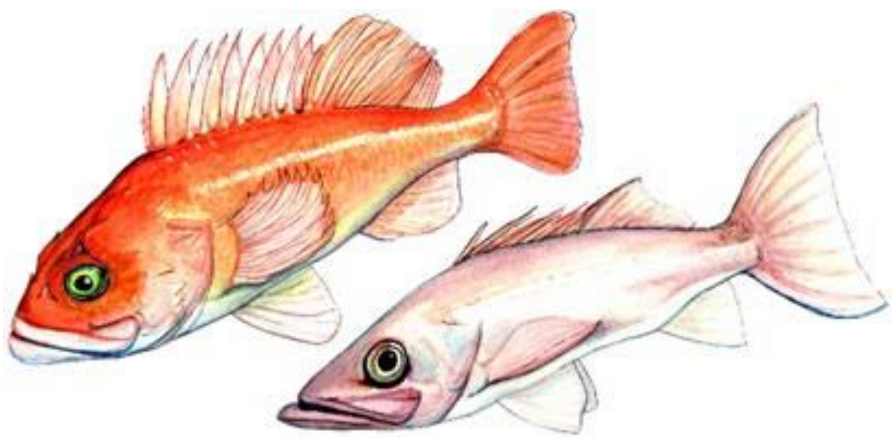
ROCKFISH RECOVERY PLAN

Puget Sound / Georgia Basin
Yelloweye Rockfish (*Sebastes ruberrimus*)
and Bocaccio (*Sebastes paucispinis*)



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LITERATURE CITATION SHOULD READ AS FOLLOWS:
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NOTE: In 2021, a typographic error was discovered in the implementation schedule (Table 21) and corrected. This affected the estimated implementation cost on Page 113, which was also corrected. All values now reflect their originally intended calculation and the citation remains NMFS (2017).

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Abbreviations and Acronyms

Committee on the Status of Endangered Wildlife in Canada	COSEWIC
Department of Defense	DOD
Department of Natural Resources, WA	DNR
Department of Ecology, WA	Ecology
Fisheries and Oceans Canada	DFO
Distinct Population Segments	DPS
Environmental Protection Agency, US	EPA
Endangered Species Act	ESA
Fisheries Conservation Plan	FCP
Incidental Take Permit	ITP
National Oceanic and Atmospheric Administration	NOAA
Northwest Fisheries Science Center	NWFSC
Northwest Indian Fisheries Commission	NWIFC
Northwest Straits Foundation	NWF
Northwest Straits Initiative	NWSI
National Marine Fisheries Service	NMFS
Marine Resource Committees	MRCs
Multibeam Echosounder	MBES
Ocean Acidification	OA
Polybrominated diphenyl ethers	PBDEs
Polychlorinated biphenyls	PCBs
Remotely Operated Vehicle	ROV
Rockfish Conservation Area	RCA
Species at Risk Act (Canada)	SARA
Spawning Potential Ratio	SPR
United States Fish and Wildlife Service	USFWS
Washington Department of Fish and Wildlife	WDFW
Young-of-Year	YOY

EXECUTIVE SUMMARY

Overview—Recovering Listed Rockfish: Total rockfish abundance in Puget Sound has declined approximately 70 percent in the last 40 years. Yelloweye rockfish (*Sebastes ruberrimus*) and bocaccio (*Sebastes paucispinis*) have declined to an even greater extent (Drake et al. 2010).

This recovery plan outlines actions and research for the conservation and survival of threatened yelloweye rockfish and endangered bocaccio using the best available science per the requirements of the Endangered Species Act (ESA). The recovery plan links management actions to an active research program to fill data gaps and a monitoring program to assess these actions' effectiveness. Research and monitoring results will provide information to refine ongoing actions and prioritize new actions to achieve the plan's goal: to restore the listed species to the point where they no longer require the protections of the ESA.

Current Species Status: Yelloweye rockfish and bocaccio occupy the waters of the Pacific coast from California to Alaska. Yelloweye rockfish and bocaccio in the waters of the Puget Sound/Georgia Basin were each determined to be a Distinct Population Segment (DPS) (75 Fed. Reg. 22276). The Puget Sound/Georgia Basin DPS of yelloweye rockfish was listed as "threatened" and bocaccio was listed as "endangered" under the ESA on April 28, 2010 (75 Fed. Reg. 22276). The DPSs include all yelloweye rockfish and bocaccio (listed rockfish) found in waters of Puget Sound, the Strait of Georgia, and the Strait of Juan de Fuca east of Victoria Sill. Critical habitat was designated for all species of listed rockfish in 2014 under section 4(a)(3)(A) of the ESA (79 Fed. Reg. 68041, November 13, 2014). Recent research has found evidence for two populations of yelloweye rockfish within the DPS—one in Hood Canal and one within the rest of the Puget Sound/Georgia Basin.

There is no single reliable historical or contemporary population estimate for yelloweye rockfish or bocaccio within the Puget Sound/Georgia Basin DPS (Drake et al. 2010). Despite this limitation, there is clear evidence that each species' abundance has declined dramatically (Drake et al. 2010). The best available data indicates that the total rockfish population in the Puget Sound region is estimated to have declined approximately 3 percent per year for the past several decades, corresponding to an approximate 70 percent decline from 1965 to 2007 (Drake et al. 2010). The decline of yelloweye rockfish and bocaccio is estimated to be greater than the 70 percent observed in the total rockfish decline during that time period (Drake et al. 2010).

Regulatory measures have been taken by the State of Washington over the last several decades to protect all rockfish, including a commercial ban on rockfish fishing in the late 1980s and early 1990s, more recent closures of commercial fisheries with rockfish bycatch (Palsson et al. 2009; WDFW 2010b), a moratorium initiated in 2010 on recreational rockfish catch, and a 120-foot (36.6-m) depth limit while bottom fishing (WDFW 2014). Despite these measures, listed rockfish continue to be at risk from bycatch in some of the areas of the DPSs.

Though historical overfishing has been recognized as the primary cause of the decline of rockfishes in Puget Sound (Palsson et al. 2009; Drake et al. 2010; Williams et al. 2010), there is some uncertainty about the relative impact of some fisheries today, and of the additional remaining threats, which include degraded water quality and habitat, contaminants, derelict fishing gear, and other threats (Palsson et al. 2009; Drake et al. 2010; WDFW 2013).

The life history of listed rockfish species, including long lives, slow growth, and late maturity combined with low survival rates of young make recovery especially challenging. Even if all threats are effectively reduced or eliminated, it is likely recovery will take several decades.

Recovery Objectives: 1) Continue to improve our knowledge of the current and historical population status of yelloweye rockfish and bocaccio and their habitats. This information is necessary so that populations can be characterized on a management unit basis and a detailed program can be developed for implementing recovery actions to most efficiently achieve the delisting criteria. 2) Reduce or eliminate existing threats to listed rockfish from fisheries/anthropogenic mortality. 3) Reduce or eliminate existing threats to listed rockfish habitats and restore degraded or removed rockfish habitat.

Recovery Strategy and Program: The plan addresses all of the known threats—drawing on existing information to prioritize actions. The plan uses an adaptive management approach for conducting the research required to manage and recover listed rockfish and inform implementation of actions to ensure each of the potential threats does not limit recovery. Comments on a draft plan from the Recovery Team, the public, peer reviewers, stakeholders, and co-managers were valuable in finalizing the recovery strategy and program outlined in this final plan.

The plan identifies research to better understand potential impacts from fisheries and other threats, as well as the efficacy of regulations put into place to minimize the effects of threats. The plan calls for research where more information is needed and for action where sufficient information exists to move forward. For example, the plan includes evaluation of fishery regulations and further assessment of the impact of some fisheries, and considers additional protections after further assessment over the long term. In some areas, listed rockfish bycatch risk may be relatively high from some fisheries despite regulations put into place in 2010 or before to limit bycatch. The plan recommends the potential use of marine reserves or rockfish conservation areas to contribute to the restoration of rockfish population abundance and size and age diversity because their use for rockfish conservation is well-supported in the research. We do not suggest specific sites for these conservation areas, but include biological and sociological parameters to consider during any process to establish them, as well as tribal treaty rights considerations.

The recovery program laid out in the plan includes approximately 45 actions to address the following topics:

- Actions to enable a greater understanding of listed rockfish population abundance, demographics, and habitat associations.
  - Example action: fishery-independent population and spatial surveys (such as Remotely Operated Vehicle (ROV) surveys) in the nearshore and deepwater environments.
- Fisheries management consistent with recovery goals.
  - Example action: assess the need for and establish marine reserves or rockfish conservation areas (areas not subject to potential anthropogenic mortality) where prioritized.
- Protection and restoration of rockfish habitats and the Puget Sound/Georgia Basin ecosystem.
  - Example action: nearshore protection/restoration, with an emphasis on native kelp.
- Development of an education, outreach, and public involvement plan.

- Example action: improve rockfish species identification by fishers and documentation of bycatch.
- Securing public support for listed rockfish recovery.
  - Example action: work with partners to seek a variety of types of funds to support recovery over a long time frame.

Recovery Criteria: To develop objective and measurable biological criteria to quantitatively evaluate rockfish recovery, we use spawning potential ratio (SPR). SPR compares the spawning ability (or reproductive capacity) of a stock in the fished condition to the stock's spawning ability (or reproductive capacity) in the unfished condition. Changes in SPR through time provide insight into population viability and recovery trajectory. The calculation of SPR typically requires estimates of the current fishing mortality (F), natural mortality (M), age and growth parameters, and maturity (and selectivity is typically estimated) at age. While these parameters are often inputs or estimates from data-rich stock assessments, more data-limited SPR estimators have been developed for some species. Unfortunately, the estimation of these parameters is often data intensive and difficult, especially for data-poor species like yelloweye rockfish and bocaccio in Puget Sound/Georgia Basin. However, a variation on this approach uses ratios of life history parameters that are easier to obtain and length data, and we have applied this approach for listed rockfish. The status of SPR over defined time periods is the biological criterion for delisting yelloweye rockfish and downlisting/delisting bocaccio in the Puget Sound/Georgia Basin DPSs.

We identify different scenarios of levels of SPR and time periods, which if reached would provide sufficient population viability for each species (in association with an assessment of the threats-based criteria) for delisting/downlisting each species as applicable (Tables ES1 to ES4). We also identified threats-based criteria for known threats; examples of these criteria are shown in Tables ES5 and ES6. The downlisting criteria for bocaccio generally require completed research and/or that programs are in place to understand, limit, and mitigate threats, while delisting criteria for both yelloweye rockfish and bocaccio requires that the threats are found to not limit recovery of the listed species.

Table ES1. Yelloweye rockfish biological-based delisting criteria (non-Hood Canal population).

	Overall Minimum Productivity (SPR)	**Minimum Time at Target**
Scenario A	15% (and increasing after first sampling event finds 15%)	25 years (no less than five systematic sampling events with 80% probability/confidence interval)
Scenario B	20 to 24%	15 years (no less than four systematic sampling events with 80% probability)
Scenario C	25% (and above)	10 years (no less than three systematic sampling events with 80% probability)

Table ES2. Yelloweye rockfish biological-based delisting criteria (Hood Canal population).

	Overall Minimum Productivity (SPR)	**Minimum Time at Target**
Scenario A	20 to 24%	15 years (no less than four systematic sampling events with 80% probability)
Scenario B	25% (and above)	10 years (no less than three systematic sampling events with 80% probability)

Table ES3. Bocaccio biological-based downlisting criteria.

Overall Minimum Productivity (SPR)	**Minimum Time at Target**
10% and increasing	15 years (no less than four systematic sampling events with 80% probability)

Table ES4. Bocaccio biological-based delisting criteria.

	Overall Minimum Productivity (SPR)	**Minimum Time at Target**
Scenario A	15% (and increasing after first sampling event finds 15%)	15 years (no less than four systematic sampling events with 80% probability)
Scenario B	20% and above	10 years (no less than three systematic sampling events with 80% probability)
Scenario C	25% and above	5 years (no less than two systematic sampling events with 80% probability)

Table ES5. *Example* Threats-based delisting criteria for yelloweye rockfish.

Listing Factor 1: Destruction, Modification, or Curtailment of Habitat or Range	
Derelict fishing gear	Programs are in place to facilitate, and require reporting, preventing, and promptly removing derelict fishing gear (i.e., shrimp pots, fishing nets) that has been demonstrated to result in bycatch or result in harm to yelloweye rockfish and yelloweye rockfish habitat.
Contaminants/ Bioaccumulants	Contaminant levels in yelloweye rockfish, prey species, or surrogate rockfish populations (i.e., quillback rockfish, *Sebastes maliger*) in the Puget Sound/Georgia Basin indicate a reduction or slowing of accumulation of legacy contaminants, such as PCBs and DDTs. This could include data showing that overall contaminant levels in the population are decreasing or accumulation is slowing, or information that younger fish have a proportionally reduced contaminant load. A decrease in the number of contaminated sites would also indicate a reduction in contaminants in a portion of the habitat of yelloweye rockfish.
Nutrients	Management actions and programs are in place to prevent and reduce nutrient inputs. The effects of nutrient inputs (food chain, hypoxia) are found to be not limiting recovery.
Invasive species/ Non-native species	Invasive species that can affect habitat (e.g., tunicates, seaweeds, others) are found to be not limiting recovery. Programs are in place to remove or mitigate the effects of invasive species on yelloweye rockfish and yelloweye rockfish habitat.

Table ES6. *Example* Threats-based downlisting and delisting criteria for bocaccio.

Listing Factor 2: Over-utilization for Commercial, Recreational, Scientific, or Educational Purposes		
	Downlisting Criteria	**Delisting Criteria**
Bycatch/Catch	Bocaccio are protected from bycatch/catch by fishery regulations and research permitting sufficient to support maintenance and enhancement of abundance, LB-SPR/biomass, spatial structure, and diversity (bycatch/catch can be reliably estimated from empirical data sources). Bycatch is mitigated when it occurs (i.e., use of descending devices and safe handling techniques).	Bocaccio are protected from bycatch/catch by fishery regulations and research permitting sufficient to support maintenance and enhancement of abundance, LB-SPR/biomass, spatial structure, and diversity (bycatch/catch can be reliably estimated from empirical data sources). Bycatch is mitigated when it occurs (i.e., use of descending devices and safe handling techniques).

Coordination, Estimated Date, and Recovery Cost: Recovery of listed rockfish is a long-term effort that requires cooperation and coordination from organizations and communities around Puget Sound. Many actions that will benefit listed rockfish and their habitats are already underway and involve such cooperation. This plan was developed with involvement and input from a variety of co-managers and stakeholders, including Federal and state agencies, some treaty tribes, individuals from non-profit groups, and the fishing and academic communities.

At present, it is difficult to project a date for recovery. As we obtain information on present abundance, as well as information to assess the impact on how threats may limit recovery and how the threats can be effectively mitigated, more robust time and expense projections will be developed.

The cost of the approximately 45 actions recommended in this plan for the first 5 years of recovery is about $16,843,126. Assuming that recovery takes one and a half generations (of yelloweye rockfish) or approximately 60 years, the total recovery costs over 60 years would be approximately $82,970,000. The annual cost of recovery is estimated to decrease substantially after the first 5 to 10 years if the necessary baseline research and management actions are performed. There are numerous parallel efforts underway, independent from listed rockfish recovery, to protect and restore the Puget Sound ecosystem. Examples of such efforts include oil spill prevention measures, contaminated sediment clean-up projects, and restoration of nearshore environments. These efforts will provide benefits to listed rockfish and their habitats and prey base and are thus highlighted in the plan. However, the costs of these actions are not included in the total cost of rockfish recovery because they would occur independent of this plan. Similarly, actions conducted to restore listed rockfish and their habitats will benefit other listed species that utilize the Puget Sound area, such as Puget Sound Chinook salmon (*Oncorhynchus tshawytscha*), and may provide economic benefits. We are unable to quantify the economic benefits of listed rockfish recovery actions, but the benefits to the ecosystem and economy could completely or partially offset the total recovery costs estimated here.

I. BACKGROUND

A. PURPOSE OF THE RECOVERY PLAN

The Endangered Species Act of 1973 (ESA) requires NOAA's National Marine Fisheries Service (NMFS) to develop recovery plans for marine species listed under the ESA. The purpose of recovery plans is to guide implementation of recovery of the species. Plans address threats to ensure the species are once again self-sustaining components of their ecosystem and no longer require the protections of the ESA.

This recovery plan (plan) is for yelloweye rockfish (*Sebastes ruberrimus*) and bocaccio (*Sebastes paucispinis*) distinct population segments (DPSs) of the Puget Sound/Georgia Basin, hereafter referred to as "listed rockfish." The range of these DPSs includes all the waters of Puget Sound south of the North Strait of Georgia, and the Strait of Juan de Fuca east of Victoria Sill (Figure 1), with the yelloweye rockfish DPS extending further north than bocaccio into the waters of Johnstone Strait.

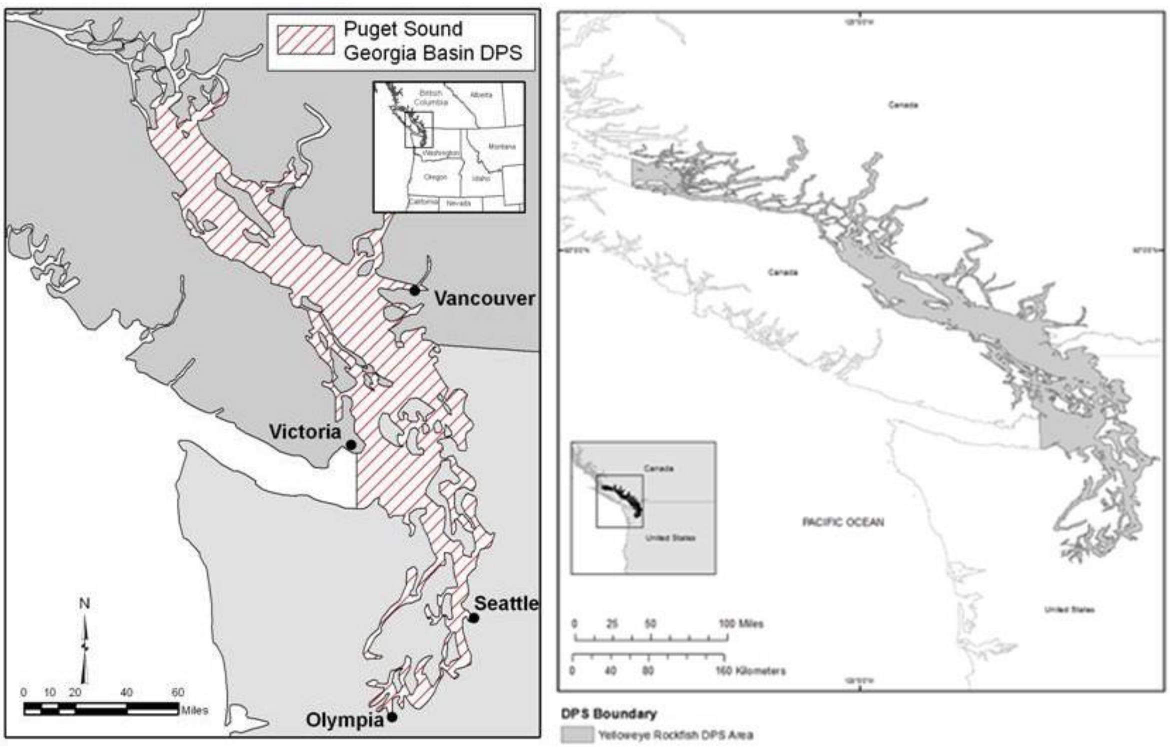

Figure 1. Bocaccio DPS (left) and yelloweye rockfish DPS (right).

This recovery plan provides a roadmap for restoring the DPSs of listed rockfish and their habitat to levels that support recovery and allow the species to become viable components of their ecosystems.

Although recovery plans are not regulatory and their implementation is voluntary, they are important tools that help: 1) provide context for regulatory decisions; 2) provide criteria for status reporting and delisting decisions; 3) organize, prioritize, and sequence recovery actions; and 4) organize research, monitoring, adaptation, and evaluation efforts.

NMFS will encourage Federal agencies and non-Federal jurisdictions to take recovery plans under serious consideration as they make the following kinds of decisions and allocate their resources: 1) actions carried out to meet section 7(a)(1) obligations to use their programs in furtherance of the purposes of the ESA and to carry out programs for the conservation of threatened and endangered species; 2) actions that are subject to ESA sections 4(d), 7(a)(2), or 10; 3) revisions of land use and resource management plans; and 4) other natural resource decisions at the state, tribal, and local levels.

Multispecies Planning Considerations

An analysis of recovery plans indicated that multispecies and ecosystem recovery plans were less likely to result in improving status trends than single species plans (Boersma et al. 2001). This may be for a variety of reasons, such as insufficient funding for multiple species versus single species (Boersma et al. 2001); thus, in cases where the status or recovery needs of rockfish differ, they will be discussed separately in the recovery plan. We use a multispecies plan not only because of taxonomic and geographic similarities between the species but also because they face similar threats and research gaps that need to be addressed for recovery. Funding initiatives will also stress the needs of the two species, as well as the efficiencies gained by combined pursuit of research and recovery actions. Progress toward the individual species' recovery and threat abatement will be monitored (Clark and Wallace 2002) through recovery actions outlined in this document.

Appendices to Support Implementation

We have developed appendices to assist in recovery implementation for listed rockfish. The appendices provide detailed information regarding a variety of research and recovery actions outlined in this plan, including: 1) education, outreach, and public involvement; 2) fisheries management; 3) barotrauma research and adaptive management; 4) benthic habitat conservation; 5) nearshore habitat and kelp conservation; 6) sediment and water quality; 7) climate change and ocean acidification; 8) funding opportunities for rockfish conservation; and 9) predation. In addition, we have included an appendix summarizing the public comments on the draft recovery plan.

B. LEGAL STATUS OF THE SPECIES

Based on information related to rockfish life history, and the environmental and ecological features of Puget Sound and the Georgia Basin, we identified Puget Sound/Georgia Basin DPSs for yelloweye rockfish and bocaccio (Drake et al. 2010). On April 28, 2010, we listed the Puget Sound/Georgia Basin DPSs of yelloweye rockfish and canary rockfish as threatened under the ESA, and bocaccio as endangered (75 Fed. Reg. 22276). We based the decision to list the yelloweye rockfish and canary rockfish DPSs as threatened and the bocaccio DPS as endangered on an evaluation of their status using the best available science and an evaluation of the listing factors that include: 1) present or threatened destruction, modification, or curtailment of habitat or range; 2) over-utilization for commercial, recreational, scientific, or educational purposes; 3) disease and predation; 4) inadequacy of existing regulatory mechanisms; and 5) other natural or human-made factors affecting continued existence. Critical habitat was designated for all three species of rockfish in 2014 under section 4(a)(3)(A) of the ESA (79 Fed. Reg. 68041, November 13, 2014). In 2014, we initiated a cooperative research project to investigate listed rockfish genetics (see sidebar). As a result of the project and subsequent analysis, on January 23, 2017 (82 Fed. Reg. 7711) we removed canary rockfish from the List of Threatened and

Endangered Species under the ESA because they were found to not be discrete from coastal populations and no longer met the criteria to be considered a DPS. Hence, this recovery plan only addresses yelloweye rockfish and bocaccio DPSs.

We identified several extinction risk factors common to each DPS (Drake et al. 2010):

- Declining trends in abundance within each DPS contribute significantly to extinction risk.
- Each species has an inherently low growth rate and low productivity and these characteristics are likely exacerbated by the relative paucity of larger, older fish. There is evidence of size truncation for each species, which shifts reproductive output to younger and less productive females.
- These characteristics increase the extinction risk for each species when combined with continued primary threats from fisheries (bycatch), loss of nearshore habitat, chemical contamination, climate change, and areas of low dissolved oxygen. Specifically, some commercial and recreational fisheries can cause direct mortality to rockfish and modify habitats and remove prey species; nearshore habitat degradation and loss can harm rearing habitats used by juveniles for predation refuge and feeding; chemical contamination can harm listed rockfish through accumulation in their food sources or direct exposure to the contaminant; and areas of low dissolved oxygen can alter listed rockfish behavior and habitat use, as well as cause direct mortality to rockfish and their prey.

ADAPTIVE MANAGEMENT AT WORK

Since the 2010 listing, NOAA Fisheries and numerous partners have pursued research to enable further understanding of listed rockfish population levels, habitat use, genetics, threats, bycatch, and other information important to recovery. The genetics project highlights the success of this cooperation.

The genetics project involved Northwest Fisheries Science Center, recreational fishing guides, anglers, WDFW, and Canada's Department of Fisheries and Oceans working together to gather biological samples of listed rockfish. The genetic analysis showed canary rockfish in the Puget Sound/Georgia Basin are not discrete from canary rockfish off the Pacific Coast. As a result, we removed canary rockfish from the endangered species list in 2017 (82 Fed. Reg. 7711).

Based on an evaluation of abundance trends, spatial structure, and diversity as well as the threats listed above, we 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 DPS of yelloweye rockfish is at moderate risk of extinction throughout all of its range (Drake et al. 2010). In 2016, we completed 5-year reviews of the listed species under the ESA and recommended that the status of yelloweye rockfish remain as threatened and that the status of bocaccio remain as endangered (NMFS 2016).

Washington State has listed 13 species of rockfish as "Species of Concern," including yelloweye rockfish and bocaccio (WDFW 2012b). The Washington Department of Fish and Wildlife (WDFW) created a Plan for Rockfish Recovery in 2011 that included policies, strategies, and actions for all rockfish (WDFW 2011).

In Canada, the yelloweye rockfish population status in inside waters in British Columbia, which extends from east of Vancouver Island down to the U.S. border of Puget Sound, was designated as "special concern" by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 2008 (COSEWIC 2008; DFO 2012). The coastal (outside) population of yelloweye rockfish status was also identified as "special concern." The bocaccio population is recognized as one unit (DFO 2009), including coastal (outside) and inside waters. This population's status was identified as threatened in 2002 (COSEWIC 2002); COSEWIC re-examined the bocaccio population and identified them as endangered in 2013 (COSEWIC 2013). Yelloweye rockfish inside and outside populations were also designated as "special concern" under the Canadian Species at Risk Act (SARA) in 2011. The bocaccio population is also being considered for listing under the Canadian SARA. Currently, these populations are managed through the Canadian Fisheries Act and Environmental Protection Act. If listed under SARA, they will be given additional protection and the development of a management plan will commence (COSEWIC 2008).

C. RECOVERY PLANNING COORDINATION

This recovery plan was developed with the involvement and input from various participants. The Rockfish Recovery Team was the primary author of the plan, and other individuals provided invaluable input, review, and feedback. Some of the primary coordinating partnerships are outlined below.

Rockfish Recovery Team

A review of recovery plans found that plans written by a team comprising non-Federal participants as well as Federal employees were more likely to result in improving status trends of endangered species (Boersma et al. 2001). Therefore, it was determined that members of the academic and fisheries science and management communities would be invited to be on the recovery team in addition to Federal employees. The team is composed of experts with backgrounds in genetics, marine ecology, fisheries biology, stock assessment, fisheries management, and other technical knowledge and local expertise needed for recovery planning.

Puget Sound Treaty Tribes and Tribal Trust and Treaty Responsibilities

In early 2013, NMFS sent a letter to each Puget Sound Treaty Tribe and the Northwest Indian Fisheries Commission (NWIFC) informing them of the recovery planning process. As a result of these letters, NMFS and several treaty tribes had several meetings during summer of 2013 and fall of 2014 to discuss the draft plan. The NWIFC also designated representatives to participate on the Rockfish Recovery Team and the NWIFC and treaty tribes were invited to provide feedback on an early draft recovery plan in 2015.

Puget Sound treaty Indian tribes retain strong spiritual and cultural ties to marine life, based on thousands of years of use for tribal religious/cultural ceremonies, subsistence, and commerce. Many Northwest Indian tribes have treaties reserving their right to fish in usual and accustomed fishing places including areas covered by this recovery plan. These treaty tribes are co-managers of fisheries with the State of Washington. The NMFS Regional Administrator, in testimony before the U.S. Senate Indian Affairs Committee (June 2003), emphasized the importance of this co-manager relationship: "We have repeatedly stressed to the region's leaders, tribal and non-tribal, the importance of our co-management and trust relationship to the tribes."

Rockfish Workgroup

Collaboration with and outreach to stakeholders was initiated by NMFS soon after the rockfish ESA listing. It continued through various workgroups, speaking engagements, informal meetings, and phone calls, and by soliciting individual review and comments on draft documents throughout the recovery planning process. These stakeholders include Federal, tribal, and state partners; researchers and academics with rockfish expertise; conservation groups; and recreational angling groups. Specifics of this stakeholder involvement follow.

In June 2011, NMFS, the SeaDoc Society, and WDFW hosted a workshop titled "Rockfish Recovery in the Salish Sea; Research and Management Priorities." This workshop convened scientists, managers, and industry professionals to focus on recent and ongoing research and recovery efforts for rockfish and their habitats in the Salish Sea to enable further collaboration and recovery. The first day of the workshop included sessions detailing recent research on the historical context of rockfish depletion, benthic habitat surveys and abundance estimates, stressors, ecosystem and species interactions, juvenile recruitment, and genetics. The second day of the workshop focused on agency, tribal, and Canadian perspectives on rockfish recovery, and included concurrent sessions designed to list additional research priorities related to reserves and population biology. The proceedings of the workshop were published in Tonnes (2012).

After the June 2011 workshop, a group of interested entities (thereafter termed the Rockfish Workgroup) continued to meet regularly, and individual members shared rockfish research and discussed research priorities for rockfish conservation in the Salish Sea (the Salish Sea encompasses the Puget Sound/Georgia Basin, but also includes the Strait of Juan de Fuca to Neah Bay). This informal group also received updates on the recovery planning process. The Rockfish Workgroup has included attendees from the Seattle Aquarium, Point Defiance Aquarium, the SeaDoc Society, the Wild Fish Conservancy, the Sierra Club, Puget Sound Anglers, the Coastal Conservation Association, Natural Resource Consultants, the University of Washington, University of Alaska, the Northwest Fisheries Science Center, NMFS, WDFW, U.S. Geological Survey, the Puget Sound Partnership, the Northwest Straits Commission, and the Lummi Indian Nation.

Canada

Approximately half of the DPSs' geographic ranges are within Canadian waters. In 2001, the Department of Fisheries and Oceans (DFO) developed an inshore rockfish conservation plan (Yamanaka and Lacko 2001), which continues to be implemented today. In 2011, a retired DFO representative presented and provided a paper entitled "Rockfish Conservation: The British Columbia Experience" at the Salish Sea Rockfish Workshop. Prior to initiating recovery planning, we invited DFO representation on the Recovery Team, which was declined. We also invited representatives from DFO to review the early draft plan in 2015. Two individual rockfish experts from Canada conducted peer review on the plan itself.

Recreational Fishers

In June 2011, NMFS partnered with the University of Washington to conduct a survey of recreational anglers in Puget Sound to inform rockfish recovery planning. The survey was conducted with approximately 500 recreational anglers at the 15 most commonly used boat launches in Puget Sound. The survey was designed to understand angler knowledge of rockfish life history and regulations, current fishing practices, perceptions of threats to rockfish, and preferences for rockfish recovery, as well as relationships between those variables and demographics of the anglers (Sawchuk 2012; Sawchuk et al. 2015). This research was used to inform the Education, Outreach, and Public Involvement Appendix (Appendix I).

Additionally, we have presented research on many occasions to recreational fishing groups. Finally, we have worked cooperatively on projects with fishing guides and fishers, many from the Puget Sound Anglers (PSA). See Section F Conservation Measures and Research.

Washington Department of Fish and Wildlife

NMFS and WDFW worked closely during the recovery planning process. Two members of the rockfish recovery team are members of the WDFW Marine Fish Science Unit and are actively involved in rockfish research and management. These members worked closely with NMFS, particularly on the areas of monitoring, research, cooperative research, and fisheries management. WDFW also provided feedback on an early draft recovery plan (Unsworth 2015) and provided a letter on the draft plan that was released for public review (Unsworth 2016).

Scientific Peer Review

Several rockfish experts from Alaska, Canada, California, and Washington peer reviewed an early version of the draft recovery plan, and their individual input was incorporated as appropriate. The peer reviews led to changes in the final plan, including revisions to the delisting and downlisting criteria, and revised and additional research and recovery measures.

Public Input

The draft recovery plan was provided to the public for comment from August 16, 2016 through November 16, 2016. In addition, NMFS held meetings for public comment in Olympia, Friday Harbor, Anacortes, and Seattle. Ninety-five comments were provided through the regulations.gov website. Additional oral comments were provided at the public meetings. NMFS organized these comments and revised the draft recovery plan, as appropriate, in accordance with this feedback. Appendix X, Summary of Public Comments on the draft Recovery Plan, includes a summary of the public comments and references the sections in the final recovery plan where revisions were made in response to comments.

Public and WDFW comments led to several revisions to the final plan:

- The delisting and downlisting criteria were revised and clarified. The most significant change was the use of Spawning Potential Ratio to replace Fractional Lifetime Egg Production (FLEP) as the primary biological metric to assess population status. This final plan uses SPR, which does not require the historical population information needed for a FLEP assessment and which may not be sufficiently available.
- The description of fisheries and assessment of risk of bycatch of yelloweye rockfish and bocaccio was expanded. We include the approximate number of fishing trips annually within each

Management Unit and a qualitative risk of bycatch. Additional information regarding some tribal fisheries was added.

- Most public comments were related to fisheries management, particularly rockfish conservation areas (RCA) and marine protected areas (MPAs). While some comments were in favor of establishing them, a large proportion of commenters were not. We revised this plan to prioritize the Management Units for the establishment of additional fisheries protections and added additional scientific information regarding the efficacy of reserves. We also revised the plan by identifying the need for additional time to monitor the effectiveness of existing fisheries regulations and enforcement prior to starting the process of designating RCAs/MPAs.
- A large proportion of commenters stated they did not support additional fisheries protections because of concerns about predation on rockfish that is limiting recovery. In response, we created an appendix (IX) that summarizes what is known about predation on rockfish, with an emphasis on the Puget Sound/Georgia Basin, and outlines research projects related to predation that would improve recovery implementation.

II. BIOLOGICAL BACKGROUND

A. SPECIES DESCRIPTION AND TAXONOMY

Worldwide, there are over 100 species of rockfishes (the *Sebastes* or *Sebastolobus*), the majority of which are found along the western coast of North America (Love et al. 2002). These fishes are characterized by having spines on their head (at least as juveniles); stiff dorsal fins; spines with venom glands at the base of dorsal, anal, and pectoral fins; internal fertilization of eggs; and birth of live larvae (Love et al. 2002). Rockfish are mid-level predators that commonly occupy reef habitats, though are also found on complex soft bottom or in association with subtidal vegetation. A significant portion of the marine fish community within Puget Sound waters is composed of rockfish, which account for at least 28 of an estimated 253 (~11 percent) fish species (Pietsch and Orr 2015). The following section details the unique biological traits of rockfish and their relevance to recovery.

B. LIFE HISTORY/ECOLOGY

Rockfish are iteroparous (i.e., have multiple reproductive cycles during their lifetime) and are typically long-lived. This trait allows the adult population to persist through many years of poor reproduction until a good recruitment year occurs, likely dictated by climatic or oceanic conditions (Tolimieri and Levin 2005; Leaman 1991). As adults, listed rockfish generally inhabit relatively deep waters with steep and complex bathymetry, though they may also occur over less complex habitat or in the water column in association with sheer walls. Their diets are diverse and include many species of marine invertebrates and fish. Below, we describe rockfish life history by larval, juvenile, and subadult/adult stages, which reflect distinct habitat use and food sources.

Larval Stage Life History, Habitat Use, and Ecosystem Requirements

Female yelloweye rockfish and bocaccio produce from 1 to 3 million larvae annually, depending upon age and body size. Rockfish are viviparous, meaning the eggs are fertilized internally, the embryonic fish develop within the mother, and the young are released as larvae (Love et al. 2002). Larval rockfish have been documented throughout all major basins of Puget Sound (Greene and Godersky 2012). Larval rockfish are often observed under free-floating algae, seagrass, and detached kelp (Shaffer et al. 1995; Love et al. 2002), and also occupy the full water column (Weis 2004). Larval marine fishes, including rockfishes, have high mortality rates. For instance, in a laboratory setting (without risk of predation), rockfish larvae experienced 70 percent mortality 7 to 12 days after birth (Canino and Francis 1989). Their small size, relative inability to store food within their gut, and slow swimming speeds likely contribute to this high mortality rate by making them vulnerable to predators and starvation. Poor larval survival in most years provides evidence that rockfish populations persist through what has been termed "the storage hypothesis" (Warner and Chesson 1985), where episodic high recruitment success is important in driving population size. Poor larval survival in most years is balanced by the long lives of reproductive adults; thus, when good conditions occur there are new larval cohorts that benefit from them (Drake et al. 2010). Episodic recruitment rates also mean that high fecundity rates do not appear to mitigate risk of extinction or enable more rapid recovery from exploitation (Dulvy et al. 2003). We do not know the relative importance of these factors in the Puget Sound/Georgia Basin.

The timing of larval release for each species varies throughout their geographic range. In Puget Sound, there is some evidence that yelloweye larvae are extruded in early spring to late summer (Washington et al. 1978) and in British Columbia between April and September with a peak in May and June (Yamanaka et al. 2006). Along the coast of Washington State, bocaccio release larvae between January and April (Love et al. 2002).

Pelagic larval duration (PLD) is defined as the length of time larvae may drift before settling to juvenile habitat or adult habitat, and it is an indication of the spatial scales of connectivity and sources for population replenishment. For shelf/slope species of fishes, such as the yelloweye rockfish, PLD in the California Current is greater than 120 days (Shanks and Eckert 2005), and for bocaccio PLD is 150 to 170 days (Shanks et al. 2003). Population genetic studies have shown that despite longer PLD, rockfish often exhibit population structure over regional scales (Siegle et al. 2013).

Rockfish and Kelp along the Pacific Coast

~By Nicole Naar~

Along the Pacific Coast, rockfish and kelp are linked through both bottom-up and top-down trophic relationships. Healthy kelp forests provide habitat and primary production that support diverse marine food webs (Klinger 2015). Isotopic analyses have demonstrated kelp's contribution to food chains including rockfishes (von Biela et al. 2015), traced the decline of kelp signatures in rockfish samples since European contact (Szpak et al. 2013), and linked greater kelp cover to increased rockfish recruitment (Markel 2011).

However, kelp forests are vulnerable to trophic cascades, which occur when the elimination of predators leads to a proliferation of kelp grazers (Steneck et al. 2002). Rockfish are important mesopredators in temperate marine ecosystems that may influence community structure. Therefore, overharvesting of rockfish and other predatory fish populations may be linked to the decline of kelp forests within Puget Sound.

Juvenile bocaccio in a kelp forest in waters of California. Photo by Adam Obaza.

Juvenile Stage Life History, Habitat Use, and Ecosystem Requirements

Generally, juvenile rockfish move from the pelagic environment and associate with benthic environments when they reach about 1.2 to 3.6 inches (3 to 9 cm) in length and approximately the age of 3 to 6 months (Love et al. 2002). As they grow, juveniles of each species gradually move to areas of high rugosity (roughness) and rocky habitat in deeper waters (Love et al. 1991; Johnson et al. 2003; Love et al. 2002). This movement to deeper water may be driven by environmental conditions that are less favorable for juveniles; over the fall and winter, temperatures decrease, turbulence increases, and submerged aquatic vegetation coverage decreases (Halderson and Richards 1987; Matthews 1989; Love et al. 1991; Carr 1991; Doty et al. 1995).

Areas with floating and submerged kelp (families *Chordeace, Alariaceae, Lessoniacea, Costariaceae,* and *Laminaricea*) support the highest densities of most juvenile rockfish species (Matthews 1989; Halderson and Richards 1987; Carr 1991; Carr and Syms 2006; Hayden-Spear 2006; Springer et al. 2010). Kelp is photosynthetic and requires high ambient light levels and a lack of fine sediment in the water column (Mumford 2007). There are 23 annual or perennial species of kelp in Puget Sound, two of which have a floating canopy and the rest non-floating stipitate or prostrate canopies (Mumford 2007). When solid substrates occur in lower intertidal and subtidal zones, kelp is often the dominant aquatic flora and forms dense canopies (Mumford 2007). Kelp are attached with a root-like structure, called a holdfast, to solid substrates such as bedrock, large rocks or pebbles, clam shells, or artificial substrates. Kelp grows in areas of high to moderate wave energy or currents to depths as great as 65 feet (20 m) (Mumford 2007; reviewed by Springer et al. 2010; Schiel and Foster 2015; Carr and Reed in press). Most kelp species form blades 3 to 6 feet (1 to 2 m) long, though the one floating variety within the range of the DPSs (*Nereocystis luetkeana*) grows to over 33 feet (10 m) long.

Juvenile yelloweye rockfish are not typically found in intertidal waters (Love et al. 1991; Studebaker et al. 2009). A few juveniles have been documented in shallow nearshore waters (Love et al. 2002; Palsson et al. 2009), but most settle in habitats along the shallow range of adult habitats in areas of complex bathymetry and rocky/boulder habitats and cloud sponges in waters greater than 98 feet (30 m) (Richards 1986; Love et al. 2002; Yamanaka et al. 2006). In British Columbia, juvenile yelloweye rockfish have been observed at a mean depth of 239 feet (73 m), with a minimum depth of 98 feet (30 m) (Yamanaka et al. 2006). Juvenile yelloweye rockfish occur in similar habitats as adults, though in areas with smaller crevices, including cloud sponge formations, crinoid aggregations on top of rocky ridges, and over cobble substrates (Weispfenning 2006; Yamanaka et al. 2006; Banks 2007).

Young-of-year juvenile bocaccio occur on shallow rocky reefs and nearshore areas (Moser 1967; Anderson 1983; Kendall and Lenarz 1986; Carr 1991; Love et al. 1991; Love et al. 1996; Murphy et al. 2000; Love et al. 2002). Young bocaccio associate with macroalgae, especially kelps (Laminariales), and sandy areas that support seagrasses. They form aggregations near the bottom in association with drift algae and throughout the water column in association with canopy-forming kelps. It is likely that nearshore habitats used by juvenile bocaccio and other rockfish juveniles offer a beneficial mix of warmer temperatures, food, and refuge from predators (Love et al. 1991). Habitat formed by kelp provides structure for feeding, refuge from predators, and reduced currents that enable energy conservation for juvenile bocaccio.

Juvenile yelloweye rockfish and bocaccio have been only rarely documented in Puget Sound (Palsson et al. 2009). This may be due to a relative lack of studies in Puget Sound that assessed nearshore rockfish assemblages prior to the onset of fisheries removals of adult rockfish. Many small post-settlement rockfish are difficult to identify at the species level (Anderson 1983; Love et al. 2002), though juvenile yelloweye rockfish are relatively easy to identify. Love et al. (1991) describe three reasons that post-settlement habitat is essential for rockfish populations: 1) the successful recruitment of substrate-associated juveniles by larvae dispersed in the pelagic environment is crucial to the survival of local populations; 2) density-dependent regulation of populations may occur at the early juvenile stage; thus, the quality and quantity of these habitats could strongly influence subadult and adult abundance (Johnson 2006a, 2006b, 2007); and 3) larval abundance can be a poor predictor of subsequent adult year-class strength, suggesting that post-settlement rearing habitat can strongly influence subsequent population viability.

Adult Stage Life History, Habitat Use, and Ecosystem Requirements

Adult yelloweye rockfish remain near the substrate and have relatively small home ranges, while some bocaccio have larger home ranges, move long distances, and spend time suspended in the water column (Demott 1983; Love et al. 2002; Friedwald 2009). Depth is generally the most important determinant in the distribution of many rockfish species of the Pacific Coast (Chen 1971; Williams and Ralston 2002; Anderson and Yoklavich 2007; Young et al. 2010). Adult yelloweye rockfish and bocaccio generally occupy habitats from approximately 90 to 1,394 feet (30 to 425 m) (Orr et al. 2000; Love et al. 2002).

There have not been historical or contemporary systematic surveys of rockfish populations in all of the basins of Puget Sound (Drake et al. 2010). Fisheries catch data can be used to assist in determining rockfish habitat (Yamanaka and Logan 2010), but the lack of systematic record keeping and unreliable species identification from commercial and recreational fishing in Puget Sound limits the utility of available fishery data (Palsson et al. 2009; Sawchuk 2012; Sawchuk et al. 2015). In addition, spatial information on rockfish fishing areas reflects both fisher behavior and underlying species distributions. Where most historical fisheries data do exist, the precise location of the catch is not documented (e.g., Bargmann 1977). The documented occurrences of yelloweye rockfish and bocaccio are from a wide range of years and with diverse sampling methods such as research trawls, drop cameras, SCUBA, ROVs, and commercial and recreational fishing (Table 1). Most of these documented occurrences are for subadult and adult life stages, with relatively few young-of-year fish documented.

Adult yelloweye rockfish and bocaccio frequently occupy habitats within and adjacent to areas that are highly rugose. These are benthic habitats with moderate to extreme steepness; complex bathymetry; and/or substrates consisting of fractured bedrock, rock, and boulder-cobble complexes (Yoklavich et al. 2000; Love et al. 2002; Wang 2005; Anderson and Yoklavich 2007) and glass sponges (cloud sponges are a type of glass sponge) (Marliave et al. 2009). Most of the benthic habitats in Puget Sound consist of unconsolidated materials such as mud, sand, clays, cobbles, and boulders (Burns 1985), and despite the relative lack of rock, some of these benthic habitats are moderately to highly rugose. More complex marine habitats are generally used by larger numbers of fish species relative to less complex areas (Anderson and Yoklavich 2007; Young et al. 2010; Pacunski et al. 2013) and thus support food sources for subadult and adult yelloweye rockfish and bocaccio. Biogenic structure (e.g., kelps) also provides refuge from predators and may provide shelter from currents, thus leading to energy conservation (Young et al. 2010).

Though areas near rocky habitats or other complex structure are most readily used by adults of each species, alternative benthic habitats are also occupied. In Puget Sound, adult yelloweye rockfish and bocaccio have been documented in areas with non-rocky substrates such as sand, mud, and other unconsolidated sediments (Haw and Buckley 1971; Washington 1977; Miller and Borton 1980; Reum 2006). Surveys from outside the range of the DPSs also have documented each species in relatively less complex habitats, though generally on a less frequent basis than more complex habitats. Yelloweye rockfish have also been documented in areas with mud and mud/cobble habitats in waters off the coasts of Washington (Wang 2005), California (Yoklavich et al. 2000), Oregon (Stein et al. 1992), and British Columbia, Canada (Richards 1986), and have been observed adjacent to large and isolated boulders in areas of flat and muddy bottoms in Alaskan waters (O'Connell and Carlile 1993). Bocaccio also occupy benthic areas with soft-bottomed habitats, particularly those adjacent to structure such as boulders and crevices (Yoklavich et al. 2000; Anderson and Yoklavich 2007). Bocaccio are also known to occupy the water column well off the bottom, making their documentation with traditional bottom sampling methods problematic.

Table 1. Summary of listed rockfish habitat use.

Species	Approximate Size Range	Habitat Associations (e.g., biogenic structure, substrate)	Depth Range
Larval yelloweye rockfish	<1.2 in (3cm)	Water column, free-floating algae, seagrass, detached kelp	Variable
Juvenile yelloweye rockfish	1.2-3.6 in (3-9cm)	Rocky habitat / complex structure, cloud sponges	98-293 ft (30-73m)
Subadult / adult yelloweye rockfish	>3.6 in (9cm+)	Rocky habitat / complex structure, occasionally other (sand, mud, etc.)	90-1,394 ft (30-425m)
Larval bocaccio	<1.2 in (3cm)	Water column, free-floating algae, seagrass, detached kelp	Variable
Juvenile bocaccio	1.2-3.6 in (3-9cm)	Water column, in association with drift algae, seagrasses, and canopy forming kelp	>6 ft (2m), variable
Subadult/adult bocaccio	>3.6 in (9cm+)	Water column, rocky habitat / complex structure, occasionally other (sand, mud, etc.)	Variable, 90-1,394 ft (30-425m)

Age and Growth Rates

Yelloweye rockfish are one of the longest lived of the rockfishes, with some individuals reaching more than 100 years of age. Yelloweye rockfish reach 50 percent maturity at sizes of 16 to 20 inches (40 to 50 cm) and ages of 15 to 20 years (Rosenthal et al. 1982; Yamanaka and Kronlund 1997). The maximum age of bocaccio is unknown, but may range from 40 to 50 years. Bocaccio are estimated to reach 50 percent maturity at 14 to 20 inches (35 to 50 cm) and become reproductively mature near ages 4 to 6 years (Stanley et al. 2001; Love et al. 2002).

Reproduction, Recruitment, and Natural Mortality Rate

Depending on the size and age of the fish, individual female yelloweye rockfish produce up to 2,700,000 larvae and bocaccio produce up to 2,298,000 larvae annually (Love et al. 2002). Larval rockfish have a low rate of survival in their first year of life and recruitment is erratic and poorly understood in the Puget Sound/Georgia Basin. Larvae birthed by older female rockfish have significantly greater growth rates and starvation tolerance compared to larvae of younger females (Berkeley et al. 2004).

The mean natural mortality rate for rockfish varies by species and environmental conditions. The mean natural mortality rate is approximately 3 percent per year for yelloweye rockfish and 8 percent per year for bocaccio (Table 2) (Gunderson and Vetter 2006; Palsson et al. 2009).

Table 2. Characteristics of ESA-listed rockfish species.

Common Name	Maximum Age (yrs.)	Age at 50% Maturity (yrs.)	Range Natural Mortality Rate (% per year)	Depth range (ft.) (Adults)
Yelloweye rockfish	118+	19-22	2 to 4.6 percent	90-1400
Bocaccio	50	4	8	90-1400

Note: Adapted from Orr et al. 2000, Love et al. 2002, Gunderson and Vetter 2006, and Palsson et al. 2009.

Diet and Feeding Behavior

Food sources for yelloweye rockfish and bocaccio occur throughout Puget Sound. However, each of the basins has unique biomass and species compositions of fish and invertebrates that vary temporally and spatially (Rice 2007; Rice et al. 2012). Absolute and relative abundance and species richness of most fish species in the Puget Sound/Georgia Basin increase with latitude (Rice 2007; Rice et al. 2012). Despite these differences, each basin hosts common food sources for yelloweye rockfish and bocaccio as described below.

Larval and juvenile rockfish feed on very small organisms such as zooplankton, particularly copepods, phytoplankton, small crustaceans, invertebrate eggs, krill, and other invertebrates (Moser and Boehlert 1991; Love et al. 1991; Love et al. 2002). Larger juveniles also feed upon small fish (Love et al. 1991). Adult yelloweye rockfish and bocaccio have diverse diets that include many species of fish and invertebrates, including but not limited to crabs (*Crustacea spp.*), various rockfish (*Sebastes spp.*), flatfish (*Pleuronectidae* and *Paralichthyidae spp*), juvenile salmon (*Oncorhynchus spp*), walleye pollock (*Gadus chalcogrammus*), Pacific hake (*Merluccius productus*), Pacific cod (*Gadus macrocephalus*), green sea urchin (*Stongylocentrotus droebachiensis*), lingcod (*Ophiodon elongatus*) eggs, various shrimp species (*Pandalus spp.)*, and surf perch (*Rhacochilus spp.*). Common forage fish that are part of rockfish diets include Pacific herring (*Clupea pallasii*), surf smelt (*Hypomesus pretiosus*), and Pacific sand lance (*Ammodytes hexapterus*) (Washington et al. 1978; Lea et al. 1999; Love et al. 2002; Yamanaka et al. 2006).

Natural Predators

Rockfishes of all sizes are an important food resource for a variety of predators in Puget Sound (Palsson et al. 2009). There is little data regarding specific predators of yelloweye rockfish and bocaccio of the Puget Sound/Georgia Basin, thus we refer to available information regarding predation on *Sebastes* species generally. Rockfish are preyed upon by numerous fish species, birds, and several marine mammals (Mills et al. 2007; Lance et al. 2012; Buzzell et al. 2014). Larvae and juveniles are eaten by birds, salmon, rockfish, lingcod, and other fish species (Mills et al. 2007). Juveniles and adults are eaten by lingcod and some marine mammals (mostly pinnipeds) (Love et al. 2002; Palsson et al. 2009). As with many other marine fish species, as rockfish grow, their potential predators are generally reduced in number because of their larger sizes, physiological development, and behavioral changes (Gislason et al. 2010).

It is important to note that the impact of predation on rockfish cannot be determined from the quantity and frequency of rockfish occurrence in predator diets alone. Data on the sizes and quantity of rockfish consumed by predators should be used in combination with models that assess the ecological conditions in which predation has an influence on rockfish population dynamics. A more detailed review of predation on rockfish may be found in Appendix IX, Predation.

The Role of Rockfish in Indigenous Pacific Northwest Subsistence

~By Nicole Naar~

Archaeological evidence indicates that indigenous cultures in the Pacific Northwest have consumed rockfishes for at least the past 1,500 years (McKechnie 2007) and likely for much longer (Mitchell 1990). Although rockfish were secondary to salmon and likely harvested opportunistically within Puget Sound, they were a primary food source along the outer coast of Washington, Vancouver Island, and coastal British Columbia (Williams et al. 2010). For example, nearly 66 percent of the identified skeletal specimens found at a Nuu-chah-nulth site on Vancouver Island were from *Sebastes* species (McKechnie 2007), and rockfish were a significant part of the diet at various mainland Comox (Kennedy and Bouchard 1990), Makah (Renker and Gunther 1990), and Klallam (Wessen 1990) sites. The North Salish harvested rockfish and other saltwater fish year-round (Kennedy and Bouchard 1990), while the Nuu-chah-nulth (Arima and Dewhirst 1990), Snoqualmie (Turner 1976), Makah, and Klallam (Wessen 1990) captured them in the summer months. Rockfish and other deep water fish were harvested from dugout canoes using hook and line (Williams et al. 2010; Stewart 1977; Gunther, field notes) (figure below). Among the mainland Comox, "[t]he best fishermen owned special songs that they sang to the rockfish as they jigged for them" (Kennedy and Bouchard 1990:445). Once captured, rockfish were usually consumed fresh by members of the household unit after roasting or boiling (Turner 1976), but the Kwakwaka'wakw also dried the fish for later consumption (Boas 1921). The Makah also used the spines of the yelloweye rockfish to make pins for blankets, and a part of the skull was used as a berry spoon (Gunther, field notes).

C. ABUNDANCE, PRODUCTIVITY, CONNECTIVITY, AND DIVERSITY

We summarize our knowledge of each species at the DPS level according to the following demographic viability parameters: abundance and productivity, spatial structure/connectivity, and diversity. These viability criteria are outlined in McElhaney et al. (2000) and reflect concepts that are well founded in conservation biology and are generally applicable to a wide variety of species. These criteria describe demographic conditions that individually and collectively provide strong indicators of extinction risk (Drake et al. 2010). Below, we summarize the demographic information applicable to the DPSs and then present specific demographic information for each DPS. This section also identifies factors influencing demographics and how parameters have changed over time. The term Puget Sound proper refers to the waters east of and including Admiralty Inlet, and North Puget Sound refers to the San Juan/Strait of Juan de Fuca area within the DPSs.

Abundance and Productivity

Abundance

There is no single, reliable historical or contemporary abundance estimate for the yelloweye rockfish or bocaccio DPSs in the Puget Sound/Georgia Basin (Drake et al. 2010). Despite this limitation, there is clear evidence that each species' abundance has declined dramatically (Drake et al. 2010). 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 DPS'area (Stanley et al. 2012). In Puget Sound, catches of yelloweye rockfish and bocaccio have declined as a proportion of the overall rockfish catch (Figure 2 and Figure 3, from Drake et al. 2010). Analysis of SCUBA surveys, recreational catch, and WDFW trawl surveys indicated total rockfish populations in the Puget Sound region are estimated to have declined between 3.1 and 3.8 percent per year for the past several decades, which corresponds to a 69 to 76 percent decline from 1977 to 2014 (Tonnes et al. 2016).

These patterns are consistent with results of a study that assessed historical trends in rockfish abundance based on local knowledge of resource users and scientists (Beaudreau and Levin 2014). Beaudreau and Levin (2014) reconstructed trends in relative abundance of seven species of rockfish in Puget Sound, including ESA-listed species, since the 1940s from interviews with fishers, divers, and researchers. Trends in abundance indices indicated that seven rockfish species in Puget Sound have been in decline since at least the 1960s, and the two ESA-listed species were viewed as relatively lower in abundance across all time periods compared to other rockfishes. Trends from local knowledge likely reflected true patterns in nature, based on the following: 1) there was a high degree of agreement among respondents about patterns in species abundance, and 2) trends from interview data showed strong concordance with scientific surveys of Puget Sound species for which historical data were available (i.e., harbor seal, *Phoca vitulina*; Pacific herring, *Clupea pallasii*; lingcod, *Ophiodon elongatus*) (Beaudreau and Levin 2014). Abundance indices from local knowledge sources could be used in combination with contemporary survey and fishery-dependent data to generate plausible estimates of historical abundance prior to the use of biological surveys (Beaudreau and Levin 2014).

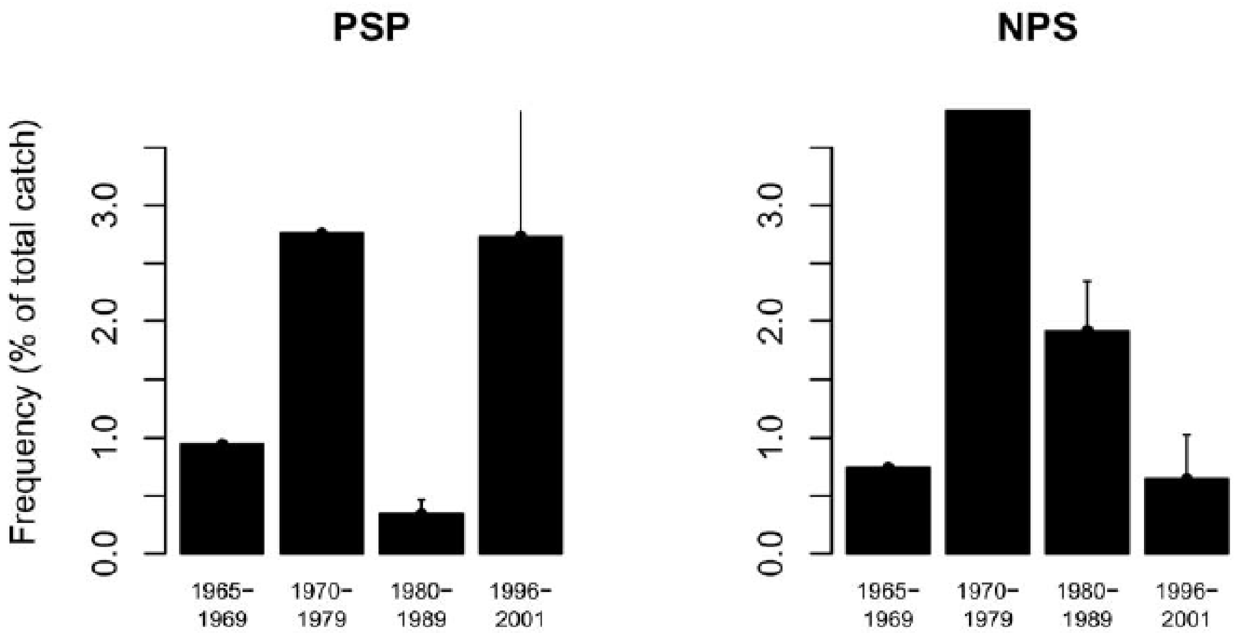

Figure 2. Frequency (% total) for yelloweye rockfish in the recreational catch in Puget Sound proper (PSP) and North Puget Sound (NPS) (Source: Drake et al. (2010).

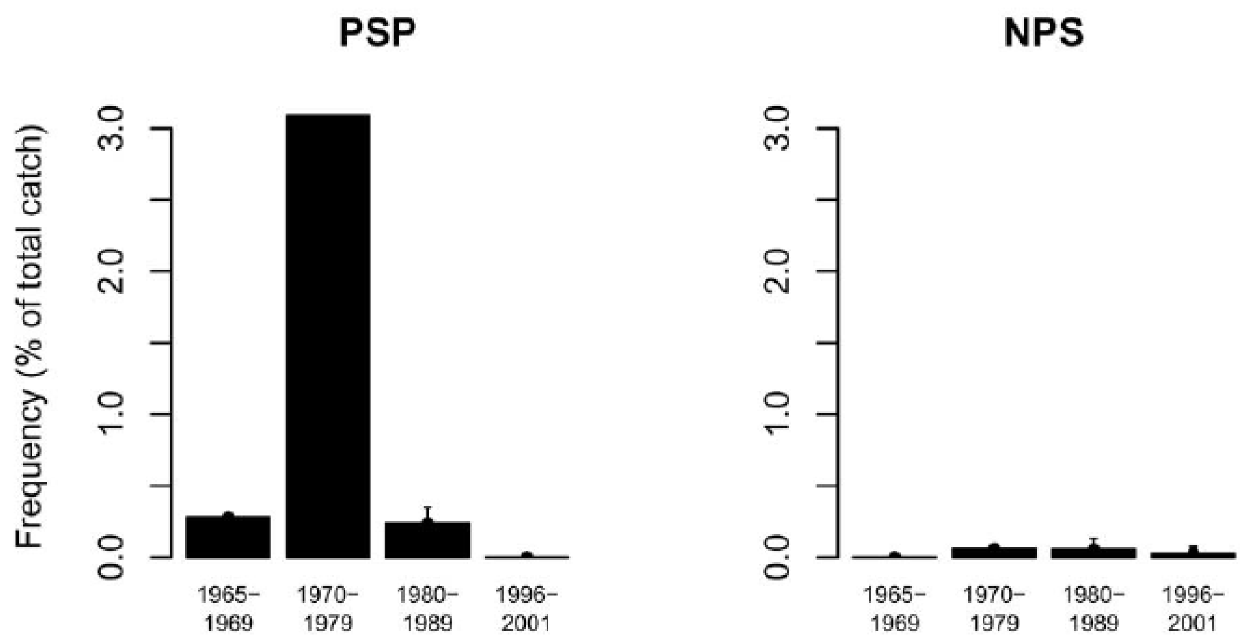

Figure 3. Frequency (% total) for bocaccio in the recreational catch in Puget Sound proper (PSP) and North Puget Sound (NPS) (Source: Drake et al. (2010).

Fishery-independent estimates of abundance come from spatially and temporally limited research trawls, drop camera surveys, and underwater ROV surveys conducted by WDFW. These abundance estimates included in Table 3 should be interpreted in the context of the sampling design and gear. The trawl surveys were conducted on the bottom to assess marine fish abundance. These trawls generally sample non-rocky substrates where yelloweye rockfish and bocaccio are less likely to occur (Drake et al. 2010). The drop camera surveys sampled habitats less than 120 feet (36.6 m) deep, which is potential habitat for juveniles, but less likely habitat for adult yelloweye rockfish and bocaccio. Similarly, because juvenile yelloweye rockfish are less dependent on rearing in shallow nearshore environments, the likelihood of documenting them with drop camera surveys in water shallower than 120 feet (36.6 m) is low. Therefore, trawl surveys and drop cameras would likely underestimate listed species, especially yelloweye rockfish.

The WDFW ROV surveys were conducted exclusively within the rocky habitats of the San Juan Basin in 2008, and represent the best available abundance estimates to date for one basin of the DPS for each species because of their survey area, number of transects, and stratification methods (Pacunski et al. 2013). Rocky habitats have been mapped within the San Juan Basin, which allows a randomized survey of these areas to assess species assemblages and collect data for abundance estimates. WDFW conducted 200 transects and categorized each rocky habitat survey as either “shallower than” or “deeper than” 120 feet (36.6 m). The total area surveyed within each stratum was calculated using the average transect width multiplied by the transect length. The mean density of yelloweye rockfish and bocaccio was calculated by dividing the species counts within each stratum by the area surveyed. Population estimates for each species were calculated by multiplying the species density estimates by the total survey area within each stratum (Pacunski et al. 2013). Because WDFW did not survey non-rocky habitats of the San Juan Basin with the ROV, these estimates do not account for listed rockfish in non-rocky habitat in 2008. WDFW expanded the survey data to estimate total abundance in the San Juan Basin (Table 3). From the bottom trawl and drop camera surveys, WDFW has reported abundance estimates in the North Sound and Puget Sound proper (Table 3).

Table 3. Abundance estimates for yelloweye rockfish and bocaccio.

WDFW Survey Method	**Yelloweye Population Estimate**		**Percent Standard Error (or Variance)**	
	North Sound	**Puget Sound proper**		
Bottom Trawl	Not detected	600 fish	NA	400 (variance)
Drop Camera	Not detected	Not detected	NA	NA
Remotely Operated Vehicle	47,407 fish (San Juan Basin only)		29	
WDFW Survey Method	**Bocaccio Population Estimate**		**Percent Standard Error**	
	North Sound	**Puget Sound proper**		
Bottom Trawl	Not detected	Not detected	NA	NA
Drop Camera	Not detected	Not detected	NA	NA
Remotely Operated Vehicle	4,606 fish (San Juan Basin only)		100	

Though the bottom trawl and drop camera surveys did not detect bocaccio in Puget Sound proper, bocaccio were historically caught in recreational fisheries (Palsson et al. 2009; Williams et al. 2010) and have been caught in genetic research and ROV surveys in 2015. Bocaccio were most commonly documented within the South Sound and Main Basin in recent decades (Drake et al. 2010; Williams et al. 2010). The lack of detected bocaccio from these sampling methods in Puget Sound proper is likely due to the following factors: 1) populations are depleted, 2) the general lack of rocky benthic areas in Puget Sound proper may lead to densities of each species that are naturally less than the San Juan Basin, 3) the study design or effort may not have been sufficient to detect each species, and 4) bottom trawls do not effectively sample core rockfish habitats (i.e., high-relief rock). Though bocaccio were likely never a predominant component of the multi-species rockfish abundance within the Puget Sound/Georgia Basin (Drake et al. 2010), their present-day abundance is likely a fraction of their historical abundance.

Though yelloweye rockfish were detected in Puget Sound proper with bottom trawl surveys, we do not consider the WDFW estimate of 600 fish to be comprehensive for the same reasons outlined above for bocaccio. Throughout the Puget Sound/Georgia Basin (in U.S. waters), yelloweye rockfish are very likely most abundant within the San Juan Basin. Though there is no reliable population census (ROV or otherwise) within all the Puget Sound/Georgia Basin for comparison, the San Juan Basin has the most suitable rocky benthic habitat (Palsson et al. 2009) and historically was the area of greatest numbers of recreational catch (Moulton and Miller 1987; Olander 1991).

Productivity

Productivity is the measurement of a population’s growth rate through all or a portion of its life cycle. Life history traits of yelloweye rockfish and bocaccio suggest generally low levels of inherent productivity because they are long-lived, mature slowly, and have sporadic episodes of successful reproduction (Musick 1999; Tolimieri and Levin 2005).

Yelloweye rockfish productivity may also be impacted by an Allee effect. This situation arises when reproductive adults are removed from the population and remaining individuals are eventually unable to encounter mates. This process then further reduces population density and can lead to extinction. Adult yelloweye rockfish typically occupy relatively small ranges (Love et al. 2002), and the extent to which they may move to find suitable mates is unknown. However, there is insufficient information to determine that this is currently occurring for yelloweye rockfish and further research is needed (Hutchings and Reynolds 2004).

Tolimieri and Levin (2005) found that the bocaccio population growth rate is around 1.01, indicating a very low intrinsic growth rate for this species. This species demonstrates some of the highest recruitment variability among rockfish species, with many years of poor recruitment being the norm (Tolimieri and Levin 2005) and an estimated natural mortality of 8 percent (Palsson et al 2009). Given their severely reduced abundance, Allee effects could be particularly acute for bocaccio, even considering the propensity of some individuals to move long distances and potentially find mates, though the extent of these effects are yet unknown.

Overfishing can have dramatic impacts on the size or age structure of rockfish populations as anglers may select for larger individuals, reducing the size of individuals in the breeding population. The change in female size structure is particularly important, as larger and older females of various rockfish species have a higher weight-specific fecundity (number of larvae per unit of female weight) (Bobko and Berkeley 2004; Boehlert et al. 1982; Sogard et al. 2008). Survival is also improved in offspring of larger females because they provide more nutrients to larvae by developing a larger oil globule released at parturition, which provides energy to the developing larvae (Berkeley et al. 2004; Fisher et al. 2007), and in black rockfish enhances early growth rates (Berkeley et al. 2004). This change in reproductive success is part of a broader phenomenon termed maternal effects, defined as alterations in parental phenotypes or the environment that influence offspring (Heath and Blouw 1998). A consistent maternal effect in rockfishes relates to the timing of larval release. The timing of larval birth can be critical because corresponding with favorable oceanographic conditions is essential for reproductive success and most individual fishes release larvae for only 2 days each year. Several studies of rockfish species have shown that larger or older females release larvae earlier in the season compared to smaller or younger females (Nichol and Pikitch 1994; Sogard et al. 2008). Maternal effects illustrate the compound effect artificial selection from overfishing may have on rockfish population growth.

Reproductive function as well as other life history stages of rockfish are likely affected by contaminants (Palsson et al. 2009), though the extent of this effect is not known (Drake et al. 2010). Contaminants such as polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), and chlorinated pesticides appear in rockfish collected in urban areas (West and O'Neil 1998; West et al. 2001). While the highest levels of contamination occur in urban areas, toxins can be found in the tissues of fish throughout Puget Sound (West et al. 2001). Although few studies have investigated the effects of toxins on rockfish ecology or physiology, other fish in the Puget Sound region that have been studied do show a substantial impact, including reproductive dysfunction of some sole species (Landahl et al. 1997). A more comprehensive review of contamination effects on rockfishes may be found in Appendix VI.

Future climate-induced changes to rockfish habitat could alter their productivity (Drake et al. 2010). Harvey (2005) created a bioenergetic model for rockfish, showing that their productivity is highly influenced by climate conditions. For instance, El Niño-like conditions generally lowered growth rates and increased generation time. The negative effect of the warm water conditions associated with El Niño appear to be common across rockfishes (Moser et al. 2000). Recruitment of all species of rockfish appears to be correlated at large scales (Caselle et al. 2010). Field and Ralston (2005) hypothesized that such synchrony was the result of large-scale climate forcing. Exactly how climate influences rockfish in Puget Sound is unknown; however, given the general importance of climate to rockfish recruitment, it is likely that climate strongly influences the dynamics of listed rockfish population viability (Drake et al. 2010).

In summary, though abundance and productivity data for yelloweye rockfish and bocaccio are limited, it is likely that both abundance and productivity have been reduced largely by fishery removals, contaminants, and habitat degradation within the range of both Puget Sound/Georgia Basin DPSs (Drake et al. 2010).

Spatial Structure and Connectivity

Spatial structure (also referred to as distribution) consists of both the geographical distribution of individuals in the population and the processes that generate that distribution (McElhaney et al. 2000). A population's spatial structure is driven by habitat quality, spatial configuration, and dynamics as well as dispersal characteristics of individuals within the population (McElhaney et al. 2000). Prior to contemporary fishery removals, each of the major basins in the range of the DPSs likely hosted relatively large populations of yelloweye rockfish and bocaccio, though their distribution was likely not uniform throughout the basins of Puget Sound (Moulton and Miller 1987; Washington 1977; Washington et al.

1978; Williams et al. 2010). Wide distribution enables each species to potentially exploit good habitat, which may be naturally limited in portions of Puget Sound, and protect them from potentially negative environmental fluctuations or conditions. These types of fluctuations may include change in prey abundance for various life stages and/or change in environmental conditions, such as temperature, that influence the number of annual recruits. Wide spatial distribution also provides a measure of protection from larger scale anthropogenic changes that damage habitat suitability, such as oil spills or hypoxia that can cause acute local or regional effects. Rockfish population resilience may be sensitive to changes in connectivity among various groups of fish (Hamilton 2008). Exchange of water masses that influence larval transport and population connectivity between the basins of Puget Sound is naturally restricted by relatively shallow sills located at Deception Pass, Admiralty Inlet, the Tacoma Narrows, and in Hood Canal (Burns 1985). The Victoria Sill bisects the Strait of Juan de Fuca and runs from east of Port Angeles north to Victoria (Drake et al. 2010). These sills regulate water exchange from one basin to the next, and thus likely moderate the movement of rockfish larvae (Drake et al. 2010). When localized depletion of rockfish occurs, it can reduce resiliency of the entire DPS (Levin 1998; Hilborn et al. 2003; Hamilton 2008). It is likely that natural biogeographic limits to rockfish dispersal (as evidenced by a population of yelloweye rockfish in Hood Canal that is separate from the rest of the Puget Sound/Georgia Basin yelloweye rockfish population, discussed below) and distribution make them particularly susceptible to localized depletion as a result of fishery harvest.

Yelloweye rockfish spatial structure and connectivity has been reduced by the decline of fish within each basin. This reduction is likely most acute within the basins of Puget Sound proper. The severe decline of fish in these basins may eventually result in a contraction of the DPS' range (Drake et al. 2010). Although yelloweye rockfish are probably most abundant within the San Juan Basin, the likelihood of juvenile recruitment from this basin to the adjacent basins of Puget Sound proper is likely naturally low because of the generally retentive circulation patterns that occur within each of the major basins of Puget Sound proper. Combined with limited adult movement, yelloweye rockfish DPS viability may be highly influenced by the localized loss of populations within the DPS, which decreases spatial structure and connectivity.

Bocaccio may have been historically limited in their spatial distribution. They were likely historically most abundant in the Main Basin and South Sound (Drake et al. 2010; Williams et al. 2010) with no known documented occurrences in the San Juan Basin until 2008 (Pacunski et al. 2013). Spatial structure and connectivity in the DPS likely comes from the propensity of some adults and pelagic juveniles to migrate long distances, which could re-establish aggregations of fish in formerly occupied habitat (Drake et al. 2010). The apparent reduction of populations of bocaccio in the Main Basin and South Sound represents a further reduction in the historically limited distribution of bocaccio, and adds significant risk to the viability of the DPS.

In summary, spatial structure and connectivity for each species have been adversely impacted, in large part because of fishery removals (Palsson et al. 2009; Drake et al. 2010).

Life History Diversity, Demographic and Genetic Structure

Characteristics of life history diversity for rockfishes include age/size structure, fecundity, timing of larval release, larval condition, age at reproductive maturity, and molecular genetic characteristics. In spatially and temporally varying environments, there are three general reasons why diversity is important for species and population viability: 1) it allows a species to use a wider array of environments, 2) it protects a species against short-term spatial and temporal changes in the environment, and 3) genetic diversity provides the raw material for adaptation to long-term environmental changes. More information is needed to understand factors influencing diversity and how these factors may have changed populations over time.

Yelloweye rockfish demographic information

Data from the 1970s through 2000s indicate that yelloweye rockfish size and age distributions became truncated (Figure 4). Recreationally caught yelloweye rockfish in the 1970s spanned a broad range of sizes. By the 2000s, there was some evidence of fewer older fish in the population (Drake et al. 2010). As a result, the reproductive burden may be shifted to younger and smaller fish. This shift in demographic structure could alter the timing and condition of larval release, which may be mismatched with habitat conditions within the range of the DPS and reduce the viability of offspring (Drake et al. 2010).

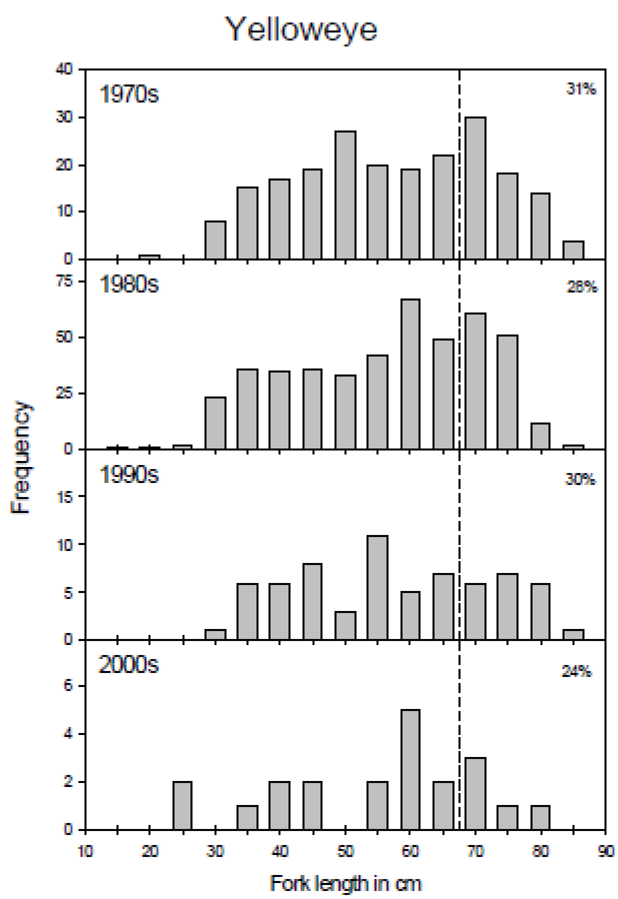

Figure 4. Yelloweye rockfish length frequency distributions (cm) for four decades. Approximately one third of harvested individuals in the 1970s were larger than the size depicted by the vertical dashed line (Source: Drake et al. 2010).

WDFW scientists observed a strong rockfish recruitment event in 2006 (Lowry et al. 2013), and there is evidence of improved population size distribution of yelloweye rockfish from data gathered in 2014 and 2015 (Figure 5). Size frequency information was collected during the 2014-2015 genetics research study (described in Section F and NMFS 2016), which was initiated to gain genetic data to better delineate the population structure for the listed species (Andrews et al. 2015). Yelloweye rockfish show some evidence of recruitment within the last 10 years (Figure 5). Nine of the sampled yelloweye rockfish were less than 15.8 inches (40 cm) in fork length (FL). Using the von Bertalanffy growth parameters from Love et al. (2002), these fish are approximately 7 to 10 years of age at 13.8 inches. Thus, the data suggest some recent replenishment of local populations of yelloweye rockfish although the extent is not known. In addition, several observations of young-of-year (YOY) yelloweye rockfish in Puget Sound have been documented by local recreational divers, the Seattle Aquarium, and WDFW (NMFS, unpublished database).

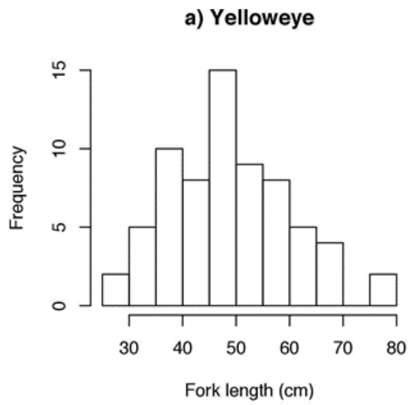

Figure 5. Yelloweye rockfish length frequency distributions (cm) from fish caught in 2014 and 2015 (Andrews et al. 2015).

Yelloweye rockfish genetic information

New collection and analysis of yelloweye rockfish tissue samples reveal significant genetic differentiation between the inland (DPS) and coastal samples. 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; NMFS 2016). In addition, yelloweye rockfish from Hood Canal were genetically differentiated from other Puget Sound/Georgia Basin fish (cluster in the upper right of Figure 6), indicating a previously unknown degree of population differentiation within the DPS (Ford 2015; NMFS 2016). Other genetic analysis has found that yelloweye rockfish in the Georgia Basin had the lowest molecular genetic diversity of a collection of samples along the coast (Siegle et al. 2013). Although the adaptive significance of such microsatellite diversity is unclear, it may suggest low effective population size, increased drift, and thus lower genetic diversity in the Puget Sound/Georgia Basin DPS.

TWO POPULATIONS OF YELLOWEYE ROCKFISH

Recent genetic research has found that yelloweye rockfish in Hood Canal are genetically differentiated from other yelloweye rockfish within the DPS—constituting two separate populations of fish within the Puget Sound/Georgia Basin.

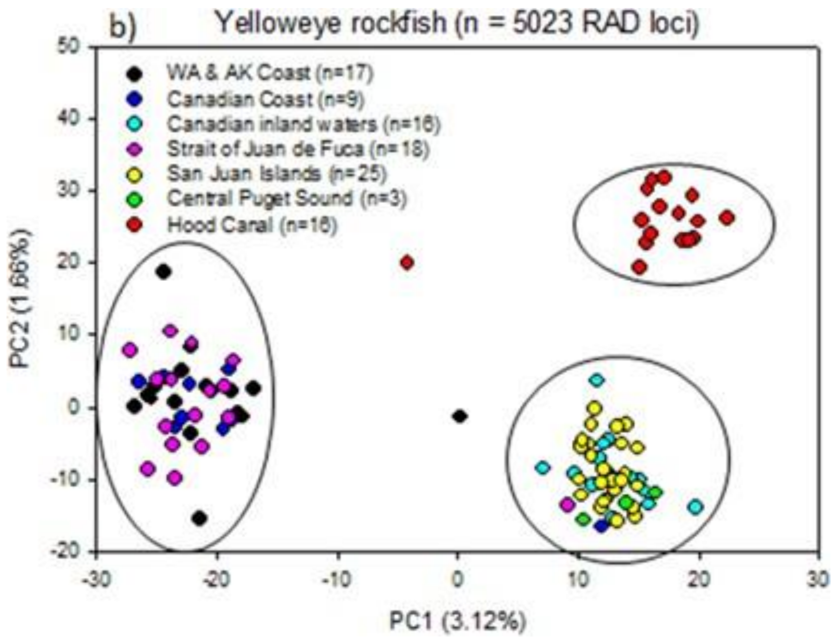

Figure 6. Three clusters of yelloweye rockfish based on a principal components analysis of the genetic variation between individuals inside and outside the DPS and among specific regions (Andrews et al. 2015).

Bocaccio demographic information

Size-frequency distributions for bocaccio in the 1970s indicate a wide range of sizes, with recreationally caught individuals from 9.8 to 33.5 inches (25 to 85 cm) (Figure 7). This broad size distribution suggests a spread of ages, with some successful recruitment over many years. A similar range of sizes is also evident in the 1980s catch data (Palsson et al. 2009; Drake et al. 2010). The temporal trend in size distributions for bocaccio also suggests size truncation of the population, with larger fish becoming less common over time. By the 2000s, no size distribution data for bocaccio were available. The potential loss of diversity in the bocaccio DPS, in combination with their relatively low productivity, may result in a mismatch with habitat conditions and further reduce population viability (Drake et al. 2010).

In summary, although there may have been some recruitment in recent years, size and age structure of both species has likely been adversely impacted by past fishery removals, with catch biased toward larger individuals, thereby altering demographic structure. During the 2014/2015 collection and analysis of yelloweye rockfish tissue, scientists also tried to collect bocaccio tissue. Because of their rarity, genetic analysis for bocaccio included only three samples from within the DPS area (Andrews et al. 2015); this is not sufficient information to change the prior status review determination (Ford 2015; NMFS 2016).

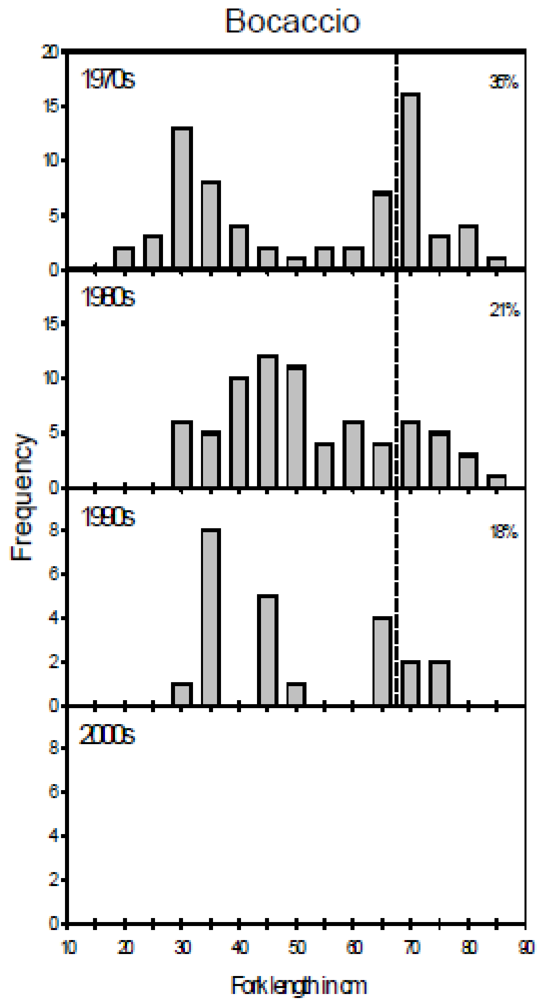

Figure 7. Bocaccio length frequency distributions (cm) for four decades. Approximately one third of harvested individuals in the 1970s were larger than the size depicted by the vertical dashed line (Note: there is no vertical dashed line in the 2000s because no bocaccio were recorded in catch) (Source: Drake et al. 2010).

D. MANAGEMENT UNITS AND HABITAT CHARACTERISTICS

The yelloweye rockfish DPS and the bocaccio DPS span a range of habitats in the Puget Sound/Georgia Basin that are adjacent to urban hubs, agricultural areas, and remote regions. They also span regions that exhibit different oceanographic conditions. Therefore, we use five geographically based management units (Figure 8) to describe different habitat characteristics to further assist with delisting and downlisting criteria, rank threats by management unit, and identify specific research and recovery actions. The DPS boundary for yelloweye rockfish has also been extended further north into Canada to include Johnstone Strait and Queen Charlotte Channel (Figure 8) (NMFS 2016).

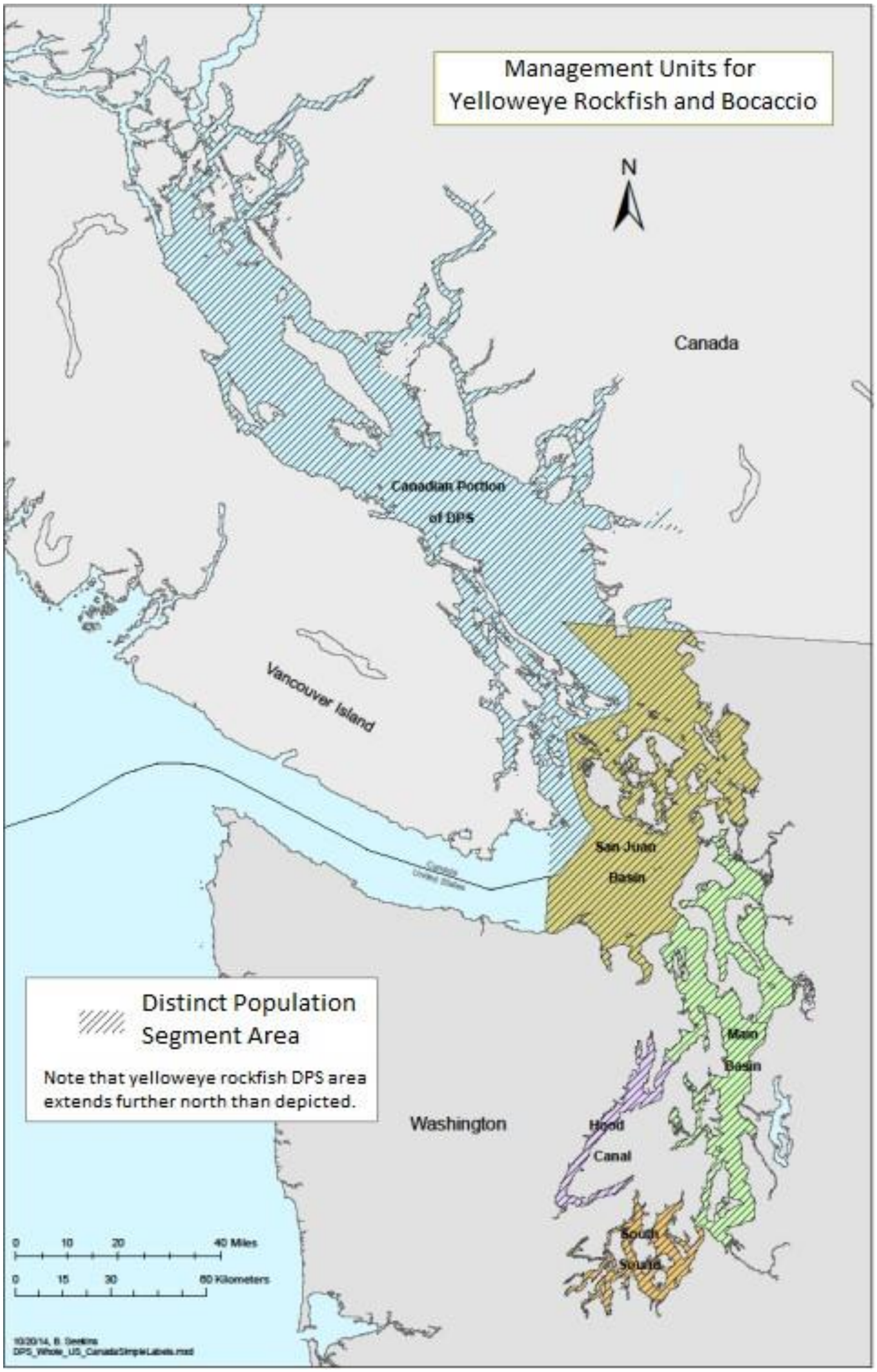

Figure 8. DPSs area and Management Units.

Management Unit and Habitat Descriptions

The range of the two DPSs includes Puget Sound and Georgia Basin, which make up the southern arm of an inland sea located on the Pacific Coast of North America and connected to the Pacific Ocean by the Strait of Juan de Fuca. Puget Sound can be subdivided into biogeographic basins that encompass contiguous, ecologically unique, and spatially isolated freshwater, estuarine, and marine habitats (Downing 1983; Burns 1985). Puget Sound is a fjord-like estuary covering 2,331.8 square miles (6,039.3 sq. km). Puget Sound is fed by 14 major river systems and consists of a series of interconnected basins separated by prominent sills. Most of the water exchange in Puget Sound proper is through Admiralty Inlet, and the configuration of sills and deep basins results in the partial recirculation of water masses and the retention of contaminants, sediment, and biota (Strickland 1983). Tidal action, freshwater inflow, and ocean currents interact to circulate and exchange salty marine water from the Strait of Juan de Fuca at depth and less dense fresh water from the surrounding watersheds at the surface, producing a net seaward flow of water at the surface (Strickland 1983).

The sills largely define the boundaries between the biogeographic 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 restrict water exchange, and 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, water temperatures, and water quality (Ebbesmeyer et al. 1984; Burns 1985; Rice 2007). In addition, each basin differs in biological condition; depth profiles and contours; subtidal benthic, intertidal habitats; and shoreline composition and condition (Downing 1983; Ebbesmeyer et al. 1984; Burns 1985; Rice 2007; Drake et al. 2010). Puget Sound has approximately 2,400 miles (3,862 km) of shoreline, ranging from rocky sea cliffs to coastal bluffs and river deltas. Most of the shoreline of Puget Sound proper is composed of erodible gravel, sand, and clay deposited by glaciers more than 15,000 years ago, while much of the San Juan Basin's shoreline is composed of rock and large cobble materials (Downing 1983).

The five Management Units are listed below and shown in Figure 8. The first four are based on the aforementioned conditions. The fifth management unit, which includes the Canadian portion of the Puget Sound/Georgia Basin, is a political boundary because the U.S. does not have authority in Canadian waters.

(1) The San Juan/Strait of Juan de Fuca Basin
(2) Main Basin
(3) South Puget Sound
(4) Hood Canal
(5) The Canadian portion of the Puget Sound/Georgia Basin

The San Juan/Strait of Juan de Fuca Basin: This basin is the northwestern boundary of the U.S. portion of the DPSs' ranges. The basin includes Bellingham Bay and is delimited to the north by the Canadian border, to the west by the entrance to the Strait of Juan de Fuca, to the south by the Olympic Peninsula and Admiralty Inlet, and to the east by Whidbey Island and the mainland between Anacortes and Blaine, Washington. The predominant feature of this basin is the Strait of Juan de Fuca, which is 99.4 miles (160 km) long and 13.7 miles (22 km) wide at its western end and over 24.9 miles (40 km) at its eastern end

(Thomson 1994). Drake et al. (2010) considered the western boundary of the DPSs' range as the Victoria Sill because it is hypothesized to control larval dispersal for rockfish (and other biota) of the region.

The San Juan/Strait of Juan de Fuca Basin has the most rocky shoreline and benthic habitats of the U.S. portion of the DPSs. Most of the basin's numerous islands have rocky shorelines and extensive, submerged, aquatic vegetation and floating kelp beds that support juvenile bocaccio settlement to benthic habitats, provide cover from predation, and support rearing. Approximately 93 percent of the rocky benthic habitats of the U.S. portion of the range of all three DPSs are in this basin (Palsson et al. 2009).

Commercial and recreational fisheries occur in the San Juan Basin, as well as scientific research, that may encounter listed rockfish as bycatch. The highest concentration of derelict fishing nets in the DPSs' ranges remain here, including many nets in waters deeper than 100 feet (30.5m). This basin has the most kelp in the DPSs' ranges, and because of its commonality, commercial kelp harvest may be proposed for the San Juan Islands area. The Ports of Bellingham and Anacortes are located in this basin, and numerous dredging and dredge disposal projects and nearshore development, such as new docks, piers, and bulkheads, occur in this basin. These development actions have the potential to alter nearshore rearing habitats of bocaccio. Two open-water dredge material disposal sites are located in the basin, one in Rosario Strait and the other northwest of Port Townsend. These are termed dispersive sites because they have higher current velocities; thus, dredged material does not accumulate at the disposal site and settles on benthic environments over a broad area (Army Corps of Engineers 2010). Sediment disposal activities in these specific areas may temporarily alter dissolved oxygen levels and alter the ability of juvenile rockfish to seek out prey. There are several areas with contaminated sediments along the eastern portion of this basin, particularly in Bellingham Bay and Guemes Channel near Anacortes.

The Main Basin: The Main Basin is delimited to the north by the marine waters east of Whidbey Island at Deception Pass, to the west by a line between Point Wilson near Port Townsend and Partridge Point on Whidbey Island, and to the south by Tacoma Narrows. The Skagit, Snohomish, and Stillaguamish Rivers flow into this northern portion of the basin and contribute the largest influx of freshwater inflow to Puget Sound (Burns 1985). The sill at the border of Admiralty Inlet and the eastern Straits of Juan de Fuca regulates water exchange of Puget Sound (Burns 1985). Water retention is estimated to be 1 month in the southern portion of this basin and 5.4 months in the northern portion, largely because of the sills at Admiralty Inlet and Deception Pass (Ebbesmeyer et al. 1984).

The nearshore of the Main Basin consists of bluff-backed beaches with unconsolidated materials ranging from mud and sand to mixes of gravels and cobbles (McBride et al. 2006). Some of these nearshore areas support the growth of kelp and support juvenile bocaccio settlement, cover from predation, and rearing. Much of the northern part of this basin is relatively shallow with moderately flat bathymetry near the Skagit, Stillaguamish, and Snohomish River deltas and does not support essential nearshore features such as holdfasts for kelp, and rock and cobble areas for rearing juvenile bocaccio. The southern portion of the basin has more complex bathymetry compared to the north, with deeper waters adjacent to Whidbey Island, southern Camano Island, and off of Mukilteo. Subtidal surface sediments in Admiralty Inlet tend to consist largely of sand and gravel, whereas sediments just south of the inlet and southwest of Whidbey Island are primarily sand. Sediments in the deeper areas of the central portion of the Main Basin generally consist of mud or sandy mud (PSWQA 1987). Benthic areas in this basin with steep and irregular bathymetry and high rugosity support growth, refuge, reproduction, and feeding opportunities.

Possession Point is centrally located within this basin at the southern end of Whidbey Island and has relatively steep eastern, southern, and western edges. It also has some rocky substrates and has relatively consistent aggregations of forage fish (Squire and Smith 1977). There are benthic areas deeper than 98 feet (30 m) along Possession Point, Admiralty Inlet, and the rims of Puget Sound beyond the nearshore that feature sloping bathymetry and areas of high rugosity that support growth, refuge, reproduction, and feeding opportunities for both yelloweye rockfish and bocaccio. The waters in this basin are generally stratified, with surface waters warmer in summer (generally 50° to 55°F [10° to 13°C]) and cooler in winter (generally 45° to 50°F [7° to 10°C]) (Collias et al. 1974).

In Port Susan and Saratoga Passage, salinities of surface waters (27.0 to 29.5 psu) are generally lower than in the southern portion of the basin because of runoff from the major rivers; moreover, after heavy rain these salinities range from 10 to 15 psu. Subsurface temperatures are usually between 46° and 54°F (8° and 12°C). In the deeper portions of the Main Basin, salinities are generally approximately 30 psu in summer and fall, but decrease to approximately 29 psu during the more rainy months.

This basin has consistently higher temperatures and lower salinity relative to the San Juan Basin. Dissolved oxygen levels vary seasonally, with lowest levels of about 5.5 mg/L occurring at depth in summer months, and highest levels of about 7.5 mg/L near the surface. Occasionally, summertime highs reach 13 to 14 mg/L at the surface.

Activities in this basin that may affect listed rockfish and their habitat include bycatch from commercial and recreational fisheries, scientific research, dredging projects and dredge disposal operations, nearshore development projects, and tidal energy projects. Vessel traffic in this basin is common as cargo ships transit to/from the Strait of Juan de Fuca to the Ports of Seattle and Tacoma and other destinations in the Main Basin and South Puget Sound (Bassett et al. 2012). An estimated 23 derelict nets in waters shallower than 100 feet (30.5 m) and one in deeper waters remain in this basin (NRC 2014). Pollution and runoff are particular concerns in this basin because of the extensive amounts of impervious surface and activities associated with urbanization. Two open-water dredge disposal sites are located in the basin—one located in Elliot Bay and the other in Commencement Bay. These are non-dispersive disposal sites, which are areas where currents are slow enough that dredged material is deposited on the disposal target area rather than dispersing broadly with prevailing currents (Army Corps of Engineers 2010). An estimated 36 percent of the shoreline in this area has been modified by human activities (Drake et al. 2010), and bulkhead/pier repair projects and new docks/piers are proposed regularly in this basin. There are several areas with contaminated sediments in this basin, particularly in Port Gardner, Elliot Bay, Sinclair Inlet, and Commencement Bay.

South Puget Sound: This basin includes all waterways south of Tacoma Narrows. This basin is characterized by numerous islands and shallow (generally < 65 feet [20 m]) inlets with extensive shoreline areas. The sill at Tacoma Narrows restricts water exchange between the South Puget Sound and the Main Basin, and water retention is an estimated 1.9 months (Ebbesmeyer et al. 1984). This restricted water exchange influences environmental characteristics of South Puget Sound, such as nutrient levels and dissolved oxygen, and perhaps its biotic communities (Ebbesmeyer et al. 1984; Rice 2007).

The nearshore and intertidal areas of this basin consist of a wide assortment of sediments (Bailey et al. 1998). The most common sediments and the percent of the intertidal area they cover are: mud, 38.3 ± 29.3 percent; sand, 21.7 ± 23.9 percent; mixed fine, 22.9 ± 16.1 percent; and gravel, 11.1 ± 4.9 percent.

Subtidal areas have a similar diversity of surface sediments, with shallower areas consisting of mixtures of mud and sand and deeper areas consisting of mud (PSWQA 1987). Kelp has likely declined in the South Puget Sound, but some areas still support the growth of kelp and also support juvenile bocaccio settlement, cover from predation, and rearing. The southern inlets of this basin include Oakland Bay, Totten Inlet, Budd Inlet, and Eld Inlet, in addition to the Nisqually River delta.

Sediments in Tacoma Narrows and Dana Passage consist primarily of gravel and sand. With a mean depth of 121 feet (37 m), this basin is the shallowest of the biogeographic basins (Burns 1985), and benthic areas deeper than 98 feet (30 m) occur in portions of the Tacoma Narrows. The rims of South Puget Sound beyond the nearshore have sloping bathymetry and areas of high rugosity that support growth, refuge, reproduction, and feeding opportunities. The major urban areas, and thus more pollution and runoff into South Puget Sound, are found in the western portions of Pierce County. Other urban centers in the southern Puget Sound area include Olympia and Shelton.

The major channels of the southern basin are moderately stratified compared to most other greater Puget Sound basins. Salinities generally range from 27 to 29 psu and, although surface temperatures reach 57° to 59°F (14° to 15°C) in summer, the temperatures of subsurface waters generally range from 50° to 55°F (10° to 13°C) in summer and from 46° to 50°F (8° to 10°C) in winter (Ecology 1999). Dissolved oxygen levels generally range from 6.5 to 9.5 mg/L. Salinity in the inlets tends to be similar to those of the major channels, whereas temperatures and dissolved oxygen levels in the inlets are frequently much higher in summer. Two of the larger inlets, Carr and Case, have surface salinities ranging from 28 to 30 psu in the inlet mouths and main bodies, but lower salinities range from 27 to 28 psu at the heads of the inlets (Collias et al. 1974). Summertime surface waters in Budd, Carr, and Case Inlets commonly have temperatures that range from 59° to 66°F (15° to 19°C) and dissolved oxygen values of 10 to 15 mg/L.

Activities in this basin that may affect both yelloweye rockfish and bocaccio and their habitat include bycatch from commercial and recreational fisheries, scientific research, dredging and dredge disposal, nearshore development, pollution and runoff, aquaculture operations, and potential tidal energy projects. An estimated 20 derelict nets in waters shallower than 100 feet (30.5 m) and one in deeper waters remain in this basin (NWSI 2014b). A non-dispersive dredge disposal site is located off Anderson/Ketron Island (Army Corps of Engineers 2010) and is monitored for impacts collaboratively by WDFW and DNR. A potential tidal energy site is located in the Tacoma Narrows area. Important point sources of waste include sewage treatment facilities, and about 5 percent of the nutrients (as inorganic nitrogen) entering greater Puget Sound enter this basin through non-point sources (Embrey and Inkpen 1998). An estimated 34 percent of the shoreline in this area has been modified by human activities (Drake et al. 2010), and bulkhead/pier repair projects and new docks/piers are proposed regularly in this basin. There are several areas with contaminated sediments in this basin (Appendix VI).

Hood Canal: Hood Canal branches off the northwest part of the Main Basin near Admiralty Inlet and is the smallest of the greater Puget Sound basins, being 55.92 miles (90 km) long and 0.62 to 1.24 miles (1 to 2 km) wide (Drake et al. 2010). Water retention is estimated at 9.3 months; exchange in Hood Canal is regulated by a 164-foot (50-meter) deep sill near its entrance that limits the transport of deep marine waters in and out of Hood Canal (Ebbesmeyer et al. 1984; Burns 1985).

The major components of this basin consist of the Hood Canal entrance, Dabob Bay, the central basin, and the Great Bend at the southern end. A combination of relatively little freshwater inflow, the sill at

Admiralty Inlet, and bathymetry lead to relatively slow currents; thus, water residence time within Hood Canal is the longest of the biogeographic basins, with net surface flow generally northward (Ebbesmeyer et al. 1984). The intertidal and nearshore zone consists mostly of mud (53.4 ± 89.3 percent of the intertidal area), with similar amounts of mixed fine sediment and sand (18.0 ± 18.5 percent and 16.7 ± 13.7 percent, respectively) (Bailey et al. 1998). Some of the nearshore areas of Hood Canal support the growth of kelp and have cobble and gravel substrates intermixed with sand that support juvenile bocaccio settlement, cover from predation, and rearing. Surface sediments in the subtidal areas also consist primarily of mud and cobbles (PSWQA 1987). The shallow areas of the Great Bend, Dabob Bay, Hamma, Quilcene, Duckabush, Dosewallips, Tahuya, and Skokomish River deltas feature relatively muddy habitats that do not support essential nearshore features such as holdfasts for kelp, and rock and cobble areas for rearing juvenile bocaccio. Benthic areas deeper than 98 feet (30 m) occur along the rim of nearly all of Hood Canal, and these areas have sloping and steep bathymetry and areas of high rugosity that support growth, refuge, reproduction, and feeding opportunities.

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

Activities in Hood Canal that could affect yelloweye rockfish and bocaccio include commercial and recreational fisheries, scientific research, nearshore development, non-indigenous species management, and pollution and runoff. An estimated three derelict nets in waters shallower than 100 feet (30.5 m) and two in deeper waters remain in this basin (NRC 2014). The unique bathymetry and low water exchange have led to episodic periods of low dissolved oxygen (Newton et al. 2007), though the relative role of nutrient input from humans in exacerbating these periods of hypoxia is in doubt (Cope and Roberts 2012). Dissolved oxygen levels have decreased to levels that cause behavioral changes and kill rockfish (i.e., below 1.0 mg/L) (Palsson et al. 2008), and beginning in 2004, bottom fishing in Hood Canal became prohibited. An estimated 34 percent of the shoreline in this area has been modified by human activities (Drake et al. 2010), and bulkhead/pier repairs and new docks/piers are regularly proposed in this basin. The non-indigenous tunicate *Ciona savignyi* has been documented at 86 percent of sites surveyed in Hood Canal (Drake et al. 2010).

Canada: The waters of Canada from the international border in the San Juan Basin northward on the inside of Vancouver Island to the Johnstone Strait constitute the northern portion of the Puget Sound/Georgia Basin bocaccio DPS range. This waterway is commonly termed the Strait of Georgia, which is 137.94 miles (222 km) long, 12.43 to 24.85 miles (20 to 40 km) wide, and covers approximately of 4,225 square miles (6,800 square km). Depths average 508 feet (155 m), with only 5 percent of the strait estimated to have depths greater than 1,181 feet (360 m) (Wilson et al. 1994).

Major components of this unit include the Fraser River and large networks of islands, such as the Gulf Islands, that result in shallow tidal passes. Water flow and currents in the Strait of Georgia are complex and are driven by a large influx of fresh water from the Fraser River, a large tidal range, and prevailing winds. The Fraser River provides regionally significant nutrient and contaminant loadings to the Strait of

Georgia. Aside from the Fraser River estuary and nearby shorelines, much of the shorelines in the Strait of Georgia consist of rock and cobble formations, much of which support various species of kelp.

Activities in the inside waters of the Canadian portion of the San Juan Basin northward include First Nations fishing, commercial fishing, and recreational fishing. As of 2006, 100 percent at-sea monitoring standards were put into place for the entire commercial groundfish fishery. This monitoring was intended to eliminate unreported catch of rockfish throughout the commercial groundfish fishery and allow all rockfish to be accounted for within their total allowable catch (TAC). There are also a number of Rockfish Conservation Areas in these waters (Yamanaka et al. 2006; DFO 2015).

Sediment contamination including elevated levels of PAHs, lead, and mercury have been found in various areas of this basin, particularly near the City of Vancouver (Goyette et al. 1988), Howe Sound, and other industrialized areas (Wilson et al. 1994). Other recognized threats in Canada include fisheries (Yamanaka et al. 2006). Oceanographic conditions are a natural limiting factor that may affect successful rockfish recruitment in Canada (Yamanaka et al. 2006), though this effect still requires further regional research.

Critical Habitat Designation

Critical habitat was designated for listed rockfish in 2014 under section 4(a)(3)(A) of the ESA (79 Fed. Reg. 68041, November 13, 2014) (Figure 9; Table 4). The specific areas designated for bocaccio total approximately 1,004.50 square miles (1616.59 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 414.10 square miles (666.43 sq. km) of deepwater marine habitat in Puget Sound, all of which overlap with areas designated for 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 U.S. jurisdiction; therefore, although waters in Canada are part of the DPSs’ ranges for the two 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.

On January 23, 2017 we issued a final rule to remove the Puget Sound/Georgia Basin canary rockfish (*Sebastes pinniger*) DPS from the Federal List of Threatened and Endangered Species and remove its critical habitat designation (82 Fed. Reg. 7711).

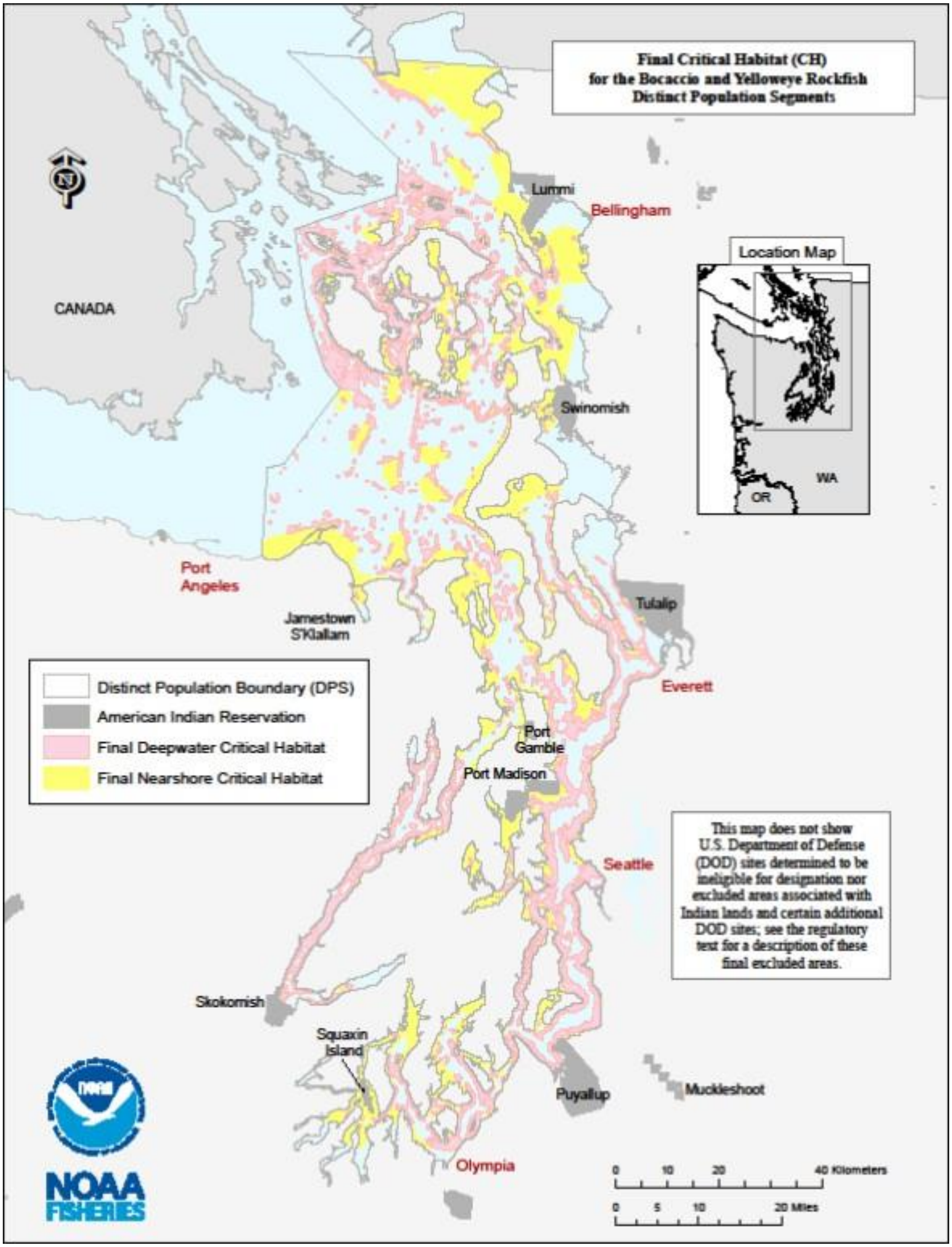

Figure 9. Critical habitat for yelloweye rockfish and bocaccio.

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 and bocaccio (Table 4), 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." The physical or biological features essential to the conservation of yelloweye rockfish and bocaccio fall into major categories reflecting key life history phases:

Adult bocaccio, and adult and juvenile yelloweye rockfish: We designated sites deeper than 98 feet (30 m) that possess (or are adjacent to) areas of complex bathymetry. These features are essential to conservation because they support growth, survival, reproduction, and feeding. Several attributes of these sites affect the quality of the area and are useful in considering the conservation value of the feature, in determining whether the feature may require special management considerations or protection, and in evaluating the effects of a proposed action in a section 7 consultation if the specific area containing the site is designated as critical habitat. These attributes include: 1) quantity, quality, and availability of prey species to support individual growth, survival, reproduction, and feeding opportunities; 2) water quality and sufficient levels of dissolved oxygen to support growth, survival, reproduction, and feeding; and 3) structure and rugosity to support feeding and predator avoidance.

Juvenile bocaccio only: We designated juvenile settlement sites located in the nearshore[1] with substrates such as sand, rock, and/or cobble compositions that also support kelp and eelgrass. These features are essential for conservation because they enable forage opportunities and refuge from predators, and enable behavioral and physiological changes needed for juveniles to occupy deeper adult habitats. Several attributes of these sites affect the quality of the area. They are useful in considering the conservation value of the feature to determine whether the feature may require special management considerations or protection, and in evaluating the effects of a proposed action in a section 7 consultation if the specific area containing the site is designated as critical habitat. These attributes include: 1) quantity, quality, and availability of prey species to support individual growth, survival, reproduction, and feeding; 2) water quality and sufficient levels of dissolved oxygen to support growth, survival, reproduction, and feeding; and 3) structure and rugosity (geologic, macroalgae, seagrass) to support predator avoidance.

[1] Most nearshore areas are contiguous with the shoreline from the line of extreme high water out to a depth no greater than 98 feet (30 m) relative to mean lower low water. Several nearshore areas designated as critical habitat are not associated with a beach, but are shallower than 98 feet (30 m) and can support kelp and rearing habitat. They include areas of Hein Bank, Partridge Bank, Coyote Bank, Middle Bank, and several areas north of Orcas Island.

Table 4. Physical and biological features and management considerations of subadult and adult habitat for yelloweye rockfish and bocaccio, prior to exclusions[1].

DPS Basin	Nearshore Square Miles (for juvenile bocaccio only)	Deepwater Square Miles (for adult and juvenile yelloweye rockfish and adult bocaccio)	Physical or Biological Features	
San Juan/Strait of Juan de Fuca	349.4	203.6	Deepwater sites >98 feet (30 m) that support growth, survival, reproduction, and feeding opportunities	Nearshore juvenile rearing sites with sand, rock, cobbles, and/or structure-forming macroalgae (e.g., kelp) to support forage and refuge
Whidbey Basin	52.2	32.2		
Main Basin	147.4	129.2		
South Puget Sound	75.3	27.1		
Hood Canal	20.4	46.4		

[1] After exclusions, total nearshore critical habitat includes 590.4 square miles (a reduction from 644.7 square miles) and deepwater critical habitat includes 414.1 square miles (a reduction from 438.5 square miles).

E. FACTORS CONTRIBUTING TO DECLINE AND FEDERAL LISTING

When evaluating a species for protection under the ESA, the Secretary of Commerce must consider whether any one (or more) of five listing factors affect the species. Listing factors deal with those aspects of the species' biology or habitat that affect the level of threat to the species' continued persistence. The ESA requires that each of the factors that contributed to the species' listing be addressed in the recovery actions identified in the recovery plan.

The five listing factors are:

1. Present or Threatened Destruction, Modification, or Curtailment of Habitat or Range
2. Over-utilization for Commercial, Recreational, Scientific, or Educational Purposes
3. Disease and Predation
4. Inadequacy of Existing Regulatory Mechanisms
5. Other Natural or Human-made Factors Affecting Continued Existence

NMFS' listing determinations regarding the rockfish DPSs (75 Fed. Reg. 22276, April 28, 2010, updated 79 Fed. Reg. 20802, April 14, 2014) and additional technical reports (e.g., Palsson et al. 2009; Drake et al. 2010; WDFW 2011) identified the factors of concern for rockfish. In 2016, we completed a 5-year review under the ESA that included a review of the listing factors (NMFS 2016). The review included updated information on threats and actions being implemented to address them and concluded that the collective risk to yelloweye rockfish and bocaccio of the Puget Sound/Georgia Basin's persistence has not changed significantly since the listing determinations in 2010. Below we summarize threats and sources of those threats identified in the listing documents and 5-year review that incorporated updated information available since 2010, noting potential threats that require more research to understand whether they are limiting rockfish recovery. Following the summary addressing all of the threats for listed rockfish throughout their range, there is a threats assessment that is broken down into the four geographically based management units in the United States, and one in Canada. The threats assessment conducted for each unit provides more detailed information on the level of threat from each source.

Factor 1: Present or Threatened Destruction, Modification, or Curtailment of Habitat or Range

Degradation and/or Loss of Nearshore Habitat

The nearshore provides important habitat for juvenile bocaccio, which most readily use rocky areas with and without kelp, and also use sandy areas and areas that support eelgrass (Moser 1967; Carr 1983; Kendall and Lenarz 1986; Love et al. 1991; Murphy et al. 2000; Love et al. 1991; Love et al. 2002). Macroalgae and eelgrass provide structure for feeding, predation refuge, and buffer against currents to enable energy conservation for juvenile bocaccio (Love et al. 1991).

The human population in the greater Puget Sound region has increased rapidly over the last three decades with approximately 4 million residents. Hutchinson (1988) indicated that overall losses by area of intertidal habitat were 58 percent for greater Puget Sound and 18 percent for the Strait of Georgia since European settlement. Four river deltas (the Duwamish, Lummi, Puyallup, and Samish) have lost more than 92 percent of their intertidal marshes (Simenstad et al. 1982). At least 76 percent of the wetlands around greater Puget Sound have been eliminated, especially in urbanized estuaries. Substantial declines of mudflats and sand flats have also occurred in the deltas of rivers draining to estuaries (Levings and Thom 1994). More recent estimates suggest that more than 80 percent of all tidal wetlands have been converted to human-dominated land uses (Collins and Sheikh 2005). Furthermore, nearly 52 percent of central Puget Sound and about 35 percent of the shorelines of Whidbey Island, Hood Canal, and South Puget Sound have been modified by humans (Nearshore Habitat Program 2001). A third of all Puget Sound shoreline is armored, and in south-central Puget Sound over 60 percent is armored (Simenstad et al. 2011).

The development of nearshore areas likely continues to degrade rearing habitats, such as kelp, and prey resources for rockfish (NMFS 2016). From an analysis of development permits it appeared that in 2014, for the first time, more shoreline armoring has been legally removed than installed (Hamel et al. 2015). However, permitted projects are not always carried out and unpermitted armoring can occur, and while this result was taken from the best available data, the actual change in shoreline armoring may differ from the cited report.

This development and loss of nearshore habitat impairs the productivity of some food sources for rockfish, and alters the quality of nearshore rearing habitats for juvenile bocaccio. For more information and research priorities see Appendix V, Nearshore Habitat and Kelp Conservation.

Degradation and/or Loss of Benthic/Deepwater Habitat

The known and potential threats of deepwater habitat include derelict fishing gear, dredging and sediment disposal, invasive species, artificial reefs (which could act to either augment or threaten habitat), alternative energy structures, and cable laying. Dredging and disposal activities may affect benthic habitats and water quality features. Sediment plumes within the water column may disrupt the ability of rockfish to pursue prey, may temporarily reduce dissolved oxygen levels, and may obscure and homogenize depressions used by adult fish (NMFS 2014). The loss of rocky habitats as a result of sedimentation has been documented near the Skagit River delta (Grossman et al. 2007). Dredging often occurs in areas with a variety of contaminated sediments that can be released into the water column by the dredging and disposal process. These contaminants may be taken up by phytoplankton, zooplankton, benthic invertebrates, demersal fish, forage fish, and other fishes (Army Corps of Engineers 2010), which can then be bioaccumulated by long-lived predators such as rockfish. Additionally, Palsson et al. (2009) note that benthic habitat can also be degraded by construction of bridges, sewer lines, and other structures; deployment of cables and pipelines; and by burying from dredge spoils and natural subtidal slope failures.

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 Puget Sound. See further details in Appendix IV, Benthic Habitat Conservation and in Appendix VI, Sediment and Water Quality.

Invasive / Nonindigenous Species

Invasive or nonindigenous species are an emerging threat to biogenic habitat in Puget Sound. *Sargassum muticum* is an introduced brown alga now common throughout much of Puget Sound (Drake et al. 2010). The degree to which *S. muticum* influences native macroalgae, eelgrass, or rockfish is not understood (Drake et al. 2010). However, invasive *S. muticum* has been shown to compete with and impair the re-establishment of giant kelp forests in southern California (Ambrose and Nelson 1982). Several species of nonindigenous tunicates have also been identified in Puget Sound (Cordell et al. 2012). For example, *Ciona savignyi* was initially seen in one location in 2004, but within 2 years spread to 86 percent of sites surveyed in Hood Canal (Drake et al. 2010). The exact impact of invasive tunicates on rockfish or their habitats is unknown, but results in other regions (e.g., Levin et al. 2002) suggest the potential for introduced invertebrates to have widespread impacts on rocky reef fish populations by changing habitat conditions (Drake et al. 2010). For more information and research priorities see Appendix IV, Benthic Habitat Conservation.

Contaminants

Over the last century, human activities have introduced oil and a variety of other toxins into the Georgia Basin at levels that may affect rockfish populations or the prey that support them. The sources of these toxins range from oil and chemical spills, to chronic discharges from point (i.e., sewage) and non-point sources, such as surface water runoff from roads and developed areas. Evidence of decades of contaminant inputs are found in several urban embayments in Puget Sound that have high levels of heavy metals and organic compounds (Palsson et al. 2009), and about 32 percent of the sediments in the Puget Sound region are considered to be moderately or highly contaminated (Puget Sound Action Team 2007). Organisms that live in or eat these sediments are consumed, thus transferring contaminants up the food web to higher level predators like rockfishes and to a wider geographic area (Drake et al. 2010).

Not surprisingly, contaminants such as PCBs, chlorinated pesticides (e.g., DDT), and PBDEs appear in rockfish collected in urban areas (West and O’Neil 1998; West et al. 2001; West et al. 2001b). While the highest levels of contamination occur in urban areas, toxins can be found in the tissues of fish in all regions of Puget Sound (Puget Sound Action Team, 2007). Rockfish collected in rural areas of the San Juan Islands contained high levels of mercury and hydrocarbons (West et al. 2001).

Although few studies have investigated the effects of toxins on rockfish ecology or physiology, other fish in the Puget Sound region that have been studied do show a substantial impact. As an example, in English sole, a demersal fish in Puget Sound that may live in the same depth ranges as rockfishes, reproductive impairment has been documented in individuals from contaminated areas (Landahl et al. 1997). Rockfishes are longer-lived than English sole, and reproductive function of adult rockfish is also likely affected by contaminants (Palsson et al. 2009) as well as other life history stages (Drake et al. 2010). Some areas with good habitat structure for rockfish are also located in areas that are now subject to high levels of contaminants. This is evidenced by the fact that rockfish were historically captured in great numbers in these areas (Palsson et al. 2009; Puget Sound Action Team 2007; NOAA 2010).

Contaminants may influence growth rates of rockfish. For example, Palsson et al. (2009) describe a case in which male rockfish were found to have lower growth rates than females—an unusual pattern for rockfish because males typically grow faster than females. The explanation may be that male rockfish tend to accumulate PCBs while the female's body burden does not increase with time because they lower their toxin level when they release larvae (West et al. 2001b). Thus, the observed difference in growth rate may result from the higher contaminant concentration in males versus females (Drake et al 2010).

Rockfish rely to some degree on pelagic prey and thus may experience greater exposure to persistent bioaccumulative toxins, or bioaccumulants, across a greater spatial range (not just urban areas) than the discussion above suggests. Prey, such as Pacific herring in Puget Sound, have unusually high body burdens of toxins that can biomagnify in their predators. Long lifespan and residency in Puget Sound, both characteristics of the listed rockfish species, increase the risk of exposure. In addition, environmental levels of legacy toxins such as PCBs were probably higher in Puget Sound's pelagic species in the 1970s and 1980s, the period when the listed species declined (Drake et al. 2010).

Microplastics are an emerging concern for marine ecosystems. Microplastics come from large plastic trash that has been reduced into smaller particles or they may also come from manufactured plastics such as microbeads in products like facial soap, body wash, and toothpaste. A laboratory experiment found that microplastic particles stunted larval growth, decreased activity rates and predator-avoidance strategies of European perch larvae (Lönnstedt and Eklöv 2016). The perch larvae also preferentially ate microplastic particles instead of plankton. These findings may be of concern for many marine species because microplastic particles often accumulate in shallow coastal areas where developmental stages of many organisms, in addition to fish, occur (Lönnstedt and Eklöv 2016). Rochman et al. (2015) surveyed fish for presence of anthropogenic debris and found that 33 percent of yellowtail rockfish and 20 percent of blue rockfish surveyed contained particles. For more information and research priorities on all contaminants see Appendix VI, Sediment and Water Quality.

Nutrient Addition and Low Dissolved Oxygen

Water quality in Puget Sound is influenced by sewage, animal waste, and nutrient input. Portions of Hood Canal have episodic periods of low dissolved oxygen, though the relative role of nutrient input from humans in exacerbating these episodes is in doubt (Cope and Roberts 2012). Typically, rockfish move out of areas with dissolved oxygen less than 2 mg/L; however, when low dissolved oxygen waters were upwelled to the surface in 2003, about 26 percent of the rockfish population was killed (Palsson et al. 2008). In addition to Hood Canal, periods of low dissolved oxygen are becoming more widespread in waters south of Tacoma Narrows (Palsson et al. 2009).

Ecology has been monitoring water quality in the Puget Sound region for several decades. Monitoring includes fecal coliform, nitrogen, ammonium, and dissolved oxygen. In 2005, of the 39 sites sampled, 8 were classified as highest concern and 10 were classified as high concern. Hood Canal has seen persistent and increasing areas of low dissolved oxygen since the mid-1990s. For more information and research priorities see Appendix VII, Climate Change and Ocean Acidification.

Listing Factor 2: Over-utilization for Commercial, Recreational, Scientific, or Educational Purposes

Bycatch and Barotrauma

Historical overfishing played a major role in the declines of rockfish in Puget Sound (Palsson et al. 2009; Williams et al. 2010), and while fishery regulations continue to evolve and are markedly different than they were historically, the ongoing effects of fishing are long-lasting and may constitute an ongoing threat (Drake et al. 2010; Collie et al. 2013). Fishing can have dramatic impacts on the size or age structure of rockfish populations because even minor levels of fishing can remove disproportionate numbers of older and larger fish (Drake et al. 2010). Notably, when the size and age of females declines, productivity declines, as older and larger females release a higher number of larvae that are equipped with a more developed oil globule that protects against the risk of starvation (Berkeley et al. 2004; Sogard et al. 2008). Additionally, in a broad range of species, there is evidence that age or size truncation is associated with increased variability in recruitment (Hsieh et al. 2006). When reproduction is limited to younger ages, breeding individuals may not have the opportunity to reproduce during environmental conditions that enhance output (Longhurst 2002) and populations more closely follow short-term fluctuations in the environment (Hsieh et al. 2006). Palsson et al. (2009) found that fished areas contain lower abundance of rockfish and smaller sizes than no-take marine protected areas. WDFW considers bycatch of rockfish to be a “high impact stressor” on rockfish populations (Palsson et al. 2009). WDFW estimates the bycatch from recreational fisheries on an annual basis, and has placed a moratorium on retaining rockfish in Puget Sound and the San Juan Islands. WDFW also closed several commercial fisheries that have rockfish bycatch. See Appendix II, Fisheries Management, for more information.

What is Barotrauma?

All rockfishes possess a closed swim bladder, which is a gas-filled organ that regulates buoyancy. When brought up from deep waters, decreasing pressure allows the gas to expand, which can cause injury and prevent the fish from swimming back down on its own. External symptoms of gas expansion include a swollen and tight belly, stomach protruding into the mouth, and distended and/or bubbles in eyes (see photo below), which may all cause injury or death to the fish. For more information on barotrauma, including research priorities and techniques and tips to properly release rockfish, please refer to Appendix III, Barotrauma Research and Adaptive Management.

Yelloweye rockfish caught in the San Juan Islands area during a genetics research project. This fish has barotrauma. Photo courtesy of Kelly Andrews.

A study of yelloweye rockfishes indicated that when they are caught and released at the surface, the mortality rate is high; however, survival is increased when they are released at depth with a decompression device (Hochalter and Reed 2011). Other studies of rockfish released at depth indicate good short-term survival of released fish (Parker et al. 2006; Jarvis and Lowe 2008). 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 (Hannah et al. 2014).

However, questions about long-term survival probability and effects on productivity and reproduction remain (Schroeder and Love 2002; Jarvis and Lowe 2008; Pribyl et al. 2009; Pribyl et al. 2011; Rankin et al. 2017). There is some 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). In addition, one yelloweye rockfish observed in Hood Canal by WDFW was observed as gravid several months after barotrauma.

It is notable that when rockfish are released at depth using descending devices (recompression) there are many variables that may influence long-term survival, such as angler experience and handling, thermal shock, and depth of capture (Schroeder and Love 2002; Jarvis and Lowe 2008; Pribyl et al. 2009; Pribyl et al. 2011). Cox et al. (2007) found that bycatch mortality reduction measures implemented across a variety of resource users did not perform as well as the reduction measures implemented by managers and scientists (Cox et al. 2007). A 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.

Appendix II, Fisheries Management, and Appendix III, Barotrauma Research and Adaptive Management, summarize recommended research and actions to address bycatch and barotrauma.

Listing Factor 3: Disease and Predation

<u>Predation</u>

Rockfishes are an important food resource for a variety of predators in Puget Sound (Palsson et al. 2009), but there is little data regarding specific predators of yelloweye rockfish and bocaccio of the Puget Sound/Georgia Basin. Rockfish are preyed upon by numerous fish species, birds, and several marine mammals (Mills et al. 2007; Lance et al. 2012; Buzzell et al. 2014). Larvae and juveniles are eaten by birds, salmon, rockfish, lingcod, and other fish species (Mills et al. 2007). Juveniles and adults are eaten by lingcod and some marine mammals (Love et al. 2002; Palsson et al. 2009).

Adult yelloweye rockfish and bocaccio have several physical defenses and behaviors to reduce the likelihood of predators (Roche and Halstead 1972). They occupy deep waters, often near structure such as rock and boulders, where they can seek refuge and thus reduce their vulnerability to predation (Griffiths and Harrod 2007). Like other rockfish species, adults have venom glands at the base of their fins to deter predators. In addition, rockfishes are deep-bodied, with long dorsal spines that may inhibit gape-limited predators. These factors likely influence consumption rates of adult rockfish by some predators, such as pinnipeds.

Patterns of rockfish predation by marine mammals and fishes have been shown to vary over space and time. Rockfish predation by harbor seals, the most abundant pinniped species in Puget Sound and the most common pinniped in the San Juan Islands (Jeffries et al. 2000), varies annually by location and time of the year (Lance and Jeffries 2007). Harbor seal populations have increased from hundreds during the 1970s to more than 10,000 in the late 1990s, a 7- to 10-fold increase in estimated abundance; since the 1990s their population has remained stable (Jeffries et al. 2003). The harbor seal is the only pinniped species that breeds in Washington waters, and is the only pinniped with known haul-out sites in the San Juan Islands (Jeffries et al. 2000). Harbor seals are considered a threat to local fisheries in many areas (Olesiuk et al. 1990; Bjorge et al. 2002) and concerns have arisen about their impact on fisheries in Washington, Oregon, and California, where consumption of fish by California sea lions and harbor seals are estimated to be almost half of what was harvested in commercial fisheries in the late 1990s (NMFS 1997). Rockfish (all species) occurred in 12 percent of harbor seal diets in the San Juan area in 2006 and 2007, compared to 2.3 percent in 2005 and 2006 (Lance and Jeffries 2007). Most of these rockfish were juveniles. However, in scat collection areas adjacent to marine reserves in the San Juan Islands, rockfishes composed a minor portion of harbor seal diets (Lance et al. 2012). Tagged harbor seals did not forage inside marine reserves in the San Juan Islands (Peterson et al. 2012), and during the collection from 2005 to 2008, rockfishes were found to compose 0.95 percent (or 16/1,682 scat samples) of harbor seal diets throughout all seasons (Lance et al. 2012). The authors of that study suggested that the abundance of other species was an important factor in this low predation rate as harbor seals fed primarily on species that are seasonally and regionally abundant, such as herring (year-round), adult salmon (in summer), and sand lance, anchovy, and juvenile walleye pollock (in winter and spring) (Lance et al. 2012). Recent analysis of harbor seal diets in the San Juan Islands found rockfish exceeding 10 percent of the average diet, with relatively large proportions of black rockfish (*Sebastes melanops*), yellow rockfish (*S. flavidus*), copper rockfish (*S. caurinis*), and Puget Sound rockfish (*S. emphaeus*). No listed rockfish were found in seal diets in this study (Bromaghin et al. 2013). A study in Hood Canal found rockfish present in 1 percent of seal scats, a result similar to areas adjacent to marine reserves in the San Juan Islands (London et al. 2002). While rockfish may constitute a small component of seal diets, increases in seal populations may still negatively affect rockfishes, warranting further investigation into factors affecting variation.

Other mammalian predators also require consideration. About 2,000 Steller sea lions occur seasonally in Washington waters, particularly in the San Juan Islands (Palsson et al. 2009). About 8 percent of the Steller sea lion diet is rockfish (Lance and Jeffries 2007). Though not abundant, their large size and aggregated distribution suggest that their local impact could be substantial (Drake et al. 2010). Rockfish have been found as prey of killer whales (*Orcinus orca*) (Ford et al. 1998), but are not known to be a considerable component of the Puget Sound resident killer whales' diet (Palsson et al. 2009; Hanson et al. 2010). A study from the San Juan Islands showed that rockfish were present in 2.7 to 21.9 percent of river otter (*Lontra canadensis*) scat, depending on the sampling location (Buzzell et al. 2014). Juvenile rockfish occurred more frequently in river otter scat than adult rockfish.

Rockfish are a common lingcod prey item, making up 11 percent of their diet by weight, on average, and occurring in 10.5 percent of sampled lingcod stomachs in Puget Sound (Beaudreau and Essington 2007). Lingcod consumed rockfish ranging from 1.57 to 9.45 inches (4 to 24 cm) in standard length, but most of these were Puget Sound rockfish (*S. emphaeus*), a small-bodied species. Total consumption of rockfishes by lingcod was 5 to 10 times greater in no-take marine reserves compared to nearby fished areas (Beaudreau and Essington 2009). Rockfish predation by lingcod in the San Juan Islands also varied by season, site, and predator size (Beaudreau and Essington 2007). As one of the primary consumers of rockfish, this predator/prey relationship warrants further exploration.

Fifteen species of marine birds breed along the Washington coast, seven of which also breed in the San Juan Islands/Puget Sound area (Speich and Wahl 1989). The predominant marine birds in the San Juan Islands are pigeon guillemots (*Cepphus columba*), double-crested cormorants (*Phalacrocorax auritus*), pelagic cormorants (*Phalacrocorax pelagicus*), and members of the western gull and glaucous-winged gull complex (*Larus occidentalis* and *L. glaucescens*) (Speich and Wahl 1989). The first three species are locally abundant. Whether or not these avian predators have an impact on rockfish populations is unknown (Drake et al. 2010).

It is important to note that the impact of predation on rockfish cannot be determined from the quantity and frequency of rockfish occurrence in predator diets alone. Data on the sizes and quantity of rockfish consumed by predators should be used in combination with models that assess the ecological conditions in which predation has an influence on rockfish population dynamics. For further exploration of predation impacts on rockfish, see Appendix IX.

Disease

Infectious diseases may be a factor in both the decline of threatened or endangered wildlife species and in their recovery (Gaydos et al. 2004). Rockfish are susceptible to diseases and parasites (Love et al. 2002), but their impact on the listed rockfish is not known (Drake et al. 2010). Because rockfish are a long-lived species with inconsistent reproductive success, diseases that affect fecundity or reproduction could adversely affect population size and viability (Gaydos et al. 2004). Additionally, small population sizes may make species more susceptible to disease (Gaydos et al. 2004), as may the relatively small home ranges of listed rockfish. Palsson et al. (2009) also suggest that stress associated with poor water quality may exacerbate the incidence and severity of naturally occurring diseases, thereby directly or indirectly decreasing survivorship of the listed rockfish, as has been seen in other fishes (Hershberger et al. 2002).

There are few data on diseases in all *Sebastes* species, and fewer data on yelloweye rockfish and bocaccio, especially in the Puget Sound/Georgia Basin. Necropsies of 119 Puget Sound rockfishes (*Sebastes emphaeus*) captured by hook and line in four sites around the San Juan Islands in 2003 revealed intraerythrocytic blood parasites in approximately 45 percent the fish (van der Straaten et al. 2005). Intraerythrocytic blood parasites had previously only been reported as “relatively rare” in fishes of the northeast Pacific Ocean, which may suggest they had previously gone undetected or unstudied, or that they represent an emerging infection (van der Straaten et al. 2005). In the same sites sampled by van der Straaten et al. (2005), 302 Puget Sound rockfishes (*S. emphaeus*) were captured and tested for *Ichthyophonus* infection (Halos et al. 2005). Ichthyophonus was found in approximately 11 percent of the fish tested. This parasite has also been found in canary rockfish, though not in the Puget Sound/Georgia Basin (Halos et al. 2005).

In coastal British Columbia a visible infection was identified and described as “black mold” in rockfishes that fishermen had brought to market (Conboy and Speare 2002). Fourteen visibly infected fish of various *Sebastes* species were tested to determine the cause of infection. Researchers found the main cause of infection was the intraepithelial deposition of eggs from a trichuroid nematode (genus *Huffmanela)*, coupled with an inflammatory response (Conboy and Speare 2002). There are several different species of

Huffmanela, and this is the first documentation of the parasite in rockfish species in the northeast Pacific Ocean (Conboy and Speare 2002). Eight of the 14 rockfish tested also exhibited lymphocytic myocarditis associated with *Ichthyophonus hoferi.* This fungus commonly affects the heart muscle of Pacific herring, which are prey of rockfishes (Conboy and Speare 2002). All of the rockfishes also had low levels of the blood fluke miracidia in their gill pillar channels accompanied by interstitial bronchitis, which has previously been reported in other rockfishes on the Pacific coast of Canada (Conboy and Speare 2002). Finally, in 1995, 42 bocaccio collected by commercial fishermen in northern and southern California waters were found to have *Kudoa miniauriculata*, which in some cases can cause an inflammatory reaction. This parasite was found in over 40 percent of the bocaccio tested. Several other species of *Kudoa* are known to be found in fishes in both the Pacific and Atlantic Oceans off the United States (Whitaker et al. 1996).

Listing Factor 4: Inadequacy of Existing Regulatory Mechanisms

Bycatch

Despite increasingly restrictive regulations, rockfish are still incidentally taken in some recreational and commercial fisheries managed by WDFW and the tribes. As detailed under *Listing Factor 2: Over-utilization*, fishing can have dramatic effects on the size or age structure of the population (Drake et al. 2010). The effects can influence ongoing productivity because even minor levels of fishing can remove disproportionate numbers of older and larger fish (Drake et al. 2010), thereby shifting reproduction to younger and smaller-sized fish that produce fewer young that are less equipped to survive starvation (Berkeley et al. 2004; Sogard et al. 2008). Many fisheries with rockfish bycatch have been closed (WDFW 2010b), but some fisheries (such as fisheries targeting spot prawn, halibut, and bottom fish) that may affect recovery remain open, and their impact is not well known because bycatch data are insufficient and a lack of population information in some areas in which these fisheries occur (see Section F. Conservation Measures, Research, and Monitoring for further discussion). Regulations enacted in 2010 restrict recreational anglers from retaining rockfish within the U.S. portion of the DPSs and anglers are also no longer allowed to fish deeper than 120 feet (36.6 m) for bottom fish (this does not include halibut) (WDFW 2014).

The majority of the existing marine protected areas (MPAs) in the U.S. portion of the DPSs do not encompass rockfish habitat and they were not intended to serve as a regional network for rockfish protection (75 Fed. Reg. 22276, April 28, 2010). The life-history characteristics that make rockfish vulnerable to overfishing also make them good candidates for protection in MPAs (Yoklavich 1998). Rockfish and other species with similar life histories have been key species for protection in networks of MPAs that have been developed in several states and countries, particularly on the west coast of North America in Alaska; British Columbia, Canada; Oregon; California; and Baja California Sur, Mexico. The WDFW has established 25 marine reserves within the DPSs, and 16 host rockfish (Palsson et al. 2009), though most of these reserves are within waters shallower than those typically used by adult yelloweye rockfish or bocaccio (75 Fed. Reg. 22276, April 28, 2010). Most reserves in Puget Sound were established over several decades with unique and somewhat unrelated ecological goals, and encompass relatively small areas (average of 23 acres). The net effect of existing reserves to listed rockfish abundance, productivity, and spatial structure is probably very small (75 Fed. Reg. 22276, April 28, 2010). Less than 0.1 percent of Puget Sound is protected at the highest level of restriction as either no-take or no-access areas (Van Cleve et al. 2009; Osterberg 2012). Compared to fished areas, studies have found higher fish densities, sizes, or reproductive activity in the assessed WDFW marine reserves (Palsson and Pacunski 1995; Palsson 1997; Eisenhardt 2001; Palsson et al. 2004). WDFW's 2011 Puget Sound Rockfish Conservation Plan also calls for a network of MPAs for recovery (WDFW 2011), but pursuing this management approach has recently been de-emphasized by WDFW (Unsworth 2015).

In general, the characteristics of a network of reserves that are relevant to enhancing populations of yelloweye rockfish and bocaccio include sites in each of the major regions of the DPSs, and sites that provide some connectivity to each other for larvae transport (75 Fed. Reg. 22276, April 28, 2010). Finally, the sites would need to be large enough to collectively encompass quality and diverse habitats that facilitate productivity of individual fish and reserve resiliency to outside disturbances and stressors (Sobel and Dahlgren 2004).

Most tribes in the Puget Sound region limit rockfish harvest to subsistence only with no targeted commercial fisheries for rockfish. Therefore, the greatest threat of rockfish bycatch from tribal fisheries may occur in the commercial halibut fishery in the San Juan/Strait of Juan de Fuca area.

In 2007, the Canadian government designated approximately 135 rockfish conservation areas (RCAs) that encompass 30 percent of the area of the inside waters of Vancouver Island. These reserves do not allow directed commercial or recreational harvest for any species of rockfish, nor do most allow harvest of marine species that may incidentally catch rockfish (NOAA 2010). These RCAs have been shown thus far to have good compliance within the commercial fishing industry because of the use of boat tracking technology, but they likely have low recreational compliance; therefore, increased education, outreach, and enforcement is recommended (Haggarty 2014). Compliance is seen as one of the most important factors driving success of no-take areas (Gill et al. 2017).

Appendix II, Fisheries Management, discusses in-depth steps to limit bycatch.

Listing Factor 5: Other Natural or Human-made Factors Affecting Continued Existence

<u>Genetic Changes</u>

Inbreeding

Smaller and more isolated populations are more vulnerable to external environmental changes (Keller and Waller 2002) and more prevalent inbreeding, or mating, between closely related individuals (Hoglund 2009), which reduces fitness. There are no known published studies regarding inbreeding in rockfish; thus, we look to other species to understand the potential effects of inbreeding. Small populations may have limited potential for adaptive evolution to environmental disturbances because of reduced genetic diversity (Franklin and Frankham 1998; Willi et al. 2006). The synergistic effects between inbreeding and environmental disturbance can be extensive and have been studied in both laboratory and wild populations. Laboratory-reared zebrafish (*Danio rerio*) exposed to chemicals (in this case to the fungicide clotrimazole), for example, exhibited more greatly intensified deleterious effects of inbreeding on key reproductive traits compared to zebrafish that were inbred but not exposed to the chemicals (Bickley et al. 2012). In harbor seal pups, inbreeding as measured by multi-locus heterozygosity of 14,585 RAD loci explained 49 percent of the variance in lungworm infestation (Hoffman et al. 2014). The interaction may cause increased selection for less inbred individuals, which may reduce average individual reproductive success and therefore population productivity (Forcada and Hoffman 2014).

The contribution of inbreeding to extinction risk compared to demographic factors is still unresolved. A study combining a meta-analysis of inbreeding effects in birds and mammals and stochastic population projections applying these estimates concluded that average inbreeding reduced median times to extinction by an average of 37 percent (O'Grady et al. 2006). Other studies found limited genetic contribution to extinction risk (Wootton and Pfister 2013). Nevertheless, the more precautionary principle is to assume such effects, supported by findings that loss of genetic diversity generally precedes population collapse and extinction (Frankham 2005).

Hybridization

Reduced population sizes may induce or increase the rate of hybridization (Currat et al. 2008), which may occur between populations within species or between species. Intraspecific hybridization with coastal conspecifics may lead to the genetic dilution and possible extinction of locally adapted populations. Depending on the genetic differentiation between populations and intrinsic reproductive barriers, hybridization may result in a range of effects, from an increase of fitness because of hybrid vigor to a reduction in fitness as a result of outbreeding depression (McClelland and Naish 2007). Hybrid vigor is commonly only observed in highly inbred populations (Hedgecock and Davis 2007), though it can lead to the genetic rescue of such populations (Tallmon et al. 2004). More common in marine species is probably outbreeding depression, which reduces fitness in hybrids between locally adapted populations. In Atlantic cod, for example, reproductive barriers among geographically proximate populations appear to be sufficiently strong to prevent backcrossing, even though hybrids between populations were found (Bradbury et al. 2014). Many *Sebastes* species are further along the speciation continuum, and cryptic species were recently found in several *Sebastes* groups (e.g., vermillion rockfish (*S. miniatus*) (Hyde et al. 2008), rougheye rockfish (*S. aleutianus*) (Gharrett et al. 2005), Southern Hemisphere rockfishes (Rocha-Olivares et al. 1999), and Atlantic *Sebastes* (Daníelsdóttir et al. 2008). These findings suggest at least the possibility of incipient speciation of listed rockfish. If so, hybridization between Puget Sound/Georgia Basin and coastal populations may constitute a threat to the defined DPSs. Such intraspecific hybridization would be difficult to detect other than by genetic approaches, making genetic monitoring of the population essential.

Interspecific hybridization has been described for both Pacific and Atlantic species of *Sebastes*, and may also pose a threat to the integrity and existence of listed rockfish. Extensive hybridization between copper (*S. caurinus*), quillback (*S. maliger*), and brown (*S. auriculatus*) rockfish was found in Puget Sound, possibly because of the increased abundance of those species (Schwenke 2012). Up to 40 percent of sampled fish were hybrids, though no F1 hybrids were found (Schwenke 2012). This suggests weak reproductive barriers, even though the three species have not formed a hybrid swarm and are morphologically easily distinguishable. In Atlantic *Sebastes* species, hybridization appears to be widespread (Roques et al. 2001; Pampoulie and Daníelsdóttir 2008; Artamonova et al. 2013). Although there is no evidence for hybridization in listed rockfish, loss of genetic identity of threatened and endangered rockfish species because of hybridization may become a concern if population sizes stay at low levels.

Hatchery Supplementation

Although not currently an issue, genetic changes as a result of any future rockfish aquaculture/hatchery practices and trans-basin introductions may alter the genetic structure of wild rockfish stocks (Palsson et al. 2009). However, there is little research on the topic specifically regarding rockfish, making the threat difficult to assess (Palsson et al. 2009). A recent review by NOAA on genetic risks of marine aquaculture and stock enhancements lists three main types of adverse genetic change to wild populations: 1) loss of genetic diversity within populations, 2) loss of diversity among populations, and 3) loss of fitness (Waples et al. 2012). Most of these effects are well known from Pacific salmon (*Oncorhynchus* spp.), where hatchery supplementation has mitigated effects of dam construction, habitat destruction, and exploitation, but has also caused considerable issues with genetic integrity and fitness of endangered populations (Ford 2002; Naish et al. 2008). Because of the high fecundity of marine fishes such as rockfish, such effects of domestication selection and 'swamping' of wild populations are probably more pronounced (Waples et al. 2012). Any supplemental breeding program for listed rockfish should be well-considered and executed with clear goals, balance the extinction risk with the possible adverse genetic changes, and take measures to minimize possible adverse genetic changes or introduction of diseases into wild populations.

Competition

Rockfishes are known to partition their food and habitat resources (Larson 1980; Carr 1991). Harvey et al. (2006) used bioenergetics models to suggest that recovery of coastal populations of bocaccio may be inhibited by more common species of rockfish congeners. In Puget Sound, more abundant species, such as copper and quillback rockfish, may interact with juvenile yelloweye or bocaccio rockfish and compete for food and habitat resources. Evidence documenting competition among rockfishes in Puget Sound is generally lacking (Drake et al. 2010), and competition among marine fishes is difficult to demonstrate empirically in the wild (Link and Auster 2013). Though competition within and among species is natural, any anthropogenic influences that affect competition (e.g., habitat alterations) should be closely scrutinized.

Release of Propagated Fish

Chinook salmon (*Oncorhynchus tshawytscha)* and coho salmon (*Oncorhynchus kisutch*) consume larval and juvenile rockfish, and also compete for prey with small size classes of rockfish (Buckley 1997); thus, large releases of hatchery salmon have the potential to influence the population dynamics of listed rockfish. Influxes of delayed release (yearling) Chinook salmon and coho salmon into Puget Sound occur, and delayed-release hatchery fishes are more likely to stay in Puget Sound (Palsson et al. 2009), where they could potentially consume rockfishes.

Derelict Fishing Gear

Derelict fishing gear, such as lost nets and shrimp pots, alter benthic habitats and likely kill yelloweye rockfish and bocaccio, and/or their prey (NRC 2008). Lost crab pots are also prevalent in Puget Sound and alter habitat, but derelict crab pots have been found to result in very low catch of rockfish (two rockfish found in nearly 3,000 derelict crab pots removed) (K. Antonelis, electronic mail, NRC, December 10, 2013). Commercial gill nets compose the majority of derelict nets in Puget Sound (Good et al. 2010). An estimated 16 to 42 gill nets are lost annually in Puget Sound salmon fisheries (NRC 2010). It is estimated that around 12,000 commercial and recreational crab pots, and an estimated 523 to 893 shrimp pots are lost annually in Puget Sound (Antonelis et al. 2011; NRC 2014). Actively fished shrimp pots result in bycatch of juvenile rockfish in the Puget Sound/Georgia Basin (Favro et al. 2010; NRC 2014), and are estimated to result in a low of 253 to a high of 2,809 caught rockfish (of a variety of species) in Puget Sound annually (NRC 2014). Derelict shrimp pots can result in bycatch of juvenile rockfish, but no estimates of annual bycatch have been developed to date (NRC 2014).

Derelict gear may also cause degradation to habitat where it is ensnared through scouring, obstructing, and sediment entrapment (Gilardi et al. 2010; Good et al. 2010; Antonelis 2013). Specifically, fine sediments may be trapped out of the water column, making a layer of soft sediment over rocky areas and changing habitat quality and suitability for benthic organisms (Good et al. 2010). Lost nets can cover habitats used by rockfish for shelter and pursuit of food, rendering the habitat unavailable, and can also reduce the abundance and availability of rockfish prey that include invertebrates and fish (Good et al. 2010).

Copper rockfish (top) in a derelict shrimp pot. Canary rockfish (bottom) in a derelict gillnet. Photos courtesy of Natural Resources Consultants.

As of the end of 2013, the Northwest Straits Foundation (NWF), in partnership with WDFW and volunteers, has removed 4,605 derelict fishing nets (primarily gillnets), 3,173 crab pots, and 47 shrimp pots from Puget Sound over the course of 11 years. There is an estimate of 274 remaining nets in shallower water (< 105 feet [32 m]) and at least 205 are in deeper water (> 105 feet [32 m]) (NWSI 2014b). Appendix IV, Benthic Habitat Conservation, summarizes recommended research and actions to address derelict fishing gear.

Climate Change

Global carbon dioxide (CO_2) concentrations have increased from approximately 280 ppm 250 years ago to present levels of approximately 387 ppm, and nearly half of this increase has occurred in the past three decades (IPCC 2007). Approximately one-third of the CO_2 produced in the last 200 years has been taken up by the oceans (Sabine et al. 2004). The effects of climate change include, but are not limited to, changes in temperature; distribution shifts of species; changes in primary production; changes in biodiversity; declining mid-water oxygen concentrations; changes in upwelling and vertical mixing; sea-level rise; expanding ocean dead zones; an increase in the magnitude, frequency, and duration of harmful algal blooms; erosion; and more severe and frequent inundation from the combined effects of rising sea levels and intensified and more frequent storms (Harley et al. 2006; IPCC 2007; Feely et al. 2008; Fabry et al. 2008; Moore et al. 2008; Brewer and Peltzer 2009; Nicholls and Cazenave 2010; Ainsworth et al. 2011; Feely et al. 2012; Dalton et al. 2013; others).

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).

Direct studies on the effect of climate variability on rockfish are rare, but all studies performed to date suggest that climate plays an extremely important role in population dynamics. Tolimieri and Levin (2005) examined the effects of climate variability on bocaccio recruitment. They found that the dynamics of bocaccio populations were governed by rare recruitment events, and that these rare events resulted when specific climate conditions (such as various combinations of temperature and upwelling regimes) occurred at different times in their early life history. The coincidence of such climate patterns only occurred 15 percent of the time. Harvey (2005) created a generic bioenergetics model for rockfish, finding that productivity of rockfish is highly influenced by climate conditions, such that El Niño-like conditions generally lowered growth rates and increased generation time. The negative effect of the warm water conditions associated with El Niño appears to be common across rockfishes (Moser et al. 2000). Field and Ralston (2005) noted that recruitment of all species of rockfish appeared to be correlated at large scales and hypothesized that such synchrony was the result of large-scale climate forcing. Exactly how climate influences listed rockfish in the Puget Sound/Georgia Basin is unknown; however, given the general importance of climate to Puget Sound and to rockfish, it is likely that climate strongly influences the dynamics of the listed species (Drake et al. 2010). Appendix VII further outlines climate change effects, local monitoring, and recommended research.

Ocean Acidification

Ocean acidification (OA) results from increased absorption of carbon dioxide into marine waters caused by elevated atmospheric CO_2. The projected pH decrease is 0.3 to 0.4 for the 21st century, equivalent to an approximately 150 percent increase in H^+ and a 50 percent decrease in CO_3^{2-}, which is essential for the biology and survival of a wide range of marine organisms (Fabry et al. 2008; Doney et al. 2009). The west coast of the United States is particularly vulnerable to enhanced OA because the Pacific Coast's continental shelf is relatively narrow and therefore experiences upwelling events. Deeper waters are often more acidic and upwelling lowers the pH in more productive nearshore areas (Feely et al. 2010).

OA will adversely affect calcification, or the precipitation of dissolved ions into solid calcium carbonate structures, for a number of marine organisms, which could alter trophic functions and the distribution and/or availability of prey (Fabry et al. 2008; Feely et al. 2010).

Pteropods (*Euthecosomatous pteropods*), which require $CaCO_3$ to form their shells, may be first among the major groups of planktonic calcifiers to experience reduced calcification (Fabry et al. 2008). Though effects of a reduction in this prey species on rockfish have not been studied, in pink salmon (*Oncorhynchus gorbuscha*) it was found that a 10 percent decrease in pteropod production could lead to a 20 percent decrease in mature body weight (Fabry et al. 2008).

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 molluscs, and copepods (Fabry et al. 2008; Marshall et al. 2017), which are important prey items for larval and juvenile rockfish (Love et al. 1991; Love et al. 2002). As food webs are complex, impacts to one group of species may lead to dramatic changes in the ecosystem. A modeling exercise on the direct and indirect effects of OA on Puget Sound ecosystems showed reductions in copepods (microscopic zooplankton) would lead to large-scale ecosystem changes

(Busch et al. 2013). However, the authors noted that results must be interpreted with care given the complex nature of the modeling exercise.

In addition to altering the food web, OA can alter the physiology, metabolism, and reproductive biology of fishes. Increased temperature and OA have been linked to impaired immune systems of marine organisms, such as shellfish and fishes, and increased disease frequency (Feely et al. 2012). There have been very few published studies to date on direct effects of OA on rockfish. 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; Simpson et al. 2011; Chung et al. 2014). In a laboratory setting, OA did result in changes to juvenile splitnose rockfish (*Sebastes diploproa)* behavior (Hamilton et al. 2014). More research is needed to better understand the effects of OA on rockfish and their ecosystems and to evaluate if this threat is limiting listed rockfish recovery. Appendix VII, Climate Change and Ocean Acidification, further details the effects of OA, local monitoring efforts, and suggested research.

Anthropogenic Noise and Vessel Traffic

Little is known about the overall effect of anthropogenic noise levels on fishes (Popper and Hastings 2009). A recent study of coral reef fish larvae found that vessel traffic noise may have a disruptive effect on orientation and settlement (Holles et al. 2013), which are important to finding appropriate habitat to many marine fishes, including rockfishes. Air guns have been shown to significantly depress catch rates of some commercial fish species (Skalski et al. 1992; Engas et al. 1996). For example, catch rates of *Sebastes* species in the commercial hook-and-line fishery along the central California coast (including bocaccio) exposed to a single 1639-cm^3 air gun with a source level of 223 dB re 1μPa were found to decline in catch per unit effort (CPUE) by approximately 52 percent compared to control trials (Skalski et al. 1992). Pile driving may also have lethal or sublethal effects on fishes, including reduced avoidance of predators, inability to find mates, or traveling to less favorable habitat (Popper and Hastings 2009; Mueller-Blenkle et al. 2010; Slabbekoorn et al. 2010). Fishes exposed to acute sound impacts may also experience barotrauma (Casper et al. 2013). Given rockfishes' sensitivity to barotrauma and the numerous other sublethal and lethal impacts of noise on fishes, it is likely that acute sound level spikes in the vicinity of rockfish may adversely affect survival.

Regionally, vessel traffic within Admiralty Inlet is high and 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 rockfishes. Instead of an acute impact, these chronic changes in noise may have sublethal impacts on rockfishes that may make survival and reproduction more difficult.

Few published studies assess mortality from vessel traffic on fishes. Ichthyoplankton, such as larval rockfishes, may be particularly 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 has shown that although mortality is low, larval loss may be size dependent and smaller larvae will be more susceptible to mortality (Kilgore et al. 2001). Another recent study assessed mortality on copepods, prey of rockfish and many other marine organisms, and suggested that marine food webs may be affected, especially in more enclosed areas (Bickel et al. 2011).

Summary of Threats Assessment

The Recovery Team assessed current and expected future threats to listed rockfish persistence and recovery within each of the management unit basins. To develop this threats assessment, we evaluated the best available information regarding habitat, fisheries, prey, listed rockfish conditions, and other factors.

Below we summarize the threats for each management unit where sufficient information is available. Where there is not enough information at the management-unit scale, we provide a summary for the whole Puget Sound/Georgia Basin. Because of the complexities of fisheries in the DPSs, we also include a separate assessment based on effort and gear type below (see also Tables 6 through 8). Detailed summaries of all of the threats are found below this summary table (Tables 9 through 13). The risk in Table 5 was calculated by considering the severity of the threat, the level of certainty the listed species are affected, the geographic range of the threat, and the likelihood that the actions outlined in this plan may reduce the threat.

Table 5. Summary of Threats Assessment for Management Units and Puget Sound/Georgia Basin.

	Listing Factor	**Canada**	**San Juan**	**Main Basin**	**South Sound**	**Hood Canal**
Derelict Fishing Gear	E	1	1	2	4	4
Commercial Catch/Bycatch	B, D	3	*1	*3	4	4
Recreational Catch/Bycatch	B, D	3	1	2	4	4
Nearshore Habitat Disruption	A	4	3	1	1	2
Deepwater Habitat Disruption	A	3	3	3	3	3
Non-native Species Habitat Disruption	E	P	P	P	P	P
Hypoxia/Nutrient Addition	E	4	4	3	2	1
Chemical Contamination/ Bioaccumulants	A	3	3	1	1	2
Puget Sound/Georgia Basin						
Marine Mammal Predation	C	4				
Fish Predation/Hatchery Practices	C, E	4				
Competition	C	P				
Diseases	C	P				
Oil Spills	E	1				
Genetic Changes (Inbreeding/Hybridization)	E	P				
Anthropogenic Noise	E	P				
Ocean Acidification	E	1				
Climate Change	E	1				

A = Present or threatened destruction, modification, or curtailment of its habitat or range
B = Over-utilization for commercial, recreational, scientific, or educational purposes
C = Disease or predation
D = Inadequacy of existing regulatory mechanism
E = Other natural or manmade factors affecting its continued existence
1 = High risk
2 = Moderate risk
3 = Low risk
4 = Very Low risk
P = Potential threat. Not enough information to determine if it is a threat at the current time, but could plausibly become a threat in the future.
*Further information required to assess the extent and effects of commercial fisheries in this area and this ranking could change.

Threats Assessment for Fisheries

Past fishing is likely a primary cause of the depletion in listed rockfish (Palsson et al. 2009; Drake et al. 2010). The threat that fishing creates today is indirect through bycatch. To inform management actions recommended in this plan, we assess the relative threat of catch/bycatch for listed rockfish for fisheries within the U.S. portion of the Puget Sound/Georgia Basin, with narratives for fisheries with larger potential to catch listed rockfish. We also provide a narrative for each of the management units based on the known existing fisheries that occur in each area. For many of these fisheries we do not have reliable bycatch numbers or estimates for listed rockfish; thus, we assess the catch risk qualitatively based on the characteristics of effort and gear-type (Table 6).

Table 6. Known fisheries in Puget Sound and their relative risk of rockfish bycatch. This table has been modified from WDFW's incidental take permit from 2012, but also incorporates updated information and known tribal fisheries. "Commercial" may refer to tribal or non-tribal commercial fisheries.

Type	License Group/ Gear	Potential to Encounter Listed Rockfish	Fishery Access (managed by WDFW)	Comments
MARINE FISH				
Commercial	Forage fish lampara net	Low	Open access	This gear type has little or no risk of bycatch.
	Forage fish drag seine	None	Open access and limited entry	This gear type has no risk of bycatch.
	Herring dip net	None	Limited entry	Fishery closed because of low abundance.
	Herring purse seine	Low	Limited entry	Fishery closed because of low abundance.
	Halibut longline (tribal fishery only)	High	Limited entry	This gear type has high potential for rockfish bycatch.
SALMON				
Commercial	Gill net	Low	Limited entry	These fishing methods target the midwater zone which is likely not occupied by listed rockfish.
	Purse seine	Low	Limited entry	
	Reef net	Low	Limited entry	Does not fish in deep waters, thus avoiding listed adult rockfish, and mesh size too large for juvenile listed rockfish.
	Beach seine	Low	Limited entry	Does not fish in deep waters, thus avoiding listed adult rockfish, and mesh size too large for most juvenile listed rockfish.
SHELLFISH				
Commercial	Crab ring net	None		These gear types have little or no risk of rockfish bycatch.
	Clam mechanical harvester	None		
	Burrowing shrimp	None	Open access	
	Shrimp trawl	Low	Limited entry	This gear fishes non-rugose habitat, but very limited rockfish bycatch may still occur.
	Squid	None	Open access	

Type	License Group/ Gear		Potential to Encounter Listed Rockfish	Fishery Access (managed by WDFW)	Comments
	Dungeness crab pot		Low (mostly derelict gear)	Limited entry	These gear types have little or no risk of rockfish bycatch.
	Geoduck dive		None		
	Sea cucumber dive		None	Limited entry	
	Sea urchin dive		None	Limited entry	
OTHER FIN FISH					
Recreational	Salmon	Hook-and-line	Moderate	Unlimited entry	Risk depends on fishing method (e.g., trolling, jigging, mooching) and proximity to complex habitat. High effort in this fishery. See discussion in *threats* section below.
	Halibut	Hook-and-line	High		Similar habitats are fished.
	Halibut	Spear fishing	None		Divers should be sure of species identification (ID) before shooting (no rockfish of any species can be targeted).
	Lingcod	Hook-and-line	High		Habitats are the same and listed rockfish typically co-occur. 120-foot rule reduces bycatch risk.
	Lingcod	Spear fishing	None		Divers should be sure of species ID before shooting.
	Other bottom fish	Hook-and-line	Moderate		Risk depends on fishing method, target species, and habitat. 120-foot rule may reduce bycatch risk.
	Other bottom fish	Spear fishing	None		Divers should be sure of species ID before shooting and no rockfish of any species are allowed.
	Forage fish	Hook-and-line	None		This gear type has little or no risk of bycatch.
	Forage fish	Dip net	None		This gear type has little or no risk of bycatch.
SHELLFISH					
Recreational	Crab	Ring and trap	Low	Unlimited entry	This gear type has little or no risk of bycatch.
	Crab	Dip net	None		
	Shrimp	Pot	Low to Moderate		Risk depends on habitat fished; bycatch of juveniles can occur.
	Squid	Hook-and-line	None		Conducted from piers. This gear type has little or no risk of bycatch.
	Bivalves	Shovel or tube	None		Intertidal. This gear type has no risk of bycatch.

Listed rockfish are caught by some recreational fisheries targeting other species, particularly salmon, bottom fish, and halibut. The WDFW estimates the number of recreational fishing trips as part of their catch estimate calculations. (See Table 7 for annual estimates from 2010-2014.)

Table 7. Annual estimated recreational fishing trips in the U.S. portion of the Puget Sound/Georgia Basin; estimates from WDFW from 2010-2014.

Recreational Fishing Trips with Rockfish Bycatch Potential	San Juan /Strait of Juan de Fuca (annual number of individual fishing trips)	Main Basin	Hood Canal	South Sound
Target Species: salmon	87,395	291,469	11,208	24,587
Target Species: bottom fish	15,640	21,846	606	6,020
Target Species: halibut	11,738	2,579	132	0
Target Species: other	3,098	10,475	2,219	3,247
TOTAL	117,871	326,369	14,060	33,854

Salmon Fisheries and Rockfish Bycatch Risk

The vast majority of recreational fishing trips in the Puget Sound/Georgia Basin target Chinook, coho, pink, and/or chum salmon. Recreational and commercial salmon fishers use diverse equipment, with each gear type having a different risk of incidentally catching yelloweye rockfish and bocaccio. Based on data collected through creel surveys between 1986 and 1999, Palsson (2002) estimated anglers targeting salmon in Puget Sound caught 0.65 groundfish, including 0.05 rockfish per angler trip. The incidental groundfish catch, and likely rockfish catch, varied by marine catch area from a high of 2.09 groundfish per angler trip in Marine Catch Area 5 (Sekiu-Pillar Point), to a low of 0.024 groundfish per angler trip in Marine Catch Area 11 (Tacoma-Vashon) (Palsson 2002; NMFS 2004). The WDFW salmon fishery test boat uses recreational fishing gear, and from 2003 to 2016 has not caught a yelloweye rockfish or a bocaccio (WDFW 2016), yet the net impact from the salmon fishery on listed rockfish may be larger than other fisheries sectors because of the large number of fishing trips (Palsson et al. 2009). Aside from the test boat data, we do not have detailed data sets that explain bycatch for many of these fishing gears and sectors; thus, we provide a qualitative description of them and highlight data/estimates of bycatch where it is available.

Many recreational salmon anglers use downriggers that consist of cables and weights that deliver fishing gear to specific depths, mostly while trolling artificial lures. A smaller fraction of recreational salmon fishers, often referred to as “moochers,” use 1 to 6 ounces of weight with herring as bait, and free drift or slowly troll. Some anglers also use weighted artificial lures and free drift while jigging. Salmon and rockfish have several overlapping prey items that include herring, sand lance, and smelt, making them vulnerable to the use of herring as bait and fishing lures imitating these prey items. As a result, anglers targeting salmon occasionally unintentionally hook yelloweye rockfish and bocaccio. Though the frequency of listed rockfish bycatch by recreational salmon anglers is extremely low, the large numbers of angler trips nonetheless results in measurable incidental catches. Most methods of recreational salmon fishing have the potential to encounter listed rockfish, with the risk increasing the deeper the gear is fished.

The WDFW estimates the annual bycatch of rockfish from anglers targeting salmon, halibut, bottom fish and other marine fishes. There are a number of uncertainties regarding the WDFW recreational fishing bycatch estimates because: 1) they are based on dockside (boat launch) interviews of 10 to 20 percent of fishers, and anglers whose trips originated from a marina are generally not surveyed; 2) because rockfish can no longer be retained by fishermen, the surveys rely upon fishermen being able to recognize and remember rockfish released by species. Recent research has found the identification of rockfish to species is poor; only 5 percent of anglers could identify bocaccio and 31 percent identify yelloweye rockfish in a study performed throughout the Puget Sound region (Sawchuk et al. 2015); and 3) anglers may under-report the numbers of released fish. A study in Canadian waters compared creel survey reports to actual observer generated information on recreational fishing boats in the Southern Georgia Strait. Substantial differences were documented, with the number of released rockfish observed significantly higher than the number reported by recreational anglers during creel surveys (Deiwert et al. 2005).

These factors could make the actual bycatch of yelloweye rockfish or bocaccio higher or lower than WDFW's estimates. There is additional uncertainty regarding these estimates because WDFW continues to change the methodology to calculate them; thus, we show data from each method to represent a potential range of bycatch for yelloweye rockfish and bocaccio. WDFW has provided bycatch estimates from the 2003 through 2009 time period (WDFW 2011b) and provided updated catch estimates for the 2003 through 2011 time period (WDFW 2014a). The previous (WDFW 2011b) estimates have larger yelloweye and bocaccio bycatch numbers than the new estimates even though they span the same time period from 2003 through 2009 (the new estimates include the years 2010 and 2011). WDFW's estimates of rockfish bycatch from 2014 are similarly small, with the exception of bocaccio. In 2014, WDFW estimated that 132 bocaccio where caught by anglers targeting salmon (all in the San Juan Islands area). The average annual estimated bycatch of yelloweye rockfish from salmon anglers ranges from 4 (WDFW 2014a) to 111 (WDFW 2011b) fish. The average annual estimated bycatch of bocaccio from salmon anglers ranges from 2 (WDFW 2014a) to 132 (WDFW 2011b) fish. Note that it is likely that not all of these fish are killed when they are caught as bycatch (see Appendix III, Barotrauma Research and Adaptive Management).

Most commercial salmon fishers in Puget Sound use purse seines and gill nets (WDFW 2010a). A relatively small number of salmon are harvested within the DPS by reef nets and beach seines. Gill nets and purse seines rarely catch rockfish of any species. From 1990 to 2008, no rockfish were recorded caught in the purse seine fishery (WDFW 2010a). In 1991, one rockfish (of unknown species) was recorded in the gill net fishery, and no other fish were caught through 2008 (WDFW 2010a). Low encounter rates may be attributed to a variety of factors. For each net type, the mesh size restrictions that target salmon based on size tend to allow juvenile rockfish to pass through. Gill net and purse seine operators also tend to avoid fishing over rockfish habitat, as rocky reef structures can damage their gear. In addition, nets are deployed in the upper portion of the water column away from the deeper water rockfish habitat, thus avoiding interactions with most adult rockfish. In the mid-1990s, commercial salmon net closure zones were established in much of Puget Sound for seabird protection. Some of these closed areas overlap with rockfish habitat, reducing the potential for encountering rockfish. Specific areas are: 1) a closure of the waters inside the San Juan Islands, 2) a closure extending 1,500 feet (457.2 m) along the northern shore of Orcas Island, and 3) closure of waters 3 miles from the shore inside the Strait of Juan de Fuca (WDFW 2010b).

Bottom Fish Fisheries and Rockfish Bycatch Risk

Recreational anglers targeting bottom fish such as lingcod and cabezon (and to a lesser extent flatfish) use lures and bait that catch yelloweye rockfish and bocaccio. As a result, some anglers targeting bottom fish unintentionally hook listed rockfish. Targeting rockfish and the retention of rockfish of any species is not allowed, nor is fishing in waters deeper than 120 feet (36.6 m) where subadult and adult listed rockfish are most likely to reside. WDFW also has a prohibition on barbed hooks and limits fishing gear to two individual hooks (no treble hooks). In 2012, WDFW estimated that the 120-foot (36.6 m) rule would result in a reduction of bycatch from anglers targeting bottom fish by approximately 75 percent for yelloweye rockfish (WDFW 2012c). We do not have data regarding the compliance levels with the 120-foot (36.6 m) rule, but in 2011 the majority of anglers targeting lingcod and other bottom fish were not aware of the regulation (Sawchuk 2012).

There is a small tribal commercial dogfish fishery. The fishery utilizes gillnets with a seven-inch mesh to limit bycatch of other species. The fishery consists of less than 10 fishers, with two to three who regularly fish. It occurs in bays, which generally do not include rockfish habitat, and the nets are not deployed deep in the water column, thus decreasing chance of rockfish bycatch. This fishery is confined to northern Puget Sound.

There is also a tribal commercial bottom trawl fishery consisting mainly of one fisher who typically fishes a couple times a year. Tribal scientists have observed the fishery because of concerns about crab bycatch and they have not seen any rockfish bycatch. This fishery occurs in Bellingham Bay and targets flatfish.

Halibut Fisheries and Rockfish Bycatch Risk

Recreational and commercial fishers targeting halibut use lures and bait that catch yelloweye rockfish and bocaccio and other rockfish species. Historically, many recreational anglers would simultaneously target halibut and rockfish (Olander 1991), and because of their similar habitat usage, catches of deep-water rockfish during halibut fisheries can be common. For the recreational fishery, WDFW regulations for anglers targeting bottom fish (such as lingcod) do not allow fishing in waters deeper than 120 feet (36.6 m) (where subadult and adult listed rockfish are most likely to reside). This regulation does not apply to anglers targeting halibut. The recreational halibut regulations include a prohibition on barbed hooks and limit fishing gear to two individual hooks (no treble hooks). In recent years, halibut fishing has been restricted to several days annually during the spring in order to apportion the catch among geographic areas and user groups.

The tribal commercial halibut fishery has increased its catch nearly annually in recent years. In 2009, the tribal commercial fishery had 258 landings and caught 61,443 pounds of halibut. In 2013, the fishery had 550 landings and caught 150,211 pounds of halibut.

In U.S. waters of the Puget Sound/Georgia Basin, gear used in the tribal commercial fisheries include:

- Hook-and-line (rod and reel, no more than two hooks)
- Hand line (no more than two hooks)
- Longline (snap gear only with typically 400 to 800 hooks)
- Bottom troll (no more than six lines)

Fish caught on longline gear are typically hooked and suspended near the seafloor for minutes to hours; thus, some fish are likely harmed or killed by predators such as dogfish, sixgill sharks, harbor seals, and sea lions. Yelloweye rockfish are historically a commonly caught rockfish in halibut longline fisheries within the DPS area (Table 8), and have been commonly caught in halibut long-line fisheries in DPS waters of the Georgia Strait (NMFS 2013). Bocaccio are less commonly caught in long-line fisheries (NMFS 2013).

Table 8. Proportion of yelloweye rockfish and bocaccio in the total rockfish catch for past set line fisheries in the North Puget Sound (non-tribal set line fisheries have been closed by WDFW). Table created from data in Palsson et al. 2009.

	1970-1987	**1988**	**1989**	**1990**	**1991-1992**	**1993-2003**
Yelloweye	28%	49.8%	72.5%	83.4%	91.9%	48.8%
Bocaccio	2.8%	0.0%	0.0%	0.0%	0.0%	0.0%

Spot Prawn Fisheries and Rockfish Bycatch Risk

The spot prawn trap fishery consists of recreational, non-treaty commercial, and treaty commercial/subsistence sectors. The yearly harvest quotas are split evenly between the state recreational and commercial sectors and the treaty fisheries. Seasons and quotas are set using data collected during test fisheries conducted by WDFW and participating treaty tribes. The non-treaty commercial fishery, limited to 18 licenses, takes place from June through September with a weekly harvest cap of 600 pounds (272 kg) per fisher. Typically, traps used in the commercial fishery are a truncated cone shape surrounded by nylon mesh and weighing approximately 5 to 7 pounds (2.3 to 3.2 kg). Entrance rings are 3-inch (7.6-cm) diameter and aligned with the bait cup, usually containing pellet type bait. Strings of 15 to 25 traps are attached to a heavy groundline 29.53 to 98.43 feet (9 to 30 m) apart. Buoyed anchors mark the ends of each string, and soak times range from 2 to 48 hours. The treaty fishery has grown in participation in the past decade, with under 200 fishers participating each year, employing similar gear as the non-treaty commercial fleet. The treaty fishery occurs over a relatively short period of time, mostly in April and May, with openings commonly lasting only a few hours (NRC 2012, 2014).

The recreational fishery occurs on specific days in the month of May, and the number of days varies between management regions. The maximum trap limit is two traps per licensed fisher, with no more than four traps per vessel, and daily harvest is limited to 80 individual spot prawn per licensee. The recreational fleet uses similar web mesh trap designs as the commercial fleet, but typically with added weight. More common in the recreational fishery are the square-, round-, and octagonal-shaped, wire mesh traps with two to four entry ramps leading to a bait container, often filled with canned cat food or similar bait. Each trap is fished separately, attached to a single buoy line and buoy. Soak times vary depending on the location and timing of the effort, and the derby style openings usually last 45 minutes to 3 hours (NRC 2012, 2014).

While the limited number of permits allowed prevents growth of the non-treaty commercial fleet, the recreational and treaty spot prawn fleets have increased significantly since the 1990s. Much of the recreational and commercial fishing effort for spot prawn occurs in waters ranging from 196.85 to 393.7 feet (60 to 120 m) deep, along relatively steeply sloped and rugose benthic areas of Puget Sound (Martinis 2015), coinciding with juvenile and adult rockfish primary habitats, especially deep water species such as listed rockfish.

Rockfish have been documented as bycatch in active spot prawn fisheries and have been observed in derelict pots. Recent studies from British Columbia have reported rockfish bycatch rates in actively fished prawn traps (Favaro et al. 2010, 2012), and the majority of those rockfish were juveniles. While the bycatch rates reported in British Columbia were relatively low, the large amount of fishing effort associated with spot prawn fisheries raised concern about the overall effect this bycatch posed on rockfish populations, especially considering the low survival rate of discarded rockfish following the effects of barotrauma (Favaro et al. 2010). A total of 58 derelict prawn traps have been incidentally removed during derelict net and crab trap removal efforts in Puget Sound. Two of those derelict prawn traps contained a total of eight rockfish (*Sebastes* spp.), two of which were dead. By comparison, only two juvenile rockfish have been found in over 3,900 removed derelict crab traps in Puget Sound (NRC 2012).

Rockfish Catch Risk Based on Existing Fisheries in Each Management Unit

The narrative below provides a qualitative bycatch risk for the management units in the U.S. portion of the Puget Sound/Georgia Basin.

<u>San Juan/Strait of Juan de Fuca</u>

We rank this region as having High bycatch risk for the commercial and recreational fishing sectors. This region has the second most salmon fishing trips and bottom fishing trips within the U.S. portion of the DPS, the highest number of recreational halibut trips (Table 7), and a commercial tribal halibut fishery with high risk of rockfish bycatch (Table 6). Of the currently open commercial and recreational fishing sectors, halibut fishing likely has the highest risk of bycatch, and this management unit has the largest number of fishing trips targeting halibut for each sector. The 120-foot (36.6-m) rule for recreational fishers targeting bottom fish (which does not apply to halibut fishing) reduces risk of bycatch, but the bathymetry of most of the San Juan/Strait of Juan de Fuca is extremely complex, with steep walled pinnacles a very common feature around each island and offshore benthic area. This complex bathymetry makes compliance with the 120-foot (36.6-m) rule challenging as the depth can change rapidly in small horizontal distances, and it makes enforcing the rule difficult because of the uncertainty in assessing from a distance whether a boat is fishing in 120 feet (36.6 m) or more of water. This region also has high numbers of commercial and recreational spot prawn fisheries, but bycatch of rockfish in this region is less compared to other areas (NRC 2012). The San Juan Islands National Wildlife Refuge areas and associated buffer areas may contribute to rockfish protection (Don 2002). However, one study (Don 2002) found that management and protection of the marine areas surrounding refuge sites could be inadequate to constitute a de facto MPA network and that implementation and success of the MPA network would depend upon the creation of partnerships with other existing agencies and institutions.

<u>Main Basin</u>

We rank this management unit as having Low bycatch risk for commercial fishing and Moderate for recreational fishing sectors. This basin has the most annual recreational salmon fishing trips as well as the most bottom fishing trips and a relatively low number of halibut fishing trips (Table 8). A relatively small amount of recreational halibut fishing occurs mostly in the northwestern portion of this basin (near Mutiny Bay and Port Townsend), and it is likely few, if any, commercial halibut trips occur here because of the paucity of halibut in these waters. Recreational and commercial shrimp pot fisheries are popular in this basin.

Hood Canal

We rank this region as having Low bycatch risk for commercial fishing and Very Low for recreational fishing sectors. Recreational bottom fishing in most areas of Hood Canal have been closed since 2004 because of concerns about hypoxia. Halibut fishing is also closed in this basin. Recreational salmon fishing occurs in this basin in smaller numbers than other management units, and recreational and commercial shrimping are very popular.

South Sound

We rank this region as having Low bycatch risk for commercial fishing and Low bycatch risk for recreational fishing sectors. Bycatch risk in the South Sound is minimal because of the low amount of bottom fishing trips and no halibut fishing occurring there. Relatively high numbers of recreational salmon fishing trips occur in this basin; thus, the greatest risk of bycatch likely is from this fishing sector.

Detailed Threats Assessment – Habitat and Other Factors

Several identified and potential threats and limiting factors may negatively impact rockfish populations. They may cause direct mortality, increased vulnerability to predation or disease, or reduced fitness and productivity (Palsson et al. 2009). The threats are assessed for each management unit, and the results are presented in Tables 9 through 13 according to these criteria: 1) the severity of the threat, 2) the level of certainty that the listed species are affected in the respective Management Unit, 3) the geographic extent of the threat, and 4) the likelihood that the actions outlined in this plan could reduce the threat. The severity of a threat refers to effects it has on the listed species (High—causes direct mortality, loss of productivity, fitness, and other key attributes; Moderate—does not cause decreased fitness or direct mortality and affects a moderate number of other attributes; Low—does not cause decreased fitness or direct mortality and affects a low number of other attributes). The level of certainty that a species is affected refers to the amount of evidence that the threat affects the species in that management unit (High—direct evidence or multiple lines of indirect evidence; Moderate—indirect evidence; Low—little or no evidence). Geographic extent refers to the spatial extent of the threat within the management unit (High—throughout much the basin; Moderate—in a moderate amount of the basin; Low—isolated areas; Very Low—occurs in a negligible amount of the basin). The likelihood of an action reducing a threat refers to the actions outlined in this plan and the likelihood they may reduce the threat (High—action has been proven to decrease threat; Moderate—action is likely to reduce the threat; Low—action has small ability to reduce the threat; Very Low—action may or may not reduce the threat). An example of these actions are removal of derelict fishing gear in an area with a lot of derelict gear (High) compared to assessing competition for prey and habitat between rockfish and other fish species like salmon and other groundfish. The criteria may also be rated as Unknown, meaning more information is needed.

Overall Evaluation of Risk: The threats criteria described above are combined and assessed to calculate the overall risk of the threats. Criteria include the geographic extent of the threat within the management unit (or DPSs) and the severity of the threat in that same area. 1 = High risk, 2 = Moderate risk, 3 = Low risk, 4 = Very low risk, P = Potential threat, not enough information to determine if it is a threat at the current time, but could plausibly become a threat in the future based on information known at this time.

Listing Factors: 1) Present or threatened destruction, modification, or curtailment of a species' habitat or range; 2) over-utilization for commercial, recreational, scientific, or educational purposes; 3) disease or predation; 4) inadequacy of existing regulatory mechanisms; 5) other manmade factors affecting its continued existence. The primary listing factors we identified as responsible for decline of the DPSs of rockfishes at the time of listing appear with an (*) in Tables 9 through 13, along with other factors that may have contributed to decline.

Life Stage Affected: L = larval; J = juvenile; A = adult

Historical, Current, Future Effects: H = historical; C = current; F = future

High, Moderate, Low, Very Low, Unknown, Potential: High = H, Moderate = M, Low = L, Very Low = VL, Unknown = U, Potential = P

Tables 9 through 13 are for yelloweye rockfish and bocaccio, and are broken down by management unit. Differences between species are highlighted with a footnote.

Table 9. Threats Assessment for Management Unit 1: San Juan/Strait of Juan de Fuca Basin.

(San Juan/Strait of Juan de Fuca Basin -- MCAs 6 and 7)											
Descriptive Information						**Threat Ranking Information**					
Listing Factor	**Threat**	**Source**	**Key Ecological Attributes Affected**	**Life Stage Affected**	**Historical, Current, Future Effect**	**Severity of Threat**	**Level of Certainty Species is Affected**	**Geographic Extent of Threat**	**Recovery Action(s)**	**Likelihood Recovery Action(s) Reduce Threat**	**Overall Ranking**
Fisheries Interactions											
1, 2, 5	*Derelict Gear (in nearshore and benthic environments)	Primarily commercial salmon nets, shrimp pots	Mortality, Reproduction, Productivity	J, A	H, C, F	H	H	H	3.1.1, 3.2.1	H	1
2, 4	*Fisheries Removals (commercial bycatch)	Primarily bycatch from fisheries targeting halibut and shrimp	Mortality, Reproduction, Productivity, Fitness	J, A	H, C, F	H	M	U	2.1-2.6	H	1
2, 4	*Fisheries Removals (recreational bycatch)	Bycatch by anglers targeting salmon, bottom fish, and halibut; inadequate enforcement	Mortality, Reproduction, Productivity, Fitness	J, A	H, C, F	H	M	H	2.1-2.6, 4.1-4.5	H	1
Habitat											
1, 4	*Habitat Disruption (**nearshore)	Nearshore development / Modification	Productivity	J, A	H, C, F	L	M	L	3.1, 3.1.2, 3.10, 3.11	H	3
1, 4	*Habitat Disruption (benthic)	Sediment disposal practices, development	Productivity, Fitness	J, A	H, C, F	H	L	L	3.2, 3.2.2, 3.2.3, 3.10, 3.11	M	3
1	*Non-native Species that Alter Habitat (*Sargassum*, tunicates)	Global shipping and fisheries practices, natural disasters	Productivity	J, A	H, C, F	U	U	U	3.1.3	U	P
1, 4	*Hypoxia/ Nutrient Addition	Primarily local point and non-point pollution	Mortality, Productivity	L, J, A	H, C, F	H	L	L	3.4	L	4

(San Juan/Strait of Juan de Fuca Basin -- MCAs 6 and 7)											
Descriptive Information						**Threat Ranking Information**					
Listing Factor	**Threat**	**Source**	**Key Ecological Attributes Affected**	**Life Stage Affected**	**Historical, Current, Future Effect**	**Severity of Threat**	**Level of Certainty Species is Affected**	**Geographic Extent of Threat**	**Recovery Action(s)**	**Likelihood Recovery Action(s) Reduce Threat**	**Overall Ranking**
1, 4	*Chemical Contamination (bioaccumu-lants)	Primarily local point and non-point pollution	Fitness, Growth, Reproduction, Productivity, Behavior	L, J, A	H, C, F	H	L	L	3.3, 3.3.1	H	3

* Primary listing factor as designated by Palsson et al. 2009 and Drake et al. 2010.
** Most directly affects bocaccio.

Table 10. Threats Assessment for Management Unit 2: Main Basin and Whidbey Basin.

(Main Basin and Whidbey -- MCAs 9, 10, and 11 and 8-1, 8-2)											
Descriptive Information						**Threat Ranking Information**					
Listing Factor	**Threat**	**Source**	**Key Ecological Attributes Affected**	**Life Stage Affected**	**Historical, Current, Future Effect**	**Severity of Threat**	**Level of Certainty Species is Affected**	**Geographic Extent of Threat**	**Recovery Action(s)**	**Likelihood Recovery Action(s) Reduce Threat**	**Overall Ranking**
Fisheries Interactions											
1, 2, 5	*Derelict Gear (in nearshore and benthic environments)	Primarily commercial salmon nets, shrimp pots	Mortality, Reproduction, Productivity	J, A	H, C, F	H	H	L	3.1.1, 3.2.1	H	2
2, 4	*Fisheries Removals (commercial bycatch)	Primarily current bycatch from fisheries targeting halibut, shrimp	Mortality, Reproduction, Productivity, Fitness	J, A	H, C, F	H	U	U	2.1-2.6	H	***3
2, 4	*Fisheries Removals (recreational bycatch)	Bycatch by anglers targeting salmon, bottom fish, spot prawns, and halibut; inadequate enforcement	Mortality, Reproduction, Productivity, Fitness	J, A	H, C, F	H	M	H	2.1-2.6, 4.1-4.5	H	2
Habitat											
1, 4	*Habitat Disruption (**nearshore)	Nearshore development	Productivity	J, A	H, C, F	L	H	H	3.1, 3.1.2, 3.10, 3.11	M	1
1, 4	*Habitat Disruption (benthic)	Sediment disposal practices, development	Productivity, Fitness	J, A	H, C, F	H	L	L	3.2, 3.2.2, 3.2.3, 3.10, 3.11	M	3
1	*Non-native Species that Alter Habitat, (*Sargassum*, tunicates)	Global shipping and fisheries practices; natural disasters	Productivity	J, A	H, C, F	U	U	U	3.1.3	U	P

(Main Basin and Whidbey -- MCAs 9, 10, and 11 and 8-1, 8-2)											
Descriptive Information						**Threat Ranking Information**					
Listing Factor	**Threat**	**Source**	**Key Ecological Attributes Affected**	**Life Stage Affected**	**Historical, Current, Future Effect**	**Severity of Threat**	**Level of Certainty Species is Affected**	**Geographic Extent of Threat**	**Recovery Action(s)**	**Likelihood Recovery Action(s) Reduce Threat**	**Overall Ranking**
1, 4	*Hypoxia/ Nutrient Addition	Primarily local point and non-point pollution	Mortality, Productivity	L, J, A	H, C, F	H	M	L	3.4	M	3
1, 4	*Chemical Contamination (bioaccumu-lants)	Primarily local point and non-point pollution	Fitness, Growth, Reproduction, Productivity, Behavior	L, J, A	H, C, F	H	H	H	3.3, 3.3.1	H	1

* Primary listing factor as designated by Palsson et al. 2009 and Drake et al. 2010.
** Most directly affects bocaccio.
***Further information required to assess the extent and effects of commercial fisheries in this area and this ranking could change.

Table 11. Threats Assessment for Management Unit 3: South Sound.

(South Sound Basin – MCA 13)											
Descriptive Information						**Threat Ranking Information**					
Listing Factor	**Threat**	**Source**	**Key Ecological Attributes Affected**	**Life Stage Affected**	**Historical, Current, Future Effect**	**Severity of Threat**	**Level of Certainty Species is Affected**	**Geographic Extent of Threat**	**Recovery Action(s)**	**Likelihood Recovery Action(s) Reduce Threat**	**Overall Ranking**
Fisheries Interactions											
1, 2, 5	*Derelict Gear (in nearshore and benthic environments)	Primarily commercial salmon nets	Mortality, Reproduction, Productivity	J, A	H	H	L	L	3.1.1, 3.2.1	M	4
2, 4	*Fisheries Removals (commercial bycatch)	There are few commercial fisheries remaining here	Mortality, Reproduction, Productivity, Fitness	J, A	H, C, F	H	L	L	2.1-2.6	L	3
2, 4	*Fisheries Removals (recreational bycatch)	Bycatch by anglers targeting salmon, bottom fish; inadequate enforcement	Mortality, Reproduction, Productivity, Fitness	J, A	H, C, F	H	L	L	2.1-2.6, 4.1-4.5	M	3
Habitat											
1, 4	*Habitat Disruption (**nearshore)	Nearshore development	Productivity	J, A	H, C, F	L	H	H	3.1, 3.1.2, 3.10, 3.11	M	1
1, 4	*Habitat Disruption (benthic)	Sediment dis-posal practices, development	Productivity, Fitness	J, A	H, C, F	H	L	L	3.2, 3.2.2, 3.2.3, 3.10, 3.11	M	3
1	*Non-native Species that Alter Habitat	Global shipping and fisheries practices; natural disasters	Productivity	J, A	H, C, F	U	U	U	3.1.3	U	P
1, 4	*Hypoxia/ Nutrient Addition	Primarily local point and non-point pollution	Mortality, Productivity	L, J, A	H, C, F	H	H	M	3.4	M	2
1, 4	*Chemical Contamination (bioaccumu-lants)	Primarily local point and non-point pollution	Fitness, Growth, Reproduction, Productivity, Behavior	L, J, A	H, C, F	H	H	H	3.3, 3.3.1	H	1

* Primary listing factor as designated by Palsson et al. 2009 and Drake et al. 2010.
** Most directly affects bocaccio.

Table 12. Threats Assessment for Management Unit 4: Hood Canal Basin.

(Hood Canal – MCA 12)											
Descriptive Information						**Threat Ranking Information**					
Listing Factor	**Threat**	**Source**	**Key Ecological Attributes Affected**	**Life Stage Affected**	**Historical, Current, Future Effect**	**Severity of Threat**	**Level of Certainty Species is Affected**	**Geographic Extent of Threat**	**Recovery Action(s)**	**Likelihood Recovery Action(s) Reduce Threat**	**Overall Ranking**
Fisheries Interactions											
1, 2, 5	*Derelict Gear (in nearshore and benthic environments)	Primarily commercial salmon nets, shrimp pots	Mortality, Reproduction, Productivity	J, A	H	H	L	L	3.1.1, 3.2.1	H	4
2, 4	*Fisheries Removals (current commercial bycatch)	Primarily bycatch from fisheries targeting spot prawns	Mortality, Reproduction, Productivity, Fitness	J, A	H, C, F	H	L	L	2.1-2.6	M	3
2, 4	*Fisheries Removals (current recreational bycatch)	Bycatch by anglers targeting salmon, spot prawns; inadequate enforcement	Mortality, Reproduction, Productivity, Fitness	J, A	H, C, F	H	L	VL	2.1-2.6, 4.1-4.5	M	4
Habitat											
1, 4	*Habitat Disruption (**nearshore)	Nearshore development	Productivity	J, A	H, C, F	M	H	M	3.1, 3.1.2, 3.10, 3.11	H	2
1, 4	*Habitat Disruption (benthic)	Sediment disposal practices, development	Productivity, Fitness	J, A	H, C, F	H	L	L	3.2, 3.2.2, 3.2.3, 3.10, 3.11	M	3
1	*Non-native Species that Alter Habitat (*Sargassum*, tunicates)	Global shipping and fisheries practices; natural disasters	Productivity	J, A	H, C, F	U	U	U	3.1.3	U	P
1, 4	*Hypoxia/ Nutrient Addition	Primarily natural conditions exacerbated by	Mortality, Productivity	L, J, A	H, C, F	H	H	M	3.4	M	1

		local point and non-point pollution									
1, 4	*Chemical Contamination (bioaccumu-lants)	Primarily local point and non-point pollution	Fitness, Growth, Reproduction, Productivity, Behavior	L, J, A	H, C, F	H	M	M	3.3, 3.3.1	H	2

* Primary listing factor as designated by Palsson et al. 2009 and Drake et al. 2010.
** Most directly affects bocaccio.

Table 13. Threats Assessment for Management Unit 5: Primary listing factors in Canada and all Puget Sound/Georgia Basin (other factors).

Canada											
Descriptive Information						**Threat Ranking Information**					
Listing Factor	**Threat**	**Source**	**Key Ecological Attributes Affected**	**Life Stage Affected**	**Historical, Current, Future Effect**	**Severity of Threat**	**Level of Certainty Species is Affected**	**Geographic Extent of Threat**	**Recovery Action(s)**	**Likelihood Recovery Action(s) Reduce Threat**	**Overall Ranking**
Fisheries Interactions											
1, 2, 5	*Derelict Gear (in nearshore and benthic environments)	Primarily commercial salmon nets, shrimp pots	Mortality, Reproduction, Productivity	J, A	H, C, F	H	H	H	3.1.1, 3.2.1	H	1
2, 4	*Fisheries Removals (commercial catch/bycatch)	Primarily bycatch from fisheries targeting shrimp, salmon, and groundfish	Mortality, Reproduction, Productivity, Fitness	J, A	H, C, F	H	M	L	2.1-2.6	M	3
2, 4	*Fisheries Removals (recreational catch/bycatch)	Primarily bycatch from fisheries targeting bottom fish and salmon	Mortality, Reproduction, Productivity, Fitness	J, A	H, C, F	H	M	U	2.1-2.6, 4.1-4.5	M	3
Habitat											
1, 4	*Habitat Disruption (**nearshore)	Nearshore development	Productivity	J, A	H, C, F	L	L	L	3.1, 3.1.2, 3.10, 3.11	M	4
1, 4	*Habitat Disruption (benthic)	Sediment disposal practices, development	Productivity, Fitness	J, A	H, C, F	H	L	L	3.2, 3.2.2, 3.2.3, 3.10, 3.11	M	3
1	*Non-native Species that Alter Habitat (*Sargassum*, tunicates)	Global shipping and fisheries practices; natural disasters	Productivity	J, A	H, C, F	U	U	U	3.1.3	U	P
1, 4	*Hypoxia/ Nutrient Addition	Primarily local point and non-point pollution	Mortality, Productivity	L, J, A	H, C, F	H	L	L	3.4	M	4
1, 4	*Chemical Contamination (bioaccumu-lants)	Primarily local point and non-point pollution	Fitness, Growth, Reproduction, Productivity, Behavior	L, J, A	H, C, F	H	L	L	3.3, 3.3.1	H	3

Canada											
Descriptive Information						**Threat Ranking Information**					
Listing Factor	**Threat**	**Source**	**Key Ecological Attributes Affected**	**Life Stage Affected**	**Historical, Current, Future Effect**	**Severity of Threat**	**Level of Certainty Species is Affected**	**Geographic Extent of Threat**	**Recovery Action(s)**	**Likelihood Recovery Action(s) Reduce Threat**	**Overall Ranking**
ALL PUGET SOUND/GEORGIA BASIN (US and Canada) ***Species and Ecosystem Interactions***											
3	Marine Mammal Predation	Pinnipeds, otters	Mortality, Fitness, Productivity	J, A	H, C, F	H	M	L	3.5.2	VL	4
3	Fish Predation	Lingcod, rockfish, salmon	Mortality, Fitness, Productivity	L, J, A	H, C, F	H	U	L	3.5.2	VL	4
5	Hatchery Practices	Salmon hatcheries	Mortality, Fitness, Productivity	L, J	H, C, F	H	U	L	3.7	M	4
5	Competition	Chinook salmon, coho salmon, other rockfish spp., other groundfish spp.	Productivity	L, J, A	H, C, F	L	L	L	3.5.3	VL	P
3	Diseases	Unknown, though we do know of a number of parasites affecting rockfish	Mortality, Productivity, Fitness	U	H, C, F	H	U	U	3.6	L	P
5	Inbreeding	Mating between related individuals in small populations	Fitness, Productivity, Reproduction, Genetic Integrity	L, J, A	U	H	U	U	1.4, 1.4.1	L	P
5	Hybridization	Low encounter rate of suitable mates in small populations	Fitness, Productivity, Genetic Integrity	L, J, A	U	H	U	U	1.4, 1.4.1	L	P
1	Oil Spills	Global and local shipping and boating	Mortality, Reproduction, Productivity	L, J, A	H, C, F	H	H	H	3.9	H	1
4, 5	Ocean Acidification	Global and local carbon dioxide output; local land	Reproduction, Productivity, Behavior,	L, J, A	H, C, F	H	H	H	3.5, 3.5.1	L	1

Canada											
Descriptive Information						**Threat Ranking Information**					
Listing Factor	**Threat**	**Source**	**Key Ecological Attributes Affected**	**Life Stage Affected**	**Historical, Current, Future Effect**	**Severity of Threat**	**Level of Certainty Species is Affected**	**Geographic Extent of Threat**	**Recovery Action(s)**	**Likelihood Recovery Action(s) Reduce Threat**	**Overall Ranking**
		use practices; lack of collective action or legislation, natural upwelling	Fitness								
4, 5	Climate Change	Global and local carbon dioxide output; lack of collective action or legislation	Likely Reproduction, Productivity, Behavior, Fitness	L, J, A	H, C, F	H	H	H	3.5, 3.5.1	L	1
5	Anthropogenic Noise	Construction, shipping, military exercises	Likely Behavior, Productivity	L, J, A	H, C, F	M	L	U	3.8	M	P

* Primary listing factor as designated by Palsson et al. 2009 and Drake et al. 2010.
** Most directly affects bocaccio.

F. CONSERVATION MEASURES, RESEARCH, AND MONITORING

This section provides an overview of conservation efforts that have been undertaken for yelloweye rockfish and bocaccio of the Puget Sound/Georgia Basin since their listing, and discusses overall efficacy of all efforts and protections. In some cases, these conservation efforts are relatively new and may not have had time to demonstrate their biological benefit. In such cases, provisions for adequate monitoring and funding of conservation efforts are essential to ensure that intended conservation benefits are realized. Further protective action, research, and outreach efforts are still urgently needed to ensure recovery of the ESA-listed DPSs. Further information on research and monitoring efforts, along with recommended additional research that address many of the primary threats outlined in this recovery plan are discussed in further detail in the appendices. The appendices are included to provide additional detail for specific topics and aid in implementation.

Fisheries Management

Washington State

In 2010, the Washington State Fish and Wildlife Commission formally adopted regulations that ended targeting and retention of rockfish by recreational anglers in Puget Sound and closed fishing for bottom fish in waters deeper than 120 feet (36.6 m) (does not apply to anglers targeting halibut) to reduce bycatch. Additionally, on July 28, 2010, WDFW closed the following non-tribal commercial fisheries in Puget Sound (WDFW 2010):

- the set net fishery
- the set line fishery
- the bottom trawl fishery
- the inactive scallop trawl fishery
- the inactive pelagic trawl fishery
- the inactive bottom fish pot fishery

WDFW also applied for and received a 5-year Incidental Take Permit (ITP) and developed a Fisheries Conservation Plan (FCP) with NOAA (WDFW 2012c). The FCP includes the monitoring and management of two fisheries authorized by the State of Washington to minimize the 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.

Canada

The Department of Fisheries and Oceans (DFO) manages fisheries in Area 4(b) of the inside waters of Vancouver Island separately from outside waters. Area 4(b) encompasses all of the Canadian portion of the DPSs' ranges and includes some waters outside of the DPSs' ranges to the west and north. In 2001, DFO began a process to improve inshore[2] rockfish management by: 1) accounting for all catch (landed and released), 2) decreasing fishing mortality, 3) establishing areas closed to activities that result in bycatch, and 4) improving stock assessment and monitoring (Yamanaka and Lacko 2001). DFO adopted a

[2] Inshore rockfish include yelloweye, black, copper, quillback, China, and tiger rockfish.

policy to ensure that inshore rockfish are subjected to fisheries mortality equal to or less than half of natural mortality.

In 2007, the DFO formally designated 30 percent of inside rockfish habitat as Rockfish Conservation Areas (RCAs) (Figure 10). The DFO defined and mapped rockfish habitat from commercial fisheries log CPUE density data as well as change in slope bathymetry analysis (Yamanaka and Logan 2010). Within the RCAs, DFO allows some harvest of marine biota.[3] However, these reserves do not allow directed commercial or recreational harvest for any species of rockfish or the harvest of many other marine species that 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 2014). Systematic monitoring of the RCAs may be lacking as well (Haggarty 2014). Because the RCAs are relatively new, it is uncertain how effective they have been in protecting rockfish populations (Haggarty 2014), but one analysis found that sampled RCAs in Canada had 1.6 times the number of rockfish compared to unprotected areas (Cloutier 2011), while a second found no difference in rockfish density and size structure between RCAs and control sites (Haggarty et al. 2016). Outside the RCAs, recreational fishers generally may keep one rockfish per day from May 1 to September 30. Commercial rockfish catches in Area 4(b) are managed by a quota system (DFO 2011a). DFO's 2015 Integrated Groundfish Management Plan calls for a TAC of 110 tonnes (242,508 pounds) of bocaccio from commercial trawling in Area 4(b) (DFO 2015). For yelloweye rockfish, the TAC is 6 tonnes from the commercial hook-and-line fishery and 1 ton for the halibut fishery (DFO 2015). As of 2006, 100 percent at-sea monitoring standards were put in place for the entire groundfish fishery. This monitoring is intended to eliminate unreported catch of rockfish throughout the commercial groundfish fishery and allow all rockfish to be accounted for within their TACs (Yamanaka et al. 2006).

[3] Recreational fishing allowed in RCAs: invertebrates by hand picking or dive, crab by trap, shrimp/prawn by trap, smelt by gillnet. Commercial fishing allowed in RCAs: invertebrates by hand picking or dive; crab and prawn by trap; scallops by trawl; salmon by seine or gillnet; herring by gillnet and seine; spawn-on-kelp sardine by gillnet, seine, and trap; smelt by gillnet; euphausiid (krill) by mid-water trawl; opal squid by seine; groundfish by mid-water trawl. (http://www.pac.dfo-mpo.gc.ca/fm-gp/maps-cartes/rca-acs/permitted-permis-eng.htm)

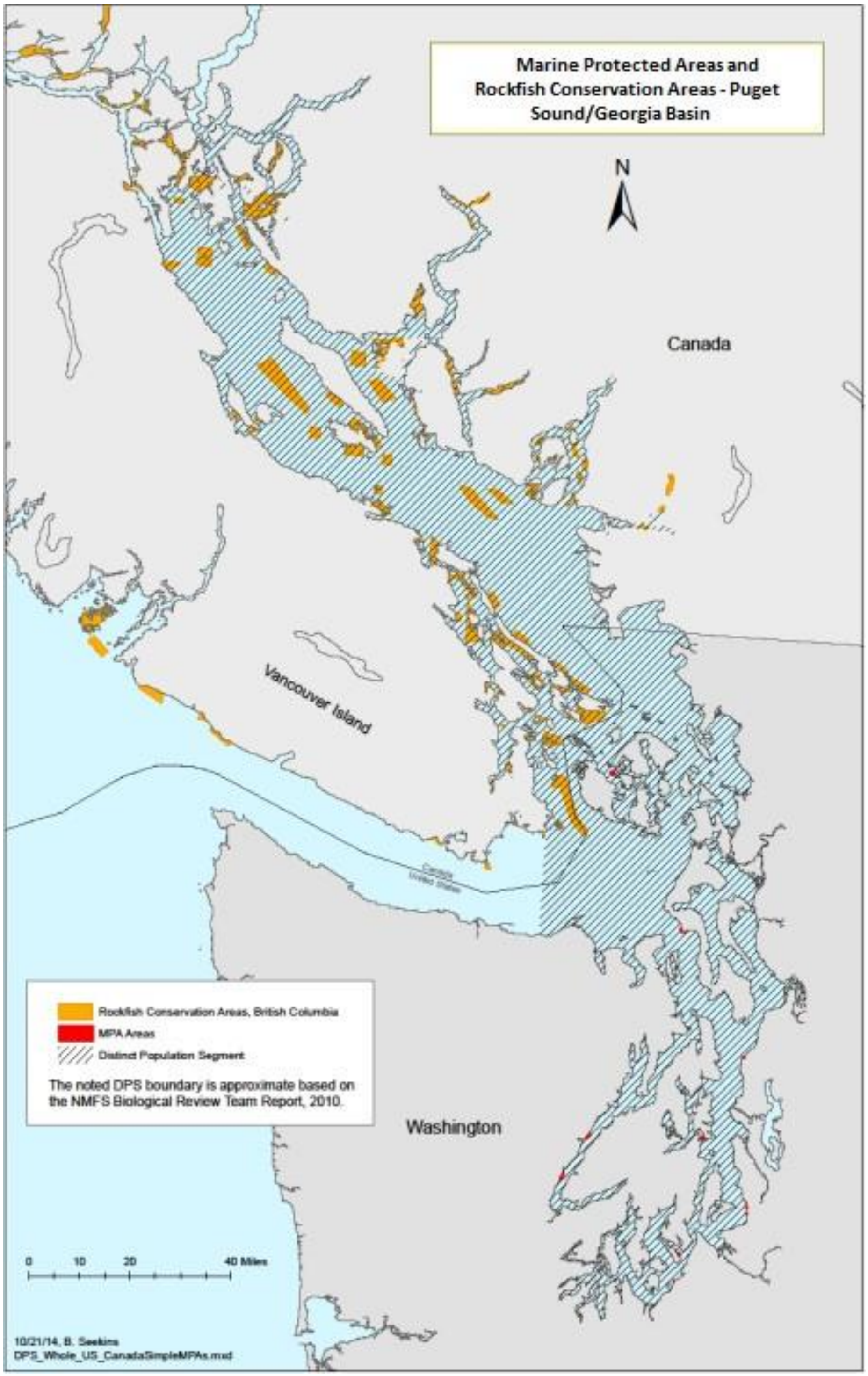

Figure 10. Rockfish Conservation Areas in Canada and reserves in Puget Sound that do not allow most fishing.

Cooperative Research

Creating partnerships for the purposes of researching various aspects of rockfish recovery has already proven valuable in engaging a diverse group of stakeholders. This section summarizes a number of completed and ongoing research programs.

In recognition of the knowledge that fishers can bring to the recovery effort, NMFS began an initiative soon after the Federal listing to both further assess bycatch and involve fishers in research and recovery of rockfish. Beginning in late 2010, NMFS partnered with the University of Washington to assess recreational anglers' knowledge and perceptions regarding rockfish threats and recovery actions. This project documented angler knowledge of rockfish life history, regulations, and species identification abilities; perceived threats to rockfish; fishing practices; and preferred recovery measures (Sawchuk 2012; Sawchuk et al. 2015). The survey findings have been used to inform Appendix I, Education, Outreach, and Public Involvement, and guided further angler engagement.

In 2012, NMFS partnered with the Northwest Straits Foundation to commission a study to assess spatial distribution and magnitude of derelict shrimp pots and their potential impacts to rockfish in Puget Sound. The study utilized sidescan sonar surveys, an analysis of the WDFW creel surveys, and an online survey that was made available for shrimp fishers. This study has enabled a foundational knowledge of the potential impact shrimp pots may have on rockfish. In 2013, NMFS partnered with the Northwest Straits Foundation to conduct an assessment of bycatch rates of rockfish in actively fished shrimp pots based on WDFW test fisheries data (NRC 2014).

In 2012, NMFS and the SeaDoc Society sponsored an assessment of cooperative research projects (Browning 2013). The assessment examined several cooperative research projects involving partnerships between fishers and researchers/fishery managers, and it has been used to guide future collaborative efforts.

Rockfish Cooperative Research Program

In 2014 and 2015, NMFS, WDFW, Puget Sound Anglers, and local fishing guides partnered on a cooperative research rockfish genetics project. This project assessed listed rockfish genetics by gathering samples through hook-and-line sampling.

The project resulted in new genetics information that revealed that canary rockfish in the Puget Sound/Georgia Basin are not discrete from the coastal fish, thus leading to their delisting from the ESA in 2017.

Another cooperative study to assess rockfish bycatch in local lingcod fisheries was initiated in 2017. Each project has provided important information for rockfish recovery efforts.

Captain Jay Field and Kelly Andrews with a yelloweye rockfish caught in the San Juan Islands. Photo courtesy of Kelly Andrews.

In 2013 and 2014, NMFS, WDFW, and the SeaDoc Society began two cooperative research projects with recreational fishing guides to assess rockfish bycatch in fisheries targeting lingcod and halibut, and to gain genetic samples of listed rockfish. In 2017, NMFS began a study with local fishing guides to assess rockfish bycatch in lingcod fisheries.

The cooperative genetics research utilized the experience of recreational fishing guides who had ideas about where to find the rare species of rockfish. Over the course of 74 fishing trips, guides and researchers collected fin clips and length data from listed rockfishes (Andrews et al. 2015). All of the fin clips were analyzed, which resulted in the delisting of canary rockfish of the Puget Sound/Georgia Basin in early 2017. Analyses indicated a lack of genetic differentiation between coastal and Puget Sound/Georgia Basin samples of canary rockfish, as seen in the lack of distinct clusters in the principal components analysis (Figure 11). 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. These analyses all suggest there is no evidence of genetic differentiation of canary rockfish across the boundaries of the DPS (Andrews et al. 2015). A full report of this project and the results for all the listed species is found in our 5-year review on our website (NMFS 2016).[4]

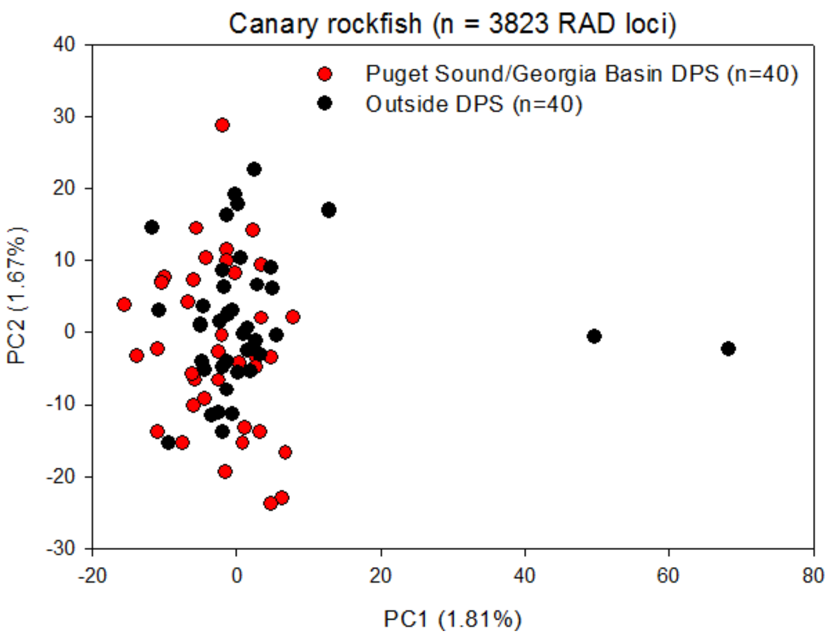

Figure 11. No distinct genetic structure observed in canary rockfish based on a principal components analysis of the genetic variation between individuals inside and outside the DPS (Andrews et al. 2015).

In 2014, NMFS and WDFW began a rockfish habitat-stratified ROV survey in Puget Sound proper. This research enables an assessment of the population while also collecting important habitat information necessary to better characterize rockfish habitat. This cooperative research is key to assessing the status of the population now and into the future. The 2015 survey sampling plan is depicted in Figure 12.

[4]http://www.westcoast.fisheries.noaa.gov/publications/protected_species/other/rockfish/5.5.2016_5yr_review_report_rockfish.pdf

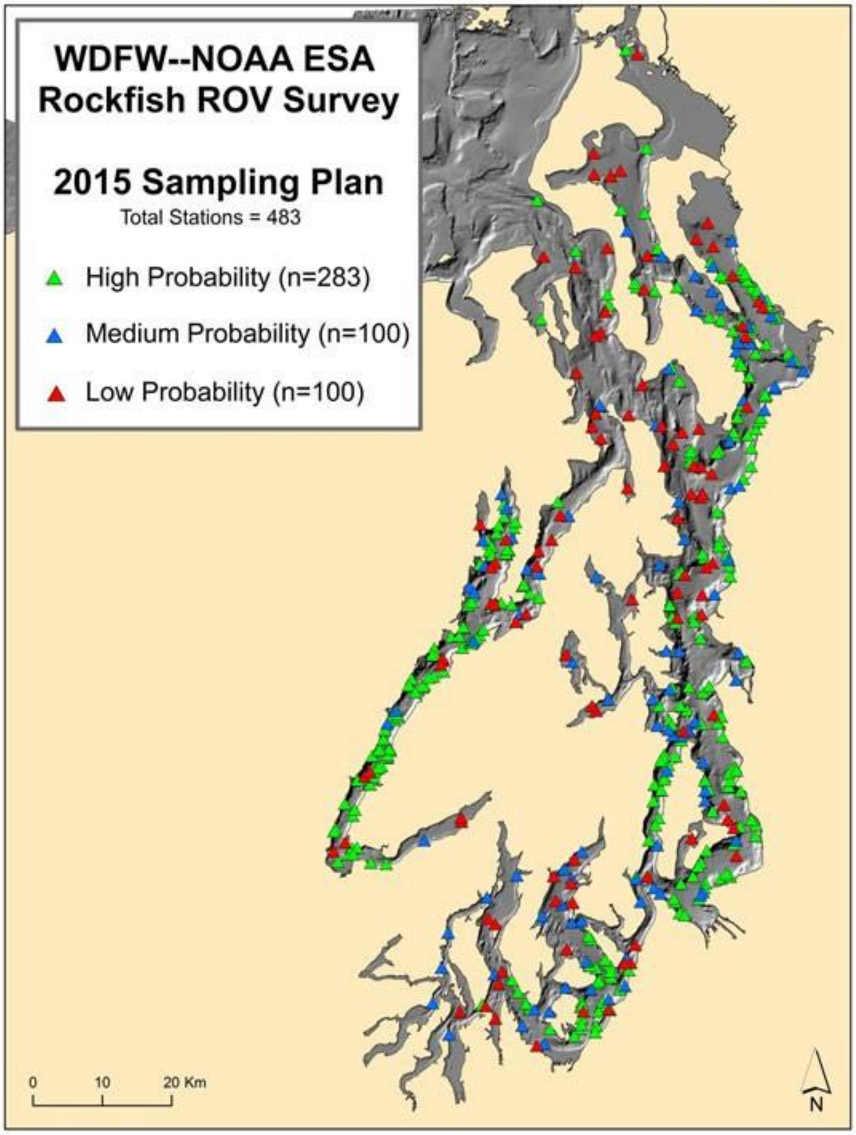

Figure 12. 2015 Rockfish ROV survey target sites.

Derelict Fishing Gear Removal and Prevention

Removal: Funding from the American Recovery and Reinvestment Act and other Federal funds enabled the Northwest Straits Initiative to remove over 4,500 derelict fishing nets and 140 derelict pots from waters shallower than 100 feet (30.5 m), restoring hundreds of acres of Puget Sound habitat. Conservation efforts directed at removing derelict nets have reduced the threat of mortality and rocky habitat degradation; however, there remain an unknown number of deepwater nets that still require removal.

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) (NRC 2010). Removal methodology for deepwater nets has been identified 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.

Research: NMFS funded a pilot survey using side-scan sonar for derelict fishing nets in waters deeper than 100 feet (30.5 m) off the west coast of San Juan Island, resulting in the documentation of over 50 nets (Figure 13). NMFS was also involved in research to assess possible methods to remove derelict fishing nets at depths great than 98 feet (30 m) and worked with the Northwest Straits Foundation (NSF) and Natural Resources Consultants (NRC) to quantify lost shrimp pots and bycatch of rockfish in actively fished shrimp pots.

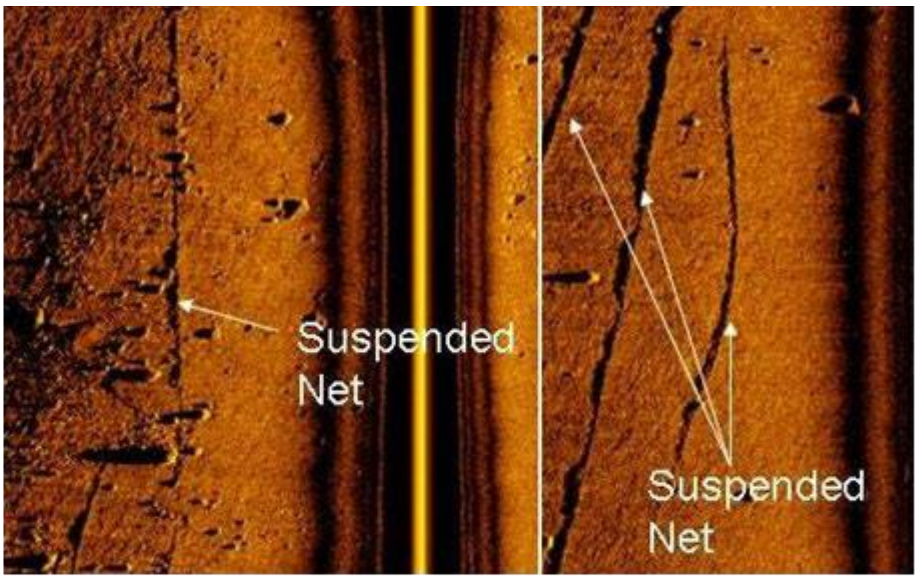

Figure 13. Sidescan sonar images of deepwater derelict nets located on Point Roberts Reef of the San Juan Basin. Suspended nets have a larger acoustic shadow than nets flush with the bottom. Image courtesy of Natural Resource Consultants.

Further, NMFS has worked with the NSF and NRC to identify and quantify mortality (including rockfish) in derelict fishing gear (Good et al. 2010). With the help of the NMFS Genetics Program, this group of collaborators identified some rockfish bone samples using molecular markers to quantify and compile a list of affected species.

In 2013, NMFS funded a study by the NSF and the NWIFC that utilized ideas and recommendations from commercial fishers and fishing gear experts to assess how to better prevent the loss of nets and encourage the quick retrieval of derelict gillnets from Puget Sound fisheries. They used information from personal interviews, letters, email exchange, and an anonymous online survey (Gibson 2013).

State Regulations: On March 29, 2012, the Washington Governor signed into law Senate Bill 5661, making it mandatory for non-tribal commercial fishers to report lost nets to WDFW within 24 hours of loss so that they can be retrieved (Washington State Legislature 2012). 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).

Additionally, WDFW and NSF, assisted by funding from NMFS, have established a reporting, response, and retrieval network that allows online and telephone reporting of derelict nets by members of the public. After a report is received it is evaluated and, if appropriate, a unit is mobilized to locate and remove the gear before it can sink and affect both marine organisms and their habitat.

Education and Outreach

In 2012, the Puget Sound Anglers began outreach to local anglers to better identify rockfish and use rapid-submergence techniques to reduce the effects of barotrauma. This outreach was related to the findings of the NMFS/University of Washington angler study that was introduced at the beginning of the Cooperative Research section (Sawchuk 2012; Sawchuk et al. 2015). WDFW has also produced materials on rockfish bycatch avoidance, identification, handling procedures, and recompression (http://wdfw.wa.gov/fishing/bottomfish/rockfish/mortality.html) and has recently added informational signage to a number of boat launches throughout Puget Sound. Additionally, WDFW has piloted a voluntary recreational fishing logbook program at several ports along the outer coast and in the Strait of Juan de Fuca. This program is now making its way into Puget Sound, starting with some recreational charter boat captains. In 2017, NMFS, WDFW, and the Seattle Aquarium partnered to install rockfish conservation signage at major boat launches in each Management Unit. The signage is designed to assist anglers' knowledge of rockfish species, fishing regulations, and release practices. In recent years, NMFS, WDFW, Puget Sound Anglers, and the Pacific States Marine Fisheries Commission have distributed thousands of descending devices to local anglers.

In 2003, the Puget Sound Recreational Fisheries Enhancement Fund (PSRFEF) Oversight Committee was created by the legislature to advise WDFW on issues related to improving the recreational fisheries within Puget Sound (http://wdfw.wa.gov/about/advisory/psrfef/). PSRFEF developed program goals (adopted in 2013) to measure progress of improving recreational bottom fish fisheries by utilizing outreach and education to decrease the mortality on rockfish (WDFW 2013). Specific performance measures pertaining to recovering bottom fish include increasing angler identification of rockfish species, increasing the use of descender tools, and decreasing angler encounters (e.g., bycatch) of rockfish.

Habitat Mapping

A Puget Sound benthic habitat mapping team consisting of the United States Geological Survey (USGS), SeaDoc Society/Tombolo Laboratory, the University of Washington, WDFW, NMFS, and others is working to better map and characterize benthic habitat conditions in Puget Sound. The USGS is working on detailed benthic habitat characterizations for most, but not all, of Puget Sound proper. In the San Juan Islands, a cooperative study involving WDFW and the SeaDoc Society/Tombolo Laboratory is using high resolution multibeam bathymetry data, interpreted habitat types informed by geology, and fish occurrence data from visual surveys to develop probabilistic occurrence maps for the listed rockfish and a variety of other benthic organisms. These maps will inform future survey efforts, critical habitat designation, and fishery management actions.

Historical Rockfish Abundance Trends and Assemblages

NMFS partnered with the University of Washington to conduct an analysis of historical rockfish data in Puget Sound and reported in Washington et al. (1977). The analysis calculated the catch per unit of effort of nine species of local rockfish (including listed rockfish), determined depth of capture, and assessed potential habitat associations (Browning 2013).

A seven-decade time series of relative abundance was developed for seven species of rockfish in Puget Sound, including the listed rockfish, from interviews with fishers, divers, and researchers (Beaudreau and Levin 2014). Trends in abundance indices indicated that all seven species in Puget Sound have been in decline since at least the 1960s. The listed rockfish were viewed as relatively lower in abundance across all time periods compared to other rockfishes. The study showed that expert knowledge in combination with available scientific data may help resolve patterns of abundance for rockfishes and other data-poor species.

G. RESEARCH AND MONITORING IN PROGRESS

There are a number of important research projects underway, and these are summarized in Table 14.

Table 14. Research projects in progress to address rockfish attributes and inform recovery.

Entity	Research Type	General Rockfish Attribute(s) Research Will Address				
		Abundance	Spatial Structure/ Habitat Usage	Connectivity	Diversity (age/size)	Injury / Mortality
WDFW/NMFS	Remotely operated video surveys	✓	✓	✓	✓	
NMFS/University of Washington	Larval dispersal			✓		
NMFS/Select Fishing Guides	Bycatch and gear/bait attributes					✓
NMFS/WDFW/ Northwest Straits Foundation/NRC	Shrimp pots, bycatch rates, and derelict gear				✓	✓
NMFS/WDFW/ Sea Doc Society/others	Fine scale habitat associations		✓			
WDFW	Trawl surveys		✓		✓	
NMFS/WDFW/ NWSI	Dive surveys – YOY and kelp restoration	✓	✓		✓	

Entity	**Research Type**	**General Rockfish Attribute(s) Research Will Address**				
		Abundance	**Spatial Structure/ Habitat Usage**	**Connectivity**	**Diversity (age/size)**	**Injury / Mortality**
Puget Sound Restoration Fund/NMFS	Bull kelp life history		✓			
WDFW/NMFS	Evaluation of barotrauma post release (ROV obs.)		✓		✓	✓

III. RECOVERY STRATEGY

This section presents NMFS' recommended strategy for recovering yelloweye rockfish and bocaccio, including the primary focus of the recovery effort and how it addresses the known threats and biological needs of the species. The plan is comprehensive to address all of the threats, draws on existing information to prioritize actions, and identifies research to inform an adaptive approach to develop, prioritize, and implement actions as data gaps are filled. This section provides the rationale for the recommended recovery program, linking information presented in the background section to information provided in the sections on recovery objectives, criteria, and actions.

A. KEY FACTS AND ASSUMPTIONS

Population Decline and Life History—The abundance of yelloweye rockfish and bocaccio within the Puget Sound/Georgia Basin DPSs have each declined, likely as a result of past overharvest and other interacting factors (Palsson et al. 2009; Yamanaka and Logan 2010; Drake et al. 2010). The life history of listed rockfish includes long generation times and naturally low productivity. Past fishery removals and anthropogenic factors such as contaminants and other habitat degradation have likely exacerbated vulnerabilities related to their life history. Listed rockfish take many years to become reproductive adults, making them extremely vulnerable to threats that unduly impact adults, including overfishing, and slow to recover once depleted (Drake et al. 2010). The connectivity of larval and juvenile listed rockfish is probably naturally limited between Management Units (particularly within U.S. waters) by relatively shallow sills, and the effects of localized depletions of rockfish are likely exacerbated by these natural hydrologic constrictions (Drake et al. 2010).

Fisheries—Under current protective regulations, listed rockfish catch in the U.S. portion of the DPSs' ranges is incidental to other fisheries targeting salmon, bottom fish, halibut, and shrimp (see Section E. Factors Contributing to Decline and Federal Listing, *Threats Assessment for Fisheries*). Identifying and quantifying this bycatch is difficult because of largely inaccurate species identification by recreational anglers (Sawchuk 2012; Sawchuk et al. 2015) and limited frequency of angler surveys, and because of the lack of systematic bycatch tracking in some remaining commercial fisheries.

Recent State of Washington regulations that ended the retention of rockfish and prohibited fishing for bottom fish in waters deeper than 120 feet (36.6 m) have likely reduced bycatch of listed rockfish, though compliance is uncertain because most anglers were found to be unaware of the rule (Sawchuck 2012). In addition, effective enforcement of the 120-foot (36.6-m) rule is challenging because of the large spatial area which it covers, and the rule does not address recreational and commercial fisheries targeting salmon, shrimp, or halibut. Releasing rockfish at-depth with a descending device likely reduces mortality, but a recent survey found that only 3 percent of anglers report releasing rockfish bycatch at-depth within Puget Sound (Sawchuk 2012). There is emerging evidence that long-term survival of yelloweye rockfish and bocaccio released at-depth and with barotrauma is good, and in one study female yelloweye rockfish were found to be reproductively viable after recompression (Blain 2014). However, there are many variables that may influence long-term survival of rockfish after recompression, such as angler experience and handling, thermal shock, and depth of capture (Schroeder and Love 2002; Jarvis and Lowe 2008; Pribyl et al. 2009; Pribyl et al. 2011).

Recreational and commercial fisheries in the Canadian portion of the DPSs may retain limited numbers of rockfish. Rockfish Conservation Areas (RCAs) were designated in 30 percent of inside Vancouver Island rockfish habitat in 2007, and though commercial compliance with them is high, recreational compliance with them may be low (Haggarty 2014). Cloutier (2011) documented 1.6 times the number of rockfish in RCAs compared to outside unprotected areas and Frid et al. (2016) saw abundance and size increases of several rockfish species, including yelloweye rockfish, in central British Columbia RCAs; overall, it is likely that the RCAs in Canada are too recently established to determine their overall effectiveness, though compliance is thought to be an issue with their effectiveness thus far (Haggarty 2014). Compared to fished areas, studies have found higher fish densities, sizes, or reproductive activity in the assessed WDFW marine reserves (Palsson and Pacunski 1995; Palsson 1997; Eisenhardt 2001; Palsson et al. 2004). However, because most reserves in Puget Sound were established over several decades with unique and somewhat unrelated ecological goals, and encompass relatively small areas (average of 23 acres), the net effect of existing reserves to listed rockfish abundance, productivity, and spatial structure are probably very small (75 Fed. Reg. 22276, April 28, 2010). The San Juan Islands National Wildlife Refuge comprises 83 discrete areas throughout the archipelago that each have a 200-yard (182.9 m) prohibited entry buffer. Research has shown that these areas could act as an MPA but enforcement is inadequate to achieve that level of protection (Don 2002) and recent research has shown enforcement to be one of the most important factors driving success of protected areas (Gill et al. 2017).

The life history characteristics that make rockfish vulnerable to overfishing also make them good candidates for protection in MPAs (Yoklavich 1998), and rockfish and other species with similar life histories have been key species for protection in networks of MPAs that have been developed in several states and countries, particularly on the west coast of North America in Alaska; British Columbia, Canada; Oregon; California; and Baja California Sur, Mexico (Keller et al. 2014). Results from central California show that rockfish biomass increases in protected areas (Paddack and Estes 2000), though meaningful changes may occur more on the order of decades (2015).

Therefore, in the areas we have assessed to have remaining high risk of bycatch despite the regulations put into place by WDFW in 2010 to limit bycatch (areas are the San Juan Basin and the eastern Strait of Juan de Fuca (generally east of Port Angeles)) (Table 15), we recommend further assessing the need to establish marine protected or rockfish conservation areas to protect listed rockfish. If needed, rockfish conservation areas would potentially be created after a period of 5 years following release of this final recovery plan. These areas also have the most rockfish habitat. In other areas where additional information is needed, we recommend further assessment to determine whether spatial protection or other improved fisheries management protections are warranted.

Table 15. Detailed assessment for priorities for MPA/RCA establishment by Management Area.

Mgmt. Unit	**Fisheries w/ Rockfish Bycatch Risk[1]**	**Rec. Trips (Bottom fish) Rockfish Bycatch Risk[2]**	**Rec. Trips (Halibut) Rockfish Bycatch Risk[2]**	**Rec. Trips (Salmon) Rockfish Bycatch Risk[2]**	**Rec. Trips (Other) Rockfish Bycatch Risk[2]**	**Significant Regulations Affecting Rockfish Bycatch w/ Known High Compliance[3]**	**Spatial Isolation Risk (Genetics + Geography)[4]**	**Rockfish Habitat[5] (sq. mi.)**	**Priority Ranking**
Canada	-	-	-	-	-	-	-	-	N/A-RCA network exists
San Juan Is / Strait of Juan de Fuca	Halibut longline – *High* risk; Salmon fisheries – Low risk Shrimp fisheries – Low risk	78,202 Moderate risk	58,688 *High* risk	436,977 Moderate risk	15,489 Un-known risk	WDFW closure of most commercial fisheries with rockfish bycatch; no recreational rockfish targeting or retention	Moderate genetic Moderate spatial	533	High
Main Basin (includes Whidbey Basin)	Salmon fisheries – Low risk Halibut longline – *More information needed for assessment* Shrimp fisheries – Low risk	109,228 Moderate risk	12,896 Low risk	1,457,346 Moderate risk	52,373 Un-known risk	WDFW closure of most commercial fisheries with rockfish bycatch; no recreational rockfish targeting or retention	Moderate genetic Moderate spatial	361	Medium
South Sound	NA	30,102 Low risk	0 N/A	122,933 Low risk	16,237 Un-known risk	WDFW closure of most commercial fisheries with rockfish bycatch; no recreational rockfish targeting or retention	*High* genetic *High* spatial	102.4	Low
Hood Canal	Shrimp fisheries – Low risk	3,028 Low risk	132 Very Low risk	56,042 Low risk	11,097 Un-known risk	Long-term WDFW recreational bottom fish closure; no recreational rockfish targeting or retention	*High* genetic *High* spatial	66.8	Low

[1] Risk is rated by considering both risk of bycatch by fishery/fishing type and number of trips/effort for both commercial and recreational fisheries.
[2] Includes 2010-2014 WDFW creel survey trip estimates. Risk is rated by considering both risk of bycatch by fishery and number of trips.
[3] In 2010, WDFW also put into place a no retention regulation and 120-ft. depth restriction while bottom fishing to decrease rockfish bycatch in recreational fisheries (this regulation is difficult to enforce, compliance is unknown, and it does not apply to fishers targeting halibut) and closed several commercial fisheries (see list in Recovery Plan, Section F, and full list of fisheries and bycatch risk in Section E, Table 6).
[4] This column considers listed rockfish decline as a result of spatial and genetic isolation, which can exacerbate fisheries effects. Hood Canal and South Sound waters also both have long residency times and Hood Canal is subject to episodes of low dissolved oxygen.
[5] Includes nearshore and deepwater critical habitat prior to exclusions, 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).
Note: recreational shrimp fisheries are not listed in the table. Though we assess this fishery to be low risk, further information about the risk of this fishery as well as the effects of the commercial fishery will be integrated into this assessment as it becomes available.

Habitat Relationships—The relationship between larval and post-settlement rockfish in the DPSs and their habitats is poorly understood and needs further research. Adult listed rockfish habitat usage in most of Puget Sound proper also needs further research and has been recently addressed through ROV surveys in collaboration with WDFW. Marine habitats have been degraded by chemical contamination, derelict fishing gear, dredge disposal, fill, nearshore degradation, poor water quality, and possibly mobile fishing gear such as bottom trawls (Drake et al. 2010; WDFW 2011). The protection and restoration of marine habitats—including structure such as nearshore kelp beds and rocky/complex benthic habitat—is warranted because these areas/features are necessary for listed rockfish recruitment and reproduction (Love et al. 1991; Palsson et al. 2009; Young et al. 2010; Springer et al. 2010).

***Public Involvement*—**Education, outreach, and public involvement are essential because support and participation from stakeholders are fundamental to successful conservation (Stankey and Shindler 2006). This support is particularly essential for management that relies largely upon self-regulation and self-reporting by user groups, such as occurs in recreational fisheries (Sawchuk 2012; Sawchuk et al. 2015). In addition, continuing the inclusion of anglers, fishing guides, divers, the PSRFEF Oversight Committee, and others in cooperative research will enable collection of additional information about listed rockfish and their habitats while helping foster trust and inclusion into recovery plan implementation.

B. PRIMARY FOCUS AND OBJECTIVES OF RECOVERY EFFORTS

The primary focus and objectives of the recovery effort collectively serve to address the gaps in our knowledge about listed rockfish and reduce threats so the recovery goals outlined in this plan have the greatest likelihood of being achieved. Additional details on aspects of the recovery effort by primary focus area can be found in the appendices, which are intended to facilitate implementation of actions. The recovery effort for yelloweye rockfish and bocaccio will require a focus on several actions, some of which will be conducted concurrently and some of which will necessarily follow others.

Based on the key facts and assumptions and information regarding biology and threats, the recovery strategy focuses on research to enable a greater understanding of listed rockfish population abundance, distribution, diversity, genetics, demographics, and habitat associations. Better understanding of population characteristics and habitat associations, as well as the extent of some threats, is important to enable management for long-term survival and recovery of such long-lived species.

The recovery strategy calls for fishery management that improves accounting of bycatch and mortality rates consistent with rebuilding each species, expanded use of descending devices to reduce barotrauma, the establishment of Marine Reserves/Rockfish Conservation Areas where potential bycatch remains high, and focused enforcement of fisheries, particularly newly enacted regulations to protect listed rockfish.

The recovery strategy also calls for the protection and restoration of listed rockfish habitat, including key habitats in the nearshore (< 98.4 ft [< 30 m]), and deep water (> 98.4 ft [> 30 m]) from threats such as derelict fishing gear, construction, hypoxia, and contaminants. Restoration actions include the removal of derelict fishing gear, rehabilitation of altered shorelines to improve rearing habitats, the production of rockfish prey species, and clean-up of contaminated sediments. Research on the effects of contaminants, ocean acidification, and other anthropogenic disturbances are important to understand changes to productivity and long-term survival of each species. Systematic surveys of listed rockfish populations will enable observations of population changes over time, adjustment of management actions where warranted, and gauge attainment of the recovery criteria. Finally, this plan includes actions for enhancing public outreach and education, which is vital to garner long-term support for listed rockfish recovery.

C. ADAPTIVE MANAGEMENT

This plan calls for continued improvement of knowledge, checking assumptions, monitoring progress, and adjusting actions prior to and throughout implementation (Figure 14). The process of adaptive management—making decisions, implementing them, learning from the results of implementation, and adjusting decisions as necessary—is recognized as an important management tool (especially in data-poor scenarios) to reduce uncertainty over time. It will also safeguard against inaction and/or misdirection of funding and facilitate integration of the best available science into policy.

Research is identified as a focus of the recovery strategy and, as new information is collected, it will inform implementation of the fishery, habitat, outreach, and funding strategies. We prioritize using adaptive management to: 1) assess rockfish population abundance, distribution, diversity, genetics, demographics, and habitat associations; 2) better understand the relative risk of threats to rockfish and abate their impact on recovery where possible; 3) take appropriate fisheries management, habitat research, and protection actions; and 4) conduct a gap analysis to identify additional needed research, monitoring, policies, or funding.

Figure 14. The Adaptive Management Process.

IV. RECOVERY GOAL, OBJECTIVES, AND CRITERIA

A. RECOVERY GOAL

The goal of this recovery plan is to improve yelloweye rockfish and bocaccio abundance, productivity, and spatial structure in the Puget Sound/Georgia Basin to viable and self-sustaining levels such that yelloweye rockfish can be removed from the Endangered Species List and bocaccio can be downlisted to threatened status and subsequently removed from the Endangered Species List.

B. RECOVERY OBJECTIVES

The first objective of the recovery plan is to continue to improve our knowledge of the current and historical status of yelloweye rockfish and bocaccio and their habitats. This will be necessary so that populations can be characterized on a management unit basis and a detailed plan can be adaptively managed to carry out recovery actions in a way that will most efficiently achieve the delisting criteria.

The second objective of the recovery plan is to reduce or eliminate existing threats to listed rockfish from fisheries and other anthropogenic threats.

The third objective of the recovery plan is to reduce or eliminate existing threats to listed rockfish habitats and restore important rockfish habitat.

C. RECOVERY CRITERIA

In order to determine when recovery objectives have been achieved, we must provide, to the maximum extent practicable, objective, measurable criteria which, when met, would result in a determination that yelloweye rockfish and bocaccio of the Puget Sound/Georgia Basin should be removed from the Endangered Species List. Recovery criteria need to be established for each recovery objective and must provide evidence that the greatest threats have been eliminated or controlled and are unlikely to return if protections provided under the ESA are removed.

There is some uncertainty in our knowledge regarding anthropogenic and natural factors that could potentially be limiting yelloweye rockfish and bocaccio. It may be possible to recover listed rockfish without addressing additional potential threats with uncertain impacts. If the greatest known threats are addressed and a positive response in population demographics is not observed, then additional threat-based objectives and criteria may need to be developed.

The criteria are organized into two categories: Biological and Demographic Recovery Criteria, which encompass principles of abundance, distribution, productivity, and genetic diversity, and Threat-based Recovery Criteria, which address the greatest known threats impeding recovery. The best available information must be used in order to ascertain whether the species has met the recovery criteria and qualifies for delisting or downlisting.

Recovery Criteria—Background

A decision to list or delist a species focuses on its biological performance and the threats to its continued existence. Our approach to developing objective, measurable criteria focuses on two areas: performance of the population over a defined period of time (biological criteria) and the reduction of threats that may have caused the population decline or that limit recovery (threats criteria). In order to propose downlisting/delisting a species, we conduct a review of both the biological criteria and threats criteria. In practicality, conducting this dual assessment would occur when yelloweye rockfish or bocaccio of the Puget Sound/Georgia Basin are found to be approaching the biological criteria as a result of systematic surveys and other applicable information about the population characteristics.

The following sections provide the basis for the criteria and set out objective, measurable criteria for delisting and downlisting. Under the ESA, we must, to the maximum extent practicable, incorporate the recovery plan criteria, which when met would result in a determination that the species be removed from the list. There is one set of biological and threats-based criteria to downlist bocaccio and one set of each criteria to delist bocaccio and yelloweye rockfish. Each species will be evaluated separately.

<u>Introduction—Assessing Progress in Meeting Biologically Based Delisting Criteria</u>

We identify listed rockfish population characteristics in terms of population status that would contribute to long-term viability, support delisting/downlisting decisions, and account for uncertainties. To inform these population characteristics, we assessed the best available information regarding *Sebastes* population recovery off the Pacific Coast managed under rebuilding plans (Pacific Fishery Management Council 2014). Yelloweye rockfish and bocaccio populations outside of the DPSs' area have each begun to rebuild from levels below 25 percent of initial unfished biomass (Pacific Fishery Management Council 2014; NMFS 2017). The rebuilding of these rockfish populations has demonstrated that biomass levels ranging from 10 percent to 20 percent of initial, unfished biomass can impart sufficient resiliency to maintain and grow population levels (Pacific Fishery Management Council 2014). While biomass is not measurable for yelloweye rockfish and bocaccio within the DPSs' area, we instead look at the potential spawning capacity. Delisting targets for yelloweye rockfish range from 15 percent to 25 percent of Spawning Potential Ratio (SPR). The downlisting target for bocaccio is 10 percent of SPR, and 15 percent to 25 percent SPR for delisting.

Data Sources: To measure whether the biological-based criteria for listed rockfish are being met, we will need to sample listed rockfish with systematic surveys conducted at least every 5 years at to-be-determined sites in each of the management units in the U.S. portion of the DPSs' ranges. We will work with the government of Canada to develop/review complementary surveys in the Canadian portion of the DPS. In waters of the U.S. portion of the DPSs, this information will likely primarily come from fishery-independent information through ROV surveys, but additional observations through other research types or fisheries bycatch reports could provide very useful information.

The biological-based population characteristics are discussed separately below, but nonetheless overlap in terms of gauging population viability.

Productivity (as a proxy for biomass recovery): The productivity of listed rockfish can be measured in several different ways, and additional metrics may be developed or refined in the future as data streams change. A commonly used biological reference point applicable to rockfish is spawning potential ratio (SPR), calculated as:

$$SPR = \frac{Total\ Egg\ Production_{Fished}}{Total\ Egg\ Production_{Unfished}}$$ [5]

Changes in SPR through time provide insight into population viability and recovery trajectory. The calculation of SPR typically requires estimates of the current fishing mortality (F), natural mortality (M), age and growth parameters, and maturity (and selectivity is typically estimated) at age. While these parameters are often inputs or estimates from data-rich stock assessments, more data-limited SPR estimators have been developed to account for uncertainties of the sampled population. Hordyk et al. (2015a, 2015b) have developed a method (length-based SPR or LB-SPR) for identifying SPR using length data and ratios of life history and fishing related parameters (M/k and L_m/L_∞) without knowledge of the individual parameters where M is natural mortality, k is growth rate, L_m is length at maturity, and L_∞ is maximum length. Length data may be taken from any number of sampling approaches, including ROV surveys and fishing. This approach calculates the current population's spawning potential compared to a theoretically unfished population's spawning potential. SPR is the ratio of both values over defined time periods and is the biological criterion for delisting yelloweye rockfish and downlisting/delisting bocaccio in the Puget Sound/Georgia Basin DPSs.

Measuring Historical SPR: The calculation of historical SPR is not necessary for the purposes of delisting or downlisting species, but still provides useful information on past population status or trends and habitats occupied (where available). As mentioned above, there is limited historical/unfished population data for yelloweye rockfish and bocaccio from within the DPSs' area. Known historical size structure data for listed rockfish is summarized in Drake et al. (2010) and Washington et al. (1978). Data summarized in Drake et al. (2010) show the length of each species of fish caught in recreational fisheries over several time periods beginning in the 1970s. Washington et al. (1978) reported length data from research using recreational fishing methods from 1974 to 1977. LB-SPR can be applied to all available years of data to compare historical SPR to current SPR.

Spatial Structure: Relative presence (and population characteristics) of listed rockfish within each of the management units is a metric to gauge population viability. The first step to gauge the potential change of spatial structure/distribution of listed rockfish is to determine the amount of rockfish habitat and, in turn, how much of it is occupied. Rockfish habitat has been estimated in Canada (Yamanaka and Logan 2010) and within the rest of the management units in the U.S. via critical habitat designation (79 Fed. Reg. 68041, November 13, 2014). Also, see the details of habitat mapping projects noted in the Cooperative Research section above. Habitat valuation will be improved with additional surveys and the development of a habitat suitability model to provide a more sophisticated understanding of listed rockfish habitat. Spatial structure/distribution will be assessed through the systematic surveys to be developed across the U.S. portion of the DPSs, and will provide information on presence/absence, life stage, and productivity of listed rockfish across a range of habitats. This data will be used to calculate LB-SPR, in addition to similar data that may be gathered through fisheries or other research efforts.

[5] Equation taken from Hordyk et al. 2015a

Diversity (Demographic Structure): Population viability is enhanced with multiple size and age classes of fish because this allows the species to use a wider array of environments, which protects a species against short-term spatial and temporal changes in the environment. Length-based measurements assist in gauging changes in a population's diversity over time for delisting/downlisting. The proportion of listed rockfish in each management unit and as an aggregate DPS identified as young-of-year, juveniles, and adults are captured through length-based estimate data to be used in SPR calculations.

Summary of Approach: For yelloweye rockfish we have separate target levels for each population (Hood Canal and the rest of the DPS). Each population must reach specified target levels for delisting consideration of the DPS. We utilize more conservative population target levels for yelloweye rockfish in Hood Canal because they occupy a spatially isolated environment and have less habitat area available than the rest of the DPS population. For yelloweye rockfish and bocaccio we provide generalized scenarios to gauge population status as part of determining delisting/downlisting criteria for each species (see Tables 16 through 19 below). We identify different levels of SPR and time that if they are reached, would provide sufficient population viability for each species (in association with an assessment of the threats-based criteria) for delisting/downlisting.

The minimum time at SPR target level, number of sampling events, and 80 percent probability level (or confidence interval) collectively provide a precautious metric to ensure that biologically based criteria are measured and interpreted in a systematic and conservative manner, and thus reduce the likelihood of over-estimating the SPR of yelloweye rockfish and bocaccio of the Puget Sound/Georgia Basin.

Introduction—Assessing Progress in Meeting Threats-based Delisting Criteria

The threats criteria are designed to address the five statutory listing factors (see Section E. Factors Contributing to Decline and Federal Listing) described in the ESA listing determination for each species. These same factors must be considered in delisting, with objectives related to each factor included as part of the recovery criteria. Because listed rockfish live in deep waters and are difficult to sample, we may rely on surrogate rockfish species from within the Puget Sound/Georgia Basin in certain sections. The downlisting criteria for bocaccio generally require completed research and/or that programs are in place to understand, limit, and mitigate threats. The delisting criteria for both yelloweye rockfish and bocaccio require that the threats are found to not limit recovery of the listed species.

Yelloweye Rockfish

Table 16. Yelloweye rockfish biological-based delisting criteria (*non-Hood Canal population*).

	Overall Minimum Productivity (SPR)	**Minimum Time at Target**
Scenario A	15% (and increasing after first sampling event finds 15%)	25 years, (no less than five systematic sampling events with 80% probability)
Scenario B	20 to 24%	15 years (no less than four systematic sampling events with 80% probability)
Scenario C	25% (and above)	10 years (no less than three systematic sampling events with 80% probability)

Table 17. Yelloweye rockfish biological-based delisting criteria (*Hood Canal population*).

	Overall Minimum Productivity (SPR)	Minimum Time at Target
Scenario A	20 to 24%	15 years (no less than four systematic sampling events with 80% probability)
Scenario B	25% (and above)	10 years (no less than three systematic sampling events with 80% probability)

Yelloweye Rockfish Threats-based Delisting Criteria (applicable to both populations)

Listing Factor 1: Destruction, Modification, or Curtailment of Habitat or Range

A. *Derelict Fishing Gear (i.e., shrimp pots, fishing nets)*. Programs are in place to facilitate and require reporting, preventing, and promptly removing derelict fishing gear that has been demonstrated to result in bycatch or result in harm to yelloweye rockfish and yelloweye rockfish habitat.
B. *Contaminants/Bioaccumulants.* Contaminant levels in yelloweye rockfish, prey species, or surrogate rockfish populations (i.e., quillback rockfish, *Sebastes maliger*) in the Puget Sound/Georgia Basin indicate a reduction or slowing of accumulation of legacy contaminants, such as PCBs and DDTs. This could include data showing that overall contaminant levels in the population are decreasing or accumulation is slowing, or information that younger fish have a proportionally reduced contaminant load. A decrease in the number of contaminated sites would also indicate a reduction in contaminants in a portion of the habitat of yelloweye rockfish.
C. *Nutrients*. Management actions and programs are in place to prevent and reduce nutrient inputs. The effects of nutrient inputs (food chain, hypoxia) are not found to be limiting recovery.
D. *Invasive species/Non-native Species*. Invasive species that can affect habitat (e.g., tunicates, seaweeds, others) are found to be not limiting recovery. Programs are in place to remove or mitigate the effects of invasive species on yelloweye rockfish and yelloweye rockfish habitat.

Listing Factor 2: Over-utilization for Commercial, Recreational, Scientific, or Educational Purposes.

A. *Bycatch/Catch*. Yelloweye rockfish are protected from bycatch/catch by fishery regulations and research permitting sufficient to support maintenance and enhancement of abundance, LB-SPR/biomass, spatial structure, and diversity (bycatch/catch can be reliably estimated from empirical data sources). Bycatch is mitigated when it occurs (i.e., use of descending devices and safe handling techniques).

Listing Factor 3: Disease/Predation

A. *Disease*. Sufficient knowledge exists to determine that disease and parasite effects on productivity and survival are not currently limiting yelloweye rockfish recovery.
B. *Predation*. Monitor for possible predation on yelloweye rockfish that impedes population maintenance and growth. Conclusions are drawn that predation is not limiting recovery of yelloweye rockfish populations.

Listing Factor 4: Inadequate Regulatory Mechanisms

A. *Habitat*. Programs are in place to protect, and restore where necessary, rearing and adult habitats.
B. *Fisheries*. Enforcement adequately controls bycatch and poaching.
C. *Contaminants/Bioaccumulants*. Regulations are in place to limit the introduction of harmful contaminants and remove large, known areas of contaminated sediments. There is evidence of decreasing levels of contaminants detected in yelloweye rockfish, prey species, or surrogate rockfish populations (i.e., quillback rockfish, *Sebastes maliger*) in the Puget Sound/Georgia Basin, or evidence that the current level of contaminants is not limiting recovery.

Listing Factor 5: Other Factors Affecting the Species' Continued Existence

A. *Hatchery Releases*. Research has been carried out to determine if/how hatchery-released fish (i.e., salmon) affect yelloweye rockfish recovery. Any releases that are determined to be harmful to recovery potential are subsequently controlled or mitigated.
B. *Climate Change and Ocean Acidification*. Research has been undertaken to better understand and adapt to deleterious effects of climate change and ocean acidification. Action has been taken to limit deleterious effects on yelloweye rockfish, or the deleterious effects of climate change and ocean acidification have been slowed or reversed or determined unlikely to limit their recovery.
C. *Oil Spills*. Effective oil spill prevention and response plans are in place for the Puget Sound/Georgia Basin (i.e., the Northwest Area Contingency Plan).
D. *Genetic Changes.* Research has been conducted to understand the extent of inbreeding and hybridization on the listed species, and neither have been found to be limiting yelloweye rockfish recovery.

Long-term Monitoring Criteria

A long-term monitoring plan and criteria will be developed as part of any proposal to delist the species. We recommend that potential criteria take into consideration the long generation times of the listed species.

Bocaccio

Table 18. Bocaccio biological-based downlisting criteria.

Overall Minimum Productivity (SPR)	Minimum Time at Target
10% and increasing	15 years (no less than four systematic sampling events with 80% probability)

Bocaccio Threats-based Downlisting Criteria

Listing Factor 1: Destruction, Modification, or Curtailment of Habitat or Range

A. *Nearshore habitats*. Nearshore nursery habitats are protected from adverse development and are determined to be of sufficient size and quality to provide adequate food, shelter, and other essential requirements for juvenile bocaccio.
B. *Derelict Fishing Gear (i.e., shrimp pots, fishing nets)*. Programs are in place to facilitate and require reporting, preventing, and promptly removing derelict fishing gear that has been demonstrated to result in bycatch or result in harm to bocaccio and bocaccio habitat.
C. *Contaminants/Bioaccumulants.* Contaminant levels in bocaccio, prey species, or surrogate rockfish populations (i.e., quillback rockfish, *Sebastes maliger*) in the Puget Sound/Georgia Basin that indicate a reduction or slowing of accumulation of legacy contaminants, such as PCBs and DDTs. This could include data showing that overall contaminant levels in the population are decreasing or accumulation is slowing, or information that younger fish have a proportionally reduced contaminant load. A decrease in the number of contaminated sites would also indicate a reduction in contaminants in a portion of the habitat of bocaccio.
D. *Nutrients*. Management actions and programs are in place to prevent and reduce nutrient inputs.
E. *Invasive species/Non-native Species*. Research has been conducted to assess the effects of invasive species on bocaccio and bocaccio habitat (e.g., tunicates, seaweeds, others).

Listing Factor 2: Over-utilization for Commercial, Recreational, Scientific, or Educational Purposes.

A. *Bycatch/Catch*. Bocaccio are protected from bycatch/catch by fishery regulations and research permitting sufficient to support maintenance and enhancement of abundance, LB-SPR/biomass, spatial structure, and diversity (bycatch/catch can be reliably estimated from empirical data sources). Bycatch is mitigated when it occurs (i.e., use of descending devices and safe handling techniques).

Listing Factor 3: Disease/Predation

A. *Disease*. Research has been conducted to assess the effects of disease and parasites on the productivity and survival of bocaccio.

B. *Predation*. Monitor for possible predation on bocaccio that impedes population maintenance and growth.

Listing Factor 4: Inadequate Regulatory Mechanisms

A. *Habitat*. Programs are in place to protect, and restore where necessary, rearing and adult habitats.
B. *Fisheries*. Enforcement adequately controls bycatch and poaching.
C. *Contaminants/Bioaccumulants*. Regulations are in place to limit the introduction of harmful contaminants and remove large, known areas of contaminated sediments.

Listing Factor 5: Other Factors Affecting the Species' Continued Existence

A. *Hatchery Releases*. Research has been carried out to determine if/how hatchery-released fish (i.e., salmon) affect bocaccio recovery.
B. *Climate Change and Ocean Acidification*. Research has been undertaken to better understand and adapt to deleterious effects of climate change and ocean acidification.
C. *Oil Spills*. Effective oil spill prevention and response plans are in place for the Puget Sound/Georgia Basin (i.e., the Northwest Area Contingency Plan).
D. *Genetic Changes.* Research has been conducted to understand the extent of inbreeding and hybridization on bocaccio.

Table 19. Bocaccio biological-based delisting criteria.

	Overall Minimum Productivity (SPR)	**Minimum Time at Target**
Scenario A	15% (and increasing after first sampling event finds 15%)	15 years, (no less than four systematic sampling events with 80% probability)
Scenario B	20% and above	10 years (no less than three systematic sampling events with 80% probability)
Scenario C	25% and above	5 years (no less than two systematic sampling events with 80% probability)

Bocaccio Threats-based Delisting Criteria

Listing Factor 1: Destruction, Modification, or Curtailment of Habitat or Range

A. *Nearshore habitats*. Nearshore nursery habitats are protected from adverse development and are determined to be of sufficient size and quality to provide adequate food, shelter, and other essential requirements for juvenile bocaccio, such that population abundance can increase.
B. *Derelict Fishing Gear (i.e., shrimp pots, fishing nets)*. Programs are in place to facilitate and require reporting, preventing, and promptly removing derelict fishing gear that has been demonstrated to result in bycatch or result in harm to bocaccio and bocaccio habitat.

C. *Contaminants.* Contaminant levels in bocaccio, prey species, or surrogate rockfish populations (i.e., quillback rockfish, *Sebastes maliger*) in the Puget Sound/Georgia Basin that indicate a reduction or slowing of accumulation of legacy contaminants, such as PCBs and DDTs. This could include data showing that overall contaminant levels in the population are decreasing or accumulation is slowing, or information that younger fish have a proportionally reduced contaminant load. A decrease in the number of contaminated sites would also indicate a reduction in contaminants in a portion of the habitat of bocaccio.

D. *Nutrients*. Management actions and programs are in place to prevent and reduce nutrient inputs. The effects of nutrient inputs (food chain, hypoxia) are not found to be limiting recovery.

E. *Invasive species/Non-native Species*. Research has been conducted to assess the effects of invasive species on bocaccio and bocaccio habitat (e.g., tunicates, seaweeds, others). Effects are found to not limit recovery, or programs are in place to remove or mitigate the effects of invasive species on bocaccio and bocaccio habitat.

<u>Listing Factor 2: Over-utilization for Commercial, Recreational, Scientific, or Educational Purposes.</u>

A. *Bycatch/Catch*. Bocaccio are protected from bycatch/catch by fishery regulations and research permitting sufficient to support maintenance and enhancement of abundance, LB-SPR/biomass, spatial structure, and diversity (bycatch/catch can be reliably estimated from empirical data sources). Bycatch is mitigated when it occurs (i.e., use of descending devices and safe handling techniques).

<u>Listing Factor 3: Disease/Predation</u>

A. *Disease*. Research has been conducted to assess the effects of disease and parasites on the productivity and survival of bocaccio. The effects have been determined to not limit recovery of bocaccio.

B. *Predation*. Monitor for possible predation on bocaccio that impedes population maintenance and growth. Conclusions are drawn that predation is not unduly limiting recovery of bocaccio.

<u>Listing Factor 4: Inadequate Regulatory Mechanisms</u>

A. *Habitat*. Programs are in place to protect, and restore where necessary, rearing and adult habitats.

B. *Fisheries*. Enforcement adequately controls bycatch and poaching.

C. *Contaminants/Bioaccumulants*. Regulations are in place to limit the introduction of harmful contaminants and remove large, known areas of contaminated sediments. There is evidence of decreasing levels of contaminants detected in bocaccio, prey species, or surrogate rockfish populations (i.e., quillback rockfish, *Sebastes maliger*) in the Puget Sound/Georgia Basin, or evidence that the current level of contaminants is not limiting recovery.

Listing Factor 5: Other Factors Affecting the Species' Continued Existence

A. *Hatchery Releases*. Research has been carried out to determine if/how hatchery-released fish (i.e., salmon) affect bocaccio recovery. Any releases that are determined to be harmful to recovery potential are subsequently controlled or mitigated.
B. *Climate Change and Ocean Acidification*. Research has been undertaken to better understand and adapt to deleterious effects of climate change and ocean acidification. Action has been taken to limit deleterious effects on bocaccio, or the deleterious effects of climate change and ocean acidification have been slowed or reversed or determined unlikely to limit their recovery.
C. *Oil Spills*. Effective oil spill prevention and response plans are in place for the Puget Sound/Georgia Basin (i.e., the Northwest Area Contingency Plan).
D. *Genetic Changes.* Research has been conducted to understand the extent of inbreeding and hybridization on the listed species, and neither have been found to be limiting recovery.

Long-term Monitoring Criteria

A long-term monitoring plan and criteria will be developed as part of any proposal to delist the species. We recommend that potential criteria take into consideration the long generation times of the listed species.

V. RECOVERY PROGRAM

We developed a list of specific recovery actions to implement the Recovery Strategy and ensure that yelloweye rockfish and bocaccio reach a spatially and demographically viable state. The recovery actions are intended to increase abundance, support healthy demographic structure and diversity, protect and restore habitat, and sufficiently alleviate the past, current, and potential future threats. Because of the general lack of information regarding listed rockfish abundance and distribution, and regarding some of the threats these species face, the following recovery program provides research and recovery actions to fill key data gaps and address the most significant threats during the first 5 years (Phase I).

Phase I will include:

1. Research to enable a greater understanding of listed rockfish population abundance, distribution, diversity, genetics, demographics, ecology, and habitat associations (some actions are already underway or have been completed).
2. Fisheries research, monitoring, and management consistent with recovery goals.
3. Protection, restoration, and research of rockfish habitats and the Puget Sound/Georgia Basin ecosystem on which they rely.
4. Implementation of an education, outreach, and public involvement plan (Appendix I).
5. Securing public support and funding for listed rockfish recovery.

Phase II (years 5 through 15) will include:

A continuation of Phase I actions 1 through 5 and address lower priority habitat threats.

This recovery plan details an outline and narrative that describes the recovery actions that, once implemented, should achieve the goal of recovering yelloweye rockfish and bocaccio. Specifically, these actions will provide demographic data needed to assess the populations and address the greatest threats to promote recovery. These threats were ranked as high, medium, low, or unknown for overall risk in the threats assessment. If these recovery actions are fully implemented and recovery of listed rockfish recovery is not achieved, then it is likely that additional threats that are currently ranked lower may need to be re-assessed and addressed in the future (Phase II). In order to better understand and develop specific recovery actions for the remaining threats, it is imperative to develop and implement a comprehensive long-term research plan. Most actions apply to both yelloweye and bocaccio and we identify where actions apply to whole DPSs or particular Management Units. Some actions could be conducted in one Management Unit (such as telemetry studies), but nonetheless inform management throughout the DPSs.

An Implementation Schedule follows the recovery action outline and narrative. It provides a summary of the actions, prioritizes them, identifies lead entities and potential partners to carry out the actions, and provides an estimate of rockfish recovery program costs over a 5-year period (Phase I). For the high priority actions, we have developed more detailed appendices to help guide recovery implementation, research, and adaptive management. The recovery actions are identified in the outline and narrative, and detailed information about the threats and opportunities, tools, and research needed are detailed in the appendices.

A. RECOVERY ACTION OUTLINE

Step-down Outline.

This outline serves to summarize research and recovery actions needed to meet the goals and objectives of the recovery plan.

Recovery Action 1. Research to enable a greater understanding of listed rockfish population abundance, distribution, diversity, genetics, demographics, ecology, and habitat associations.

- 1.1 Fishery-independent surveys of abundance, distribution, and size-structure in the nearshore and deepwater environments, with identification of index survey sites and long-term survey methodology in each Management Unit in U.S. waters.
    - 1.1.1 Surveys every 5 years in each Management Unit to observe changes in population abundance, distribution, diversity, demographics, and habitat associations, which will inform adaptive management and support delisting/downlisting considerations.
- 1.2 Improved benthic habitat mapping and rockfish habitat characterization, prioritizing management units of Hood Canal, South Sound, and Main Basin.
    - 1.2.1 Benthic habitat mapping and rockfish habitat characterization will be used to develop a probabilistic habitat model to assess spatial structure and support recovery actions, and potentially evaluate progress toward achieving delisting or downlisting for the DPSs.
    - 1.2.2 Supplementary multibeam data collection will be needed to understand habitat characteristics and listed rockfish habitat associations throughout the DPSs. Though this has been done in some areas, further data collection is required.
- 1.3 Assessment of historical fishing and scientific records and historical “grey literature” for the DPSs.
    - 1.3.1 Develop statistical methods to integrate these multiple sources of historical data on rockfish size structure and abundance to establish an understanding of baseline abundance and size structure.
- 1.4 Periodically assess genetic structure in DPSs to inform effective dispersal distances, population size, and variance in reproductive success.
    - 1.4.1 Develop a model to determine genetic thresholds of inbreeding and hybridization within the DPSs.
- 1.5 Annual juvenile (YOY) rockfish surveys in each of the Management Units.
- 1.6 Larval surveys in each Management Unit.
    - 1.6.1 Surveys will be used to assist the development of a connectivity model.
- 1.7 Assess home range and movement of various life stages of listed rockfish via tagging or other methods.
- 1.8 Develop population models to evaluate critical life stages dictating rockfish population growth.
- 1.9 Develop and assess statistical methods for integrating multiple sources of data on rockfish size structure and abundance (i.e., ROV surveys, drop camera surveys, fisheries information, etc.) into informative indices of current trends in rockfish size and abundance.
- 1.10 Conduct and/or assess comparative studies of rockfish abundance and demographic structure inside and outside established marine reserves/MPAs.

Recovery Action 2. Fisheries management consistent with recovery goals.

- 2.1 Account for all catch and bycatch within the DPSs with statistically valid techniques.
  - 2.1.1 Further assess fisheries in the DPSs by integrating ongoing ROV survey data and additional bycatch risk data.
- 2.2 Ensure that anthropogenic mortality falls within accepted risk-averse precautionary guidelines at appropriate scales (note that this includes the use of devices to mitigate barotrauma and research of long-term survival).
- 2.3 Establish marine reserves and/or rockfish conservation areas (areas not subject to potential anthropogenic mortality) in prioritized areas in the U.S. portion of the DPSs.
  - 2.3.1 Monitoring and adaptive management of established areas to assess and improve their efficacy.
- 2.4 Conduct further research on bycatch to develop and implement measures to avoid and mitigate barotrauma and other sources of bycatch mortality.
- 2.5 Assess long-term survival and productivity of recompressed yelloweye rockfish and bocaccio in the wild and take appropriate management actions to improve recompression practices, if appropriate.
- 2.6 Additional enforcement of fishery regulations with emphasis on reducing listed rockfish mortality.

Recovery Action 3. Protection, restoration, and research of rockfish habitats and the Puget Sound/Georgia Basin ecosystem on which they rely.

- 3.1 Nearshore (< 98.4 feet [30 m]) protection, research, and restoration.
  - 3.1.1 Continue programs to prevent, report, and remove derelict fishing gear from nearshore environments.
  - 3.1.2 Assess potential of native kelp restoration projects and pursue restoration projects as applicable.
  - 3.1.3 Assess non-indigenous species (e.g., *Sargassum muticum*, Japanese wireweed, and tunicates, *Ciona savignyi*, *S. clava*, and *D. vexillum*) to determine if they are degrading or impairing rearing habitats such that they are limiting recovery.
- 3.2 Protection, research, and restoration of deepwater (> 98.4 feet [30 m]) benthic habitats.
  - 3.2.1 Continue programs to prevent, report, and remove derelict fishing gear from deepwater environments.
  - 3.2.2 Continue to assess sediment disposal practices to determine if they are limiting recovery.
  - 3.2.3 Assess and determine if the additional habitat created by artificial reefs is necessary/sufficient to support listed rockfish recovery.
- 3.3 Assess the impact of contaminants and bioaccumulants (including emerging contaminants such as microplastics) on listed rockfish survival, health, productivity, and behavior.
  - 3.3.1 Clean up or cap contaminated sediments and reduce contaminant inputs, emphasizing the South Puget Sound and Main Basin.
- 3.4 Prevent and reduce excessive nutrient input (e.g., from septic systems and other human sources) with emphasis in the South Puget Sound, Main Basin, and Hood Canal.

3.5 Develop ecological models to evaluate critical life stages dictating rockfish population growth, understand the potential impacts of climate change and ocean acidification on rockfish population dynamics, and assess the potential for predation and competition to limit listed rockfish recovery.
  - 3.5.1 Predict, assess, and manage for habitat changes as related to climate change and ocean acidification and synergistic effects in the DPSs.
  - 3.5.2 Determine conditions under which predation could limit recovery.
  - 3.5.3 Determine the potential for interspecific competition to limit recovery within the DPSs using field studies, experimentation, and modeling.

3.6 Assess disease to determine if it is limiting recovery of the DPSs.

3.7 Assess the effects of hatchery salmon releases (as warranted) to determine if they are limiting recovery of the listed rockfish species.

3.8 Evaluate effects of anthropogenic noise on listed rockfish behavior and productivity to determine if it is limiting recovery.

3.9 Continue oil spill prevention and response within the DPSs.

3.10 Continue state and Federal review of permitted activities to minimize impacts to rockfish habitats and their prey base.

3.11 Continue to enforce habitat protection laws and regulations; improve as warranted to protect rockfish habitat.

Recovery Action 4. Implement education, outreach, and public involvement plan.

4.1 Improve rockfish identification and documentation of bycatch by recreational and commercial fishers.

4.2 Encourage rockfish catch avoidance and educate anglers why it is a preferred conservation measure. Increase use of descending devices to mitigate barotraumas.

4.3 Improve knowledge of rockfish life history and habitat usage, the role rockfish play in the Puget Sound ecosystem, and current efforts to recover rockfish.

4.4 Improve understanding of rockfish fishing regulations.

4.5 Continue the *Cooperative Research Program* and create an Innovative Fishing Program and other outreach projects to further cooperative fishing research, and fishers', scuba divers', and the publics' engagement in rockfish recovery.

Recovery Action 5. Secure public support and funding for listed rockfish recovery.

5.1 Seek a variety of funding sources, including Federal, state, and private grants over a long time frame.

5.2 Establish collaborative research and cooperative funding agreements among state, Federal, tribal, university, and private entities.

B. RECOVERY NARRATIVE

This section provides additional context to the research and recovery outlines above. Note that the asterisk (*) corresponds to the highest priority level in the implementation schedule.

Recovery Action 1. Research to enable a greater understanding of listed rockfish population abundance, distribution, diversity, genetics, demographics, ecology, and habitat associations. Our understanding of current and historical rockfish abundance, distribution, genetics, demographics, and habitat associations in most Management Units is currently limited. Understanding of each of these elements is required to address critical information gaps and assess the status of the population, evaluate and refine delisting and downlisting criteria, assist in evaluating proposed Federal actions under ESA section 7 jeopardy analyses, and track progress towards attaining recovery goals. Many of these actions will be conducted in partnership with WDFW and other agencies and partners, as appropriate.

1.1. Fishery-independent surveys of abundance, distribution, and size structure in the nearshore and deepwater environments, with possible identification of index survey sites in each Management Unit in U.S. waters.* WDFW and NMFS will design an ROV survey program that focuses on listed rockfish and their habitat, in addition to obtaining information for other ecosystem component species. Observation and surveys of yelloweye rockfish and bocaccio adults are challenging because adults are found in deep waters (normally from 90 to 1,394 feet [30 to 425 m]) occurring in or around complex bathymetry. Analogous population monitoring should be continued in Canadian waters as well. These surveys are necessary to assess the status of the DPSs, evaluate and refine delisting and downlisting criteria and critical habitat, and conduct section 7 jeopardy analyses.

1.1.1 Surveys should be conducted every 5 years in each Management Unit to observe changes in population abundance, distribution, diversity, genetics, demographics, and habitat associations to inform adaptive management and assess the status of the DPSs.* ROV surveys may be used in combination with drop camera or other surveys.

1.2. Improved benthic habitat mapping and rockfish habitat characterization, prioritizing Management Units of Hood Canal, South Sound, and Main Basin.* Habitat mapping is required to assess the status of the DPSs, provide information needed to conduct efficient ROV surveys, and help develop a probabilistic habitat model.

1.2.1 Benthic habitat mapping and rockfish habitat characterization will be used to develop a probabilistic habitat model to assess spatial structure/distribution and support recovery actions, and potentially evaluate progress toward achieving delisting or downlisting for the DPSs.* The model will integrate habitat characteristics within the Puget Sound/Georgia Basin and historical and contemporary locations of yelloweye rockfish and bocaccio. It will provide a habitat suitability gradient (or similar metric).

1.2.2 Supplementary multibeam data collection will be needed to understand habitat and listed rockfish habitat associations throughout the DPSs.* Though this has been done in some areas, mainly near the San Juan Island archipelago, further data collection is required.

1.3 Assessment of historical fishing and scientific records and historical “grey literature” for the DPSs.* Historical abundance and distribution of listed rockfish is poorly understood, and assessing recovery will be improved by understanding past trends.

1.3.1 **Development of statistical methods for integrating multiple sources of historical data on rockfish size structure and abundance.*** This product will enable an understanding of baseline abundance and size structure.

1.4 **Assess genetic structure, determine effective dispersal distances, population size, and variance in reproductive success.*** Genetic analysis, particularly of bocaccio, will help define possible metapopulation structure in addition to assessing the boundaries of the DPSs' ranges and potential introgression with fish from outside of the DPS (as applicable). A non-lethal assessment of genetic structure may also be used to determine effective dispersal and population size.

1.4.1 **Develop a model to determine genetic thresholds of inbreeding and hybridization within the DPSs.** This will enable an assessment of the viability of the DPSs.

1.5 **Annual juvenile (YOY) rockfish surveys in each of the Management Units.*** These surveys will be necessary for understanding primary rearing locations, habitat threats, and restoration opportunities. Frequent surveys (e.g., at least every other year) will provide documentation of both episodically successful settlement events and the more common years in which little settlement occurs.

1.6 **Larval surveys in each Management Unit.** Surveys will help determine larval abundance, dispersal, connectivity, and seasonal and interannual abundance.

1.6.1 Surveys could be used to develop a connectivity model.

1.7 **Assess home range and movement of various life stages of listed rockfish via tagging or other methods.*** Home range and movement of listed rockfish, particularly bocaccio, is poorly understood within the DPSs. This assessment would aid in the development of the habitat model to assess the population as well as inform fisheries management.

1.8 **Develop population models to evaluate critical life stages dictating rockfish population growth.*** Better understanding of which life stages confer the most benefit to the population will help us better understand what life stages to prioritize in conservation efforts.

1.9 **Develop and assess statistical methods for integrating multiple sources of data on rockfish size structure and abundance into informative indices of current trends in rockfish size and abundance.*** Recent methods to assess rockfish size structure and abundance vary (e.g., ROV surveys, drop camera surveys, fisheries information, etc.). Combining these methods to provide estimates on rockfish size structure and abundance may inform delisting and downlisting criteria, as well as delisting and downlisting decisions.

1.10 **Conduct and/or assess comparative studies of rockfish abundance and demographic structure inside and outside established marine reserves/MPAs.*** Scientifically established, well-enforced marine reserves have been shown to protect structure of reproducing rockfish, increase abundance and diversity, and have beneficial effects that may spill over outside the reserve areas. Few studies in the Puget Sound/Georgia Basin are available to conduct before-after/control-experiment studies or to assess present efficacy and placement of current reserves.

Recovery Action 2. Fisheries management consistent with recovery goals. To limit listed rockfish bycatch, current fisheries management, enforcement, and data collection needs to be improved. Available data is insufficient for determining the relative threat of some commercial and recreational fisheries. Many of these actions will be conducted in cooperation with Puget Sound Treaty Tribes, WDFW, and other parties, as appropriate.

2.1 Account for all catch and bycatch within the DPSs with statistically valid techniques.* Estimates of listed rockfish bycatch in recreational and some commercial fisheries needs improvement. Within the recreational fishery, studies in the Salish Sea have found that anglers have under-reported their bycatch of rockfish (and other species) and also have difficulty identifying rockfish to species, highlighting the uncertainty in current self-reported bycatch estimates. There are also a number of private boat docks and marinas that are not subject to the creel surveys, bringing into further question the current bycatch estimates. There is also a lack of bycatch data for some fisheries. Quantifying all fisheries bycatch is necessary to understand listed rockfish mortality rates and thus impacts to population abundance, productivity, and spatial structure, and is in keeping with principles of fisheries management outlined in Appendix II, Fisheries Management.

2.1.1 Further assess fisheries in the DPSs by integrating ongoing ROV survey data and additional bycatch risk data. This action is detailed in Appendix II, Fisheries Management, and can be used to assess whether further management actions (including establishment of marine reserves or conservation areas outside the San Juan Islands/Strait of Juan de Fuca) are needed.

2.2 Ensure that anthropogenic mortality falls within accepted risk-averse precautionary guidelines at appropriate scales (note that this includes the use of devices to mitigate barotrauma and research of long-term survival).* This action first requires accurate catch and bycatch estimates. Accurate estimates will enable a determination of whether bycatch mortality of listed rockfish fall within acceptable levels. These guidelines are detailed in Appendix II, Fisheries Management.

2.3 Establish marine reserves and/or rockfish conservation areas not subject to potential anthropogenic mortality. Rockfish Conservation Areas have been established across 30 percent of rockfish habitat in the part of the range of the DPSs that extends into Canada. Establishing analogous areas within the prioritized area (San Juan Islands/eastern Strait of Juan de Fuca) (Table 20) in the U.S. portion of the range of the DPSs may help to restore metapopulation structure, abundance, and protect spawning biomass, support proportionally appropriate size and age structure, buffer for uncertainty regarding climate change impacts, habitat changes over time, benefit other fish, and other goals (see Appendix II, Fisheries Management). WDFW put regulations into place in 2010 to help limit rockfish bycatch; however, as identified in the threats assessment (Section E), the San Juan Islands and the Strait of Juan de Fuca may still be at relatively high risk for rockfish bycatch. Thus, while this plan includes continued enforcement and evaluation of fishery regulations, it also suggests beginning the public and scientific process to assess the need for establishing protected areas in the San Juan Islands/eastern Strait of Juan de Fuca, likely after the first 5 years of implementation, and considering additional protections after further assessment in other areas over the long term.

Appendix II provides the general biological goals, size and shape attributes, and ecological design considerations for establishing reserves/RCAs, but does not recommend specific sites. Appendix II, Fisheries Management, also discusses tribal guidance and socioeconomic considerations for the establishment of reserves/RCAs.

Table 20. Priority for Marine Reserves/Rockfish Conservation Areas.

Management Unit within U.S. portion of the Puget Sound/Georgia Basin	**RCAs/MPAs – relative priority**	
	Yelloweye rockfish	**Bocaccio***
San Juan Islands/Strait of Juan de Fuca	High Priority	Low Priority
Main Basin	Medium Priority	Low Priority
Hood Canal	Low Priority	Low Priority
South Sound	Low Priority	Low Priority

* Bocaccio move more as adults than yelloweye rockfish, which have very high site fidelity; therefore, the benefits of RCAs/MPAs to bocaccio may be less than the benefits to yelloweye rockfish.
Priorities were calculated by examining effort (commercial effort and type and recreational fishing trips and type), available rockfish habitat, existing protections to protect rockfish by each management unit, and risk to listed rockfish decline as a result of spatial and genetic isolation.

2.3.1 Monitoring and adaptive management of established areas to assess and improve their efficacy.* Monitoring will provide information needed for adaptive management of these areas and ensure they are effective. Also, sharing long-term monitoring results with the public is anticipated to be important for long-term support of these areas. Appendix II, Fisheries Management, also discusses monitoring and adaptive management of reserves/RCAs.

2.4 Conduct further research on bycatch to develop and implement measures to avoid incidental catch and mitigate barotrauma and other sources of bycatch mortality.* Bycatch avoidance is preferred because long-term effects of recompression on listed rockfish are not currently well understood. Education on catch avoidance, safe handling techniques, and the use of descending devices, expanding on existing work by WDFW (http://wdfw.wa.gov/fishing/bottomfish/rockfish/mortality.html), should also occur to mitigate the effects of barotrauma to the greatest extent achievable (also see 4.2). See Appendix III, Barotrauma Research and Adaptive Management.

2.5 Assess long-term survival and productivity of recompressed yelloweye rockfish and bocaccio in the wild and take appropriate management actions to improve recompression practices, if appropriate. The survival, sublethal effects, and productivity of recompressed listed rockfish are poorly understood, but there is evidence of internal hemorrhaging, infection, and difficulty returning to neutral buoyancy. As additional information is gathered about long-term effects, management and fisheries actions may be modified. See Appendix III, Barotrauma Research and Adaptive Management.

2.6 Additional enforcement of fishery regulations with emphasis on reducing listed rockfish mortality.* Continued and additional enforcement of regulations for recreational and commercial fisheries with risk of listed rockfish catch/bycatch (including derelict gear) is necessary. Research has found that some recreational anglers within the Salish Sea area may under-report their bycatch, have difficulty identifying rockfish to species, and are not familiar with some of the rockfish regulations. Also, after establishment of protected areas (2.3), enforcement will also be required to ensure those areas are effective to help achieve recovery goals.

Recovery Action 3. Protection, restoration, and research of rockfish habitats and the Puget Sound/Georgia Basin ecosystem on which they rely. Protection and restoration of rockfish habitats is a priority action and essential for recovery. General principles and the best available science about rockfish habitat use guide immediate actions, and research actions are outlined to address information gaps.

3.1 Nearshore (< 98.4 feet [30 m]) protection, research, and restoration.* Juvenile bocaccio recruit to kelp, and to a lesser extent eelgrass, in the nearshore. Natural rearing habitats, including existing kelp or eelgrass, or areas that could support kelp (i.e., areas with substrate that could support kelp holdfasts), need to be preserved. See Appendix V, Nearshore Habitat and Kelp Conservation.

3.1.1. Continue programs to prevent, report, and remove derelict fishing gear from nearshore environments.* Prevention, reporting, and removal of derelict fishing gear has restored hundreds of acres of rockfish habitat, and the continuation of such programs is important to ensure habitat needed for recovery is available and to decrease the threat of mortality or habitat degradation from lost gear.

3.1.2. Assess potential of native kelp restoration projects and pursue restoration projects as applicable.* Native kelp, and to a lesser extent eelgrass, is important for juvenile bocaccio recruitment. Native kelp is important for rearing forage fish of yelloweye rockfish and bocaccio. As such, research should be conducted into the feasibility of kelp and eelgrass restoration, and restoration actions should be taken if found viable.

3.1.3. Assess non-indigenous species (*Sargassum muticum,* Japanese wireweed, and tunicates, *Ciona savignyo, S. clava*, and *D. vexillum*) to determine if they are degrading or impairing rearing habitats such that they are limiting recovery. Research has shown that *S. muticum* alters macroalgal communities; additionally, it competes with and impairs the reestablishment of giant kelp forests in California. *C. savignyi, S. clava*, and *D. vexillum* have increased in Puget Sound, but their distributions and effects may not have reached full potential. However, the degree to which all of these non-indigenous species affect native macroalgae, eelgrass, or rockfish is not understood, so further assessment is needed.

3.2. Protection, research, and restoration of deepwater (> 98.4 feet [30 m]) habitats.* Adult listed rockfish live in deep water, making its protection and restoration a priority. See Appendix IV, Benthic Habitat Conservation.

3.2.1. Continue programs to prevent, report, and remove derelict fishing gear from deepwater environments.* As in nearshore environments, preventing, reporting, and removal of derelict fishing gear in deepwater habitat will protect these habitats and decrease the threat of mortality from lost gear. Because many shallow-water nets have already been removed, an emphasis on removal from deepwater environments is appropriate.

3.2.2. Periodically assess sediment disposal practices to determine if they are limiting recovery. Periodic assessments of disposal practices will help managers make adjustments, if appropriate.

3.2.3. Assess and determine if artificial reefs are needed for listed rockfish recovery. An assessment of the role, function, and necessity of artificial reefs would inform their potential use and efficacy for listed rockfish recovery.

3.3. Assess the impact of contaminants and bioaccumulants (including emerging contaminants such as microplastics) on listed rockfish survival, health, productivity, and behavior.* Potential impacts of bioaccumulants on listed rockfish are not well understood, but research thus far indicates they may have significant deleterious effects and additional research is needed. Appendix VI, Sediment and Water Quality, addresses these needs.

3.3.1. Clean up/cap contaminated sediments and reduce contaminant inputs, emphasizing the South Puget Sound and Main Basin.* Reducing contaminant input and contaminated sediment restoration or capping is a priority as toxins and contaminants may have a large impact on rockfish productivity and health. Generally, the South Puget Sound and Main Basin contain the most legacy and present contamination. See Appendix VI, Sediment and Water Quality.

3.4. Prevent and reduce excessive nutrient input (e.g., from septic systems and other human sources) with emphasis in the South Puget Sound, Main Basin, and Hood Canal).* Anthropogenic input of nutrients may contribute to hypoxia and kill listed rockfish and/or their prey base. Portions of Hood Canal, in particular, have episodic periods of low dissolved oxygen, though the relative role of nutrient input from humans in exacerbating these episodes is in question. In addition to Hood Canal, periods of low dissolved oxygen are becoming more widespread in waters south of Tacoma Narrows. The input of nutrients could particularly threaten nearshore habitats of juvenile bocaccio because it can compromise the growth and recruitment of eelgrass by causing plankton blooms or excess growth of epiphytes that collectively reduce light levels. Potential modifications for projects that result in pollution and runoff include changing the outfall location to less sensitive habitats and using enhanced pollutant treatment techniques.

3.5. Develop ecological models to evaluate critical life stages dictating rockfish population growth, understand the potential impacts of climate change and ocean acidification on rockfish population dynamics, and assess the potential for predation and competition to limit rockfish recovery.* Climate change may cause increasing surface temperatures, changes to precipitation evaporation, vertical mixing, and other changes to marine ecosystems. Ocean acidification may cause changes in the physiology, behavior, metabolism, and reproductive biology of fish. Ocean acidification could also impact the food web, resulting in unknown changes of food availability to upper-level predators such as rockfish. Improving models would inform further assessment of the relative impacts of threats to listed rockfish, including but not limited to climate change, OA, predation, and competition. Further, developing a better understanding of critical life stages that may influence rockfish population growth will enable managers to better direct resources toward threats that could limit this growth. See Appendix VI, Sediment and Water Quality, and Appendix VII, Climate Change and Ocean Acidification.

3.5.1. **Predict, assess, and manage for habitat changes as related to climate change and ocean acidification and synergistic effects in the DPSs.*** Little is known about the effect climate change and ocean acidification will have on listed rockfish, but recent research indicates that the combined effects of OA, hypoxia, and other factors could cause more severe and more frequent deleterious effects in inland waters than in the open ocean. Research and prediction capabilities are needed to understand and plan to adaptively manage habitats used by listed rockfish in the face of these changes.

3.5.2. **Determine conditions under which predation could limit recovery.** Models will also enable understanding of levels of predation under varying conditions, and how or if predation could limit recovery. See Appendix IX, Predation, for additional information.

3.5.3. **Determine the potential for interspecific competition to limit recovery within the DPSs using field studies, experimentation, and modeling.** Little is understood about interspecific competition within Puget Sound, and various analysis methods would enable understanding of how or if competition could limit recovery.

3.6. **Assess disease to determine if it is limiting recovery of the DPSs.** The effect of disease on rockfish is not well understood, especially on listed rockfish, and further research is needed to determine the extent and severity of disease in rockfish to determine if it may be limiting recovery over time.

3.7. **Assess the effects of hatchery salmon releases (as warranted) to determine if they are limiting recovery of the listed species.** The effects of hatchery salmon on listed rockfish requires further assessment to determine if predation by or competition with hatchery fish may be limiting recovery.

3.8. **Evaluate effects of anthropogenic noise on listed rockfish behavior and productivity to determine if it is limiting recovery**. The effects of anthropogenic noise on listed rockfish in Puget Sound is poorly understood, though research in other marine species indicates it could be significant, especially as vessel traffic and other anthropogenic noise is anticipated to increase in Puget Sound. An assessment of anthropogenic noise would assist in determining if sound affects listed rockfish productivity, habitat use, and behavior and limits recovery.

3.9. **Continue oil spill prevention and response within the DPSs.*** Response and prevention are already conducted in the range of the DPSs. These activities are highlighted here to stress their importance to a healthy ecosystem that supports listed rockfish.

3.10. **Continue state and Federal review of permitted activities to minimize impacts to rockfish habitats and their prey base.*** Regulatory agencies should continue to assess activities that could affect listed rockfish, their habitat, and their prey-base.

3.11. **Continue to enforce habitat protection laws and regulations; improve as warranted to protect listed rockfish habitat.*** Enforcement of current habitat protections is important to support a healthy ecosystem for rockfish recovery.

Recovery Action 4. Implement the Outreach and Education Plan. Outreach and education, particularly directed at commercial and recreational anglers, have been prioritized because individual actions may engender more accurate bycatch estimates, decrease effects of bycatch and barotrauma, and garner support for listed rockfish recovery in general. See Appendix I, Education, Outreach, and Public Involvement, for the detailed Plan.

4.1 Improve rockfish identification and documentation of bycatch by recreational and commercial fishers.* Many recreational anglers are unable to reliably identify rockfish to species. Literature produced and distributed by WDFW, the Puget Sound Anglers, and NMFS has improved education, but much remains to be done. Because anglers must self-report bycatch returned at sea, reliable identification is important to validate bycatch estimates. Some fisheries with risk of bycatch may not be well monitored for bycatch, which is needed to assess the risk of bycatch as well as identify actions to decrease the risk, if needed.

4.2. Encourage rockfish catch avoidance and educate fishers why it is preferred over recompression; increase use of best practices to mitigate barotraumas.* Catch avoidance is preferred over recompression because of concerns about long-term survival, health, and productivity after recompression; thus, education and outreach to fishers should highlight this priority (2.4). Additionally, when recreational and commercial anglers cannot avoid rockfish bycatch, education and outreach is needed to ensure best practices for handling and rapid recompression using descending devices because there is strong evidence that experience and handling time can affect recompression outcomes. WDFW efforts to this end should be expanded upon (http://wdfw.wa.gov/fishing/bottomfish/rockfish/mortality.html).

4.3. Improve knowledge of rockfish life history and habitat usage, their role in the ecosystem, and current efforts to recover rockfish.* Fishers who understand rockfish life history are more likely to support recovery efforts. Further, understanding the roles that rockfish play in the local ecosystem may make rockfish recovery more relevant to commercial fishers, recreational anglers, and other stakeholders. Finally, improving fishers' knowledge of ongoing efforts to recover rockfish will improve understanding of challenges and opportunities to recovery.

4.4. Improve understanding of rockfish fishing regulations.* Some recreational fishers are not aware of some of the regulations enacted to protect rockfish. Education and outreach may help fishers' awareness of fishing regulations and the reasons for their existence. Additionally, providing education for commercial fishers about the requirement to report lost derelict gear may engender expedient retrieval of lost gear, as has been demonstrated by a WDFW/NWSF program.

4.5. Continue the *Cooperative Research Program*, create an *Innovative Fishing Program* and other outreach projects to further cooperative fishing research and fishers' engagement in rockfish recovery.* Although public support is also a goal of education and outreach, the plan will focus on recreational and commercial fishers and SCUBA divers because they are most likely to come into contact/observe rockfish. Further engagement, such as additional cooperative research as part of the *Cooperative Research Program* or other projects, may engender support for rockfish recovery and conservation as well as provide needed research.

Recovery Action 5. Secure public support for listed rockfish recovery. Strong public support is crucial to accomplish the criteria and goals established in this plan. Assessment and monitoring of rockfish, their habitats, and their threats; implementing fishery changes; and implementing an education and outreach program will require considerable funding to achieve this plan's goals and objectives. While some funding programs have supported rockfish recovery (e.g., ESA section 6 grants), current funding is inadequate to implement all of the actions identified in the recovery plan. This plan identifies necessary actions and will help support partners seeking funding opportunities. Below, we identify potential sources for obtaining necessary funding support.

5.1 Seek a variety of types of funds, including Federal, state, and private grants over a long time frame.* The rockfish recovery effort has obtained funding primarily from within NMFS through ESA section 6 grants to Washington State and through the Dedicated Rockfish Research Fund created by the Washington State Legislature. Single entities alone cannot support the rockfish recovery effort; typically, the funding scope of one grant program can cover the costs of only a subset of the actions necessary to recover the species. As this recovery program is implemented, there will be an increasing need to secure long-term funding for monitoring the species' status over a timeframe that spans several decades. Appendix VIII, Funding Opportunities for Rockfish Conservation, is a partial list of programs and awards that may support rockfish recovery and may be pursued by a variety of organizations.

5.2 Establish collaborative research and cooperative funding agreements among state, Federal, tribal, university, and private entities.* Cooperative agreements formed between and within state, Federal, tribal, university, and private entities will enable the capacity needed to recover listed rockfish. The effort to pool resources and expertise may also help avoid redundancy in effort and extend the scope of available funds.

VI. IMPLEMENTATION SCHEDULE AND PRELIMINARY COST ESTIMATES

This Implementation Schedule (Table 21) outlines recovery research and actions, priority numbers, and estimated rockfish recovery program costs over a 5-year period. The Implementation Schedule provides projections of which actions may continue beyond year 5, but there is considerable uncertainty regarding how long recovery will take. Currently, we do not have reliable biomass information for listed rockfish. As prioritized information is obtained on present and past biomass, as well as information to assess the impact on how threats may limit recovery and how the threats can be effectively mitigated, more robust time and expense projections will be developed.

The cost of the approximately 45 actions recommended in this plan for the first 5 years of recovery is estimated to be $23,364,356. Assuming that recovery takes one and a half generations (of yelloweye rockfish), or approximately 60 years, the total recovery costs over 60 years would be approximately $82,970,000. The annual cost of recovery is estimated to decrease substantially after the first 5 to 10 years, once the necessary baseline research and management actions are performed. Note that the process of establishing RCAs would begin after the first 5 years of implementing the recovery plan and, therefore, only costs associated with the public process to identify plausible sites are included on the Implementation Schedule. Development of RCAs with appropriate monitoring and public input is estimated to cost approximately $6,516,874 after the first five years.

There are numerous parallel efforts underway, independent from rockfish recovery, to protect and restore the Puget Sound ecosystem. Such efforts include oil spill prevention measures, contaminated sediment clean-up projects, and other important projects. These efforts will provide benefits to listed rockfish and their habitats and prey base and are thus highlighted in the plan. However, the cost of these actions will not be included in the total cost of rockfish recovery because they would occur independent of this plan. Similarly, actions conducted to restore listed rockfish and their habitats will benefit other listed species that utilize the Puget Sound area, such as Puget Sound Chinook salmon (*Oncorhynchus tshawytscha*), and may provide economic benefits. We are unable to quantify the economic benefits of listed rockfish recovery actions, but it is likely the benefits to the ecosystem and economy would offset the total recovery costs estimated here.

All recovery actions and descriptions reflect the actions as numbered in the Step-down Outline and Recovery Narrative. Priorities in the Implementation Schedule are assigned as follows:

> Priority 1 – An action that must be taken to prevent extinction or to prevent the listed species from declining irreversibly in the foreseeable future.
>
> Priority 2 – An action that must be taken to prevent significant decline in the listed species population/habitat quality or some other significant negative impact short of extinction.
>
> Priority 3 – All other actions necessary to provide for recovery of yelloweye rockfish and bocaccio.

Recovery of listed rockfish is a long-term effort that requires cooperation and coordination from a number of agencies, organizations, and communities around Puget Sound. Lead entities and potential partners are listed in the Implementation Schedule. Listing a party in the Implementation Schedule does not require the identified party to implement the action(s) or secure funding for implementing the actions(s), but it does denote which organizations may be appropriate for performing those actions. Abbreviations used appear in the key below. A more detailed breakdown of how cost estimates in the Implementation Schedule (Table 21) were calculated is available upon request.

Key to Implementation Table Abbreviations

Department of Defense	*DOD*
Department of Natural Resources, WA	*DNR*
Department of Ecology, WA	*ECY*
Fisheries and Oceans Canada	*DFO*
Environmental Protection Agency, US	*EPA*
Northwest Fisheries Science Center	*NWFSC*
Northwest Straits Foundation	*NWF*
Northwest Straits Initiative	*NWSI*
National Marine Fisheries Service	*NMFS*
Marine Resource Committees	*MRCs*
The Nature Conservancy	*TNC*
United States Army Corps of Engineers	*USACOE*
United States Geological Survey	*USGS*
Washington Department of Fish and Wildlife	*WDFW*

Table 21. Implementation schedule for research and recovery actions.

Implementation Schedule
Yelloweye Rockfish and Bocaccio Research and Recovery Actions ***(action is for both species unless otherwise indicated in the comments section)***
Labor Costs Source: 2012 American Fisheries Society Salary Survey of Fishery Professionals (Table 2, Public Agencies, WA State, average labor costs for Levels 1-5) and consultation with applicable agencies
Operation Costs Sources: Funded NWFSC proposals, IE Economic Report prepared for the Plan, Section 6 Funding Proposals from WDFW and DNR, WDFW and other agency or non-profit consultation, and other applicable sources

Action #	Action Description	Priority #	Action Duration	*Lead Entities and Potential Partners	Estimated Fiscal Year Costs (2016 US$)					Comments
					FY1	FY2	FY3	FY4	FY5	
1. Actions to enable a greater understanding of listed rockfish population abundance, distribution, diversity, genetics, demographics, ecology, and habitat associations										
1.1	Fishery independent population abundance and spatial structure ROV surveys (nearshore and/or deep water)	1	FY 1, and every 5 years after	*WDFW, *NMFS, PS Treaty Tribes, Seattle Aquarium, DFO	500,114				500,114	Required to assess population abundance, distribution, and recovery.
1.1.1	Regular ROV survey monitoring to observe changes in population abundance, distribution, diversity, genetics, demographics, and habitat associations	1	FY 1 and 5, and every 5 years after	*WDFW, *NMFS, PS Treaty Tribes, Seattle Aquarium, DFO						Required to indicate when some delisting/ downlisting criteria are met. Cost included in action 1.1.

Action #	Action Description	Priority #	Action Duration	*Lead Entities and Potential Partners	Estimated Fiscal Year Costs (2016 US$)					Comments
					FY1	FY2	FY3	FY4	FY5	
1.2	Benthic habitat mapping and rockfish habitat characterizatio n	1	FY1 and 2	*WDFW, *NMFS, NWFSC, USGS, TNC, SeaDoc Society, DFO, DNR, Academia	77,500	77,500				Action required to assess population habitat use and management.
1.2.1	Research output of action 1.2 will be used to develop a probabilistic habitat model and report to assess spatial structure	1	FY 3	*WDFW, *NMFS, NWFSC, USGS, TNC, SeaDoc Society, DFO, DNR, Academia			51,667			Model will aid fishery management and meta-population assessment.
1.2.2	Supplemental multibeam bathymetry data collection	2	FY4 and beyond	*WDFW, *NMFS, NWFSC, USGS, TNC, SeaDoc Society, DFO, DNR, Academia				410,128		This is not needed throughout the DPS, but is needed in many areas.
1.3	Assessment of historical fishing and scientific records and grey literature	1	FY1 and 2	*WDFW, *NMFS, *NWFSC, DFO, Academia	84,843	84,843				Required to inform recovery targets.

Action #	Action Description	Priority #	Action Duration	*Lead Entities and Potential Partners	Estimated Fiscal Year Costs (2016 US$)					Comments
					FY1	FY2	FY3	FY4	FY5	
1.3.1	Development of method to integrate multiple types of historical data to establish an understanding of baseline abundance and size structure	1	FY 2	*WDFW, *NMFS, *NWFSC, DFO, Academia		38,750				Required to understand present populations relative to historical.
1.4	Assess genetic structure in DPSs, effective dispersal distances, and population size	1	FY 1-2	*NMFS, *NWFSC, *WDFW, DFO, Seattle Aquarium, Academia	155,822	155,822				Required to understand DPSs' boundaries and potential meta-population structure. Genetic data necessary for bocaccio.
1.4.1	Develop a model to determine genetic thresholds of inbreeding and hybridization within the DPSs	1	FY 3	*NMFS, *NWFSC, *WDFW, DFO, Academia			32,292			Needed for the delisting and downlisting criteria to assess the status of populations.
1.5	Annual YOY surveys in each of the management units	1	FY 1, 3, and 5; and every 5 years after	*WDFW, *NMFS, NWFSC, REEF, SeaDoc Society, Seattle Aquarium, PS Treaty Tribes, NWSI, DNR, Academia	257,128		257,128		257,128	Necessary for understanding primary rearing locations, habitat threats, and restoration opportunities.

Action #	Action Description	Priority #	Action Duration	*Lead Entities and Potential Partners	Estimated Fiscal Year Costs (2016 US$)					Comments
					FY1	FY2	FY3	FY4	FY5	
1.6	Larval surveys in each management unit	2	FY 2-4, and every 10 years after	*NMFS, *WDFW, PS Treaty Tribes, DFO, USACOE, Academia		66,261	66,261	66,261		Needed to understand larval abundance, dispersal, and conditions associated with recruitment and connectivity.
1.6.1	Research output of action 1.6 will be used to develop a connectivity model	2	FY 3-5, and every 15 years after	*WDFW, *NWFSC, *NMFS, Academia			80,048	80,048	80,048	Needed to inform fishery management, meta-population assessment, habitat restoration, and possible reserve siting.
1.7	Assess home range and movement of various life stages of ESA-listed rockfish	2	FY 3 and 5	*WDFW, *NWFSC, *NMFS, Academia			48,894		48,894	Assessments inform the habitat model as well as fisheries management actions.
1.8	Develop population models to evaluate critical life stages dictating rockfish population growth	2	FY2	*WDFW, *NWFSC, *NMFS, Academia		51,667				Model will help guide adaptive management and prioritize actions.

Action #	Action Description	Priority #	Action Duration	*Lead Entities and Potential Partners	Estimated Fiscal Year Costs (2016 US$)					Comments
					FY1	FY2	FY3	FY4	FY5	
1.9	Develop and assess statistical methods for integrating multiple historical and present sources of data on rockfish size structure and abundance into informative indices of current trends in rockfish size and abundance	1	FY2	*WDFW, *NWFSC, *NMFS, Academia		95,314				Essential for use of data sources from various methods and times of collection to assess the listed populations' status.
1.10	Conduct and/or further assess comparative studies of rockfish abundance and demographic structure inside and outside of established marine reserves/MPAs in Puget Sound/Georgia Basin to establish knowledge baseline	1	FY 2-3	*WDFW, *NWFSC, *NMFS, Seattle Aquarium, REEF, SeaDoc Society, Wild Fish Conservancy, Academia, DFO		113,128	113,128			Robust baseline data enable assessments of the efficacy of past and future sites and aid in adaptive management actions.

Action #	Action Description	Priority #	Action Duration	*Lead Entities and Potential Partners	Estimated Fiscal Year Costs (2016 US$)					Comments
					FY1	**FY2**	**FY3**	**FY4**	**FY5**	
2. Fisheries management consistent with recovery goals										
2.1	Account for all catch and bycatch with statistically valid techniques	1	Annually through recovery	*WDFW, *PS Treaty Tribes, *DFO, *NMFS	157,500	157,500	157,500	157,500	157,500	Further investment will inform management decisions. See Appendix II.
2.1.1	Further assess fisheries by integrating ROV survey data and additional bycatch risk data	1	FY 1-5 and FY 5-15, and every 10 years through recovery	*WDFW, *PS Treaty Tribes, *DFO, *NMFS	77,500	77,500				Further assessment will inform management decisions. See Appendix II.
2.2	Ensure that anthropogenic mortality falls within accepted risk-adverse precautionary guidelines at appropriate scales	1	FY 1-5, and every 2 years after	*NMFS, *WDFW, *PS Treaty Tribes, *DFO	38,750	38,750	38,750	38,750	38,750	Needed to ensure the DPSs are managed in accordance with best available science. Appendix II.
2.3	Establish areas not subject to potential anthropogenic mortality (marine protected areas [MPAs] or rockfish conservation areas [RCAs] in priority areas)	1,2,3 (see table 20)	FY 1-5, and FY 6-8 at least	*WDFW, *NMFS, *PS Treaty Tribes, *NWIFC, other interested parties	885,556	885,556	885,556	885,556	885,556	Action will limit anthropogenic mortality. Cost estimates derived from IE Economics report. Appendix II.
2.3.1	Monitoring and adaptive management of MPAs/RCAs	1	FY 5, and every 5 years	*WDFW, *NMFS, *PS Treaty Tribes, *NWIFC, other					293,128	Need for adaptive management of MPAs/RCAs. Appendix II.

Action #	Action Description	Priority #	Action Duration	*Lead Entities and Potential Partners	Estimated Fiscal Year Costs (2016 US$)					Comments
					FY1	FY2	FY3	FY4	FY5	
				interested parties						
2.4	Implement measures to avoid and mitigate barotrauma; conduct further research on both avoidance and mitigation	1	FY 1-5, and every 10 years after	*NMFS, *WDFW, *PS Treaty Tribes, NWFSC, Academia, SeaDoc Society, recreational and/or commercial fishers, Aquaria*, *NWIFC, and other parties	147,012	147,012	147,012	147,012	147,012	Limits bycatch mortality.
2.5	Assess long-term survival and productivity of recompressed yelloweye rockfish and bocaccio in the wild and take appropriate management actions	1	FY 1-5, and every 10 years after	*NMFS, *WDFW, *PS Treaty Tribes, NWFSC, Academia, SeaDoc Society, recreational and/or commercial fishers	111,384	111,384	111,384	111,384	111,384	Action will inform adaptive management. Appendix III.
2.6	Additional enforcement of fishery regulations	1	FY 1-5 and every 2 years after	*WDFW, *PS Treaty Tribes, *NWIFC, *NMFS, NWFSC, Academia, SeaDoc Society, Fishers, Aquaria	137,012	137,012	137,012	137,012	137,012	Needed to enforce regulations to protect listed rockfish. Estimates from WDFW. Appendix II.

Action #	Action Description	Priority #	Action Duration	*Lead Entities and Potential Partners	Estimated Fiscal Year Costs (2016 US$)					Comments
					FY1	FY2	FY3	FY4	FY5	
3. Protection, restoration, and research of rockfish habitats and the Puget Sound/Georgia Basin ecosystem										
3.1	Nearshore (< 30 m) protection/ restoration	1	FY 1-5, and beyond	*WDFW, *NMFS, *NWSF, NWS Commission, DNR, MRCs, Academia, Fishers						See Appendix V (most applicable to bocaccio). Costs detailed in action 3.1.1, 3.1.2, and 3.1.3.
3.1.1	Continue to prevent, report, and remove derelict fishing gear from nearshore environments	1	FY 4, and every 5 years after	*WDFW, *NMFS, *NWSF, NWS Commission, DNR, MRCs, Academia, Fishers				86,423		Removals completed in much of Puget Sound, important to preserve habitat.
3.1.2	Assess potential of native kelp (and possibly eelgrass) restoration projects through mapping projects and begin kelp restoration R&D plantings	1	FY 2-4, and at least every 10 years after	*WDFW, *DNR, *NMFS, PS Restoration Fund, NWS Commission, NWSI, MRCs, Academia, Fishers		743,125	743,125	743,125		This is important for bocaccio recruitment and rockfish prey. See Appendix V.
3.1.3	Assess non-indigenous species to determine if they are degrading or impairing rearing habitats	3	FY 5, and every 10 years after	*WDFW, *DNR, *NMFS, Sea Doc Society, MRCs, REEF, Academia, PS Restoration Fund, NWS Commission, NWSI					180,942	Needed to assess how invasives may affect recovery. Appendix IV and V (overlap between nearshore and deep water in this action).

Action #	Action Description	Priority #	Action Duration	*Lead Entities and Potential Partners	Estimated Fiscal Year Costs (2016 US$)					Comments
					FY1	FY2	FY3	FY4	FY5	
3.2	Protect and restore deepwater (> 30 m) benthic habitat	1	FY 1-5, and beyond	*WDFW, *NMFS, *NWSF, MRCs, Local Fishers and Groups, *DNR, Sea Doc Society, MRCs, REEF, Academia						See Appendix IV. Cost details included in action 3.2.1, 3.2.2, and 3.2.3.
3.2.1	Continue programs to prevent, report, and remove derelict fishing gear from deepwater environments	1	FY 1-5, and every 10 years after	*WDFW, *NMFS, *NWSF, MRCs, Local Fishers and Fisher Groups,	1,130,705	1,130,705	1,130,705	1,130,705	1,130,705	Needed to preserve habitat and decrease bycatch. Appendix IV.
3.2.2	Periodic assessments of sediment disposal practices to determine if they are limiting recovery	3	FY 4, and every 5-10 years after	*NMFS, *USACOE, *EPA, ECY*WDFW, *NWSF, MRCs, Local Fishers and Fisher Groups				127,043		Needed for adaptive management. Appendix VI.
3.2.3	Assess if artificial reefs are needed for listed rockfish recovery	3	FY 5, and every 20 years after	*WDFW, *NMFS, NWFSC, Academia, Interested Angling Organizations *USACOE, *EPA, ECY					60,177	May enhance habitat. Appendix IV.
3.3	Assess impact of bio-accumulants and other contaminants on listed	1	FY 1-5, and every 5 years after	*NMFS, *WDFW, *ECY, *EPA, NWFSC, Academia Interested	128,564	128,564	128,564	128,564	128,564	Will engender refining actions to reduce contaminant threats. See Appendix VI.

Action #	Action Description	Priority #	Action Duration	*Lead Entities and Potential Partners	Estimated Fiscal Year Costs (2016 US$)					Comments
					FY1	FY2	FY3	FY4	FY5	
	rockfish survival, health, productivity, and behavior			Angling Organizations						
3.3.1	Clean up (or cap) contaminated sediments, reduce contaminant inputs	1	FY 1-5, and annually after	*ECY, *WDFW, *NMFS, *USACOE, *EPA* NWFSC, Academia						Action is being carried out; continuation of action is needed.
3.4	Prevent and reduce nutrient input	1	FY 1-5, and annually after	*ECY, *NMFS, *WDFW, Local and State Jurisdictions, Residents, *USACOE, *EPA						Action is being carried out; continuation of action is needed.
3.5	Develop ecological models to evaluate critical life stages dictating rockfish population growth and understand the impacts climate change, OA, predation, and competition may have to limit recovery	1	FY 2-5, and annually after	*NWFSC, *NMFS, *WDFW, ECY, DNR, Academia						Cost for model in action 1.8 will be built on in actions 3.5.1, 3.5.2, and 3.5.3. (Costs included in those actions)
3.5.1	Predict, assess, and manage for habitat changes as	1	FY 3-5, and every 5 years after	*NWFSC, *NMFS, *WDFW, ECY, DNR, Academia*			95,314	95,314	95,314	Needed to plan and adaptively manage habitats used by listed rockfish. Appendix VII.

Action #	Action Description	Priority #	Action Duration	*Lead Entities and Potential Partners	Estimated Fiscal Year Costs (2016 US$)					Comments
					FY1	FY2	FY3	FY4	FY5	
	related to climate change, OA, and synergistic effects in the DPSs									
3.5.2	Determine conditions under which predation could limit recovery	2	FY 3 and 5, and every 5 years after	*NWFSC, *NMFS, *WDFW, Sea Doc Society, Academia			166,942		166,942	Needed for adaptive management.
3.5.3	Determine the potential for interspecific competition to limit recovery within the DPSs using field studies	3	FY 4, and every 10 years after	*NWFSC, *NMFS, *WDFW, SeaDoc Society, Academia				154,942		Needed for adaptive management.
3.6	Assess disease to determine if it is limiting recovery	2	FY 1 and 5, and every 5 years after	*NWFSC, *NMFS, Academia, SeaDoc Society, Aquaria	38,750				38,750	Needed for adaptive management.
3.7	Assess effects of hatchery salmon releases to determine if they are limiting recovery	2	FY 2-4, and every 10 years after	*WDFW, *NMFS, *NWFSC, PS Treaty Tribes		185,128	185,128	185,128		Needed for adaptive management.

Action #	Action Description	Priority #	Action Duration	*Lead Entities and Potential Partners	Estimated Fiscal Year Costs (2016 US$)					Comments
					FY1	FY2	FY3	FY4	FY5	
3.8	Evaluate effects of anthropogenic noise on ESA-listed rockfish behavior and productivity to determine if it is limiting recovery	2	FY 3-5, and every 10 years after	*WDFW, *NMFS, NWFSC, Academia			159,295	159,295	159,295	Needed for adaptive management.
3.9	Continue oil spill prevention and response	2	FY 1-5, and annually after	*ECY, *EPA, *NMFS	0	0	0	0	0	Action is being carried out; continuation of action is needed.
3.10	Continue state and Federal review of permitted activities to minimize impacts to rockfish habitats and their prey base	1	FY 1-5, and annually after	*NMFS, *WDFW, *ECY, *DNR, *Army Corps of Engineers, *EPA, *DFO	0	0	0	0	0	Action is being carried out; continuation of action is needed.
3.11	Continue to enforce habitat protection laws and regulations; improve as warranted to protect listed rockfish habitat	1	FY 1-5, and annually after	*NMFS, *WDFW, *ECY, *DNR, *Army Corps of Engineers, *EPA, *DFO	0	0	0	0	0	Action is being carried out; continuation of action is needed.

Action #	Action Description	Priority #	Action Duration	*Lead Entities and Potential Partners	Estimated Fiscal Year Costs (2016 US$)					Comments
					FY1	FY2	FY3	FY4	FY5	
4. Implement Education and Outreach Plan										
4.1	Improve rockfish identification and documentation of bycatch	1	FY 1-5, and annually after	*WDFW, *NMFS, *PS Treaty Tribes, NWIFC, Seattle Aquarium, NWSI, MRCs, Recreational and Commercial Fishers	59,447	59,447	59,447	59,447	59,447	More accurate bycatch estimates will inform management. Appendix I and Appendix II.
4.2	Encourage avoidance of rockfish and educate anglers why it is preferred over release at depth/increase use of best practices to mitigate barotrauma	1	FY 1-5, and every 5 years after	*WDFW, *NMFS, *PS Treaty Tribes, NWIFC, NWSI, MRCs, Recreational and Commercial Fishers	39,447	39,447	39,447	39,447	39,447	Anticipated to help limit mortality. Appendix I.
4.3	Improve knowledge of rockfish life history and habitat usage, the role rockfish play in the Puget Sound ecosystem, and current efforts to recover rockfish	1	FY 1-5, and annually after	*WDFW, *NMFS, *PS Treaty Tribes, NWSI, MRCs, Recreational and Commercial Fishers, NWIFC.	12,224	12,224	12,224	12,224	12,224	Action needed to make listed rockfish relevant to stakeholders. Appendix I.

Action #	Action Description	Priority #	Action Duration	*Lead Entities and Potential Partners	Estimated Fiscal Year Costs (2016 US$)					Comments
					FY1	FY2	FY3	FY4	FY5	
4.4	Improve understanding of rockfish fishing regulations	1	FY 1-5, and annually after	*WDFW, *PS Treaty Tribes, *NMFS, NWSI, MRCs, Recreational and Commercial Fishers	12,224	12,224	12,224	12,224	12,224	Action needed to decrease rockfish bycatch. Appendix I.
4.5	Continue the Cooperative Research Program, create an Innovative Fishing Program and other outreach projects to further cooperative fishing research and fishers' engagement in rockfish recovery	1	FY 1-5, and every 2 years after	*NMFS, *WDFW, *NWFSC, PS Treaty Tribes, SeaDoc Society, Recreational and Commercial Fishers	39,375	39,375	39,375	39,375	39,375	Will garner support for recovery and form cooperative methods to collect trusted data in a cost-effective manner. Appendix I.
5. Secure financial support for ESA-listed rockfish recovery										
5.1	Seek a variety of types of funds, including Federal, state, and private grants over a long time frame	1	FY 1-5, and annually after	All						Insufficient funding limits recovery. Costs included in current operating costs.

Action #	Action Description	Priority #	Action Duration	*Lead Entities and Potential Partners	Estimated Fiscal Year Costs (2016 US$)					Comments
					FY1	FY2	FY3	FY4	FY5	
5.2	Establish cooperative funding agreements among state, Federal, and private entities to avoid redundancy and extend the scope of available funds	1	FY 1-5, and annually after	All						Insufficient funding limits recovery. Costs included in current operating costs.
TOTAL Cost (First 5 Years)										
$23,364,356										

VII. LITERATURE CITED

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APPENDIX I: EDUCATION, OUTREACH, AND PUBLIC INVOLVEMENT

APPENDIX II: FISHERIES MANAGEMENT

APPENDIX III: BAROTRAUMA RESEARCH AND ADAPTIVE MANAGEMENT

APPENDIX IV: BENTHIC HABITAT CONSERVATION

APPENDIX V: NEARSHORE HABITAT AND KELP CONSERVATION

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APPENDIX I

EDUCATION, OUTREACH, AND PUBLIC INVOLVEMENT

OVERVIEW

This appendix describes in detail the particular audiences, objectives, and projects for outreach and education to support the recovery of yelloweye rockfish and bocaccio (hereafter listed rockfish) of the Puget Sound/Georgia Basin (summarized in Table 1 at the end of this appendix) (also see Section V. A. Recovery Program, Recovery Action Outline). As described in the Recovery Plan (Section V. Recovery Program, Recovery Action 4), education, outreach, and public involvement are prioritized because understanding, support, and participation from stakeholders are fundamental to successful conservation (Stankey and Shindler 2006). This support is particularly essential for the aspects of management that rely upon self-regulation and self-reporting by user groups, such as in recreational fisheries (Haw and Buckley 1968; Reynard and Hilborn 1986).

Historically, overfishing associated with targeted fisheries and bycatch from both the recreational and commercial sectors was the main cause of rockfish decline in Puget Sound (Palsson et al. 2009; Williams et al. 2010; Drake et al. 2010). Despite increasingly restrictive management measures, including the recent non-retention rule for recreational fishing and the closure of some commercial fisheries with rockfish bycatch, bycatch remains a threat to listed rockfish (Palsson et al. 2009; Drake et al. 2010; WDFW 2011) within some portions of the Puget Sound/Georgia Basin.

Recreational anglers and divers are more likely to encounter rockfish as compared with other stakeholders. Actions by recreational anglers will play an important role in decreasing rockfish mortality that is due to incidental catch. Only about 13 percent of local recreational anglers are part of formal organizations, such as Puget Sound Anglers or the Coastal Conservation Association (Sawchuk 2012; Sawchuk et al. 2015). As such, communicating with these stakeholders is challenging because of their large numbers and lack of formal representation. Therefore, recreational anglers are the primary audience and focus of education and outreach, in addition to commercial fishers, divers, the general public, and students.

Research Informing Education and Outreach to Puget Sound Recreational Anglers

NOAA Fisheries partnered with the University of Washington to conduct a survey of recreational anglers in Puget Sound to inform recovery planning, especially with regard to recreational angler education and outreach (Sawchuk 2012; Sawchuk et al. 2015). The survey took place in the summer of 2011 and was representative of boat-based recreational anglers (n = 443) in the marine catch areas that overlap with the U.S. portion of the ranges of the DPS (WDFW Marine Catch Areas 6 through 13). The results provided a baseline understanding of recreational anglers' knowledge about rockfish biology, regulations, and identification abilities; perceptions of threats to rockfish; preferences for recovery; and other information necessary for targeted education and outreach (Sawchuk 2012; Sawchuk et al. 2015).

This outreach and education plan is based on the results of this research and on the findings and principles laid out in several other peer-reviewed publications (Kellert 1985; Mascia et al. 2003; Stankey and Shindler 2006; Martin-Lopez et al. 2007; Granek et al. 2008; Verweij et al. 2010; Beaudreau et al. 2011).

Goal

The overarching goal of this education and outreach plan is to develop a high degree of rockfish knowledge and stewardship that will lead to increased engagement by stakeholders in rockfish conservation (Granek et al. 2008).

Target Audience(s): (1) Recreational anglers, (2) commercial fishers, (3) SCUBA divers, (4) the general public, and (5) students, through both formal and informal venues.

This plan provides specific objectives and projects for each audience. Table 1 at the end of this appendix summarizes objectives and projects.

(1) *Recreational Anglers*

Objectives:

1. Improve rockfish identification and subsequently the accuracy of bycatch reporting.
2. Encourage rockfish catch avoidance and illustrate to anglers why it is preferred over release at depth.
3. Increase the use of best practices to mitigate barotraumas when rockfish are encountered.
4. Improve knowledge of rockfish life history, habitat usage, and the role rockfish play in the Puget Sound ecosystem to better communicate the importance of conservation.
5. Improve understanding of rockfish fishing regulations and current efforts to recover rockfish.
6. Encourage further angler engagement in rockfish recovery to increase support for rockfish conservation.

Objective 1: Improve rockfish identification and accuracy of bycatch reporting.

Rationale: Research has found that recreational anglers' ability to identify rockfish by species was generally poor (Sawchuk 2012; Sawchuk et al. 2015). Of the boat-based angling population surveyed (n = 443), 31 percent of anglers correctly identified yelloweye rockfish and 5 percent correctly identified bocaccio. Correct identification was considerably higher among anglers who stated they had fished for rockfish in the past, but lower for anglers who had never targeted rockfish. Thus, because rockfish are scarce and fewer anglers will catch rockfish, it is anticipated fewer anglers may be familiar enough with rockfish to properly identify species in the field.

Project(s):

Distribute rockfish identification materials at boat launches, marinas, dive shops, boating supply stores, boat shows, organized angler meetings, angler websites, agency websites, and other areas where Puget Sound anglers congregate. Prioritize boat launches and marinas with the highest traffic (Everett, Shilshole, and Alki attract the majority of anglers; others with high use include Point Defiance, Redondo, Mukilteo, Anacortes, Bellingham, Port Townsend, Olympia, Potlatch, and Friday Harbor; hereafter referred to as "angler contact locations").

- Continue to broadly distribute the WDFW Species Identification Card, or "fish bycatch log" (http://wdfw.wa.gov/fishing/bottomfish/identification/rockfish/rockfish_species_id.pdf), which allows fishers to correctly identify and create daily species tallies of fish they release. These totals can then be reported to dockside creel samplers when encountered.

- ➢ Research and develop a mobile app to aid in rockfish identification (current apps do not include rockfish, though FishID, Find-A-Fish, and other existing resources could be expanded) and disseminate this information as it becomes available through web-based forums and signage. If an app is decided upon, integrate upload of photos taken by anglers with mapping apps and fish identification to collect data in real time.
- ➢ Use social media, such as Facebook, to increase the frequency of views of photos of different types of rockfish.

Rockfish signage at Sequim/John Wayne Marina. In 2017, educational signage was installed at all major boat launches in Puget Sound.

Anticipated Outcome(s): Improved identification of rockfish and/or use of photos for verification of bycatch will increase the accuracy of bycatch estimates that are necessary for rockfish management and recovery (Palsson et al. 2009). Further, more accurate identification is anticipated to decrease confusion among anglers who may frequently encounter more common rockfish species and presume that all populations are healthy (Beaudreau et al. 2011).

Evaluation and Measurement:

- Number of identification materials taken from angler contact locations
- Number of uploads of identification apps
- Visits to websites with identification information and relevant social media posts
- Completion of identification signs at angler contact locations

<u>Objective 2</u>: Encourage rockfish catch avoidance and educate anglers why it is preferred over release at depth (recompression).

Rationale: Recent research has found that long-term survival and changes in productivity and reproduction are difficult to predict in rockfish successfully descended following barotrauma (Schroeder and Love 2002; Jarvis and Lowe 2008; Pribyl et al. 2009; Pribyl et al. 2011). However, survival rates and embryo viability in yelloweye rockfish are high (Blain 2014). Predicting long-term effects of recompression is problematic because of the difficulty in controlling the many variables that may influence long-term survival, such as angler experience, time at the surface, thermal shock, and depth of capture, making avoidance greatly preferred over capture and release (Schroeder and Love 2002; Jarvis and Lowe 2008; Pribyl et al. 2009; Pribyl et al. 2011). There is also evidence that bycatch reduction measures implemented across a variety of users are not as successful as the experimental bycatch reduction measures implemented by managers and scientists (Cox et al. 2007). Therefore, while recompression is preferred when a rockfish is caught, the best-case scenario for recovery is a reduction in bycatch.

Project(s):

- Distribute materials at angler contact locations and develop new strategies that help anglers avoid rockfish bycatch.
- Continue to work with anglers to communicate current regulations that prevent rockfish bycatch.

Anticipated Outcome(s): Anglers practice techniques for catch avoidance, and mortality, bycatch, and incidence of barotrauma is reduced.

Evaluation and Measurement:

- Number of catch avoidance materials taken from angler contact locations
- Educational website traffic

Objective 3: Increase the use of descending devices.

Rationale: Research has shown that releasing rockfish at depth may reduce immediate mortality rates and effects of barotrauma. However, angler experience and handling time may be significant factors affecting survival (Schroeder and Love 2002; Jarvis and Lowe 2008; Pribyl et al. 2009; Pribyl et al. 2011), illustrating the importance of education and outreach. Further, the study of boat-based anglers in Puget Sound revealed that very few anglers (approximately 3 percent) were releasing rockfish at depth. In addition, a small number of anglers had attempted to puncture the swim bladder (Sawchuk 2012), which could cause bacterial infections or mortality.

Project(s):

- Distribute information on how to safely release rockfish at depth, in addition to the rockfish catch avoidance materials described in Objective 2.
- Consider requiring the use of descending devices (i.e., via WDFW regulation). Continue or expand the WDFW and Puget Sound Anglers project in which descending devices are purchased and distributed for free or at reduced cost. More widely disseminate educational recompression videos, such as Milton Love's video at https://www.youtube.com/watch?v=EiZFghwVOyI.

Anticipated Outcome(s): More anglers releasing rockfish bycatch at depth, safely and with reduced mortality.

Evaluation and Measurement:

- Number of distributed materials on descending techniques and descending devices

Objective 4: Improve knowledge of rockfish life history, habitat usage, and ecological role in Puget Sound.

Rationale: Anglers aware of rockfish longevity are more likely to support conservation efforts (Sawchuk 2015). Many anglers are not aware of other aspects of basic rockfish life history and their contribution to the overall ecosystem (Sawchuk 2012; Sawchuk et al. 2015). User groups usually value and exhibit knowledge of species viewed as having economic, utilitarian, or cultural significance (Kellert 1985; Martin-Lopez et al. 2007). With rockfish fisheries closed, anglers may not value rockfish recovery efforts unless they understand the contributions of rockfish to the ecosystem that supports species that anglers perceive as having value (Kellert 1985; Martin-Lopez et al. 2007). There is anecdotal evidence that some anglers are apathetic toward rockfish (Sawchuk 2012), despite rockfish constituting a significant portion of the total fish community in Puget Sound (approximately 11 percent by species) (Donnelly and Burr 1995; Palsson et al. 2009). There are also food web dynamics to consider. For example, larval and juvenile rockfish are an important prey source for Chinook salmon and coho salmon (Daley et al. 2009). An understanding of the many ways rockfish influence fishing, even when not targeted, would increase interest among anglers.

Project(s):

- Distribute materials on rockfish life history, habitat usage, and the role rockfish play in the Puget Sound ecosystem at angler contact locations.
- Create a short (3 to 5 min.) video to educate anglers about rockfish and what anglers can do to protect them, and use existing educational videos, such as this regional video on stock assessments at http://www.youtube.com/watch?v=3UbWMdpavUE.

Anticipated Outcome(s): Anglers with greater knowledge about rockfish biology and ecology are expected to become more supportive of rockfish recovery measures (Kellert 1985; Martin-Lopez et al. 2007; Granek et al. 2008; Sawchuk et al. 2015).

Evaluation and Measurement:

- Number of rockfish educational materials taken from angler contact locations
- Completion and distribution of the education video

Objective 5: Improve understanding of rockfish fishing regulations and current efforts to recover rockfish.

Rationale: Many anglers were not aware of the current rockfish regulations in 2011, a year after two major regulation changes occurred (no recreational take of rockfish and no bottom fishing below 120 feet) (Sawchuk 2012). While approximately 90 percent of boat-based anglers fishing for bottom fish were aware of the "no rockfish retention" regulation, only about 40 percent knew about the 120-foot depth restriction while bottom fishing that is intended to decrease the chance of rockfish bycatch and barotraumas. Of the anglers who stated they fished for salmon, 36 percent did not know about the no retention regulation (Sawchuk 2012). Many anglers also expressed a concern about the lack of enforcement of existing regulations (Sawchuk 2012). Though efforts to expand knowledge of these regulatory changes have continued since 2011, it is still likely that many anglers do not fully understand the regulations in place for rockfish, let alone the reasons behind them.

Project(s):

- Create and distribute material that is designed to help anglers understand rockfish fishing regulations and current research and management recovery efforts at angler contact locations in coordination with WDFW. Consider further highlighting rockfish regulations in WDFW fishing regulation pamphlet.

- Promote existing WDFW materials in new ways. Emphasize the WDFW Turn in Poachers (TIP) program through social media to enable and encourage anglers to report illegal fishing activity, and consider a joint WDFW/NMFS incentive program to increase use of the TIP program.
- Promote FishMapp or other apps that show anglers the locations of area closures in Washington. Integrate closure mapping apps with fish identification and photo upload apps (see Objective 1) to enable greater ease of use. Also, promote Fish WA webmap service that shows closed areas but also directs anglers to Major Fishing Areas where fishing prospects are strong.

Anticipated Outcome(s): Increased angler understanding of the regulations is anticipated to improve compliance. Similarly, an understanding of current efforts to recover rockfish, in the form of regulations, research, or information about the recovery planning process, is expected to foster increased awareness of the challenges facing rockfish recovery and generate support for the recovery process.

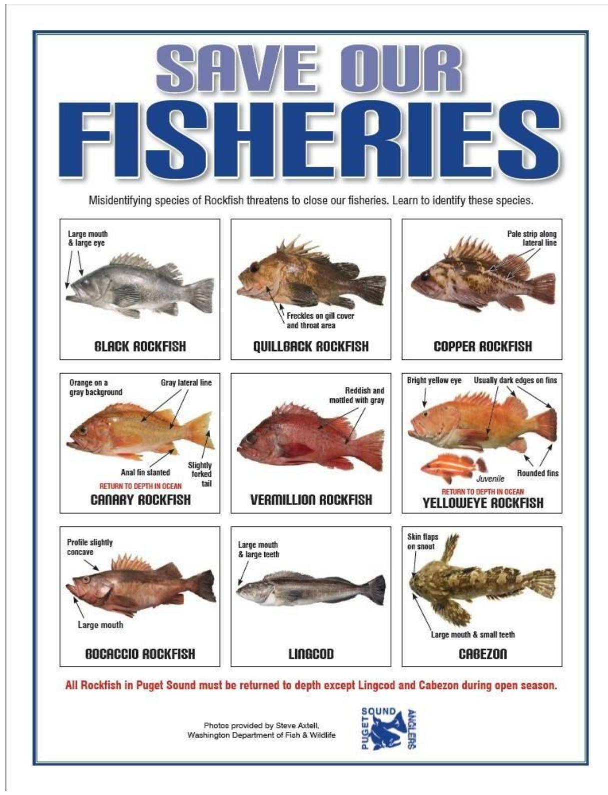
Evaluation and Measurement:

- Number of materials taken from angler contact locations
- Use of the TIP program
- Uploads of mappings apps
- Hits on webpages containing regulations relevant to rockfish

<u>Objective 6</u>: Encourage further recreational angler engagement in rockfish recovery to increase support for rockfish conservation.

Rationale: Anglers bring a variety of experience and expertise to research and monitoring projects. Cooperative projects with anglers and managers/scientists may increase the perceived legitimacy of the research outcomes and the consequent management decisions, resulting in better compliance with regulations (Kuperan and Sutinen 1998). When anglers are encouraged to take responsibility for helping solve management problems it often results in improved stewardship of resources (Granek et al. 2008). Group processing of information may also help reconcile differences between anglers and managers/scientists who use different sources and time frames to come to differing conclusions about the resources (Verweij et al. 2010).

Additionally, there have been successful examples of anglers educating other anglers. Puget Sound Anglers has created and disseminated an angler education guide on rockfish species identification and barotrauma reduction. Just as gear adoption is typically greater when gear is created by a local angler (Jenkins 2010), education and outreach may also be more effective when done by local anglers.



Rockfish identification aid developed by Puget Sound Anglers.

Project(s):

- Create an *Innovative Fishing Initiative* that is designed to promote more cooperative research, monitoring, or compliance partnership programs with local anglers, divers, WDFW, NMFS, MRCs, and other interested local groups in addition to the projects already completed or underway. Ideally, new programs would be duplicated by other collaborators in the Puget Sound/Georgia Basin region and build on the foundation of previous work, expanding to a research and conservation collaborative with stakeholders.
- Encourage further angler education by meeting with angler groups to understand how NMFS and WDFW can support their education efforts through reposting their materials on the agency websites, notifying them of funding opportunities, providing background or scientific materials, or providing other support.

Anticipated Outcome(s): Increased efficacy of rockfish education and outreach, and increased numbers of anglers participating in education, outreach, and stewardship.

Evaluation and Measurement:

- Number of research projects conducted by the *Initiative*
- Percentage of anglers that know regulations, use descending devices, and understand the unique life history of rockfish.

(2) *Commercial Fishers*

Objectives:

1. Continue and expand education and outreach to prevent new lost fishing gear, including:
    - net handling techniques for newer entrants to commercial fisheries to decrease the likelihood of lost nets and pots that could cause mortality to rockfish or harm habitat
    - encourage the use of strong yet biodegradable nets
    - educate anglers about reporting lost gear for expedient retrieval
2. Improve commercial fishers' knowledge about:
    - the longevity of rockfish
    - the importance of rockfish to the ecosystem and commercially targeted species

Objective 1: Continue and expand outreach to prevent new lost fishing gear, including net handling techniques for newer entrants to commercial fisheries to decrease the likelihood of lost nets and pots; encourage the use of strong yet biodegradable nets; and educate fishermen about reporting lost gear for expedient retrieval.

Rationale: Derelict nets can kill rockfish and derelict pots harm their habitat. Antonelis (2013) found that the majority of lost gillnets were lost by new entrants into the fishery and/or lost because of a lack of experience and understanding of the area. Currently, the Northwest Straits Foundation (NWSF) and WDFW have a program designed to increase outreach around preventing lost fishing gear (Gibson 2013). In addition, the use of biodegradable gear would shorten the lifetime of the net and thus the amount of time it would incidentally catch rockfish and harm habitat if lost.

Project(s): Support education and outreach efforts directed at newer and existing fishery entrants through funding or other in-kind support.

Anticipated Outcome(s):

Fewer derelict nets and pots, decreased mortality because of newly lost nets, and a decreased amount of time that nets and pots pose a threat to rockfish and their habitat.

Evaluation and Measurement:

- New derelict gear found and reported by commercial fishermen
- Number of participants in the various education efforts

Objective 2: Improve commercial fishers' knowledge about the longevity of rockfish and their importance to the ecosystem and the commercially targeted species.

Rationale: User groups usually value and exhibit knowledge of species of economic, utilitarian, or cultural significance (Kellert 1985; Martin-Lopez et al. 2007). With the rockfish fishery currently closed and expected to remain so into the foreseeable future, commercial fishermen may not value rockfish unless they understand the contributions of rockfish to the ecosystem.

Project(s):

- Partner with NWSF and WDFW to include in their materials used to train new entrants into fisheries descriptions of rockfish life history/ecology and potential management actions resulting from bycatch, prioritizing halibut, shrimp pot, and salmon fishery participants.

Anticipated Outcome(s): Increased knowledge about how rockfish bycatch could affect management of fisheries, such as salmon or halibut, is also anticipated to promote efforts to avoid bycatch and net loss.

Evaluation and Measurement:

- The number of newly lost nets and pots, the number of reports of lost gear, and gear innovations to prevent or mitigate the loss of commercial fishery gear will be tracked to measure progress toward this objective.

(3) *SCUBA Divers*

Objectives:

1. Improve rockfish identification and reporting.
2. Improve knowledge of rockfish life history, habitat usage, and the role rockfish play in the Puget Sound ecosystem.
3. Utilize current citizen science and develop a young-of-year survey program to encourage more diver engagement in rockfish recovery.

Objective 1: Improve rockfish identification and reporting.

Rationale: Accurate identification of rockfish species, particularly young-of- year rockfish that may be encountered by SCUBA divers, would increase knowledge of the listed species and potentially increase diver investment in rockfish and the utility of future or ongoing cooperative research projects.

Project(s):

Distribute rockfish identification materials (see example on next page) at Puget Sound boat launches, marinas, dive shops, boating supply stores, boat shows, organized diver meetings, diver websites, agency websites, and other areas where divers congregate, prioritizing known diver locations (e.g., Hood Canal, Alki, Friday Harbor, etc.).

- Encourage diver organizations (e.g., REEF) to continue training for accurate species identification, location documentation, how to report sightings, and general rockfish stewardship.
- Encourage reports/pictures of listed rockfish to rockfishid@noaa.gov.

- Develop a rockfish YOY guidebook for scuba divers.
- Utilize social media to increase the viewing frequency of photos of different types of rockfish and recognize success in accurate reporting.

Anticipated Outcome(s): Increased accuracy and reporting of rockfish sightings will contribute to our knowledge of rockfish distribution. More accurate identification is also anticipated to decrease confusion by some stakeholders who may frequently see the more common rockfish species and presume that all species are doing well (Beaudreau et al. 2011), thereby increasing stewardship of the listed species.

Evaluation and Measurement: Number of submissions to rockfishID@noaa.gov and participants actively searching for listed YOY will be tracked to measure progress toward this objective.

__Objective 2__: Improve knowledge of rockfish life history, habitat usage, and the role rockfish play in the Puget Sound ecosystem.

Rationale: User groups with an understanding of species biology (e.g., rockfish longevity) were more likely to support conservation efforts. Additionally, user groups usually value and exhibit knowledge of species viewed as having economic, utilitarian, or cultural significance (Kellert 1985; Martin-Lopez et al. 2007). Without understanding the history of rockfish fisheries and subsequent population decline, divers may not value rockfish recovery efforts unless they understand the contributions of rockfish to the ecosystem (Kellert 1985; Martin-Lopez et al. 2007). Rockfish constitute a significant portion of the total fish assemblage in Puget Sound and are likely present on many popular dive sites, but divers may not be aware of their contributions to the greater ecosystem.

Rockfish scuba outreach flyer developed by NOAA's communication team.

Project(s):

- Distribute materials at angler/diver contact locations designed to help divers understand rockfish life history, habitat usage, and the role rockfish play in the Puget Sound ecosystem.
- Create a short (3 to 5 min.) video to educate stakeholders (same as Objective 4 for Recreational Anglers) about rockfish and what they can do to protect them, and use existing educational videos, such as this regional video on stock assessments at http://www.youtube.com/watch?v=3UbWMdpavUE.
- Engage the dive community through informal presentations at non-profit institutions and clubs heavily populated with recreational divers.

Anticipated Outcome(s): Divers with greater knowledge of rockfish and their role in the ecosystem are anticipated to become more supportive of and involved with rockfish recovery measures (Kellert 1985; Martin-Lopez et al. 2007; Granek et al. 2008; Sawchuk 2012; Sawchuk et al. 2015).

Evaluation and Measurement:

- Number of rockfish educational materials taken from diver locations, presentations delivered to interested stakeholder groups and completion and distribution of the education video will be tracked to measure progress toward this objective. Track number of reports of rockfish by divers in response to NOAA flyer (previous page).

Objective 3: Utilize current citizen science and encourage more diver engagement in rockfish recovery to increase support for rockfish conservation, in particular through development of a citizen YOY survey protocol.

Rationale: Divers already bring a variety of experience, expertise, and often enthusiasm to research and monitoring projects (e.g., REEF). Citizen divers would be able to collect data over wider spatial and temporal scales than current funding of research groups would allow. In addition, cooperative projects that include divers, anglers, and managers/scientists may provide more robust data resulting from variable sampling approaches that minimize overall bias (Beaudreau et al. 2011). Cooperative projects may also increase the perceived legitimacy of the research outcomes and the consequent management decisions, resulting in better compliance with regulations (Kuperan and Sutinen 1998).

Project(s):

- As described above, create an *Innovative Fishing Initiative* that is designed to further promote cooperative research, monitoring, or compliance partnership programs with local divers, anglers, WDFW, NMFS, MRCs, and other interested local groups in addition to the projects already completed or are underway. New programs would ideally be created so they may be duplicated by other collaborators in the Puget Sound/Georgia Basin and build on the foundation of previous work, expanding to a research and conservation collaborative with stakeholders.
- Encourage diver education by meeting with diver groups to understand how NMFS and WDFW can support their education efforts through reposting their materials on the agency websites, notifying them of funding opportunities, providing background or scientific materials, or providing other support.
- Develop a citizen science YOY survey program that will collect data throughout the five basins of Puget Sound. This work will provide valuable data on spatial and temporal dynamics of rockfish recruitment and provide a tangible path for divers to aid in the recovery of listed rockfish.

Anticipated Outcome(s): Increased efficacy of rockfish education and outreach, and increased numbers of divers participating in education, outreach, and stewardship. This outreach is anticipated to increase diver stewardship and support for rockfish recovery and lead to a closer working relationship and exchange of ideas between divers and managers/scientists.

Evaluation and Measurement:

- Number of research projects conducted by the *Initiative* and number of joint meetings will be tracked to measure progress toward this objective.

(4) ***General Public***

Objectives:

1. Improve knowledge of rockfish life history and their role in the Puget Sound ecosystem, especially with regard to ecosystem benefits from rockfish recovery.
2. Increase public support for funding of rockfish recovery.
3. Improve the public's knowledge about the steps they can take to support rockfish recovery and improve the Puget Sound ecosystem.

Objective 1: Improve knowledge of rockfish life history in the Puget Sound ecosystem, especially with regard to ecosystem benefits (such as benefits to salmon) from rockfish recovery.

Rationale: Support and participation from stakeholders are fundamental to successful conservation and are often a function of literacy on the issues (Stankey and Shindler 2006). Because rockfish recovery will require sustained support over decades, stakeholder involvement is essential. Like outreach to anglers, it will be important to highlight the role rockfish play in the ecosystem. Members of the public may also be more likely to support recovery when they understand how long-lived rockfish can be and when they understand the ecosystem links that rockfish have to salmon, which are better understood and supported in the region.

Project(s):

- ➢ Partner with the Seattle Aquarium and other environmental education groups to expand their outreach material about rockfish (i.e., kits that could be used by a variety of educators) explaining the importance of rockfish in Puget Sound, as well as use information already produced (by the Seattle Aquarium or others). Distribute this information through social media, YouTube, websites, press releases, signs, aquaria and zoos, and other public places.
- ➢ Coordinate with the Seattle Aquarium to introduce rockfish information into the Seattle Beach Naturalist Program curriculum and other outreach programs. Build upon and expand current activities (i.e., games, art, etc.) that help people connect with rockfish, such as the Seattle Aquarium's rockfish scavenger hunt.

Anticipated Outcome(s): Increased understanding of rockfish that will translate into long-term public support for rockfish recovery.

Evaluation and Measurement:

- Numbers of programs using outreach material distributed by the Seattle Aquarium and other environmental education groups.
- Partner with the Seattle Aquarium and other aquaria to evaluate progress toward objective and consider using their internal evaluation of success.

Objective 2: Increase public support and backing for funding of rockfish recovery.

Rationale: Recovery will be long term and require support from the public to be successful, including funding (Stankey and Shindler 2006).

Project(s):

- Partner with WDFW, zoos and aquaria, non-profit organizations, and conservation organizations to develop a campaign around supporting rockfish recovery efforts (i.e., combine funding for aforementioned projects). Encourage partners to evaluate the feasibility of new and innovative fundraising, such as crowd-funding recovery work. WDFW currently has a rockfish recovery fund that is supported by license sales; consider how this fund could be increased by related sales, such as a rockfish license plate.

Anticipated Outcome(s): Increased support and funding for rockfish recovery.

Evaluation and Measurement:

- Rockfish funding provided to WDFW and other organizations will be tracked to measure progress toward this objective.

Objective 3: Improve the public's knowledge about the steps they can take to support rockfish recovery and improve the Puget Sound ecosystem on which rockfish and other species depend.

Rationale: Some of the threats faced by rockfish, such as poor water quality, climate change, and ocean acidification, are the result of (or exacerbated by) accumulation of non-point source pollution and will require, in part, behavioral changes by the public to reduce these sources of pollution.

Project(s):

- Use existing NOAA Fisheries Service material that directs people to take local actions (http://www.westcoast.fisheries.noaa.gov/education/takeaction/index.html) and, with partner organizations, further develop calls to action that can aid recovery. Disseminate these messages via social media, websites, festivals, and other public events. Add social media links to all signs, brochures, websites, etc. to broaden public outreach. Emphasize that what is good for rockfish is good for the ecosystem at large, and that every positive action helps. Use the existing "5-ways" stewardship handout and create others for further dissemination. Use consistent branding in outreach to recreational anglers.

Anticipated Outcome(s): Small-scale, local changes in behavior that reduce threats to rockfish.

Evaluation and Measurement:

- Number of materials disseminated will be tracked to measure progress toward this objective.

(5) ***Formal and Informal Education for Students***

Objectives:

1. Improve knowledge of rockfish life history and their role in the Puget Sound/Georgia Basin ecosystem, especially with regard to interactions with salmon and other species.
2. Improve knowledge about the steps young people can take to support rockfish recovery and about the role of management in the recovery process.

Objective 1: Improve knowledge of rockfish life history and the role rockfish play in the Puget Sound/Georgia Basin ecosystem, especially with regard to interactions with salmon and other species.

Rationale: Rockfish recovery will require support for many decades, and current students may become recreational anglers, commercial fishers, and decision-makers.

Project(s):

- Expand NMFS school and classroom work to include rockfish in the curriculum using the STEM approach and aligning all efforts with Next Generation Science Standards.
- Develop and disseminate new lessons or units specifically on rockfish.

Anticipated Outcome(s): Long-term support for rockfish recovery and education of future recreational anglers, commercial fishers, and decision-makers.

Evaluation and Measurement:

- Number of lessons developed and disseminated.

Objective 2: Improve awareness among young adults and children about the available steps to support rockfish recovery and about the role of management in the recovery process.

Rationale: Some of the threats faced by rockfish, such as poor water quality, climate change, and ocean acidification, are the result of (or exacerbated by) accumulation of non-point source pollution and will require behavior changes by the public to reduce these impacts. It is also important to connect the role of management to recovery to achieve support for recovery actions for future generations.

Project(s):

- Use existing and create new material that directs students to take local actions (as mentioned above, “5-ways stewardship”: prevent toxic chemicals from entering waterways, help prevent water pollution, minimize plastics use and waste, minimize driving, etc.), and develop further calls to action with partner organizations that can aid recovery and disseminate these messages through outreach to schools.
- Use social studies standards to help students understand connections between humans and oceans and the roles civic engagement have in sustainable resource management.

Anticipated Outcome(s): Small-scale, long-term local changes in behavior that reduce threats to rockfish recovery.

Evaluation and Measurement:

- Integration of rockfish educational material in school materials

Table 1.Summary of rockfish outreach and education projects.

Objectives	Project(s)
Recreational Anglers	
1. Improve rockfish identification and bycatch documentation.	• Widely disseminate existing identification materials (WDFW, Puget Sound Anglers) to angler contact locations. • Create signs for boat launches. • Consider mobile fishing apps for improved rockfish identification.
2. Educate anglers about the importance of rockfish catch avoidance.	• Increase distribution of existing catch avoidance materials (WDFW) to angler contact locations, including information about why it is preferred over catch and release at depth.
3. Educate anglers about how to safely release rockfish at depth to decrease barotraumas.	• Disseminate information at angler contact locations on best handling techniques. • Consider, with WDFW, requiring use of descending devices; continue/expand current WDFW/Puget Sound Angler program that distributes devices free or at reduced cost.
4. Improve knowledge of rockfish life history, habitat use, and the role they play in the ecosystem.	• Create and distribute at angler contact locations material to help anglers better understand rockfish; use existing material. • Create a short educational video.
5. Improve understanding of regulations and current efforts to recover rockfish.	• Use existing WDFW materials and create new ones on regulations and recovery actions for distribution at angler contact locations.
6. Encourage more angler engagement in rockfish recovery.	• Continue and expand cooperative rockfish research with anglers; promote further education of anglers by anglers.
Commercial Fishers	
1. Continue education to prevent new derelict gear loss; improve new entrants' net handling capabilities.	• Support the Northwest Straits Commission/WDFW and other entities in their education and outreach efforts for new entrants into fisheries through funding or other in-kind contributions.
2. Improve fishers' knowledge about rockfish life history and their role in the ecosystem.	• Partner with the Northwest Straits Commission/WDFW to include life history and ecological information in their net loss trainings, as well as information about how rockfish bycatch could affect their bottom line.
Divers	
1. Improve rockfish identification and YOY documentation.	• Widely disseminate existing identification materials (WDFW, Puget Sound Anglers) to diver contact locations. • Cooperate with local groups already doing identification (e.g., REEF/Seattle Aquarium). • Encourage reports of listed rockfish documented by divers to *rockfishid@noaa.gov*.

Objectives	Project(s)
2. Improve knowledge of rockfish life history, habitat use, and the role they play in the ecosystem.	• Create and distribute at diver contact locations material to help divers better understand rockfish. • Create a short educational video.
3. Encourage more diver engagement in rockfish recovery.	• Continue and expand cooperative rockfish research with divers; promote further education of divers by divers.
General Public	
1. Improve knowledge of rockfish life history and their role in the ecosystem.	• Use existing material from the Seattle Aquarium/other partners and distribute further through social media, press releases, public places, etc. • Develop an Outreach Kit; resources, such as hands on model of "Rosy the Rockfish;" and identification tip handouts. • Coordinate with Seattle Aquarium to introduce more rockfish information into their Beach Naturalist curriculum and other outreach programs.
2. Increase support for funding of rockfish recovery.	• Partner with zoos/aquaria to develop a campaign around supporting rockfish recovery efforts. Encourage partners to consider crowd funding.
3. Improve knowledge about the steps the public can take to support recovery.	• Use existing "5-ways stewardship" handout and create others for further dissemination. Use consistent branding in outreach to recreational anglers.
Formal and Informal Student Education	
1. Improve children's knowledge about rockfish life history and their role in the ecosystem.	• Expand NOAA fisheries current school and classroom work to include rockfish in the curriculum using the STEM approach and diversity initiatives and aligning efforts with Next Generation Science Standards. • Create a rockfish mural painting contest to raise awareness.
2. Improve knowledge about the steps children can take to support rockfish recovery.	• Use existing and create new calls to action to help children understand ways they can help rockfish recovery through informed, everyday choices. Use social studies standards to help students understand connections between oceans and humans, and the role of governance and civic engagement in resource management.

Finally, because improving knowledge about rockfish and their role in the ecosystem is a priority for all stakeholders, we have worked with partners to develop a graphic to communicate this often complex information in a simplified manner. This graphic is intended to create more awareness about rockfish and their role in the Puget Sound ecosystem, as well as to provide increased recognition of rockfish-related outreach products.

CONCLUSION

This appendix describes in detail the particular audiences, objectives, and projects for outreach and education to support the recovery of listed rockfish. Education, outreach, and public involvement are prioritized because understanding, support, and participation from stakeholders are fundamental to successful conservation. Early partnerships with recreational fishers, scuba divers, and WDFW has led to the initiation and completion of successful conservation/education projects. Sustained effort will be needed to expand and diversify these partnerships and further support listed rockfish recovery.

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APPENDIX II

FISHERIES MANAGEMENT

Rockfish Bycatch Management in the U.S. Portion of the Puget Sound/Georgia Basin DPSs

OVERVIEW

This appendix provides guidance for managing the risk of fisheries bycatch of yelloweye rockfish and bocaccio (hereafter listed rockfish) within the boundaries of the U.S. portion of the Puget Sound/Georgia Basin DPSs, as discussed in the Recovery Plan (Section II. E. Factors Contributing to Decline and Federal Listing). Direct harvest is not allowed under current Washington State (non-tribal) fishery regulations, though bycatch from some fisheries does occur. Recommendations for fishery management to protect listed rockfish are based on the general principles described below, which are used to conserve rockfish within the range of the DPSs under Canadian jurisdiction (Yamanaka and Logan 2010), and are included in numerous publications regarding rockfish conservation on the West Coast (i.e., Parker et al. 2000). These principles were used to inform Section V. A. Recovery Action 2, Fisheries Management, consistent with recovery goals in the Recovery Plan.

As described in the Recovery Plan (Section V. Recovery Program, Recovery Action number 4):

Fishery Management Principles:

1. Improve knowledge of listed rockfish status and spatiotemporal habitat usage.
2. Account for all bycatch to the greatest extent practicable with statistically valid estimation techniques.
3. Limit bycatch mortality to risk-averse, precautionary guidelines at appropriate scales.
4. Establish areas that are closed to fisheries with potential bycatch mortality in accordance with the priorities listed in Table 3.
5. Enforce fishery regulations, with emphasis patrols directed at newly enacted rules.

The following sections expand upon these principles for their application to U.S. waters of the DPSs.

1. Improve knowledge of stock status and spatiotemporal habitat usage.

Improving knowledge of listed rockfish status includes enhanced information about abundance, spatial structure, diversity and productivity (population characteristics), and habitat associations. This requires investigations of both historical and contemporary population characteristics, and investigations listed in Table 1 should be prioritized for each management unit:

Table 1. Research needs to assess stock status and habitat use by Management Unit.

Research Need (P: Primary data need, S: Secondary data need)					
	San Juan	**Main Basin**	**Hood Canal**	**South Puget Sound**	**Canada**
ROV and other surveys for species presence/ demographic information and habitat associations (*spatial structure*) +*	P	P	P	S	P
High-resolution benthic habitat mapping*	S[2]	P	P	P	S
Historical spatial data archive (*consisting of fishery/research records, fishing guide books, and interview-derived data*)	P	P	P	P	S
Larval abundance surveys	S	S	S	S	S
Annual nearshore/young-of-year surveys	P	P	P	P	P
Identification of genetic structure (for bocaccio).	P	P	P	P	P

[2] Greene and Barrie (2011) have developed high resolution habitat maps for much of the San Juan Basin. Additional mapping is needed in the eastern and southern portion of this basin.
* Additionally, these data can then be used to develop a rockfish connectivity/habitat suitability model.
[+] Surveys should occur periodically (at minimum every 5 years) as part of continued adaptive management and monitoring of recovery actions and population status.

2. Account for all bycatch with statistically valid estimation techniques.

Accounting for commercial and recreational fishery bycatch of listed rockfish is essential for estimating mortality rates and subsequent impacts to population abundance, productivity, spatial structure, and recovery. Most non-tribal commercial fisheries that targeted rockfish/bottom fish have been closed by WDFW over the past several decades; thus, it is likely that the greatest risk of bycatch comes from recreational fisheries and a few remaining commercial fisheries. Accurately enumerating bycatch for recreational fisheries is extremely difficult. The WDFW recreational bycatch estimates for listed rockfish are highly variable—ranging from zero to several hundred in 1 year (WDFW 2012[1]). This variability may be due to a number of factors, including: 1) low encounter frequency for listed rockfish; 2) poor species identification of rockfish by many anglers in Puget Sound[2]; 3) the lack of creel survey data on fishing trips from marinas, private docks, or other places without a public boat launch; 4) the low frequency of angler interviews at public boat ramps (10 to 20 percent of trips), which could lead to sporadic or episodic documentation of bycatch, especially when combined with low rockfish encounter rates; and 5) under-reporting bycatch for various reasons, including an incomplete understanding of harvest restrictions.

The Pacific States Fishery Management Council has developed methods to determine the ratio of lethal and non-lethal take for listed rockfish bycatch, depending on the depth of capture (PFMC 2008, 2014). This assessment method should be modified, as appropriate, pending further long-term survival and productivity studies of released listed rockfish and the use of descending devices.

Further fisheries assessment in most of the DPSs (in all areas outside the San Juan Islands/Strait of Juan de Fuca) (see Tables 3 and 4 below) areas are needed to complete this action. This can be done by

1 WDFW. 2012. Fishery conservation plan submitted to NOAA.
2 Sawchuk, J. 2012, Sawchuk et al. 2015. (5 percent of bocaccio and 31 percent of yelloweye rockfish correctly identified to species by recreational anglers).

integrating ongoing rockfish ROV survey data and additional bycatch risk data. This action could result in a peer-reviewed report that recommends: a) pursuit of additional protective measures (as warranted) and/or b) additional data collection. This report could be used to inform further communication and action on this topic.

3. Limit bycatch mortality to risk-averse, precautionary guidelines at appropriate scales.

Outside of the Puget Sound/Georgia Basin, yelloweye rockfish and bocaccio are managed under the provisions of the Magnuson-Stevens Fishery Conservation and Management Act (MSA), and yelloweye rockfish and bocaccio have been designated as "overfished." Yelloweye rockfish were declared overfished in 2002 (Taylor 2011) and bocaccio were declared overfished in 1996 (Field 2011). Bocaccio were declared "rebuilt" in 2017 (He and Field 2017). The "overfished" designation is for stocks estimated to be below 25 percent of unexploited biomass ($B_{25\%}$) and require the development of a Rebuilding Plan. Rebuilding Plans typically include analyses to determine the minimum time to recover to biomass maximum sustainable yield ($B_{MSY;}$ biomass that enables a fish stock to deliver maximum sustainable yield) and the fishing mortality that is consistent with stock recovery within the required timeframe of the MSA. While ESA-listed rockfish in the Puget Sound/Georgia Basin are not managed under the provisions of the MSA, the Rebuilding Plans for coastal yelloweye rockfish and bocaccio nonetheless provide insight into implementing fisheries management in Puget Sound consistent with recovery for the following reasons:

- The Biomass (B) of yelloweye rockfish or bocaccio of the Puget Sound/Georgia Basin has not been determined throughout the full range of each DPS. In Canada, yelloweye rockfish biomass is estimated to be 12 percent of the unfished stock size on the inside waters of Vancouver Island (DFO 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). It is very likely, given the information available, that levels are well below $B_{25\%}$.
- Rebuilding Plans are developed with best available science and analysis of the probabilities of species recovery, and important aspects of the life history of yelloweye rockfish and bocaccio are generally better understood for coastal populations compared to listed rockfish of the Puget Sound/Georgia Basin.
- The current Rebuilding Plans for yelloweye rockfish and bocaccio outside the Puget Sound/Georgia Basin include important life-history information and exploitation ceilings, with annual mortality rates equating to 20 percent to 30 percent of natural mortality (Table 2).

Table 2. Natural mortality and fisheries mortality within rebuilding plans.

	FSPR rebuild (fisheries mortality per spawning biomass recruit)	Natural mortality (instantaneous)	Fisheries mortality (instantaneous)
Yelloweye rockfish	0.0095	0.0462381	0.205458
Bocaccio	0.0467	0.15	0.3113333

Using the framework and exploitation ceilings of the Rebuilding Plans for listed rockfish requires the assumption that basic life history of coastal yelloweye rockfish and bocaccio are similar to the listed DPSs in Puget Sound. This is likely the case, with the caveat that productivity of rockfish in Puget Sound may be reduced compared to coastal rockfish. West et al. (2014) found that quillback rockfish (*Sebastes maliger*) growth from oceanic to inland waters of the Salish Sea was reduced, which was attributed to a potential combination of water properties (temperature and salinity), habitat quality, fishery exploitation, and pollution. In addition, most of the Puget Sound Basins are relatively isolated because of the sills at Deception Pass, Tacoma Narrows, and Hood Canal. These sills likely reduce larval transport from one basin to the next. Based on these considerations, fishery management assessments for listed rockfish in the Puget Sound/Georgian Basin DPSs should, to the greatest extent practicable, use exploitation rates that are below rates used for yelloweye rockfish and bocaccio under MSA rebuilding scenarios.

Where sufficient data are available, assessing the effects of bycatch mortality on population viability of rockfish should occur in the context of 1) the percentage of the population killed; 2) the impacts on population demographics from selectivity; and 3) the spatial scope of specific impacts (on a management unit scale, as appropriate). To date, there is only very coarse information on the amount of bycatch, where the bycatch occurs, and the overall population size for yelloweye rockfish and bocaccio in the Puget Sound/Georgia Basin. The Recovery Plan includes research projects to increase our knowledge of population size and demographic characteristics, but gaining additional precision on bycatch from fisheries may be difficult.

Appropriate Scales for Assessing Mortality

To protect metapopulation structure, precautionary mortality rates should be measured on the scale of each of the four management units in the U.S. portion of the DPSs. At present, there are no population estimates in the management units aside from the San Juan management unit; thus, the application of assessing mortality rates at the management unit scale should occur after there are empirically derived population estimates for each species in each management unit.

4. **Establish areas that are closed to fisheries with potential bycatch mortality in accordance with the priorities listed in Table 3 and Table 4.**

This Recovery Plan identifies conservation or protected areas as an action to address fishery interactions and support recovery in accordance with the priorities listed in Table 3 and further details in Table 4. Refer to the threats assessment within the Recovery Plan for risk of bycatch from fisheries that provides rationale for these priorities (Tables 5-13 in Recovery Plan). The protection of specific areas that host rockfish can reduce threats and contribute to the restoration of population abundance, and size and age diversity. The benefits of conservation from protection areas has been well documented in the literature (Aburto-Oropeza 2011; Guidetti et al. 2014; Frid et al. 2016), and the need for these areas was also called for by WDFW (WDFW 2011), though pursuing this management approach has recently been de-emphasized by WDFW (WDFW 2015; WDFW 2016). Marine protected areas (MPAs) for rockfish and other species with similar life histories have been key for protection in networks of MPAs that have been developed in several states and countries, particularly on the west coast of North America in Alaska; British Columbia, Canada; Oregon; California; and Baja California Sur, Mexico.

WDFW put regulations into place in 2010 to limit bycatch; however, as identified in the threats assessment, the San Juan Basin and the eastern Strait of Juan de Fuca are still at high risk for bycatch (see Tables 3 and 4), though the extent of this bycatch is not well understood. We recommend beginning the scientific and public process to better track bycatch and bycatch risk, and assess the need for establishing marine protected or rockfish conservation areas for this high priority area to protect listed rockfish, with potential designation after the first 5 years of implementation of this plan. These areas also have the most rockfish habitat. In other areas where additional information is needed, we recommend further assessment to determine whether spatial protection or other improved fisheries management protections are needed.

Table 3. Relative priorities for MPA/RCA establishment by Management Area.

Management Unit within U.S. portion of the Puget Sound/Georgia Basin	**RCAs/MPAs Priority**	
	Yelloweye rockfish	**Bocaccio***
San Juan/Strait of Juan de Fuca	High Priority	Low Priority
Main Basin	Medium Priority	Low Priority
Hood Canal	Low Priority	Low Priority
South Sound	Low Priority	Low Priority

* Bocaccio move more as adults than yelloweye rockfish, which have very high site fidelity; therefore, the benefits of RCAs/MPAs to bocaccio may be less than the benefits to yelloweye rockfish.

Priorities were calculated by examining effort (commercial effort and type and recreational fishing trips and type), available rockfish habitat, existing protections to protect rockfish by each management unit, and risk to listed rockfish decline as a result of spatial and genetic isolation.

Table 4. Detailed Assessment for Priorities for MPA/RCA establishment by Management Area.

Mgmt. Unit	**Fisheries w/ Rockfish Bycatch Risk[1]**	**Rec. Trips (Bottom Fish) Rockfish Bycatch Risk[2]**	**Rec. Trips (Halibut) Rockfish Bycatch Risk[2]**	**Rec. Trips (Salmon) Rockfish Bycatch Risk[2]**	**Rec. Trips (Other) Rockfish Bycatch Risk[2]**	**Significant Regulations Affecting Rockfish Bycatch w/ Known High Compliance[3]**	**Spatial Isolation Risk (Genetics + Geography)[4]**	**Rockfish Habitat[5] (sq. mi.)**	**Priority Ranking**
Canada	-	-	-	-	-	-	-	-	N/A-RCA network exists
San Juan Is / Strait of Juan de Fuca	Halibut longline – *High* risk Salmon fisheries – Low risk Shrimp fisheries – Low risk	78,202 *High* risk	58,688 *High* risk	436,977 Moderate risk	15,489 Un-known risk	WDFW closure of most commercial fisheries with rockfish bycatch; no recreational rockfish targeting or retention	Moderate genetic Moderate spatial	533	High
Main Basin (includes Whidbey Basin)	Salmon fisheries – Low risk Halibut longline – *More information needed for assessment* Shrimp fisheries – Low risk	109,228 *High* risk	12,896 Low risk	1,457,346 Moderate risk	52,373 Un-known risk	WDFW closure of most commercial fisheries with rockfish bycatch; no recreational rockfish targeting or retention	Moderate genetic Moderate spatial	361	Medium

Mgmt. Unit	Fisheries w/ Rockfish Bycatch Risk[1]	Rec. Trips (Bottom Fish) Rockfish Bycatch Risk[2]	Rec. Trips (Halibut) Rockfish Bycatch Risk[2]	Rec. Trips (Salmon) Rockfish Bycatch Risk[2]	Rec. Trips (Other) Rockfish Bycatch Risk[2]	Significant Regulations Affecting Rockfish Bycatch w/ Known High Compliance[3]	Spatial Isolation Risk (Genetics + Geography) [4]	Rockfish Habitat[5] (sq. mi.)	Priority Ranking
South Sound	NA	30,102 Low risk	0 N/A	122,933 Low risk	16,237 Un-known risk	WDFW closure of most commercial fisheries with rockfish bycatch; no recreational rockfish targeting or retention	*High* genetic *High* spatial	102.4	Low
Hood Canal	Shrimp fisheries – Moderate risk	3,028 Low risk	132 Very Low risk	56,042 Low risk	11,097 Un-known risk	Long-term WDFW recreational bottom fish closure; no recreational rockfish targeting or retention	*High* genetic *High* spatial	66.8	Low

[1] Risk is rated by considering both risk of bycatch by fishery/fishing type and number of trips/effort for both commercial and recreational fisheries.
[2] Includes 2010-2014 WDFW creel survey trip estimates. Risk is rated by considering both risk of bycatch by fishery and number of trips.
[3] In 2010, WDFW also put into place a no retention regulation and 120-ft. depth restriction while bottom fishing to decrease rockfish bycatch in recreational fisheries (this regulation is difficult to enforce, compliance is unknown, and it does not apply to fishers targeting halibut) and closed several commercial fisheries (see list in Recovery Plan, Section F. and full list of fisheries and bycatch risk in Section E. Table 4).
[4] This column considers listed rockfish decline as a result of spatial and genetic isolation, which can exacerbate fisheries effects. Hood Canal and South Sound waters also both have long residency times and Hood Canal is subject to episodes of low dissolved oxygen.
[5] Includes nearshore and deepwater critical habitat prior to exclusions, 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).
Note: recreational shrimp fisheries are not listed in the table. Though we assess this fishery to be low risk, further information about the risk of this fishery as well as the effects of the commercial fishery will be integrated into this assessment as it becomes available.

Though there are some marine reserves within the Puget Sound region, they cover a relatively small area and most do not encompass rockfish habitat and are poorly enforced (Don 2002). While existing reserves that encompass rockfish habitat generally support higher densities of rockfish than outside areas (Palsson et al. 2009), most reserves in Puget Sound were established over several decades with unique and somewhat unrelated ecological goals. Therefore, given these traits of existing reserves, their net benefit to listed rockfish abundance, productivity, and spatial structure is probably very small (75 Fed. Reg. 22276, April 28, 2010). Recreational anglers targeting bottom fish are limited to depths shallower than 120 feet (36.6m), which if enforced, provides good protection for deepwater yelloweye rockfish and bocaccio. However, this rule addresses one fishery sector, and other recreational and commercial fisheries result in bycatch that is difficult to quantify. As a result, additional risk assessments in the San Juan area in particular are warranted.

Some of the guidance for this section comes from a workshop held for creating marine harvest refugia for West Coast rockfish (Yoklavich 1998), a document specifying the establishment criteria of no-take refuges for rockfish in Puget Sound (Palsson 2004), and from a Salish Sea rockfish workshop conducted in 2011 (Tonnes 2012).

There are numerous terms used to refer to protected areas in the water, including marine protected areas, marine reserves, marine sanctuaries, bottom fish recovery zones, and stewardship areas, among others. We refer to two separate types of protected areas that could be used to contribute to listed rockfish recovery (see side panel). If correctly established, a network of Rockfish Conservation Areas (RCAs) or Marine Reserves/Protected Areas (or a combination) will contribute to listed rockfish recovery. These protected area types are referred to as "reserves" within this appendix.

> The term **Rockfish Conservation Area (RCAs)** refers to specific areas designed to rebuild rockfish stocks. An RCA has specific fishing restrictions intended to eliminate catch/bycatch of rockfish at the site and to protect rockfish habitats.
>
> The term **Marine Reserve or Marine Protected Area** refers to specific designated areas that: 1) may offer habitat protections above and beyond adjacent non-reserve sites, and 2) prohibit harvest of fish and invertebrates within the site. Marine Reserves or Marine Protected Areas usually protect a greater diversity of fish, invertebrates, and habitats than RCAs.

Many researchers have documented that well-established and well-enforced reserve systems have numerous positive effects, such as increased species abundance, biomass, richness, size, and reproductive output (e.g., Cote et al. 2001; Gell and Roberts 2003; Lester et al. 2009; Molloy et al. 2009; Edgar et al. 2014; and others).

The *biological goals* for additional reserves in the U.S. portion of the rockfish DPSs should include:

- Support metapopulation diversity/restore overall abundance/protect and maintain spawning biomass to sustainable levels.
- Enable proportionally appropriate size and age structure of a population.
- Buffer for uncertainty regarding fish populations, habitat changes over time, etc.
- Buffer for natural (e.g., disease) or anthropogenic (e.g., oil spills) catastrophic events.
- Benefit as many forage species as possible (forage assemblage recovery is good for rockfish recovery).
- Enhance protection of rockfish habitat and prey resource habitat where warranted.

In order to best achieve these biological goals a reserve system should have the following *attributes*:

- 20 to 30 percent of listed rockfish habitat, within a particular management unit, free from risk of bycatch.
- Potential "replicate" reserve and non-reserve sites that enhance effectiveness monitoring and adaptive management (and index monitoring sites).
- Proximity between sites that enables larval and juvenile connectivity.[3]
- Multiple sites that cover a range and diversity of listed rockfish habitats.

[3] Connectivity could be estimated based on surveys and modeling that accounts for local oceanographic conditions and larval behavior, etc. See Shanks et al. 2003.

The *ecological design* (size/shape, number, and location of sites) of a reserve system should consider the following factors:

- Quality and diversity of habitats protected—perhaps the most important factor. A diversity of habitats are required to support different species and ontogenetic stages (e.g., Yoklavich 1998; Carr and Raimondi 1999; Crowder et al. 2000; Roberts et al. 2005; Shanks et al. 2003; Parnell et al. 2006).
- Fishery management (and enforcement/compliance rates, potential effects of displaced fisheries) measures occurring *outside* of the reserve system, and relative risk of bycatch inside and outside the reserves.
- Home ranges of the targeted species (e.g., Shanks et al. 2003; STAC 2008) and their prey species (diet and seasonal movement patterns), recognizing that benefits of reserves usually increase with size (Edgar et al. 2014).
- Characteristics of local benthic habitats (rugosity, slope, flow velocity, substrates) and variability in these attributes that might produce a dynamic patch-based complex of habitat types.
- Existing fish and invertebrate population characteristics (abundance/size distributions and relative diversity of fish and invertebrate species).
- Evidence of historical occupancy and abundance of target species.
- Onshore to offshore corridors to encompass a range of depths.
- Proximity to and quality of rearing/settlement habitats.
- Localized oceanographic features such as tidal gyres, tidal pumps, wind forcing, and estuarine circulation (some of these features may determine recruitment areas and/or larval retention and connectivity to adjacent rockfish habitats).
- Adjacency to existing reserves or no-take areas.
- Adjacency to marine mammal haul-out sites and a predation risk assessment (e.g., Lance et al. 2012).

In addition to biological and ecological considerations and attributes, recognizing Puget Sound Treaty tribal rights and input is essential to the process of reserve design and designation. The Northwest Indian Fisheries Commission (Frank 2003) provided a suggested *General Assessment Framework* for proposed marine protected areas in Puget Sound. This assessment framework included a number of questions, many of which provide a template for communication with co-managers and stakeholders, and socioeconomic analysis for a reserve system. These questions are summarized below:

1) What is the threat, problem, or situation that is triggering the proposal for an MPA?
2) What is the current status of the resource and what is the desired future status (goals and objectives) that will result from the proposed management action?
3) What are the specific goals and objectives identified for the proposed affected area (including the anticipated time periods over which the goals and objectives will be achieved)?
4) Is the scientific information sufficient to determine need and an appropriate response?
5) Which marine resource(s) is targeted by the research and recovery proposal?
6) How does this proposal fit in with harvest management plans and habitat management plans (for upland, nearshore, and deepwater areas) related to the targeted resource?

7) What other alternatives, voluntary or regulatory, will achieve the same goals and objectives (identified in response to question 2 above) with less impact on tribes exercising their treaty rights?
8) How will progress be monitored and "success" be measured? Who will conduct these monitoring and evaluation activities?
9) How will adaptive management be utilized to modify the goals and objectives of the MPA?
10) Who are the parties that make the decisions? On what basis?

In addition to the guidance within Frank (2003), including other socioeconomic factors within the process of reserve design and designation is essential to development of a reserve system that can succeed biologically. There have been several recent assessments of marine reserve creation in Puget Sound that discussed socioeconomic considerations, such as access and stakeholder participation (Van Cleave et al. 2009; Osterberg 2012). As part of local attempts to recover bottom fish, McConnell and Dinnel (2002) developed a "social matrix" to grade eight potential marine reserve sites in Skagit County. The factors considered included valuations of the degree of historical monitoring, commercial salmon fishing, sport salmon fishing, tribal salmon fishing, present degree of habitat protection, ease of stewardship, educational value, local sport fisher agreement, local commercial fisher agreement, and local diver agreement (McConnell and Dinnel 2002). Additional socioeconomic issues associated with the establishment of reserves that should be considered include, but are not limited to, the following:

- Best practices for constituent communication (Marine Protected Areas Federal Advisory Committee 2014).
- Engaging communities in marine protected areas: concepts and strategies (Davies et al. 2014).
- Lessons learned from recent marine protected area designations in the United States (Bernstein et al. 2004).

Monitoring and Adaptive Management of Reserves:

A detailed monitoring and adaptive management plan will need to be developed for any reserve system in Puget Sound. The framework for such a plan should include:

- Phased implementation to allow surveys to occur prior to designation, and assessment of the presence of target species and habitats.
- Development of regional and/or site-specific management plans regarding allowed activities, outreach, enforcement, and monitoring.
- Periodic fishery-independent (e.g., ROV, scuba) surveys within reserves and reference sites (e.g., Babcock and MacCall 2011) to document potential changes to habitat characteristics, listed rockfish (and prey) habitat associations, abundance, and population characteristics enabling a calculation of length-based spawning potential ratio.
- Results from these surveys and other research actions will be used to inform future management and research and be made available to stakeholders.
- Ongoing coordination with stakeholders regarding the success and any necessary adaptive management of conservation areas.

5. Enforce fishery regulations.

Currently, enforcement of some recreational and commercial fisheries may be insufficient to protect against intentional catch or unintentional bycatch (Drake et al. 2010). Literature on reserves identifies enforcement as a key factor in the success of protected areas (e.g., Edgar et al. 2014). Therefore, despite challenges presented by limited resources and the large areal extent of the recreational and commercial fishery operational areas, enforcement is imperative.

A Canadian study that compared creel survey reports to actual observer-generated information on recreational fishing boats in the Georgia Strait found substantial differences in the two data sets. The number of released fishes observed was significantly higher than those reported by anglers during creel surveys (Deiwert et al. 2005). This incorrect accounting may be particularly problematic for the listed deepwater species of rockfish that may not survive their release (Palsson et al. 2009).

There may be various reasons for this regulatory non-compliance. Sawchuk (2012) found that many recreational anglers within the DPSs in Puget Sound were not aware of some of the regulations intended to protect rockfish. While approximately 90 percent of boat-based anglers fishing for bottom fish were aware of the “no rockfish retention” regulation, only about 40 percent knew about the 120-foot (36.6-m) depth restriction while bottom fishing (Sawchuk 2012). Of the anglers who stated they fished for salmon, 36 percent did not know about the no retention regulation (Sawchuk 2012). Many anglers also expressed a concern about insufficient enforcement of existing regulations and poaching when questioned about their perceived risks to rockfish (Sawchuk 2012). The 120-foot (36.6-m) depth restriction regulation may be especially difficult to enforce because boats drift into deeper waters and because an enforcement officer may not be able to tell which type of fish an angler is targeting (e.g., halibut vs. lingcod) (Sawchuk 2012).

Additional on-the-water patrols may help to ensure recreational bycatch is not under-reported and that regulations enacted to protect listed rockfish are known and followed. In particular, there should be more emphasis on enforcing the recently enacted 120-foot depth limit while bottom fishing and assessing the enforcement probabilities of that regulation. If RCAs or MCAs are utilized, patrols should focus on those areas, which could be more straightforward to enforce.

Though most commercial fisheries with rockfish bycatch have been closed, further enforcement for that sector is recommended. Enforcement coordination with WDFW and the Puget Sound Treaty Tribes is important to decrease or prevent listed rockfish bycatch, particularly with regard to fisheries that target halibut, shrimp/spot prawns, and bottom fish.

CONCLUSION

This appendix provides guidance for managing the risk of fisheries bycatch of listed rockfish within the boundaries of the U.S. portion of the Puget Sound/Georgia Basin DPSs. These recommendations were based on general principles already used to conserve rockfish within the range of the DPSs under Canadian jurisdiction (Yamanaka and Logan 2010), and are included in numerous publications regarding rockfish conservation on the West Coast (i.e., Parker et al. 2000). The establishment of these principles, most notably marine reserves/RCAs, would require robust attention to tribal treaty rights and guidance (Frank 2003) as well as socioeconomic considerations in order to lead to their designation, compliance, and ultimate biological success.

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APPENDIX III

BAROTRAUMA RESEARCH AND ADAPTIVE MANAGEMENT

OVERVIEW

Barotrauma is a source of mortality for rockfish and is identified as a high threat in the Recovery Plan (Section II. E. Factors Contributing to Decline and Federal Listing). This appendix outlines research, outreach, and adaptive management to understand and mitigate impacts of barotrauma. All species of rockfish, including yelloweye rockfish and bocaccio (listed rockfish), can be injured or killed by barotrauma effects when caught in fisheries or during research activities.

For rockfish caught in waters deeper than 60 feet (18.3 m), the primary cause of injury and death is often barotrauma. Barotrauma occurs when rockfish are brought up from depth and exposed to significant changes in pressure. 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). These injuries cause various levels of disorientation, which can result in fish remaining at the surface after they are released and making them subject to predation, damage from solar radiation, and gas embolisms (Hannah and Matteson 2007; Palsson et al. 2009). Injuries can include harm from differences in water pressure experienced by fish brought to the surface from depth (barotraumas), differences in water temperatures between the sea and surface, and hypoxia upon exposure to air. The severity of these injuries and probability of mortality may be dictated by the amount of time fish are held out of the water and their general handling on deck (Jarvis and Lowe 2008). Physical trauma may lead to increased vulnerability to predation after fish are released at the surface and as the fish returns to the sea floor, or when the fish is recovering on the bottom (Palsson et al. 2009; Pribyl et al. 2011; Rankin et al. 2017). Barotrauma injuries are species-specific (Hannah and Matteson 2007; Jarvis and Lowe 2008; Hochhalter 2012) and incidence of barotrauma may by highest in the areas with the highest fishing pressure (management units include the Main/Whidbey Basin and the San Juan Basin).

Washington State regulation requires all species of rockfish in Puget Sound to be released (WDFW 2013). If released at the surface, some rockfish can descend by themselves while others cannot, depending upon the depth of capture and other conditions (Hannah et al. 2008; Hochhalter 2012). In recent years, a number of devices have been developed to enable the release of rockfish at or near the depth of capture to improve survival. Some studies of rockfish released at depth indicate good short-term survival (Parker et al. 2006; Jarvis and Lowe 2008; Hochalter and Reed 2011). However, questions about long-term survival probability and effects on productivity and reproduction remain (Schroeder and Love 2002; Jarvis and Lowe 2008; Pribyl et al. 2009; Pribyl et al. 2011). A study of yelloweye rockfish caught in the hook-and-line fishery found that individuals released at depth with a decompression device had much higher survival rates than those released at the surface (Hochalter and Reed 2011). Another study demonstrated that rosy rockfish (*Sebastes rosaceus*) with barotrauma-induced exophthalmia (bulging eyes) recompressed in a controlled chamber showed improved visual function after 4 days and further improvement at 1 month (Rogers et al. 2011).

There are many variables that may influence long-term survival of recompressed rockfish, such as angler experience and handling, thermal shock, and depth of capture (Schroeder and Love 2002; Jarvis and Lowe 2008; Pribyl et al. 2009; Pribyl et al. 2011). There is also evidence that bycatch mortality reduction measures implemented across a variety of resource users do not perform as well as the experimental bycatch mortality reduction measures implemented by managers and scientists (Cox et al. 2007). Further, a recent study of boat-based anglers in Puget Sound revealed that few anglers have tried to release rockfish at depth (approximately 3 percent), while a smaller number of anglers attempted to puncture the swim bladder (Sawchuk 2012), which could cause bacterial infections or mortality and is therefore not recommended.

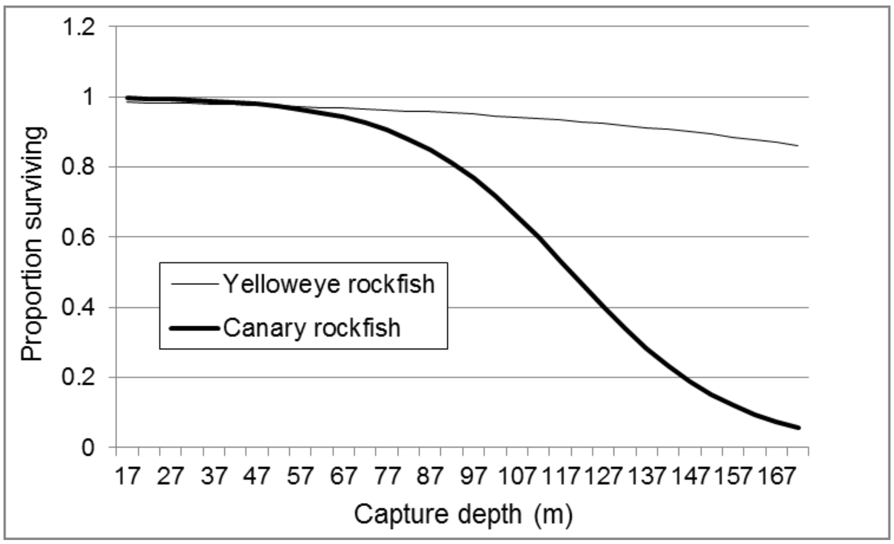

Figure 1. Fitted logistic curve of the proportion of yelloweye rockfish and canary rockfish surviving 48 hours after hook-and-line capture and recompression as a function of capture depth (m). (Image from Hannah et al., 2014.)

Recent research found that short-term (48 hours) survival for recompressed yelloweye rockfish was 95.1 percent, while 77.8 percent of canary rockfish survived when caught in less than 328 feet (100 m) (Figure 1) (Hannah et al. 2014). The Pacific Fisheries Management Council (PFMC) Groundfish Management Team also estimated mortality rates incorporating release with descending devices for cowcod, canary, and yelloweye rockfish (PFMC 2014) by developing a generalized linear model of the proportion of fish released dead by depth and by species based on information from observer program data (PFMC 2008). The 2014 rates accounted for reduced mortality as a result of being rapidly returned to depth, mitigating barotrauma, sun exposure, and surface predation-related mortality. The estimation method incorporated short-term mortality rates from cage studies and longer-term mortality rates from acoustic tagging studies. The mortality estimates and associated confidence intervals in each depth bin were estimated using a Bayesian Hierarchical Method, which accounted for variation between species and the sample size of each species using data from the latitude of the focal species (PFMC 2014). The report did not include discard mortality rates for bocaccio. Thus, only the discard mortality rates for yelloweye rockfish are reported below (Table 1).

Table 1. Bayesian Hierarchical Method: Total discard mortality (%) estimates by depth bin for yelloweye rockfish at the surface, and reflecting the use of descending devices incorporating short-term mortality, long-term mortality, unaccounted for mortality, and upper 60, 75, 90, and 95 percent confidence intervals as precautionary buffers for uncertainty. (Source: PFMC 2014.)

Depth (fm)	Current Surface Mortality	Mortality w/ Descending Device	Estimate w/ 60% CI	Estimate w/ 75% CI	Estimate w/ 90% CI	Estimate w/ 95% CI
0-10	22%	22%[1]	22%[1]	22%[1]	22%[1]	22%[1]
10-20	39%	22%	23%	24%	26%	27%
20-30	56%	22%	23%	24%	24%	27%
30-50	100%	23%	24%	25%	27%	28%
50-100	100%	35%	39%	45%	57%	65%
>100	100%	100%	100%	100%	100%	100%

[1]The value reflects surface mortality because mortality estimates for descending devices are not expected to exceed surface release.

There is also some emerging evidence that female yelloweye rockfish can remain reproductively viable after recompression. A recent study conducted in Alaska found that fifteen recompressed female yelloweye rockfish remained reproductively viable 1 to 2 years after the event (Blain 2014) and one yelloweye rockfish in Hood Canal (observed by WDFW ROV surveys, see photo at right) was gravid several months after recompression. Blain (2014) also found no evidence that embryo quality was adversely affected 1 to 2 years after the recompression event in the study. This emerging research requires more study to assess the long-term effects that barotrauma and recompression may have on productivity.

Yelloweye rockfish observed in ROV research in Hood Canal. This fish was found gravid after suffering from barotrauma. Photo courtesy of WDFW.

Barotrauma Research and Management Priorities

We prioritize the following suite of measures to minimize barotrauma-related mortality to yelloweye rockfish and bocaccio (also see Section V. A. Recovery Program, Recovery Action Outline):

1) **Catch avoidance.** Given the uncertainty regarding the long-term survival, health, and productivity of released fish, avoidance of catch and bycatch is the first priority.

   Action—Education and Outreach: Until additional research is conducted to better understand techniques to avoid bycatch, NOAA, WDFW, and other partners will continue to conduct outreach and education to advise anglers to avoid known rockfish habitat areas and to move to a different location if a rockfish is caught. See Appendix I, Education, Outreach, and Public Involvement, for further details.

2) **Listed rockfish should be released with a descending device.** Although catch avoidance is greatly preferred over recompression because of questions regarding long-term survival and productivity, releasing rockfish at depth likely reduces the effects of barotrauma (Parker et al. 2006; Jarvis and Lowe 2008; Hochalter and Reed 2011; Pribyl et al. 2012).

   Action—Education and Outreach[4]: Because angler experience and knowledge are important variables in successful rockfish recompression, education is needed on how to identify rockfish to species and efficiently use a descending device consistent with WDFW recommendations and best practices guidelines. See Appendix I, Education, Outreach, and Public Involvement.

   Action—Mandatory Release with Descending Devices: Fisheries with risk of rockfish bycatch should be required to have a descending device on board and ready to use.

3) **Research should be conducted on rockfish catch avoidance methods and long-term survival and productivity of rockfish after use of descending devices in single and multiple catch-and-recompress events.**

   Action—Research of Catch Avoidance Methods: In cooperation with WDFW, Puget Sound Treaty Tribes, and other partners, NOAA will investigate new ways to avoid incidental catch of rockfish. Research should occur regarding potential fishing gear that may be used to decrease or eliminate listed rockfish bycatch. This type of research would include lure or bait size/color, hook size/shape, distance of the lure/bait off the bottom, etc.

   Action—Research into Recompression Effects: Because barotrauma injuries can be species-specific (Hannah and Matteson 2007; Jarvis and Lowe 2008; Hochhalter 2012), research specific to listed rockfish will best inform long-term survival estimates. Research conducted on more abundant populations of yelloweye rockfish and especially bocaccio outside of the ranges of the DPSs (i.e., outer coast) is preferred. Research should address the following variables: (1) long-term survival after single and multiple catch-and-recompression events, (2) productivity (reproductive output), (3) susceptibility to predation, (4) behavioral changes, and (5) other long-term physiological impacts of recompressed fish.

4) **Adaptive Management.** Fisheries managers should review new research results on a periodic basis and make appropriate recommendations or regulatory changes as part of adaptive management.

[4] The Puget Sound Anglers (PSA) have already conducted numerous education and outreach efforts to demonstrate recompression techniques to fishers, 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. A continuation of these efforts is needed.

CONCLUSION

This appendix provides guidance for managing the risk of barotrauma to listed rockfish within the boundaries of the U.S. portion of the Puget Sound/Georgia Basin DPSs. For rockfish caught in waters deeper than 60 feet (18.3 m), the primary cause of injury and death is often barotrauma. Barotrauma occurs when rockfish are brought up from depth and exposed to significant changes in pressure. Proposed barotrauma research and management priorities are detailed here that would provide both short-term and long-term solutions to this mortality risk.

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APPENDIX IV

BENTHIC HABITAT CONSERVATION

OVERVIEW

This appendix summarizes the known and potential threats to benthic habitats to better inform actions to support the recovery of yelloweye rockfish and bocaccio (listed rockfish) of the Puget Sound/Georgia Basin. Listed rockfish typically occupy deep waters which have been relatively unobserved and studied; thus, potential threats to these habitats are generally poorly documented and understood. As described in the Recovery Plan (Section II. E. Factors Contributing to Decline and Federal Listing) and in the Critical Habitat designation, the known and potential threats include derelict fishing gear, dredging and sediment disposal, invasive species, artificial reefs (which could act to both augment or threaten habitat), alternative energy structures, and cable laying. We list research to understand the magnitude and effects of these threats and potential management actions to mitigate the effects (also see Section V. A. Recovery Program). Climate change and ocean acidification (addressed in Appendix VII), and sediment and water quality (addressed in Appendix VI) likely affect benthic habitats as well.

<u>Derelict Fishing Gear</u>

Derelict fishing gear poses a threat to marine organisms and their habitat. Derelict nets and shrimp pots are two known types of derelict fishing gear in the Puget Sound/Georgia Basin that can kill rockfish and their prey (Good et al. 2010; NRC 2012). Nets are lost because of inclement weather, tidal and current action, catching (snagging) upon the seafloor, the weight of catch causing submersion, vessels inadvertently traveling through them, or a combination of these and additional factors (NRC 2008). Many nets hang on bottom structure that is also attractive to rockfish. This structure consists of high-relief rocky substrates or boulders located on sand, mud, or gravel bottoms (Good et al. 2010). The combination of complex structure and currents tend to stretch derelict nets open and suspend them within the water column, making them more deadly to marine biota (Good et al. 2010; NMFS 2013).

Derelict gear can persist for decades in the marine environment, causing mortality to marine organisms of all types, including mammals, birds, fish (including rockfish), and invertebrates, while also degrading habitat through scour, obstruction, and sediment entrapment (Morton 2005; Gilardi et al. 2010; Good et al. 2010; Antonelis 2013). Specifically, fine sediments may be trapped out of the water column, creating a layer of soft sediment over rocky areas that changes habitat quality and suitability for benthic organisms (Good et al. 2010). Lost nets can cover substrate used by rockfish for shelter and pursuit of food, rendering the habitat unavailable, and can also reduce the abundance and availability of rockfish prey (Good et al. 2010). As of 2014, 479 derelict nets were estimated within Puget Sound, of which 274 are in shallower water (< 105 feet (32 m)) and 205 are in deeper water (> 105 feet (32 m)). By management unit, 241 shallower water nets and 199 deeper water nets are thought to be in the San Juan/Georgia Strait Basin; 23 shallower water nets and 4 deeper water nets in the Main Basin; 7 shallower water nets in South Puget Sound; and 3 shallower water nets and 2 deeper water nets in Hood Canal (NWSI 2014b).

Other types of lost fishing gear could also pose a threat to listed rockfish and their habitats. Recreational and commercial shrimp and crab fishermen employ pots that rest on the seafloor. When these pots are lost, they may continue to catch fish and invertebrates (Matsuoka et al. 2005; Favaro et al. 2010). Derelict shrimp pots have been documented to catch juvenile rockfish, though the overall extent of bycatch is unknown (NRC 2012), while derelict crab pots have generally not been found to result in bycatch of rockfish. An estimated 12,193 commercial and recreational crab pots and an estimated 326 to 651 shrimp pots are lost annually in Puget Sound (Antonelis et al. 2011; NRC 2012; NMFS 2014a). However, a side-scan survey in a limited area of Puget Sound showed a much higher number of shrimp pots than would be expected from reports of lost gear (NRC 2012).

Suggested Research: Derelict Nets

The habitat impacts of derelict nets in waters less than 98.4 feet (30 m) are well documented (e.g., Good et al. 2010), in addition to the potential causes of net loss by commercial fishermen (Gibson 2013). Future proposed research thus emphasizes the extent and potential benefits of removing deep-water nets:

- Additional side-scan sonar surveys of deepwater rockfish habitats would locate and enumerate potential net targets. Net targets should be verified with drop camera or ROV surveys, which can also provide insight to the effects of deepwater nets to fish and habitat.
- Continue deepwater net removal investigations and research.
- Assess the "Category 3: Possible changes to gear" recommendations in Gibson (2013). These ideas may require research/experimentation to determine effectiveness prior to widespread use.
- Explore the use of longitudinal suspender lines (e.g., Chehalis River and Columbia River fisheries), which are heavier and allow more force to be applied from the surface to the leadline during the recovery of an entangled net.
- Explore the use of a breakaway leadline as used in Alaska and Columbia River fisheries. This enables a net to drift over a snag without hanging up the entire net, although it does not provide a fisherman the solid pull that can help free leadline from a snag (and thus beyond the spot where another portion of gear might get hung up).
- Explore the use of low frequency pingers (e.g., Fumunda) attached in locations other than the corkline that could assist in locating lost gear with hydrophones; for tracking purposes, a lower frequency carries farther.
- Explore the use of a corrosive link to attach sections of leadline to a recovery float. For example, a line rolled inside a tube with a trigger mechanism attached to a corrosive link, whereby a tube opens and the float inflates with gas capsules.
- Explore the use of biodegradable webbing to avoid the long-term persistence of derelict nets.
- Explore the efficacy of mesh depth restrictions as in the salmon gillnet fisheries in British Columbia and Alaska (i.e., change net gear-depth limit such that the vertical mesh count is restricted, limiting the extended distance between corkline and leadline to 60 or 90 meshes deep).
- Conduct a collaborative fisheries research project that is designed to test the efficacy of mesh limits/net depth restrictions.

Suggested Projects: Derelict Net Prevention

Gibson (2013) provided recommendations to prevent the loss of nets in order to avert the re-accumulation of gillnets in current and future saltwater gillnet fisheries. She developed a list of best practices that gillnet fishers could employ to reduce the loss of nets, and recommended the following discrete projects to further the derelict gillnet prevention effort:

- Preparation of a comprehensive guide to best fishing practices that is tailored to each gillnet fishery, and, where possible, include bathymetric information specific to local areas of high relief.

Make such a guide widely available through port offices and fishing gear supply stores in Bellingham, Anacortes, Seattle, Friday Harbor, and elsewhere.

- Provide free, annual training on "trade secrets" for newcomers to the fishery. For example, new non-treaty gillnetters in Puget Sound are required to take a "Fish Friendly" class provided by WDFW if they fish in areas 7/7A. However, there are more newcomers to the treaty fisheries who also would benefit from further training.
- Establish a peer-based incentive system to monitor gillnet gear that would otherwise be left unattended, prioritizing areas where the likelihood of net entanglement and/or loss is high.

Suggested Research: Derelict Shrimp Pots

Based on the observations and results from the shrimp pot loss analysis and side-scan sonar surveys conducted by NRC (2012), the following are recommendations for research priorities to further understand the potential impact to rockfish of derelict (or active) shrimp pots in Puget Sound:

- Further explore rockfish bycatch rates in shrimp pots from WDFW Hood Canal test fishery data.
- Investigate side-scan sonar survey targets reported in the study to verify they are shrimp pots and not crab pots, record presence or absence of live and dead rockfish by species, and estimate length of time pots have been derelict.
- Investigate the length of time shrimp pots remain viable when derelict in order to fully understand the potential impacts shrimp pots have on rockfish.
- Assess the potential for derelict shrimp pots to affect localized, isolated populations of rockfish in areas where effort and pot loss are high.

Suggested Projects: Derelict Shrimp Pots and Crab Pots

The following are recommendations for management actions aimed at reducing shrimp pot loss and rockfish mortality in the recreational shrimp pot fishery, in addition to a general project relative to crab pot loss:

- Initiate an education program for recreational fishers to help minimize shrimp pot loss.
- Fishers should be encouraged to release live-caught rockfish at depth, similar to what is currently being proposed in the sport finfish fishery, in order to minimize mortality because of barotrauma.
- An assessment of timing the opening of the shrimp fishery to coincide with mild tides to see if pot loss rates are reduced compared to days with larger tide cycles.
- Though actively fished and/or derelict crab pots do not appear to result in bycatch of rockfish, support of crab pot loss prevention and removal efforts would nonetheless avoid potential impacts to benthic habitats.

Invasive / Non-Indigenous Species

Invasive or non-indigenous species (NIS) are an emerging threat to biogenic habitat in Puget Sound and are poorly understood, but could potentially pose a threat to listed rockfish. 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). For example, *Sargassum muticum* is an introduced brown alga that is now common throughout much of Puget Sound (Drake et al. 2010). The degree to which *S. muticum* influences native macroalgae, eelgrass, or rockfish is not presently understood; however, research has shown it alters macroalgal communities (Britton-Simmons 2004). In addition, several species of non-indigenous tunicates have been identified in Puget Sound. For example, *Ciona savignyi* spread from one location in 2004, to 86 percent of sites surveyed in Hood Canal within 2 years (Drake et al. 2010). The exact impact of invasive tunicates on rockfish or their habitats is unknown, but results in other regions (e.g., Levin et al. 2002) suggest the potential for introduced invertebrates to have widespread impacts on rocky reef fish populations (NMFS 2013a). 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). As novel NIS are expected to increase over time (Levine and D'Antonio 2003), understanding their potential effects on rockfish and exploring potential control methods may be necessary for a complete recovery effort.

The non-native tunicate, *Ciona*. Photo by Adam Obaza.

Suggested Research and Projects: Invasive Species

We recommend an assessment of the possible impacts *S. muticum, C. savignyi, S. clava*, and *D. vexillum* may have on rockfish and their habitat. If adverse impacts (such as altered rockfish behavior, habitat usage, etc.) are found, we recommend a feasibility assessment of the removal, or other control efforts, of non-indigenous species along the seafloor, in addition to understanding ways to stem their spread.

Artificial Reefs

There have been few artificial habitat projects in Puget Sound since the 1980s and it is uncertain if additional reefs would contribute to recovery of listed rockfish. Though most of Puget Sound lacks natural rocky reefs, listed rockfish have been documented among non-rocky, but relatively complex benthic habitats. The use of these non-rocky habitats may be a unique ecological feature of rockfish along the Pacific coast. As such, the restoration of listed rockfish populations through the use of artificial reefs may or may not address a factor that limits recovery. Historically, hundreds of bottom trawl vessels fished in Puget Sound, and the extent of alteration to the seafloor from this fishery has not been determined. Given these uncertainties, WDFW's Puget Sound Rockfish Conservation Plan guides placement of future artificial habitats in areas with degraded benthic habitats (WDFW 2010). There have been recent proposals to conduct research on newly placed artificial reefs in conjunction with removal of some of the over 20 known tire reefs in Puget Sound (Holmes and Tobeck 2011).

Quillback rockfish inhabiting an artificial reef in central Puget Sound. Photo by Adam Obaza.

Creation of an artificial reef is a complex process involving extensive planning, monitoring, and coordination among Federal and state agencies, non-governmental organizations, fishers, and the general public. Placement of a reef requires thorough evaluation of project goals, habitat characteristics, oceanographic setting, and responsibility for long-term maintenance.

Artificial habitats consist of materials such as boulder piles, concrete rubble, tires, shipwrecks, and other materials that are not native to the local benthic habitat (NMFS 2014a), or can consist of materials that are native to local habitats but have been lost or removed (e.g., large driftwood in Puget Sound). Rockfishes are found among artificial habitats relatively soon after their placement (Palsson et al. 2009). These habitats attract fish from the surrounding environment (Laufle and Pauley 1985), but more research may help evaluate the ecological performance of fishes at man-made vs. natural reefs (Love et al. 2005; Granneman and Steele 2014) because many variables may ultimately affect production (Bohnsack 1989). Therefore, any potential artificial reefs created for rockfish recovery must be carefully planned to enable maximum potential effectiveness, and assessed in terms of their impacts on fish and benthic habitats. Material type, size, depth, proximity to existing natural reefs and submerged aquatic vegetation, substrate type, and other factors may all affect rockfish productivity on an artificial reef (Buckley 1997; NOAA 2007; Jiang et al. 2013).

The first step to adequately designing an artificial reef would be to conduct a demographic sensitivity analysis to determine which life stages create potential bottlenecks for rockfish recovery (Gerber and Heppell 2004). With that information, a specific reef design could be developed to enhance vulnerable life stage(s). As adult rockfish may consume juveniles, it may be beneficial to separate adult and juvenile habitat (Buckley 1997).

Studies completed thus far show that there could be a potential basis for enhancement of rockfish populations by artificial structures. Buckley (1997) found that juvenile rockfish occupy small refuge habitats within reef systems. Many of the artificial reefs in Puget Sound were constructed of large materials that did not have this refuge habitat. Manipulation of existing artificial reefs to include refuge habitat could increase production of juvenile rockfish. Ontogenetic and life history factors are important considerations because artificial reefs may not increase biomass if bottlenecks to the population occur in other habitats used in different life history stages, and because increased production is more likely for highly territorial or philopatric species that may be habitat limited (Bohnsack 1989).

However, Bohnsack (1989) cautions that because artificial reefs are effective fish attractors, they may make the resident fish more susceptible to fishing, requiring other management measures be taken instead of, or in conjunction with, artificial reefs to prevent further depletion of listed stocks.

Suggested Research and Projects: Artificial Reefs

Proposed artificial reef project(s) in the Puget Sound/Georgia Basin should be approached as a controlled experiment to assess fish population and benthic habitat response using Before-After-Control-Impact Paired Series (BACIPS) design (Osenberg et al. 2002). In particular, the experimental artificial reef placement should be prioritized in areas of degraded habitats (e.g., previously placed tire reefs).

CONCLUSION

As compared with fishing-related impacts, the effects of reductions in benthic habitat quality and quantity on listed rockfish are relatively unknown. This lack of knowledge stems in part from the nature of listed rockfish habitat, which is deep and relatively inaccessible. However, habitat-related issues are often of great concern in recovering diminished populations and evidence of derelict net impacts in particular suggests a potential source of rockfish mortality. Therefore, further research into their effects on listed rockfish and their benthic habitat is warranted to enhance recovery.

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APPENDIX V

NEARSHORE HABITAT AND KELP CONSERVATION

OVERVIEW

Nearshore habitat protection and restoration in the Puget Sound/Georgia Basin is identified as a high priority action in the Recovery Plan (see Section VI. Implementation Schedule and Preliminary Cost Estimates) and is outlined in this appendix. 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. This habitat also experiences a high rate of disturbance from anthropogenic activities.

Prior to European settlement, Puget Sound shorelines were a mosaic of coastal lagoons and expansive deltas interspersed with bluffs supporting immense trees. Human development since the early 1800s has transformed and simplified Puget Sound shorelines. Approximately one-third of the shoreline has been altered for industrial uses, infrastructure, and housing (Broadhurst 1998). Virtually all of the large shoreline trees were cut by the late 1800s (Prasse 2006).

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 are less understood. One of the more prominent nearshore habitats are the floating and submerged kelp beds (families *Chordaceae*, *Alariaceae*, *Lessoniacea*, *Costariaceae*, and *Laminaricea*) that support the highest densities of most juvenile rockfish species (Matthews 1990; 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 (see Section II. Biological Background). Kelp is photosynthetic and requires high ambient light levels and a lack of fine sediment in the water column that can reduce light or smother the gametophytes (Mumford 2007). There are over 20 annual or perennial species of kelp in Puget Sound; two species have a floating canopy and the other species have non-floating stipulate or prostrate canopies (Mumford 2007). When solid substrates occur in lower intertidal and subtidal zones, kelp is often the dominant aquatic flora and forms dense canopies (Mumford 2007). Kelp are attached with a root-like structure, called a holdfast, to solid substrates such as bedrock, large rocks or pebbles, clam shells, or artificial substrates. Kelp grows in areas of high to moderate wave energy or currents to depths as great as 65 feet (20 m) (Mumford 2007). Most kelp species form blades 3 to 6 feet (1 to 2 m) long, though the one floating variety within the range of the three DPSs (*Nereocystis luetkeana*) grows to over 33 feet (10 m) long.

Given the importance of kelp (and naturally rocky/complex shorelines) to juvenile rockfish, this appendix emphasizes research and conservation of these areas, noting that restoration of the nearshore targeted for salmon and general ecosystem recovery will likely complement the recovery of listed rockfish. We note that previous nearshore restoration planning for Puget Sound Chinook salmon and the recent *Strategies of Nearshore Protection and Restoration in Puget Sound* provide important roadmaps for conserving the shorelines of Puget Sound. Restoring the nearshore, even in areas that are unlikely to be occupied by listed rockfish, will nonetheless support important ecosystem functions—such as the production of rockfish prey (i.e., surf smelt, *Hypomesus pretiosus*).

In 2010, WDFW and the Washington State Department of Natural Resources (DNR) developed and submitted a proposal to NOAA for ESA section 6 funding to advance the management and restoration needs of kelp habitats and associated at-risk rockfish species assemblages (WDFW 2010). The proposal has not been funded to date. WDFW has been conducting research, monitoring, and evaluation programs for nearshore fishes and fish habitat for over 20 years, and DNR has been conducting research and monitoring on nearshore habitats since 1988. This appendix uses an abbreviated version of the section 6 proposal as a template for conserving nearshore habitats particularly important to rockfish.

Rearing in the nearshore is thought to play a critical role in the successful recruitment of juvenile rockfish (Love et al. 1991), yet there is much to be learned about how nearshore conservation and restoration efforts within Puget Sound may be adapted to specifically address the survival and recovery of listed rockfish. The distribution and dynamics of kelp are poorly understood in Puget Sound, and the overall trend in abundance is ambiguous. The WDFW and DNR section 6 proposal provided three goals related to kelp and rockfish:

1) Provide a straightforward basis for understanding and measuring the distribution of kelp in Puget Sound.
2) Provide a food web model characterizing life stage-specific rockfish use of nearshore habitats. This would include a stable isotope study of kelp-derived carbon in rockfish diets.
3) Provide a basis for identifying changes in kelp abundance and depth distribution, along with their causes, that can be used to prioritize conservation and restoration actions, with special reference to rockfishes.

Effectively addressing recovery of kelp-dependent species like rockfish (including bocaccio) requires an understanding of the relative abundance and spatial distribution of kelp and, ultimately, the mechanisms by which these characteristics change in Puget Sound. Available data typically address the relative abundance and distribution of only two floating species (*Nereocystis luetkeana* and *Macrocystis integrifolia*), and the lack of surface expression of non-floating species has historically prevented cost-effective monitoring (Mumford 2007). A review of historical data (Thom and Hallum 1990) suggested a 58 percent increase in floating kelp beds in Puget Sound since the earliest mapping in the 1850s (Mumford 2007). However, anecdotal evidence of losses exists for central Puget Sound (Thom and Hallum 1990), but these data are spatiotemporally coarse. Mumford (2007) noted reports from concerned citizens regarding losses of kelp beds around Bainbridge, Fox, and Marrowstone Islands and personally observed the loss of over 90 percent of beds in southern Puget Sound. DNR mapped floating and non-floating kelp using helicopter-based shoreline surveys along 11 percent and 31 percent, respectively, of the 3,061-mile (4,926-km) Puget Sound shoreline as part of the ShoreZone inventory (Nearshore Habitat Program 2001). These surveys scored kelp abundance into three categories (absent, patchy, or continuous) within variable-length,

A black rockfish utilizing *Nereocystis luetkeana* off Whidbey Island. Photo by Adam Obaza

geomorphologically defined shoreline segments averaging 0.5 mile (0.8 km), but the width of the kelp footprint (i.e., perpendicular to the shoreline) and therefore total area was not addressed.

These ShoreZone inventory surveys cannot reliably identify changes in kelp distribution, and subsequent efforts should consider more robust monitoring techniques. In addition, DNR has obtained photographic data using aerial overflights on floating kelp taken at the same time each year from 1989 through 2009 (van Wagenen). However, these surveys cover only the outer coast and the Strait of Juan de Fuca eastward to just north of Port Townsend. Berry et al. (2005) showed that kelp canopy area generally increased during the first 15 years of this monitoring, but identified localized losses. The kelp canopy may have expanded as a result of a decrease in herbivores such as urchins (from increases in the sea otter population and human harvest of urchins in areas of increased kelp abundance [Estes et al. 2004]), and reductions in kelp canopy may have occurred because of loss of cobble and exposed bedrock, a loss of detritus feeders, an increase in herbivores, declining water quality, and illegal harvest (Mumford 2007). The causal basis of regional changes in kelp distribution or composition in Puget Sound, however, remain poorly understood.

Despite the fact that kelp habitats are among the most biodiverse and functionally valuable in the world, they have garnered relatively little attention in Puget Sound (Mumford 2007). The functions, ecosystem services, and products provided by kelp in Puget Sound are poorly documented, and are widely assumed based on data collected largely outside Puget Sound.

Suggested Research Projects

Here we provide objectives to assess and implement conservation actions for nearshore habitat and kelp that support listed rockfish recovery (also see Section V. A. Recovery Program and Section VI. Implementation Schedule and Preliminary Cost Estimates).

Objective 1: Literature Review and Food Web Model Development

Develop an approach to advance the management and restoration needs of nearshore habitats and their at-risk rockfish species assemblage.

Action: Objective 1 is to conduct a literature review and build a food web model focused on kelp-rockfish habitat associations and other important kelp community interactions. This model would provide an explicit structure for identifying the ecosystem links and vulnerabilities to rockfishes, characterize hypothesized stressors to kelp (historical, current, future), and describe their associated uncertainties. Parameter estimates developed for the model could be used in the food web models developed as part of the Integrated Ecosystem Assessment by the NOAA Fisheries Science Center.

Methodology: Develop a food web model of kelp ecosystems where rockfishes, particularly the ESA-listed species, are the focus. This model can be developed from a literature review and expert judgments that identify the links, stressors, and threats to rockfishes and kelp. Historical, current, and anticipated stressors to rockfishes and kelp can be addressed for both aspects of kelp life history (e.g., kelp sporophyte and gametophyte) and for different climate change scenarios (e.g., changes in sea level, ocean acidification).

The model could then be used to guide development of conservation and restoration approaches, and research to fill critical information gaps (Objective 3). The magnitude of threats to kelp in Puget Sound could be estimated and ranked in order of severity. Seafloor modification data can then be examined for potential impacts on rockfishes and their habitat, such as areas with a high intensity of marine transportation, tidal and wave energy development, anchoring, and other modification. These threats could then be quantified in terms of their geographic, temporal, and physical magnitude through existing empirical data and expert judgment that employ Bayesian Belief Networks (Marcot et al. 2001) or other systems used to characterize uncertainty surrounding expert opinion.

Harvey and colleagues (2010) published a food web model for the central basin of Puget Sound. They constructed a mass-balance model consisting of 65 functional groups, including a floating kelp group. This model operated at the scale of an oceanographic subbasin, and therefore the intricacies of the food web within smaller-scale kelp habitats were not addressed. The same group will be developing a food web model for all of Puget Sound. Like their most recent effort, this model will analyze the Puget Sound marine ecosystem at the scale of oceanographic subbasins. The food web model proposed here would draw upon Harvey et al. (2010), and have the detail to contribute to ongoing Puget Sound-wide food web modeling efforts as part of the Integrated Ecosystem Assessment by NOAA Fisheries Science Center.

Individual projects that should be conducted to augment model development include assessments of some hypothesized reasons for localized kelp decline, including (1) overabundance of and grazing by urchins and kelp crab (*Pugettia producta*), possibly because of the decline of their predators (i.e., cabezon, cod, and rockfish) (see Section II. Biological Background); (2) nearshore alteration including disruption of localized and regional sediment supplies; (3) boat traffic and nearshore development; and (4) pollution. In addition, a stable isotopes analysis would complement this work by providing an additional quantitative basis for food web linkages.

Objective 2: Improve Understanding of Historical and Current Kelp Abundance and Distribution

Action: All existing datasets could be assembled to reconstruct an historical picture of kelp in Puget Sound. Annual eelgrass surveys for Puget Sound, currently conducted by DNR, could be expanded to include non-floating kelp. This process would result in the first estimate of the current abundance and distribution of non-floating kelp throughout Puget Sound based on probabilistic sampling using underwater videography. Long-term changes in floating kelp abundance could be assessed by conducting an aerial photography-based survey of greater Puget Sound and updating the trends analysis of Thom and Hallum (1990). Changes in non-floating kelp could be assessed through diver-based surveys of a limited number of sites with historical information available for comparison. Together, these data sets could provide a basis for addressing important objectives in managing kelp habitat in Greater Puget Sound.

Methodology: Past and current kelp abundance and distribution can be assessed by compiling historical data sets, collecting additional monitoring data, and comparing similar data sets to detect trends over time. This work should be divided into three sub-projects, based on considerations related to sampling methodology and available information:

- Floating kelp, the type with the most extensive existing information, should be assessed through collecting aerial photography-based data on its current distribution, and by updating the trends analysis work of Thom and Hallum (1990) by mapping floating kelp throughout Puget Sound using the long-term monitoring methods used for the outer coast and Strait of Juan de Fuca (van Wagenen 1989-2009).

- Non-floating kelp and macroalgae have substantially less existing information and greater sampling challenges. Trends in non-floating kelp and macroalgae could be assessed through re-sampling diver-based surveys at a minimum of five sites within Puget Sound. This comparison would provide information on changes at key sites, but the results would be limited in their geographic scope.
- The current abundance and distribution of non-floating kelp and macroalgae throughout Puget Sound could be determined[5] through expanding existing probabilistic sampling methods developed for long-term eelgrass monitoring, including the development of a standardized survey method for local volunteers. This work would provide the first estimate of non-floating kelp and macroalgae abundance and depth distribution throughout Puget Sound, and contribute important fundamental information on a critical habitat that would be used for management, modeling, marine spatial planning, and research.

Objective 3: Develop Conservation and Restoration Approaches

Action: Develop protection, conservation, and restoration approaches for kelp and macroalgae habitats by providing a review of kelp restoration literature, with a special focus on rockfish habitat needs; providing methods for monitoring restoration effectiveness; and making recommendations for protection and conservation measures, and how to conduct a pilot restoration effort.[6]

Methodology: To accomplish this objective, three approaches could be taken: (1) assemble and synthesize the literature on kelp conservation and restoration, notably that from California (e.g., Vasquez and McPeak 1994) and Puget Sound (e.g., Elliott Bay Marina mitigation) (see Carney et al. 2005), in addition to kelp cultivation, primarily in China; (2) analyze the impact of different kelp stressors (i.e., grazers, development, and pollution) and identify ways to minimize them; and (3) identify management measures and restoration approaches to recover kelp.

Guidelines could be developed for improved management and restoration of kelp. WDFW and DNR cooperatively manage kelp by virtue of their responsibility for stewardship of the marine bedlands (DNR) and management of fish and wildlife and elements of their habitat, including marine vegetation (WDFW 2010). NOAA Fisheries also has a role as kelp is designated as a Habitat Area of Particular Concern for

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[5] Habitat mapping sonar could also be considered and possibly conducted in conjunction with other surveys (i.e., for derelict gear or other needed habitat surveys).

[6] 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. Additionally, the PSRF maintains a citizen science program, KELP WATCH, to help monitor and protect kelp in Puget Sound for a more comprehensive picture of kelp coverage. 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.

Pacific Coast Groundfish, a subset of Essential Fish Habitat under the Magnuson-Stevens Fishery Conservation and Management Act, that receives additional scrutiny during the regulatory process, in addition to the review of projects under section 7(a)(2) of the ESA. As threats are identified, systematic reviews of current management practices for kelp and other submerged vegetation could occur, resulting in a more coordinated approach.

Additional Objective: Systematic surveys of young-of- year rockfishes should occur annually within each of the basins of Puget Sound. Survey locations and frequency of surveys should be expanded from the WDFW surveys. These surveys should assess nearshore habitats for seasonality and densities of juvenile rockfish in general because juvenile rockfishes are often difficult to identify visually. Bocaccio and other nearshore associated rockfishes (e.g., copper rockfish) use similar habitats. These surveys could be integrated with the above-mentioned surveys of kelp habitats as well as potential sites for restoration/kelp outplanting, and where possible, could occur opportunistically with surveys targeting other species, such as juvenile salmonids.

Anticipated Results

- A conceptual model for the kelp food web that explicitly highlights rockfish-kelp interactions and that informs the Atlantis food web model for Puget Sound.
- A Puget Sound-wide map of the historical and current footprints for selected kelp and macroalgae morphotypes or in some cases, species, based only on existing data.
- A preliminary analysis of the change in the kelp footprint for selected kelp morphotypes or, in some cases, species.
- Recommendations for a conservation and restoration plan, including monitoring needs for kelp habitats that emphasize rockfish habitat needs.

CONCLUSION

Nearshore habitat protection and restoration in the Puget Sound/Georgia Basin is identified as a high priority action in the Recovery Plan because the nearshore is thought to play a critical role in the successful recruitment of juvenile rockfish. There is much to be learned about how nearshore conservation and restoration efforts within Puget Sound may be adapted to specifically address the survival and recovery of listed rockfish. Given the importance of kelp and the nearshore to juvenile rockfish, we have identified research and conservation of these areas including understanding and measuring the distribution of present day and historical distribution of kelp, developing a food web model to help investigate possible causes of kelp decline (including possible trophic cascades), and provide a basis for identifying changes in kelp abundance, along with their causes, that can be used to prioritize conservation and restoration actions within a specialized region-wide conservation plan.

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APPENDIX VI

SEDIMENT AND WATER QUALITY

OVERVIEW

This appendix provides background and recommended efforts and research priorities regarding sediment and water quality contaminants and listed rockfish. Human activities have introduced many toxic chemicals into Puget Sound that alter water and sediment quality and affect listed rockfish along with their habitats and prey. Subsequently, contaminants are identified in this recovery plan as a high threat to listed rockfish (Section II. E. Factors Contributing to Decline and Federal Listing). Contaminants enter from direct and indirect pathways, including surface runoff, inflow from fresh and salt water, aerial deposition, discharges from wastewater treatment plants and combined sewer overflows, oil spills, and migrating biota (Crowser et al. 2007). Once harmful contaminants enter Puget Sound, their retention and flushing is controlled by the toxic persistence of the chemical, ocean circulation and climate, and the physical structure of the basins. Because Puget Sound has several sills that restrict water movement and mixing, persistent chemicals have relatively long residence times. In addition, many marine species exhibit a high degree of residency within Puget Sound that results in increased chemical exposure through benthic and pelagic food webs (West et al. 2008; O'Neill and West 2009).

Relatively recent analyses indicate that 1 percent of the marine sediments in Puget Sound are highly degraded by chemical contamination, whereas 57 percent show intermediate degrees of deterioration and 42 percent remain relatively clean (Long et al. 2001). Hot spots for contaminated sediments are centered near major urban areas where industrial and domestic activities are concentrated. Locations of particular concern include Bellingham Bay, Fidalgo Bay, Everett Harbor and Port Gardner, Elliott Bay, Commencement Bay, Sinclair Inlet and other sites near Bremerton, and Budd Inlet (Long et al. 2001; EVS Environmental Consultants 2003), but contamination can extend widely into some rural bays and may include nursery areas for many of the species in Puget Sound. Analyses of contaminants in fish and mussels suggest that some pollutants are most abundant in the Main Basin and South Puget Sound (Mearns 2001; O'Neill and West 2001; West et al. 2001a; EVS Environmental Consultants 2003).

During the past few decades, regulatory actions, improved waste handling, and ongoing cleanup efforts have led to improvements in regional water quality. Important actions taken include the cessation of PCB production and DDT use in the 1970s and the elimination of most dioxin and furan emissions from pulp and paper mills during the 1980s and early 1990s. As authorized by the Clean Water Act, the National Pollutant Discharge Elimination System (NPDES) permit program controls water pollution by regulating point sources that discharge pollutants into waters of the United States. Permits are issued for discharges from industrial and municipal wastewater facilities and describe limitations for allowed discharge based on technology or water quality standards.

In most cases, the NPDES permit program is administered by authorized states. Since its introduction in 1972, the NPDES permit program is responsible for significant improvements to our nation's water quality; however, there are questions about whether permit requirements and standards are sufficient to protect habitat and wildlife. Progress has been made in the cleaning and containment of the 31 Superfund sites in the Puget Sound basin, of which at least 11 leaked contaminants into coastal 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). For example, mean PCB concentrations in harbor seal pups from Puget Sound fell from more than 100 mg/kg wet weight in 1972 to about 20 mg/kg wet weight in 1990 (Calambokidis et al. 1999). Despite these improvements, the presence of some chemicals (e.g., PCBs and DDT) 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). By contrast, environmental levels of many emerging contaminants, which are typically poorly regulated, are likely increasing (Pal et al. 2010).

Atmospheric transport of pollutants is another important contaminant source for marine ecosystems. Because of the prevailing wind patterns of the northern hemisphere, a number of substances (e.g., PCBs, DDT, other pesticides, dioxins, furans, and metals) are carried from Asia to the northeastern Pacific (Iwata et al. 1993; Tanabe et al. 1994).

In 2006, the Washington State Department of Ecology (Ecology) partnered with other agencies to identify an initial list of the chemicals of concern that may harm the Puget Sound ecosystem (Ecology 2011). Several persistent bioaccumulative toxicants (PBTs) and metals identified may pose a threat to rockfish. PBTs are highly fat soluble and have poor water solubility, which allows them to accumulate in the fatty tissues of organisms. Many PBTs can bioaccumulate and biomagnify such that long-lived, mid- and upper-trophic level species, such as rockfish, accumulate relatively large amounts of these compounds throughout their lives and have body burdens several orders of magnitude greater than species with shorter life spans at lower trophic levels.

The primary toxic chemicals of concern to the health and recovery of listed rockfish include the polycyclic aromatic hydrocarbons (PAHs), organochlorines (e.g., PCBs and DDTs), brominated flame retardants such as the polybrominated diphenyl ethers (PBDEs), other endocrine disruptors, and mercury/methylmercury. Here, we briefly describe the use of, associated health effects from, and regulation for these chemicals of concern.

PAHs. PAHs are both man-made and naturally occurring. They are created during the partial burning of petroleum products such as oil, gas, and coal. In laboratory studies, PAHs have caused tumors, reproductive problems, and birth defects; can affect the immune system; and are known animal carcinogens. Temporal monitoring of Puget Sound sediments has shown higher levels of PAH concentrations in 2000 than in the early 1990s (Partridge et al. 2005), especially in some urban bays (PSAT 2007).

PCBs. PCBs in sediment from Puget Sound have increased in concentration beginning in 1930, reaching peak levels in the early 1960s (Lefkovitz et al. 1997; Johannessen et al. 2008). Some benthic species have shown location-specific declines in PCB concentrations. For example, reductions in PCB concentrations in English sole (*Parophrys vetulus*) in Sinclair Inlet likely are due to reduced PCB input (e.g., from contaminated sediment removal, enhanced wastewater treatment, and stormwater outfall retrofits) (O’Neill et al. 2011). However, little to no decline was observed in English sole from non-urban sampling sites in the Central and South Puget Sound Basins (West and O’Neill 2007). DDT was first used as an insecticide in the late 1930s and its use increased until 1960. Because of its toxic effects on wildlife (Cottam and Higgins 1946) and its potential health risk to humans, the general use of DDT was banned in the U.S. in the 1970s. Although environmental levels of PCBs and DDTs have substantially declined since they were banned, they are still found in high concentrations in the Puget Sound ecosystem.

PBDEs. Brominated flame retardants (e.g., PBDEs) have been used in the manufacturing of furniture, electronics, textiles, and other household products. Several PBDE forms have been linked to neurodevelopmental toxicity, immunotoxicity, and neurotoxicity in laboratory animals. In Puget Sound, PBDEs in English sole, Pacific herring, and coho salmon may have decreasing or stable trends, likely because of voluntary cessation of penta-BDE and octa-BDE production almost a decade ago (West et al. 2011).

ECDs. Endocrine disruptors can act as hormone mimics or blockers. These disruptors may be linked to pharmaceuticals and personal care products (e.g., diagnostic agents and cosmetics). Exposure to xenoestrogens, a group of endocrine disruptors, has led to feminization and possible reproductive disruption of some male fish in Puget Sound by triggering abnormal vitellogenin production (West et al. 2001b), a protein normally produced in adult female fish and associated with egg production.

Mercury. Mercury is a naturally occurring compound that can also be released into the air from industrial pollution. It exists in many forms and is found in numerous man-made products, including auto switches, thermometers, dental waste, and batteries. Methylmercury is an organic compound with a widespread presence in the aquatic environment and is known to bioaccumulate. In 2003, Washington State began implementing a mercury reduction plan to reduce and eliminate mercury in consumer products.

Nutrient input. In addition to chemicals and metals, sediment and water quality in Puget Sound is also influenced by sewage, animal waste, and other nutrient inputs. Ecology has been monitoring water quality, including fecal coliform, nitrogen, ammonium, and dissolved oxygen (DO), in Puget Sound for decades. In 2005, 8 of 39 sites sampled were classified as highest concern, and 10 were classified as high concern. Portions of Hood Canal have episodic periods of low DO, but the relative role of nutrient input from humans in exacerbating the episodes is in doubt (Cope and Roberts 2012). 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). In addition to Hood Canal, periods of DO are becoming more widespread in waters south of Tacoma Narrows (Palsson et al. 2009). Hypoxia and other synergistic effects will be discussed in the climate change and ocean acidification sections below.

Microplastics. Microplastics are an emerging concern for marine ecosystems. Microplastics come from large plastic trash that has been reduced into smaller pieces or they may also come from manufactured plastics such as microbeads in products like facial soap, body wash, and toothpaste. Microplastics and their effects on marine ecosystems have not been studied as widely as other contaminants, but recent studies have shown that they can affect fish larvae both chemically and physically, increasing rates of mortality (Lönnstedt and Eklöv 2016). Gut content analysis of several rockfish in California found microplastics (Rochman et al. 2015). Some countries, including Canada in which part of the DPSs occur, have banned plastic microbeads from cosmetic products in an effort to limit their deleterious effects on ecosystems.

Toxic Chemicals in Rockfish and Other Benthic Species

The Puget Sound Ecosystem Monitoring Program (PSEMP) is a coordinated effort by several agencies to assess trends in the quality of the Puget Sound environment. It is generally focused on three classes of contaminants, including PCBs, PAHs, PBDEs, and other endocrine disrupting compounds. In the past, the Washington Department of Fish and Wildlife (WDFW) monitored contaminant concentrations in several benthic species, including three species of rockfish (copper [*Sebastes caurinus*], quillback [*S. maliger*], and brown [*S. auriculatus*]). The WDFW's PSEMP unit currently evaluates contaminant levels in English sole (*Parophrys vetulus*) that are considered an appropriate indicator species for contaminants that accumulate in sediment and that inhabit benthic environments like listed rockfish (PSAT 2007). WDFW's PSEMP unit has also monitored contaminant concentrations in pelagic species, such as Pacific herring, (*Clupea pallasii*) and several salmon species (*Oncorhynchus spp*.). Herring are prey for many species, including rockfish, and play an important role in transferring contaminants to upper trophic-level species. PSEMP also has a long-term sediment monitoring program in which ten sediment stations have been monitored annually since 1989 (see Partridge et al. 2005; Dutch et al. 2011a, 2011b), though program funding has decreased in recent years.

Marine sediment can act as a repository by burying contaminants but may also be a source of contaminant exposure for benthic food webs. About 32 percent of the sediments in Puget Sound are considered moderately or highly contaminated, primarily in urban bays (PSAT 2007; Palsson et al. 2009). Organisms that live in or ingest these sediments transfer persistent toxicants up the food web to higher-level predators like rockfishes and to wider geographic areas through dispersal of both primary consumers and their predators.

Because most adult rockfish have high site fidelity, their contaminant profiles likely reflect their local environment (West and O'Neill 1998). Therefore, it is not surprising that contaminants such as PCBs, chlorinated pesticides (e.g., DDT), and PBDEs appear in the tissues of rockfish collected in urban areas (Palsson et al. 2009). Male rockfish collected in urban areas (e.g., Elliot Bay, Sinclair Inlet, and Commencement Bay) had high concentrations of mercury and PCBs compared to rockfish in other areas and to females in the same areas (West and O'Neill 1998; West et al. 2001a; PSAT 2007). This trend is also found in other benthic species. PAH exposure in English sole from urban areas was three to four times higher than English sole from non-urban areas (PSAT 2007). Concentrations of PBDEs in English sole were 10 times higher in urban areas than English sole from the Georgia Strait (PSAT 2007). Toxicants can also be found in fish tissue in all regions of Puget Sound (PSAT 2007), including high levels of mercury and hydrocarbons in rockfish in rural areas of the San Juan Islands (West et al. 2002). West et al. (2011) found that contaminant levels in English sole from urban locations have so far showed no declining trend in PCBs, PBDEs, and EDCs (endocrine disruptors) (failed target), while most non-urban locations showed no increasing trend (met target). PAHs appear to be declining in English sole from three urban locations and were low in non-urban locations (see Figure 1).

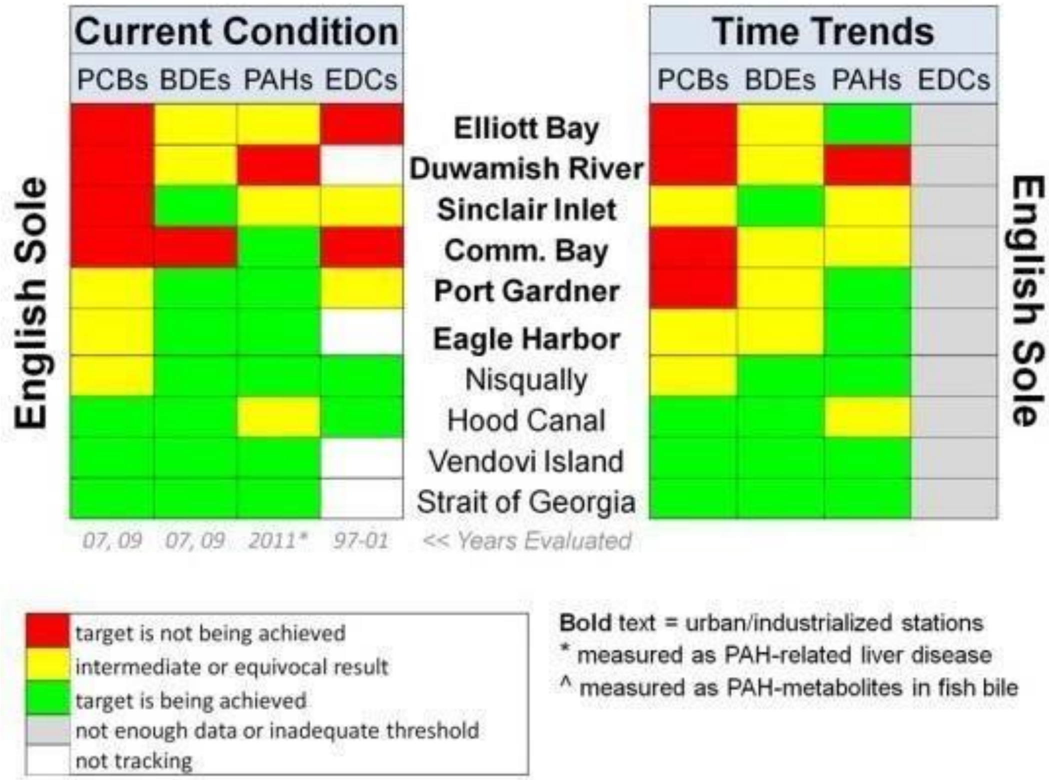

Figure 1. Summary of current conditions and long-term time trends in contaminants for English sole in various regions of the Greater Puget Sound, Washington. (Adapted from West et al. 2011.)

Rockfish occupy similar environments to English sole, but in contrast are at a higher trophic level and thus have been shown to have higher concentrations of PBTs (PSAT 2007). Yelloweye rockfish is Puget Sound had the highest measured concentrations of mercury of all fish species tested (West et al. 2001). 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).

In part, rockfish rely on pelagic prey, such as Pacific herring, and thus may be more exposed to toxic chemicals originating from a spatial range greater than that directly used by a given rockfish. Several PBTs bind to particles in the water column or to lipids in biota (De Wit 2002). Pelagic species, including larval and juvenile rockfish, can be exposed to these PBTs through bioconcentration (i.e., direct partitioning from the water column) or diet. Concentrations of PCBs in herring from Puget Sound are 3 to 9 times higher and DDT concentrations are 1.5 to 2.5 times higher than in herring from the Strait of Georgia (West et al. 2008). The higher levels of contamination are likely because herring are a resident species in Puget Sound and primarily feed in areas with regional contaminant sources (West et al. 2008). Resident Chinook salmon also have higher levels of PCBs and PBDEs than Chinook salmon that migrate out of Puget Sound (O'Neill et al. 2004; O'Neill and West 2009). Thus, larval and juvenile rockfish in the more urban basins (i.e., in southern/central Puget Sound) may be exposed to higher levels of contaminants than rockfish from northern Puget Sound (Palsson et al. 2009).

Several factors that may influence the bioaccumulation and concentration levels of contaminants in species include the marine distribution of the individual, the general proximity to urban and non-urban areas, trophic status, and age and sex of the individual. Lastly, lipid (fat) content is a factor because many persistent pollutants are lipophilic compounds. During reproduction, females may transfer some PBTs to their young. Generally, reproductive females have lower PBT levels than adult males. For example, male quillback rockfish sampled from Elliot Bay had increasing PCB concentrations with age and higher total PCB concentrations than female quillback rockfish of the same age (West and O'Neill 2012).

Potential Adverse Health Effects in Rockfish and Other Benthic Species from Exposure to Toxic Chemicals

Exposure to toxic chemicals can affect the health and viability of a population (e.g., via mortality, reproductive impairment, and growth). Sublethal effects may also harm an individual's fitness; for example, by altering thyroid function, which can affect metabolic rate, respiration, and the nervous system (Meador et al. 2002). Once PBTs are liberated from lipid storage in fish and become mobilized (e.g., during reproduction), they circulate to more sensitive target tissues. Thus, PBT toxicity will vary throughout an individual's life.

There are no studies to date that define specific adverse health effects 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 ranging from sublethal as described in the above paragraph to lethal (Meador et al. 2002). Adult male quillback rockfish sampled from Elliot Bay had higher PCB concentrations than this threshold (West et al. 2011). West et al. (2011) 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 (Drake et al. 2010).

Johnson et al. (2008) observed vitellogenin induction in male English sole (i.e., evidence of reproductive dysfunction). Exposure was highest in fish at urban sites near high stormwater discharge input, combined sewer overflows, and wastewater discharge (Johnson et al. 2008). Nearly half of male English sole from Myrtle Edwards Park in Elliot Bay produced vitellogenin (Johnson et al. 2008). Reduced reproductive function in English sole from contaminated areas effectively decreases productivity (Landahl et al. 1997). Reproductive function in rockfish is also likely affected by contaminants (Palsson et al. 2009). West et al. (2001b) detected vitellogenin in 2 of 11 male quillback rockfish sampled from Elliot Bay.

Estrogenic compounds, once combined, can enhance toxicity and thus deleterious effects can occur at lower doses or exposures. Brian et al. (2007) provide evidence of mixture effects on fitness and fecundity in flathead minnow exposed to five estrogenic chemicals. Of particular importance, reproductive performance was affected even when the concentrations of chemicals in the mixture were at levels below "no-effect-observed-concentrations" (Brian et al. 2007). These results highlight the need for risk assessments to include an examination of mixture effects from exposure to estrogenic mixtures to prevent underestimating the actual risk to the species.

Contaminant-induced immunotoxicity (e.g., increased disease susceptibility) has been observed in several fish and wildlife species. In addition to disease susceptibility in English sole as the result of PAH exposure (Collier and Varanasi 1991), Johnson et al. (2002) found that risk of PAH-induced health effects (e.g., liver disease and impacts to growth and reproduction) increased as PAH concentration in the sediment exceeded a threshold of 1,000 parts per billion. Exposure to PBDEs can also increase disease susceptibility in juvenile salmon (Arkoosh et al. 2010). Rockfish are susceptible to diseases and parasites (Love et al. 2002). Although the impact of diseases and parasites in Puget Sound rockfishes is unknown, stress associated with poor water quality may exacerbate the incidence and severity of naturally occurring diseases to the point of directly or indirectly decreasing survivorship of rockfish (Palsson et al. 2009).

Few studies have examined the effects of microplastics on animals. A recent lab experiment found that European perch larvae exposed to microplastic particles at levels currently present in seas inhibited hatching of fertilized eggs, stunted larval growth, and decreased activity rates and predator-avoidance strategies, thus increasing mortality rates (Lönnstedt and Eklöv 2016). The larvae also preferentially ate microplastic particles instead of plankton. These findings may be of concern for many marine species because microplastic particles often accumulate in shallow coastal areas where developmental stages of many organisms in addition to fish occur (Lönnstedt and Eklöv 2016).

The full effects of contaminants on rockfish remain unknown. In Table 1 we summarize the contaminants and their effects discussed in this section. The recovery potential for rockfish may be directly impacted by contamination in urban embayments, such as Elliot Bay and Sinclair Inlet. In these contaminated areas, we might expect to find relatively high densities of rockfish exposed to high levels of toxicants. Because past fishing effort was likely higher on portions of rockfish populations in more rural areas with lower levels of toxic pollution (i.e., the San Juan Basin), more contaminated, urban rockfish may contribute disproportionately to spawning potential (Palsson et al. 2009). Such a scenario could limit recovery of listed rockfish by limiting the lifetime egg production of females and the effective breeding potential of males.

Table 1: Summary of persistent bioaccumulative toxicants (PBTs) and potential effects to fish health.

Contaminant	**Effects on Productivity and/or Diversity of Fish**
PAHs	Cancer, reproductive problems, birth defects, immune suppression
PBDEs	Impaired neurological development, immune suppression
ECDs (Endocrine disruptors) (i.e., xenoestrogens)	Reproductive disruption, reduced fitness and fecundity
Mercury/methylmercury	Impaired neurological development
Organochlorines (i.e., PCBs, DDTs)	Cancer, impaired development
PCBs	Lower growth rates, reduced fitness and fecundity
Microplastics	Suppressed egg hatching and larval growth, altered predator-avoidance behavior and feeding behavior, and increased mortality rates
All of the above Persistent Bio-accumulative Toxicants (PBTs)	May result in a disproportionately high spawning biomass from contaminated rockfish because most rockfish are in non-urban areas with higher fishing pressure

Recommended Efforts and Research Priorities

There have been few studies that have investigated the direct effects of contaminants on rockfish and there are no current toxicant monitoring or research efforts for rockfish in Puget Sound. Furthermore, over the past 15 years, the WDFW budget designated for status and trend monitoring of toxicants in Puget Sound has been cut in half (TWG Vital Signs summary 2013). Because of this long-term lack of funding, monitoring for toxicants in salmon has been eliminated and monitoring for toxicants in English sole and Pacific herring has been reduced. The development of a sampling method and initiation of a monitoring plan for endocrine disrupters in English sole has also never been funded. Current monitoring for toxicants in English sole includes eight locations every other year (previously included 20 locations every year). Previous funding provided monitoring of six herring stocks each year; current funding supports three stocks every other year. Additionally, metals are analyzed in both English sole and herring at a reduced rate of approximately every 5 years. Currently, Ecology conducts annual sediment quality monitoring at ten long-term monitoring stations.

In addition to reinstating and continuing the above monitoring to previous levels, the Puget Sound Ecosystem Monitoring Program Toxics Work Group recommends evaluating contaminants of emerging concern. The work group is prioritizing a suite of chemicals for monitoring. Finally, research and monitoring to better understand the effects of contaminants on rockfish specifically would aid in prioritizing recovery actions and management, and efforts to minimize or remediate contaminant input would aid in recovery. We recommend the following rockfish-specific research and actions to address contaminants (also see Section V. A. Recovery Program):

- Determination of thresholds at which rockfish at all life history stages may be affected by the primary contaminants in Puget Sound summarized in this appendix (PAHs, organochlorines [e.g., PCBs and DDTs], brominated flame retardants such as the PBDEs, other endocrine disruptors, and mercury/methylmercury) along with coordination with appropriate agencies, such as the Puget Sound Partnership, to monitor these contaminants in rockfish and limit them in Puget Sound (through both efforts to decrease contaminant inputs and remediation).
- Risk assessments examining effects from exposure to estrogenic mixtures and mixtures of other PBTs.
- Long-term research comparing concentrations of PBTs in rockfish and their larvae in urban and non-urban areas and assessing the possible effects on productivity and population viability.
- Determine levels of microplastics in rockfish at all life stages in Puget Sound, study the transmission of microplastics in the food web (e.g., do rockfish larvae and adults eat them directly or accumulate them from their prey?), study the direct and indirect effects of microplastics on rockfish, and understand how individual-level effects of microplastics on individual rockfish may affect populations.

Dredging and Sediment Disposal

Most dredging within Puget Sound occurs in and near deltas of local rivers to maintain navigation channels and access to existing marinas. Dredging often occurs in areas with a variety of contaminated sediments that can be released into the water column by the dredging and disposal process. These contaminants may be taken up by phytoplankton, zooplankton, benthic invertebrates, demersal fish, forage fish, and other fishes (Army Corps of Engineers 2010), which can then be bioaccumulated by long-lived predators such as rockfish. As discussed above, many of these contaminants are associated with disease and with the disruption of behavior and immune system functions (West et al. 2001b; Palsson et al. 2009). In addition, dredging removes benthic invertebrates that form lower trophic levels of the food web. Re-colonization studies suggest that recovery (generally meaning the later phase of benthic community development after disturbance when species that inhabited the area prior to disturbance begin to re-establish) may not straightforward, and can be regulated by physical factors that include particle size distribution, currents, and compaction/stabilization processes following disturbance (Sardá et al. 2000; Gilkinson et al. 2005).

The Army Corps of Engineers and Environmental Protection Agency lead the administration of the Puget Sound Dredge Disposal Agency (PSDDA) program, and dredging projects are regulated by the Army Corps of Engineers through section 404 of the Clean Water Act. There are five non-dispersive disposal sites in the ranges of the DPSs where currents are slow enough that dredged material is deposited on the disposal site. There are two dispersive sites in the DPSs that exhibit higher current velocities that move dredged material onto adjacent benthic environments (NMFS 2014). Most of the dredge disposal sites are not located over prime adult rockfish habitats, though sediment disposal could nonetheless alter benthic habitats used by listed rockfish and their prey by altering local bathymetry and sediment quality (in positive or negative ways). Sediment disposal is unlikely to exacerbate bioaccumulation within listed rockfish because 1) the PSDDA program has resulted in a net removal of contaminated sediments within Puget Sound and 2) this trend is expected to continue for the foreseeable future. Over the past 22 years, approximately 5 percent of the dredged sediment has been deemed too contaminated for in-water disposal and was disposed of at upland sites. As an example, nearly 50 percent of the dredged sediments of Elliot Bay and the Duwamish River area have been disposed of at upland locations.

Suggested Research and Actions—Dredging and Sediment Disposal

We recommend the assessment of possible modifications to dredging and disposal to conserve listed rockfish and their habitat. Our recommended actions include:

- Assess the spatial and temporal extent of dredging activities and the deposition of dredge spoils, and require dredge spoil to be placed in approved upland disposal sites where appropriate.
- Assess potential sublethal effects of contaminants for the various life stages of listed rockfish (or surrogate) health, behavior, and productivity.
- Analyze the dissolved and particulate PCB and PBDE in the open waters of the Puget Sound/Georgia Basin. This may be accomplished through ongoing studies or new studies initiated under the PSDDA program.
- Include PBDEs on the list of potentially bioaccumulative substances that require testing under the PSDDA program.
- Continue to develop models and/or conduct field tests to determine the trajectory of drift, concentrations, and deposition of sediment disposed of at the dispersive sites.
- Annually assess new scientific research for bioaccumulative compounds encountered under the PSDDA program, including new and existing literature regarding effect thresholds (that include synergistic and sublethal effects) for aquatic species.
- Develop a long-term database of dredge and fill activities to provide a spatial dataset that, when superimposed with rockfish habitat, would likely inform management actions to minimize impacts.

CONCLUSION

This appendix provided background, recommended efforts, and research priorities regarding sediment and water quality contaminants and listed rockfish. The primary toxic chemicals of concern include PAHs, organochlorines, brominated flame retardants such as the PBDEs, other endocrine disruptors, and mercury/methylmercury. We briefly described the use of, associated health effects from, and regulation for these chemicals of concern and research and recovery efforts**.**

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APPENDIX VII

CLIMATE CHANGE AND OCEAN ACIDIFICATION

OVERVIEW

This appendix identifies the known and potential effects of climate change and ocean acidification (OA) on listed rockfish, their prey sources, and their habitats within the Puget Sound/Georgia Basin. Notably, these different stressors, in addition to other anthropogenic stressors, such as nutrient addition, will likely have synergistic and cumulative effects that are difficult to predict or attribute to any single source, and as identified in the Recovery Plan (see Section E. Factors Contributing to Decline and Federal Listing), the threat level is high. At the end of each section, general priorities for research and associated actions are identified.

Climate change priorities include investigating listed rockfish-specific responses to temperature changes and synergistic climate change effects, and investigating the restoration and analysis of the potential capabilities of seaweeds and sea grasses in nearshore areas to provide juvenile rockfish habitat, support rockfish prey, ameliorate unfavorable water quality conditions, and, if indicated, promote conservation and restoration of seaweed and sea grass habitats, which is also a priority for OA.

Lastly, OA priorities include investigating listed rockfish-specific responses to changing pH levels, including effects on growth, physiology, productivity, and behavioral responses; targeting quantification of regional factors that contribute to OA and developing cooperation among appropriate agencies to reduce their effects; and analyzing the potential for protected areas to ameliorate the synergistic effects of contaminants, climate change, and OA and their many secondary effects (e.g., disease, decreased productivity, increased hypoxia, etc.).

Background—Climate Change

Since pre-industrial times, global concentrations of greenhouse gases, including carbon dioxide, methane, and nitrous oxides have increased considerably (IPCC 2007). Carbon dioxide (CO_2) concentrations have increased from approximately 280 ppm 250 years ago to present levels of approximately 387 ppm, mostly because of the burning of fossil fuels and deforestation (IPCC 2007). Nearly half of this increase has occurred in the past three decades (IPCC 2007), and around one-third of the CO_2 produced in the last 200 years has been taken up by oceans (Sabine et al. 2004). Atmospheric CO_2 concentrations may exceed 500 ppm and global temperatures may rise by at least 2°C by approximately 2050 to 2100 (Hoegh-Guldberg et al. 2007; Feely et al. 2008). These values have not occurred on earth for at least the past 420,000 years, during which time most extant marine organisms evolved (Hoegh-Guldberg et al. 2007).

In addition to anthropogenic climate change, the ocean along the Pacific Coast of North America is influenced by a number of natural climatic factors such as the El Niño/Southern Oscillation and the Pacific Decadal Oscillation, during which their warm and cool phases affect ocean temperature and stratification (Mantua and Hare 2002). These and other naturally occurring factors strongly influence inter-annual and inter-decadal variability in ocean conditions and can confound the effects of anthropogenic climate change (Mantua and Hare 2002; Chavez et al. 2003). The effects of climate change include, but are not limited to, changes in temperature, distribution shifts of species, OA, changes in primary production, changes in biodiversity, declining mid-water oxygen concentrations, changes in upwelling and vertical mixing, sea-level rise, erosion, and more severe and frequent inundation of low-lying areas from the combined effects of rising sea levels and intensified and more frequent storms (Harley et al. 2006; IPCC 2007; Feely et al. 2008; Fabry et al. 2008; Nicholls and Cazenave 2010; Ainsworth et al. 2011; Feely et al. 2012; Dalton et al. 2013; Mauger et al. 2015; others). Ocean acidification co-occurs with climate change and, like climate change, is caused by anthropogenic CO_2 emissions. The following subsections discuss more commonly studied responses to climate change: temperature change and sea-level rise, in addition to some of the synergistic impacts the multiple effects of climate change may cause. OA and its effects will be discussed in a separate section.

Temperature Change

In all but six of the years from 1980 to 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. Specifically, by the 2050s, the average year in the Puget Sound region is projected to be +4.2 degrees F (range: +2.9 to +5.4 degrees F) warmer under a low greenhouse gas scenario (Mauger et al. 2015).

The close correspondence between Puget Sound air and water temperatures (Moore et al. 2008a) indicate that not only will Puget Sound water temperatures increase, but that the annual period with temperatures exceeding 55.4°F (13°C) will greatly expand (Moore et al. 2008b). Larval recruitment in rockfish is strongly linked to particular climate conditions (Love et al. 2002); thus, this life stage may be particularly susceptible to changes in temperature.

Increased temperature may have many effects on the Puget Sound/Georgia Basin ecosystem and marine species, including, but not limited to, distribution shifts of marine species that may involve introduction or elimination of some invasive species and diseases, increased cases and duration of harmful algal blooms (HABs), sea level rise (SLR), decreased primary production, increased stratification, and hypoxia (Harley et al. 2006; Moore et al. 2008b; Feely et al. 2010; Feely et al. 2012).

Long-term warming could result in northerly shifts for some rockfish, in addition to decreased larval survival and decreased maximum size and fecundity because temperature, atmospheric pressure, ocean circulation, and other factors affect growth, survival, and density of rockfishes (PFMC 2011).

Sea-Level Rise

Sea water thermal expansion because of ocean warming and water mass input from land ice melt and land water reservoirs contribute to SLR (IPCC 2007). In addition to natural perturbations of the climate system, anthropogenic activities such as groundwater extraction and deforestation may exacerbate SLR, particularly in low-elevation urbanized coastal zones (Church and White 2006).

Sea level has risen by an average of 0.07 ± 0.01 inch (1.7 ± 0.3 mm)/year since 1950 after remaining relatively stable for approximately the last 3,000 years (Church and White 2006; Nicholls and Cazenave 2010). However, satellite data collected more recently (from 1993 to 2009) recorded rates of 0.13 ± 0.02 inches (3.3 ± 0.4 mm)/year, suggesting that SLR may be accelerating (Ablain et al. 2009). Global SLR is projected to increase by approximately 23.6 inches (60 cm) by 2100 (IPCC 2007) to as much as 3.28 feet (1 m) because of recently identified declines in polar ice sheet mass (Pfeffer et al. 2008). However, Washington State is situated above an active subduction zone, which may mean that SLR could differ from the global average, depending on the activity of the zone (Dalton et al. 2013). Puget Sound lowlands are thought to be more stable in the north, but are tilting downward toward Tacoma in the south. This subsidence may amplify SLR and could effectively double the rate in areas of South Puget Sound, such as Olympia (Craig 1993).

In south Puget Sound, SLR could, among other impacts, contaminate surface and groundwater; cause shoreline erosion and landslides, which may lead to a loss of tidal and estuarine habitat (Craig 1993); and may cause shifts in species distribution (Harley et al. 2006). The effect on the nearshore is of particular note because it is used by juvenile bocaccio, and likely has a critical role in their successful recruitment (Love et al. 1991).

Although rates vary by location, sea level rose over the last century 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).

Synergistic and/or Cumulative Effects of Climate Change

The synergistic and/or cumulative effects of climate change may have numerous impacts on the marine environment. This section discusses some of those potential impacts.

Increasing CO_2 results in lower sea surface O_2 concentrations. Brewer and Peltzer (2009) reported that ocean zones devoid of aerobic life will expand as a result of rising CO_2 concentrations. The O_2 deficit may be exacerbated and deepened by reduced ventilation of the mid-water from ocean warming and local eutrophication events. Further reductions of O_2 subsequently follow because hypoxia often increases respiration. These synergistic effects may cause a physiological strain on marine animals that could impair their performance and result in energy use that would otherwise be used for predation, reproduction, and other functions (Brewer and Peltzer 2009), thereby reducing overall fitness and productivity.

Ainsworth et al. (2011) modeled five rarely studied, climate change-induced effects and their cumulative or synergistic impacts on marine food webs, including changes in the annual mean level of primary production, latitudinal range shifts of fish and invertebrates because of temperature changes, changes in the size structure of zooplankton communities, ocean acidification, and ocean deoxygenation. The analysis primarily examined fisheries landings and fisheries biomass in addition to other ecosystem characteristics. Model results revealed that fisheries landings generally declined to a greater extent in response to the cumulative effects of the five climate effects than would have been expected additively from each of the effects alone, and indicates possible synergies between the effects (Ainsworth et al. 2011). The model also revealed that though total biomass of fished and unfished functional groups both declined, the unfished groups declined to a lesser extent in response to the synergistic climate effects (Ainsworth et al. 2011). Harley et al. (2006) similarly found that fishing pressure may exacerbate effects of climate change.

Estuaries experience increased frequency and severity of hypoxia because of the combined effects of increased greenhouse gases causing temperature rise and increased stratification. These effects, in combination with nutrient loading, may become especially problematic in areas of Puget Sound where water circulation is restricted, such as in Hood Canal and South Puget Sound (Newton et al. 2002).

In Puget Sound, the magnitude, frequency, and duration of harmful algal blooms (HAB) may increase with higher sea surface temperatures, lower pH, and changes to vertical mixing, upwelling, and precipitation caused by increased greenhouse gases (IPCC 2007; Moore et al. 2008b; Mauger et al. 2015). For example, increased sea surface temperature could not only increase the spatial range in some species responsible for HAB, but could also extend the duration of HABs because many harmful algae species require higher temperatures. Higher temperatures may be prolonged because of climate change (Moore et al. 2008b). Additionally, when HABs decompose they may cause serious declines in dissolved oxygen in the marine environment (Moore et al. 2008b), which could produce hypoxic conditions.

Current Monitoring and Research, and Recommended Efforts and Research Priorities

There are a number of academic and agency groups involved in monitoring the potential effects of climate change on water quality in Puget Sound. The Puget Sound Ecosystem Monitoring Program (PSEMP) has been monitoring temperature, pH, sediment, and other measures for many years in Washington marine waters. The Washington Department of Ecology has also been monitoring marine waters at over 40 stations. The University of Washington Climate Impacts Group, Northwest Climate Science Center, and other regional groups conduct research into climate change and its effects. Adaptation and management will require continued and expanded monitoring of water quality, the nearshore habitat, and potential climate change effects as well as development of models of the impacts of climate change. Specifically, a better understanding of the relative impact of different regional drivers on climate change effects will aid in an understanding of management and mitigation possibilities. However, much research is also required for specific impacts of climate change on rockfish and therefore we recommend the following research and actions:

- Determine rockfish-specific responses (particularly by life stage and species) in any behavioral, physiological, or ecological aspect relevant to survival, reproduction, and growth to maturity in relation to changes in temperature and synergistic climate change effects.
- Investigate the capabilities of seaweeds and sea grasses in nearshore areas to provide juvenile rockfish habitat, support rockfish prey, and ameliorate unfavorable water quality; and pending research outcomes, take appropriate management actions.

OCEAN ACIDIFICATION: WORLDWIDE AND IN PUGET SOUND

Since the beginning of the industrial revolution approximately 250 years ago, the amount of anthropogenic CO_2 has steadily increased by over 100 parts per million (IPCC 2007), which may have serious implications for ocean conditions and marine life (Feely et al. 2012). The ocean absorbs roughly one-third of the CO_2 from the atmosphere (Sabine et al. 2004) and the net effect is ocean acidification (OA). OA is defined as an overall reduction in the ocean's pH, the concentration of carbonate ion (CO_3^{2-}, required for calcifying organisms), and the saturation states of aragonite and calcite (Fabry et al. 2008; Feely et al. 2008; Doney et al. 2009; Feely et al. 2010).

The worldwide projected pH decrease is 0.3 to 0.4 for the 21st century, equivalent to an approximately 150 percent increase in H^+ and a 50 percent decrease in CO_3^{2-}, which is essential for the biology and survival of a wide range of marine organisms (Fabry et al. 2008; Doney et al. 2009).

The west coast of the United States is particularly vulnerable to enhanced OA associated with seasonal upwelling because the Pacific Coast's continental shelf is relatively narrow. While narrow shelves have historically driven upwelling that results in high productivity on the west coast, they now induce more corrosive water to reach coastal marine organisms (Feely et al. 2010). Deep ocean waters, naturally under-saturated with respect to calcium carbonate and corrosive to shelled organisms, are expanding toward the ocean surface at the rate of 3.3 to 6.6 feet (1 to 2 m) per year in the North Pacific (Feely et al. 2008). Feely et al. (2008) have demonstrated that even a decrease in emissions output today would not prevent even more corrosive waters in the future from reaching Pacific coastlines, which could affect many marine organisms.

The pH of the Northeast Pacific Ocean surface waters decreased by 0.1, which corresponds with +26 percent increase in H+ concentration since the pre-industrial era and by 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).

In Puget Sound, water circulation is influenced by four basins (Whidbey, Main, Hood Canal, and South Sound) of varying depths, carved out by glaciers connected by shallow sills that check the flow of water. The northern and central areas of Puget Sound are affected primarily by inflow from the Pacific Ocean at the Strait of Juan de Fuca in deep waters, and the upper layer outflow is through Admiralty Inlet (Feely et al. 2010). This oceanic inflow influences OA in Puget Sound and the Strait of Juan de Fuca and the inflow varies seasonally and interannually (Feely et al. 2012). Water is well-mixed but corrosive during wintertime, and more stratified with more corrosive waters in the deeper layer during the summer and fall (Feely et al. 2012). The southern areas of Puget Sound typically exhibit slow flushing, restricted mixing, and stronger stratification (Newton et al. 2002). As an urban estuary, Puget Sound also has large fluxes of nutrients and pollutants in addition to fresh water, organic matter, and sediment inputs that affect circulation (Feely et al. 2010).

Ocean Acidification Effects on Marine Organisms and Rockfish

Trophic and Prey Effects

OA will adversely affect calcification, or the precipitation of dissolved ions into solid calcium carbonate ($CaCo_3$) structures, for a number or marine organisms, which could alter trophic functions and the distribution and/or availability of prey for a variety of marine life (Fabry et al. 2008; Feely et al. 2010). Euthecosomatous pteropods are a significant $CaCO_3$ producer and may be first among the major groups of planktonic calcifiers to experience reduced calcification because of their geography, physical structure (highly soluble aragonite shells), and saturation state (Fabry et al. 2008; Bednarsek et al. 2014). As OA causes the saturation state of calcite and aragonite to decrease, it is expected that these organisms will produce under-calcified or thinner structures. Pteropod dissolution damage is already occurring in the California Current Ecosystem (Bednarsek et al. 2014). Though implications of these effects on rockfish have not been studied, a 10 percent decrease in pteropod production could lead to a 20 percent decrease in mature body weight in pink salmon (Fabry et al. 2008).

While pteropods are expected to experience severe effects of OA earlier than other marine organisms, there are still many other important groups that rely on calcium carbonate that could be impacted by OA. Coccolithophores, a type of unicellular phytoplankton, are some of the most abundant primary producers in marine habitats and are important to coastal ecosystems. After their calcium carbonate coccoliths (microscopic plates that cover the planktonic cells) are formed, coccolithophores are vulnerable to dissolution unless the surrounding sea water contains saturating concentrations of carbonate ions (Feely et al. 2010). Foraminifera, molluscs, and some species of echinoderms also demonstrate reduced calcification and sometimes dissolution of $CaCO_3$ skeletal structures because of OA. 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 molluscs, and copepods (Fabry et al. 2008), which are important prey items for larval and juvenile rockfish (Love et al. 1991; Love et al. 2002).

Research on the impacts to various copepod species from OA has been substantial relative to other marine species, and it reveals that copepod responses to OA vary by species and life stage (Feely et al. 2012). There is evidence that OA may cause decreased growth, egg production, and hatching success, and increased mortality (Feely et al. 2012; Mayor et al. 2012; Zhang et al. 2012). Fitzer et al. (2012) also demonstrated that even if copepods adapt to OA conditions, there may be a trade-off between reproductive effort and self-maintenance because high levels of pCO_2 (partial pressure or concentration of CO_2 in the blood) may negatively affect feeding and respiration rates for some species.

OA may also cause alterations in the food web through behavioral changes. For example, some of the zooplankton and fish that feed on euthecosomatous pteropods could switch to other prey types, but that switch could result in greater predation pressure on some species of juvenile fish (Fabry et al. 2008). Increased temperature and OA have been linked to impaired immune systems of marine organisms, such as shellfish and fish, and increased disease frequency (Feely et al. 2012). It is likely that changes in host-parasite relationships will change with ocean conditions and vary among species (Feely et al. 2012).

Further research is needed to understand the implications of OA on trophic functions in the Puget Sound ecosystem and their effects on rockfish. Thus far, studies conducted in other areas have shown that the effects of OA will be variable (Ries et al. 2009) and species-specific (Miller et al. 2009). As mentioned above, though organisms may be able to overcome corrosive conditions through responses such as modifying internal fluid chemistry, these responses could be energetically costly and may reduce productivity, growth, or survivorship (Wood et al. 2008; Fitzer et al. 2012; Feely et al. 2012).

Direct Effects on Rockfish

Adult fish generally have the ability to largely control internal physiology, including acid-base equilibrium. Conversely, early life history stages of fish often lack the physiological control mechanisms present in adults (Feely et al. 2012). For example, early larval stages lack gills, an important organ for maintaining acid-base balance, making some larval stages more sensitive to changes in ocean chemistry. These sensitivities may vary among fish species and life history stages (Feely et al. 2012). Although fish appear to be among the most tolerant of marine animals to changes in ocean chemistry, their mechanisms to compensate for these changes have been shown to reduce growth and reproductive output, thereby decreasing lifetime productivity (Fabry et al. 2008).

There have been very few published studies to date on direct effects of OA on rockfish. In a recent study, OA was found to affect juvenile rockfish behavior (Hamilton et al. 2014). Light/dark recognition and determination of object proximity, characterized as “anxiety” by the authors, significantly changed in juvenile splitnose rockfish (*Sebastes diploproa*) after 1 week of exposure to OA conditions that are projected for the next century off the California shore. The study indicated that OA could have severe effects on rockfish behavior (Hamilton et al. 2014). However, when rockfish were returned to control sea water, they resumed their normal behavior after 12 days. Copper rockfish (*S. caurinus*) exhibited reduced critical swimming speed, depressed aerobic scope, changes in metabolic enzyme activity, and increases in the expression of transcription factors and regulatory genes when exposed to low pH seawater while blue rockfish (*S. mystinus*) showed no significant changes in those traits but did significantly change expression of muscle structural genes, suggesting acclimatization potential (Hamilton et al. 2017). Additional research is needed to understand listed rockfish responses to OA, especially with regard to effects on fitness and productivity.

In other fishes, there is evidence that OA conditions expected in this century could have serious consequences on behavior and sensory functions important to recruitment, settlement, prey and predator detection, and overall survival (i.e., Munday et al. 2009; Simpson et al. 2011; Chung et al. 2014). For example, larval orange clownfish (*Amphiprion percula)* in experimentally CO_2-enriched conditions experienced impairment of olfactory cues that resulted in the inability to avoid predators and in choosing inappropriate habitat, both of which are likely to result in higher mortality (Munday et al. 2009). These conditions also affected auditory capabilities in recently settled juvenile orange clownfish, resulting in these fishes failing to avoid potential predators (Simpson et al. 2011). These results could also be significant across other functions where hearing is important, such as habitat selection and orientation, and these functions are also important for rockfish.

Synergistic Effects of OA, Other Anthropogenic Stressors, and Natural Biological and Physical Functions in the Puget Sound/Georgia Basin

Some natural biological and physical functions in Puget Sound cause water to be corrosive and hypoxic, such as restricted circulation and mixing, respiration, and strong stratification, especially in Hood Canal and South Puget Sound (Newton et al. 2002; Feely et al. 2010). However, naturally occurring poor water quality conditions typically driven by climate forcing and geology are exacerbated by anthropogenic activities such as OA, nutrient enrichment, and habitat modification/loss (Feely et al. 2010).

The Department of Ecology has found that nitrate concentrations in Puget Sound are increasing (Krembs et al. 2012), which could cause areas of increased primary production. As large amounts of phytoplankton die and sink, they decrease DO levels and lower pH through respiration, which could fuel hypoxic conditions in stratified waters (Feely et al. 2012). The southern part of Hood Canal basin exhibits these hypoxic conditions and contains some of the lowest pH levels and aragonite saturation states observed in Washington coastal waters (Feely et al. 2010). These areas, with naturally occurring hypoxic and corrosive conditions, are particularly susceptible to additional anthropogenic pressures (Feely et al. 2010; Feely et al. 2012). However, the relative importance of anthropogenic nutrient input in exacerbating these episodes in Hood Canal still warrants further investigation (Cope and Roberts 2012).

Synergistic stressors may cross thresholds for some organisms living near the edge of their physiological tolerances, causing ecosystem shifts that may result in mass mortalities (Chan et al. 2008). Typically, rockfish move out of areas with DO less than 2 mg/L (2 ppm); however, when low DO waters in Hood Canal upwelled to the surface in 2003, about 26 percent of the rockfish population was killed (Palsson et al. 2009). Therefore, synergistic changes in water quality may occur too quickly for rockfish to safely avoid the area and can result in mortality.

Potential Climate Change and Ocean Acidification Mitigation for Listed Rockfish in Puget Sound

Techniques to locally mitigate for the effects of climate change and OA are in the early stages of development. Several of these options are discussed in this section.

Phytoplankton, seaweeds, seagrasses, macroalgae, and other marine primary producers remove carbon from the atmosphere and/or water column through photosynthetic and metabolic activities. Recent research shows these organisms contribute approximately 50 percent of global carbon fixation and up to 70 percent of global carbon storage (Chung et al. 2011). Some seaweeds and seagrasses could potentially mitigate excess carbon in marine habitats (Chung et al. 2011), providing potential for the local drawdown and short-term mitigation of carbon in Puget Sound (Feely et al. 2012). Native or established species in Washington State such as *Ulva* spp., *Palmaria palmata*, *Porphyra* spp., *Laminaria* spp., *Nereocystis luetkeana*, *Macrocystis pyrifera*, *Sargassum muticum*, and *Zostera* spp. have high photosynthetic rates (Chung et al. 2011; Feely et al. 2012). Although high photosynthetic rates tend to be associated with high carbon assimilation rates, variable amounts of fixed carbon may be re-released through respiration and decomposition (Feely et al. 2012). Thus, local potential for mitigation will likely be determined by re-release of carbon and other oceanographic processes (Feely et al. 2012). However, this mitigation potential has not been tested, which highlights the need for conservation and restoration of existing seagrasses and seaweeds (Feely et al. 2012).

Along with other mitigation strategies, Marine Reserves (or Rockfish Conservation Areas) are additionally recommended as a tool to buffer against the effects of climate change because fishing has been found to potentially exacerbate the effects of climate change (Harley et al. 2006; Ainsworth et al. 2011). The stable communities generated in marine reserves may be more resilient to climate disturbances (Hughes et al. 2003).

Minimizing regional air pollution may help reduce regional OA effects. Increases in ambient atmospheric CO_2 levels in Seattle and over Dabob Bay and Twanoh vary across daily and monthly time scales but are generally associated with traffic (commute hours) and weather events (warm, calm days) in Seattle (Feely et al. 2012). In addition to minimizing CO_2, efforts to minimize regional air pollution may help because high concentrations of atmospheric nitrogen oxides (NOX) and sulfur dioxide (SO_2) can also acidify marine waters (Feely et al. 2012).

Current Monitoring and Research, and Recommended Efforts and Research Priorities

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 recently developed an expanded ocean acidification monitoring network. This tool will collect data on marine species and the 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 1).

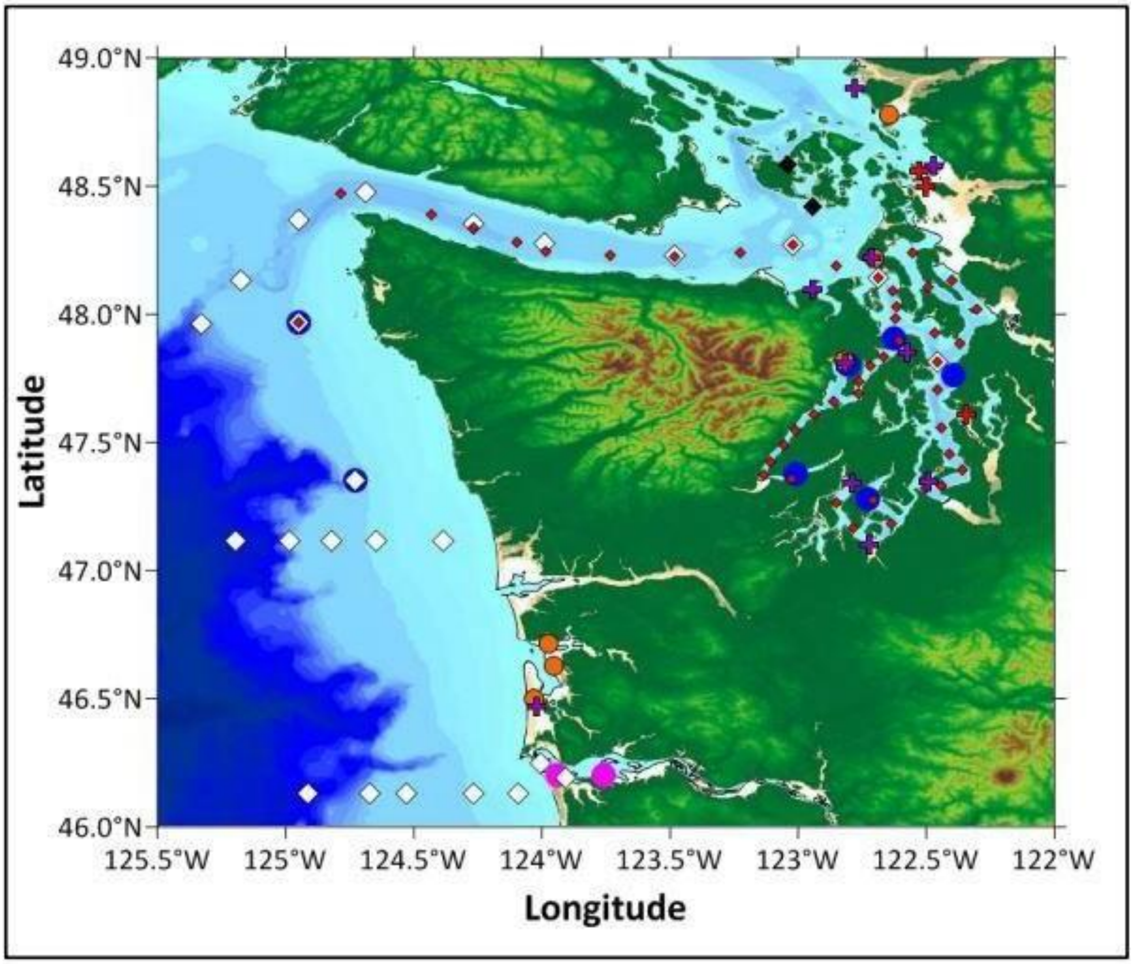

Figure 1. WOAC monitoring network. White, red, and black diamonds are ship cruise stations; blue dots are OA buoys (or soon to be); pink dots are OA moorings; orange dots are shellfish grower sites; and crosses are nearshore monitoring stations, including those of WA DNR (purple). (Excerpted from WOAC Integrated Monitoring for Ocean Acidification in Washington's Waters science information sheet (2015).)

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 kelp restoration in Puget Sound could protect shellfish and other sensitive species from the effects of ocean acidification, which would benefit listed rockfish not only by protecting prey resources but also by supplementing habitat for juvenile life stages.

The Blue Ribbon Panel on Ocean Acidification Scientific Summary of OA in Washington State Marine Waters provided several recommendations for research and monitoring to further understanding of the status and trends of OA in Puget Sound (Feely et al. 2012). Research activities include development of a monitoring network, identification and quantification of contributing factors to OA, characterization of local marine organisms' responses to OA and associated stressors, and building capacity for short-term forecasting and long-term predictions and models (Feely et al. 2012) that could inform adaptive management.

We recommend the following rockfish-specific OA research and actions (also see Section V. A. Recovery Program):

- Investigate responses of listed rockfish life history stages to OA, focusing on growth, survival, and reproduction.
- Investigate physiological thresholds of each life history stage of listed rockfish (or other rockfish species) to decreased pH.
- Investigate and quantify regional contributing factors to OA and cooperate with appropriate agencies to reduce their effects.
- Determine the potential of kelp, seaweeds, and/or seagrasses to mitigate the effects of OA and support listed rockfish habitat.
- Determine the potential capabilities of protected areas for listed rockfish and rockfish prey species to ameliorate the synergistic effects of contaminants, climate change, and OA and their many effects (e.g., disease, decreased productivity, increased hypoxia, etc.).

CONCLUSION

This appendix identified the known and potential effects of climate change and OA on listed rockfish, their prey sources, and their habitats within the Puget Sound/Georgia Basin. Notably, these different stressors, in addition to other anthropogenic stressors, such as nutrient addition, will likely have synergistic and cumulative effects that are difficult to predict and the threat level is high. Climate change priorities include investigating listed rockfish-specific responses to temperature changes and synergistic climate change effects, and investigating the restoration and analysis of the potential capabilities of seaweeds and sea grasses in nearshore areas to provide juvenile rockfish habitat, support rockfish prey, ameliorate unfavorable water quality conditions, and, if indicated, promote conservation and restoration of seaweed and sea grass habitats. Priorities related to OA include investigating listed rockfish-specific responses to changing pH levels, including effects on growth, physiology, productivity, and behavioral responses; targeting quantification of regional factors that contribute to OA and developing cooperation among appropriate agencies to reduce their effects; and analyzing the potential for protected areas to ameliorate the synergistic effects of contaminants, climate change, and OA and their many secondary effects.

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APPENDIX VIII

FUNDING OPPORTUNITIES FOR ROCKFISH CONSERVATION

The Recovery Plan identifies long-term, sustained funding as an integral part of recovery. This appendix (Table 1) includes potential funding sources for several strategies identified in this document to support recovery, including education and outreach, bycatch reduction, monitoring, research of many kinds, habitat restoration, cooperative research, and coordination between NMFS, co-managers and other entities.

Table 1. Potential funding sources for rockfish conservation.

Topic	Details	Frequency	Amount	Granter
Outreach and Education	Projects that enhance fish populations including: (1) engaging anglers in data collection, (2) enhancing marine habitats, and (3) educating anglers about barotrauma.	May 1 deadline, annually	$500 to $5000	West Marine http://www.westmarine.com/webapp/wcs/stores/servlet/PressRoomView?langId=1&storeId=11151&catalogId=10001&nav=LeftNav&page=Press-Release-2013-03-06
	Marine debris prevention, education, and outreach partnership projects. Eligible applicants are institutions of higher education, non-profits, for-profit organizations, regional fishery management councils / commissions, state, local, and tribal governments.	October deadline for letter of intent, January deadline for proposal	$15,000 to $100,000	NOAA Fisheries Marine Debris Program http://marinedebris.noaa. http://www.grants.gov/view-opportunity.html?oppId=279133
	Projects may vary in scope from interpreting historical or cultural resources in NOAA's care to capturing oral histories of employees or constituents.	November deadline, annually	$12,000	NOAA Preserve America Grant www.preserveamerica.noaa.gov
	Five major types of projects are funded: (1) habitat project activities that restore and/or preserve fish/wildlife habitat, (2) research projects that increase knowledge of fish / wildlife species, (3) education projects that inform or provide hands-on experience to enhance understanding of fish / wildlife and their habitat, (4) facility development projects that provide or enhance access to fish / wildlife-related recreational opportunities, (5) artificial production projects that rear and release fish or wildlife for public recreation or to restore populations (all production projects must be pre-approved by WDFW to apply). Individual citizens, non-profits, schools, universities, and political subdivisions, such as conservation districts and tribes may apply.	Every 2 years, starting with 2015-2017 grant round. Check website for application deadlines (the 2015 deadline was February 28)	Variable. In the 2015-2017 grant round $1.36 million was available. The program strives to make funds available to a large number of grantees.	WDFW Aquatic Lands Enhancement Account (ALEA) Volunteer Cooperative Grant Program http://wdfw.wa.gov/grants/alea/ Further details at: https://alea.fluidreview.com/

Topic	Details	Frequency	Amount	Granter
Outreach and Education (continued)	EPA is looking to support locally focused environmental education (EE) projects that increase public awareness and knowledge about environmental issues. Projects should promote environmental stewardship and help develop informed, knowledgeable and responsible citizens in the community(ies) in which the project is located.	Approx. April 8, deadline	Approx., but no more than, $91,000	Environmental Education Grants Program, Environmental Protection Agency Details: http://go.usa.gov/cytgJ Background: http://go.usa.gov/3u7Xw
Bycatch Reduction	Seek to develop technological solutions and changes in fishing practices to minimize bycatch. Could include barotrauma reduction, bycatch in pot fisheries, derelict nets, etc.	March or April deadline, annually	$2,500,000 potentially distributed among different projects	Bycatch Reduction Engineering Program, NOAA Fisheries http://www.nmfs.noaa.gov/by_catch/bycatch_BREP.htm
	WWF holds an International Smart Gear Competition each year, designed to inspire innovative ideas for fishing devices that reduce bycatch.	August deadline usually, annually	$30,000 grand prize, also have smaller prizes (total prizes are $65,000)	WWF http://worldwildlife.org/initiatives/international-smart-gear-competition
				NOAA CRWG (details under Cooperative Research)
				NOAA CRP (details under Cooperative Research)
Research	Research priorities may change year to year. In 2014/2015, priorities included maximizing fishing opportunities and jobs; improving the cost effectiveness and capacity for fishery observations; increasing the supply, quality, and diversification of domestic seafood; and improving the quality and quantity of fishery information from U.S. territories.	December 1 deadline, usually, annually	Variable	NOAA Saltonstall-Kennedy Grant Program http://www.nmfs.noaa.gov/mb/financial_services/skhome.htm
	Research into the persistence and chemical impacts of marine debris. Original, hypothesis-driven projects that address one of these focus areas is the subject of this funding opportunity.	February deadline, annually	$25,000 - $200,000	NOAA Marine Debris Program http://marinedebris.noaa.gov/funding/welcome.html
	Bold, innovative, multi-partner, interdisciplinary ocean exploration projects in the following areas of interest: (1) physical, chemical, and biological characterizations of unknown or poorly known regions of the deep ocean, especially areas deeper than 1,640 feet (500 m); (2) baseline characterization of marine archaeological resources at any	Pre-proposal October, full proposal due January	$50,000 to $1.5 million, depending on appropriations	NOAA Ocean Exploration and Research Program http://oceanexplorer.noaa.gov/about/what-we-do/funding-opportunities.html

Topic	Details	Frequency	Amount	Granter
	depth; and (3) technology that advances ocean exploration and has application to NOAA-related missions.			
Research (continued)	WSG-sponsored research combines scientific excellence and a focus on problems and opportunities that ocean users and managers face, such as resource management, sustainable coastal development, and ecosystem health.	January deadline, annually	Variable	WA SeaGrant http://wsg.washington.edu/research/index.html Email wsgrfp@uw.edu to be added to the RFP notification list.
	Research applications will focus on examining ocean acidification (OA) in the context of eutrophication, hypoxia, and other stresses in coastal environments. This research will project regional impacts to economically important species and ecosystem services and provide a wider ecosystem context for the single-species studies and carbonate system measurements and monitoring undertaken by NOAA and other agencies.	Variable	$300,000 to $500,000 per yr. per proposal; for 3 yr. proposals only, total available for 3 yrs. is $1,500,000	NOAA/ NOS/ NCCOS/ CSCOR http://www.grants.gov/web/grants/view-opportunity.html?oppId=259279 Contact Elizabeth Turner 603-862-4680
	The Biological Oceanography Program supports research in marine ecology broadly defined: relationships among aquatic organisms and their interactions with the environments of the oceans or Great Lakes. Projects submitted to the program for consideration are often interdisciplinary efforts that may include participation by other OCE Programs. (for academia only)	February 15, annually	Variable, recent awards have been as much as $990,000	National Science Foundation, Biological Oceanography http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=11696&org=NSF&sel_org=NSF&from=fund Past awards can be seen at link above
	The Chemical Oceanography Program supports research into the chemical components, reaction mechanisms, and geochemical pathways within the ocean and its interfaces with earth and atmosphere. Major emphases: material inputs/ outputs from marine waters; ortho-chemical and biological production and transformation of chemical compounds and phases; and determination of reaction rates and equilibria. Research into chemistry, distribution of inorganic/ organic substances introduced or produced within marine environments including those from estuarine waters to the deep sea encouraged. (for academia only)	February 15, annually	Variable, recent awards have been as much as $825,000	National Science Foundation, Chemical Oceanography http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=11698&org=NSF&sel_org=NSF&from=fund Past awards can be seen at link above
	The Physical Oceanography Program supports research on a range of topics associated with the structure and movement of the ocean, with the way in which it transports, with the way the	February 15, annually	Variable, recent awards have been	National Science Foundation, Physical Oceanography

Topic	Details	Frequency	Amount	Granter
	ocean's physical structure interacts with the biological and chemical processes within it, and with interactions between the ocean and the atmosphere, solid earth, and ice that surround it. (for academia only)		as much as $2,450,000	http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=12729&org=NSF&sel_org=NSF&from=fund Past awards can be seen at link above
Research (continued)	The Packard Foundation solicits grants to support the collection of clear, consistent and useful data on the state of marine resources to fill information gaps and manage those resources more effectively.	Variable	Variable	The Packard Foundation https://www.packard.org/what-we-fund/grants-database/
	The Walton Foundation seeks to secure healthy, sustainable fisheries through policy changes, innovations in fisheries management and market pressure. Grants may be funded that develop scientific information and tools to enable better fisheries management, safeguard critical fish habitats, strengthen the capacity of fishermen, and governments to rebuild fisheries and promote fishery policies and programs that create positive incentives to encourage responsible fishing.	Variable	Variable	The Walton Foundation http://www.waltonfamilyfoundation.org/grants/grant-proposals
	Funds work that supports acoustics research and mapping.	Variable	Variable	NOAA Ocean Acoustics Program http://www.nmfs.noaa.gov/pr/acoustics/
				WDFW ALEA Volunteer Cooperative Grant Program (details under Outreach and Education)
				NOAA CRWG (details under Cooperative Research)
				NOAA CRP (details under Cooperative Research)
Habitat Restoration	In cooperation with the NOAA Restoration Center, the NOAA Marine Debris Program supports locally driven, community-based marine debris prevention and removal projects. These projects benefit coastal habitat, waterways, and wildlife, including migratory fish.	End of October or early November deadline, annually	$15,000 to $250,000	NOAA Fisheries Marine Debris Program http://marinedebris.noaa.gov/funding/welcome.html
	Funding priorities for this program include: (1) disposal opportunities: provide collection bins at strategic ports for commercial fishermen to unload gear; (2) regulation: collaborate with state managers to address legal impediments of derelict fishing gear removal; (3)	October deadline, annually	$25,000 to $150,000	NFWF, NOAA Fisheries Marine Debris Program, Covanta Energy, Schnitzer Steel Industries, Inc.

Topic	Details	Frequency	Amount	Granter
	technological innovation: identify, test, and deploy innovations to address accidental introduction of derelict fishing gear into the marine environment and innovations to reduce the effectiveness of gear once lost; and (4) outreach and education: educate the public about the impacts of derelict fishing gear and Fishing for Energy initiatives to make measurable change.			http://www.nfwf.org/fishingforenergy/Pages/home.aspx
	NOAA's Community-based Restoration Program is currently soliciting applications for restoration projects that use a habitat-based approach to foster species recovery and increase fish production. The funding opportunity will focus on projects that will aid in recovering Endangered Species Act-listed species and rebuilding sustainable fish populations or their prey.	April 6, 2016, likely annually	$100,000 to $5,000,000 over a 1 to 3 yr. project	NOAA-NMFS Habitat Conservation http://www.habitat.noaa.gov/funding/coastalrestoration.html Contact Kate Brogan 301-427-8030
Habitat Restoration (continued)		Variable	Variable	WDFW ALEA Volunteer Cooperative Grant Program (details under Outreach and Education)
				NOAA CRWG (details under Cooperative Research)
				NOAA CRP (details under Cooperative Research)
Cooperative Research	Projects should address areas identified under Section 318 of the MSRA: (1) Collecting data to improve, supplement, or enhance stock assessments, including use of fishing vessels/ acoustics /other marine tech. (Sect. 318(c)(i)). (2) Assessing the amount and type of bycatch or post-release mortality occurring in a fishery (Section 318(c)(ii)). (3) Conducting conservation engineering projects designed to reduce bycatch, including avoidance of post-release mortality, reduction of bycatch in high seas fisheries, and transfer of such fishing techniques to other nations (Section 318(c)(iii)). (4) Identifying habitat areas of particular concern and conducting projects relevant to the conservation of habitat (Section 318(c)(iv)). (5) Collecting and compiling economic and social data (Section 318(c)(v)).	October deadline, annually	$20,000-$200,000	Cooperative Research Working Group (CRWG), NOAA Fisheries http://www.nmfs.noaa.gov/by_catch/docs/cooperative_research_working_group_tor.pdf Internal NOAA grant; document saved to shared drive Proposal should be sent to Keith Bosley

Topic	Details	Frequency	Amount	Granter
	Fisheries Innovation Fund: supports a variety of projects focusing on sustainable fisheries through community programs, innovations in gear, etc.	October deadline, annually	$50,000 to $200,000 which can be used over 2 years	NFWF, NOAA Fisheries, Moore Foundation, and Walton Foundation. http://www.nfwf.org/Pages/fisheriesfund/home.aspx#.Uctg48rotRw
	Funded by Congress, the CRP allows scientists and fishermen to work together to improve understanding of the complex interactions between fishery resources and fishing practices. Program projects cover a range of research topics, including bycatch reduction. Awarded regionally.	Variable	Variable	Cooperative Research Program (CRP), NOAA Fisheries http://www.st.nmfs.noaa.gov/cooperative-research/index
				NOAA-NMFS (MARFIN) (details under Other – Species Recovery)
Monitoring				NOAA CRWG (details under Cooperative Research)
				NOAA Saltonstall-Kennedy Grant Program (see details under Research)
Other (Species Recovery)	Species Recovery grants to states and tribes may support management, research, monitoring, and outreach activities that provide direct conservation benefits to listed species, recently de-listed species, and proposed and candidate species that reside within a given state.	October deadline, annually	Variable	NOAA section 6 funds to States and Tribes http://www.nmfs.noaa.gov/pr/conservation/states/grant.htm Apply to Grants.gov.
	The Marine Fisheries Initiative (MARFIN) is a competitive Federal assistance program that funds projects seeking to optimize research and development benefits from U.S. marine fishery resources through cooperative efforts involving the best research and management talents to accomplish priority activities. Projects funded under MARFIN provide answers for fishery needs covered by the NMFS Strategic Plan, available from NMFS, particularly those goals relating to: rebuilding over-fished marine fisheries, maintaining currently productive fisheries, and integrating conservation of protected species and fisheries management. Funding priorities for MARFIN are formulated from recommendations received from non-scientific and technical	Variable, last deadline was October 2014	Up to $525,000	NOAA-NMFS (MARFIN) http://www.grants.gov/web/grants/view-opportunity.html?oppId=258831 Contact Robert Sadler 727-551-5760

Topic	Details	Frequency	Amount	Granter
	experts and from NMFS research and operations officials. No preference between short- and long-term projects.			
				NOAA-NMFS Habitat Conservation (details under Habitat Restoration)
				WDFW ALEA Volunteer Cooperative Grant Program (details under Outreach and Education)

APPENDIX IX

PREDATION

OVERVIEW

This appendix briefly summarizes what is known about predation on rockfish, with an emphasis on the Puget Sound/Georgia Basin, and outlines research projects related to predation that would improve recovery implementation (also see Section V. A. Recovery Program). As rockfish progress from larvae to adult, they transition from a common prey item to mid-level trophic consumers in rocky reef ecosystems. Therefore, rockfish experience varying degrees of predation pressure throughout their life cycle that may have a broader effect on population status. Given the number of anthropogenic stressors yelloweye rockfish and bocaccio face in the Puget Sound/Georgia Basin, understanding the effect of predation at each life stage is necessary to comprehensively identify sources of mortality and assess recovery potential.

Rockfish are integral components of the Puget Sound/Georgia Basin food web, a complex suite of predator/prey relationships among many species in the region (Figure 1). Any abundance shifts in species in the food web, through artificial or natural processes, may cause substantial changes to an ecosystem. Fishing and reductions in habitat quality and quantity, along with numerous other factors, have already led to many such changes throughout marine and estuarine systems of the Puget Sound/Georgia Basin. Understanding implications of predation is further complicated by a lack of historical data on abundance and community structure. Filling data gaps in food web relationships under a variety of conditions (e.g., no-take areas, habitat type) will enable managers to recover listed rockfish more efficiently.

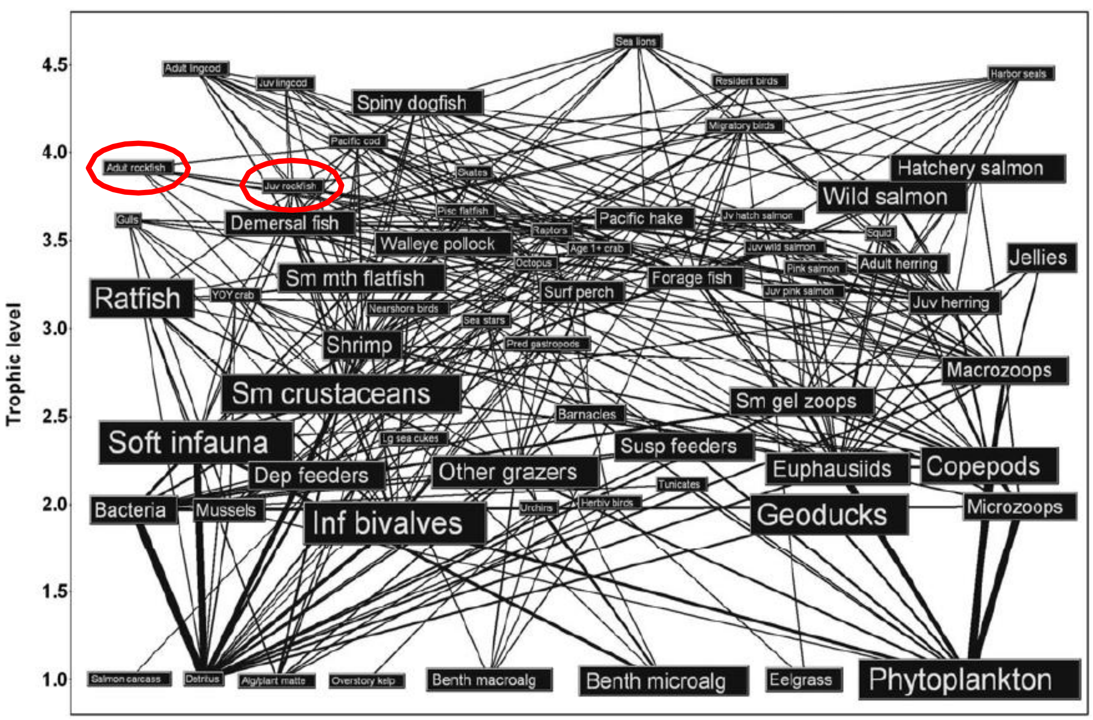

Figure 1. Diagram of the Puget Sound food web from Harvey et al. 2010.

While quantitative values of natural mortality are preferred, they are generally difficult to estimate (Parker et al 2000) and their calculation is beyond the scope of this appendix. Instead, the general impacts of natural mortality via predation are discussed in relation to recovery actions.

Predation of Rockfish by Life Stage

Larvae/Pelagic Juveniles. Rockfish begin their life-cycle as pelagic larvae and develop into a pelagic juvenile stage (Figure 2) that lasts approximately 120 days for most rockfish and 150 days for bocaccio (Shanks et al. 2003; Laidig 2010; Ralston et al. 2013).

Figure 2. Illustration of larval rockfish by C. Makeyev.

During these stages, individuals are strongly influenced by oceanic currents and upwelling (Bjorkstedt et al. 2002) and are less able to take shelter among structure that may provide refuge from predators. As a result, a diverse group of predators forage on larval rockfish during this vulnerable period. Juvenile Chinook salmon and coho salmon rely on these life stages as prey during their first months at sea (Hunt et al. 1999; Daly et al. 2009). Larval rockfish have also been found inside market squid (*Loligo opalescens*) (Brodeur et al. 1987). An ongoing theme regarding larval rockfish abundance is the importance of oceanic conditions. Research into timing of seabird reproduction and rockfish growth has shown synchronization with upwelling (Black et al. 2010). This correlation may partially explain why many species of seabird consume rockfish (Hatch and Sanger 1992; Sydeman et al. 1997; Becker et al. 2007). Given the relative high abundance of rockfish larvae and diversity of species that rely upon them, the first stages of their lives are ecologically significant for their energy export to predators.

Despite high mortality, in part driven by predation, there is little concern regarding the impact of consumption of early life stages on rockfish populations. Laidig et al. (2007) showed that the effects of oceanic conditions on larval survival, as opposed to consumption by predators, may have the greatest effect on year class strength. Predators may actually serve to aid in management as their diet composition can be used to determine rockfish abundance (Mills et al. 2007) and further quantify the relationship between oceanic and climate variables and rockfish reproduction. Rockfish larvae are an important component of the pelagic food web and further research into the factors that influence their abundance will aid yelloweye rockfish and bocaccio recovery, though predation at this stage is currently of lesser concern as compared with other life stages.

Known Rockfish Predators by Life Stage

Larvae and Pelagic Juveniles

- **Salmon**
- **Seabirds**
- **Market Squid**

Benthic Juvenile

- **Larger juvenile rockfish**
- **Adult rockfish**
- **Lingcod**

Adult Rockfish

- **Lingcod**
- **Pinnipeds**

Suggested Research Projects:

- Relative Predation in Puget Sound
- Stage Based Predation Model

Benthic Juveniles. After their pelagic stages, juvenile rockfish recruit to structured habitats such as kelp, seagrass (*Zostera marina*), and rocky reefs (Buckley 1997). Yelloweye rockfish often recruit in deep water (> 100 feet) to rocky structures and cloud sponges. Bocaccio frequently settle in shallower water amongst vegetation that provides shelter. Piscivorous fishes are the most frequent predator of rockfish during this life stage, including adult rockfish (Kinoshita et al. 2013), lingcod (Beaudreau and Essington 2007), and kelp greenling (Hobson et al. 2001). Juvenile bocaccio are relatively large compared with other species of rockfish during this life stage and are known to prey upon them as well.

Unlike the larval and pelagic juvenile stages, predation during the benthic juvenile stage (Figure 3) may limit population growth (Love et al. 1991; Hobson et al. 2001). The degree of limitation on the adult life stage is not entirely clear, as predation may fluctuate based on the number of rockfish in the area. This relationship, known as density-dependence, would reduce annual variation in the number of rockfish entering the next age class. Johnson (2006) found that manipulation of both predator abundance (juvenile bocaccio) and habitat complexity (kelp density) during multiple experiments using both caged and open units altered the level of density dependence in juvenile rockfish.

Figure 3. Illustration of young-of-year yelloweye rockfish and bocaccio by C. Makeyev.

Areas with increased habitat complexity (i.e., refuges such as rocky reef and kelp) exhibit lower mortality, and juvenile rockfish populations become more dependent on recruitment success and less on predation (Johnson 2007; Kamimura and Shoji 2013). The alteration of the nearshore of Puget Sound, and possible loss/reduction of bull kelp in Puget Sound may have simplified rearing habitats that would be preferred by juvenile yelloweye rockfish and bocaccio, which may result in increased vulnerability to predation. Juvenile rockfish that have settled into benthic habitats are still vulnerable to predation (Figure 4), but levels of predation are a function of rockfish recruit abundance and habitat complexity.

Suggested Research Projects are discussed further below:

- Relative Predation in Puget Sound
- Ocean acidification and predation risk
- Stage-based Population Model
- Habitat-based Predation
- Predation associated with artificial reefs and differing habitat types

Figure 4. Photo of lingcod and young-of-year rockfish in British Columbia (Eiko Jones http://www.eikojonesphotography.com)

Adults. As rockfish reach their subadult and adult life stages, they often move to deeper water and associate more closely with reef structure (Love et al. 1991; Bolton 2014). This shift in habitat, along with greater sizes (Jorgensen et al. 2006; Frid et al. 2013) and venomous spines (Roche and Halstead 1972), results in reduced predation rates on subadult and adult rockfish, particularly relative to other fishes in the same environment (Figure 5). Given that rockfish are long-lived, slow growing, and exhibit increasing reproductive output with size but with inconsistent interannual reproduction, it is evolutionarily beneficial that adults are able to survive for many years to increase chances of reproductive success. Primary predators on these life stages include pinnipeds and large lingcod (Tinus 2012; Ward et al. 2012). Relative to other items in their diet, rockfish compose a small component of harbor seal forage (Lance et al. 2012). However, harbor seal populations have increased in Puget Sound since the early 20th century (Jeffries et al. 2003). Therefore, even if rockfish are a small component of their diet, the increased population may lead to greater total rockfish consumption. Lingcod are capable of ingesting larger rockfish, but their diet is primarily composed of individuals between 1.6 to 9.5 inches (4 to 24 cm), providing further evidence of a size refuge in larger rockfishes (Beaudreau and Essington 2007). Of fourteen prey items analyzed in lingcod, adult rockfish were the least preferred prey item, followed by subadult rockfish (Tinus 2012). Based on this literature, rockfish experience relatively little predator pressure during subadult and adult life stages (Figure 6).

Suggested Research Projects are described further below:

- Relative Predation in Puget Sound
- Stage-based Population Model
- Habitat-based Predation
- Predation associated with artificial reefs

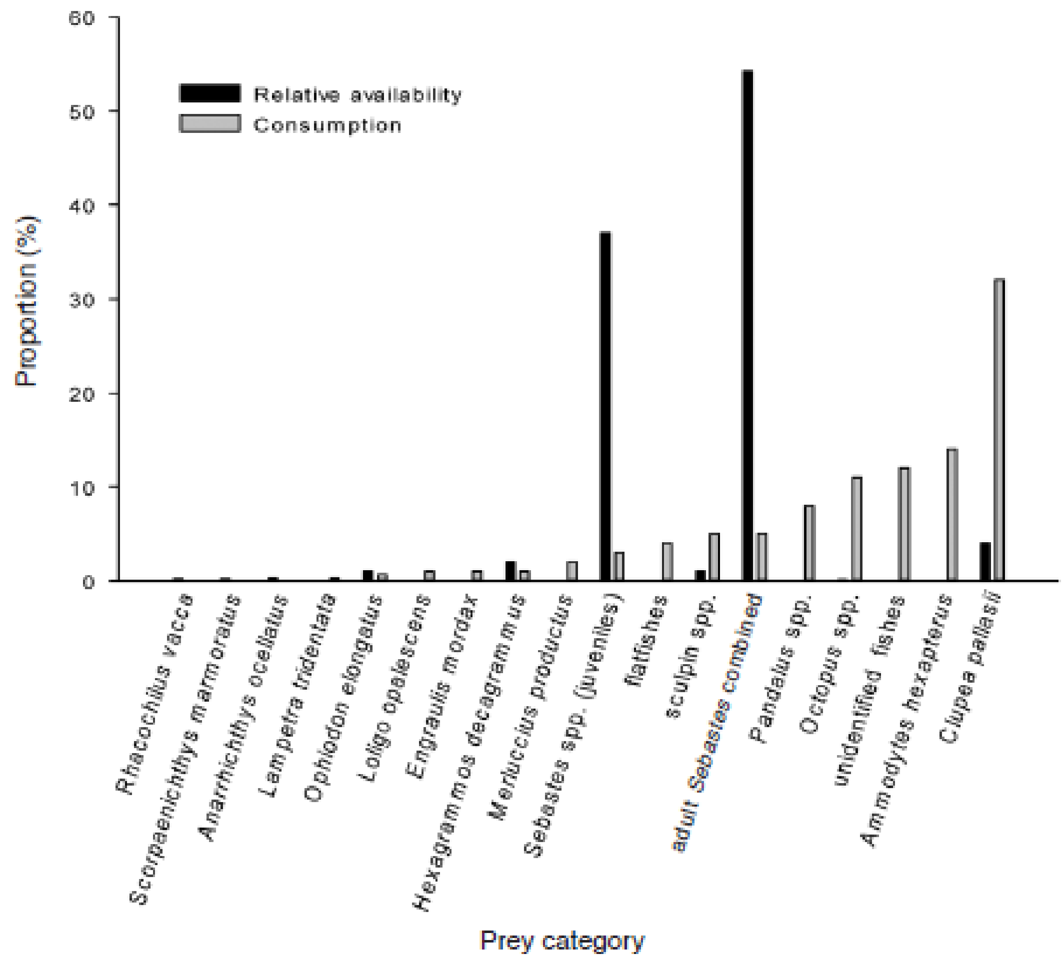

Figure 3

Proportional relative availability (dark bars) of potential prey as determined from nine dive surveys off Oregon for sites 1 and 2 combined, and proportional consumption (light bars) of prey by lingcod (*Ophiodon elongatus*) for sites 1 and 2 combined. The lack of overlap between realized consumption and relative availability indicates that lingcod were not preferentially consuming the most apparently abundant prey types, which were rockfishes (*Sebastes* spp.).

Figure 5. Diet composition of lingcod relative to prey abundance (from Tinus 2012).

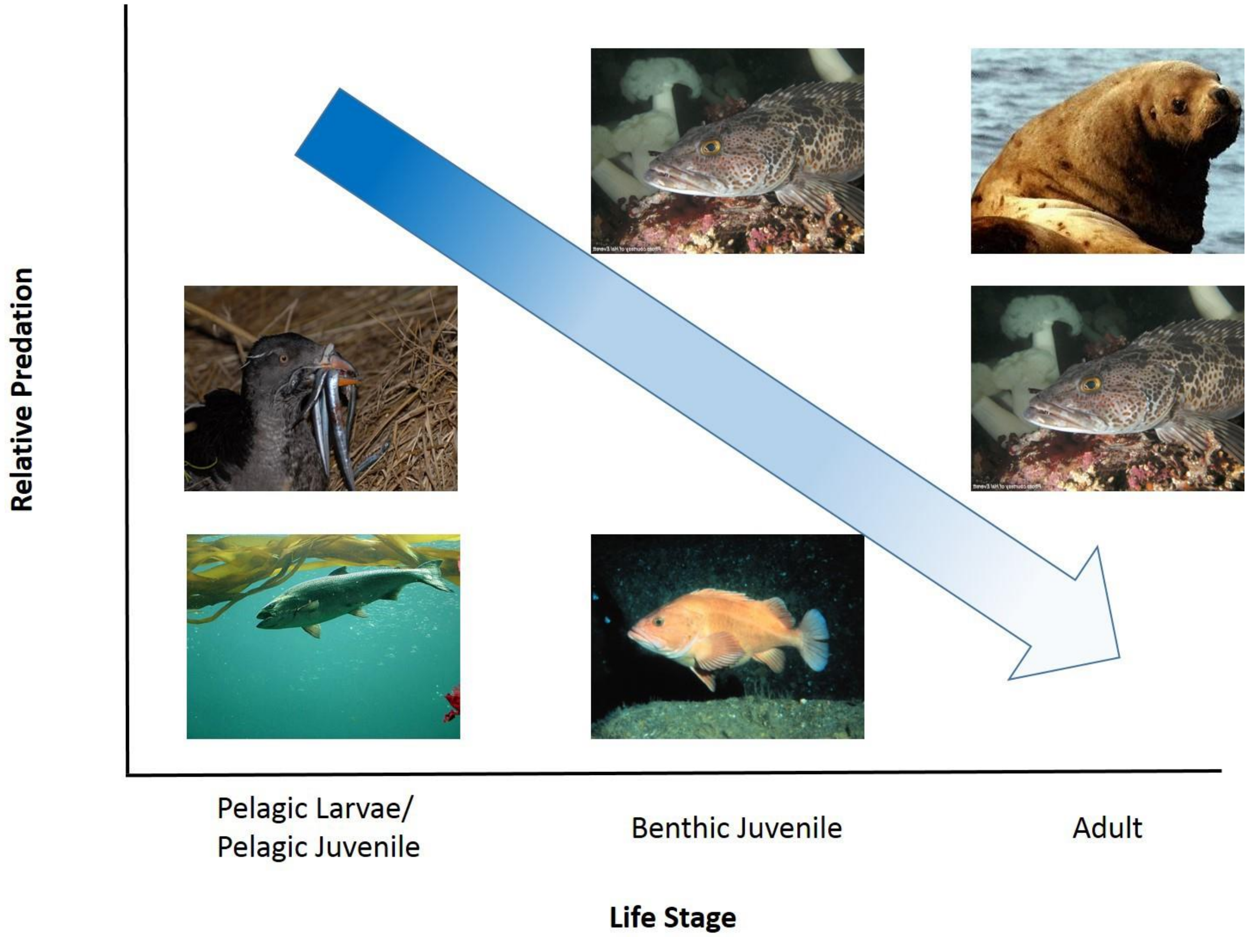

Figure 6. The general trend of rockfish predation ( ) throughout various life stages depicted alongside the primary predators at each life stage. During the pelagic larvae and pelagic juvenile phases, rockfish are consumed by seabirds (represented by the rhinoceros auklet) and salmon. Lingcod and rockfish frequently consume benthic juveniles while pinnipeds and lingcod most frequently consume adult rockfish. Note that this relationship over time is conceptual only and the actual trend may not be linear.

Predation and Rockfish Conservation Areas

Design and implementation of reserves, such as the rockfish conservation areas discussed in this recovery plan (see Section II. F. Conservation Measures, Research, and Monitoring, and Appendix II. Fisheries Management), is complicated and frequently controversial. An often criticized element of reserves is failing to account for the impact of natural mortality through predation that may offset any benefit of reduced fishing pressure. Inconsistency among study results within reserves further confuses the issue. For example, Cloutier (2011) found that rockfish conservation areas in British Columbia had 1.6 times the rockfish density as reference areas while Haggarty et al. (2016) found no difference in rockfish density or size structure between protected and unprotected areas in the same region. The increase in predators within a marine reserve may actually benefit the ecosystem as it re-establishes top predators that kept their prey from reaching populations that would adversely affect habitat (Shears and Babcock 2002). For example, removal of top predators may allow herbivores, such as urchins and kelp crabs, to become so great in number that they prevent establishment of kelp forests. A definitive analysis of the benefit of marine reserves to rockfish recovery is beyond the scope of this appendix (see Section II. F. Conservation Measures, Research and Monitoring and Appendix II. Fisheries Management); however, we provide a discussion of existing literature on rockfish predation.

As per the previous section regarding predation throughout the various rockfish life stages, natural mortality within a reserve would be inevitable, particularly in earlier life stages. The question as to whether natural predation would increase through protection of upper level consumers (e.g., lingcod) to a point that rockfish populations were more vulnerable in reserves is more complex. Beaudreau and Essington (2007) found an increased concentration of rockfish in lingcod gut contents within reserves. However, there was no incorporation of surrounding rockfish density into this study. That is, reserves may have had a greater abundance of available rockfish prey and predation could have increased commensurate with this difference in prey availability. In Oregon, lingcod predation on rockfish was very low compared with rockfish abundance (Tinus 2012) (Figure 3). The depth ranges of lingcod overlap in only a small subset of the listed species' ranges, suggesting predation may impact only a small portion of the population. Rockfish found in harbor seal scat are also relatively low (Lance et al. 2012).

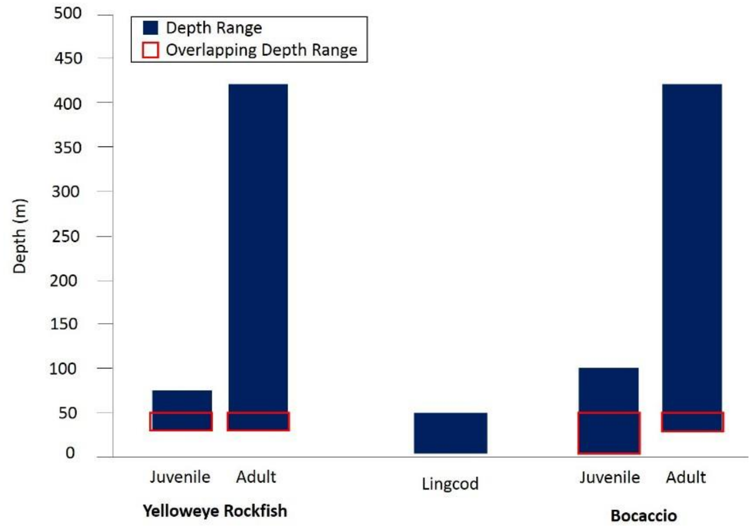

Figure 7. Depth distribution of lingcod (Beadreau and Essington 2011) and listed rockfish species.

Given the variable predation across life stages, understanding the stage most responsible for population growth would clarify if potential increased predation would influence recovery. Unfortunately, no stage-based population model of rockfish exists that would determine key life stages for conservation of the species (Crowder et al. 1994). That rockfish may consume individuals in earlier life stages, or even smaller individuals within the same life stage (Johnson 2006), further complicates this issue as increases in adult rockfish or recovery of larger species (e.g., bocaccio) may adversely affect recruitment. If predation is density dependent, as has been shown in the literature (Johnson 2006), then predators may adjust their diets toward rockfish during years of higher recruitment. Density-dependent predation on rockfish would support the hypothesis that lingcod consume additional rockfish in reserves (compared to non-reserves) because of increased prey availability. Further research would help clarify some of these issues, but given the complexity of coastal systems the outcomes would likely reveal tradeoffs involved in establishment of marine reserves and may not show a definitive benefit or harm from reserve creation.

If additional research shows that natural mortality via predation is nullifying the benefit of rockfish conservation areas, measures may need to be taken to adjust the recovery approach. These measures may include selective removal of lingcod from reserves, if possible, and/or adjustment of reserve design and distribution. Adaptive management of rockfish recovery based on the best available science will increase the chances of success.

Proposed Research

Relative Predation in Puget Sound. Beaudreau and Essington (2007) found that lingcod consume more rockfish inside reserves in the San Juan Islands. However, rockfish have also been found to be a lower preference prey item for lingcod (Tinus 2012). A broader effort on evaluating the relative impact of predation on rockfish should be completed throughout the Puget Sound/Georgia Basin along with a focus on existing marine reserves and include a scat-based assessments of pinniped predation. This work could incorporate lingcod gut content analysis along with rockfish and lingcod density measures across a range of habitat types and regions of Puget Sound. Surveys for various rockfish predators in Puget Sound already exist to some degree, including pinnipeds (Jeffries 2013), seabirds (Ward et al. 2015), and adult rockfish (Pacunski et al. 2008). Some of these surveys could be altered to create a more comprehensive index of predators; for example, ROV surveys could be conducted to more explicitly monitor habitats used by lingcod. The results of this study would evaluate overlap among rockfish and their predators and be incorporated into consideration and potential design of rockfish conservation areas.

Figure 8. Yelloweye rockfish taken from lingcod gut. Photo used with permission from Ron Garner.

Ocean Acidification and Predation Risk. The burning of fossil-fuels has led to additional concentrations of atmospheric CO_2 that leads to increased absorption in the oceans (Appendix VII. Climate Change and Ocean Acidification). The increased concentration of CO_2 lowers pH in a process known as ocean acidification (Feely et al. 2010). The consequences of ocean acidification are not yet fully understood. However, Hamilton et al. (2014) showed that decreased pH may impact a rockfish's ability to determine proximity to objects and light/dark preference. Rockfish may rely on these senses to avoid predators and therefore ocean acidification may impact the ability of rockfish to avoid predation. Further research in the field and lab would help determine the potential population impacts to rockfish.

Stage-Based Population Model. In order to determine the most important life stage for recovery of rockfish populations, a stage-based population model that incorporates known life history parameters and stressors should be created. The results of this model could be incorporated into various aspects of management. For the purposes of this appendix, it would clarify if the stages most vulnerable to predation (e.g., larvae, pelagic, and benthic juvenile) inform long-term population trends. If one of those stages, in particular the benthic juvenile stage, is limiting, then further research should be conducted to quantify that impact and assess if methods to improve survival are available.

Habitat-based Predation. Recently settled yelloweye rockfish and bocaccio in the benthic juvenile stage likely experience variable survival based on their surrounding habitat. For example, rockfishes in structured habitats, such as eelgrass or kelp, may have lower predation rates than in soft-bottom areas with low relief. Furthermore, within-habitat characteristics (e.g., kelp density or eelgrass height) may also affect predation. Research on the relationship between habitat and predation of benthic juveniles would improve population models and may inform habitat protection and restoration projects in the Puget Sound/Georgia Basin.

Predation Associated with Artificial Reefs and Differing Habitat Types. There are already a number of artificial reefs in Puget Sound and there are potential plans for several more in the future. Placement of these structures can be controversial and a great deal of research effort has addressed their environmental impact (Bohnsack 1989; Granneman and Steele 2015). However, the effect of these structures to rockfish populations is not well known, though some preliminary research has shown that design may be altered to benefit YOY (West et al. 1994). As artificial reefs are likely to remain in Puget Sound/Georgia Basin and could expand in the future, evaluating predation of rockfish on these structures (as well as existing anthropogenic structure) would help improve their location and design for recovery of listed rockfish.

CONCLUSION

Understanding the role that natural processes, such as predation, play in rockfish recovery is integral to appropriate management. Though information on predators across life stages on some *Sebastes* species is available, the degree of population loss through predation as it relates to rockfish recovery is not fully understood. Research into various aspects of this process and incorporation of all relevant existing literature will provide a strong scientific background for making management decisions.

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APPENDIX X

SUMMARY OF PUBLIC COMMENTS ON THE DRAFT RECOVERY PLAN

Over 100 public comments were provided on the draft Rockfish Recovery Plan through various media, including online at regulations.gov, one of the public meetings hosted throughout the region, or email. The comments were summarized into categories and are displayed in the table below. Along with each comment are locations where that topic may be reviewed in the final Recovery Plan. In some cases, the recovery plan was substantially revised on the basis of a public comment. For example, an entire appendix (Appendix IX) was drafted in response to concerns over natural predation impacting listed rockfish. In other cases, a change was not made but the issue had already been addressed in the referenced section.

Number of Commenters	Comment Summary	Comment Type	See Agency Response In
61	Don’t support RCAs because existing regulations are sufficient/current regulations need time to work (e.g., 120-ft rule and no retention)	Oral and Written	II.E
51	Don’t support RCAs because tribes would be exempt	Oral and Written	I.C, Appendix II
49	Don't support RCAs because of concerns about predation (lingcod and pinniped mentioned)/think there should be more focus on limiting predation	Oral and Written	II.B, II.E, Appendix IX
36	Think more should be done to limit tribal commercial bycatch (longliners and gillnetters noted)	Written	I.C, II.E, V.B.2.1, Appendix II, Appendix III
30	Don’t believe there is science to support RCAs from current Canada, Puget Sound examples	Oral and Written	III.A, Appendix II
24	Think more should be done to limit pollution/need more specifics about pollution prevention in Plan	Written	V.A.3.3, V.A.3.4, V.A.3.9, Appendix VI
23	Support use of descending devices for conservation	Oral and Written	Appendix III
15	More should be done to remove derelict gear	Oral and Written	II.F, Appendix I, Appendix IV
10	More should be done to restore and or protect habitat	Oral and Written	V.A.3, Appendix IV, Appendix V
6	There should be sunset provision in Plan, so that after delisting RCAs would be re-opened	Written	III.C, V.A.2.3
4	Do support RCAs/ MPAs and all of Plan	Written	

Number of Commenters	Comment Summary	Comment Type	See Agency Response In
3	Would like to see more justification/changes to delisting or downlisting (DDL) criteria	Oral and Written	IV.C
2	Spatial structure and age structure within DDL criteria is too vague. DDL criteria is not precautionary enough (should protect female rockfish & measures to prevent localized depletion)	Written	IV.C
2	Minimum time at certain population levels in DDL criteria is too short. Number of sampling events to judge DDL criteria are too few	Written	IV.C
2	Would like improved enforcement of existing regulations	Oral	V.A.2.6
1	Don't agree that FLEP should be used in the DDL criteria. Don't believe that rockfish in Puget Sound have similar productivity to coastal rockfish	Written	IV.C
1	Don't agree with MPAs because they would infringe upon tribal treaty rights	Written	I.C
1	NMFS should engage more with the public on rockfish recovery issues	Oral	II.F, V.A.4, Appendix I
1	Make sure rockfish recovery efforts build on previous work	Oral	II, Appendices II-VII and IX
1	Support MPAs provided they are planned in a scientifically robust manner	Oral	III.A, Appendix II
1	Believes NMFS should work cooperatively with other governments that manage resource (e.g., Canada)	Oral	I.C
1	Believes the San Juan Islands National Wildlife Refuge add to rockfish projection	Oral	Appendix II

CONCLUSION

Public and agency comments (in addition to peer reviews) led to several revisions to the final Recovery Plan. The most significant changes were revisions to the delisting and downlisting criteria, a more detailed description of fisheries, and a refined assessment of risk of bycatch of yelloweye rockfish and bocaccio for each Management Unit. We revised the plan to prioritize the Management Units for the establishment of additional fisheries protections and added additional scientific information regarding the efficacy of reserves. We also revised the Recovery Plan by identifying the need for additional time to monitor the effectiveness of existing fisheries regulations and enforcement prior to starting the process of designating MPAs/RCAs. In response to public comments regarding predation on rockfish, we created Appendix IX that summarizes what is known about predation on rockfish, with an emphasis on the Puget Sound/Georgia Basin, and outlines research projects related to predation that would improve recovery implementation.