# 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.

### <u>Research Informing Education and Outreach to Puget Sound Recreational Anglers</u>

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

**Objective 2:** 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.

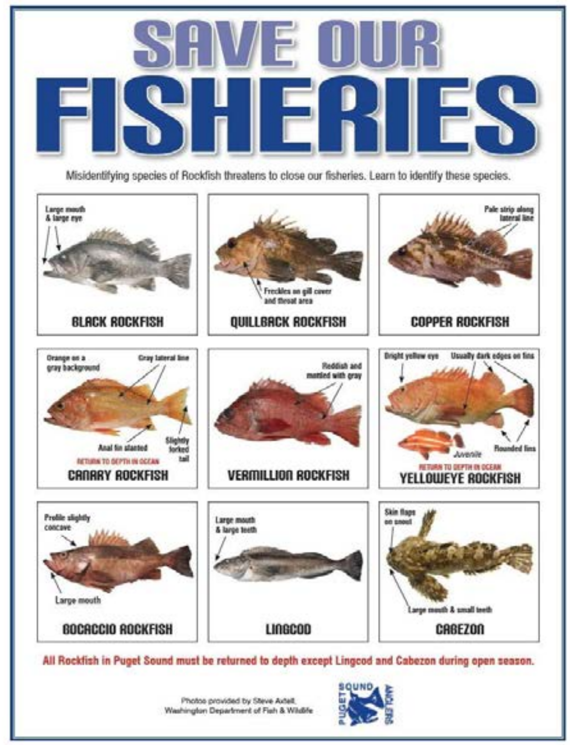
**Evaluation and Measurement:**

- 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

**Objective 6:** 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

**<u>Objective 2</u>:** 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) *<u>SCUBA Divers</u>***

**<u>Objectives:</u>**

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.

**<u>Objective 1</u>:** 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.

**<u>Objective 2</u>:** 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.

**<u>Objective 3</u>:** 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.<br>• Create signs for boat launches.<br>• 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.<br>• 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.<br>• 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.<br>• Cooperate with local groups already doing identification (e.g., REEF/Seattle Aquarium).<br>• 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.<br>• 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.<br>• Develop an Outreach Kit; resources, such as hands on model of "Rosy the Rockfish;" and identification tip handouts.<br>• 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.<br>• 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.

ROCKFISH
CONSERVATION
Bottom-up Recovery
of Puget Sound

## 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.

## ACKNOWLEDGEMENTS

Thanks to Peggy Foreman for her contributions to this appendix.

## REFERENCES

Antonelis, K. 2013. Derelict Gillnets in the Salish Sea: Causes of gillnet loss, extent of accumulation and development of a predictive transboundary model. Master's thesis. University of Washington School of Marine and Environmental Affairs, Seattle, WA.

Beaudreau, A.H., P.S. Levin P.S., K.C. Norman. 2011. Using folk taxonomies to understand stakeholder perceptions for species conservation. Conservation Letters. Volume 4, pages 451-463.

Blain, B. 2014. The effects of barotrauma and deepwater-release mechanisms on the reproductive viability of yelloweye rockfish in Prince William Sound, Alaska. Thesis presented to the faculty of the University of Alaska Fairbanks in partial fulfillment of the requirements for the Degree of Master of Science.

Cox, T.M., R.L. Lewison, R. Zydelis, L.B. Crowder, C. Safina, and A.J. Read. 2007. Comparing effectiveness of experimental and implemented bycatch reduction measures: the ideal and the real. Conservation Biology. Volume 21(5), pages 1155-1164.

Daley, E.A., R.D. Brodeur, and L.A. Weitkamp. 2009. Ontogenetic shifts in diets of juvenile and subadult coho and Chinook salmon in coastal marine waters: important for marine survival? Transactions of the American Fisheries Society. Volume 138(6), pages 1420-1438.

Donnelly, R.F. and R.L. Burr. 1995. Relative abundance and distribution of Puget Sound trawl-caught demersal fishes. Proceeding of Puget Sound Research. Volume 2, pages 860-868.

Drake J.S., E.A. Berntson, J.M. Cope, R.G. Gustafson, E.E. Holmes, P.S. Levin, N. Tolimieri, R.S. Waples, S.M. Sogard, and G.D. Williams. 2010. Status of five species of rockfish in Puget Sound, Washington: Bocaccio (*Sebastes paucispinis*), Canary Rockfish (*Sebastes pinniger*), Yelloweye Rockfish (*Sebastes ruberrimus*), Greenstriped Rockfish (*Sebastes elongatus*) and Redstripe Rockfish (*Sebastes proriger*). U.S. Department of Commerce, NOAA Tech. Memo. NMFS-NWFSC-108.234 pp.

Gibson, C. 2013. NWSC and NWIFC report prepared for NOAA Protected Resources Division: Preventing the Loss of Gillnets in Puget Sound Salmon Fisheries. http://www.westcoast.fisheries.noaa.gov/publications/protected_species/other/rockfish/puget_sound_derelict_gill_net_prevention_report.pdf.

Granek, E.F., E.M.P. Madin, M.A. Brown, W. Figueira, D.S. Cameron, Z. Hogan, G. Kristianson, P. De Villiers, J.E. Williams, J. Post, S. Zahn, and R. Arlinghaus. 2008. Engaging recreational fishers in management and conservation: global case studies. Conservation Biology. Volume 22(5), pages 1125-1134.

Haw, F. and R.M. Buckley. 1968. The ability of Washington anglers to identify some common marine fishes. California Fish and Game. Volume 54, pages 43-48.

Jarvis, E.T. and C.G. Lowe. 2008. The effects of barotrauma on the catch-and-release survival of southern California nearshore and shelf rockfish (Scorpaenidae, *Sebastes* spp.). Canadian Journal of Fisheries and Aquatic Sciences. Volume 65, pages 1286-1296.

Jenkins, L.D. 2010. Profile and influence of the successful fisher-inventor of marine conservation technology. Conservation Society. Volume 8, pages 44-54.

Kellert, S.R. 1985. Social and perceptual factors in endangered species management. The Journal of Wildlife Management. Volume 49, pages 528-536.

Kuperan, K. and J.G. Sutinen. 1998. Blue water crime: deterrence, legitimacy and compliance in fisheries. Law and Society Review. Volume 32(2), pages 309-338.

Martin-Lopez, B., C. Montes, and J. Benayas. 2007. The non-economic motives behind the willingness to pay for biodiversity conservation. Biological Conservation. Volume 139, pages 67-82.

Mascia, M.B., J.P. Brosius, T.A. Dobson, B.C. Forbes, L. Horowitz, M.A. McKean, and N.J. Turner. 2003. Conservation and the social sciences. Conservation Biology. Volume 17(3), pages 649-650.

Palsson, W.A., T. Tsou, G.G. Bargmann, R.M. Buckley, J.E. West, M.L. Mills, Y.W. Cheng, and R.E. Pacunski. 2009. The biology and assessment of rockfishes in Puget Sound. Washington Department of Fish and Wildlife, FPT 09-04, Olympia, WA.

Pribyl A.L., C.B. Schreck, M.L. Kent, and S.J. Parker. 2009. The differential response to decompression in three species of nearshore Pacific rockfish. North American Journal of Fisheries Management. Volume 29, pages 1479-1486.

Pribyl A.L., M.L. Kent, S.J. Parker, and C.B. Schreck. 2011. The response to forced decompression in six species of Pacific rockfish. Transactions of the American Fisheries Society. Volume 140, pages 374-383.

Renyard, T.S. and R. Hilborn. 1986. Sport angler preferences for alternative regulatory methods. Canadian Journal of Fisheries and Aquatic Sciences. Volume 43, pages 240-242.

Sawchuk, J.H. 2012. Angling for Insight: Examining the recreational fishing community's knowledge, perceptions, practices, and preferences to inform rockfish recovery planning in Puget Sound, Washington. Master Thesis, University of Washington. School of Marine and Environmental Affairs.

Sawchuk J.H., A.H. Beaudreau, D. Tonnes, and D. Fluharty. 2015. Using stakeholder engagement to inform endangered species management and improve conservation. Marine Policy. Volume 54, pages 98-107.

Schroeder, D. and M. Love. 2002. Recreational fishing and marine fish populations in California. CalCOFI Rep. Volume 43, pages 182-190.

Stankey, G.G., and B. Shindler. 2006. Formation of Social Acceptability Judgments and their Implications for Management of Rare and Little-Known Species. Conservation Biology. Volume 20, pages 28-37.

Sutinen, J., and R.J. Johnston. 2003. Angling management organizations: integrating the recreational sector into fishery management. Marine Policy. Volume 27, pages 471-487.

Verweij, M.C., W.L.T. van Densen, and A.J.P. Mol. 2010. The tower of Babel: Difference perceptions and controversies on change and status of North Sea fish stocks in multi-stakeholder settings. Marine Policy. Volume 34, pages 522-533.

Washington Department of Fish and Wildlife (WDFW). 2011. Final Puget Sound Rockfish Recovery Plan: policies, strategies and actions. http://wdfw.wa.gov/publications/00035/apr2011_rockfish_conservation_plan.pdf.

Williams, G.D., P.S. Levin, P. S., W.A. Palsson. Rockfish in Puget Sound: An ecological history of exploitation. Marine Policy. Volume 34, pages 1010-1020.

# 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<br><br>Salmon fisheries – Low risk<br><br>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<br><br>Moderate spatial | 533 | High |
| **Main Basin (includes Whidbey Basin)** | Salmon fisheries – Low risk<br><br>Halibut longline – *More information needed for assessment*<br><br>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<br><br>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<br>*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<br>*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.

**REFERENCES**


Aburto-Oropeza, O., B. Erisman, G.R. Galland, I. Mascareñas-Osorio, E. Sala and E. Ezcurra. 2011. Large recovery of fish biomass in a no-take marine reserve. PLoS ONE 6(8): e23601

Babcock, E.A. and A.D. MacCall. 2011. How useful is the ratio of fish density outside versus inside no-take marine reserves as a metric for fishery management control rules? Canadian Journal of Fisheries and Aquatic Sciences. Volume 68, pages 343–359. doi:10. 1139/F10-146.

Bernstein, B., S. Iudicello, and S. Stringer. 2004. Lessons learned from the recent marine protected area designations in the United States. A report to the National Marine Protected Areas Center NOAA. Final Report, June 11, 2004.

Carr, M.H. and P.T. Raimondi, P. T. 1999. Marine protected areas as a precautionary approach to management. Reports of California Cooperative Oceanic Fisheries Investigations. Volume 40, pages 71-76.

Cote, I.M., I. Mosqueira, and J.D. Reynolds. 2001. Effects of marine reserve characteristics on the protection of fish populations: A meta-analysis. Journal of Fish Biology. Volume 59, pages 178-189.

Crowder, L.B., S.J. Lyman, W.F. Figueira, and J. Priddy. 2000. Source-sink population dynamics and the problem of siting marine reserves. Bulletin of Marine Science. Volume 66(3), pages 799-820.

DFO. 2011. Regional Science Advisory Process on the Pacific Review of Yelloweye Rockfish (*Sebastes ruberrimus*), September 22, 2010. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2011/011. iv + 16 p.

Deiwert, R.E., Nagtelgal D.A, Hein K. 2005. A Comparison of the Results of the 1998 Georgia Strait Creel Survey with an Independent Observer Program. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2716, Fisheries and Oceans Canada.

Don, C.N. 2002. Evaluation of Near-shore Buffer Zones of the San Juan Islands National Wildlife Refuge Relative to their Function as a Marine Protected Area Network. Masters' Thesis, University of Washington Graduate School.

Drake J.S., E.A. Berntson, J.M. Cope, R.G. Gustafson, E.E. Holmes, P.S. Levin, N. Tolimieri, R.S. Waples, S.M. Sogard, and G.D. Williams. 2010. Status of five species of rockfish in Puget Sound, Washington: Bocaccio (*Sebastes paucispinis*), Canary Rockfish (*Sebastes pinniger*), Yelloweye Rockfish (*Sebastes ruberrimus*), Greenstriped Rockfish (*Sebastes elongatus*) and Redstripe Rockfish (*Sebastes proriger*). U.S. Department of Commerce, NOAA Tech. Memo. NMFS-NWFSC-108. 234 pages.

Edgar, G.J., R.D. Stuart-Smith, T.J. Willis, S. Kininmonth, S.C. Baker, S. Banks, N.S. Barrett, M.A. Becerro, A.T.F. Bernard, J. Berkhout, C.D. Buxton, S.J. Campbell, A.T. Cooper, M. Davey, S.C. Edgar, G. Forsterra, D.E. Galvin, A.J. Irigoyen, D.J. Kushner, R. Moura, P.E. Parnell, N.T. Shears, G. Soler, E.M.A. Strain, and R.J. Thomson. 2014. Global conservation outcomes depend on marine protected areas with five key features. Nature. Volume 506, pages 216-220.

Field, J.C. 2011. Rebuilding analysis for bocaccio in 2011. Available at: http://www.pcouncil.org/wp-content/uploads/Bocaccio_Rebuild_2013.pdf.

Frank, B. 2003. Tribal guidance for Marine Protected Areas. Letter to the Secretary of Commerce.

Frid, A., M. McGreer, D.R. Haggarty, J. Beaumont and E.J. Gregr. 2016. Rockfish size and age: the crossroads of spatial protection, central place fisheries and indigenous rights. Global Ecology and Conservation. Volume 8, pages 170-182.

Gell, F.R. and C.M. Roberts. 2003. Benefits beyond boundaries: the fishery effects of marine reserves. Trends in Ecology and Evolution. Volume 18, pages 448-455.

Greene, H.G. and Barrie, J.V. (eds.). 2011. Potential marine benthic habitats and shaded seafloor relief, southern Gulf Islands and San Juan Archipelago, Canada and U.S.A. Geological Survey of Canada, Open File 6625, 4 sheets.

Guidetti, P., P. Baiata, E. Ballesteros, A. DiFranco, B. Hereu, E. Macpherson, F. Micheli, A. Paid, P. Panzalis, A.A. Rosenberg, M. Zabala and E. Sala. 2014. Large-scale assessment of Mediterranean marine protected areas effects on fish assemblages. PLoS ONE 9(4): e91841

He, X. and J.C. Field. 2017. Draft stock assessment update. Status of bocaccio, *Sebastes paucispinis*, in the Conception, Monterey and Eureka INPFC areas for 2017. Agenda Item F.4 Attachment 3. June 2017

Lance, M.M., W.Y. Chang, S.J. Jeffries, S.F. Pearson, and A.A. Guitierrez. 2012. Harbor seal diet in northern Puget Sound: implications for the recovery of depressed fish stocks. Marine Ecology Progress Series. Volume 464, pages 257-271.

Lester, S.E., B.S. Halpern, K. Grorud-Colvert, J. Lubchenco, B.I. Ruttenberg, S.D. Gaines, S. Airame, and R.A. Warner. 2009. Biological effects with no-take marine reserves: A global synthesis. Marine Ecology Progress Series. Volume 384, pages 33-46.

Marine Protected Areas Federal Advisory Committee. 2014. Best practices for constituent communication. Recommendations to the Department of Commerce and the Department of the Interior.

McConnel, M.L. and P.A. Dinnel. 2002. Rocky reef bottomfish recovery in Skagit County Phase II final report Assessment of eight potential marine reserve sites and final site recommendations. Skagit County Marine Resources Committee. October 2002.

Molloy, P.P., I.B. McLean, and I.M. Cote. 2009. Effects of marine reserve age on fish populations: A global meta-analysis. Journal of Applied Ecology. Volume 46, pages 743-751.

Murawski, S.A., S.E. Wigley, M.J. Fogarty, P.J. Rago, and D.G. Mountain. 2005. Effort distribution and catch patterns adjacent to temperate MPAs. ICES Journal of Marine Science. Volume 62, pages 1150-1167.

Osterberg, A. 2012. Developing a Network of Marine Protected Areas in Puget Sound. A Synthesis Report on Challenges, Opportunities and Policy Options. A report prepared for the Puget Sound Partnership under WA Sea Grant Hershman Fellowship program.

Pacunski, R., W. Palsson, and H. G. Greene. 2013. Estimating Fish Abundance and Community Composition on Rocky Habitats in the San Juan Islands Using a Small Remotely Operated Vehicle. Washington Department of Fish and Wildlife. Fish Program. Olympia, WA.

Palsson, W.A. 2004. The development of criteria for establishing and monitoring no-take refuges for rockfishes and other rocky habitat fishes in Puget Sound.

Palsson, W.A., T. Tsou, G.G. Bargmann, R.M. Buckley, J.E. West, M.L. Mills, Y.W. Cheng, and R.E. Pacunski. 2009. The biology and assessment of rockfishes in Puget Sound. Washington Department of Fish and Wildlife, FPT 09-04, Olympia, WA.

Parker, S.J., S.A. Berkeley, J.T. Golden, D.R. Gunderson, J. Heifetz, M.A. Hixon, R. Larson, B.M. Leaman, M.S. Love, J.A. Musick, V.M. O'Connell, S. Ralston, H.J. Weeks, and M.M. Yoklavich. 2000. Management of Pacific Rockfish. Fisheries. Volume 25, pages 22-30.

Parnell, P.E., P.K. Dayton, C.E. Lennert-Cody, L.L. Rasmussen, and J.J. Leichter. 2006. Marine reserve design: optimal size, habitats, species affinities, diversity, and ocean microclimate. Ecological Applications. Volume 16(3), pages 945-962.

PFMC (Pacific Fishery Management Council). 2008. Groundfish Management Team (GMT) report on the development of a discard mortality matrix for ocean and estuary recreational fisheries. MS Report: 15.

PFMC. 2014. Groundfish Management Team (GMT) report on proposed discard mortality for cowcod, canary, and yelloweye rockfish released using descending devices in the recreational fishery. Supplemental GMT Report 2.

Roberts, C. M., J.P. Hawkins, and F.R. Gell. 2005. The role of marine reserves in achieving sustainable fisheries. Philosophical Transactions of the Royal Society of London B: Biological Sciences. Volume 360(1453), pages 123-132.

Sawchuk, J.H. 2012. Angling for Insight: Examining the recreational fishing community's knowledge, perceptions, practices, and preferences to inform rockfish recovery planning in Puget Sound, Washington. Master Thesis, University of Washington. School of Marine and Environmental Affairs.

Sawchuk J.H., A.H. Beaudreau, D. Tonnes, and D. Fluharty. 2015. Using stakeholder engagement to inform endangered species management and improve conservation. Marine Policy. Volume 54, pages 98-107.

Scientific and Statistical Committee. 2000. Statement on default maximum sustainable yield fishing rate within the harvest rate policy. Supplemental SSC Report D. 13, 2: June.

Science and Technical Advisory Committee (STAC). 2008. Science and Technical Advisory Committee of Oregon's Ocean Policy Advisory Council (OPAC) on Size and Spacing of Marine Reserves Workshop. Charleston, OR. http://www.oregon.gov/LCD/OPAC/docs/resources/oregon_size_and_spacing_workshopreport.pdf.

Shanks, A.L., B.A. Grantham, and M.H. Carr. 2003. Propagule Dispersal Distance and the Size and Spacing of Marine Reserves. Ecological Applications Volume 13(1), Supplement: The Science of Marine Reserves: S159-S169.

Siegle, M.R., E.B. Taylor, K.M. Miller, R. E. Withler, and K.L. Yamanaka. 2013. Subtle population structure in yelloweye rockfish (*Sebastes ruberrimus*) is consistent with a major oceanographic division in British Columbia, Canada.

Stanley, R.D., M. McAllister, and P. Starr. 2012. Updated stock assessment for bocaccio (*Sebastes paucispinis*) in British Columbia waters for 2012. DFO Canadian Scientific Advisory Secretariat Research Document 2012/109. 73 pages.

Taylor, I.G. 2011. Rebuilding analysis for yelloweye rockfish base on the 2011 update stock assessment.

Tonnes, D. 2012. Editor. Rockfish Recovery in the Salish Sea: Research and Management Priorities. NOAA Fisheries Service

Van Cleve, F.B., G. Bargmann, M. Culver, and the MPA Work Group. 2009. Marine Protected Areas in Washington: Recommendations of the Marine Protected Areas Work Group to the Washington State Legislature. Washington Department of Fish and Wildlife, Olympia, WA.

Washington Department of Fish and Wildlife (WDFW). 2011. Final Puget Sound Rockfish Recovery Plan: policies, strategies and actions. http://wdfw.wa.gov/publications/00035/apr2011_rockfish_conservation_plan.pdf.

WDFW. 2012. Puget Sound recreational fishery sample data, 1989-current. Fish Program, Fish Management Division, Puget Sound Sampling Unit.

WDFW. 2015. Comments on the Early Review Document of the Draft Rockfish Recovery Plan, from James Unsworth, WDFW, to Chris Yates, NMFS Protected Resources Division, May 1, 2015.

WDFW. 2016. Comments on the Draft Rockfish Recovery Plan, from James Unsworth, WDFW, to Chris Yates, NMFS Protected Resources Division, November 7, 2016.

West, J. E., T.E. Helser, and S.M. O'Neill. 2014. Variation in quillback rockfish (*Sebastes maliger*) growth patterns from oceanic to inland waters of the Salish Sea. Bulletin of Marine Science. Volume 90(3), pages 747-761.

Yamanaka, K.L. and L.C. Lacko. 2001. Inshore Rockfish (*Sebastes ruberrimus*, *S. maliger*, *S. caurinus*, *S. melanops*, *S. nigrocinctus*, and *S. nebulosus*) Stock Assessment for the West Coast of Canada and Recommendations for Management. Can. Sci. Adv. Sec. Res. Doc. Volume 139, page 102.

Yamanaka K.L. and G. Logan. 2010. Developing British Columbia’s inshore rockfish conservation strategy. Marine and Coastal Fisheries: Dynamics, Management and Ecosystem Science. Volume 2, pages 28-46.

Yoklavich, M. 1998. Marine harvest refugia for West Coast rockfish: a Workshop. NOAA-TM-NMFS-SWFSC-255.

# 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.

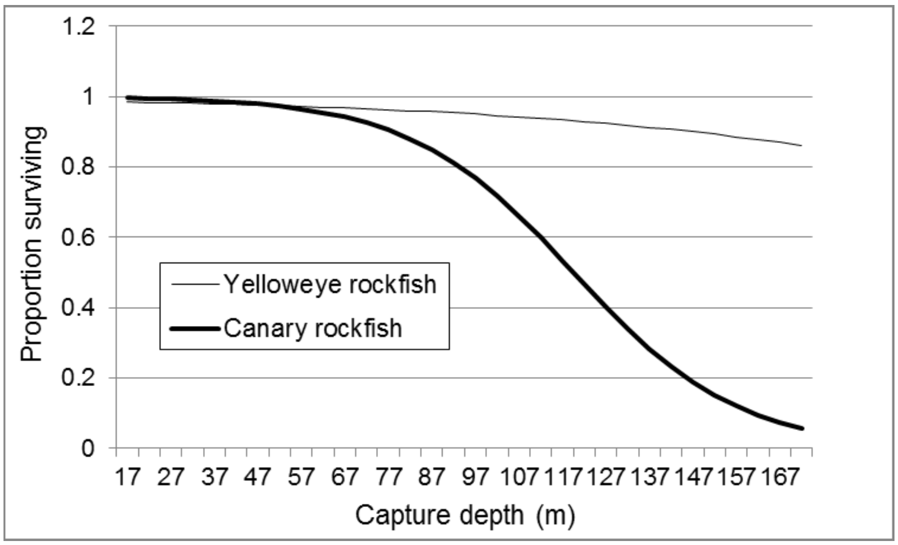



Figure 1. Fitted logistic curve of the proportion of yelloweye rockfish and canary rockfish surviving 48 hours after hook-and-line capture and recompression as a function of capture depth (m). (Image from Hannah et al., 2014.)

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.

## ACKNOWLEDGEMENTS

Thanks to Chris Lunsford and Cara Rodgveller for their helpful reviews.

## REFERENCES

Blain, B. 2014. The effects of barotrauma and deepwater-release mechanisms on the reproductive viability of yelloweye rockfish in Prince William Sound, Alaska. Thesis presented to the faculty of the University of Alaska Fairbanks in partial fulfillment of the requirements for the Degree of Master of Science.

Don, C.N. 2002. Evaluation of near-shore buffer zones of the San Juan Islands National Wildlife Refuge relative to their function as a marine protected area. Master's Thesis. School of Marine Affairs, University of Washington. 91 pages.

Cox, T.M., R.L. Lewison, R. Zydelis, L.B. Crowder, C. Safina, and A.J. Read. 2007. Comparing effectiveness of experimental and implemented bycatch reduction measures: the ideal and the real. Conservation Biology. Volume 21(5), pages 1155-1164.

Hannah, R. and K.M. Matteson. 2007. Behavior of nine species of pacific rockfish after hook-and-line capture, recompression, and release. Transactions of the American Fisheries Society. Volume 136, pages 24-33.

Hannah, R., S.J. Parker, and K.M. Matteson. 2008. Escaping the Surface: The Effect of Capture Depth on Submergence Success of Surface-Released Pacific Rockfish. North American Journal of Fisheries Management. Volume 28(3), pages 694-700.

Hannah, R.W., P.S. Rankin, and M.T. Blume. 2014. The divergent effect of capture depth and associated barotrauma on post-recompression survival of canary (*Sebastes pinniger*) and yelloweye rockfish (*S. ruberrimus*). Fisheries Research 157: 106-112.

Hochhalter, S.J., and D.J. Reed. 2011. The effectiveness of deep-water release at improving survival of discarded yelloweye rockfish. North American Journal of Fisheries Management. Volume 31(5), pages 852-860.

Hochhalter, S.J. 2012. Modeling submergence success of discarded yelloweye rockfish (*Sebastes ruberrimus*) and quillback rockfish (*Sebastes maliger*): Towards improved estimation of total fishery removals. Fisheries Research. Volume 127, pages 142-147.

Jarvis, E.T. and C.G. Lowe. 2008. The effects of barotrauma on the catch-and-release survival of southern California nearshore and shelf rockfish (*Scorpaenidae, Sebastes* spp.). Canadian Journal of Fisheries and Aquatic Sciences. Volume 65, pages 1286-1296.

Rankin, P.S., R.W. Hannah, M.T.O. Blume, T.J. Miller-Morgan, DVM CertAqV, J.R. Heidel, DVM DACVP. 2017. Delayed effects of capture-induced barotrauma on physical condition and behavioral competency of recompressed yelloweye rockfish, *Sebastes ruberrimus*. Fisheries Research. Volume 186(1), pages 258-268

PFMC (Pacific Fishery Management Council). 2008. Groundfish Management Team (GMT) report on the development of a discard mortality matrix for ocean and estuary recreational fisheries. MS Report: 15.

PFMC (Pacific Fishery Management Council). 2014. Groundfish Management Team (GMT) report on proposed discard mortality for cowcod, canary, and yelloweye rockfish released using descending devices in the recreational fishery. Supplemental GMT Report 2.

Palsson, W. A., T. Tsou, G. G. Bargmann, R. M. Buckley, J. E. West, M. L. Mills, Y. W. Cheng, and R.E. Pacunski. 2009. The biology and assessment of rockfishes in Puget Sound. Washington Department of Fish and Wildlife, FPT 09-04, Olympia, WA.

Parker, S.J., H.I. McElderry, P.S. Rankin, and R.W. Hannah. 2006. Buoyancy Regulation and Barotrauma in Two Species of Nearshore Rockfish. Transactions of the American Fisheries Society. Volume 135, pages 1213-1223.

Pribyl A.L., C.B. Schreck, M.L. Kent, and S.J. Parker. 2009. The differential response to decompression in three species of nearshore Pacific rockfish. North American Journal of Fisheries Management. Volume 29, pages 1479-1486.

Pribyl A.L., M.L. Kent, S.J. Parker, and C.B. Schreck. 2011. The response to forced decompression in six species of Pacific rockfish. Transactions of the American Fisheries Society. Volume 140, pages 374-383.

Pribyl A.L., C.B. Schreck, M.L. Kent, K.M. Kelley, and S.J. Parker. 2012. Recovery potential of black rockfish, *Sebastes melanops* Girard, recompressed following barotrauma. Journal of Fish Diseases. Volume 35(4), pages 275-286.

Rogers, B., C. Lowe, and E. Fernández-Juricic. 2011. Recovery of visual performance in rosy rockfish (*Sebastes rosaceus*) following exophthalmia resulting from barotrauma. Fisheries Research. Volume 112, pages 1-7.

Sawchuk, J.H. 2012. Angling for Insight: Examining the recreational fishing community's knowledge, perceptions, practices, and preferences to inform rockfish recovery planning in Puget Sound, Washington. Master's Thesis, University of Washington. School of Marine and Environmental Affairs.

Schroeder, D., and M. Love. 2002. Recreational fishing and marine fish populations in California. CalCOFI Report. Volume 43, pages 182-190.

WDFW (Washington Department of Fish and Wildlife) 2013. Washington Sportfishing Rules. Olympia, Washington. Available at: http://wdfw.wa.gov/publications/01500/wdfw01500.pdf.

# 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.

### Derelict Fishing Gear

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.

## REFERENCES


Antonelis, K., D. Huppert, D. Velasquez, and J. June. 2011. Dungeness crab mortality due to lost trap and a cost-benefit analysis of trap removal in Washington State waters of the Salish Sea. North American Journal of Fisheries Management. Volume 31(5), pages 880-893.

Antonelis, K. 2013. Derelict Gillnets in the Salish Sea: Causes of Gillnet Loss, Extent of Accumulation and Development of a Predictive Transboundary Model (Master's thesis). University of Washington School of Marine and Environmental Affairs, Seattle, WA.

Bax, N., A. Williamson, M. Aguero, E. Gonzalez, and W. Geeves. 2003. Marine invasive alien species: a threat to global biodiversity. Marine Policy. Volume 27, pages 313-323.

Britton-Simmons, K.H. 2004. Direct and indirect effects of the introduced alga *Sargassum muticum* on benthic, subtidal communities of Washington State, USA. Marine Ecology Progress Series. Volume 277, pages 61-78.

Bohnsack, J.A. 1989. Are High Densities of Fishes at Artificial Reefs the Result of Habitat Limitation or Behavioral Preference? Bulletin of Marine Science. Volume 44(2), pages 631-645.

Buckley, R.M. 1997. Substrate associated recruitment of juvenile *Sebastes* in artificial reef and natural habitats in Puget Sound and the San Juan Archipelago, Washington. Washington Department of Fish and Wildlife Technical Report. RAD97-06. 320 pages.

Cordell, J.R., C. Levy, J.D. Toft. 2012. Ecological impacts of invasive tunicate associated with artificial structures in Puget Sound, Washington, USA. Biological Invasions. Volume 15(6), pages 1303-1318.

Drake J.S., E.A. Berntson, J.M. Cope, R.G. Gustafson, E.E. Holmes, P.S. Levin, N. Tolimieri, R.S. Waples, S.M. Sogard, and G.D. Williams. 2010. Status of five species of rockfish in Puget Sound, Washington: Bocaccio (*Sebastes paucispinis*), Canary Rockfish (*Sebastes pinniger*), Yelloweye Rockfish (*Sebastes ruberrimus*), Greenstriped Rockfish (*Sebastes elongatus*) and Redstripe Rockfish (*Sebastes proriger*). U.S. Department of Commerce, NOAA Technical Memorandum. NMFS-NWFSC-108, 234 pages.

Favaro, B., D.T. Rutherford, S.D. Duff, and I.M. Côté. 2010. Bycatch of rockfish and other species in British Columbia spot prawn traps: preliminary assessment using research traps. Fisheries Research. Volume 102, pages 199-206.

Gerber, L.R., and S.S. Heppell. 2004. The use of demographic sensitivity analysis in marine species conservation planning. Biological Conservation. Volume 120, pages 121-128.

Gibson, C. Preventing the Loss of Gillnets in Puget Sound Salmon Fisheries. 2013. Prepared by the Northwest Straits Commission with the Northwest Indian Fisheries Commission. Available at: http://www.westcoast.fisheries.noaa.gov/publications/protected_species/other/rockfish/puget_sound_derelict_gill_net_prevention_report.pdf.

Gilardi, K. V., D. Carlson-Bremer, J.A. June, K. Antonelis, G. Broadhurst, and T. Cowan. 2010. Marine species mortality in derelict fishing nets in Puget Sound, WA and the cost/benefits of derelict net removal. Marine Pollution Bulletin. Volume 60(3), pages 376-382.

Good, T. P., J.A. June, M.A. Etnier, and G. Broadhurst.2010. Derelict fishing nets in Puget Sound and the Northwest Straits: Patterns and threats to marine fauna. Marine Pollution Bulletin. Volume 60(1), pages 39-50.

Granneman, J.E., and M.A. Steele. 2014. Fish growth, reproduction, and tissue production on artificial reefs relative to natural reefs. ICES Journal of Marine Science.

Holmes, R. and R. Tobeck. 2011. Proposal for a scientific study of artificial reefs in Puget Sound. Coastal Conservation Association.

Jiang, Y.E., P.M. Chen, Z.J. Lin, and Z.Q. Fang. 2013. Comparison of effectiveness of various artificial reef materials for fish attraction. Journal of Applied Oceanography. 3, page 17.

Laufle, J.C. and G.B. Pauley. 1985. Fish colonization and materials comparisons on a Puget Sound artificial reef. Bulletin of Marine Science. Volume 37(1), pages 227-243.

Levin, P.S., J.A. Coyer, R. Petrik, and T.P. Good. 2002. Community-wide effects of nonindigenous species on temperate reefs. Ecology. Volume 83, pages 3,182-3,193.

Levine, J.M. and C.M. D'Antonio. 2003. Forecasting biological invasions with increasing international trade. Conservation Biology. Volume 17(1), pages 322-326.

Matsuoka, T., T. Nakashima, and N. Nagasawa. 2005. A review of ghost fishing: scientific approaches to evaluation and solutions. Fisheries Science. Volume 71, pages 691-702.

National Marine Fisheries Service (NMFS). 2013. Draft Biological Report: Proposed Designation of Critical Habitat for the Distinct Population Segments of Yelloweye Rockfish, Canary Rockfish, and Bocaccio. Northwest Region, Protected Resources Division.

National Oceanic and Atmospheric Administration. 2007. National Artificial Reef Plan (as amended): guidelines for siting, construction, development and assessment of artificial reefs. 51 pages.

Northwest Straits Initiative (NWSI). 2014a. Derelict gear removal. Available at: http://www.derelictgear.org/Progress/ARRA-Project.aspx, accessed April 1, 2014.

Northwest Straits Initiative (NWSI). 2014b. Derelict gear database, updated April 4, 2014.

Natural Resource Consultants, Inc. (NRC). 2008. Rates of marine species mortality caused by derelict fishing nets in Puget Sound, Washington. Prepared for the Northwest Straits Initiative. 16 pages.

NRC. 2010. Deepwater sidescan sonar surveys for derelict fishing nets and rockfish habitat. Submitted to Northwest Straits Foundation. Also as electronic communication from Kyle Antonelis, sent February 23, 2011.

NRC. 2012. Spatial distribution and magnitude of derelict shrimp pots and their potential impacts to rockfish in the Puget Sound. Submitted to the Northwest Straits Foundation and NOAA protected Resources Division. September 20, 2012.

NRC. 2014. Rockfish bycatch in shrimp pots and updated estimates of the magnitude of derelict shrimp pots in Puget Sound. NRC.

Occhipinti-Ambrogi, A. and D. Savini. 2003. Biological invasions as a component of global change in stressed marine ecosystems. Marine Pollution Bulletin. Volume 46, pages 542-551.

Osenberg, C.W., M. Colette, J. St. Mary, A. Wilson, and W.J. Linberg. 2002. A quantitative framework to evaluate the attraction-production controversy. 2002. ICES Journal of Marine Sciences. Volume 59, pages S241-S221.

Palsson, W.A., T. Tsou, G.G. Bargmann, R.M. Buckley, J.E. West, M.L. Mills, Y.W. Cheng, and R.E. Pacunski. 2009. The biology and assessment of rockfishes in Puget Sound. Washington Department of Fish and Wildlife, FPT 09-04, Olympia, WA.

# 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

[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.

## ACKNOWLEDGEMENTS

Thanks to Emily Bishop for her review of this appendix. We thank WDFW and DNR for providing permission to use their ESA section 6 application as a framework for this appendix.

**REFERENCES**

Berry, H. D., T.F.Mumford, and P. Dowty. 2005. Using historical data to estimate changes in floating kelp (*Nereocystis luetkeana* and *Macrocystis integrifolia*) in Puget Sound, Washington. In Proceedings of the 2005 Puget Sound George Basin Research Conference. Puget Sound Action Team, Olympia, Washington (Volume 9).

Carr, M. H. 1983. Spatial and temporal patterns of recruitment of young of the year rockfishes (genus *Sebastes*) into a central California kelp Forest. Master's thesis, San Francisco State University, CA 94132. 104 pages.

Carney, L.T., J. R. Waaland, T. Klinger, and K. Ewing. 2005. Restoration of the bull kelp *Nereocystis luetkeana* in nearshore rocky habitats. Marine Ecology Progress Series. Volume 302, pages 49-61.

Estes, J.A., E.M. Danner, D.F. Doak, B. Konar, A.M. Springer, P.D. Steinber, M.T. Tinker, and T.M. Williams. 2004. Complex trophic interactions in kelp forest ecosystems. Bulletin of Marine Science. Volume 74(3), pages 621-638.

Halderson, L. and L.J. Richards. 1987. Habitat use and young of the year copper rockfish (*Sebastes caurinus*) in British Columbia. Pages 129 to 141 *in* Proceedings of the International Rockfish Symposium, Anchorage, Alaska. Alaska Sea Grant Report, 87-2, Fairbanks, AK.

Harvey, C.J., K.K. Bartz, J. Davies, T.B. Francis, T.P. Good, A.D. Guerry, B. Hanson, K.K. Holsman, J. Miller, M.L. Plummer, J.C.P. Reum, L.D. Rhodes, C.A. Rice, J.F. Samhouri, G.D. Williams, N. Yoder, P.S. Levin, and M.H. Ruckelshaus. 2010. A mass-balance model for evaluating food web structure and community-scale indicators in the central basin of Puget Sound. U.S. Dept. Commerce, NOAA Tech. Memo. NMFS-NWFSC-106, 180 pages.

Hayden-Spear, J. 2006. Nearshore habitat associations of young-of-year copper (*Sebastes caurinus*) and quillback (*S. maliger*) rockfish in the San Juan Channel, Washington. Master of Science Dissertation, University of Washington, Seattle, WA. 38 pages.

Love, M.S., M.H. Carr, and L.J. Haldorson. 1991. The ecology of substrate-associated juveniles of the genus Sebastes. Environmental Biology of Fishes. Volume 30(1-2), pages 225-243.

Marcot, B.G., R.S. Holthausen, M.G. Raphhael, M.M. Rowland, and M.J. Wisdom. 2001. Using Bayesian belief networks to evaluate fish and wildlife population viability under land management alternatives from an environmental impact statement. Forest Ecology and Management. Volume 153, pages 29-52.

Matthews, K.R. 1990. A comparative study of habitat use by young-of-the-year, subadult, and adult rockfishes on four habitat types in central Puget Sound. Fishery Bulletin. Volume 88, pages 223-239.

Mumford, T.F. 2007. Kelp and Eelgrass in Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-05. Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Nearshore Habitat Program. 2001. The Washington state ShoreZone inventory. Washington State Department of Natural Resources, Olympia, WA.

Prasse, K. 2006. Images of America: Camano Island. Arcadia Publishing, San Francisco California.

Rice, C.A. 2006. Effects of shoreline modification in northern Puget Sound: beach microclimate and embryo survival in summer spawning surf smelt (*Hypomesus pretiosus*). Estuaries and Coasts. Volume 29(1), pages 63-71.

Sobocinski, K.L. 2003. The impact of armoring on supratidal beach fauna of Central Puget Sound. University of Washington.

Thom, R.M. and L. Hallum. 1990. Long-term changes in the areal extent of tidal marshes, eelgrass meadows and kelp forests of Puget Sound. Report to the U.S. Environmental Protection Agency, Region 10, Seattle, WA. FRI-UW-9008. Wetland Ecosystem Team, Fisheries Research Institute, University of Washington.

Van Wagenen, B. 1989-2009. Washington coastal kelp resources, Port Townsend to the Columbia River. A series of annual reports to the Nearshore Habitat Program, Washington Department of Natural Resources, Olympia, WA.

Vasquez, J.A. and R.H. McPeak. 1994. A new tool for kelp restoration. Fifth International Conference on Habitat Enhancement.

Velimirov, B, J.G. Field, C.L. Griffiths, and P. Zoutendyk. 1977. The ecology of kelp communities in the Benguela upwelling system: Analysis of biomass and spatial distribution. Helgoland Marine Research. Volume 30, pages 495-518.

Washington Department of Fish and Wildlife (WDFW). 2010. WDFW and Department of Natural Resources (DNR) Section 6 Proposal Submitted to NOAA Fisheries: Restoration and Management of Kelp Habitats and Associated At-risk Rockfish Assemblages.

# 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).

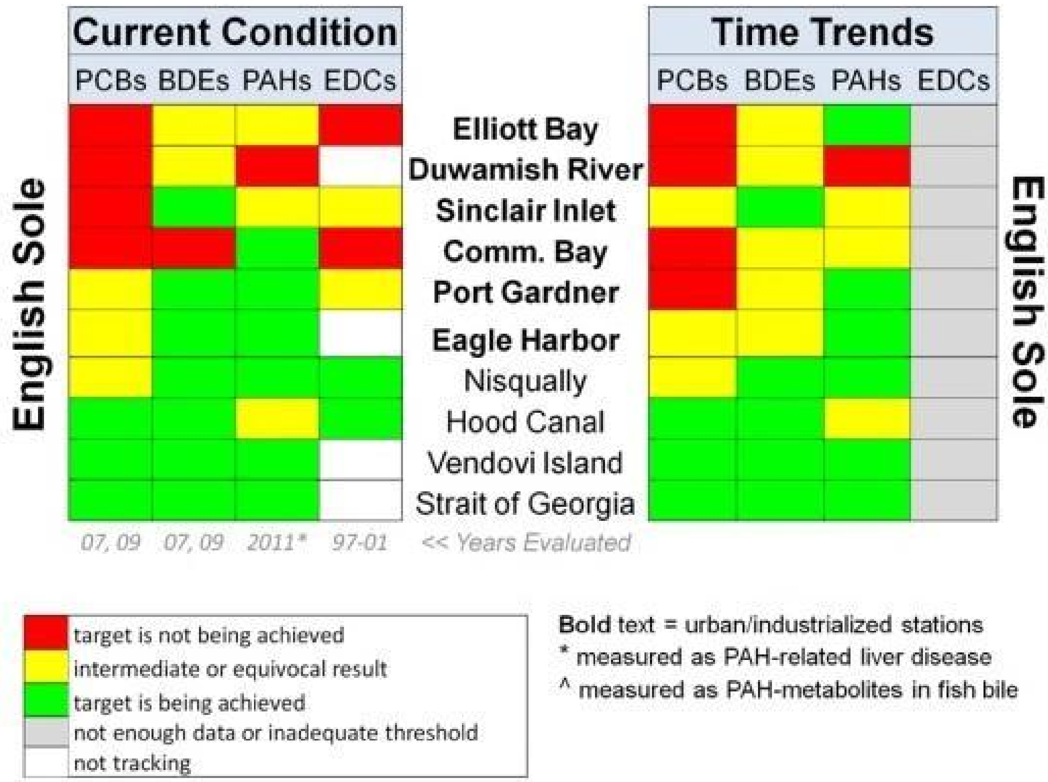



Figure 1. Summary of current conditions and long-term time trends in contaminants for English sole in various regions of the Greater Puget Sound, Washington. (Adapted from West et al. 2011.)

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**.**

**REFERENCES**

Arkoosh, M.R., D. Boylen, J. Dietrich, B.F. Anulacion, G. Ylitalo, C.F. Bravo, L.L. Johnson, FJ. Loge, and T.K. Collier. 2010. Disease susceptibility of salmon exposed to polybrominated diphenyl ethers (PBDEs). Aquatic Toxicology. Volume 98,pages 51-59.

Army Corps of Engineers (COE). 2010. Biological Assessment of the Puget Sound Dredge Disposal Agency dredge management program. 118 pages.

Brian, J.V., C.A. Harris, M. Scholze, A. Kortenkamp, P. Booy, M. Lamoree, G. Pojana, N. Jonkers, A. Marcomini, and J.P. Sumpter. 2007. Evidence of estrogenic mixture effects on the reproductive performance of fish. Environmental Science & Technology. Volume 41, pages 337-344.

Calambokidis, J., S. Jeffries, P.S. Ross, and M. Ikonomu. 1999. Temporal trends in Puget Sound harbor seals. Final Report for the U.S. Environmental Protection Agency and Puget Sound Water Quality Action Team, Cascadia Research, Olympia, Washington.

Collier, T.K., and U. Varanasi. 1991. Hepatic activities of xenobiotic metabolizing enzymes and biliary levels of xenobiotics in English sole (*Parophrys vetulus*) exposed to environmental contaminants. Archives of Environmental Contamination and Toxicology. Volume 20, pages 462-473.

Collier, T.K., S.M. O’Neill, J.E. West, and N.L. Scholz. 2007. Toxic chemical contaminants and Puget Sound. Proceedings of the 2007 Georgia Basin/Puget Sound Research Conference, Vancouver, BC.

Cope, B. and M. Roberts. 2012. Review and Synthesis of Available Information to Estimate Human Impacts to Dissolved Oxygen in Hood Canal. Environmental Protection Agency, Region 10 and Washington Department of Ecology, Olympia, WA.

Cottam, C. and E. Higgins. 1946. DDT: Its Effect on Fish and Wildlife. US Department of the Interior, Fish and Wildlife Service, Circular 11.

De Wit, C.A. 2002. An overview of brominated flame retardants in the environment. Chemosphere. Volume 46, pages 583-624.

Crowser et al. 2007. Hart Crowser, Inc.; Washington Department of Ecology; U.S. Environmental Protection Agency; and Puget Sound Partnership. Phase 1: Initial Estimate of Toxic Chemical Loadings to Puget Sound. Ecology Publication Number 07-10-079. October 2007. Olympia, Washington.

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

Dutch, M., S. Weakland, and B. Chandramouli. 2011a. Pharmaceuticals and Personal Care Products and Perfluorinated Chemicals in Puget Sound Sediments. Poster presentation – 2011 Salish Sea Ecosystem Conference, October 25-27, 2011, Vancouver, BC, Canada. Poster. Publication 11-03-041.

Dutch, M., and S. Weakland. 2011b. Polybrominated Diphenyl Ethers (PBDEs) In Puget Sound Sediments – A Baseline Update (2004-2011). Poster presentation - 2011 Salish Sea Ecosystem Conference, October 25-27, 2011, Vancouver, BC. Poster. Publication 11-03-056.

EVS Environmental Consultants. 2003. Status, trends and effects of toxic contaminants in the Puget Sound environment. Puget Sound Action Team, Olympia, Washington.

Garrett, C. 2004. Priority substances of interest in the Georgia Basin: profiles and background information on current toxics issues. GBAP Publication Number EC/GB/04/79, Canadian Toxics Work Group, Puget Sound/Georgia Basin International Task Force, Victoria, British Columbia, and Olympia, Washington.

Gilkinson, K.D., D.C. Gordon, Jr., K.G. MacIsaac, D.L. McKeown, E.L.R. Kenchington, C. Bourbonnais, W.P. Vass. 2005. Immediate impacts and recovery trajectories of macrofaunal communities following hydraulic clam dredging on Banquereau, eastern Canada. ICES Journal of Marine Science. Volume 62(5), pages 925-947.

Grant, S. C. H. and P. S. Ross. 2002. Southern resident killer whales at risk: toxic chemicals in the British Columbia and Washington environment. Can. Tech. Rep. Fish. Aquat. Sci. 2412: 123.

Gray, C. and T. Tuominen. 2001. The Fraser River is getting cleaner: will it continue to improve? In T. Droscher, editor. Proceedings of the 2001 Puget Sound Research Conference. Puget Sound Action Team, Olympia, Washington.

Iwata, H., S. Tanabe, N. Sakai, and R. Tatsukawa. 1993. Distribution of persistent organochlorines in the oceanic air and surface seawater and the role of ocean on their global transport and fate. Environmental Science and Technology. Volume 27, pages 1080-1098.

Johannessen, S.C., R.W. Macdonald, C.A. Wright, B. Burd, D.P. Shaw, A. van Roodselaar. 2008. Joined by geochemistry, divided by history: PCBs and PBDEs in Strait of Georgia sediments. Marine Environmental Research. Volume 66, pages S112-S120.

Johnson, L.L., T.K. Collier, and J.E. Stein. 2002. An analysis in support of sediment quality thresholds for polycyclic aromatic hydrocarbons (PAHs) to protect estuarine fish. Aquatic Conservation: Marine and Freshwater Ecosystems. Volume 12, pages 517-538.

Johnson, L.L., D.P. Lomax, M.S. Myers, O.P. Olson, S.Y. Sol, S.M. O'Neill, J. West, and T.K. Collier. 2008. Xenoestrogen exposure and effects in English sole (*Parophrys vetulus*) from Puget Sound, WA. Aquatic Toxicology. Volume 88, pages 29-38.

Landahl, J.T., L.L. Johnson, T.K. Collier, J.E. Stein, and U. Varanasi. 1997. Marine pollution and fish population parameters: English sole (*Pleuronectes vetulus*) in Puget Sound, WA. Transactions of the American Fisheries Society. Volume 126, pages 519-535.

Lefkovitz, L.F., V.I. Cullinan, and E.A. Crecelius. 1997. Historical trends in the accumulation of chemicals in Puget Sound. NOAA technical memorandum NOS ORCA III. National Oceanic and Atmospheric Administration. Silver Spring, MD.

Long, E.R., M. Dutch, S. Aasen, C. Ricci, and K. Welch. 2001. Spatial extent of contamination, toxicity and associated biological effects in Puget Sound sediments. In T. Droscher, editor. Proceedings of the 2001 Puget Sound Research Conference. Puget Sound Action Team, Olympia, Washington.

Lönnstedt, O.M. and P. Eklöv. 2016. Environmentally relevant concentrations of microplastic particles influence larval fish ecology. Science. Volume 352(6290), pages 1213-1216.

Love, M.S., M. Yoklavich, and L. Thorstein. 2002. The rockfishes of the Northeast Pacific. University of California Press. 404 pages.

Meador, J.P., T.K. Collier, J.E. Stein. 2002. Use of tissue and sediment-based threshold concentrations of polychlorinated biphenyls (PCBs) to protect juvenile salmonids listed under the US Endangered Species Act. Aquatic Conservation: Marine and Freshwater Ecosystems. Volume 12, pages 493-516.

Mearns, A.J. 2001. Long-term contaminant trends and patterns in Puget Sound, the Straits of Juan de Fuca, and the Pacific Coast. In T. Droscher, editor. Proceedings of the 2001 Puget Sound Research Conference. Puget Sound Action Team. Olympia, Washington.

National Marine Fisheries Service (NMFS). 2010. Threatened Status for the Puget Sound/Georgia Basin Distinct Population Segments of Yelloweye and Canary Rockfish and Endangered Status for the Puget Sound/Georgia Basin Distinct Population Segment of Bocaccio Rockfish. Federal Register 75:22276- 22290.

National Marine Fisheries Service (NMFS). 2014. Biological Report: Designation of Critical Habitat for the Distinct Population Segments of Yelloweye Rockfish, Canary Rockfish, and Bocaccio. Northwest Region, Protected Resources Division.

PSAT (Puget Sound Action Team). 2007. 2007 Puget Sound update, ninth report of the Puget Sound Ambient Monitoring Program. Puget Sound Action Team, Olympia, WA. 260 pages.

O'Neill, S.M., J.E. West, G.M. Ylitalo, C.A. Sloan, M.P. Krahn, and T.K. Collier. 2004. Concentrations of polybrominated diphenyl ethers (PBDEs) in fish from Puget Sound, WA, USA. Poster presentation: SETAC World Congress and 25th Annual Meeting in North America of Environmental Toxicology and Chemistry. Portland, Oregon.

O'Neill, S.M. and J.E. West. 2009. Marine distribution, life history traits, and the accumulation of polychlorinated biphenyls in Chinook salmon from Puget Sound, Washington. Transactions of the American Fisheries Society. Volume 138, pages 616-632.

O'Neill, S., J. West, and G. Ylitalo. 2011. Options to reduce toxic threats to Chinook salmon in marine waters of the Salish Sea. 2011 Salish Sea Conference. Vancouver, BC, October 26, 2011.

Pal, A., K.Y. Gin, A.Y. Lin and M. Reinhard. 2010. Impacts of emerging organic contaminants on freshwater resources: review of recent occurrences, sources, fate and effects. Science of the Total Environment. Volume 408, pages 6062-6069

Palsson, W.A., T. Tsou, G.G. Bargmann, R.M. Buckley, J.E. West, M.L. Mills, Y.W. Cheng, and R.E. Pacunski. 2009. The Biology and Assessment of Rockfishes in Puget Sound. Washington Department of Fish and Wildlife.

Partridge, V., K. Welch, S. Aasen, and M. Dutch. 2005. Temporal Monitoring of Puget Sound Sediments: Results of the Puget Sound Ambient Monitoring Program, 1989-2000. Publication No. 05-03-016.

PSAT (Puget Sound Action Team). 2007. State of the sound 2007. Publication PSAT:07-01. Puget Sound Action Team, Olympia, WA.

Rochman, C.M., A. Tahir, S.L. Williams, D.V. Baxa, R. Lam, J.T. Miller, F. The, S. Werorilangi, and S.J. Teh. 2015. Anthropogenic debris in seafood: plastic debris and fibers from textiles in fish and bivalves sold for human consumption. Scientific Report. Volume 5, pages 14340.

Silva, E., N. Rajapakse, and A. Kortenkamp. 2002. Something from “nothing” – Eight weak estrogenic chemicals combined at concentrations below NOECs produce significant mixture effects. Environmental Science & Technology. Volume 36, pages 1751-1756.

Sardá, R., S. Pinedo, A. Gremare, and S. Taboada. 2000. Changes in the dynamics of shallow sandy-bottom assemblages due to sand extraction in the Catalan Wester Mediterranean Sea. ICES Journal of Marine Science. Volume 57, pages 1446-1453.

Tanabe, S., H. Iwata, and R. Tatsukawa. 1994. Global contamination by persistent organochlorines and their ecotoxicological impact on marine mammals. Science of the Total Environment. Volume 154, pages 163-177.

Washington Department of Ecology (Ecology). 2011. Toxic chemicals in Puget Sound. Assessment of Selected Toxic Chemicals in the Puget Sound Basin, 2007-2011. Publication No. 11-03-055.

Washington Department of Ecology (WDOE). 2013. Sediment Quality in Central Puget Sound, Changes over a Ten-Year Period. Publication 13-03-021. Environmental Assessment Program, Marine Monitoring Unit. Olympia, WA.

West, J.E., and S.M. O'Neill. 1998. Persistent pollutants and factors affecting their accumulation in rockfishes (*Sebastes* spp.) from Puget Sound, Washington. Pages 336-345 in R. Strickland, editor. Puget Sound Research 1998 Conference Proceedings. Puget Sound Water Quality Action Team. Olympia, Washington.

West, J.E., S.M. O’Neill, G. Lippert, and S. Quinnell. Toxic contaminants in marine and anadromous fishes from Puget Sound, Washington. Results of the Puget Sound Ambient Monitoring Program Fish Component, 1989-1999. Washington Department of Fish and Wildlife 600 Capitol Way N Olympia, WA, 98501-1091. http://wdfw.wa.gov/publications/01026/wdfw01026.pdf

West, J.E. and S.M. O'Neill. 2007. Thirty years of persistent bioaccumulative toxics in Puget Sound: time trends of PCBs and PBDE flame retardants in three fish species. 2007 Research in the Georgia Basin and Puget Sound Conference. Puget Sound Action Team. Vancouver, B.C.

West, J.E., S.M. O’Neill, G. Lippert, and S. Quinnell. 2001a. Toxic contaminants in marine and anadromous fish from Puget Sound, Washington: Results of the Puget Sound Ambient Monitoring Program fish component, 1989–1999. Washington Dept. Fish and Wildlife, Olympia.

West, J., S. O’Neill, D. Lomax, and L. Johnson. 2001b. Implications for reproductive health in rockfish (*Sebastes* spp.) from Puget Sound exposed to polychlorinated biphenyls. In T. Droscher, editor. Proceedings of the Puget Sound Research Conference. Puget Sound Action Team. Olympia, Washington.

West, J.E., S.M. O’Neill, and G.M. Ylitalo. 2008. Spatial extent, magnitude, and patterns of persistent organochlorine pollutants in Pacific Herring (*Clupea pallasi*) populations in the Puget Sound (USA) and Strait of Georgia (Canada). Science of the Total Environment. Volume 394, pages 369-378.

West, J.E., S.M. O’Neill, J. Lanksbury, G.M. Ylitalo, and S. Redman. 2011. Current conditions, time trends and recovery targets for toxic contaminants in Puget Sound fish: the Toxics in Fish Dashboard Indicator. Available at http://wdfw.wa.gov/publications/01364/wdfw01364.pdf

West, J. and S. O’Neill. 2012. Poster: Toxic Contaminants as a Stressor in demersal rockfishes (*Sebastes* spp.) from Puget Sound. Puget Sound Assessment and Monitoring Program. Available at http://www.westcoast.fisheries.noaa.gov/publications/protected_species/other/rockfish/pbtsinrockfishjwest.pdf.

# 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).

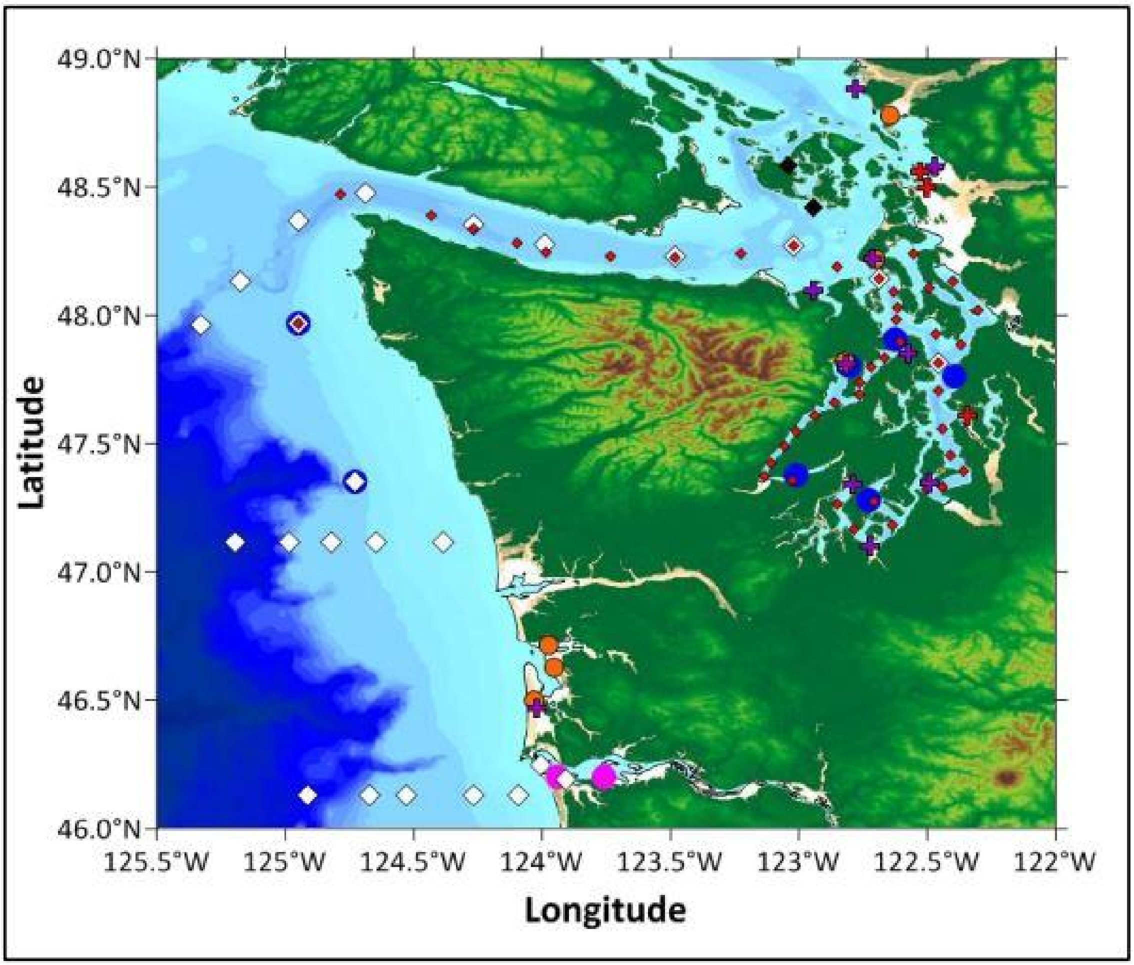



Figure 1. WOAC monitoring network. White, red, and black diamonds are ship cruise stations; blue dots are OA buoys (or soon to be); pink dots are OA moorings; orange dots are shellfish grower sites; and crosses are nearshore monitoring stations, including those of WA DNR (purple). (Excerpted from WOAC 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.

## REFERENCES

Ablain, M., A. Cazenave, G. Valladeau, S. Guinehut. 2009. A new assessment of the error budget of global mean sea level rate estimated by satellite altimetry over 1993-2008. Ocean Science. Volume 5(2), pages 193-201.

Ainsworth, C.H., J.F., Samhouri, D.S. Busch, W.W.L. Cheung, J. Dunne, T.A. Okey. 2011. Potential impacts of climate change on Northeast Pacific marine foodwebs and fisheries. ICES Journal of Marine Science. Volume 68, pages 1217–1229.

Bednarsek, N., R.A. Feely, J.C.P Reum, B. Peterson, J. Menkel, J.R. Alin, B. Hales. 2014. *Limacina helicina* shell dissolution as an indicator of declining habitat suitability owing to ocean acidification in the California Current Ecosystem. Proceedings of the Royal Society of Biological Sciences. Volume 281, pages 20140123.

Brewer, P.G. and E.T. Peltzer. 2009. Limits to Marine Life. Science. Volume 324, pages 347-348.

Chan, F., J.A. Barthy, J. Lubchenco, A. Kirincich, H. Weeks, W.T. Peterson, and B.A. Menge. 2008. Emergence of anoxia in the California current large marine ecosystem. Science. Volume 319, 5865: pages 920-920.

Chavez, F.P., J. Ryan, S.E. Lluch, and M. Niquen. 2003. From anchovies to sardines and back: Multidecadal change in the Pacific Ocean. Science. Volume 299, pages 217-221.

Chung, I.K., J. Beardall, S. Mehta, D. Sahoo, and S. Stojkovic. 2011. Using marine macroalgae for carbon sequestration: A critical appraisal. Journal of Applied Phycology. Volume 23(5), pages 877–886.

Chung, W.S., N.J. Marshall, S.A. Watson, P.L. Munday, and G.E. Nilsson. 2014. Ocean acidification slows retinal function in a damselfish through interference with $GABA_A$ receptors. The Journal of Experimental Biology. Volume 207, pages 323-326.

Church, J.A. and N.J. White. 2006. A 20th century acceleration in global sea-level rise. Geophysical Research Letters, 33, L01602, doi:10.1029/2005GL024826.

Craig, D. 1993. Preliminary assessment of sea-level rise in Olympia, WA: Technical and policy implications. Policy and Program Development Division, Olympia Public Works Department, Olympia.

Crooks, S., J. Rybczyk, K. O'Connell, D.L. Devier, K. Poppe, and S. Emmett-Mattox. 2014. Coastal Blue Carbon Opportunity Assessment for the Snohomish Estuary: The Climate Benefits of Estuary Restoration. Report by Environmental Science Associates, Western Washington University, EarthCorps, and Restore America's Estuaries.

Cope, B. and M. Roberts. 2012. Review and Synthesis of Available Information to Estimate Human Impacts to Dissolved Oxygen in Hood Canal. Environmental Protection Agency, Region 10 and Washington Department of Ecology, Olympia, WA.

Dalton, M.M. et al., eds. 2013. Climate Change in the Northwest: Implications for our Landscapes, Waters, and Communities, NCA Regional Input Reports. Oregon Climate Change Research Institute.

Doney, S.C., V.J. Fabry, R.A. Feely, and J.A. Kleypas. 2009. Ocean Acidification: The Other $CO_2$ Problem. Annual Review of Marine Science. Volume 1, pages 169-192.

Fabry, V.J., B.A. Seibel, R.A. Feely, and J.C. Orr. 2008. Impacts of ocean acidification on marine fauna and ecosystem processes. ICES Journal of Marine Science. Volume 65, pages 414-432.

Feely, R.A., C.L. Sabine, J.M. Hernandez-Ayon, D. Ianson, and B. Hales. 2008. Evidence for Upwelling of Corrosive Acidified Water onto the Continental Shelf. Science. Volume 320, 5882: pages 1490-1492.

Feely, R.A., S. Alin, J. Newton, C. Sabine, M. Warner, A. Devol, C. Krembs, and C. Maloy. 2010. The combined effects of ocean acidification, mixing, and respiration on pH and carbon saturation in an urbanized estuary. Estuarine, Coastal, and Shelf Science. Volume 88, pages 442-449.

Feely, R.A., T. Klinger, J.A. Newton, and M. Chadsey. 2012. Scientific Summary of Ocean Acidification in Washington State Marine Waters. NOAA OAR Special Report. https://fortress.wa.gov/ecy/publications/SummaryPages/1201016.html.

Fitzer, S.C., G.S. Caldwell, A.J. Close, A.S. Clare, R.C. Upstill-Goddard, and M.G. Bentley. 2012. Ocean acidification induces multi-generational decline in copepod naupliar production with possible conflict for reproductive resource allocation. Journal of Experimental Marine Biology and Ecology. Volume 418, pages 30-36.

Hamilton, T.J., A. Holcombe, and M. Tresguerres. 2014. $CO_2$-induced ocean acidification increases anxiety in Rockfish via alteration of $GABA_A$ receptor functioning. Proceedings of the Royal Society of Biological Sciences. Volume 281(1775), pages 20132509.

Hamilton, S.L., C.A. Logan, H.W. Fennie, S.M. Sogard, J.P. Barry, A.D. Makukhov, L.R. Tobosa, K. Boyer, C.F. Lovera, and G. Bernardi. 2017. Species-specific responses of juvenile rockfish to elevated $pCO_2$: from behavior to genomics. PloS one 12(1): e0169670

Harley, C.D.G., Hughes, A.R., Hultgren, K.M., Miner, B.G., Sorte, C.J.B., Thornber, C.S., Rodriguez, L.F., Tomanek, and S.L., Williams. 2006. The impacts of climate change in coastal marine systems. Ecology Letters. Volume 9(2), pages 228-241.

Hoegh-Guldberg, O., P.J. Mumby, A.J. Hooten, R.S. Steneck, P. Greenfield, E. Gomez, C.D. Harvell, P.F. Sale, A.J. Edwards, K. Caldeira, N. Knowlton, C.M. Eakin, R. Iglesias-Prieto, N. Muthiga, R.H. Bradbury, A. Dubi, and M.E. Hatziolos. 2007. Coral reefs under rapid climate change and ocean acidification. Science. Volume 318(5857), pages 1737-1742.

Hughes, T.P., A.H. Baird, D.R. Bellwood, M. Card, S.R. Connolly, C. Folke, R. Grosberg, O. Hoegh-Guldberg, J.B.C. Jackson, J. Kleypas, J.M. Lough, P. Marshall, M. Nystrom, S.R. Palumbi, J.M. Pandolfi, B. Rosen, and J. Roughgarden. 2003. Climate change, human impacts, and the resilience of coral reefs. Science. Volume 301, pages 929-933.

Intergovernmental Panel on Climate Change (IPCC). Solomon et al., Eds. 2007. The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

Krembs, C., J. Bos, S. Albertson, M. Keyzers, L. Friedenberg, J. Ruffner, B. Sackmann, B., and C. Maloy. 2012. POSTER: South Puget Sound 2011 and 2012 in review: Aerial and water column observations from Ecology's long-term monitoring program. Accessible at Washington Department of Ecology: https://fortress.wa.gov/ecy/publications/publications/1203052.pdf.

Love, M. S., M. Carr, and L. Haldorson. 1991. The ecology of substrate-associated juveniles of the genus *Sebastes*. Environmental Biology of Fishes. Volume 30, pages 225-243.

Love, M.S., M. Yoklavich, and L. Thorstein. 2002. The rockfishes of the Northeast Pacific. University of California Press. 404 pages.

Mantua, N.J. and S.R. Hare. 2002. The Pacific Decadal Oscillation. Oceanography. Volume 58, pages 35-44.

Mauger, G.S., J.H. Casola, H.A. Morgan, R.L. Strauch, B. Jones, B. Curry, T.M. Busch Isaksen, L. Whitely Binder, M.B. Krosby, and A.K. Snover. 2015. State of Knowledge: Climate Change in Puget Sound. Report prepared for the Puget Sound Partnership and the National Oceanic and Atmospheric Administration. Climate Impacts Group, University of Washington, Seattle. doi:10.7915/CIG93777D.

Mayor, D.J., N.R. Everett, and K.B. Cook. 2012. End of century ocean warming and acidification effects on reproductive success in a temperate marine copepod. Journal of Plankton Research. Volume 34(3), pages 258-262.

Miller, A.W, A.C. Reynolds, C. Sobrino, and G.F. Riedel. 2009. Shellfish Face Uncertain Future in High CO2 World: Influence of Acidification on Oyster Larvae Calcification and Growth in Estuaries. PLoS ONE, 4:5 e5661.

Moore, S.K., N.J. Mantua, J.P. Kellogg, and J.A. Newton. 2008a. Local and large-scale climate forcing of Puget Sound oceanographic properties on seasonal to interdecadal timescales. Limnology and Oceanography. Volume 53(5), pages 1746-1758.

Moore, S.K., V.L. Trainer, N.J. Mantua, M.S. Parker, E.A. Laws, L.C. Backer, and L.E. Fleming. 2008b. Impacts of climate variability and future climate change on harmful algal blooms and human health. Environmental Health, 6 (Suppl 2):S4.

Munday, P.L., D.L. Dixon, J.M. Doelson, G.P. Jones, M.S. Pratchett, G.V. Devitsina, K.B. Doving. 2009. Ocean acidification impairs olfactory discrimination and homing ability of a marine fish. Proceedings of the National Academy of Sciences. Volume 106, pages 1848-1852.

Newton, J. and K. Van Voorhis. 2002. Seasonal Patterns and Controlling Factors of Primary Production in Puget Sound’s Central Basin and Possession Sound. Publication # 02-03-059. Washington State Department of Ecology, Environmental Assessment Program. Olympia, Washington.

Nicholls, R. J. and A. Cazenave. 2010. Sea-level rise and its impact on coastal zones. Science. Volume 328(5985), pages 1517-1520.

Pacific Fishery Management Council (PFMC). 2011. Discussion document: development of an annual report on conditions in the California current ecosystem (draft). http://www.pcouncil.org/wp-content/uploads/H1b_ATT1_DD_CA_ECO_NOV2011BB.pdf

Palsson, W.A., T. Tsou, G.G. Bargmann, R.M. Buckley, J.E. West, M.L. Mills, Y.W. Cheng, and R.E. Pacunski. 2009. The Biology and Assessment of Rockfishes in Puget Sound. Washington Department of Fish and Wildlife.

Pfeffer, W. T., J.T. Harper, S. O’Neil. 2008. Kinematic Constraints on Glacier Contributions to 21st-Century Sea-Level Rise. Science. Volume 321 (5894), pages 1340-1343.

Ries, J.B., A.L. Cohen, and D.C. McCorkle. 2009. Marine calcifiers exhibit mixed responses to CO2-induced ocean acidification. Geology. Volume 37(12), pages 1131-1134.

Sabine, C.L., R.A. Feely, N. Gruber, R.M. Key, K. Lee, J.L. Bullister, R. Wanninkhof, C.S. Wong, D.W.R. Wallace,, B. Tilbrook, F.J. Millero, T-H. Peng, Kozyr, T. Ono, and A.F. Rios. 2004. The oceanic sink for CO2. Science. Volume 305, pages 367-371.

Salathe, E.P., P.W. Mote, and M.W. Wiley. 2007. Considerations of selecting downscaling method for integrated assessment of climate change impacts. International Journal of Climatology. Volume 27(12), pages 1611-1621.

Simpson, S.D., P.L. Munday, M.L. Wittenrich, R. Manassa, D.L. Dixson, M. Gagliano, and H.Y. Yan. 2011. Ocean Acidification erodes crucial auditory behavior in a marine fish. Biological Letters: rsbl20110293.

Washington Ocean Acidification Center (WOAC) 2015. Monitoring sites of the WOAC. University of Washington. https://environment.uw.edu/wp-content/uploads/2015/02/Pages-from-2015_0129_WOAC_one-pagers_integrated_monitoring_FINAL.pdf.

Wood, H. L., J. I. Spicer, and S. Widdicombe. 2008. Ocean acidification may increase calcification rates, but at cost. Proceedings of the Royal Society of Biology. Volume 275, pages 1767-1773.

Zhang, D., S. Li, G. Wang, and D. Guo. 2012. Impacts of CO2-driven seawater acidification on survival, egg production rate and hatching success of four marine copepods. Acta Oceanologica Sinica. Volume 30(6), pages 86-94.

# 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<br><br>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<br><br>http://marinedebris.noaa.<br>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<br><br>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<br><br>http://wdfw.wa.gov/grants/alea/<br><br>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<br>Details: http://go.usa.gov/cytgJ<br>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<br>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<br>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<br>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<br>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<br>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<br><br>http://wsg.washington.edu/research/index.html<br>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<br><br>http://www.grants.gov/web/grants/view-opportunity.html?oppId=259279<br>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<br><br>http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=11696&org=NSF&sel_org=NSF&from=fund<br>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<br><br>http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=11698&org=NSF&sel_org=NSF&from=fund<br>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.<br>(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<br><br>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<br><br>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<br><br>http://www.waltonfamilyfoundation.org/grants/grant-proposals |
| | Funds work that supports acoustics research and mapping. | Variable | Variable | NOAA Ocean Acoustics Program<br><br>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<br><br>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<br><br>http://www.habitat.noaa.gov/funding/coastalrestoration.html<br><br>Contact Kate Brogan 301-427-8030 |
| *Habitat Restoration (continued)* | | Variable | Variable | WDFW ALEA Volunteer Cooperative Grant Program (details under Outreach and Education)<br>NOAA CRWG (details under Cooperative Research)<br>NOAA CRP (details under Cooperative Research) |
| *Cooperative Research* | Projects should address areas identified under Section 318 of the MSRA:<br>(1) Collecting data to improve, supplement, or enhance stock assessments, including use of fishing vessels/ acoustics /other marine tech. (Sect. 318(c)(i)).<br>(2) Assessing the amount and type of bycatch or post-release mortality occurring in a fishery (Section 318(c)(ii)).<br>(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)).<br>(4) Identifying habitat areas of particular concern and conducting projects relevant to the conservation of habitat (Section 318(c)(iv)).<br>(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<br><br>http://www.nmfs.noaa.gov/by_catch/docs/cooperative_research_working_group_tor.pdf<br><br>Internal NOAA grant; document saved to shared drive<br><br>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.<br><br>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<br><br>http://www.st.nmfs.noaa.gov/cooperative-research/index |
| | | | | NOAA-NMFS (MARFIN)<br>(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<br><br>http://www.nmfs.noaa.gov/pr/conservation/states/grant.htm<br><br>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)<br><br>http://www.grants.gov/web/grants/view-opportunity.html?oppId=258831<br><br>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.

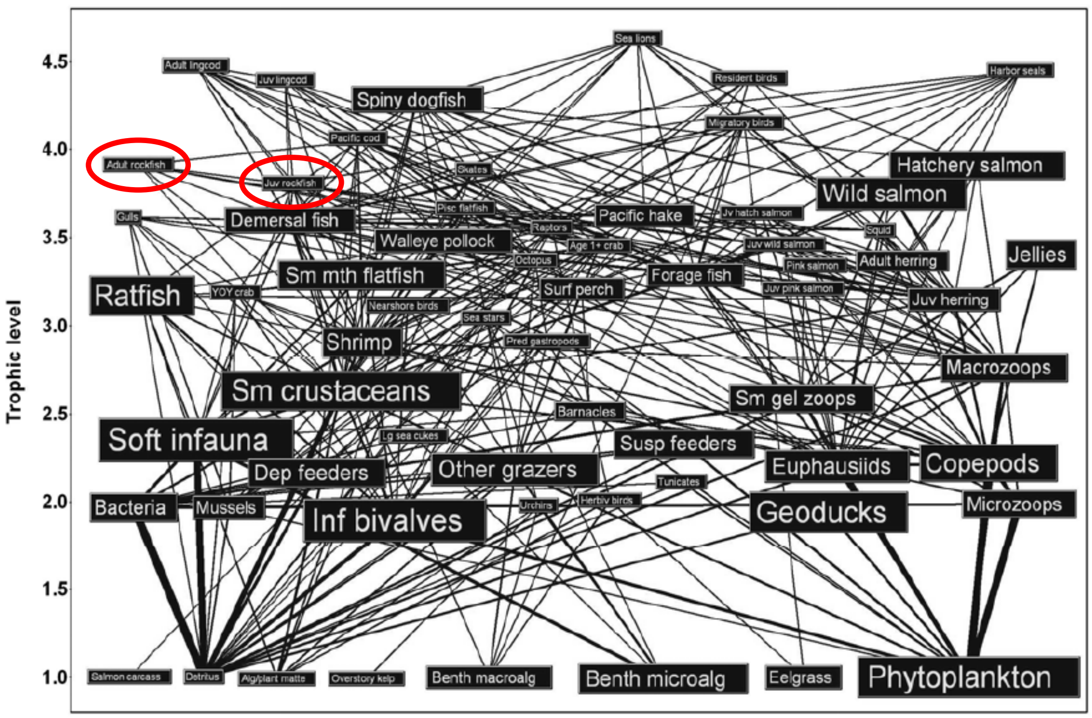



Figure 1. Diagram of the Puget Sound food web from Harvey et al. 2010.

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.

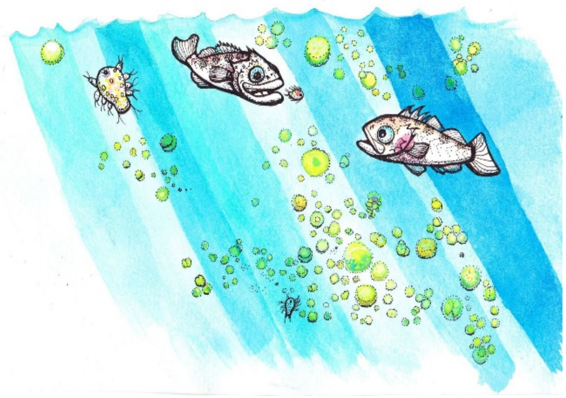


Figure 2. Illustration of larval rockfish by C. Makeyev.

**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). 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

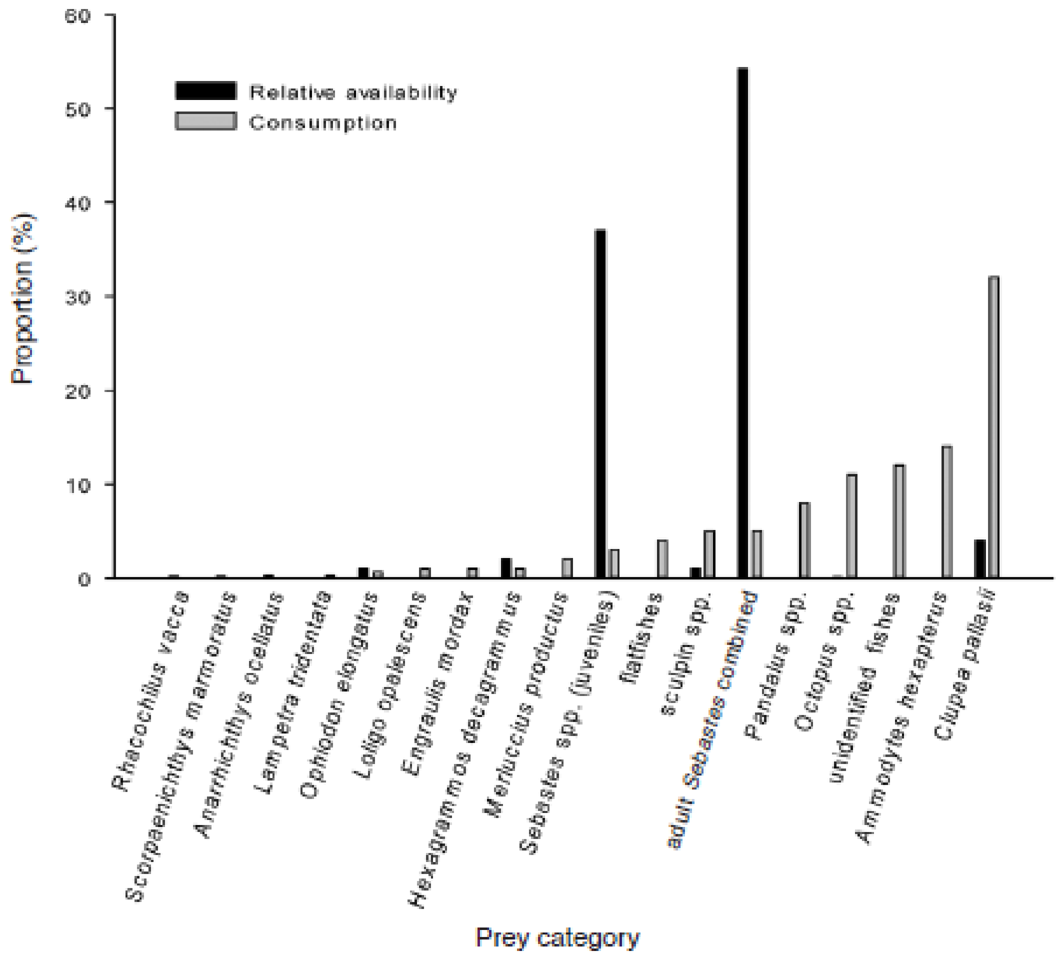



**Figure 3**

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).

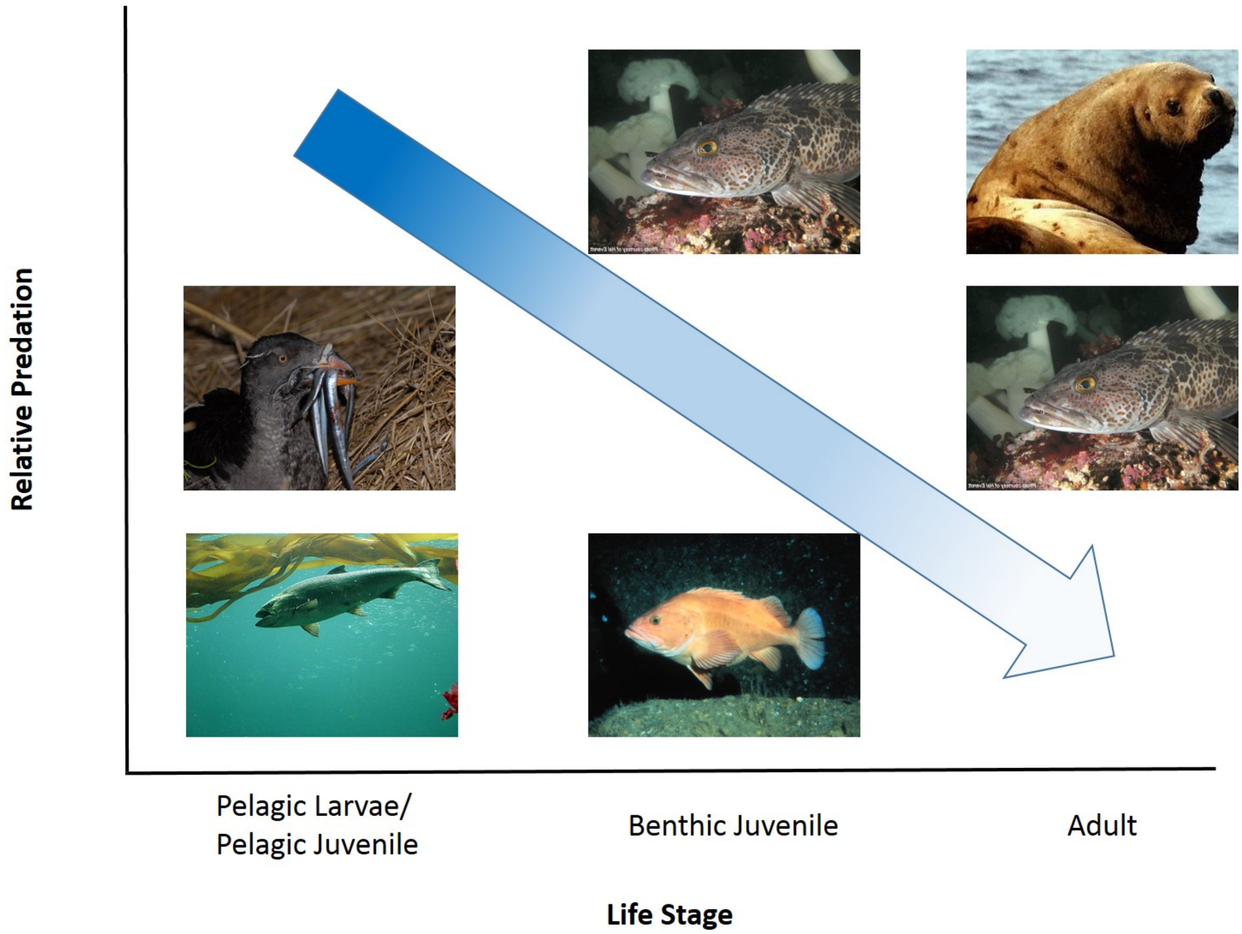



Figure 6. The general trend of rockfish predation ( ) throughout various life stages depicted alongside the primary predators at each life stage. During the pelagic larvae and pelagic juvenile phases, rockfish are consumed by seabirds (represented by the rhinoceros auklet) and salmon. Lingcod and rockfish 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).

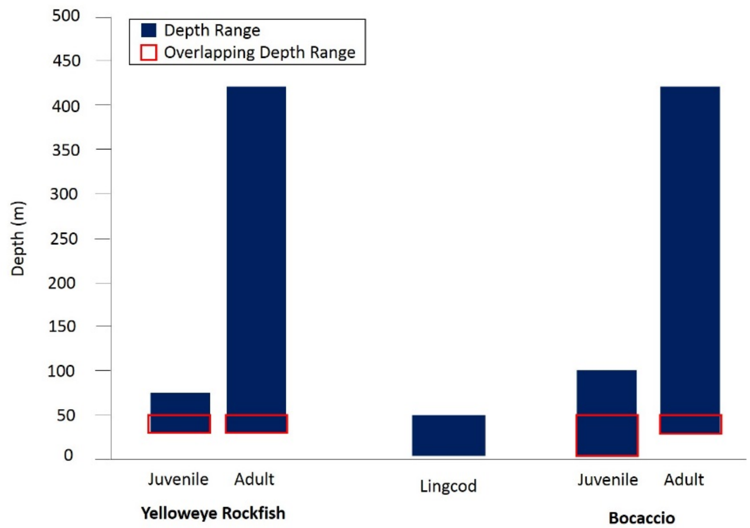



Figure 7. Depth distribution of lingcod (Beadreau and Essington 2011) and listed rockfish species.

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.

**REFERENCES**:


Beaudreau, A.H. and T.E. Essington. 2007. Spatial, temporal and ontogenetic patterns of predation on rockfishes by lingcod. Transactions of the American Fisheries Society. Volume 136(5), pages 1438-1452

Beaudreau, A.H. and T.E. Essington. 2011. Use of pelagic prey subsidies by demersal predators in rocky reefs: insight from movement patters of lingcod. Marine Biology. Volume 158(2), pages 471-483

Becker, H.B., M.Z. Peery, and S.R. Beissinger. 2007. Ocean climate and prey availability affect the trophic level and reproductive success of the marbled murrelet, an endangered seabird. Marine Ecology Progress Series. Volume 329, pages 267-279.

Bjorkstedt, E.P., L.K. Rosenfeld, B.A. Grantham, Y. Shkedy, and J. Roughgarden. 2002. Distributions of larval rockfishes *Sebastes* spp. across nearshore fronts in a coastal upwelling region. Marine Ecology Progress Series. Volume 242, pages 215-228.

Black, B.A., I.D. Schroeder, W.J. Sydeman, S.J. Bograd, and P.W. Lawson. 2010. Wintertime ocean conditions synchronize rockfish growth and seabird reproduction in the central California Current ecosystem. Canadian Journal of Aquatic and Fishery Sciences. Volume 67, pages 1149-1158.

Bohnsack, J.A., 1989. Are high densities of fishes at artificial reefs the result of habitat limitation or behavioral preference? Bulletin of Marine Science. Volume 44(2), pages 631-645.

Bolton, H.M. 2014. Habitat associations and predictive distribution models of commercially important rockfish species along California’s Central Coast. Capstone Projects and Theses. Paper 592.

Brodeur, R.D., H.V. Lorz, and W.G. Pearcy. 1987. Food habitats and dietary variability of pelagic nekton off Oregon and Washington, 1979-1984. NOAA Technical Report, NMFS 57. 32 pages.

Buckley, R.M. 1997. Substrate associated recruitment of juvenile *Sebastes* in the artificial reef and natural habitats in Puget Sound and the San Juan Archipelago, Washington. Doctoral Dissertation, University of Washington. 320 pages.

Cloutier, R.N. 2011. Direct and indirect effects of marine protection: Rockfish Conservation Areas as a case study. Master's Thesis, Simon Fraser University. 70 pages.

Crowder, L.B., D.T. Crouse, S.S. Heppell, and T.H. Martin. 1994. Predicting the impact of Turtle Excluder Devices on loggerhead sea turtle populations. Ecological Applications. Volume 4(3), pages 437-445

Daly, E.A., R.D. Brodeur, and L.A. Weitkamp. 2009. Ontogenetic shifts in diets of juvenile and subadult coho and Chinook salmon in coastal marine waters: important for marine survival? Transactions of the American Fisheries Society. Volume 138, pages 1420-1438

Feely, R.A., S.R. Alin, J. Newton, C.L. Sabine, M. Warner, A. Devol, C. Krembs, and C. Maloy. 2010. Estuarine, Coastal and Shelf Science. Volume 88, pages 442-449

Frid, A., B. Connors, A.B. Cooper, and J. Marliave. 2013. Size-structured abundance relationships between upper- and mid-trophic level predators on temperate rocky reefs. Ethology Ecology and Evolution. Volume 25(3), pages 253-268.

Granneman, J.E. and M.A. Steele. 2015. Effects of reef attributes on fish assemblage similarity between artificial and natural reefs. ICES Journal of Marine Science. Volume 72(8), pages 2385-2397.

Haggarty, D.R., J.B. Shurin, and K.L. Yamanaka. 2016. Assessing population recovery inside British Columbia's Rockfish Conservation Areas with a remotely operated vehicle. Fisheries Research. Volume 183, pages 165-179.

Hamilton, T.J., A. Holcombe, and M. Tresguerres. 2014. $CO_2$-induced ocean acidification increases anxiety in rockfish via alteration of $GABA_A$ receptor functioning. Proceedings of the Royal Society B. Volume 281, pages 20132509.

Harvey, C.J., K.K. Bartz, J. Davies, T.B. Francis, T.P. Good, A.D. Guerry, B. Hanson, K.K. Holsman, J. Miller, M.L. Plummer, J.C.P. Reum, L.D. Rhodes, C.A. Rice, J.F. Samhouri, G.D. Williams, N. Yoder, P.S. Levic, and M.H. Ruckelshaus. 2010. A mass-balance model for evaluating food web structure and community-scale indicators in the Central Basin of Puget Sound. U.S. Department of Commerce. NOAA Technical Memorandum NMFS-NWFSC-106. 180 pages.

Hatch, S.A. and G.A. Sanger. 1992. Puffins as samplers of juvenile Pollock and other forage fish in the Gulf of Alaska. Marine Ecology Progress Series. Volume 80, pages 1-14.

Hobson, E.S., J.R. Chess, and D.F. Howard. 2001. Interannual predation on first-year *Sebastes* spp. by three northern California predators. Fishery Bulletin. Volume 99, pages 292-302.

Hunt, S.L., T.J. Mulligan, and K. Komori. 1999. Oceanic feeding habits of Chinook salmon, *Oncorhynchus tshawytscha*, off northern California. Fisheries Bulletin. Volume 97, pages 717-721.

Jeffries, S., H. Huber, J. Calambokidis, and J. Laake. 2003. Trends and status of harbor seals in Washington State: 1978-1999. The Journal of Wildlife Management. Volume 67(1), pages 207-218.

Jeffries, S. 2013. Final Report: Aerial surveys of pinniped haulout sites in Pacific Northwest inland waters. Report to U.S. Navy for Contract No. N62470-10-D-3011-CTO JP02. 6 pages.

Johnson, D.W. 2006. Predation, habitat complexity, and variation in density-dependent mortality of temperate reef fishes. Ecology. Volume 87(5), pages 1179-1188.

Johnson, D.W. 2007. Habitat complexity modifies post-settlement mortality and recruitment dynamics of a marine fish. Ecology. Volume 88(7), pages 1716-1725.

Kamimura, Y. and J. Shoji. 2013. Does macroalgal vegetation cover influence post-settlement survival and recruitment potential of juvenile black rockfish *Sebastes cheni*. Estuarine, Coastal and Shelf Science. Volume 129, pages 86-93.

Kinoshita, H., Y. Kamimura, K. Mizuno, and J. Shoji. 2013. Night-time predation on post-settlement Japanese black rockfish *Sebastes cheni* in a macroalgae bed: effect of body length on the predation rate. ICES Journal of Marine Science. Volume 71(4), pages 1022-1029.

Laidig, T.E. 2010. Influence of ocean conditions on the timing of early life history events for blue rockfish (*Sebastes mystinus*) off California. Fisheries Bulletin. Volume 108(4), pages 442-449.

Laidig, T.E., J.R. Chess, and D.F. Howard. 2007. Relationship between abundance of juvenile rockfishes (*Sebastes* spp.) and environmental variables documented off northern California and potential mechanisms for the covariation. Fisheries Bulletin. Volume 105(1), pages 39-48.

Lance, M.M., W.Y. Chang, S.J. Jeffries, S.F. Pearson and A. Acevedo-Gutiérrez. 2012. Harbor seal diet in northern Puget Sound: implications for the recovery of depressed fish stocks. Marine Ecology Progress Series. Volume 464, pages 257-271.

Love, M.S., M.H. Carr, and L.J. Haldorson. 1991. The ecology of substrate-associated juveniles of the genus *Sebastes*. Environmental Biology of Fishes. Volume 30, pages 225-243.

Mills, K.L., T. Laidig, S. Ralston, and W.J. Sydeman. 2007. Diets of top predators indicate pelagic juvenile rockfish (*Sebastes* spp.) abundance in the California Current Ecosystem. Fisheries Oceanography. Volume 16(3), pages 273-283.

Pacunski, R.E., W.A. Palsson, H.G. Greene, and D.R. Gunderson. 2008. Conducting visual surveys with a small ROV in shallow water. Pages 109-128 *in* Marine Habitat Mapping Technology for Alaska, J.R. Reynolds and H.G. Greene (eds.). Alaska Sea Grant Program, AK-SG-08-03. 282 pages.

Parker, S.J., S.A. Berkeley, J.T. Golden, D.R. Gunderson, J. Heifetz, M.A. Hixon, R. Larson, B.M. Leamna, M.S. Love, J.A. Musick, and V.M. O'Connell. 2000. Management of Pacific rockfish. Fisheries. Volume 25(3), pages 22-30.

Ralston, S., K.M. Sakuma, and J.C. Field. 2013. Interannual variation in pelagic juvenile rockfish (*Sebastes* spp.) abundance – going with the flow. Fisheries Oceanography. Volume 22(4), pages 288-308.

Roche, E.T. and B.W. Halstead. 1972. The venom apparatus of California Rockfishes. Fish Bulletin. Volume 156, pages 1-49.

Shanks, A.L., B.A. Grantham, and M.H. Carr. 2003. Propagule dispersal distance and the size and spacing of marine reserves. Ecological Applications 13(1 Supplement: The Science of Marine Reserves): S159-S169.

Shears, N.T. and R.C. Babcock. 2002. Marine reserves demonstrate top-down control of community structure on temperate reefs. Oecologia. Volume 132, pages 131-142.

Sydeman, W.J., K.A. Hobson, P. Pyle, and E.B. McLaren. 1997. Trophic relationships among seabirds in central California: combined stable isotope and conventional dietary approach. The Condor. Volume 99, pages 327-336.

Tinus, C.A. 2012. Prey preference of lingcod (*Ophiodon elongates*), a top marine predator: implications for ecosystem-based fishery management. Fishery Bulletin. Volume 110, pages 193-204.

Ward, E.J., P.S. Levin, M.M. Lance, S.J. Jeffries, and A. Acevedo-Gutiérrez. 2012. Integrating diet and movement data to identify hot spots of predation risk and areas of conservation concern for endangered species. Conservation Letters. Volume 5, pages 37-47.

Ward, E.J., K.N. Marshall, T. Ross, A. Sedgley, T. Hass, S.F. Pearson, G. Joyce, N.J. Hamel, P.J. Hodum, and R. Faucett. 2015. Using citizen-science data to identify local hotspots of seabird occurrence. PeerJ. 2015 Jan 15;3:e704. doi: 10.7717/peerj.704. eCollection 2015.

West, J.E., R.M. Buckley, and D.C. Doty. 1994. Ecology and habitat use of juvenile rockfishes (*Sebastes* spp.) associated with artificial reefs in Puget Sound, Washington. Bulletin of Marine Science. Volume 55(2-3), pages 344-350.

# 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.