growth, survival, reproduction and feeding opportunities	Nearshore juvenile rearing sites with sand, rock and/or cobbles to support forage and refuge	1, 2, 3, 6, 9, 10, 11
Whidbey Basin	52.2	32.2			1, 2, 3, 4, 6, 9, 10, 11
Main Basin	147.4	129.2			1, 2, 3, 4, 6,7, 9, 10, 11
South Puget Sound	75.3	27.1			1, 2, 3, 4, 6,7, 9, 10, 11
Hood Canal	20.4	46.4			1, 2, 3, 6,7, 9, 10, 11

Management Considerations Codes: (1) Nearshore development and in-water construction (e.g., beach armoring, pier construction, jetty or harbor construction, pile driving construction, residential and commercial construction); (2) dredging and disposal of dredged material; (3) pollution and runoff; (4) underwater construction and operation of alternative energy hydrokinetic projects (tidal or wave energy projects) and cable laying; (5) kelp harvest; (6) fisheries; (7) non-indigenous species introduction and management; (8) artificial habitats; (9) research; (10) aquaculture; and (11) activities that lead to global climate change and ocean acidification. Commercial kelp harvest does not occur presently, but would probably be concentrated in the San Juan/Georgia Basin. Artificial habitats could be proposed to be placed in each of the Basins. Non-indigenous species introduction and management could occur in each Basin.

2.3.2 Five-Factor Analysis (threats, conservation measures, and regulatory mechanisms)

Section 4(a)(1)(B) of the ESA directs us to determine whether any species is threatened or endangered because of any of the following 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; (4) inadequacy of existing regulatory mechanisms; or (5) other natural or human-made factors affecting its continued existence. Section 4(b)(1)(A) requires us to make listing determination after conducting a review of the status of the species and taking into account efforts to protect such species. Below we discuss new information relating to each of the five factors as well as efforts being made to protect listed rockfish.

2.3.2.1 Present or Threatened Destruction, Modification or Curtailment of Its Habitat or Range

The final rule listing rockfish identified degradation of rocky habitat, loss of eelgrass and kelp, introduction of non-native species that modify habitat, and degradation of water quality as specific threats to rockfish habitat in the Georgia Basin (75 Fed. Reg. 22276, April 28, 2010). As identified in Subsection 2.3.1.6, Habitat or Ecosystem Conditions, benthic, pelagic, and nearshore listed rockfish habitat has been influenced by a number of positive and negative factors over the past 5 years.

Benthic habitats have benefited from the removal of thousands of derelict fishing nets, though deepwater derelict nets (NRC 2011) and the continued accumulation of derelict crab and shrimp pots (Antonelis et al. 2011; NRC 2013) change benthic habitats with uncertain impacts to habitat conditions. Some areas with contaminated sediments have been improved (Sanga 2015), yet pollutant loading continues, particularly in the Main Basin and the South Sound. The development of nearly one-third of the nearshore (Fresh 2011) likely continues to degrade rearing habitats, such as kelp, and prey resources for rockfish, but for the first time (2013) it appeared that more shoreline armoring has been legally removed than installed.

Recent research reveals that the pelagic environment has changed over the past several decades, with an overall decrease of some forage fish such as herring, and increases in others. Jellyfish have been found in much greater density in the Central and South Sound (Greene et al. 2015), potentially resulting in additional predation of larval rockfish. Anthropogenic noise in the pelagic environment of Admiralty Inlet appears to be increasing from vessel traffic (Bassett et al. 2012) which may impact habitat suitability for larval rockfish. Dissolved oxygen events continue in Hood Canal that impact rockfish, but contrary to previous thought, there is evidence that these events may be a natural component of Hood Canal (Brandenberger et al. 2011; Cope and Roberts 2012) that nonetheless impact listed rockfish and their prey.

Finally, climate change may fundamentally alter listed rockfish habitat within the Puget Sound/Georgia Basin. How these changes will affect listed rockfish habitat suitability are largely unknown, though it is thought that long-term ocean warming could result in species distribution changes, decreased larval survival, and decreased size and fecundity (PFMC 2011), and a recent experiment has already documented altered rockfish behavior from elevated CO_2 levels (Hamilton et al. 2014).

In summary, since the last status review (Drake et al. 2010), new data and research has enabled further quantification of the magnitude of habitat threats for rockfish habitat, in addition to the identification of threats that were not included in the status review. We have assessed the threat of climate change and ocean acidification separately and have ranked the both as a high risk threat.

2.3.2.2 Overutilization for Commercial, Recreational, Scientific, or Educational Purposes

The final rule listing rockfish identified overutilization for commercial and recreational purposes as the leading cause of decline to listed rockfish (75 Fed. Reg. 22276, April 28, 2010). We describe recent changes to fisheries management in the Puget Sound/Georgia Basin, as well as additional research regarding fisheries.

Fisheries

Washington, Non-Tribal

Since the 2010 listing, protection of rockfish from overutilization has improved in fisheries management. In 2010, the Washington State Fish and Wildlife Commission formally adopted regulations that ended the retention of all rockfish species by recreational anglers in Puget Sound and the San Juan Islands and closed fishing for bottom fish in all waters deeper than 120 feet (36.6 m). On July 28, 2010, the WDFW enacted the following package of regulations by emergency rule for the following non-tribal commercial fisheries in Puget Sound in order to protect dwindling rockfish populations:

1) Closure of the set net fishery
2) Closure of the set line fishery
3) Closure of the bottom trawl fishery
4) Closure of the inactive pelagic trawl fishery
5) Closure of the inactive bottom fish pot fishery

As a precautionary measure, the WDFW closed the above commercial fisheries westward of the listed rockfish DPSs’ boundary to Cape Flattery. The WDFW extended the closure west of the rockfish DPSs’ ranges to prevent commercial fishermen from concentrating gear in that area. Hood Canal has been closed to bottom fishing since 2002 because of the impacts of hypoxia.

The WDFW also developed a Fisheries Conservation Plan (FCP) for two fisheries with NOAA and applied for and received a 5-year incidental take permit (ITP). The FCP includes monitoring and management of the recreational bottom fish fishery and the commercial shrimp trawl fishery by the State of Washington to minimize interactions with listed rockfish. Potential bycatch in the shrimp trawl fishery is monitored by an observer program, and the State also provides estimates of rockfish bycatch in the recreational bottom fish fishery. The ITP was issued in 2012 and runs through 2017.

Recent studies from British Columbia have reported rockfish bycatch rates in actively fished prawn traps (Favaro et al. 2010, 2013; Rutherford et al. 2010). The majority of those rockfish were juveniles, and while the bycatch rates reported in British Columbia were relatively low, the large amount of fishing effort associated with spot prawn fisheries raises concern about the overall effect this bycatch posed on the rockfish populations (Favaro et al. 2010). An analysis of WDFW spot prawn test fishery data found the overall rockfish catch rates from 2004 to 2013 was 0.023 rockfish per trap (NRC 2014).

Washington, Tribal

Most tribes in the Puget Sound limit rockfish harvest to subsistence only with no targeted commercial fisheries. Perhaps the greatest threat of rockfish bycatch from tribal fisheries occurs in the commercial halibut fishery in the San Juan/Strait of Juan de Fuca area (MCA's 9, 6, and 7). Thirteen western Washington tribes possess and exercise treaty fishing rights to halibut which can result in rockfish bycatch (as does the non-treaty recreational fishery). The tribal commercial halibut fishery has increased within the DPS area in recent years (Table 6).

Table 6. Commercial halibut catch in Puget Sound waters.

	Puget Sound Tribes Halibut Data	
Year	Landings	Pounds
2009	258	61,443
2010	468	141,748
2011	501	167,118
2012	508	141,959
2013	550	150,211
Average	**457**	**132,496**

The halibut fishery was analyzed for impacts to listed rockfish under section 7(a)(2) of the ESA in 2014 (NMFS 2014). From 2009 to 2013 tribal commercial fisheries landed an average of 132,496 pounds of halibut in the Puget Sound area. Until 2014 there had not been any systematic record keeping of the non-halibut catch in the tribal halibut fishery in Puget Sound. In 2014, there were reports of six yelloweye rockfish and one canary rockfish caught in the tribal halibut fishery, though it is uncertain if all bycatch was identified. Some additional tribal fisheries have started again in recent years, including a limited bottom trawl and dogfish fishery. We have no reports regarding bycatch rates of listed rockfish from these fisheries.

Canada

Fisheries management in British Columbia, Canada (also partially overlapping with the range of the DPSs) has been altered to better conserve rockfish populations. These efforts led to the 2007 designation of a network of Rockfish Conservation Areas (RCAs) that encompass 30 percent of rockfish habitat of the inside waters of Vancouver Island (Yamanaka and Logan 2010). These reserves do not allow directed commercial or recreational harvest for any species of rockfish, or the harvest of other marine species if that harvest may incidentally catch rockfish. There are anecdotal reports that compliance with the RCAs may be poor and that some may be located in less than optimum areas of rockfish habitat (Haggarty 2013). Systematic monitoring of the RCAs may be lacking as well (Haggarty 2013). Because the RCAs are relatively new, it is uncertain how effective they have been in protecting rockfish populations (Haggarty 2013), but one analysis found that sampled RCAs in Canada had 1.6 times the number of rockfish compared to unprotected areas (Cloutier 2011).

Barotrauma

For rockfish caught in waters deeper than 60 feet (18.3 m) and released, the primary cause of injury and death is barotrauma. Barotrauma occurs when rockfish are brought up from depth, and the rapid decompression causes over-inflation and/or rupture of the swim bladder, which can result in multiple injuries, including organ torsion, stomach eversion, and exophthalmia (bulging eyes), among other damage (Parker et al. 2006; Jarvis and Lowe 2008; Pribyl et al. 2011). A number of devices have been invented and used to return rockfish to the depth of their capture as a means to mitigate barotrauma. A recent study of boat-based anglers in Puget Sound revealed that few anglers who incidentally captured rockfish released them at depth (approximately 3 percent), while a small number of anglers attempted to puncture the swim bladder (Sawchuk 2012), which could cause bacterial infections or mortality.

One recent study found that short term (48 hours) survival for recompressed yelloweye rockfish was good (80 percent or higher) at a variety of depths of capture, while canary rockfish survival dropped to 25 percent at depths greater than 443 feet (135 m) (Figure 16) (Hannah et al. 2014). However, long-term survival and productivity of rockfish released at depth with barotrauma is still uncertain and likely varies by species (Schroeder and Love 2002; Jarvis and Lowe 2008; Pribyl et al. 2009; Pribyl et al. 2011).

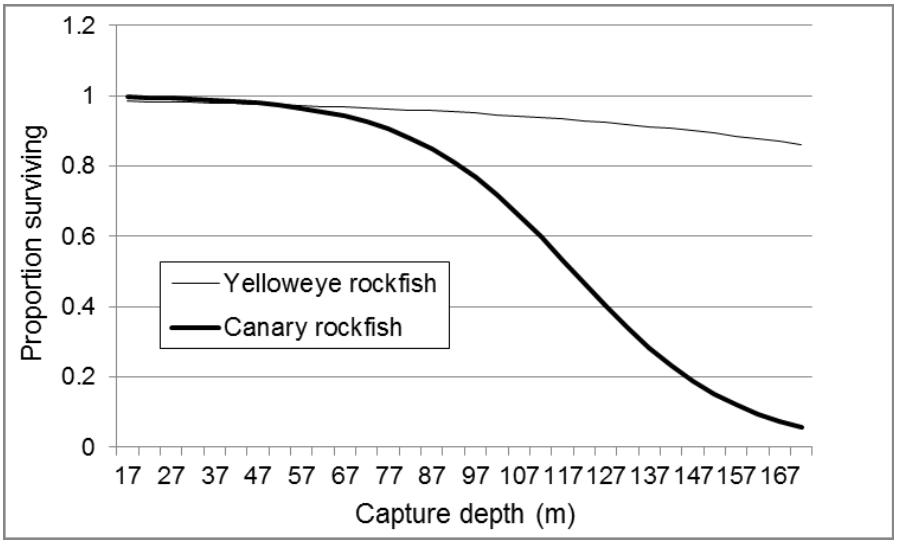


Figure 16. Fitted logistic curve of the proportion of yelloweye rockfish and canary rockfish surviving 48 hours after hook-and-line capture and recompression, as a function of capture depth (m). (Image from Hannah et al. 2014.)

The long-term productivity for rockfish after barotrauma is not well understood, but there is emerging evidence that female yelloweye rockfish can remain reproductively viable after recompression. A recent study conducted in Alaska found that recompressed female yelloweye rockfish remained reproductively viable a year or two after the event (Blain 2014) and one yelloweye rockfish in Hood Canal was observed gravid several months after barotrauma (cover photo of this review).

With evidence that recompression could be a viable way to reduce injury and increase survival of rockfish, there have been several local efforts to increase the use of descending devices. The Puget Sound Anglers (PSA) have conducted numerous education and outreach efforts to demonstrate recompression techniques to fishermen, and NOAA and WDFW have provided funding to PSA to purchase and distribute descending devices to local anglers. The PSA has distributed the devices to the saltwater fishing guides that operate in the Puget Sound area and we have distributed some descending devices to local tribal fishermen.

Scientific Research

Authorized take of listed rockfish for research in Puget Sound represents a minor component of overutilization. Scientific research and monitoring provides information necessary to determine status and trends of listed rockfish, such as the genetics study (Subsection 2.3.1.3, Genetics, Genetic Variation, or Trends in Genetic Variation) and has not been identified as a factor for decline or threat affecting recovery.

In summary, available information indicates that improvements to fisheries management have occurred since 2010. Several non-tribal fisheries with risk of bycatch have been closed, yet uncertainty remains regarding the overall sufficiency of fisheries management to support recovery. Threats from fisheries are regionally specific. For instance in South Sound basin and Hood Canal where there are fewer commercial fisheries thus less risk of rockfish bycatch compared to the San Juan area and the rest of the Puget Sound.

2.3.2.3 Disease or Predation

The final rule listing rockfish identified predation as a threat to each species, but did not quantify its relative impact (75 Fed. Reg. 22276, April 28, 2010). Rockfish are an important prey item to salmonids, birds, and lingcod, and are also eaten by marine mammals (Love et al. 2002). Several recent publications provide additional information about predation on rockfish within the Puget Sound/Georgia Basin.

Harbor seal populations were thought to be at carrying capacity in 2003 (Jeffries et al. 2003), and since the rockfish listing the local harbor seal population of the Salish Sea has apparently expanded, with an estimated 50,000 individuals within the Salish Sea (Zier and Gaydos 2014). Recent analysis of harbor seal diets in the San Juan Islands found rockfish exceeding 10 percent of the average diet of all harbor seals combined, with relatively large proportions of black rockfish (*Sebastes melanops*), yellow rockfish (*Sebastes flavidus*), copper rockfish (*Sebastes caurinis*), and Puget Sound rockfish (*Sebastes empaeus*). No listed rockfish were found in seal diets (Bromaghin et al. 2013).

New information about coastal river otter (*Lontra canadensis*) diets has been published (Buzzell et al. 2014). Coastal river otters are a ubiquitous marine mammal in local waters and one analysis found rockfish (not identified to species) were present in 2.7 percent to 21.9 percent of their scat in the San Juan Islands area. River otter scat sampled near San Juan Island itself showed an increasing proportion of consumption of rockfish (7.2 percent in 1999 to 21.9 percent in 2008) (Buzzel et al. 2014). Juvenile rockfish occurred more frequently than adult rockfish in their diets. Adult listed rockfish inhabit depths that surpass the diving capacity of river otters, but juveniles could be susceptible to river otters as they inhabit nearshore and shallower depths (Buzzel et al. 2014).

Larval rockfish are perhaps the most vulnerable life-stage for predation because of their small size, relative inability to swim at rapid speeds, abundance, and use of the open-water environment. Larval rockfish have been found to be an important component of juvenile Chinook salmon (*Oncoryhynchus kisutch*) and coho salmon (*Oncoryhynchus tshawytscha*) diets off the Pacific coast outside of the DPSs' ranges (Daly et al. 2013). Conversely, larval rockfish were found to be virtually non-existent in juvenile chum salmon (*Oncoryhynchus keta*) and Chinook salmon diets in Puget Sound in 2011 (Randall 2015, unpublished data), which is perhaps indicative of a drastically reduced abundance of this life stage in local waters.

We are not aware of new information related to rockfish disease and parasites. Rockfish are susceptible to diseases and parasites (Love et al., 2002), but the extent and population consequences of disease and parasite impacts on the yelloweye rockfish, canary rockfish, and bocaccio DPSs are not known at this time. Stress associated with poor sediment and water quality may exacerbate the incidence and severity of naturally occurring diseases to the point of directly or indirectly decreasing survivorship of listed rockfish.

In summary, quantifying the threat of predation and especially disease to listed rockfish is challenging. Similarly to the original status review (Drake et al. 2010), we have quantified the disease threat as unknown.

2.3.2.4 Inadequacy of Existing Regulatory Mechanisms

The final rule listing rockfish extensively discussed the pertinent history of fishery management in Puget Sound and its impact on rockfish depletion (75 Fed. Reg. 22276, April 28, 2010). As discussed in Subsection 2.3.2.2, Overutilization for Commercial, Recreational, Scientific, or Educational Purposes, fisheries management has improved as a result of several closures and monitoring, but uncertainties remain regarding the overall sufficiency of fishery management to support rockfish recovery. For instance, identifying and quantifying rockfish bycatch is difficult because of largely inaccurate species identification by anglers in Puget Sound (Beaudreau et al. 2011; Sawchuk et al. 2015), and compliance with existing RCAs in Canada is uncertain (Haggarty 2013).

Aside from fishery management, the final rule listing rockfish stated that "*Current protective measures for habitat in the Puget Sound region are not yet sufficient to ameliorate the threats to these species as evidenced by continuing water quality and nearshore and benthic habitat degradation*" (75 Fed. Reg. 22276, April 28, 2010). Since the listing, there is evidence of some improvements in marine habitat protection that may reflect some improved regulatory measures and their implementation. These include the continued clean-up of contaminated sediments (Subsection 2.3.1.6, Habitat or Ecosystem Conditions) and, for the first time, evidence of a net removal of shoreline armoring along Puget Sound (Dunagan 2015). However, derelict crab pots and shrimp pots continue to accumulate.

Marine habitats are influenced by local government. Under the 1971 Shoreline Management Act (SMA) and the 1990 Growth Management Act (GMA), in Washington State most cities and counties are required to develop and periodically update local comprehensive plans and development regulations and requirements to manage overall growth and shoreline-specific development in a manner that protects critical areas and natural resource lands. Cities and counties with shorelines of the state must prepare and adopt a Shoreline Master Program (SMP) that is essentially a shoreline-specific comprehensive plan, zoning ordinance, and development permit system approved by the State and implemented by the local government. Both statutes have been modified a number of times since enactment, and integrated in 2003 for cities and counties planning under both acts. There are 113 local governments with SMPs in the Puget Sound region. As of October 2015, 87 SMPs have been completed, 8 are in review, and 18 are past due. The adequacy of the existing SMPs for marine habitats and listed rockfish has not been determined.

As discussed in Subsection 2.3.1.7, Other: Critical Habitat, critical habitat was designated for each of the listed rockfish in 2014 under section 4(a)(3)(A) of the ESA (79 Fed. Reg. 68041, November 13, 2014) that includes approximately 1,083.11 square miles (1,743.10 sq. km) of deep water (< 98.4 feet [30 m]) and nearshore (> 98.4 feet [30 m]) marine habitat in Puget Sound for canary rockfish and bocaccio. The specific areas designated for yelloweye rockfish include 438.45 square miles (705.62 sq. km).

In summary, despite some improvements in management, fisheries bycatch and habitat and water quality degradation still remain threats to listed rockfish.

2.3.2.5 Other Natural or Manmade Factors Affecting Its Continued Existence

The final rule listing rockfish discussed a number of natural or man-made factors affecting their continued existence. They include intraspecific and interspecific competition, derelict fishing gear, and climate change (75 Fed. Reg. 22276, April 28, 2010). These particular factors have been addressed in Subsection 2.3.1.6, Habitat or Ecosystem Conditions, and no additional threats have been identified since the listing.

2.4 Synthesis

In 2010 we determined that populations of yelloweye rockfish, canary rockfish, and bocaccio in the Puget Sound/Georgia Basin are a “species” under the ESA, as they met the biological criteria to be considered a distinct population segment (DPS) as defined by the joint U.S. Fish and Wildlife Service (USFWS)-NMFS interagency policy of 1996 on vertebrate distinct population segments under the ESA (USFWS-NMFS 1996). We made this determination based on best available information related to rockfish life history and genetic variation among other populations of rockfish with similar life-history and the environmental and ecological features of Puget Sound/Georgia Basin, though noted “*Considerable uncertainty characterizes all of the DPS designations due to limited genetic and demographic information available for the species in question*” (Drake et al. 2010).

In 2014 and 2015 we collected genetic information from listed rockfish within a cooperative research project (see Subsection 2.3.1.3, Genetics, Genetic Variation, or Trends in Genetic Variation). The rockfish BRT reconvened in late 2015 to consider the implications of the new genetic information. The BRT was tasked with determining whether the new genetic information changed previous conclusions that yelloweye rockfish, canary rockfish, or bocaccio in Puget Sound/Georgia Basin are discrete and significant in accordance with the DPS policy (Appendix B).

The joint interagency policy on vertebrate populations (USFWS-NMFS 1996) provides guidance on what constitutes a DPS. To be considered “distinct,” a population, or group of populations, must be “discrete” from the remainder of the taxon to which it belongs and “significant” to the taxon to which it belongs as a whole. Discreteness is 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 (emphasis added).

Canary Rockfish

As discussed in Subsection 2.3.1.3, Genetics, Genetic Variation, or Trends in Genetic Variation, new genetic data for canary rockfish in the Puget Sound/Georgia Basin provides strong evidence that they are not discrete from coastal fish (Ford 2015). Because they are not discrete, in accordance with the DPS policy, we have determined that they no longer meet the criteria to be considered a DPS. New genetic data reveals that canary rockfish of the Puget Sound/Georgia Basin are part of the larger population occupying the Pacific Coast. Canary rockfish were declared overfished in 2000 and a rebuilding plan was put in place in 2001. The Pacific Fishery Management Council determined the population to be “rebuilt” under the Magnuson-Stevens Fishery Conservation Act in 2015 (Thorson and Wetzel 2015). Therefore, we recommend that the Puget Sound/Georgia Basin canary rockfish be declassified as a DPS and therefore delisted. We will proceed with a proposed rule to declassify and delist Puget Sound/Georgia Basin canary rockfish which will go out for public comment.

Yelloweye Rockfish and Bocaccio

New genetic information for yelloweye rockfish is consistent with and further supports the existence of a Puget Sound/Georgia Basin population of that is discrete from the coastal population. The new genetic information indicates that the yelloweye rockfish DPS should include areas in the Queen Charlotte Channel near Malcolm Island rather than the current DPS definition, which only includes yelloweye rockfish within the northern Strait of Georgia boundary (Ford 2015). There is insufficient new data on bocaccio to update the prior status review determination that bocaccio of the Puget Sound/Georgia Basin are distinct from coastal fish. Therefore the original conclusion that Puget Sound/Georgia Basin bocaccio meet the definition of a DPS should remain unchanged (Ford 2015).

We now consider whether the listing status of the Puget Sound/Georgia Basin yelloweye rockfish and bocaccio DPSs should be changed. The ESA defines an endangered species as one that is in danger of extinction throughout all or a significant portion of its range, and a threatened species as one that is likely to become an endangered species in the foreseeable future throughout all or a significant portion of its range. Under ESA section 4(c)(2), we must review the listing classification of all listed species at least once every 5 years. While conducting these reviews, we apply the provisions of ESA section 4(a)(1) and NMFS' implementing regulations at 50 CFR part 424. To determine if a reclassification is warranted, we review the status of the species and evaluate the five factors, as identified in ESA section 4(a)(1): (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; (4) inadequacy of existing regulatory mechanisms; and (5) other natural or man-made factors affecting a species' continued existence. We then make a determination based solely on the best available scientific and commercial information, taking into account efforts by states and foreign governments to protect the species.

Our analysis of the ESA section 4(a)(1) factors indicates that the collective risk to yelloweye rockfish and bocaccio of the Puget Sound/Georgia Basin's persistence has not changed significantly since our final listing determinations in 2010. Since we do not have sufficient data on trends for listed rockfish only, we assessed available data from recreational fisheries and scuba divers reports for all rockfish species. The growth rate (*u*) for the total rockfish (all species) trend was found to be -3.1 to -3.8 percent per year and the listed rockfish declined as a proportion of the assemblage in both the recreational and REEF surveys. Therefore, growth rate (*u*) for the listed rockfish species was likely lower (more negative) than that for total rockfish.

Improvements have been made to some habitat conditions from the removal of thousands of derelict nets and several thousand crab pots. Fisheries management has improved with closures of several fisheries that had risk of bycatch, and the 120 foot (36.6 m) depth restriction for anglers targeting bottom fish and the designation of RCAs in Canada. Conversely, new derelict crab pots and shrimp pots continue to alter benthic habitat conditions, and nearshore development likely hampers rearing habitats and production of food (such as surf smelt). Contaminant loading occurs largely from stormwater runoff and other non-point sources. Many more habitat improvements, such as the restoration of overstory kelp communities and removal of derelict fishing gear, are likely needed to achieve viability, particularly in the most impaired basins of the Central and South Sound. Some existing regulatory mechanisms could be improved to better protect Puget Sound and rockfish habitat, including shoreline management and fisheries management. In addition, impacts that climate change and ocean acidification pose to long-term recovery remain a concern.

After considering the biological viability of ESA-listed rockfish and the current status of the ESA section 4(a)(1) factors, we conclude that the status of the Puget Sound/Georgia Basin yelloweye rockfish and bocaccio DPSs has not improved significantly since they were listed in 2010. By continuing to implement actions that address the factors that limit population survival and monitoring the effects of these actions over time, we will be more likely ensure that restoration efforts meet the biological needs of each population and, in turn, contribute to the recovery of these DPSs. After completion, the listed rockfish recovery plan will be the primary guide for identifying future actions to target and address rockfish limiting factors and threats.

3 Results

3.1 Recommended Classification

The Puget Sound/Georgia Basin population of canary rockfish no longer meet the definition of a DPS and should therefore be delisted.

No change is needed in the classification of Puget Sound/Georgia Basin yelloweye rockfish DPS as threatened or in the classification of the Puget Sound/Georgia Basin bocaccio DPS as endangered.

3.2 New Recovery Number

No changes.

4 Recommendations for Future Actions

As stated in Subsection 2.4, Synthesis, the listed rockfish recovery plan will be the primary guide for identifying future actions to target and address limiting factors and threats. The recovery plan is not yet complete, but will be available before the next five-year review. Finalizing the plan and implementing priority recovery actions are the primary recommendations for future action. Actions stemming from this review and development of the draft recovery plan that would assist in improving the status of and available information generally includes:

Fisheries

- Continued actions to reduce bycatch of listed rockfish including increased bycatch avoidance, use of descending devices to improve survival after barotrauma, and increased knowledge of the actual bycatch rates.
- Education and outreach to increase angler awareness of fisheries regulations, knowledge of rockfish life history and improve species identification.

Habitat

- Protection and restoration of nearshore habitat through removal of shoreline armoring and protecting and increasing kelp coverage.
- Research on the effects of noise, contaminants, ocean acidification, and climate change on mortality, productivity, and behavior of listed rockfish.
- Protection and restoration of benthic habitat areas by actions such as cleaning up contaminated sediments, and prevention and removal of derelict fishing gear.
- Improved benthic habitat mapping and habitat characterization.

Population Research Monitoring and Evaluation

- Assess genetic structure of bocaccio and home range. Improve knowledge of habitat use, locations, etc.
- Estimate historic biomass to support delisting and downlisting decisions.
- Fishery-independent population abundance and spatial structure surveys.
- Surveys to assess long-term survival and productivity after barotrauma.

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NATIONAL MARINE FISHERIES SERVICE
5-YEAR REVIEW

Yelloweye rockfish (Sebastes ruberrimus), canary rockfish (Sebastes pinniger), and bocaccio (Sebastes paucispinis) of the Puget Sound/Georgia Basin

Current Classification: Yelloweye rockfish, canary rockfish – threatened
Bocaccio - endangered

Recommendation resulting from the 5-Year Review

Yelloweye rockfish	____ Downlist to Threatened ____ Uplist to Endangered ____ Delist __x__ No change is needed
Canary rockfish	____ Downlist to Threatened ____ Uplist to Endangered __x__Delist ____ No change is needed

Bocaccio	____ Downlist to Threatened ____ Uplist to Endangered ____ Delist __x_No change is needed

Review Conducted By: National Marine Fisheries Service, West Coast Regional Office

REGIONAL OFFICE APPROVAL:

Assistant Regional Administrator, NOAA Fisheries

Approve: Chris E Yates Date: _May 5, 2016____

Chris Yates
Protected Resources Division
West Coast Region
NOAA Fisheries

6 Appendices

Appendix A. Data and statistical analyses for abundance, population trends (e.g., increasing, decreasing, stable), demographic features (e.g., age structure, sex ratio, family size, birth rate, age at mortality, mortality rate, etc.), or demographic trends

The Data

The data reviewed to estimate population trends for the 5-year ESA Review are summarized below. The 2010 BRT report relied on three primary data sources for trend analyses: recreational fishery survey data, REEF scuba surveys, and the WDFW trawl survey.

For this 5-year Review, each time-series was updated by extending the time-series from 2007 (end date of original analysis) to 2014 (currently available data). The present analyses also consider the population trends in greater spatial detail than in the 2010 analysis. The 2010 analysis divided the United States waters into North Puget Sound (NPS) and Puget Sound Proper (PSP) (Figure A1), and the time-series were averaged for these areas prior to analysis. Here, we use separate time-series for each of the nine Marine Catch Areas (MCAs) to examine population trends in more spatial detail. We also estimate trends for Greater Puget Sound (GPS, areas 5 to 13). Finally, MCA 5 and much of MCA 6 were included in the 2010 BRT analysis but are outside the consensus DPS for the three listed species. It is relevant to determine whether excluding data from areas 5 and 6 affects the trend analysis.

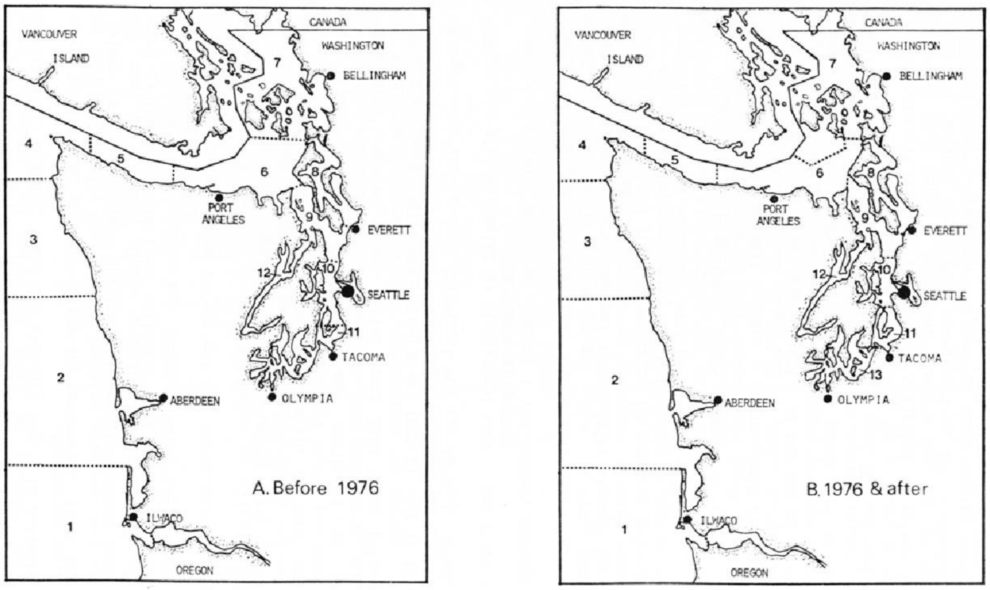

Figure A1. Marine Catch Areas (MCAs) for WDFW recreational catch data. Data from North Puget Sound (5 to 7) and Puget Sound Proper (8 to 13) are used in the analyses. (Reprinted from Palsson 1988.)

Recreational Fishery Survey Data

Surveys of recreational anglers conducted by the Washington Department of Fish and Wildlife (WDFW) are the main data source for population trends of Puget Sound rockfish. Data for 1965 through 2007 were taken from Buckley (1967), Buckley (1968), Buckley (1970), Bargmann (1977), Palsson (1988), and Palsson et al. (2009). Data for 2008 through 2014 were provided by WDFW directly (courtesy of Eric Kraig, February 18, 2015). The 2010 analyses evaluated recreational catch data for 1965 through 2007. The current analyses add data for 2008 through 2014.

Data used for the 2010 analyses were catch per angler effort (CPUE) summarized by two Puget Sound regions NPS and PSP. In the present analyses, annual estimates were recalculated by MCA (Figure A2) to give finer spatial detail in the analysis of population trends. While some data exist for 1967 through 1973, these are not available by MCA, but only by region (NPS and PSP). We have, therefore, excluded the 1967 through 1973 data from the current analyses.

Early WDFW recreational catch data were collected from punch cards sent in by licensed anglers and from dockside surveys. Since 2004, estimates of bottom fishing have come from two surveys: a creel survey to determine catch rate and species composition and a phone survey of licensed anglers to estimate overall effort.

Palsson et al. (2009) and Drake et al. (2010) discuss the limitations of the recreational catch data. For example, total catch was estimated using data from the salmon fishery from 1994 through 2003, and there have been several changes in the recreational fishing regulations for rockfish. Regulatory changes, such as the reduction in bag limits and the imposition of a 120-foot (36.6 m) maximum bottom depth for bottom fishing, likely caped angler CPUE and promoted angler targeting that led to a drop in rockfish CPUE from one regulatory period to the next. To correct for these effects, the trend analyses treat each regulatory period as a separate data set and an estimated scaling parameter adjusts the mean for each period. This process is described more fully in the data analysis section. Data for MCAs 5 through 13 are shown in Figure A2, and in Table A1 (MCA 5 to 7, NPS) and Table A2 (MCA 8 to 13, PSP).

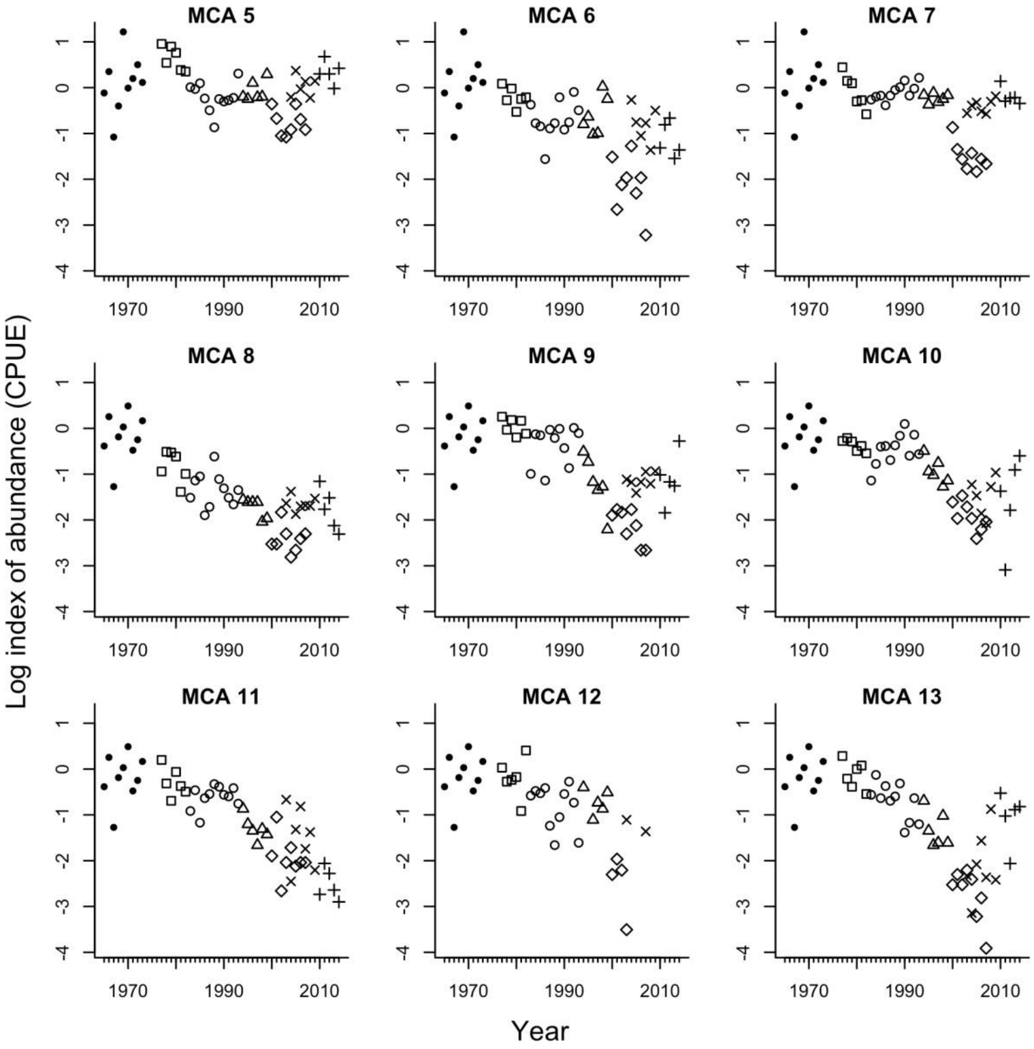

Figure A2. Log index of abundance for catch per angler effort (CPUE) for total rockfishes in nine Marine Catch Areas in Puget Sound. Symbols represent different data sources and regulatory periods for the recreational fishery.

Table A1. Recreational fishery data in catch per angler effort (CPUE) for total rockfish North Puget Sound: Washington Marine Conservation Areas (MCA) 5 to 7 for 1965 through 2014. Data are annual CPUE for the MCA.

	Buckley & Bargmann	Palsson et al. 2009	2014 Download	Palsson et al. 2009	2014 Download	Palsson et al. 2009	2014 Download
Year	North	MCA 5	MCA 5	MCA 6	MCA 6	MCA 7	MCA 7
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		2.60		1.09		1.56	
1978		1.72		0.76		1.16	
1979		2.45		0.98		1.10	
1980		2.14		0.59		0.74	
1981		1.47		0.78		0.76	
1982		1.42		0.81		0.56	
1983		1.01		0.69		0.77	
1984		0.97		0.46		0.82	
1985		1.10		0.43		0.84	
1986		0.79		0.21		0.68	
1987		0.61		0.41		0.84	
1988		0.42		0.46		0.95	
1989		0.78		0.81		1.01	
1990		0.74		0.40		1.17	
1991		0.76		0.47		0.84	
1992		0.80		0.91		0.98	
1993		1.36		0.61		1.24	
1994		0.82		0.45		0.85	
1995		0.78		0.53		0.69	
1996		1.11		0.36		0.89	
1997		0.81		0.37		0.73	
1998		0.82		1.02		0.78	

Table A1 continued. Recreational fishery data in catch per angler effort (CPUE) for total rockfish North Puget Sound: Washington Marine Conservation Areas (MCA) 5 to 7 for 1965 through 2014. Data are annual CPUE for the MCA.

1999	1.34		0.78		0.85	
2000	0.70		0.22		0.42	
2001	0.51		0.07		0.26	
2002	0.35		0.12		0.21	
2003	0.34		0.14		0.17	
2004	0.40	0.82	0.28	0.77	0.24	
2005	0.70	1.45	0.10	0.47	0.16	
2006	0.50	0.97	0.14	0.35	0.21	
2007	0.40	1.14	0.04	0.46	0.19	
2008		0.80		0.26		0.74
2009		1.16		0.61		0.83
2010		1.35		0.27		1.15
2011		1.97		0.45		0.74
2012		1.35		0.51		0.80
2013		0.98		0.21		0.81
2014		1.53		0.26		0.71

Table A2. Recreational fishery data in catch per angler effort (CPUE) for total rockfish in Puget Sound Proper: Washington Marine Conservation Areas (MCA) 8 to 13 for 1965 through 2014. Data are annual CPUE for the MCA.

		Palsson et al. 2009	2014 Download	Palsson et al. 2009	2014 Download	Palsson et al. 2009	2014 Download	Palsson et al. 2009	2014 Download	Palsson et al. 2009	2014 Download	Palsson et al. 2009	2014 Download
Year	South	MCA8	MCA8	MCA9	MCA9	MCA10	MCA10	MCA11	MCA11	MCA12	MCA12	MCA13	MCA13
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		0.39		1.29		0.76		1.22		1.03		1.33	
1978		0.60		0.97		0.81		0.73		0.76		0.81	
1979		0.59		1.20		0.75		0.50		0.79		0.68	
1980		0.54		0.82		0.61		0.94		0.84		1.00	
1981		0.25		1.18		0.68		0.69		0.40		1.08	
1982		0.37		0.89		0.58		0.61		1.50		0.58	
1983		0.22		0.37		0.32		0.40		0.56		0.57	
1984		0.32		0.88		0.46		0.63		0.62		0.88	
1985		0.35		0.86		0.67		0.31		0.59		0.53	

Table A2 continued. Recreational fishery data in catch per angler effort (CPUE) for total rockfish in Puget Sound Proper: Washington Marine Conservation Areas (MCA) 8 to 13 for 1965 through 2014. Data are annual CPUE for the MCA.

1986	0.15		0.32		0.68		0.53		0.66		0.69	
1987	0.18		0.97		0.50		0.58		0.29		0.50	
1988	0.54		0.81		0.69		0.72		0.19		0.55	
1989	0.33		0.99		0.85		0.68		0.35		0.73	
1990	0.27		0.65		1.10		0.57		0.58		0.25	
1991	0.22		0.42		0.55		0.55		0.76		0.31	
1992	0.19		1.01		0.87		0.66		0.48		0.53	
1993	0.26		0.90		0.57		0.47		0.20		0.30	
1994	0.21		0.60		0.61		0.42		0.67		0.50	
1995	0.20		0.48		0.39		0.30		0.00		0.26	
1996	0.20		0.31		0.36		0.26		0.33		0.19	
1997	0.20		0.26		0.47		0.19		0.48		0.20	
1998	0.13		0.28		0.28		0.27		0.42		0.36	
1999	0.14		0.11		0.32		0.24		0.60		0.20	
2000	0.08		0.15		0.20		0.15		0.10		0.08	
2001	0.08		0.17		0.14		0.35		0.14		0.10	
2002	0.16		0.16		0.23		0.07		0.11		0.08	
2003	0.10	0.19	0.10	0.33	0.18		0.13	0.51	0.03	0.33	0.11	0.10
2004	0.06	0.25	0.17	0.31	0.14	0.29	0.18	0.09	0.00		0.09	0.04
2005	0.07	0.15	0.12	0.24	0.09	0.23	0.12	0.27			0.04	0.12
2006	0.09	0.18	0.07	0.31	0.11	0.16	0.13	0.44			0.06	0.21
2007	0.10	0.19	0.07	0.39	0.13	0.13	0.13	0.18		0.26	0.02	0.09
2008		0.18		0.30		0.28		0.25				0.42
2009		0.22		0.39		0.38		0.11				0.09

2010	0.31	0.36	0.25	0.06		0.59
2011	0.17	0.16	0.05	0.13		0.36
2012	0.22	0.31	0.17	0.10		0.13
2013	0.12	0.29	0.40	0.07		0.41
2014	0.10	0.76	0.55	0.06		0.44

REEF Scuba Diver Surveys

The Reef Environmental Education Foundation (REEF.org) is a citizen science organization that trains recreational scuba divers to identify and record fish species (REEF 2008). The data are reported in abundance categories: single = single fish, few = 2 to 10 fish, many = 11 to 100 fish, and abundant = 101+ fish. Following Drake et al. 2010, we converted these abundance categories to minimum values (1, 2, 11, or 101 fishes) for use in the analyses presented here. We averaged observations by sites (geozones) within years to control for higher abundances at popular dive sites. We also limited data to dives from hard-bottom sites. We then calculated a yearly mean for each MCA.

Puget Sound rockfish, *S. emphaeus*, were excluded from the analyses because they are much smaller than other rockfish species, can occur in very high abundance ephemerally, and are not caught in the recreational fishery. We also excluded young-of-year (YOY). REEF.org provided a new download of records for 1998 to 2014 on October 11, 2014 (REEF 2014). This data set was used in the present analyses, and data are shown in Figure A3 and Table A3.

Table A3. REEF data used in the MARSS analysis by Washington Marine Conservation Area. North Puget Sound = Areas 5 to 7. Puget Sound Proper = Areas 8 to 13. The data do not include YOY or Puget Sound rockfish *S. emphaeus.*

Year	MCA 5	MCA 6	MCA 7	MCA 8	MCA 9	MCA 10	MCA 11	MCA 12	MCA 13
1998	NA	NA	12.43	NA	15.09	6.90	NA	10.00	NA
1999	NA	56.25	3.00	NA	8.18	NA	7.00	13.67	NA
2000	NA	30.00	9.81	NA	3.79	4.00	7.92	6.50	9.50
2001	NA	1.00	4.11	NA	8.96	6.36	7.38	10.85	8.15
2002	NA	1.50	12.55	NA	6.63	9.63	7.04	8.53	2.42
2003	20.13	NA	9.41	NA	4.58	21.05	7.97	15.37	4.70
2004	NA	NA	11.11	NA	7.75	12.55	8.64	19.47	8.73
2005	4.00	NA	6.76	11.25	8.93	4.45	7.95	14.40	10.78
2006	24.00	NA	8.85	NA	13.58	10.22	6.39	10.73	5.23
2007	11.35	51.00	9.53	6.00	15.32	10.22	8.28	13.47	5.89
2008	11.00	24.14	8.59	5.60	16.28	9.92	9.75	13.79	8.38
2009	5.75	43.00	15.48	5.75	16.97	12.34	9.85	22.36	6.02
2010	10.67	7.91	20.21	12.11	29.44	11.21	13.03	33.19	14.43
2011	17.67	11.40	14.30	11.33	37.63	11.08	17.41	30.01	8.72
2012	3.93	13.80	12.46	5.25	32.32	13.37	13.57	28.16	8.75
2013	16.15	9.50	11.83	17.00	23.70	11.51	15.15	28.53	8.34
2014	2.50	15.00	8.86	1.58	9.14	18.39	13.27	29.78	3.01

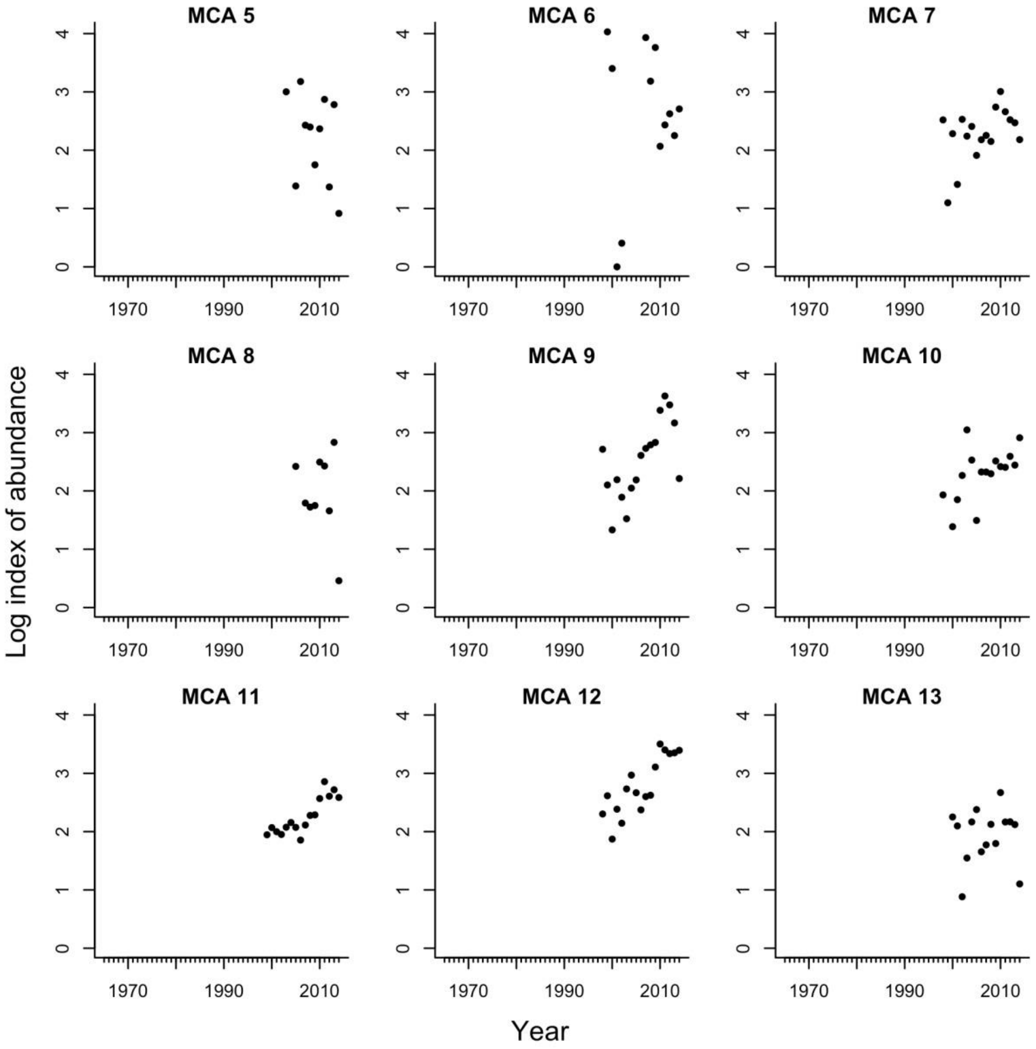

Figure A3. REEF scuba survey data used in the MARSS analysis by Washington Marine Conservation Area. North Puget Sound = Areas 5 to 7. Puget Sound Proper = Areas 8 to 13. The data do not include YOY or Puget Sound rockfish *S. emphaeus.*

WDFW Trawl Surveys

Data from the WDFW trawl survey (a fishery-independent survey) were included in the trend analyses in the 2010 analysis primarily because the 2010 BRT also considered redstripe and greenstriped rockfishes, which tend to inhabit soft bottoms. These data are not as relevant for yelloweye rockfish, canary rockfish, and bocaccio because these species tend to associate with hard bottoms to a much greater extent. Nevertheless, they are included here for completeness and comparability with the 2010 results.

Palsson et al. (2009) describe the WDFW trawl survey in detail. The survey runs from 1987 through 2014 and is depth stratified, and effort is allocated among 12 regions: east British Columbia Juan de Fuca, central Puget Sound, Discovery Bay, United States Strait of Georgia, British Columbia Strait of Georgia, Hood Canal, east United States Juan de Fuca, British Columbia Haro Strait and Boundary Pass, west United States Juan de Fuca, United States San Juan Archipelago, South Puget Sound, and the Whidbey Basin. Sampling effort among these regions was episodic for much of the survey, although it has been more consistent since 2008. Here we used data for the United States waters only (Table A4, Figure A4). For the current analysis, CPUE for total rockfish was recalculated from raw data files provided by WDFW in February 2015 (E. Kraig, pers. comm., WDFW, unpublished catch data, Feb. 18, 2015).

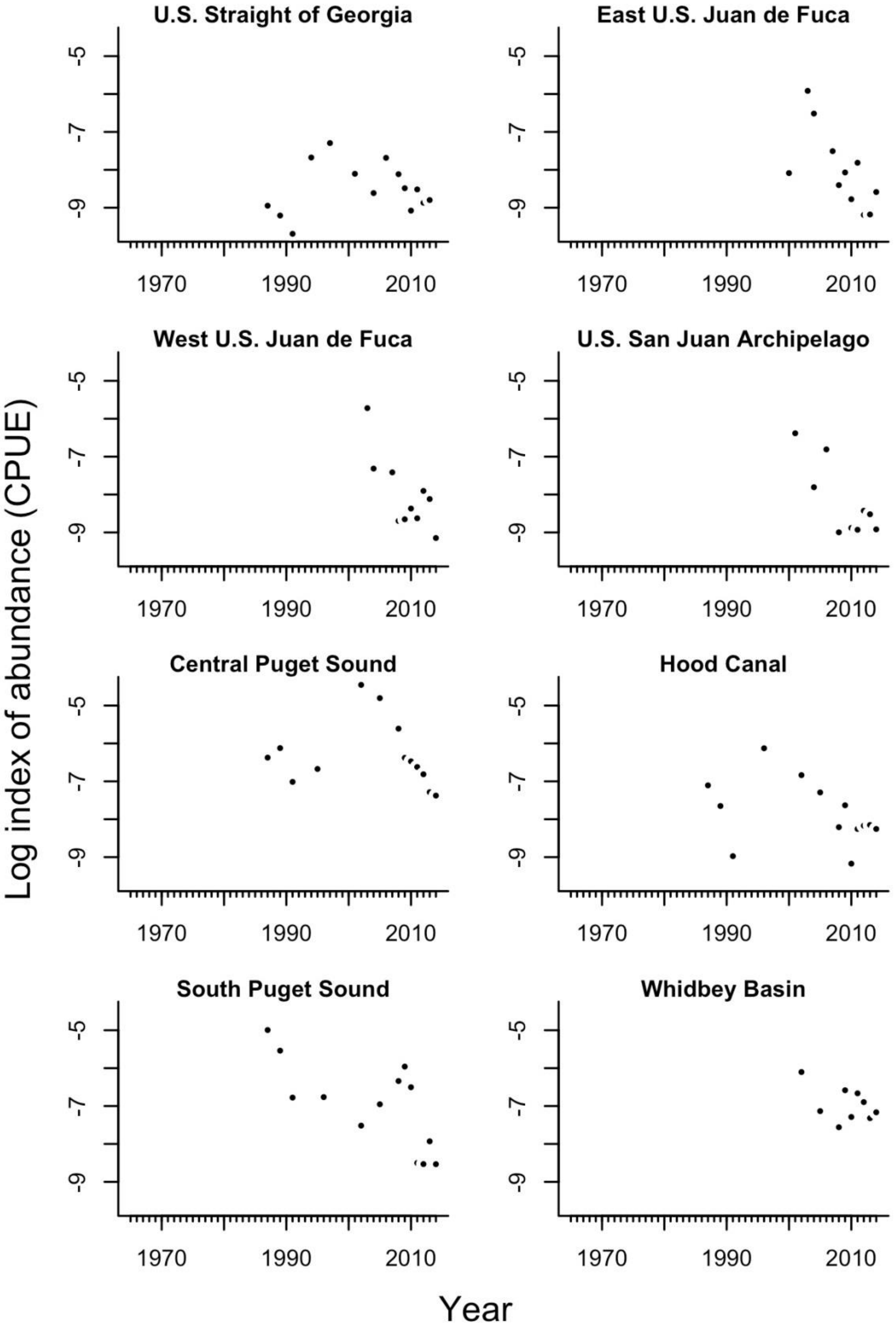
U.S. Straight of Georgia
East U.S. Juan de Fuca
West U.S. Juan de Fuca
U.S. San Juan Archipelago
Central Puget Sound
Hood Canal
South Puget Sound
Whidbey Basin
-5
-7
-9
1970
1990
2010
Log index of abundance (CPUE)
Year

Figure A4. WDFW trawl survey data as CPUE (number per m2). GB = U.S. Strait of Georgia, JE = east U.S. Juan de Fuca, JW = west U.S. Juan de Fuca, JS = San Juan Islands, HC = Hood Canal, CS = central Puget Sound, SS = South Puget Sound, WI = Whidbey Island Basin. GB, JE, JW, and JS compose North Puget Sound. CS, HC, WI, and SS compose Puget Sound Proper.

Table A4. WDFW trawl survey data as CPUE (number per km2). GB = U.S. Strait of Georgia, JE = east U.S. Juan de Fuca, JW = west U.S. Juan de Fuca, JS = San Juan Islands, HC = Hood Canal, CS = central Puget Sound, SS = South Puget Sound, WI = Whidbey Island Basin. GB, JE, JW, and JS compose North Puget Sound. CS, HC, WI, and SS compose Puget Sound Proper.

Year	GB	JE	JW	SJ	CS	HC	SS	WI
1987	0.00013				0.00170	0.00082	0.00678	
1988								
1989	0.00010				0.00219	0.00048	0.00393	
1990								
1991	0.00006				0.00090	0.00013	0.00114	
1992								
1993								
1994	0.00046							
1995					0.00126			
1996						0.00218	0.00115	
1997	0.00068							
1998								
1999								
2000		0.00031						
2001	0.00030			0.00169				
2002					0.01163	0.00107	0.00054	0.00224
2003		0.00270	0.00328					
2004	0.00018	0.00148	0.00067	0.00041				
2005					0.00820	0.00068	0.00096	0.00080
2006	0.00046			0.00110				
2007		0.00055	0.00060					
2008	0.00030	0.00022	0.00017	0.00012	0.00366	0.00027	0.00176	0.00052
2009	0.00021	0.00031	0.00017		0.00169	0.00048	0.00258	0.00138
2010	0.00011	0.00015	0.00023	0.00014	0.00154	0.00010	0.00150	0.00068
2011	0.00020	0.00040	0.00018	0.00013	0.00133	0.00026	0.00020	0.00128

2012	0.00014	0.00010	0.00037	0.00022	0.00110	0.00028	0.00020	0.00101
2013	0.00015	0.00010	0.00030	0.00020	0.00069	0.00029	0.00036	0.00066
2014		0.00019	0.00011	0.00013	0.00063	0.00026	0.00020	0.00077

Species Composition

Temporal patterns in species composition are essential to interpreting the analyses of total rockfish abundance in reference to the listed species. The rationale is described in more detail in later sections, but the trends in relative abundance of yelloweye rockfish, canary rockfish, and bocaccio as a proportion or percentage of the total catch are shown here (see Table A5 for data for each year).

Recreational Fishery Data

Bocaccio were extremely uncommon in the recreational catch with the exception of the PSP in the 1970s during the expansion of recreational fishing. It then rapidly declined in prevalence and has remained low or zero since (Figure A5).

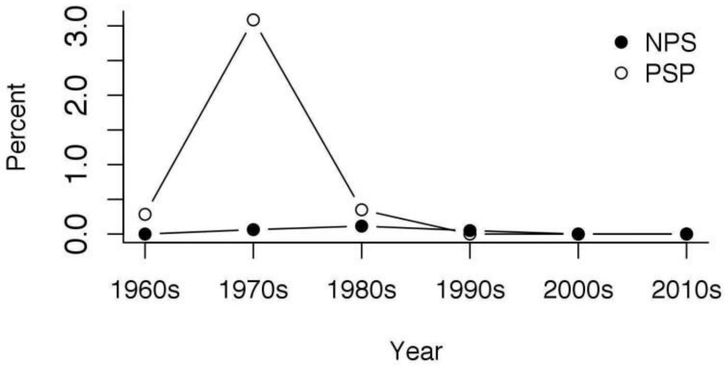

Figure A5. Prevalence of bocaccio as a percentage of the total rockfish assemblage from the WDFW recreational fishery surveys for North Puget Sound (NPS) and Puget Sound Proper (PSP). Data are means by decade (e.g., 1970 through 1979).

Canary rockfish initially made up 2 to 6 percent of the recreational catch in the 1960s. As with bocaccio, they peaked in relative abundance in the 1970s, but have declined and remained low since (Figure A6).

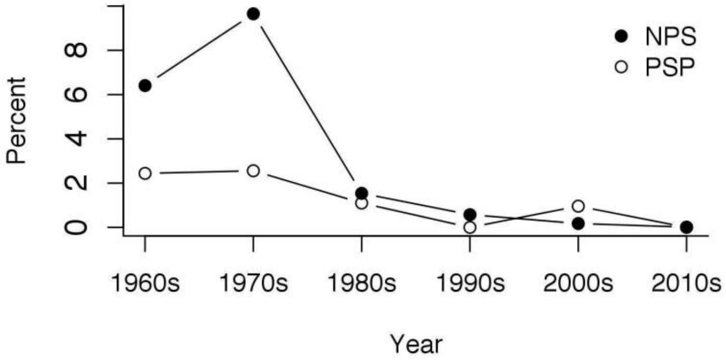

Figure A6. Prevalence of canary rockfish as a percentage of the total rockfish assemblage from the WDFW recreational fishery surveys for North Puget Sound (NPS) and Puget Sound Proper (PSP). Data are means by decade (e.g., 1970 through 1979).

Yelloweye rockfish showed a similar trend to canary rockfish, increasing in prevalence from the few data in the 1960s to represent 3 to 4 percent of the catch in the 1970s. They have since declined in relative abundance, making up less than 0.5 percent of the catch in the 2010s (Figure A7).

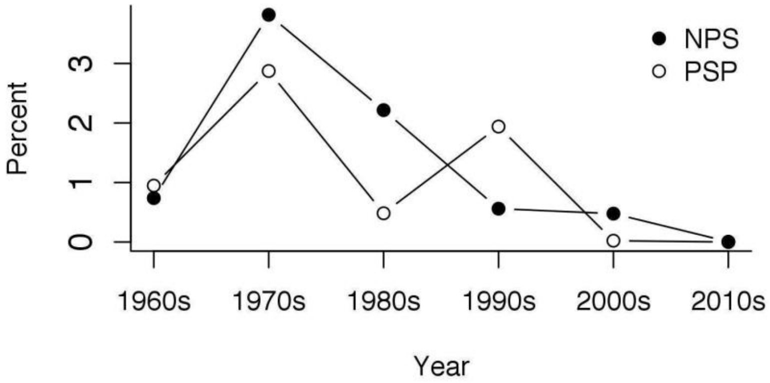

Figure A7. Prevalence of yelloweye rockfish as a percentage of the total rockfish assemblage from the WDFW recreational fishery surveys for North Puget Sound (NPS) and Puget Sound Proper (PSP). Data are means by decade (e.g., 1970 through 1979).

Table A5. Percent of the recreational catch for bocaccio, canary rockfish, and yelloweye rockfish by decade from 1965 through 2014 for North Puget Sound (MCA 5 to 7) and Puget Sound Proper (8 to 13).

	North Puget Sound			**Puget Sound Proper**		
Year	Bocaccio	Canary	Yelloweye	Bocaccio	Canary	Yelloweye
1960	0.000	6.408	0.738	0.284	2.441	0.948
1970	0.063	9.651	3.818	3.087	2.559	2.873
1980	0.114	1.538	2.216	0.349	1.100	0.483
1990	0.050	0.575	0.560	0.000	0.000	1.940
2000	0.000	0.175	0.477	0.000	0.959	0.022
2010	0.001	0.013	0.006	0.000	0.002	0.000

REEF Scuba Surveys

The REEF scuba surveys contain some information on species composition with limited observations of canary and yelloweye rockfish. Bocaccio are not shown as they were observed only twice in over 11,000 dives. The frequency of occurrence of canary and yelloweye rockfish on REEF dives increased from 2000 through around 2005, after which it declined for both species with the exception of one year for each species (Figure A8).

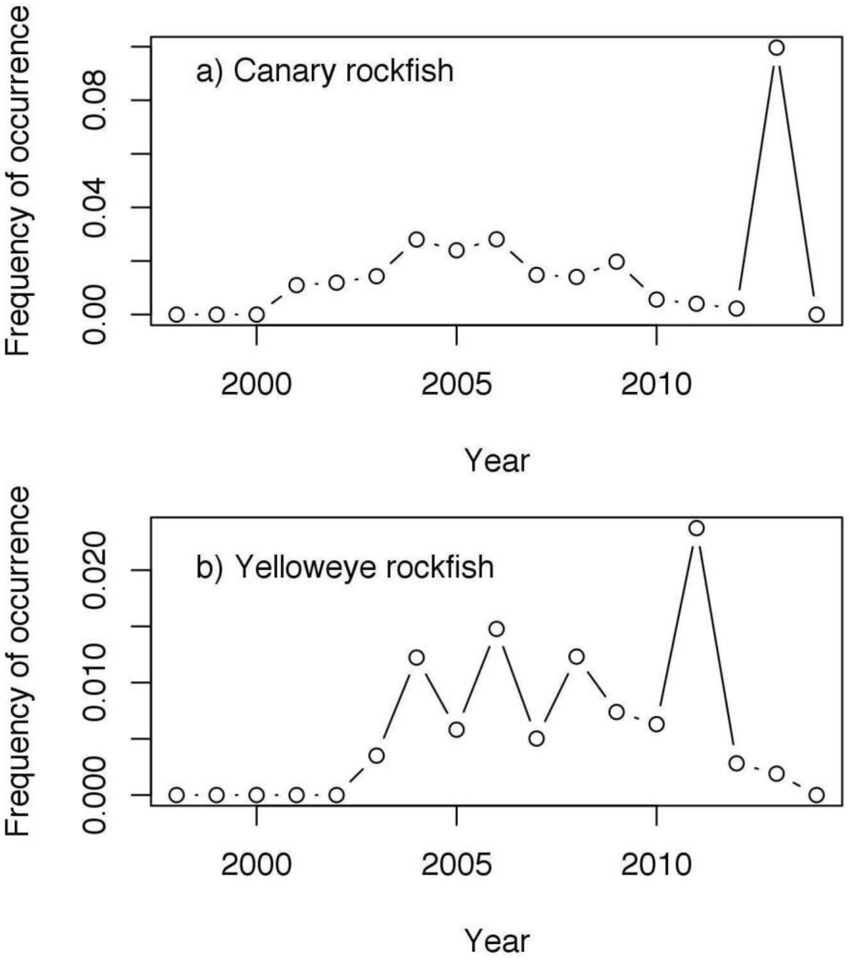

Figure A8. Frequency of occurrence for a) canary rockfish and b) yelloweye rockfish from the REEF scuba surveys in Puget Sound.

Canary and yelloweye rockfish both made up extremely minor proportions of the rockfish assemblage sampled by REEF divers (Figure A9). As with the time-series of REEF abundance indices, canary and yelloweye rockfish both increased as a proportion of the rockfish assemblage from 1998 through approximately the 2005 to 2010 time period. Both species then decreased in prevalence. Thus, there is no evidence of recent increases in proportion of the assemblage for either species.

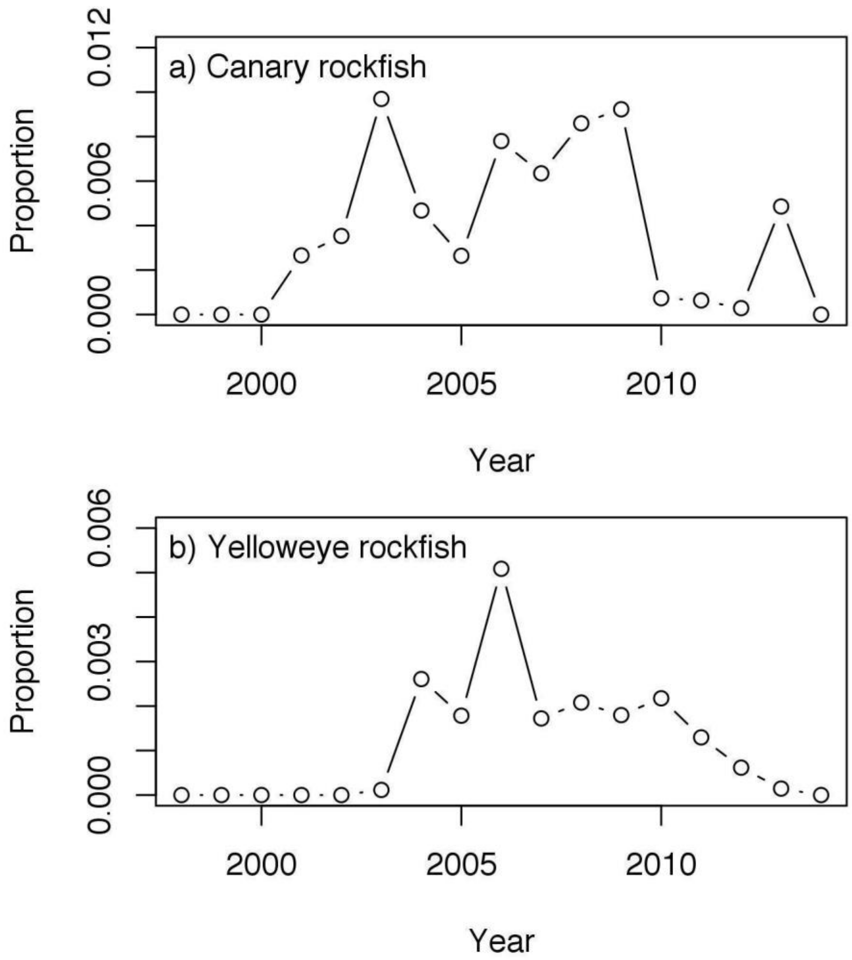

Figure A9. Proportion of a) canary rockfish and b) yelloweye rockfish in the rockfish assemblages as estimated from the REEF scuba surveys. REEF rankings (1 through 4) were converted to minimum numbers (1 = 1, 2 = 2, 3 = 11, 4 = 101) and averaged by site (geozone) and year. Results are for hard substrata only. Puget Sound rockfish, *S. emphaeus*, and YOY were excluded from the analyses.

The cause of the observed trends for both species is not known. However, these trends may have more to do with diver learning than with actual trends in canary and yelloweye rockfish abundance. Vermillion rockfish, *S. miniatus*, a similar, orange-red colored rockfish, showed the opposite trend to canary and yelloweye rockfish. It initially declined from 1999 to 2004 before increasing as a proportion of the rockfish assemblage observed by REEF divers from 2004 through 2014 (Figure A10). In the late 1990s and early 2000s, divers were learning to identify rockfish and may have misidentified these three red-colored rockfish species. As divers became more competent in correctly identifying species, mis-identification decreased as did the estimates of abundance for the two listed species.

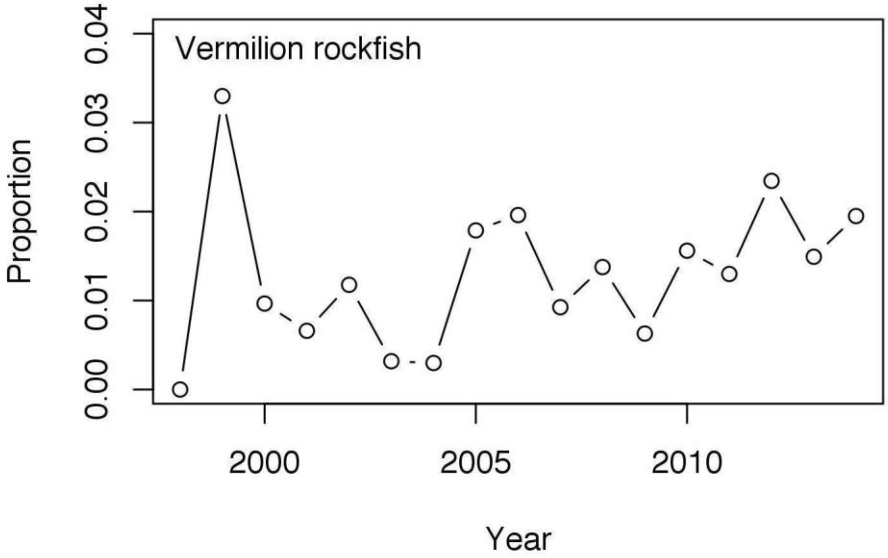

Figure A10. Proportion of vermillion rockfish, *S. miniatus*, in REEF scuba surveys from 1998 through 2014. REEF rankings (1 through 4) were converted to minimum numbers (1 = 1, 2 = 2, 3 = 11, 4 = 101) and averaged by site (geozone) and year. Results are for hard substrata only. Puget Sound rockfish, *S. emphaeus*, and YOY were excluded from the analyses.

WDFW Trawl Data

The listed species appear only occasionally in the WDFW trawl survey (Figure A11) with a total of 36 listed individuals seen over the course of the entire survey out of 11,206 total rockfish over the same period (0.32 percent). The data are too sparse to show any particular trend. Indeed, only one bocaccio was observed in the entire survey, and canary rockfish were caught in only one year.

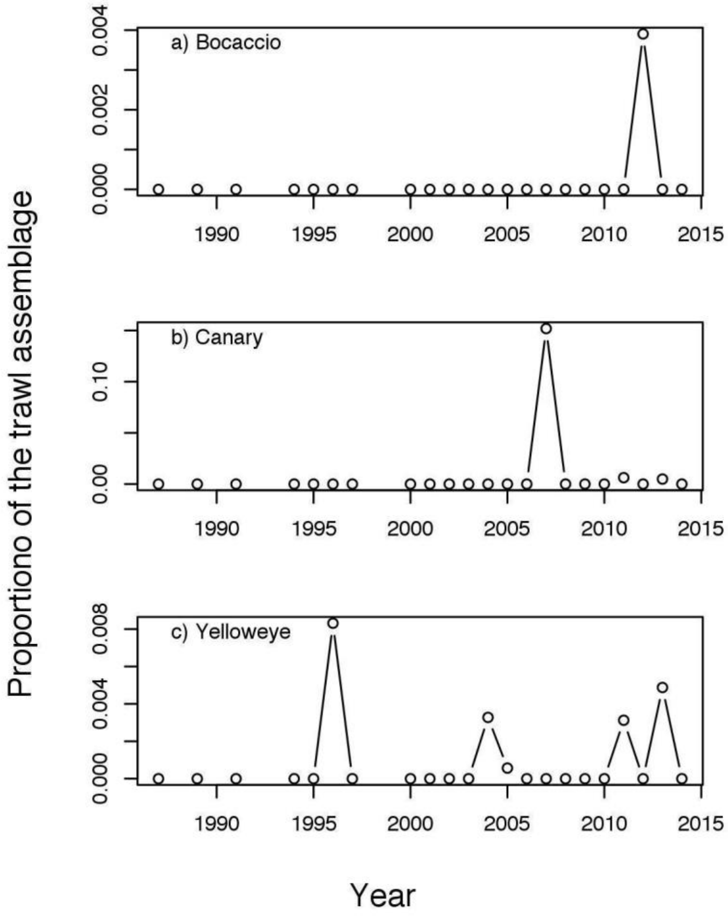

Figure A11. Proportion of yearly WDFW trawl catch from 1987 through 2014 for Greater Puget Sound for a) bocaccio, b) canary rockfish, and c) yelloweye rockfish.

Table A6. Year counts of rockfish species collected by the WDFW trawl survey. The listed species (in bold) are encountered only rarely. Black=Bl, Bocaccio=Boc, Brown=Br, Canary=Can, Copper=Cop, Darkblotched=DB, Greenstriped=GS, Pacific Ocean perch=POP, Puget Sound=PS, Quillback=QB, Redbanded=RB, Redstripe=RS, Rockfish spp=Rock, Rougheye=RE, Sharpchin=SC, Shortspine thornyhead=ShT, Splitnose=SpN, Stripetail=ST, Thornyhead spp=Th, Vermillion=Ver, Widow=Wid, Yelloweye=YE, and Yellowtail=YT.

Year	Bl	**Boc**	Br	**Can**	Cop	DB	GS	POP	PS	QB	RB	RS	Rock	RE	SC	ShT	SpN	ST	Th	Ver	Wid	**YE**	YT
1987	0	**0**	235	**0**	81	0	0	0	0	891	0	5	14	0	1	2	38	0	2	0	0	**0**	0
1988	--	**--**	--	**--**	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	**--**	--
1989	0	**0**	0	**0**	328	0	0	0	0	334	0	1	109	0	0	0	7	0	0	0	0	**0**	0
1990	--	**--**	--	**--**	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	**--**	--
1991	0	**0**	6	**0**	74	0	1	0	0	147	0	43	0	0	0	0	0	0	0	0	0	**0**	0
1992	--	**--**	--	**--**	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	**--**	--
1993	--	**--**	--	**--**	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	**--**	--
1994	0	**0**	0	**0**	10	0	1	1	1	24	0	1	0	0	0	0	0	0	0	0	0	**0**	0
1995	0	**0**	1	**0**	10	0	2	0	7	239	0	2	0	0	0	0	0	0	0	0	0	**0**	0
1996	0	**0**	19	**0**	111	0	1	0	3	309	0	3	0	0	0	13	18	0	0	0	0	**4**	0
1997	0	**0**	0	**0**	1	0	3	0	3	41	0	4	0	0	0	7	0	0	0	0	0	**0**	0
1998	--	**--**	--	**--**	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	**--**	--
1999	--	**--**	--	**--**	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	**--**	--
2000	0	**0**	0	**0**	2	0	0	0	8	9	0	0	0	0	0	0	0	0	0	0	0	**0**	0
2001	0	**0**	0	**0**	0	0	0	0	140	10	0	0	0	0	0	3	0	0	0	0	0	**0**	0
2002	0	**0**	32	**0**	242	0	7	0	280	224	0	1567	0	0	0	2	21	0	0	0	0	**0**	0
2003	8	**0**	0	**0**	1	0	80	1	29	19	0	557	0	0	0	3	1	3	0	17	0	**0**	0
2004	0	**0**	0	**0**	4	0	52	1	32	40	0	168	0	0	0	2	1	1	0	1	0	**1**	2

Table A6 continued. Year counts of rockfish species collected by the WDFW trawl survey. The listed species (in bold) are encountered only rarely. Black=Bl, Bocaccio=Boc, Brown=Br, Canary=Can, Copper=Cop, Darkblotched=DB, Greenstriped=GS, Pacific Ocean perch=POP, Puget Sound=PS, Quillback=QB, Redbanded=RB, Redstripe=RS, Rockfish spp=Rock, Rougheye=RE, Sharpchin=SC, Shortspine thornyhead=ShT, Splitnose=SpN, Stripetail=ST, Thornyhead spp=Th, Vermillion=Ver, Widow=Wid, Yelloweye=YE, and Yellowtail=YT.

Year	**Bl**	**Boc**	**Br**	**Can**	**Cop**	**DB**	**GS**	**POP**	**PS**	**QB**	**RB**	**RS**	**Rock**	**RE**	**SC**	**ShT**	**SpN**	**ST**	**Th**	**Ver**	**Wid**	**YE**	**YT**
2005	0	**0**	127	**0**	45	0	11	0	552	202	0	792	0	0	0	0	30	0	0	1	0	**1**	0
2006	0	**0**	1	**0**	10	0	3	0	114	41	1	18	0	0	0	1	0	0	0	0	0	**0**	0
2007	0	**0**	2	**24**	8	2	21	15	2	54	1	2	0	1	2	16	1	0	0	0	0	**0**	7
2008	0	**0**	99	**0**	16	0	7	0	6	359	0	8	0	0	1	1	3	0	0	1	0	**0**	0
2009	0	**0**	126	**0**	110	1	4	0	3	360	0	2	0	1	0	1	13	0	0	8	0	**0**	2
2010	1	**0**	28	**0**	26	0	4	0	4	288	1	7	0	1	0	2	0	0	0	0	0	**0**	0
2011	0	**0**	35	**2**	20	0	11	0	4	222	0	17	0	0	0	0	4	0	0	1	0	**1**	3
2012	0	**1**	17	**0**	9	0	37	0	4	171	0	13	0	0	0	0	3	0	0	0	0	**0**	1
2013	1	**0**	18	**1**	27	0	11	0	8	127	1	7	0	0	0	0	3	0	0	0	0	**1**	0
2014	1	**0**	2	**0**	29	0	2	0	9	46	0	5	0	0	0	0	0	0	0	0	0	**0**	0
Total	11	**1**	748	**27**	1164	3	258	18	1209	4157	4	3222	123	3	4	53	143	4	2	29	0	**8**	15

New Size Frequency Information

NOAA Rockfish Genetics Study

Size frequency information was collected during the NOAA rockfish genetics study, which was initiated in 2014 to gain genetic data to better delineate the DPS for the three listed species. Both yelloweye and canary rockfish show some evidence of recent recruitment within the last 10 years (Figure A12).

For example, most of the canary rockfish were 13.8 inches (35 cm) FL or less making them 4 to 6 years old (based on von Bertalanffy growth parameters from Lea et al. 1999; note, these growth parameters are for central California.). The survey caught nine yelloweye rockfish that were less than 15.8 inches (40 cm) in fork length (FL). At 13.8 inches (35 cm) FL, these fish would be approximately 7 to 10 years of age (using the von Bertalanffy growth parameters from Love et al. 2002). WDFW scientists observed a strong rockfish recruitment event in 2006 (Lowry et al. 2013). Thus, the data suggest some ‘recent’ replenishment of local populations of canary and yelloweye rockfish, although the extent is not known.

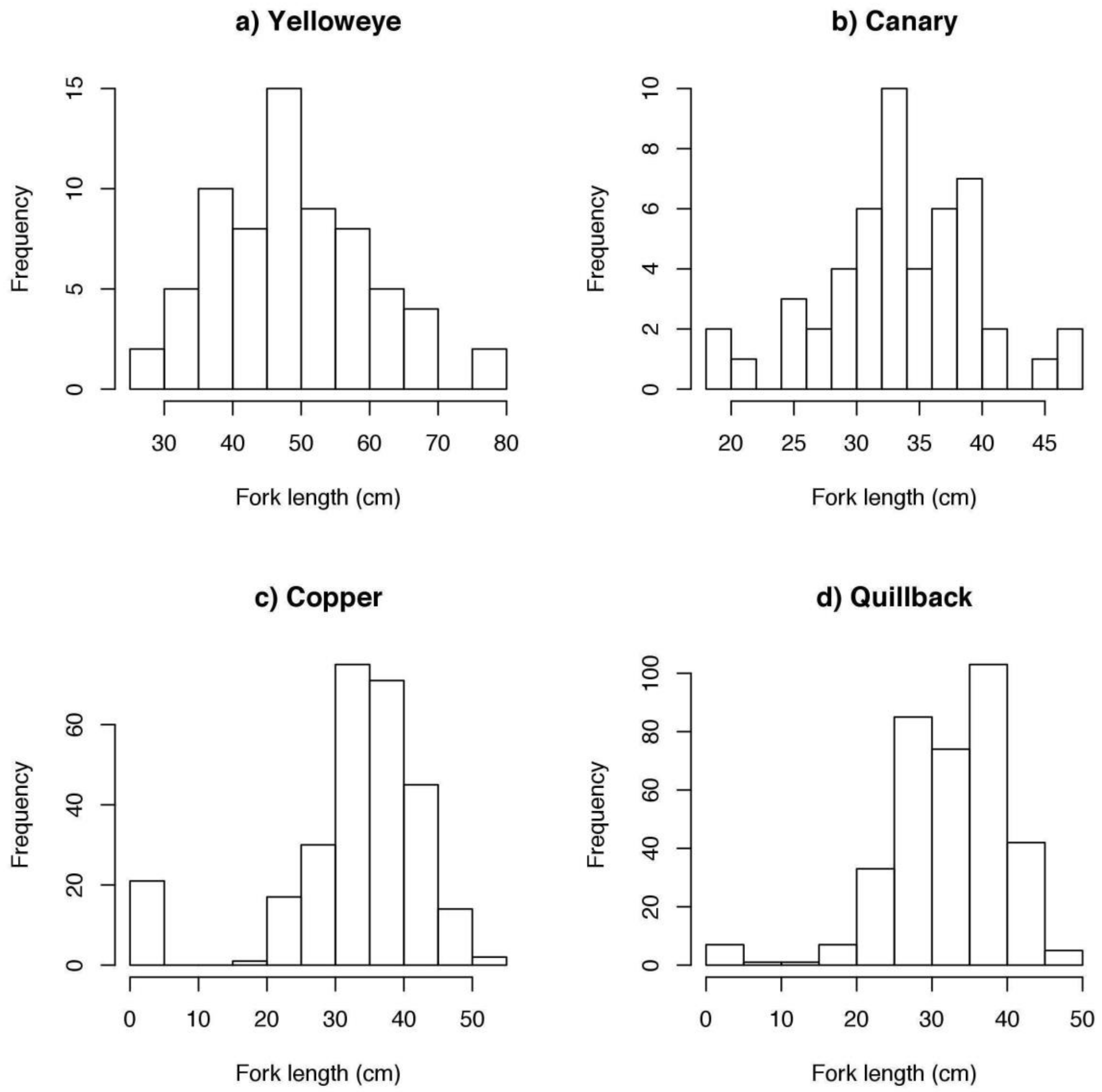

Figure A12. Size frequency of a) yelloweye rockfish, b) canary rockfish, c) copper rockfish, and d) quillback rockfish in Greater Puget Sound (MCAs ~5 to 13) from the NOAA Rockfish Genetics Study. Copper and quillback rockfishes, two of the most common rockfish species in Puget Sound, are included for comparison.

Estimates of Rockfish Population Trends in Puget Sound

Rationale

One step in listing or delisting is determining demographic risk, with the population trend (trajectory, or year-to-year variation in population size, and population growth rate) being a key indicator. The analysis here follows that for the 2010 BRT report (Drake et al. 2010) using the same methodology, but we expand the spatial detail of the analysis and extend the time-series to 2014. The analysis rationale follows that for the 2010 analysis and is summarized below.

Three data sources exist that can be used to estimate population trends for rockfish in Puget Sound:

- WDFW recreational fishery survey
- REEF scuba survey
- WDFW trawl survey

However, there are few actual observations of the three listed species in the available data, making it impossible to directly estimate population trends for these three species. Nevertheless, there is some information on species composition of the catch (primarily from the recreational fishery survey) that allows us to indirectly estimate likely population trends for the three listed species.

First, we estimate the population trajectory and growth rate for total rockfish, where total rockfish is the sum of all rockfish in a sample. We then make inferences about the listed species by evaluating evidence that they have increased or decreased as a proportion of the assemblage. For example, if the frequency of a species is constant, we infer that it has changed at the same rate as total rockfish.

More formally:

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

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

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

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

It is important to realize that the common species (i.e., copper rockfish, quillback rockfish, brown rockfish, and black rockfish) compose approximately 90 percent of ‘total rockfish’ in the different data sources used in the trend analysis. The goal of the analysis is to determine the 1977 to 2014 trend in total rockfish (i.e., what the actual population rate of decline has been from 1977 to 2014). This analysis makes no assumptions about the composition of total rockfish; it is known that the frequency of the common species relative to each other has changed. See Drake et al. 2010 for a discussion of the limitations and problems with analyzing composite and CPUE data.

Multivariate Autoregressive State-Space (MARSS) Models

We applied time-series analysis using multivariate autoregressive state-space models (MARSS) (Ives et al. 2003; Holmes et al. 2014) to estimate the population trajectory and growth rate in total rockfish in Puget Sound. MARSS models have a number of advantages in that they allow one to:

1) Combine data from multiple time-series
2) Deal with unevenly sampled time-series and missing data
3) Estimate both observation and process error
4) Investigate different parameterizations of space to ask at what scale common population processes occur

Our MARSS model, with Gaussian errors, took the form:

$$\mathbf{x}_t = \mathbf{B}\mathbf{x}_{t-1} + \mathbf{u} + \mathbf{w}t, \text{ where } \mathrm{w}_t \sim \mathrm{MVN}(0, \mathbf{Q})$$

$$\mathbf{y}_t = \mathbf{Z}\mathbf{x}_t + \mathbf{a} + \mathbf{v}t, \text{ where } \mathrm{v}_t \sim \mathrm{MVN}(0, \mathbf{R})$$

The **x** equation is the process side; $\mathbf{x}_t$ is a column vector of the modeled states (trajectories), *x*'s. In our model, the x_t's in **x** represent the log-transform of population size at year *t*. **u** is a column vector of the log population growth rate, *u*, for each state (log population trajectory). We can force the model to estimate one *u* across all the state processes or different *u*'s for each process to allow spatial variation (or lack thereof) in population growth rate. We are primarily interested in estimating the *u*'s in **u**. $\mathbf{w}_t$ is a column vector of the process errors or deviations from the expected population growth rate, *u*, at year *t*. It represents the real deviations in population change, which are not equal to the observed deviations because the observed deviations also have observation error added. The **B** matrix allows one to model density dependence via diagonal elements that are less than 1. Because the rockfish populations were known to be low, we assume that population trends were density-independent (**B** = an identity matrix).

The **y** equation is the observation side of the model; $\mathbf{y}_t$ is a column vector of the observations (the data, with potentially missing observations) at year *t*, and $\mathbf{v}_t$ is a column vector of the observation errors at year *t*. **Z** is a design matrix used to define how our observations are related to the underlying states. Here, we use **Z** to investigate the effect of space (i.e., Marine Conservation Area (a.k.a., Punch Card Area). We also used **Z** to investigate the effects of treating each gear type as a measurement of an independent state process or as measurements of the same state process but with different bias and observation errors.

Within the **y** equation, **a** is a scaling term used to combine time-series estimated on potentially different scales. One can consider it analogous to log 'catchability' (E. Ward, pers. comm., NOAA Fisheries, eric.ward@noaa.gov, May 2015). For example, regulations for the recreational fishery change through time in ways that should affect CPUE. Reducing the bag limit from 10 fish per bag to 1 fish per bag should cap CPUE and potentially affect targeting by fishers.

Likewise, CPUE data from the recreational fishery survey are on a different scale from observations from the REEF scuba surveys and from the WDFW trawl surveys. **a** estimates the scaling term for each observation, which will place all different times-series for the same process on the same estimated population trend. Note, **a** for one time-series is set to zero as the reference. All analyses were run in R (R Core Team 2014) using the MARSS package (Holmes et al. 2014).

Long-term Population Growth Rate (*u*) for Total Rockfish

We used model selection to test the data support for different spatial structures within the rockfish assemblage in Puget Sound. The approach we used is similar to that used in the original 2010 ESA evaluation (Drake et al. 2010), but we expanded the spatial detail and selected the model set to more fully study the data support for spatial structure, and we used updated time series through 2014.

The analysis was repeated using different combinations of the available data sets: a) Rec only, b) Rec and REEF, and c) Rec, REEF and Trawl. Using each combination of data sets, we tested the data support for three spatial structures of rockfish trajectories:

1) Different rockfish trajectories by MCA: each MCA is following its own trajectory independently or temporally correlated with the other MCAs.

2) Two different rockfish trajectories NPS and PSP: the north and south Puget Sound have separate trajectories (potentially temporally correlated) and each MCA or trawl area survey in those regions is tracking the regional (NPS or PSP) trajectory.

3) One rockfish trajectory for GPS: rockfish within Puget Sound are characterized by one overall trajectory and all the individual surveys are tracking this trajectory.

Each of these structures could be tested by changing the design (where 0s and 1s are placed) in the **Z** matrix in Equation 1a, which changes the number of population trajectories in the model and the relationship of the data to these trajectories. In addition to this regional structure, we also allowed that each survey could be observing a different rockfish trajectory. This might occur if the different surveys are sampling substantially different species assemblages or habitats. Thus in a model where we tested support for NPS and PSP trajectories, we tested models with only two population trajectories (NPS and PSP). In this model, all time series in those regions were treated as observations of those two trajectories. We also tested models where there were NPS and PSP trajectories for each survey type (e.g. Rec_{NPS}, Rec_{PSP}, REEF_{NPS}, etc.).

For each spatial structure, we tested different levels of model complexity in the population growth rate and trajectory covariance terms. We allowed the growth rate *u* to be different or to be equal across all trajectories, equal across regions or equal across survey types. For example, the model might specify that each MCA is characterized by an independent trajectory but those trajectories might each have the same population growth rate. Since trajectories are stochastic, they can have the same population growth rate without being identical and while still be temporally independent. We allowed the trajectories to be either correlated or independent (via the **Q** matrix). We tested full covariance (all trajectories allowed to covary) and covariance only within regions (NPS and PSP) or only within surveys for models where surveys in each region were given different trajectories. For all models, we estimated independent observational variance by MCA or trawl area and survey type. Recreational data collected during periods with different bag limits were treated as separate observational time series but shared the observation variance for the MCA. This means that all Rec surveys for the different bag limit periods in MCA 5, for example, were assumed to have the same observation variance. The data were log-transformed thus this assumption means that the distribution of proportional errors (10% up and 10% down) was the same within an MCA.

We compared models using Akiake's Information Criterion (corrected for small sample size, AICc; Burnham and Anderson 1998, Ward et al. 2010, Hampton et al. 2013). AICc can show some bias in state-space models towards selecting more complicated models, and bootstrapped parametric AIC can be more appropriate (Cavanaugh and Shumway 1997, Holmes and Ward 2010, Ward et al. 2010, Holmes et al. 2014) at smaller sample sizes. However, this bias is not a major issue given the large sample size in the current analyses (Cavanaugh and Shumway 1997). All analyses were run in R 3.1.1 (R Core Team 2014) using the MARSS package (Holmes et al. 2012).

Recent Changes in Population Trajectory

The above analyses estimate the long-term population growth rate for total rockfishes (or more specifically, long-term CPUE). That is, it estimates one growth rate for the entire period from 1977 through 2014. We also investigated the evidence for any recent recovery by allowing u to be time-varying with a different u for each regulatory period for the recreational CPUE data.

Rockfish Trend Analysis Results

MARSS: Recreational Survey Data

For the recreational survey data only, model selection identified two potential models with similar support (lowest AICcs) (Table A7). Both models included separate rockfish trajectories for NPS and PSP but one overall growth rate (u). However, the models differed in whether or not they included process covariance between the NPS and PSP rockfish trends. The model without covariance was unable to estimate process variance for the PSP trend ($Q_{PSP} = 0.000$). Because we want to estimate process variance and because the model with covariance includes as a subset the model without covariance, we chose the model with covariance as the best model (Table A8, Figure A13a).

The log-abundance index for total rockfish declined 3.8 percent per year from 1977 to 2014 (Table A8, Figure A13a) ($u = -0.038 \pm 0.008$ s.e.), or a total decline of 76 percent over this time period. The index for NPS was higher and more variable than for PSP with approximately an order of magnitude more process variance (Table A8, Figure A13). However, both the trends declined at the same rate (one *u*). Observational variance differed among MCAs by as much as an order of magnitude and was generally one to two orders of magnitude higher than process variance.

Species composition in the recreational catch differed between NPS and PSP (Table A9). Copper and quillback rockfish were common in both areas, but black rockfish were much more common in NPS while more brown rockfish were caught in PSP. Additionally, angler effort was higher in NPS.

Table A7. Model selection criteria for MARSS models with using the WDFW recreational survey data only. AICc = Akiake's Information Criterion corrected for sample size (Burnham and Anderson 1998). In columns 1 and 2, Region = 2 trajectories or growth rates for NPS and PSP, MCA = trajectories or growth rates for each of the 9 MCAs, and GPS = one Greater Puget Sound trajectory or growth rate. Cov = covariance between all population trajectories, No cov = no covariance among trajectories. Separate process variance was estimated for each trajectory. There were 54 observation time series. The number of estimated parameters for each term is in parentheses. For column 1, this is the number of initial states ($\mathbf{x}_0$) and number of *a* in **a**. There were 9 **R** parameters for each model. Bold indicates best-fit model (ΔAICc < 2.0 & fewest parameters).

Number and structure of pop. trajectories ($\mathbf{x}_0$, **a**)	Growth rates (**u**)	Pop. traj. covariance structure (**Q**)	ΔAICc	Number of parameters (**u**, **a**, **Q**, **R**, $\mathbf{x}_0$)
Region (2, 52)	**GPS (1)**	**Cov (3)**	**0**	**67**
Region (2, 52)[1]	GPS (1)	No cov. (2)	0.2	66
Region (2, 52)	Region (2)	Cov (3)	2.98	68
Region (2, 52)	Region (2)	No cov. (2)	3.18	67
GPS (1, 53)	GPS (1)	n/a (1)	4.24	65
MCA (9, 45)	GPS (1)	No cov. (9)	31.66	73
MCA (9, 45)	Region (2)	No cov. (9)	33.82	74
MCA (9, 45)	MCA (9)	No cov. (9)	45.86	81
MCA (9, 45)	GPS (1)	Cov (45)	121.11	109
MCA (9, 45)	Region (2)	Cov (45)	125.4	110
MCA (9, 45)	MCA (9)	Cov (45)	147.29	117

[1] This model was unable to estimate process variance for PSP and was dropped from consideration

Table A8. Model results for the one *u* (growth rate), two regions (NPS and PSP) model allowing covariance between NPS and PSP trajectories and using the recreational data only. Q = process variance, R = observation variance by Marine Conservation Area, NPS = North Puget Sound, PSP = Puget Sound Proper, GPS = Greater Puget Sound, CL = confidence limit.

Parameter	Estimate	Lower 95% CL	Upper 95% CL
u_{GPS}	-0.038	-0.051	-0.021
Q_{NPS}	0.021	2.84E-08	0.025
Q_{PSP}	0.001	4.40E-08	0.009
$Q_{NPS:PSP}$	0.006	1.58E-10	0.013
R_5	0.064	0.024	0.078
R_6	0.168	0.071	0.184
R_7	0.015	0.005	0.022
R_8	0.087	0.039	0.106
R_9	0.159	0.067	0.167
R_{10}	0.200	0.086	0.23
R_{11}	0.149	0.074	0.189
R_{12}	0.202	0.072	0.233
R_{13}	0.239	0.109	0.253

Table A9. Estimated catch of rockfish from 2003 through 2014 for two regions of Puget Sound: North Puget Sound (NPS) and Puget Sound Proper (PSP). Total angler trips is also shown.

Common names	Species	Estimated Catch	
		NPS	PSP
Black rockfish	*Sebastes melanops*	27,512	252
Blue rockfish	*Sebastes mystinus*	157	--
Bocaccio	*Sebastes paucispinis*	--	--
Brown rockfish	*Sebastes auriculatus*	34	3,310
Canary rockfish	*Sebastes pinniger*	45	210
China rockfish	*Sebastes nebulosus*	148	--
Copper rockfish	*Sebastes caurinus*	17,027	5,018
Greenstriped rockfish	*Sebastes elongatus*	--	--
Puget Sound rockfish	*Sebastes emphaeus*	10	--
Quillback rockfish	*Sebastes maliger*	6,682	3,395
Redstripe rockfish	*Sebastes proriger*	--	--
Tiger rockfish	*Sebastes nigrocinctus*	72	--
Vermillion rockfish	*Sebastes miniatus*	--	6
Yelloweye rockfish	*Sebastes ruberrimus*	20	--
Yellowtail rockfish	*Sebastes flavidus*	286	10
Unidentified rockfish	*Sebastes spp.*	5,765	2,323
Total Catch		51,992	12,200
Total Angler Trips		101,548	52,457

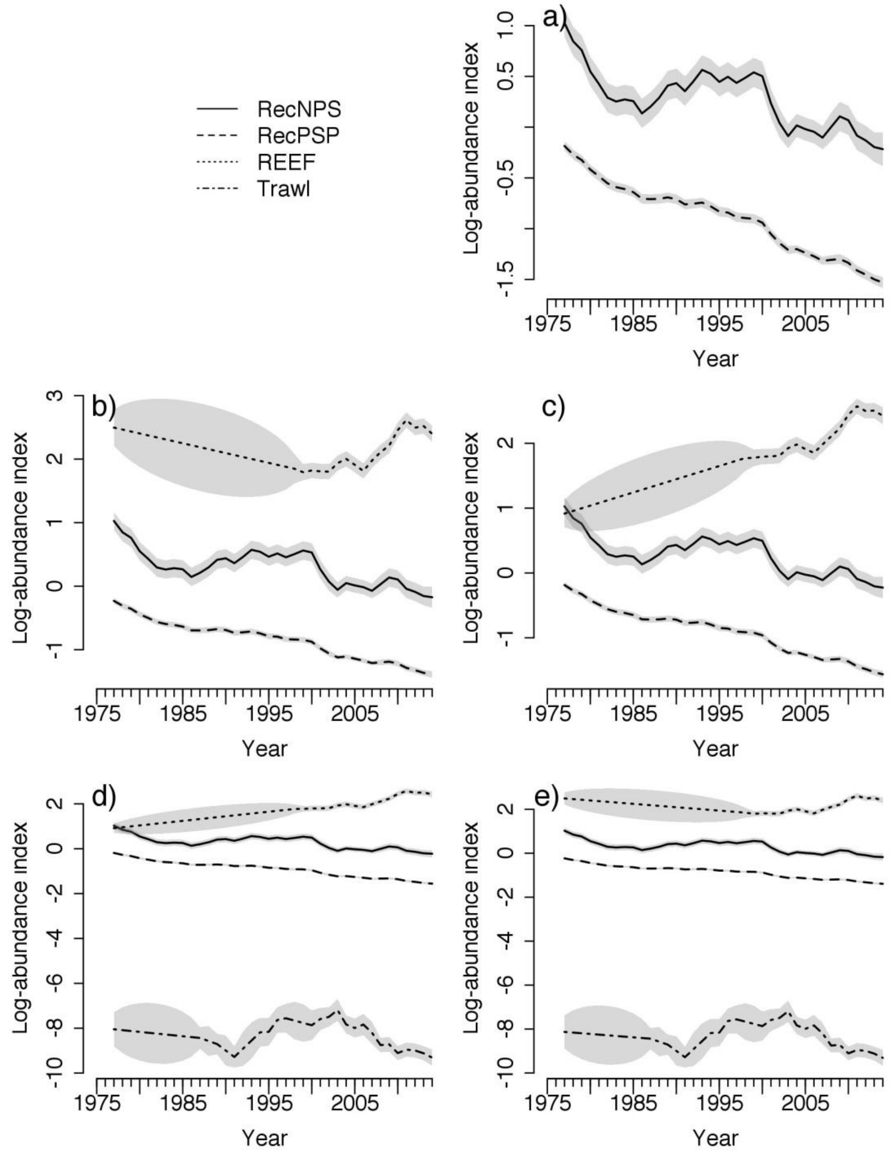

Figure A13. Estimated population trajectories for total rockfishes in Puget Sound using the best-supported models: a) Rec data only: one *u*, two trajectories, u_{GPS} = -0.038, b) Rec + REEF data: one *u*, three trajectories, u_{GPS} = -0.031, c) Rec + REEF data: two *u*'s, three trajectories, u_{Rec} = -0.039, u_{REEF} = 0.041, d) Rec + REEF + Trawl data: two *u*'s, four trajectories, $u_{\mathrm{Rec/Trawl}}$ = -0.039, u_{REEF} = 0.041, and e) Rec + REEF + Trawl data: one *u*, four trajectories, u_{GPS} = -0.031. Log abundance index is log (CPUE) from each time series. Grey envelopes indicate 95% confidence intervals. Models a, c and e were the best-fit models for each data combination.

MARSS: Recreational Fishery Survey and REEF Scuba Survey Data

Four models received similar support when the recreational survey data and REEF scuba survey data were used (Table A13b,c, Table A10). All four models included separate trends for the recreational data in NPS and PSP, but one trajectory for the REEF data in all of Puget Sound. Two models were subsets of the others, did not include covariance in Q, and were also unable to estimate process variance for the PSP recreational trend. As above, we excluded these two models because they could not estimate process variance (see MARSS Recreational Survey Data). The two best-supported models included correlation between the NPS and PSP recreational trends but not between these trends and the REEF trend (Table A11 and A12). These two models differed in whether they estimated a single growth rate across gear types ($u = -0.031 \pm 0.010$) or separate growth rates for each gear type ($u_{\text{rec}} = -0.039 \pm 0.009$, $u_{\text{REEF}} = 0.041 \pm 0.030$). These models differed by less than 2.0 AICc points, so we chose the model with the single u as the best-fit model since it had fewer parameters. Moreover, since we want to estimate the overall rate of population decline, we use the combined u of -0.031 as our estimate but note that there is evidence for different population growth rates for different gear types. This difference likely occurs because the two gears are sampling different assemblages.

Table A10. Model selection criteria for MARSS models comparing different model structures using the WDFW recreational survey (Rec) and REEF survey. Model support was quantified using AICc (Akiake's Information Criterion corrected for sample size). The geographic designations are North Puget Sound (NPS), Puget Sound Proper (PSP), MCA = management conservation area, and GPS = Greater Puget Sound. All models included separate process variance for each population trajectory with either no covariance between the trajectories or allowing covariance between all or some of the trajectories; see process covariance column with additional information in the footnotes. There were 63 observation time series: 54 Rec (9 MCAs and 6 regulatory time periods) and 9 REEF (1 for each MCA). Numbers in parenthesis are the number of estimated parameters for term. For the population trajectories, the estimated parameters are the initial value of the trajectory (x_0) and the scaling parameters (a). The number of a in $\mathbf{a}$ was 54 (the number of observation time series) minus the number of trajectories. A separate observation variance was estimated for each survey in each MCA. Thus 18 $\mathbf{R}$ parameters were estimated (one for each Rec survey in 9 MCAs plus one for each REEF survey in 9 MCAs). Bold indicates best-fit model (ΔAICc < 2.0 & fewest parameters).

Number and structure of pop. trajectories $(\mathbf{x}_0, \mathbf{a})$[2]	Growth rates $(\mathbf{u})$[3]	Pop. trajectory covariance structure $(\mathbf{Q})$[4]	ΔAICc	Number of parameters $(\mathbf{u}, \mathbf{a}, \mathbf{Q}, \mathbf{R}, \mathbf{x}_0)$
Rec_{NPS}, Rec_{PSP}, REEF (3, 60)	Survey (2)	Rec_{NPS} & Rec_{PSP} covary (4)	0.00	87
Rec_{NPS}, Rec_{PSP}, REEF (3, 60)[1]	Survey (2)	No covariance (3)	0.21	86
Rec_{NPS}, Rec_{PSP}, REEF (3, 60)[1]	GPS (1)	No covariance (3)	1.12	85
Rec_{NPS}, Rec_{PSP}, REEF (3, 60)	**GPS (1)**	**Rec_{NPS} & Rec_{PSP} covary (4)**	**1.40**	**86**
Rec_{NPS}, Rec_{PSP}, REEF (3, 60)	Rec_{NPS}, Rec_{PSP}, REEF (3)	Rec_{NPS} & Rec_{PSP} covary (4)	2.89	88
Rec_{NPS}, Rec_{PSP}, REEF (3, 60)	Rec_{NPS}, Rec_{PSP}, REEF (3)	No covariance (3)	3.14	87
Survey (2, 61)	Survey (2)	No covariance (2)	4.30	85
Region x Survey (4, 59)	Survey (2)	Surveys covary within regions (6)	4.51	89
Survey (2, 61)	GPS (1)	No covariance (2)	5.12	84
Rec_{NPS}, Rec_{PSP}, REEF (3, 60)	Survey (2)	All trajectories covary (6)	5.43	89

Region x Survey (4, 59)	GPS (1)	Surveys covary within regions (6)	5.73	88
Rec$_{\text{NPS}}$, Rec$_{\text{PSP}}$, REEF (3, 60)	GPS (1)	All trajectories covary (6)	6.55	88
Region x Survey (4, 59)	Survey (2)	Regions covary within surveys (6)	6.61	89
Survey (2, 61)	Survey (2)	All trajectories covary (3)	7.17	86
Survey (2, 61)	GPS (1)	All trajectories covary (3)	7.51	85
Region x Survey (4, 59)	Region x Survey (4)	No covariance (4)	7.86	89
Rec$_{\text{NPS}}$, Rec$_{\text{PSP}}$, REEF (3, 60)	Rec$_{\text{NPS}}$, Rec$_{\text{PSP}}$, REEF (3)	All trajectories covary (6)	8.06	90
Region x Survey (4, 59)	Region (2)	Regions covary within surveys (6)	8.61	89
Rec, REEF$_{\text{NPS}}$, REEF$_{\text{PSP}}$ (3, 60)	Survey (2)	REEF$_{\text{NPS}}$ & REEF$_{\text{PSP}}$ covary (4)	8.75	87
Rec, REEF$_{\text{NPS}}$, REEF$_{\text{PSP}}$ (3, 60)	Rec, REEF$_{\text{NPS}}$, REEF$_{\text{PSP}}$ (3)	No covariance (3)	8.85	87
Rec, REEF$_{\text{NPS}}$, REEF$_{\text{PSP}}$ (3, 60)	GPS (1)	REEF$_{\text{NPS}}$ & REEF$_{\text{PSP}}$ covary (4)	9.43	86
Region x Survey (4, 59)	GPS (1)	No covariance (4)	9.70	86
Region x Survey (4, 59)	GPS (1)	Regions covary within surveys (6)	9.70	88
Region x Survey (4, 59)	Region (2)	No covariance (4)	10.03	87
Region x Survey (4, 59)	Region x Survey (4)	Surveys covary within regions (6)	10.07	91
Rec, REEF$_{\text{NPS}}$, REEF$_{\text{PSP}}$ (3, 60)	Survey (2)	All trajectories covary (6)	11.02	89
Rec, REEF$_{\text{NPS}}$, REEF$_{\text{PSP}}$ (3, 60)	GPS (1)	No covariance (3)	11.05	85
Rec, REEF$_{\text{NPS}}$, REEF$_{\text{PSP}}$ (3, 60)	Rec, REEF$_{\text{NPS}}$, REEF$_{\text{PSP}}$ (3)	REEF$_{\text{NPS}}$ & REEF$_{\text{PSP}}$ covary (4)	11.34	88
Region x Survey (4, 59)	Region (2)	Surveys covary within regions (6)	11.95	89
Region x Survey (4, 59)	Region x Survey (4)	Regions covary within surveys (6)	12.20	91
Rec, REEF$_{\text{NPS}}$, REEF$_{\text{PSP}}$ (3, 60)	Rec, REEF$_{\text{NPS}}$, REEF$_{\text{PSP}}$ (3)	All trajectories covary (6)	13.14	90
Rec, REEF$_{\text{NPS}}$, REEF$_{\text{PSP}}$ (3, 60)	GPS (1)	All trajectories covary (6)	15.43	88

Region x Survey (4, 59)	Survey (2)	All trajectories covary (10)	15.97	93
Region x Survey (4, 59)	GPS (1)	All trajectories covary (10)	16.98	92
Region x Survey (4, 59)	Region (2)	All trajectories covary (10)	20.57	93
Region x Survey (4, 59)	Region x Survey (4)	All trajectories covary (10)	21.14	95
Region (2, 61)	GPS (1)	No covariance (2)	22.99	84
Region (2, 61)	GPS (1)	All trajectories covary (10)	23.93	85
GPS (1, 62)	GPS (1)	No covariance (2)	24.22	83
Region (2, 61)	Region (2)	No covariance (2)	25.41	85
Region (2, 61)	Region (2)	All trajectories covary (10)	26.24	86
MCA x Survey (18, 45)	Survey (2)	No covariance (18)	66.21	102
MCA x Survey (18, 45)	Region x Survey (4)	No covariance (18)	70.61	103
MCA x Survey (18, 45)	GPS (1)	No covariance (18)	79.06	100
MCA x Survey (18, 45)	Region (2)	No covariance (18)	86.34	101
MCA x Survey (18, 45)	MCA x Survey (18)	No covariance (18)	96.41	117
MCA x Survey (18, 45)	Survey (2)	All trajectories covary (171)	722.73	255
MCA x Survey (18, 45)	GPS (1)	All trajectories covary (171)	725.58	253
MCA x Survey (18, 45)	Region x Survey (4)	All trajectories covary (171)	733.34	256
MCA x Survey (18, 45)	Region (2)	All trajectories covary (171)	733.57	254
MCA x Survey (18, 45)	MCA x Survey (18)	All trajectories covary (171)	849.45	270

[1] These models were unable to estimate processes variance for Rec$_{PSP}$ and were dropped from consideration.

[2] The population trajectory column shows the number and structure of the trajectories. The structure is as labeled. For example, Rec$_{NPS}$, Rec$_{PSP}$, REEF = 3 trajectories for each of these observation types; all Rec observations in NPS observe the Rec$_{NPS}$ trajectory, all Rec observations in PSP observe the Rec$_{PSP}$ trajectory, and all REEF observations are observing the REEF trajectory.   In addition, the following abbreviations are used. Survey = one trajectory for each

survey type (Rec or REEF). Region x Survey = Rec_{NPS}, Rec_{PSP}, REEF_{NPS}, and REEF_{PSP} trajectories. MCA x Survey = Each survey in each MCA observes an different trajectory. Thus there are 9 x 2 trajectories. GPS = a single trajectory and all observations are of this one trajectory.

[3] The growth rate column shows the number of the growth rates. These are analogous to the population trajectory column. Thus, Region x Survey = separate growth rates estimated for Rec_{NPS}, Rec_{PSP}, REEF_{NPS}, and REEF_{PSP}. GPS = a single growth rate for all trajectories.

[4] The covariance column shows which covariances were estimated between the trajectories. No covariance: trajectories were treated as independent and a diagonal variance-covariance matrix was assumed. One variance estimated for each trajectory. Rec_{NPS} & Rec_{PSP} covary = covariance estimated between the Rec_{NPS} and Rec_{PSP} trajectories but set to 0 between Rec and all other trajectories. Regions covary within surveys = covariance estimated between surveys in each region thus there are Rec_{NPS}:Rec_{PSP} and a REEF_{NPS}:REEF_{PSP} covariance terms. No covariance terms between surveys (e.g., Rec_{NPS}:REEF covariance term set to 0). All trajectories covary = an unconstrained variance-covariance matrix is estimated. The size of the matrix is determined by the number of trajectories. Thus if 18 trajectories are estimated, the matrix is 18x18 and there are 18 variances and 153 covariances. Surveys covary within regions = covariance is estimated between the surveys within the same region. Thus Rec_{NPS}:REEF_{NPS} and Rec_{PSP}:REEF_{PSP} covariance terms are estimated. No covariance terms between surveys in different regions, thus the Rec_{NPS}:Rec_{PSP} covariance term is set to 0.

Table A11. Parameter estimates for the one *u* growth rate, three population trajectories (Rec_{NPS}, Rec_{PSP} and REEF) model allowing covariance between the Rec_{NPS} and Rec_{PSP} trajectories. This model used the WDFW recreational survey (Rec) and the REEF survey. *u* = population growth rate. A growth rate of -0.031 translates to approximately a 3.1% per year decline. Q = process variance and covariance. There was one process variance estimated for each of Rec_{NPS}, Rec_{PSP} and REEF plus a covariance term between the Rec trajectories ($Q_{\text{Rec NPS:Rec PSP}}$). R = observation variance by survey type and Marine Conservation Area. $R_{\text{Rec 10}}$ is the observation variance for the Rec survey in MCA 10. The geographic areas are NPS = North Puget Sound, PSP = Puget Sound Proper, GPS = Greater Puget Sound. CL = confidence limit. CLs were calculated using the estimated Hessian calculation provided in the MARSS R package.

Parameter	Estimate	Lower 95% CL	Upper 95% CL
u_{GPS}	-0.031	-0.049	-0.013
$Q_{\text{Rec NPS}}$	0.021	7.5×10^{-8}	0.028
$Q_{\text{Rec PSP}}$	0.001	1.0×10^{-7}	0.009
$Q_{\text{Rec NPS:Rec PSP}}$	0.005	-0.001	0.014
Q_{REEF}	0.026	9.5×10^{-8}	0.042
$R_{\text{Rec 5}}$	0.063	0.026	0.085
$R_{\text{Rec 6}}$	0.168	0.075	0.170
$R_{\text{Rec 7}}$	0.015	0.005	0.024
$R_{\text{Rec 8}}$	0.532	0.112	0.876
$R_{\text{Rec 9}}$	0.233	0.108	0.323
$R_{\text{Rec 10}}$	0.166	0.059	0.252
$R_{\text{Rec 11}}$	0.006	6.0×10^{-6}	0.019
$R_{\text{Rec 12}}$	0.070	0.026	0.121
$R_{\text{Rec 13}}$	0.244	0.097	0.389
$R_{\text{REEF 5}}$	0.713	0.175	1.381
$R_{\text{REEF 6}}$	1.789	0.542	2.646
$R_{\text{REEF 7}}$	0.160	0.056	0.225
$R_{\text{REEF 8}}$	0.532	0.112	0.876
$R_{\text{REEF 9}}$	0.233	0.108	0.323
$R_{\text{REEF 10}}$	0.166	0.059	0.252
$R_{\text{REEF 11}}$	0.006	6.0×10^{-6}	0.019
$R_{\text{REEF 12}}$	0.070	0.026	0.121
$R_{\text{REEF 13}}$	0.244	0.097	0.389

Table A12. Model results for the model with two *u* (different growth rates for the Rec versus REEF trajectories) and three states (Rec_{NPS}, Rec_{PSP} and REEF). See Table A11 for explanations of the labels.

Parameter	Estimate	Lower 95% CL	Upper 95% CL
u_{Rec}	-0.039	-0.056	-0.022
u_{REEF}	0.041	-0.005	0.109
$Q_{\text{Rec NPS}}$	0.017	5.74E-08	0.030
$Q_{\text{Rec PSP}}$	0.002	8.98E-08	0.008
$Q_{\text{Rec NPS:Rec PSP}}$	0.006	-1.79E-04	0.015
Q_{REEF}	0.012	5.02E-08	0.031
$R_{\text{Rec 5}}$	0.057	0.028	0.072
$R_{\text{Rec 6}}$	0.145	0.080	0.187
$R_{\text{Rec 7}}$	0.014	0.003	0.024
$R_{\text{Rec 8}}$	0.079	0.038	0.103
$R_{\text{Rec 9}}$	0.137	0.074	0.170
$R_{\text{Rec 10}}$	0.171	0.094	0.218
$R_{\text{Rec 11}}$	0.135	0.070	0.179
$R_{\text{Rec 12}}$	0.170	0.069	0.203
$R_{\text{Rec 13}}$	0.206	0.114	0.256
$R_{\text{REEF 5}}$	0.679	0.246	1.335
$R_{\text{REEF 6}}$	1.547	0.471	3.120
$R_{\text{REEF 7}}$	0.147	0.064	0.246
$R_{\text{REEF 8}}$	0.481	0.128	0.814
$R_{\text{REEF 9}}$	0.225	0.097	0.408
$R_{\text{REEF 10}}$	0.145	0.064	0.260
$R_{\text{REEF 11}}$	0.008	3.34E-05	0.024
$R_{\text{REEF 12}}$	0.066	0.027	0.118
$R_{\text{REEF 13}}$	0.235	0.086	0.381

MARSS: Recreational Fishery Survey, REEF Scuba Survey, and WDFW Trawl Survey Data

The results using all three data sets were similar to the previous modeling exercises. Four models had delta AICc values less than 2.0 (Table A13). Each included four trajectories (NPS and PSP recreational, REEF, and trawl). The best-fit model (delta AICc < 0.2 and fewest parameters) included a single population growth rate (u) for GPS and covariance between Rec_{NPS} and Rec_{PSP} ($u = 0.032 \pm 0.011$). Two additional models included a combined Rec + Trawl growth rate but a separate REEF growth rate again suggesting that the REEF survey samples a different assemblage. The fourth was unable to estimate process variance for Rec_{PSP} and was removed from consideration (Table A14, Figure A13d,e).

Table A13. Model selection criteria for MARSS models comparing different model structures using the WDFW recreational survey (Rec), REEF survey and WDFW trawl survey (Trawl). Data support for models was quantified using AICc (Akiake's Information Criterion corrected for sample size). The two regions were North Puget Sound (NPS) and Puget Sound Proper (PSP); MCA = management conservation area; GPS = Greater Puget Sound; All models included separate process variance for each population trajectory with either no covariance between the trajectories or allowing covariance between all or some of the trajectories; see process covariance column with additional information in the footnotes and footnotes for Table S1. There were 71 observation processes: 54 Rec (9 MCA plus 6 regulatory time periods), 9 REEF, and 8 Trawl. Numbers in parenthesis are the number of estimated parameters for that term. For the trajectories, the estimated parameter is the initial state (x_0). The number of *a* in **a** was 71 minus the number of population trajectories. A separate observation variance was estimated for each survey by MCA or trawl survey area. Thus 26 **R** parameters were estimated (Rec surveys in 9 MCAs, REEF surveys in 9 MCAs plus Trawl surveys in 8 areas). Bold indicates best-fit model (ΔAICc < 2.0 & fewest parameters).

Number and structure of pop. trajectories (**x**$_0$, **a**)[2]	Growth rates (**u**)[3]	Pop. trajectory covariance structure (**Q**)[4]	ΔAICc	Number of parameters (**u**, **a**, **Q**, **R**, **x**$_0$)
Rec$_{NPS}$, Rec$_{PSP}$,REEF, Trawl (4, 67)	Rec/Trawl + REEF (2)	Rec$_{NPS}$ & Rec$_{PSP}$ covary (5)	0.00	104
Rec$_{NPS}$, Rec$_{PSP}$,REEF, Trawl (4, 67)[1]	GPS (1)	No covariance (4)	1.11	102
Rec$_{NPS}$, Rec$_{PSP}$,REEF, Trawl (4, 67)	**GPS (1)**	**Rec$_{NPS}$ & Rec$_{PSP}$ covary (5)**	**1.39**	**103**
Rec$_{NPS}$, Rec$_{PSP}$, REEF, Trawl$_{NPS}$, Trawl$_{PSP}$ (5, 66)	Rec/Trawl + REEF (2)	Rec and trawl btw regions (7)	1.96	106
Rec$_{NPS}$, Rec$_{PSP}$,REEF, Trawl (4, 67)	GPS (1)	All trajectories covary (10)	2.71	108
Rec$_{NPS}$, Rec$_{PSP}$,REEF, Trawl (4, 67)	Survey (3)	Rec$_{NPS}$ & Rec$_{PSP}$ covary (5)	2.96	105
Rec$_{NPS}$, Rec$_{PSP}$,REEF, Trawl (4, 67)	Rec/Trawl + REEF (2)	All trajectories covary (10)	3.37	109
Rec$_{NPS}$, Rec$_{PSP}$, REEF, Trawl$_{NPS}$, Trawl$_{PSP}$ (5, 66)	GPS (1)	Rec and trawl btw regions (7)	3.67	105
Rec$_{NPS}$, Rec$_{PSP}$,REEF, Trawl (4, 67)	Rec/Trawl + REEF (2)	No covariance (4)	3.96	103
Rec$_{NPS}$, Rec$_{PSP}$, REEF, Trawl$_{NPS}$, Trawl$_{PSP}$ (5, 66)	Survey (3)	Rec and trawl btw regions (7)	4.66	107
Survey (3, 68)	GPS (1)	No covariance (3)	5.11	101
Rec$_{NPS}$, Rec$_{PSP}$,REEF, Trawl (4, 67)	Rec$_{NPS}$, Rec$_{PSP}$,REEF, Trawl (4)	Rec$_{NPS}$ & Rec$_{PSP}$ covary (5)	5.88	106

Rec$_{\text{NPS}}$, Rec$_{\text{PSP}}$,REEF, Trawl (4, 67)	Rec$_{\text{NPS}}$, Rec$_{\text{PSP}}$,REEF, Trawl (4)	No covariance (4)	6.10	105
Region x Survey (6, 65)	Rec/Trawl + REEF (2)	Regions covary within surveys (9)	6.54	108
Rec$_{\text{NPS,}}$ Rec$_{\text{PSP}}$,REEF, Trawl (4, 67)	Survey (3)	No covariance (4)	6.90	104
Survey (3, 68)	Survey (3)	No covariance (3)	7.21	103
Rec$_{\text{NPS}}$, Rec$_{\text{PSP}}$, REEF, Trawl$_{\text{NPS}}$, Trawl$_{\text{PSP}}$ (5, 66)	Rec, REEF, Trawl$_{\text{NPS}}$, Trawl$_{\text{PSP}}$ (4)	Rec and trawl btw regions (7)	7.51	108
Region x Survey (6, 65)	GPS (1)	Regions covary within surveys (9)	8.06	107
Survey (3, 68)	GPS (1)	All trajectories covary (6)	8.50	104
Rec$_{\text{NPS}}$, Rec$_{\text{PSP}}$, REEF, Trawl$_{\text{NPS}}$, Trawl$_{\text{PSP}}$ (5, 66)	Rec/Trawl + REEF (2)	Rec$_{\text{NPS}}$ & Rec$_{\text{PSP}}$ covary (6)	9.10	105
Region x Survey (6, 65)	Survey (3)	Regions covary within surveys (9)	9.26	109
Rec$_{\text{NPS}}$, Rec$_{\text{PSP}}$,REEF, Trawl (4, 67)	Rec$_{\text{NPS}}$, Rec$_{\text{PSP}}$,REEF, Trawl (4)	All trajectories covary (10)	9.48	111
Rec$_{\text{NPS}}$, Rec$_{\text{PSP}}$, REEF, Trawl$_{\text{NPS}}$, Trawl$_{\text{PSP}}$ (5, 66)	Rec/Trawl + REEF (2)	No covariance (5)	9.94	104
Rec$_{\text{NPS}}$, Rec$_{\text{PSP}}$, REEF, Trawl$_{\text{NPS}}$, Trawl$_{\text{PSP}}$ (5, 66)	Rec$_{\text{NPS}}$, Rec$_{\text{PSP}}$, REEF, Trawl$_{\text{NPS}}$, Trawl$_{\text{PSP}}$ (5)	Rec and trawl btw regions (7)	10.46	109
Region x Survey (6, 65)	Region (2)	Regions covary within surveys (9)	10.50	108
Rec$_{\text{NPS}}$, Rec$_{\text{PSP}}$, REEF, Trawl$_{\text{NPS}}$, Trawl$_{\text{PSP}}$ (5, 66)	GPS (1)	Rec$_{\text{NPS}}$ & Rec$_{\text{PSP}}$ covary (6)	11.07	104
Rec$_{\text{NPS}}$, Rec$_{\text{PSP}}$, REEF, Trawl$_{\text{NPS}}$, Trawl$_{\text{PSP}}$ (5, 66)	GPS (1)	No covariance (5)	11.38	103
Rec$_{\text{NPS}}$, Rec$_{\text{PSP}}$, REEF, Trawl$_{\text{NPS}}$, Trawl$_{\text{PSP}}$ (5, 66)	Survey (3)	Rec$_{\text{NPS}}$ & Rec$_{\text{PSP}}$ covary (6)	11.87	106
Region x Survey (6, 65)	Rec/Trawl + REEF (2)	No covariance (6)	11.98	105
Rec$_{\text{NPS}}$, Rec$_{\text{PSP}}$, REEF, Trawl$_{\text{NPS}}$, Trawl$_{\text{PSP}}$ (5, 66)	Survey (3)	No covariance (5)	12.14	105
Survey (3, 68)	Survey (3)	All trajectories covary (6)	12.36	106
RecNPS, RecPSP, REEF, Trawl (4, 67)	Survey (3)	All trajectories covary (10)	12.92	110
Region x Survey (6, 65)	Survey (3)	No covariance (6)	13.93	106
Rec$_{\text{NPS}}$, Rec$_{\text{PSP}}$, REEF, Trawl$_{\text{NPS}}$, Trawl$_{\text{PSP}}$ (5, 66)	GPS (1)	All trajectories covary (15)	14.22	113
Rec/Trawl$_{\text{NPS}}$, Rec/Trawl$_{\text{PSP}}$, REEF (3, 68)	Rec/Trawl + REEF (2)	Rec/Trawl$_{\text{NPS}}$ & Rec/Trawl$_{\text{PSP}}$ covary (4)	14.62	103

Rec$_{NPS}$, Rec$_{PSP}$, REEF, Trawl$_{NPS}$, Trawl$_{PSP}$ (5, 66)	Rec, REEF, Trawl$_{NPS}$, Trawl$_{PSP}$ (4)	Rec$_{NPS}$ & Rec$_{PSP}$ covary (6)	14.70	107
Rec$_{NPS}$, Rec$_{PSP}$, REEF, Trawl$_{NPS}$, Trawl$_{PSP}$ (5, 66)	Rec/Trawl + REEF (2)	All trajectories covary (15)	14.90	114
Rec$_{NPS}$, Rec$_{PSP}$, REEF, Trawl$_{NPS}$, Trawl$_{PSP}$ (5, 66)	Rec, REEF, Trawl$_{NPS}$, Trawl$_{PSP}$ (4)	No covariance (5)	14.96	106
Rec/Trawl$_{NPS}$, Rec/Trawl$_{PSP}$, REEF (3, 68)	Rec/Trawl + REEF (2)	No covariance (3)	15.45	102
Rec/Trawl$_{NPS}$, Rec/Trawl$_{PSP}$, REEF (3, 68)	GPS (1)	Rec/Trawl$_{NPS}$ & Rec/Trawl$_{PSP}$ covary (4)	16.60	102
Rec/Trawl$_{NPS}$, Rec/Trawl$_{PSP}$, REEF (3, 68)	GPS (1)	No covariance (3)	16.88	101
Region x Survey (6, 65)	Rec$_{NPS}$, Rec$_{PSP}$, REEF, Trawl (4)	No covariance (6)	16.96	107
Rec/Trawl$_{NPS}$, Rec/Trawl$_{PSP}$, REEF (3, 68)	Rec/Trawl$_{NPS}$, Rec/Trawl$_{PSP}$, REEF (3)	Rec/Trawl$_{NPS}$ & Rec/Trawl$_{PSP}$ covary (4)	17.22	104
Rec$_{NPS}$, Rec$_{PSP}$, REEF, Trawl$_{NPS}$, Trawl$_{PSP}$ (5, 66)	Rec$_{NPS}$, Rec$_{PSP}$, REEF, Trawl$_{NPS}$, Trawl$_{PSP}$ (5)	Rec$_{NPS}$ & Rec$_{PSP}$ covary (6)	17.64	108
Region x Survey (6, 65)	Region x Survey (6)	Regions covary within surveys (9)	17.80	112
Rec/Trawl$_{NPS}$, Rec/Trawl$_{PSP}$, REEF (3, 68)	Rec/Trawl$_{NPS}$, Rec/Trawl$_{PSP}$, REEF (3)	No covariance (3)	18.34	103
Rec$_{NPS}$, Rec$_{PSP}$, REEF, Trawl$_{NPS}$, Trawl$_{PSP}$ (5, 66)	Survey (3)	All trajectories covary (15)	18.40	115
Rec/Trawl$_{NPS}$, Rec/Trawl$_{PSP}$, REEF (3, 68)	GPS (1)	All trajectories covary (6)	18.54	104
Rec/Trawl$_{NPS}$, Rec/Trawl$_{PSP}$, REEF (3, 68)	Rec/Trawl + REEF (2)	All trajectories covary (6)	19.12	105
Region x Survey (6, 65)	Region (2)	No covariance (6)	20.39	105
Region x Survey (6, 65)	GPS (1)	No covariance (6)	20.51	104
Rec$_{NPS}$, Rec$_{PSP}$, REEF, Trawl$_{NPS}$, Trawl$_{PSP}$ (5, 66)	Rec, REEF, Trawl$_{NPS}$, Trawl$_{PSP}$ (4)	All trajectories covary (15)	20.93	116
Rec/Trawl$_{NPS}$, Rec/Trawl$_{PSP}$, REEF (3, 68)	Rec/Trawl$_{NPS}$, Rec/Trawl$_{PSP}$, REEF (3)	All trajectories covary (6)	21,82	106
Region x Survey (6, 65)	Region x Survey (6)	No covariance (6)	22.65	109
Rec/Trawl$_{NPS}$, Rec/Trawl$_{PSP}$, REEF$_{NPS}$, REEF$_{PSP}$ (4, 67)	Rec, REEF$_{NPS}$, REEF$_{PSP}$, Trawl (4)	No covariance (4)	23.02	105

Rec$_{NPS}$, Rec$_{PSP}$, REEF, Trawl$_{NPS}$, Trawl$_{PSP}$ (5, 66)	Rec$_{NPS}$, Rec$_{PSP}$, REEF, Trawl$_{NPS}$, Trawl$_{PSP}$ (5)	All trajectories covary (15)	24.01	117
Rec/Trawl$_{NPS}$, Rec/Trawl$_{PSP}$, REEF$_{NPS}$, REEF$_{PSP}$ (4, 67)	Region (2)	REEF$_{NPS}$ & REEF$_{PSP}$ covary (5)	25.27	104
Rec/Trawl$_{NPS}$, Rec/Trawl$_{PSP}$, REEF$_{NPS}$, REEF$_{PSP}$ (4, 67)	Region (2)	No covariance (4)	25.60	103
Rec/Trawl$_{NPS}$, Rec/Trawl$_{PSP}$, REEF$_{NPS}$, REEF$_{PSP}$ (4, 67)	NPS, PSP, REEF$_{NPS}$, REEF$_{PSP}$ (4)	REEF$_{NPS}$ & REEF$_{PSP}$ covary (5)	25.86	106
Rec/Trawl$_{NPS}$, Rec/Trawl$_{PSP}$, REEF$_{NPS}$, REEF$_{PSP}$ (4, 67)	GPS (1)	No covariance (4)	25.96	102
Region x Survey (6, 65)	Region x Survey (6)	Rec$_{NPS}$ & Rec$_{PSP}$ covary (7)	27.61	108
Rec/Trawl$_{NPS}$, Rec/Trawl$_{PSP}$, REEF$_{NPS}$, REEF$_{PSP}$ (4, 67)	GPS (1)	All trajectories covary (10)	29.98	108
Region x Survey (6, 65)	Rec/Trawl + REEF (2)	All trajectories covary (21)	30.54	120
Rec/Trawl$_{NPS}$, Rec/Trawl$_{PSP}$, REEF$_{NPS}$, REEF$_{PSP}$ (4, 67)	Region (2)	All trajectories covary (10)	33.14	109
Region x Survey (6, 65)	GPS (1)	All trajectories covary (21)	34.52	119
Region x Survey (6, 65)	Survey (3)	All trajectories covary (21)	34.57	121
Rec/Trawl$_{NPS}$, Rec/Trawl$_{PSP}$, REEF$_{NPS}$, REEF$_{PSP}$ (4, 67)	Rec, REEF$_{NPS}$, REEF$_{PSP}$, Trawl (4)	All trajectories covary (10)	35.60	111
Region x Survey (6, 65)	Rec$_{NPS,}$ Rec$_{PSP}$, REEF, Trawl (4)	All trajectories covary (21)	37.86	122
Region x Survey (6, 65)	Region (2)	All trajectories covary (21)	38.49	120
Region x Survey (6, 65)	Region x Survey (6)	All trajectories covary (21)	43.33	124
Region (2, 69)	GPS (1)	No covariance (2)	66.50	100
Region (2, 69)	Region (2)	No covariance (2)	68.95	101
Region (2, 69)	GPS (1)	All trajectories covary (3)	69.37	101
Region (2, 69)	Region (2)	All trajectories covary (3)	71.86	102
GPS (1, 70)	GPS (1)	No covariance (1)	85.52	99

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[1] These models were unable to estimate processes variance for Rec$_{PSP}$ and were dropped from consideration.

[2] The population trajectory column gives the number and designation of the trajectories. For example, Rec_{NPS}, Rec_{PSP}, REEF, Trawl = 4 trajectories as labeled. All Rec observations in NPS are of the Rec_{NPS}, all Rec observations in PSP are of Rec_{PSP}, all REEF observations are of the REEF trajectory and all Trawl observations are of the Trawl trajectory. In addition, there are the following abbreviations. Survey = one trajectory for each survey type (Rec, REEF & Trawl). Region x Survey = Rec_{NPS}, Rec_{PSP}, $REEF_{NPS}$, $REEF_{PSP}$, $Trawl_{NPS}$, and $Trawl_{PSP}$ trajectories. GPS = a single trajectory and all observations are of this one trajectory.

[3] The growth rate column shows the number of the growth rates. These are analogous to the population trajectory column (column 1). Thus, Region x Survey means that separate growth rates are estimated for Rec_{NPS}, Rec_{PSP}, $REEF_{NPS}$, $REEF_{PSP}$, $Trawl_{NPS}$, and $Trawl_{PSP}$. GPS = a single growth rate for all trajectories.

[4] The covariance column shows which covariances were estimated between the trajectories. No covariance = trajectories were treated as independent and a diagonal variance-covariance matrix was assumed. One variance estimated for each trajectory. Rec_{NPS} & Rec_{PSP} covary = covariance estimated between the Rec_{NPS} and Rec_{PSP} trajectories. All other covariances set to 0. Rec and trawl btw regions = covariance estimated between the Rec_{NPS} and Rec_{PSP} trajectories and $Trawl_{NPS}$ and $Trawl_{PSP}$ trajectories. All other covariances set to 0. Regions covary within surveys = Rec_{NPS}:Rec_{PSP}, $REEF_{NPS}$:$REEF_{PSP}$ and $Trawl_{NPS}$:$Trawl_{PSP}$ covariance terms are estimated. No covariance terms between surveys (e.g., Rec_{NPS}:REEF covariance term set to 0). All trajectories covary = an unconstrained variance-covariance matrix is estimated. The size of the matrix is determined by the number of trajectories. Thus if 18 trajectories are estimated, the matrix is 18x18 and there are 18 variances and 153 covariances.

Table A14. Model results for the one growth rate (*u*), four population trajectories (Rec_{NPS}, Rec_{PSP}, REEF, Trawl) model allowing covariance between the Rec_{NPS} and Rec_{PSP} trajectories. This model used all three data sets: the WDFW recreational survey (Rec), the REEF diver survey and the WDFW trawl survey (Trawl). The parameters are denoted as follows. Q_{A} = process variance of trajectory A, $Q_{\text{A:B}}$ = process covariance between trajectories A and B, $R_{\text{Rec\#}}$ = observation variance for the Rec survey in Marine Conservation Area #, $R_{\text{REEF\#}}$ = observation variance for the REEF survey in Marine Conservation Area #, R_{TrawlXX}= observation variance for the Trawl survey in area XX, *u* = growth rate where the number of *u* indicates the number of different u that were estimated. The geographic areas are NPS = North Puget Sound, PSP = Puget Sound Proper, GPS = Greater Puget Sound. See the legend of Figure S3 for the definitions of the geographic regions for the trawl surveys, e.g. $R_{\text{Trawl GB}}$. CL = confidence limit. CLs were calculated using the estimated Hessian calculation provided in the MARSS R package.

Parameter	Estimate	Lower 95% CL	Upper 95% CL
u_{GPS}	-0.031	-0.050	-0.013
$Q_{\text{Rec NPS}}$	0.020	7.3 x 10-8	0.027
$Q_{\text{Rec PSP}}$	0.001	1.1 x 10-7	0.007
$Q_{\text{Rec NPS:Rec PSP}}$	0.005	-3.7 x 10-4	0.012
Q_{REEF}	0.024	0.001	0.041
Q_{Trawl}	0.172	0.013	0.343
$R_{\text{Rec 5}}$	0.062	0.030	0.076
$R_{\text{Rec 6}}$	0.157	0.082	0.195
$R_{\text{Rec 7}}$	0.015	0.005	0.021
$R_{\text{Rec 8}}$	0.090	0.045	0.103
$R_{\text{Rec 9}}$	0.158	0.070	0.177
$R_{\text{Rec 10}}$	0.191	0.086	0.229
$R_{\text{Rec 11}}$	0.153	0.068	0.170
$R_{\text{Rec 12}}$	0.215	0.075	0.202
$R_{\text{Rec 13}}$	0.242	0.106	0.246
$R_{\text{REEF 5}}$	0.708	0.237	1.160
$R_{\text{REEF 6}}$	1.686	0.451	2.793
$R_{\text{REEF 7}}$	0.156	0.057	0.246
$R_{\text{REEF 8}}$	0.535	0.102	0.892
$R_{\text{REEF 9}}$	0.236	0.099	0.370
$R_{\text{REEF 10}}$	0.157	0.059	0.268
$R_{\text{REEF 11}}$	0.006	5.8 x 10-6	0.025
$R_{\text{REEF 12}}$	0.070	0.024	0.118
$R_{\text{REEF 13}}$	0.254	0.072	0.455
$R_{\text{Trawl GB}}$	0.246	0.056	0.498

$R_{\text{Trawl JE}}$	0.352	0.065	0.658
$R_{\text{Trawl JW}}$	0.276	0.040	0.496
$R_{\text{Trawl SJ}}$	0.269	0.029	0.447
$R_{\text{Trawl CS}}$	0.333	0.065	0.470
$R_{\text{Trawl HC}}$	0.229	0.029	0.370
$R_{\text{Trawl SS}}$	1.457	0.413	2.639
$R_{\text{Trawl WI}}$	0.277	0.051	0.498

Analysis of Trends by Recreational Regulatory Period

The preceding analyses all estimate *u*, one long-term population trend across the entire time-series. However, a number of regulatory changes has occurred through time. Here, we estimate a time-varying *u* and *a* to allow us to examine changes in population growth rate with each regulatory change, and more specifically, to determine if there is any evidence of more recent recovery over the final portion of the time-series.

We estimate a different *u* for each of the regulatory periods within the recreational survey data (Williams et al. 2010). Key regulatory changes were the imposition of 10/5 (NPS/PSP) bag limit in 1983, a reduction of 5/3 bag limit in 1994, a one fish per bag for all Puget Sound in 2000, and the imposition of a 120-foot (36.6 m) maximum depth for bottom-fishing in 2010. However, we shifted the 2010 boundary to 2007 through 2008 because we received the new download of data for 2008 through 2014 and there some differences in the estimation procedures. A canary and yelloweye rockfish catch ban was imposed in 2001, but is not included in the present analysis.

The analysis shows changes in *u* (the slope of the log abundance index) with each regulatory change (Table A15, Figure A14a). Most importantly, CPUE has tended to decrease in all periods with the exception of 1983 through 1993. Thus, there is no evidence of recent recovery of total rockfish from the recreational survey data alone with *u* = -0.04 for 2008 through 2014.

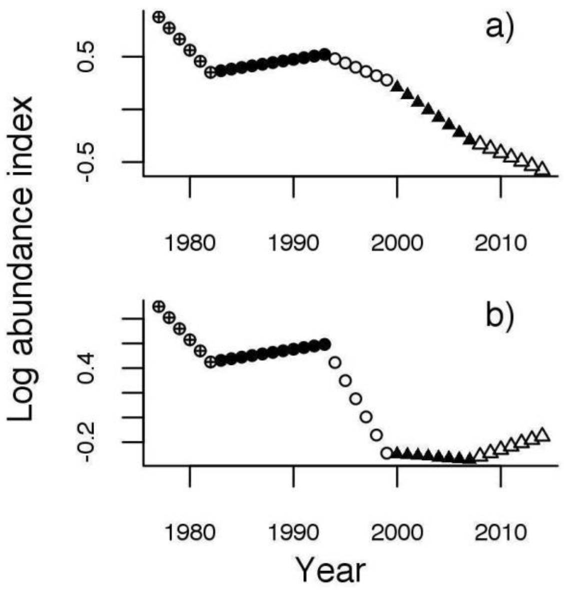

Figure A14. Log-abundance index for a) Greater Puget Sound estimated using the recreational survey data, and b) for Greater Puget Sound estimated using the recreational survey data and the REEF scuba survey data. Symbols indicate different regulatory periods as described in the text.

Table A15. Slope and standard error by regulatory time-series. See Figure A14 for a visual representation of the time-series.

	Recreational Data		Rec + REEF Data	
Year	Slope (u)	Standard Error	Slope (u)	Standard Error
1977-1982	-0.1051	0.0332	-0.09	0.04
1983-1993	0.0154	0.0132	0.01	0.01
1994-1999	-0.0404	0.0339	-0.15	0.03
2000-2007	-0.0712	0.0214	-0.01	0.02
2008-2014	-0.0409	0.0463	0.03	0.02

Including the REEF scuba survey data does suggest some recent recovery in CPUE for total rockfish (Figure A14b). In this case, the overall trajectories were similar, but there was positive slope from 2008 through 2014 suggesting some recovery for total rockfish.

These results should be taken with some caution, however. Both the recreational survey in these years and the REEF scuba survey generally, are limited to shallow water (less than ~120 feet [36.6 m]). Yelloweye rockfish, canary rockfish, and bocaccio are not typically found at these depths and recent data may not reflect trends in the listed species. Additionally, fisher behavior such as avoidance (of listed species) may also have affected the CPUE.

Which data sets to include in the trend analysis?

While model selection can help us evaluate the possibility of different processes at different spatial arrangements, it cannot help us decide which data sets to include or exclude from the analyses and which provide the best estimate of population trend. For example, initial declines as indicated by the recreational survey data were strong. The REEF data do not cover the earlier period, but do suggest some recent (within the last 10 years) increases at least at recreational scuba depths of < 130 feet (39.6 m). However, because the listed species are extremely rare at the shallower scuba depths (Love et al. 2002), the REEF data may not provide good estimates of potential trends for bocaccio, canary rockfish, and yelloweye rockfish. Moreover, while never common, over the last 5 to 10 years, canary and yelloweye rockfish have declined as a proportion of the rockfish assemblage observed by the REEF divers. Thus, any declines for these species are likely to be stronger and any increases in population size weaker than for the general trend. Theses combined factors suggest that the combined Recreational + REEF analysis should be taken with some caution and interpreted with a precautionary approach. As noted above, the trawl data likely represent a different process (state) because the listed species are only rarely caught in soft-bottom habitats.

Appendix A: Literature Cited

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Appendix B. Memorandum from Michael Ford, Director, Conservation Biology Division, Northwest Fisheries Science Center to Chris Yates, Assistant Regional Administrator, West Coast Region Protected Resources Division, December 9, 2015.

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Northwest Fisheries Science Center
2725 Montlake Boulevard East
SEATTLE, WASHINGTON 98112-2097
F/NWC1

December 9, 2015

MEMORANDUM

To: Chris Yates, Assistant Regional Administrator, West Coast Region Protected Resources Division

From: Michael Ford, Director Conservation Biology Division, Northwest Fisheries Science Center

Cc: Lynne Barre and Dan Tonnes, Puget Sound Ecosystem Branch, WCR PRD

Subject: Consideration of new genetic information for yelloweye rockfish (*Sebastes ruberrimus*) canary rockfish (*S. pinniger*) and bocaccio (*S. paucispinis*) Puget Sound/Georgia Basin DPSs

This memorandum is in response to your October 23 request to reconvene the rockfish Biological Review Team (BRT) to consider the implications of recently collected genetic data on the boundaries of the distinct population segments (DPS) of yelloweye rockfish, canary rockfish and bocaccio in the Puget Sound/Georgia Basin region (PS/GB, hereafter).

Eight members of the BRT that conducted the original status review (Drake *et al.* 2010) along with several other NWFSC and WCR staff met at the NWFSC Montlake Laboratory on November 13, 2015[1]. The BRT heard presentations by NWFSC scientists Kelly Andrews and Krista Nichols on recent genetic analyses on the population structure of the three rockfish species. The new information consisted of genetic analysis of samples of the three species collected by NWFSC staff, Washington State Department of Fish and Wildlife staff and Puget Sound anglers as part of a NMFS-funded cooperative research project. The project also analyzed samples collected from the Washington coast by the NWFSC FRAM Division trawl

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[1] BRT members participating were: Jonathan Drake, Ewann Berntson (by phone), Jason Cope, Richard Gustafson, Elizabeth Holmes, Nick Tolimieri, Robin Waples, and Susan Sogard (SWFSC, by phone). Original BRT members Phillip Levin and Gregory Williams were unable to attend.

surveys, as well as some samples provided by DFO Canada, the SWFSC and others. Information on the sampling design and analyses are provided in the two presentations, and will be written up in more detail for the 5 year status review in 2016.

The specific questions you asked the BRT to address were:

*<u>Question 1</u>: Does the new genetic information change previous conclusions that the yelloweye rockfish, canary rockfish or bocaccio in Puget Sound/Georgia Basin populations are **discrete**?*

*<u>Question 2</u>: Does the new genetic information support a **revision** to the geographic boundary of any Puget Sound/Georgia Basin populations?*

*Question 3: For all populations that are discrete, does the new genetic data or potentially revised geographic boundary change previous conclusions that they are also **significant** (and therefore meet the criteria for a DPS)?*

Below, we summarize the BRT's discussion and response to these questions for each of the three species separately.

Yelloweye rockfish

<u>Question 1</u>:

It was the consensus of the BRT that the information presented supported the previous conclusion that yelloweye rockfish from the PS/GB are discrete from coastal populations. The new data consisted of 44 samples from the U.S. portion of the PS/GB DPS, 18 samples from the Strait of Juan de Fuca, 16 samples from inland waters of British Columbia and 26 samples from the outer coasts of Washington State and British Columbia, analyzed at several thousand single nucleotide polymorphic sites (SNPs) in their genomes. Several different analytical methods indicated consistent genetic differentiation between the inland and coastal samples, at a level consistent with the limited data that were available at the time of the previous status review. In short, the new data are consistent with and further support the existence of a population of PS/GB yelloweye rockfish that is discrete from coastal populations.

<u>Question 2:</u>

The new Canadian samples provided considerably more fine-scale geographic resolution of population genetic structure in this species. It was the consensus of the BRT that the information presented indicated that the northern boundary of the yelloweye rockfish DPS appeared to be in the Queen Charlotte Channel near Malcolm Island rather than at the current boundary at the northern Strait of Georgia. In particular, the new data included samples from northern Johnstone

Strait that clustered genetically with the PS/GB samples. In addition, the BRT briefly reviewed new microsatellite data from Canada DFO (COSEWIC 2008; Yamanaka *et al* unpublished; Yamanaka *et al.* 2006) that indicated a genetic difference between populations in this area.

The BRT also noted that within the PS/GB DPS, samples from Hood Canal were genetically differentiated from other PS/GB samples, indicating a previously unappreciated degree of population differentiation within the DPS.

Question 3:

The BRT concluded that the new genetic data do not change any of the conclusions regarding population significance in the prior status review. Those conclusions were based primarily on ecological differences between the PS/GB and coastal areas, which remain unchanged by the new information.

Canary rockfish

Question 1:

It was the consensus of the BRT that the information presented does change the previous conclusion that canary rockfish in the PS/GB are discrete from coastal populations. At the time of the previous status review, there were no genetic data available for canary rockfish in the PS/GB. The prior status review concluded that the PS/GB population was likely to be discrete based upon analogy to other rockfish species that did exhibit genetic differentiation between the PS/GB and coastal areas, although the review also noted that canary rockfish had a greater propensity for long-distance adult movements than some other species.

The new data consist of 40 samples from the U.S. portion of the PS/GB DPS, 22 samples from the Strait of Juan de Fuca and 18 samples from the outer Washington State coast, genotyped at several thousand SNP loci. Several different analytical methods failed to find any consistent genetic differentiation between the coastal and PS/GB samples, thus providing no evidence of genetic discreteness of canary rockfish in the PS/GB. The BRT discussed the power of the genetic analysis, noting that the very large number of loci provided considerable power to detect differentiation among sample groups. The BRT concluded that the lack of such differentiation indicated that it was unlikely that the PS/GB samples were discrete from coastal areas. The BRT discussed the possibility that other factors, such as oceanography and ecological differences among locations, might be sufficient to indicate a discrete population, but concluded that the lack of genetic differentiation indicated sufficient dispersal and that discreteness due to environmental factors was not plausible.

Question 2:

The BRT concluded that the new information indicated that canary rockfish in the PS/GB are likely part of a DPS that also includes populations on the outer coast (DPS scenario 4 of the previous status review).

Question 3:

This question was not explicitly discussed with respect to canary rockfish since the BRT concluded that canary rockfish in the PS/GB were not discrete from coastal populations.

Bocaccio

Question 1:

It was the consensus of the BRT that there were insufficient new data on bocaccio (only 2 PS/GB DPS samples analyzed) to update the prior status review determination that PS/GB bocaccio were potentially distinct from coastal populations. The BRT noted that bocaccio have a propensity for greater adult movement than more benthic rockfish species, similar to the case for canary rockfish. There was some discussion that the lack of genetic differentiation between coastal and PS/GB canary rockfish might suggest a similar lack of genetic differentiation for bocaccio, due to similarities in the life history of the two species. Ultimately, however, the majority of the BRT concluded that there was considerable uncertainty regarding the discreteness of PS/GB bocaccio, similar to the conclusions of the previous status review. In other words, the BRT concluded that the new information was not sufficient to change the conclusions of the previous BRT.

Question 2:

The BRT determined that the new genetic data do not provide any new information on revising the DPS boundary.

Question 3:

The BRT determined that the new genetic data do not provide any new information on the significance criterion of the DPS policy as it relates to bocaccio.

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