Young-of-the-year rockfish monitoring plan for the Southern Salish Sea

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Table of Contents

List of Figures

List of Tables

Introduction

Rockfish (*Sebastes* spp.) are a diverse clade of long-lived, ovoviviparous fishes that are integral components of food webs in the northeast Pacific Ocean, serving as both mid-level predators and an important prey source for a myriad of consumers. In U.S. waters of the Salish Sea (often referred to as Puget Sound or greater Puget Sound) 28 species of rockfish are known to occur (Palsson et al. 2009; Pietsch and Orr 2015), though over 60 species occupy waters of the North American West Coast (Love et al. 2002). Various aspects of their life history, including slow growth, late age of maturity, and episodic recruitment success, allow rockfish populations to persist despite broad fluctuations in oceanic conditions. These same attributes, however, can result in low population growth rates and long generation times, making rockfishes highly susceptible to sustained fishery exploitation because extraction can easily outpace recruitment potential. As rockfish species have been targeted by both recreational and commercial fisheries throughout the 20th century, many species have experienced population declines since at least the 1970s, and two species are listed in the Salish Sea under the Endangered Species Act (ESA): yelloweye rockfish (*Sebastes ruberrimus*) as Threatened and bocaccio (*S. paucispinis*) as Endangered (NMFS 2010). Several other rockfish species are considered Species of Greatest Conservation Need under the Washington Department of Fish and Wildlife's (WDFW) State Wildlife Action Plan (WDFW 2015) and retention of all species of rockfish in U.S. waters of the Salish Sea, except the westernmost portion of the Strait of Juan de Fuca, has been prohibited since May of 2010 (WDFW 2010; WAC 220-314-010 and -020). For a review of the history of rockfish exploitation and changes in management in the Salish Sea, see Williams et al. 2010.

Conservation efforts have increased in response to population declines; however, significant data gaps still exist with regard to fundamental biology of rockfishes in the Salish Sea. As rockfish develop from planktonic larvae to benthic or semipelagic adults, their habitat associations change from open water to nearshore vegetation beds and, eventually, the use of high-relief, complex bottom features such as boulder piles and rock walls. In addition to spatial variation across habitat types and regions, rockfish reproduction and recruitment varies within and among years in ways that are not well understood (Love et al. 2002; Dauble et al. 2012; Haggarty et al. 2017; Markel et al. 2017). Oceanic and climatic drivers are primarily responsible for changes in abundance during the planktonic stage (Field et al. 2021), though the primacy of those drivers may change across large spatial scales (Caselle et al. 2010). These oceanic conditions are believed to influence rockfish year class strength via prey availability and growing conditions during early developmental phases (Laidig et al. 2007), but other factors closer to settlement may also be determinants (Markel et al. 2020). Efforts to monitor recently settled young-of-the-year (YOY) and juvenile rockfish are complicated by these highly variable patterns of recruitment, cryptic appearance, elusive behavior, and changing habitat needs. Recovery and conservation efforts require a broad understanding of individual species and life history needs beyond what is currently known. For ESA-listed and other rare rockfish species, using more common species as surrogates to infer likely settlement patterns may continue to be necessary for some time. This approach is supported by surveys conducted elsewhere that indicate recruitment of numerous rockfish species fluctuate together (Ralston et al. 2013; Stachura et al. 2014; Schroeder et al. 2019). By monitoring recruitment of all YOY rockfish in the southern Salish Sea, policy makers may infer year class strength of ESA listed species, and apply this information to numerous management issues outlined in the section below.

On September 18, 2017, a group of regional experts from regulatory agencies, conservation organizations, and citizen science groups convened a workshop to coordinate YOY rockfish monitoring efforts and work towards developing statistical analyses capable of integrating YOY rockfish data collected under different survey methodologies. This document represents a synthesis of these contributions to craft a unified path forward for YOY rockfish dive surveys in Puget Sound and integration of YOY rockfish data from other surveys under a single modeling framework. This approach of unifying disparate data sources for synergistic monitoring of a marine resource has precedent with the recent monitoring plan for floating kelp in Washington (Berry et al. 2022). The utilization of relatively shallow and nearshore habitats by YOY rockfish makes surveys on SCUBA possible. A visual census on SCUBA allows for direct observation of fishes in vegetated, high-relief, and/or shallow habitats that may be challenging for other sampling approaches. This plan will be used to guide dive data collection efforts by a wide constituency and build a robust database of these observations capable of calculating an index of recruitment across and/or within each of the management units that make up the yelloweye rockfish and bocaccio distinct population segments (DPSs) in Puget Sound and the Georgia Basin (i.e., the Salish Sea). As noted above, information for non-listed rockfish is also collected so that these species can be used as surrogates in regions where data for ESA-listed species are sparse or missing. Though there is substantial justification in the literature for recruitment synchronicity among rockfish species (Ralston et al. 2013; Stachura et al. 2014; Schroeder et al. 2019), these data will still need to be interpreted carefully to avoid any potential pitfalls from using indicator species. This index will be prudently used in conjunction with other population status and threats-based data to inform management decisions related to recovery of ESA-listed species (e.g. increased knowledge regarding the distribution of ESA-listed rockfishes at every stage of life will help focus consultation efforts on biologically significant locations and/or habitat types). Future efforts may include regional partners from British Columbia, and other monitoring organizations not incorporated here.

Policy and Conservation Basis for YOY Survey Effort

The need for a consistent, long-term YOY survey effort in the Salish Sea is emphasized by numerous state and federal resource management documents. In 2009, the WDFW produced a summary report of rockfish biology and population status for greater Puget Sound (i.e., all U.S. waters of the Salish Sea) (Palsson et al. 2009). This document listed the need to identify juvenile and adult habitats, and to better understand habitat associations at critical life stages, as crucial to future protection of rockfish at large (Research and Data needs 8.1.1 and 8.1.2.). Since that time, WDFW has directed effort toward evaluation of subadult and adult habitat associations using a remotely operated vehicle (Pacunski et al. 2013; 2020; Lowry et al. 2022; WDFW unpublished data), but a commensurate effort for YOYs and juveniles has not occurred at the same scale. In 2010, the National Marine Fisheries Service (NMFS) of the National Oceanic and Atmospheric Agency (NOAA) listed yelloweye rockfish and bocaccio under the federal Endangered Species Act (75 FR 22276), drawing heavily on Palsson et al. (2009) for fundamental aspects of biology and management to date in their status review (Drake et al. 2010). In response to broader conservation concerns among rockfish species, the WDFW developed a fishery conservation and recovery plan for all rockfish species in Puget Sound, recognizing that shared biology and habitat requirements across rockfishes would result in conservation actions benefiting the suite of species rather than just those that were listed (WDFW 2011). In this plan, the WDFW again identified the need for better information about habitat use and natural recruitment in their Habitat Protection and

Restoration, and Research, sections. Drawing on new information from research and recovery actions that the WDFW and NMFS partnered closely to develop, in 2017 NMFS released a recovery plan for Puget Sound/Georgia Basin yelloweye rockfish and bocaccio, providing an explicit roadmap to restoring populations of both species. Among other recommendations, this plan highlights a need for annual YOY surveys throughout Puget Sound (NMFS 2017, Recovery Action 1.5) and engagement with citizen dive groups to further rockfish recovery (NMFS 2017, Recovery Action 4.5). Furthermore, dive groups collecting data for use in federal management fits within NOAA's broader strategy of utilizing citizens to advance conservation actions (NOAA 2021). Though disparate efforts to monitor YOY rockfish have sprung up throughout the region to address this long-identified need, a lack of consistent funding and sampling methods has prevented development of a cohesive sampling plan that can be broadly used to inform management actions. By coordinating the research efforts described here and proposing an integrated index development method, this approach can better inform important aspects of state and federal resource agency recovery goals.

In addition to strategic planning for long-term recovery, data collected as part of this YOY survey partnership can inform regulatory conservation actions in the short term. Projects conducted, funded, or authorized by the federal government that may adversely affect a species listed under the ESA must undergo a consultation process, per Section 7 of the ESA. These consultations use the best available science (e.g. habitat use, geographic trends) to assess likely project impacts and any mitigation measures that may alleviate them (NOAA 2022). YOY data collected from this program will provide best available science for use during such consultations. Essential Fish Habitat consultations, which apply to federally managed fisheries, including those for rockfish, and are required under the Magnuson-Stevens Fishery Conservation and Management Act, will also use YOY survey data to inform impact assessments for this crucial life stage. NMFS is also responsible for conducting five-year reviews of rockfish recovery efforts in accordance with the ESA to document progress on conservation measures and evaluate species status. In the most recent rockfish five-year review, scientists ran a multivariate autoregressive state-space (MARSS) model with various data sources to estimate changes in rockfish abundance since the 1970s (Tonnes et al. 2016; Tolimieri et al. 2017). The next five-year review in this series is expected in the near future and will comprehensively synthesize new data available since 2017. As the citizen-science YOY dive survey database grows, these data will be incorporated into future models, potentially improving their performance which ultimately would assist managers in better tracking population trends.

Applications of this YOY sampling program may also inform a broad array of nearshore and offshore restoration projects in the region. Successful habitat restoration activities incorporate a thorough analysis of available data to maximize benefits to species of interest. Long-term data collected throughout the Salish Sea would be useful in designing habitat restoration projects that seek to benefit rockfish and other benthic, structure-associated species. For example, restoration of kelps, particularly bull kelp (*Nereocystis luetkeana*), is currently receiving heightened attention in the region (Calloway et al. 2020). Because these habitats are considered vital for rockfish recruitment, restoration projects located in areas closer to known YOY hotspots may be given priority for funding or other support. The scientific, restoration, and conservation benefits of YOY surveys are diverse, and can inform projects with both short- and long-term time scales.

Current and Past YOY Survey Efforts

While a great deal of effort and coordination is required to create a robust YOY monitoring system, a number of separate fish survey programs already exist that collect data useful to this effort. Understanding the data collected by these programs will reduce duplication of effort during development of new protocols, and allow for more robust analysis and long-term coordination where data are comparable. There are six organizations currently coordinating and collecting YOY rockfish data through dive surveys in greater Puget Sound, including NOAA, the Ocean Wise Research Institute, Reef Environmental Education Foundation (REEF), the Point Defiance Zoo and Aquarium (PDZA), Reef Check, and the Seattle Aquarium. The WDFW has extensive historical dive data collected from surveys conducted between 1991-2010. Although WDFW currently has limited capacity to conduct YOY-focused dive work, they may re-engage in the future as resources allow.

National Oceanic & Atmospheric Administration (NOAA)

Northwest Fisheries Science Center (NWFSC)

NOAA's NWFSC has conducted quarterly SCUBA surveys in six eelgrass meadows since 2013. These surveys record numbers of all fish (including YOY rockfish) and numerous macroinvertebrate species, as well as eelgrass characteristics. The SCUBA survey methods employed by the NWFSC include a two-person dive team swimming three, 30-m transects (2 m wide and 2 m high), making two passes on each transect. On the outbound leg, the first diver swims a measuring tape out and records all fish observations while the second diver swims behind and records macroinvertebrates. When large enough to differentiate via morphological traits, fishes were identified to species. Sizes of each fish were also recorded. Transects are separated by ~5 m and are located at ~5 m depth. On the inbound leg, both divers record data on habitat characteristics (e.g., percent cover of vegetation species, density and height of eelgrass shoots). Divers do not disturb the vegetation during the survey; only readily observable fish are counted.

In addition to SCUBA-based surveys, Standard Monitoring Units for the Recruitment of Fishes (SMURFs) and minnow traps have been deployed during specific research projects (2015-19) targeting peak settlement periods to collect YOY and juvenile (ages 1-2) individuals, respectively. Both SMURFs and minnow traps are deployed on one date and retrieved 2-7 days later, at which time fish are identified to species and counted. An advantage of these survey tools is that fish can be closely examined by hand, and genetic samples can be collected when species identification is not immediately possible.

West Coast Region Office (WCR)

Building on YOY sampling protocols of the WDFW, Seattle Aquarium, and others, NOAA's WCR developed a citizen science YOY dive survey protocol and sampling program with participation from local dive clubs and other non-government organizations. Abundance data, by morphological group, are collected using a timed roving SCUBA survey, with qualitative data taken on habitat and depth. Only fish within 1 m to either side of the diver, and within 1 m of the bottom, are counted. Data are coded into depth bins and by general habitat type and, as with the NWFSC protocol, divers do not disturb the sediment or vegetation during surveys. This effort started in 2015, and over 2,000 transects have been completed through 2022. Sixteen groups collaborate in data collection with surveys coming from over

100 participants. Sampling regularly occurs at 21 index sites and at least 86 haphazardly selected target dive sites annually. Sampling effort has steadily grown since inception of the program in 2015, with more than 2,296 survey minutes across 203 transects in January and February 2022 alone. This is currently the most robust and spatiotemporally comprehensive YOY-focused sampling effort in the region (Obaza et al. 2021) and serves as the foundation of the monitoring dive program proposed herein.

The Ocean Wise Research Institute

Since 2005, the Ocean Wise Research Institute (ocean.org) has led an annual citizen science rockfish survey effort in the Strait of Georgia. Data are collected from August to October by SCUBA divers swimming timed roving surveys. All recorded rockfish are identified to species and broken into age classes of adult (> 20 cm), juvenile (10-20 cm), and YOY (< 10 cm). Results are split regionally; a total of twenty-eight survey regions stretch from the British Columbia's central coast to Puget Sound and Washington's outer coast. Within the Salish Sea, twenty regions are identified on the Canadian side and four on the US side. Distinct habitat types and depth bins are not included as part of the survey, though surveys on soft bottom habitat are discouraged. Encounter rates are recorded as rockfish observed per survey hour.

Reef Environmental Education Foundation (REEF)

REEF is an international marine conservation organization that has conducted over 16,800 citizen science SCUBA surveys in Washington since 1998. Fish data are collected using a roving diver technique, where divers swim through a site and record species identification and their abundance by tens and hundreds. Metadata for each survey including total dive time, surveyor ID, date and location may also be included. REEF provides divers with training and associated testing such that each participant can be assigned a skill level rating. The higher testing level achieved; the greater weight is given to data submitted by an individual. Diver data is reported through an online database where it is analyzed by REEF staff. YOY rockfish are not the exclusive target of REEF surveys, which seek to more broadly characterize the fish community, but they are an integral component.

Point Defiance Zoo and Aquarium (PDZA)

The PDZA is located in Tacoma and has a lengthy history of exhibiting marine specimens from local Pacific Northwest waters. PDZA has contributed considerable magnification of survey effort by committing staff and volunteer divers to Seattle Aquarium and State-run monitoring. Since 2015, the PDZA has coordinated their sampling with NOAA's WCR program, engaging local SCUBA divers in citizen science survey efforts throughout the region and providing institutional support, such as dive vessels, a lead safety officer, and coordinated data management. In late 2019, the PDZA began once more coordinating their survey efforts with the Puget Sound Marine Fish Science Unit of the WDFW, but momentum for this partnership was delayed by the global COVID-19 pandemic and a lack of available WDFW divers.

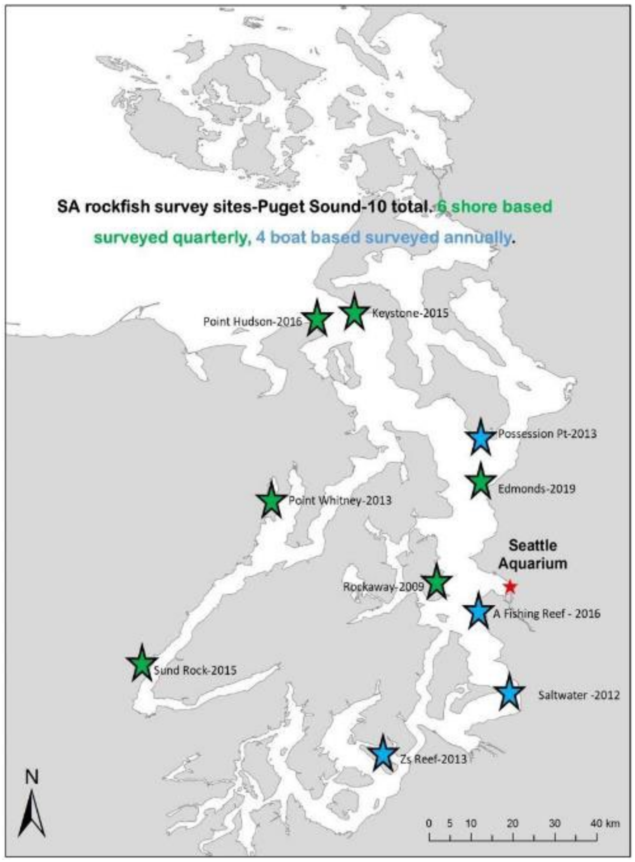


Figure 1. *Rockfish survey index sites sampled by the Seattle Aquarium in Puget Sound. The year in which surveys began is provided to the right of each site name.*

Seattle Aquarium

The Seattle Aquarium has a research conservation mission that parallels that of the PDZA. Since 2009, however, the Seattle Aquarium has independently conducted dive surveys of the fish community, including YOY rockfish, at 11 sites in Puget Sound, ranging from Point Hudson to Sund Rock in Hood Canal, and Z's Reef in southern Puget Sound (Figure 1). Surveys include quarterly counts of fish (including YOY rockfish) along 100-m permanent transects at depths ranging from ~10-25 m. Divers collect data by recording underwater video and calling out species using a tethered communications system during the dive. Recordings are made while swimming one direction along the transect deploying a tape measure, as well as while swimming the opposite direction during tape retrieval. Fish are identified and counted during post-processing, and only those fish within 1 m of the tape are included. The goal of this work is to document changes in species diversity across seasons and over years. Puget Sound observations of YOY have been consistently low, but these surveys provide crucial non-occurrence data as video recordings provide long-term records of verified absence.

Washington Department of Fish & Wildlife (WDFW)

WDFW staff have conducted SCUBA-based surveys that collected YOY rockfish data from 1991-93, 1995-2010, and 2015-17 (Frierson et al. 2018; LeClair et al. 2018; WDFW unpublished data). During the earliest efforts, divers swam tape transects and collected presence/absence data on YOY rockfish, but not density. These surveys were initially largely focused on identifying habitat characteristics associated with YOY and juvenile rockfish presence to improve the design of artificial reefs (e.g., West et al. 1994; Buckley 1997). A more formalized effort to estimate the density and abundance of marine fishes on complex rocky habitats began in 1995 with the establishment of a series of fixed index stations (Figure 2; LeClair et al. 2018). Though methods and sampling frequency varied over the years, surveys generally consisted of quarterly to biannual sampling at three, 30-m long transects at shallow, mid, and deep depths at each site. Actual transect depth differed by site, but most transects occurred on isobaths between 5 and 20 m in depth. Similar to other protocols described above, only fish within 1 m to either side of the diver and within 1 m of the bottom are included in counts. Contrary to other protocols presented above, WDFW surveys included the use of PVC poles to flush fish from vegetation and the use of lights to inspect beneath shelves and in crevices. The 1-m PVC poles also had 10 cm marks to improve accuracy of fish length estimates. Surveys in 2015-17 were exclusively focused on waters around several U.S. Navy installations but employed the same sampling protocol (e.g., Frierson et al. 2018). Associated with these final few years of surveys, WDFW staff also tested the utility of modified shrimp traps with fine mesh liners to monitor YOY rockfish.

The WDFW also conducts regular monitoring of fish populations with other tools that sometimes encounter YOY rockfish, though they are not the primary focus. The most consistent survey methods employed are benthic trawling and exploration with remotely operated vehicles (ROVs). Details on these methods are available in Blaine et al. (2020), Pacunski et al. (2020), and Lowry et al. (2022). Encounter rates of YOY rockfish are low in these surveys as neither method is designed to capture small-bodied fishes – the bottom trawl primary net mesh is 10 cm^2 and the ROV used through 2021 is equipped with a standard definition video camera that does not record video at high enough resolution to regularly detect or identify fish smaller than approximately 10 cm. Additionally, fish length data is not explicitly collected during ROV surveys due to technological limitations.

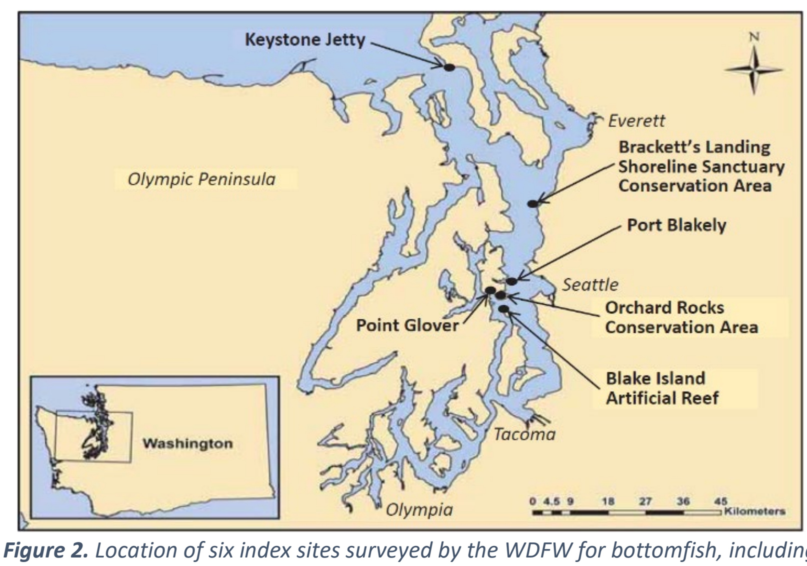


Figure 2. *Location of six index sites surveyed by the WDFW for bottomfish, including all size classes of rockfish, from 1995 through 2010 (from LeClair et al. 2018).*

Reef Check Foundation

Reef Check Kelp Forest Monitoring program is a citizen science-based program that has conducted transect based density surveys in California since 2006. In 2022 Reef Check completed the first year of surveying in Washington, training 50 citizen science divers and surveying 30 sites across the Salish Sea. Each site consists of 6 core transects and an additional 12 fish only transects, and each transect is 30m (2m wide x 2m high). A core transect includes a fish swath, invertebrate swath, a kelp swath and universal point contact transect to characterize the reef (substrate, cover and relief). Divers do not disturb the substrate or vegetation during surveys. Volunteer divers are trained to ID and count a set of indicator species on each swath type; 30 fish species, 26 invertebrate species, and 13 species of kelp. Of the 30 species counted on fish transects approximately half are rockfish species including YOY. The goal of this long-term monitoring is to produce data that can be used for the management and conservation of kelp forests and rocky reefs, and to involve the public in the scientific process to foster an educated public, supportive of science–based management and ocean stewardship.

Components of a Robust Monitoring Plan

Biologists and managers from the 2017 YOY workshop identified two primary objectives to make use of existing fish survey efforts in Puget Sound and expand on current monitoring programs: 1) use existing data to model historic trends in YOY rockfish presence, absence, abundance, and density, where possible; and 2) identify an appropriate monitoring approach to fill data gaps and improve future assessments of rockfish recruitment trends. To address the second task, workshop attendees provided guidance on components of a sufficient dive monitoring plan, determining that such a plan must be accessible for many surveyors; adaptive to dynamic staffing, budget, and environmental conditions; incorporate multiple complementary methods; and remain consistent over time.

Accessible and Adaptive Surveys

YOY rockfish presence can be highly variable across space and time as a result of a broad suite of factors, some of which are poorly understood, making large sample sizes necessary to draw valid conclusions about abundance and distribution trends. Sufficient effort will require participation from a consortium of organizations and a method to facilitate data sharing among them. To serve this purpose, an online portal has been created and will be made accessible for qualified surveyors to submit data. A surveyor is considered qualified when they have demonstrated proficiency in species identification and survey protocol. This tool is currently a simple shared spreadsheet (i.e., Google Sheet) but, if funding allows, could evolve into a secure, dedicated data portal (e.g., Amazon Web Services Aurora database). The platform selected for sharing survey data must have the capacity to store version-controlled documentation of survey protocols and other metadata (e.g., Google Drive). This repository will be secure, but openly accessible to monitoring partners, and will also contain meeting notes, presentations, published results, and other content for contextualizing new project data.

While archiving survey data in such a manner for use by analysts is crucial, information also needs to be made available to surveyors so that if a recruitment event or listed species is observed additional surveys can be rapidly performed. Being able to visualize the spatial extent of site coverage and review frequently updated survey activity would also reveal areas that may need increased survey effort. Such needs can be met by a public spatial database and web-enabled mapping tool to display near real-time information on survey findings, and an existing pilot tool is undergoing evaluation and refinement (https://public.tableau.com/app/profile/adam.obaza/viz/YOYRockfishSurveySites/YOY_Rockfish_SurveySites) (Figure 3). By providing timely information to participating surveyors, the monitoring approach can be adapted to changing circumstances and leverage collaborative opportunities to collect more comprehensive and useful data about ephemeral events. Partners can also easily scale and prioritize survey effort to match staffing and funding resources, and coordinate with other partners to maximize overall sampling efficiency across time and space.

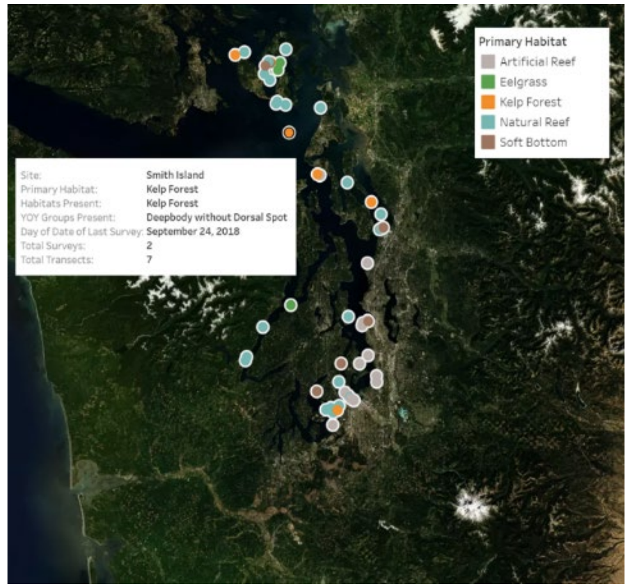


Figure 3. *Example image from a web-enabled map tool for visualizing YOY survey effort across time and space through adaptive querying.*

Complementary Survey Approaches

Researchers in the southern Salish Sea utilize various approaches to survey YOY rockfish, as documented above, depending on habitat type, site accessibility, depth, overall project goals, and various administrative factors (e.g., funding, staffing). The most common method currently used for small, cryptic fishes such as YOY rockfish is direct observation by SCUBA, and guidelines for that approach are presented below. Together, these multiple procedures can provide a robust dataset that more fully captures the spatiotemporal heterogeneity of the region. Options available include:

- direct observation through SCUBA surveys,
- SMURFs suspended in select areas of Puget Sound,
- remotely operated vehicle (ROV) and/or underwater video,
- and benthic trawling.

Within these broader procedures, methodological consistency is important so that time series of observations can be used for trend analysis. If data collected use methods with similar selectivity and bias, and produce comparable metrics (i.e., encounter rate, density) they may be analyzed together. If not directly comparable, but internally consistent, there are statistical methodologies that allow trend data from disparate methods to be incorporated into a single modeling framework (e.g., multivariate autoregressive state-space [MARSS] model). For example, Tolimieri et al. (2017) assessed adult rockfish status in Puget Sound using MARSS models to incorporate multiple data sets with different sampling methods that crossed multiple management time periods; this analysis was able to successfully describe shared, underlying trends in population status that were not readily apparent in the component datasets in isolation (Tonnes et al. 2016; Tolimieri et al. 2017)

Consistency

Surveyors have varying professional backgrounds and training, so establishing consistent characteristics of a SCUBA-based sampling protocol is necessary to achieve repeatable and comparable results. This consistency includes use of terminology and methodology. For example, a YOY rockfish must be well defined such that field identification is clear and all participants are recording the same size class. Non-SCUBA survey methods employed by the WDFW and NWFSC already involve consistent protocols described in previous reports (e.g., Frierson et al. 2018; Blaine et al. 2020; Pacunski et al. 2020; and Lowry et al. 2022) and provide a valuable example to the present effort. Given that these surveys are conducted almost exclusively by singular teams over time, with relatively little turn-over, there is less concern about the need for inter-partner consistency.

Sampling effort, geographic coverage, and temporal variation must also contain elements of consistency for trend analysis to be successful. Establishing a series of index stations that are sampled at least quarterly around a similar time to create a comparable time series is fundamental to detecting change in YOY abundance through time and across geography. Data from these core sites may then be put into a broader context by the addition of adaptive efforts throughout the region. Having consistent survey guidelines and spatiotemporal coverage allows data from a diverse suite of participants to be more readily integrated and synthesized when evaluating recruitment trends.

Monitoring Survey Design

Index Site Selection and Utilization

Index sites are often surveyed as a representative subset of locations that accurately depict trends within a larger area. For the purposes of this monitoring plan, their primary role will be to calibrate data collection from different survey groups to ensure any corrections may be made for the most accurate model output. Therefore, index sites will be used to ensure data from all sites (i.e. index and random) surveyed for this effort may be prudently applied to the model presented below. They may also be used for their traditional application, but the existing lack of data from these index sites, and a preference for sites that frequently contain YOY to improve calibration, will require careful examination of biases. The list presented below should be considered living, and open to revision as the YOY rockfish database grows.

Currently, active index sites are in each of the six sub-basins of greater Puget Sound (Admiralty Inlet, Central Sound, South Sound, Whidbey Basin, San Juan Islands, and Hood Canal), facilitating description of both local trends in recruitment and variation in inter-basin dynamics. Site selection has been based on the presence of habitat known to support YOY rockfish (kelp forests, eelgrass beds, rocky and artificial reefs), other beneficial geological features (e.g., rugose soft bottom, or hardpan), ease of access, and consistency of YOY encounter. Not all sites and habitats are equally used by rockfish, depending on factors such as species preference, life-history stage, and prey availability (Buckley 1997; Dauble et al. 2012; Palsson et al. 2009; LeClair et al. 2018; Pacunski et al. 2020; Andrews et al. 2021; Lowry et al. 2022); however, it is important to include these sites to evaluate if YOY rockfish occasionally appear during major recruitment events, providing opportunities to document previously unknown sites or changes in species distribution. If a habitat type offers lower value to YOY but has extensive coverage in the region, it may still be a major contributor to population size. Without at least nominal effort spent sampling what are assumed to be less suitable habitats, adequately describing utilization of the habitat mosaic of the southern Salish Sea by YOY rockfish will not be possible.

Monitoring frequency should be high enough to reasonably identify when a major recruitment event occurs (~ 6 weeks in duration; Moser and Boehlert 1991), though may be at lower frequencies to assess year class strength (Doherty and Fowler 1994). Frequent monitoring events help to track potentially large cohorts over time, and to explore survival relative to specific biological and physical variables. However, mobilizing frequent field efforts is resource intensive and must be balanced with the expense of spatial replication. A benefit of this collaborative effort will be the sharing of monitoring index sites among multiple organizations, allowing for higher temporal and spatial replication without the burden falling to any one entity. Having a diverse partnership also benefits the team at large by diversifying options for financial support to maintain sampling effort into the future.

Current and/or Historic Index Sites

Research observations from the 1990s through 2020, along with existing citizen and professional YOY survey data from 2015-21, were used to compile a preliminary list of valid index sites. To refine this list, an exercise was conducted on the recent survey data to identify locations with high frequencies of YOY encounter. These results, along with information on ease of access and habitat type, generated the subset of sites with best opportunity to calibrate different survey approaches.

Data for this exercise were taken from YOY surveys conducted using a timed roving diver survey in discrete habitat types and depth bins at 107 sites throughout Puget Sound. Three hundred eighty-nine survey events, made up of 1,874 roving transects were completed across these sites. Effort was not evenly distributed across sites, as citizen participants often repeat surveys in the areas they regularly dive, and access to certain sites is limited by boat use, tidal exchanges, and other factors.

Recorded rockfish for all transects within a sampling event (i.e., all surveys at a site on a single day) were aggregated to a single measure of presence/absence. The number of sampling events in which a YOY was located were divided by total sampling events within each year to return an annual site-specific frequency of YOY reporting. Those values were then averaged across all years a survey took place at a given index site to return a mean frequency of YOY presence. This approach was preferable to other metrics, such as YOY encounter rate, because reliability of YOY presence at a site is of greater concern than the number of rockfish a surveyor may encounter. Habitat characteristics of each site were then reviewed in the context of YOY presence to ensure a variety of habitat types were included.

Of the 107 sites surveyed, 86 were surveyed once or twice while only 20 were surveyed five or more times (Table 1). YOY were recorded at least once at 34 sites. These observations identify sites with high likelihood of repeated YOY rockfish encounter but do not represent the diversity of sites and habitats in Puget Sound. Using this approach, index sites were weighted towards artificial reefs in Central Sound, so additional index sites are needed to diversify surveyed habitat types. Selection of an index site for the purposes of comparison might require specific survey guides for a site. For example, Edmonds Underwater Park in Central Sound has been surveyed 29 times throughout this effort, with a 91% mean YOY encounter frequency, making it a prime index candidate. Edmonds is a large site, though, and it would be possible for two dive groups to conduct long surveys and never overlap. Without information on how evenly YOY are distributed on the site, disparate surveys from each group may both be accurate. A specific survey guide for this site would make data more comparable. The below list provides a variety of sites with individual strengths and weaknesses relative to providing adequate survey information for YOY rockfish and serve as a preliminary list of index sites. Figure 5 displays a map with associated coordinates.

Table 1. *Sites visited as part of the citizen science survey efforts at least five times between 2015 and 2020.*

Site Name	Survey Events 2015-2021	Basin
Keystone Jetty	15	Admiralty Inlet
Edmonds Underwater Park	29	Central
Les Davis Marine Park	28	Central
Alki - Cove 2	23	Central
Point Ruston Ferry	21	Central
Saltwater State Park	18	Central
Dickman Mill	12	Central
Lobster Shop Wall	11	Central
Redondo Beach	10	Central
KVI Tower	7	Central
Sunrise Beach State Park	7	Central
Sund Rock	7	Hood Canal
Flagpole Point	5	Hood Canal
Bell Island East	6	San Juan
Rosario Beach	5	San Juan
Fox Island West Wall	6	South
Day Island Wall	5	South
Sunnyside Beach State Park	5	South
Mukilteo Lighthouse	14	Whidbey
Mukilteo T-Dock	12	Whidbey

Central Sound

North Edmonds (kelp)

This site was visited by NWFSC divers from 2017-19 while collecting YOY rockfish for stable isotope and growth studies. Densities in 2017 were very high, and in 2018 and 2019 there were large numbers of YOY located in the understory kelp *Laminaria saccharina*. This relative consistency suggests this site receives larval supply in most years and is likely one of the best locations to monitor relative changes in abundance of YOY rockfish in Puget Sound. This site is also monitored for kelp canopy (*Nereocystis leutkeana*) by the Snohomish County Marine Resources Committee.

Blake Island

The Blake Island Artificial Reef was constructed in 1980, and was a regular survey site for the WDFW for 15 years from 1995-2010 (LeClair et al. 2018). The reef consists of concrete rubble and other materials, with a natural substrate of sand and gravel around it. The site is only accessible by boat, and can be tidally variable because of its location along the Kitsap Peninsula. Surveys conducted from 1995-2010 found that brown rockfish were the dominant rockfish species.

Saltwater State Park

Located partway between Tacoma and Seattle, this artificial reef is uniquely structured with discrete fingers leading from ~50 feet to ~80 feet in depth, depending on the tide. The fingers abut a cobble ramp leading towards shallow eelgrass habitat. This site has been surveyed 12 times with a 71% YOY encounter frequency. Reef fingers and cobble ramps are surveyed in a single dive (Figure 4) and would make for discrete habitat units that could be replicated across survey groups.

Figure 4. *A diver surveying for rockfish at Saltwater State park.*

Alki Cove 2

Similar to Saltwater State Park, this site is very close to Seattle, reducing the effort required to conduct a dive. The reef, composed of a series of artificial structures, is not feasible to cover in a single dive. However, anchored lines connect the structures and it would be possible to create a repeatable survey path. After 17 surveys at this site, YOY encounter frequency is 98%.

Norrander's Reef/Sunrise Beach State Park

Though the majority of dive sites in Central Sound are artificial reefs, rockfish recruitment at these sites may not be representative of many areas in the Sound. In fact, many artificial reefs in Central Sound appear to have higher mean encounter frequencies than natural reefs. Inclusion of at least one natural reef for this region is prudent, though each of the two likely candidate sites, Norrander's Reef and Sunrise Beach State Park, have drawbacks. YOY encounter frequency at both sites is low (Norrander's – 50%, Sunrise – 17%), though these values are derived from only seven total surveys conducted across the sites. Norrander's Reef is on Bainbridge Island, requiring a ferry ride for most divers and reducing access. Sunrise Reef is north of Gig Harbor, which is farther from many population centers, has difficult shore access, and experiences strong tidal currents. Both sites have discrete natural reefs that provide high likelihood of survey area overlap, making more reliable replicate surveys.

<u>Hood Canal</u>

Sund Rock

A natural reef with high and low relief sections that has received the greatest survey effort of anywhere in Hood Canal, with a mean encounter frequency of 58%. It is the only site discussed here at which a YOY yelloweye rockfish has been encountered on a survey. There is a cost to access this site from shore and coordination with the operating group must be completed beforehand, likely reducing interest. However, Hood Canal is some distance from population centers and if participants are planning a full day dive trip, there are multiple sites in the area to survey.

Octopus Hole

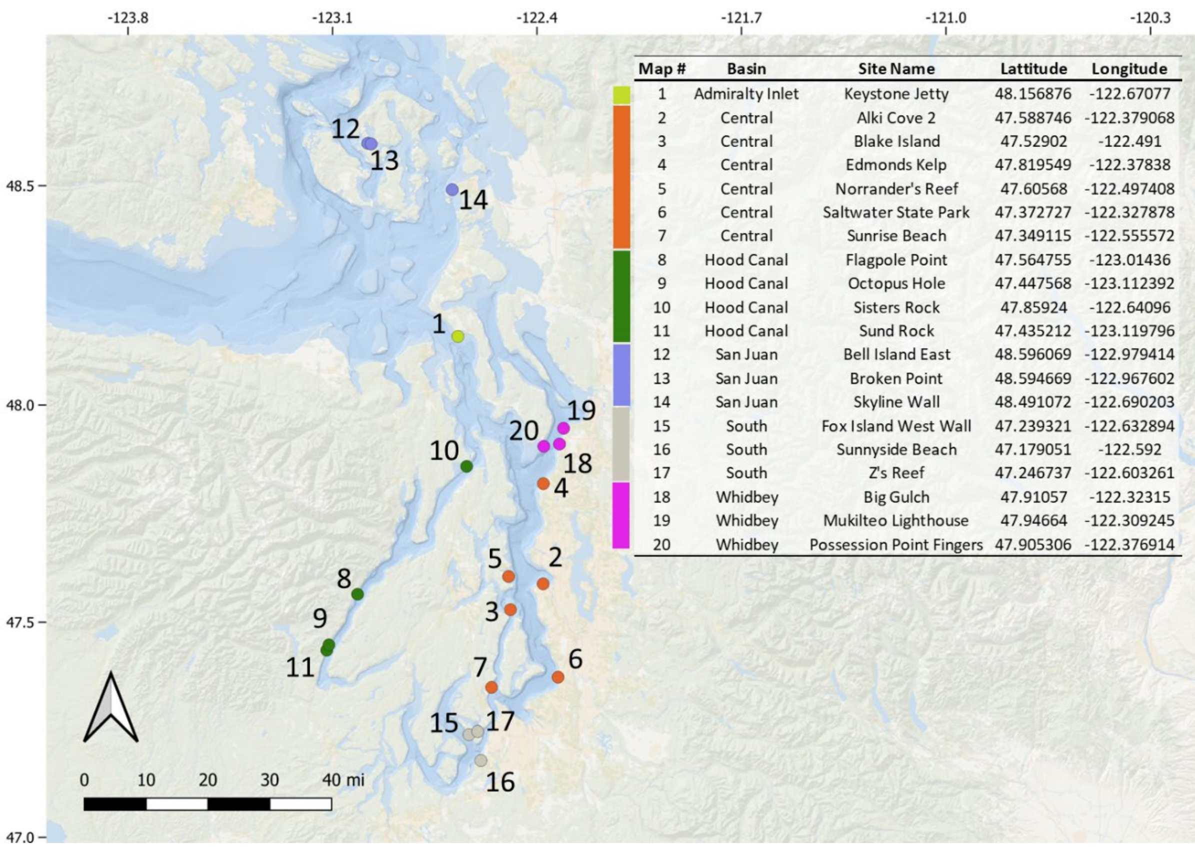
A natural reef with shore access located north of Sund Rock. It was designated as a WDFW Conservation Area in 1999 (WAC 220-303-040). It is a relatively small site, but YOY have been encountered as part of the NOAA Citizen Science Diving program. There are two reef walls that extend down to -80 feet, and it is not subject to strong tidal currents, making it a popular site for recreational divers.

Flagpole Point

A natural reef with a distinct deep (> 80 feet) section and intermediate/shallow (< 50 feet) sections on the west side of Hood Canal. Over five surveys were conducted, but no YOY rockfish have been recorded. Despite the paucity of YOY, high encounters with adult rockfish and the shore-accessible natural reef across multiple depth bins make this site worth continued visitation. Note that access is paid through Mike's Beach Resort, limiting access for some citizen science divers.

Sisters Rock

Sisters Rock is situated just southwest of the Hood Canal Bridge. It is a tidally influenced site, mostly only accessible by boat. Various rockfish species are present at the site, and while YOY have been captured in WDFW shrimp pot traps, no YOY have yet been observed on roaming dive surveys.



Map #	Basin	Site Name	Lattitude	Longitude
1	Admiralty Inlet	Keystone Jetty	48.156876	-122.67077
2	Central	Alki Cove 2	47.588746	-122.379068
3	Central	Blake Island	47.52902	-122.491
4	Central	Edmonds Kelp	47.819549	-122.37838
5	Central	Norrander's Reef	47.60568	-122.497408
6	Central	Saltwater State Park	47.372727	-122.327878
7	Central	Sunrise Beach	47.349115	-122.555572
8	Hood Canal	Flagpole Point	47.564755	-123.01436
9	Hood Canal	Octopus Hole	47.447568	-123.112392
10	Hood Canal	Sisters Rock	47.85924	-122.64096
11	Hood Canal	Sund Rock	47.435212	-123.119796
12	San Juan	Bell Island East	48.596069	-122.979414
13	San Juan	Broken Point	48.594669	-122.967602
14	San Juan	Skyline Wall	48.491072	-122.690203
15	South	Fox Island West Wall	47.239321	-122.632894
16	South	Sunnyside Beach	47.179051	-122.592
17	South	Z's Reef	47.246737	-122.603261
18	Whidbey	Big Gulch	47.91057	-122.32315
19	Whidbey	Mukilteo Lighthouse	47.94664	-122.309245
20	Whidbey	Possession Point Fingers	47.905306	-122.376914

Figure 5. *Map of all proposed index sites color coded by basin. Numbers on map correspond with table.*

San Juan Islands

Bell Island East

This site has high relief rocky reef with heavy algae in the shallows, along with interspersed kelp. Only one YOY has been located in four survey attempts, and encounters are generally low in this basin. As with many sites in the San Juan Islands, tidal current is a limiting factor. This site is located in narrow Wasp Passage between Orcas and Shaw Islands, making weather-influenced access more reliable by virtue of substantial shielding.

Broken Point

This site is similar to Bell Island, with high relief rocky reef and dense algae in the shallows, but no kelp is present on this site. YOY have been located on both the east and western side of the point and no preference was observed to one side or the other. The site is larger than Bell Island East and is unlikely to be completely surveyed in a single dive. This site is located between Orcas and San Juan Islands, making access more reliable.

Skyline Wall

This natural reef southwest of Anacortes has the benefit of being located on the mainland, while still counting as within the San Juan basin, obviating the need for participants to purchase and plan a ferry ride. The habitat at this site includes natural reef, eelgrass and a seasonal *Nereocystis* bed. Through four survey events, YOY have been recorded 50% of the time. Careful tidal planning is a must on this site, as it should only be surveyed at slack before an ebb current.

South Sound

Fox Island West Wall

This ledge habitat in ~50 feet of water is located a short drive from Gig Harbor, minimally affected by current, and has a mean YOY encounter frequency of 75%. The ledge is relatively easy to locate and not very long, making replicated shore-based surveys feasible. Additional sites around the island are also accessible by boat, making selection of random sites to pair with this index site straightforward.

Sunnyside Beach

Rock surrounding a pipeline creates a discrete habitat that enables replicated surveys by various survey groups. This site has beach access and is among the most frequently surveyed sites in South Sound. YOY encounter frequency is 33%.

Z's Reef

This natural reef on the north side of Fox Island is only accessible by boat. The habitat of interest is a discrete, 5-15-foot-high rocky feature in 40-60 feet of water that runs for almost 200 yards. This site has been surveyed twice and YOY were encountered on both occasions.

Whidbey Basin

Big Gulch (seagrass)

This site is one of the sites that NWFSC divers have surveyed for fish, invertebrates, and seagrass characteristics on a quarterly basis since 2015. YOY rockfish were routinely observed in the eelgrass (*Zostera marina*) beds in 2017-19 during stable isotope and growth study collections.

Figure 6. *YOY yellowtail rockfish among boulders at Keystone Jetty*

Mukilteo Lighthouse

A short clay wall approximately 200 feet long, in 55-60 feet (MLLW) contains many juvenile and YOY rockfish, and mean YOY encounter frequency is 93%. The site is easy to access from the beach, with available close parking, but can experience strong tidal currents. No other site in the Whidbey Basin has been surveyed as frequently. The discrete wall habitat allows for comparison of results across survey groups. The wall is also natural habitat and may provide an accurate assessment of overall rockfish trends in Puget Sound.

Possession Point fingers

On the eastern edge of the southern tip of Whidbey Island is a shore-accessible reef feature that descends to greater than 80 feet. The high-relief habitat that continues to approximately 30 feet has numerous locations for YOY to shelter. This site has been surveyed twice and YOY were encountered on both occasions. Coordination with state parks is highly recommended to obtain a gate code so that vehicles may be brought close to the entry point.

Admiralty Inlet

Keystone Jetty

This site is among the most popular in Puget Sound, though it requires a ferry ride from Port Townsend or a long drive from Seattle and careful dive planning to avoid currents. The site was designated as a Conservation Area in 2002, and the WDFW conducted regular transect dive surveys from 1995-2010 (LeClair et al. 2018). The habitat is a mix of artificial reef (a jetty with a dilapidated pier slightly to the south) and kelp forest that frequently has schools of adult yellowtail and black rockfish. Mean YOY encounter frequency is 75%, and multiple species have been observed (Figure 6). The WDFW found that the dominant species is Puget Sound Rockfish, followed by black and copper rockfish (LeClair et al. 2018).

Additional Considerations for Index Site Selection

The goal of this exercise was to select potential YOY index sites using the best available data. However, there are many possible sites in Puget Sound that have not been surveyed for a variety of reasons. Seasonality was not included in this exercise and may have had an impact on accessibility and observations at sites. Additional index sites will be added to this list as new information becomes available.

Random Sites

Numerous factors influence rockfish settlement location, including tidal currents, wind drift, food availability, and intricacies of habitat preference (West et al. 1994; Buckley 1997; Kashef et al. 2014). Many of these factors are complex, and their interactions relevant to recruitment are not fully understood in the Salish Sea. To capture these spatial dynamics, surveys must be conducted throughout the region at locations that encompass the broadest degree of variability for these presumed forcing factors. Surveying in as wide an area as possible will fill data gaps on spatial recruitment and may reveal novel sites of high value to rockfish recruits. More sites will also inform knowledge gaps on physical and biological characteristics important to settlement, as described below in the modeling section, allowing for more robust and comprehensive data analysis. The spatial data may inform understanding of rockfish recruitment in the region, presenting an opportunity to adaptively adjust the monitoring plan to accommodate expanded sampling. Selection of these sites will be at the surveyor's discretion, but should include features presently known to support rockfish recruits, including macroalgae, seagrass, or reef habitat. These sites will be surveyed opportunistically and may eventually become index sites.

Standardized YOY Survey Methodology

This plan documents recent use of multiple methods for recording YOY rockfish occurrence, abundance, and density. In some cases, these methods are employed to sample the fish community at large, rather than focusing specifically on YOY rockfish and often require specialized equipment and/or permits (e.g., SMURFs, ROVs, trawling). While these methods provide valuable contextual data to supplement focused collection of YOY rockfish distribution and abundance data, they typically cannot be implemented by citizen scientists. Here, we present methodological guidelines for SCUBA surveys as the most common and practical method for use by a broad user group to survey YOY rockfish. By using this standardized, focused sampling protocol, organizations and individuals may collect data that are readily integrated with existing datasets for long-term trend analysis. This protocol represents the minimum standards for inclusion of data in the aggregate monitoring database and partners are encouraged to collect additional data as necessary to meet organizational goals and maximize dive time efficiency. Additional support in implementation of this protocol may be obtained by contacting Adam Obaza at adam@pauamarineresearch.com.

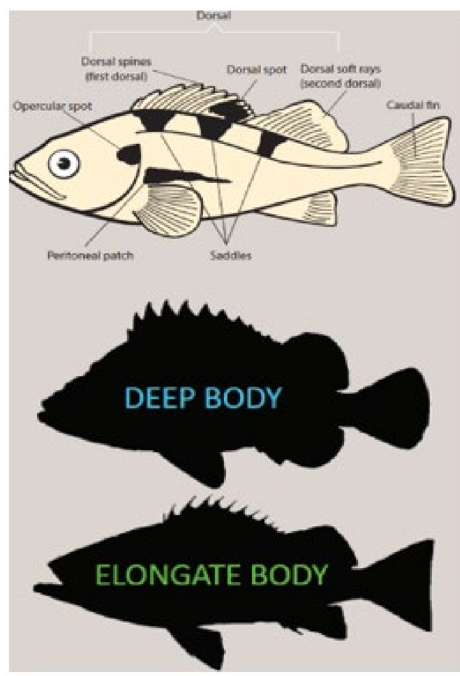


Figure 7. *Morphology and physical attributes of a generalized YOY rockfish, showing the dorsal spot, and the two morphological categories used to classify fish of unknown species.*

Rockfish Identification

Consistent with multiple existing survey programs, a YOY is defined as any rockfish under 10 cm in total length (Palsson et al. 2009; LeClair et al. 2018). An exception to this length-based definition is made for the smallest rockfish species regularly encountered in the Salish Sea, Puget Sound rockfish (*Sebastes emphaeus*). If surveyors can identify an individual Puget Sound rockfish to the species level, it should only be included in the dataset as a YOY if it is under 6 cm. Identification of YOY rockfish to species level can be difficult due to their small body size and limited morphological differentiation between groups of closely related species at small body sizes. If individuals cannot be identified to the species level, counts should be grouped using two morphological attributes: presence or absence of a dark spot on the spinous portion of the dorsal fin (i.e., dorsal spot vs. no spot), and the overall body shape in profile (i.e., deep body vs. elongate body) (Figure 7).

Figure 8 provides a key to guide species identification. Species-specific data are preferred when they can be accurately obtained. Ideally, photo or video documentation should be provided, but is not mandatory. When photo/video evidence is available, it may be used to assess surveyor bias, identify difficult species to identify, determine age classes, or indicate a need for additional training.

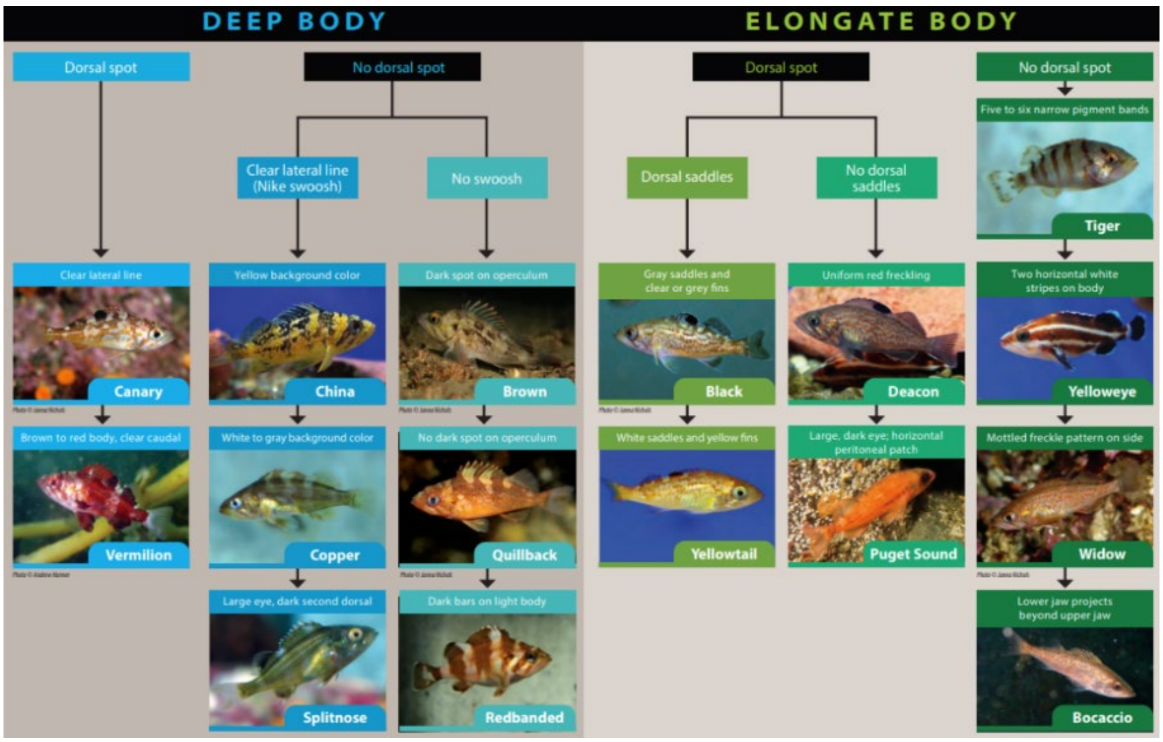


Figure 8. *Key to YOY rockfish species identification applying the dorsal spot and body shape criteria described in text and shown in Figure 6.*

Survey Mode

There are two SCUBA-based survey modes defined for the YOY rockfish monitoring plan to standardize survey effort: timed roving and band transect.

- Timed Roving Survey - A surveyor swims freely, recording all YOY rockfishes encountered within their swimming path, and documenting the total survey duration. Surveys predominantly target the area within 1 m of the substrate, though exceptions may be made for surveys in mid-water or in kelp canopy, provided that deviation is accurately noted. This method provides an indicator of effort (i.e., counts of YOY rockfish encountered per unit time) that enables comparison within and between locations over time during analysis.

- Band Transect – A surveyor deploys a transect tape of known length, or otherwise validates swimming distance using fixed artificial or natural structures, and surveys for YOY rockfish within a box bounded by the tape and a predetermined width (typically 1 m, based on reliable visibility) on either side of it. An advantage of band transects is it minimizes the likelihood of repeat observations of the same fish as the diver records observations in only one direction. This method provides a density estimate (i.e., counts of YOY rockfish per unit of area). Time of survey along the transect may also be collected to allow for direct comparison with data from timed roving surveys.

  Roving surveys where time is not recorded are useful for identifying potential new index site locations; however, this survey type is not standardized and the data collected would not be included in this monitoring plan.

Habitat Data

Rockfish in Puget Sound are known to inhabit different depth zones and habitat types (Hallacher and Roberts 1985; Love et al. 2002; Drake et al. 2010; Blaine et al. 2020; Pacunski et al. 2020; Lowry et al. 2022). In addition to recording the number of YOY rockfish encountered and time spent surveying, data on depth and habitat type should be recorded for each survey. For the purposes of this survey protocol, habitat can be characterized using broad categories (e.g., rocky reef, seagrass, kelp forest), though description of the degree of vegetative coverage (e.g., 25% eelgrass in patches around rock piles) is also helpful. Details of common example habitat types are provided in Figure 9. Depth may also be described as within a certain range and habitat as the primary type encountered during survey (e.g., 25-28 m over exposed bedrock). Attributes of the habitat should be recorded with as much specificity as possible without compromising the ability to accurately count and identify YOY rockfish as outlined in Figure 8. For this reason, having one diver record fish while their partner evaluates habitat may be preferable. A helpful depiction of major elements of the survey protocol is provided in Figure 9 for reference.

Figure 9. *Schematic depiction of timed roving YOY survey showing major sampling considerations and data elements that warrant attention.*

Example Datasheet/Slate Organization

Based on the methodological guidelines presented here, each survey will include information on depth, habitat type, number of YOY rockfish counted, and either duration of survey or survey dimensions. Because depth and habitat types may change multiple times at a given site, multiple surveys (e.g. different habitat types or depth bins) may be recorded during a single dive. An example datasheet or slate organization is provided below (Figure 10) in accordance with NOAA WCR's YOY survey program. Information on site name, basin, and date is necessary to spatially and temporally track surveys and standard names should be applied systematically to sites that are revisited multiple times (e.g., Alki Beach Site 1a). Groups using this standard survey method are welcome to modify the proposed slate organization to incorporate species-specific count data or otherwise meet their needs, but care should be taken to include all core data elements described above.

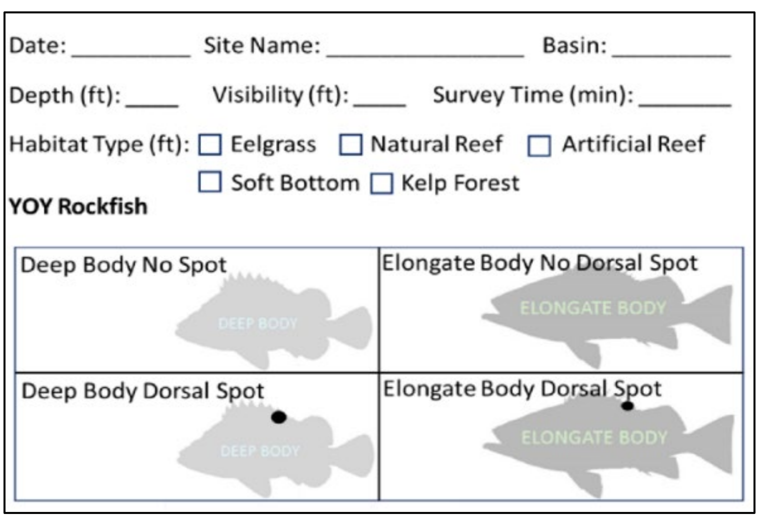


Figure 10. *Example of data sheet/slate layout currently used to collect YOY survey data by NOAA fisheries.*

Data Quality Assurance and Quality Control

This plan is intended to encourage participation from data collectors with diverse experience levels, ranging from beginner citizen scientists to expert marine biology professionals. Given this range, a level of quality assurance must be applied to the data to ensure accuracy and facilitate inclusion in trend analysis. The following guidelines are suggested for individual participating programs:

- Meaningful documentation on survey protocol, data collection, and species identification should be sought out and provided to all participants. These materials may include survey aides, such as the slate depicted in Figure 10 or a reference guide (Figures 7, 8, and 9). These documents are readily available through project leads in print and pdf forms. Regular presentations, in-water training, and regular feedback to participants will also improve participant performance.
- Index site creation outlined in this plan provides an opportunity for multiple survey groups to collect data at the same site. Comparison among these data, provided they are close enough in time, will enhance understanding of inherent variability in observation efficiency and other sources of bias. This could lead to correction factors applied to data from specific divers or groups to make data more comparable. Participating programs are also welcome to identify new index sites with adequate encounter rates and survey effort such that site-specific trends can be generated for comparison with other locations. Establishment of new sites should be coordinated with the existing NOAA citizen science program for maximum utility.
- Project leads should develop dedicated, systematic methods for error checking and otherwise validating data collected by their program before submitting it to the shared database. At a minimum, this should involve: immediate post-dive error-checking to flag spurious or conflicting observations and questions about fish identification; a double-entry or spot-check procedure for catching data entry errors; and consideration of a data confidence metric to be included with their submission based on diver experience, survey conditions, or other factors that may affect data accuracy. If data do not meet standards, they will be omitted from analysis.
- More affordable photography equipment, including GoPro and other waterproof compact cameras, have made image collection more accessible than ever. Participants may share their YOY rockfish identifications with project leaders for feedback (rockfishID@noaa.gov). Participants benefit through increased confidence and improving rockfish identification, regular communication with project leaders, and shared images represent a dataset on identification accuracy. Review of these data may facilitate development of correction factors, flag spurious observations worth additional investigation, and/or highlight identification aspects worthy of additional attention in outreach materials.

Liability and Diver Safety

All divers conducting surveys for this program are doing so under their own liability or that of their home institution. Unless maintaining active diving authorization with an institution (e.g., government agency, university, or NGO), participants should assume they are diving of their own free will and liability. It is recommended that participants be healthy enough to dive, do so with a buddy, and make informed decisions regarding conditions and equipment. Insurance through the Divers Alert Network (DAN) or another carrier is also recommended.

Statistical Methodology

The primary objective of this monitoring plan is to quantify estimates and uncertainty of recruitment across spatial management units for ESA-listed rockfish in the Puget Sound/Georgia Basin DPSs. In this context, *recruitment* refers to the annual abundance of YOY that are observed shortly (weeks-to-months) after they settle from the pelagic environment as larvae into benthic habitats. Estimates of ESA-listed rockfish recruitment provides managers that are evaluating downlisting and delisting criteria with an indication of whether the current adult population is likely to increase, decrease, or remain the same in the near future. Estimates of other species of YOY rockfish in the Puget Sound region may be useful to other agencies and organizations tasked with monitoring and management of these species within their respective jurisdictions.

One of the main hurdles in estimating YOY rockfish is the extremely high variability observed over space and time associated with life-history characteristics highlighted above. To adequately quantify this variation and estimate an index of abundance with any confidence, a large number of sampling events is required annually. The ability to use data collected from as many sources as possible, including data from a combination of professional and citizen science surveys, is critical. There are numerous analytical challenges in using data collected across multiple survey programs using different survey methods with disparate levels of detectability; however, there are statistical methods available to address these challenges and provide estimates with appropriate levels of uncertainty.

There are multiple sources of variation that contribute to the number of YOY rockfish observed during surveys or other sampling efforts. These include spatial, temporal, environmental, demographic, and methodological elements. To the extent possible, each of these sources of variation should be accounted for in our modeling framework and estimates of recruitment. Spatially, the abundance of YOY rockfish can vary across multiple geographic or management boundaries (e.g., biogeographic and oceanographic basins; state, federal and international boundaries), habitat types (e.g., kelp forests, seagrass meadows, rocky reefs, unstructured), and depths. The Rockfish Recovery Plan (NMFS 2017) identified two populations (Hood Canal and non-Hood Canal) and five management units (four in U.S. waters and one in Canadian) for yelloweye rockfish and bocaccio that we consider here. Temporally, the abundance of YOY rockfish varies across years and seasonally, in part due to species-specific dispersal timing. Environmentally, the growth, survival, and abundance of YOY rockfish may vary with the productivity within regions during larval dispersal (e.g., temperature, prey availability) and settlement (e.g., habitat quality, competition, and predator-prey dynamics). The abundance of YOY rockfish will also vary at spatiotemporal scales relevant to the abundance and size of mature adults. Finally, the number of YOY rockfish observed will vary across sampling groups (e.g., professional, citizen science) and sampling methods (e.g., SCUBA strip transects, SCUBA timed-roving, capture techniques). All of these considerations make it important to develop a flexible modeling framework that can integrate multiple data sources and account for the varying levels and hierarchy of variation.

Sources of data

There were five sources of data identified to help estimate an index of recruitment for ESA-listed rockfish in the PSGB DPS. These sources were classified by survey group and survey method. Survey groups were categorized into two classifications: professional and citizen science. Survey methods were categorized into roving SCUBA survey, timed-roving SCUBA survey, and band-transect SCUBA surveys.

Roving SCUBA surveys: These surveys are primarily conducted by volunteer citizen science SCUBA divers and are associated with data available from the Reef Environmental Education Foundation (REEF). Volunteer divers "swim freely throughout a site and record every observed fish species that can be positively identified" (REEF Survey Protocols 2022). Divers also record one of four abundance categories based on how many fish of each species were observed: Single (1 individual), Few (2-10), Many (11-100), or Abundant (>100). Divers collecting these data span a wide range of expertise levels and produce qualitative measures of abundance at a site.

Timed-roving surveys: These surveys are conducted by both professional (e.g., NOAA Western Regional Office, SeaDoc Society) and citizen science (e.g., Harbor WildWatch, Emerald Dive Club, Ocean Wise Research Institute) groups. The design of these surveys is described above and quantitative counts of YOY per unit of time surveyed are produced.

Band-transect surveys: These surveys are conducted by both professional (e.g., NWFSC, WDFW, SA) and citizen science (e.g., Reef Check) groups. Specific survey design varies among survey teams, but all consist of SCUBA divers swimming a known distance (e.g., 30 or 100 m) along a measuring tape or otherwise defined transect and counting only fish that are observed within a known width (e.g., 0.5 or 1 m) and height (e.g., 2 m) of the measurement tape. Some surveys count and record the numbers of fish in real time, while some surveys are recorded with video and fish are subsequently counted in the laboratory. These surveys result in quantitative counts of YOY per unit volume (e.g., 120 m^3) for each transect surveyed.

Model framework

Here, we developed a flexible, state-space hierarchical statistical modeling framework that can:

(1) incorporate and share information across each of the sources of data and variables,
(2) address each of the main sources of uncertainty, and
(3) quantify an index of abundance for YOY rockfish across spatial management basins in the PSGB DPSs.

We constructed two models that account for variation across years, management basins, sites and survey groups and produce an annual index of YOY abundance across different spatial management frameworks. First, we estimated an annual index across and for each of the four U.S. waters' management units as outlined in the Rockfish Recovery Plan for yelloweye rockfish and bocaccio (NMFS 2017):

<u>Puget Sound/Georgia Basin management units</u>

(1) The San Juan Islands/Strait of Juan de Fuca Basin
(2) Main Basin – includes Central Puget Sound, Admiralty Inlet, and Whidbey Basin
(3) South Puget Sound
(4) Hood Canal
(5) The Canadian portion of the DPS (excluded due to lack of data)

Secondly, we estimated an annual YOY index for all rockfish species across and for each of the two spatial populations identified in the Rockfish Recovery Plan for yelloweye rockfish and bocaccio (NMFS 2017). For yelloweye rockfish only, the Plan separates the Hood Canal basin from the rest of the management units within the PSGB DPS:

> Puget Sound/Georgia Basin DPS yelloweye rockfish populations
> (1) non-Hood Canal (includes management units 1-3 and 5 from above, but 5 was not included here due to lack of data)
> (2) Hood Canal

As more data become available over time, we will continue to produce indices across the two spatial management frameworks and will increase the complexity of the model to incorporate multiple sampling methods and progressively account for each of the remaining sources of uncertainty (e.g., seasonal, habitat type, environmental, demographic, and methodological).

Version 1 model

The statistical model is based on counts of YOY rockfish for each sampling event, where an *event* is either a single roving or timed-roving survey or a single transect. These sampling events directly observe YOY rockfish, so we model the observed count Z_{isbym} of YOY rockfish per sampling event i at site s within basin b (where basin describes the spatial management units of each of the two spatial management frameworks) in year y for each survey method m as

Observation model:

$$Z_{isbym} \sim NegBinom(exp(\lambda_{isbym}), \nu_m)$$

where λ_{isbym} represents the natural logarithm of mean abundance for each sampling event, and ν controls the amount of overdispersion (greater variability) for each survey method. The mean and variance of the Negative Binomial is calculated as

$$\text{Mean[Z]} = exp\left(\lambda_{isbym}\right)$$

and

$$\text{Var[Z]} = exp\left(\lambda_{isbym}\right) + \frac{expexp\ (\lambda_{isbym})^{\ 2}}{\nu_m},$$

respectively. We estimate a single, shared overdispersion parameter ν in the Version 1 model, but as more data from more survey methods become available, each method will have independent priors for the overdispersion parameter. We used the Negative Binomial distribution to capture the highly skewed distribution of counts observed in YOY surveys, including a large number of zero counts. This type of dataset does not meet the assumptions required for normally distributed statistical methods, even after various transformations. The negative binomial distribution accounts for the relatively discrete nature of these observations and uses an appropriate residual distribution.

In Version 1 of the model, we used data from professional and citizen science timed-roving sampling events, and modeled the expected log density λ for each sampling event as

$$\lambda_{isbym} = X_{sby} + log\ E_{im} + \alpha_m$$

where X_{sby} is the expected log density for each site-basin-year combination, E_{im} is the survey effort value (i.e., number of minutes) for each sampling event-survey method combination, and α_m is an offset for differences between survey methods, where $\alpha_{m=1} = 0$ for identifiability, m_1 represents professional timed roving surveys, and m_2 represents citizen science timed roving surveys.

The Version 1 model focuses primarily on understanding the variability in, and quantifying an annual index of, YOY abundance across and for each basin-year combination, while accounting for variation of sites within each basin. We model these processes as

Process model:

$$X_{sby} = \gamma_b + \delta_y + \psi_{by} + \kappa_{sb}$$

Fixed effects:

$$\gamma_b \sim Normal(-4, 8)$$

Random effects:

$$\delta_y \sim Normal(0, \sigma^2)$$
$$\psi_{by} \sim Normal(0, \omega^2)$$
$$\kappa_{sb} \sim Normal(0, \zeta^2)$$

where the expected mean density X_{sby} is in log space, γ_b is the only fixed effects term and is the mean density for each basin (spatial management framework) across all years sampled, δ_y represents year-to-year variation measured across all basins, ψ_{by} represents variation associated with each basin-year combination, and κ_{sb} represents the variation of spatial nesting of sites within each basin.

Estimation

We estimate the parameters of the statistical model using Stan, a Hamiltonian Markov Chain Monte Carlo (MCMC) sampler for Bayesian statistical models (Gelman et al. 2015; Carpenter et al. 2017), as implemented with the *rstan* package (v.2.21.2) in the R environment (Stan Development Team 2020; R Core Team 2020). We use 5 parallel chains with diffuse starting locations and examine Gelman-Rubin diagnostics to ensure convergence and adequate mixing among chains. We use diffuse prior distributions for all parameters and will refine priors as additional data are collected and analyzed. In Version 1 of the model the priors are defined as

$$\alpha \sim Normal(-0.5, 3)$$
$$\nu_m \sim Gamma(5, 5)$$
$$\sigma^2 \sim Normal(0, 1)$$
$$\omega^2 \sim Normal(0, 1)$$
$$\zeta^2 \sim Normal(0, 1)$$

We present the results of this version of the model in Appendix A.

Future iterations

As more data become available, there are two additional components that we will add to the model framework. First, when strip transect data are available, these survey data will enter into the model as additional categories of m. Over the course of the next five years, we expect two additional survey method categories: professional strip transects and citizen science strip transects. Because these survey methods will use a different survey effort metric (counts/m^3 as opposed to counts/min) than the timed-roving surveys, the model needs a way to convert to common units. In order to be consistent with surveys of adult populations in the PS/GB DPSs, the goal will be to quantify expected density estimates in counts/m^2. This will be implemented in the model as

$$\lambda_{isbym} = X_{sby} + log\ E_{im} + \alpha_m + \beta_m$$

where β is an offset that converts counts/min to counts/m^3. In this more complex model, the survey methods will be m_1 = professional strip transect surveys, m_2 = citizen science strip transect surveys, m_3 = professional timed-roving surveys, and m_4 = citizen science timed-roving surveys where $\alpha_{m=1,3} = 0$ and $\beta_{m=1,2} = 0$ for identifiability and the prior on $\beta_{m=3,4}$ will be

$$\beta_{m=3,4} \sim Normal(-3, 0.5)$$

Second, there is considerable variation in YOY rockfish abundance across habitat types throughout their ranges. To account for this variation, we will add habitat type as a fixed effect covariate ρ_h to this framework as

$$X_{sby} = \gamma_b + \delta_y + \psi_{by} + \kappa_{sb} + \rho_h$$

As more data becomes available, it is within the capability of the framework to add and examine environmental and demographic parameters as well.

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Appendix A. Results from Version 1 Model

The first iteration of the model used data available in October 2021 from ‘professional’ and ‘citizen science’ timed-roving SCUBA surveys from 2015 to 2020. These data consisted of 473 sampling events from citizen science timed-roving surveys and 535 sampling events from professional timed-roving sampling events across a total of 62 sites in 4 of the 5 management basins (did not include Canadian waters) identified in the Recovery Plan for yelloweye rockfish and bocaccio (NMFS 2017).

Estimates of raw counts of YOY rockfish (all species) per unit of time surveyed summarized across each ‘basin-year’ combination for each of the two management frameworks suggests near-zero indices of YOY abundance for all basins except the Main Basin in the Four-basins model, and the “Rest of DPSs'' management basin in the Two-basins model (Figure A-1). These estimates provide simple summaries of the annual status and levels of uncertainty for YOY rockfish abundance without accounting for variation associated with important factors of interest (e.g., site, basin, year).

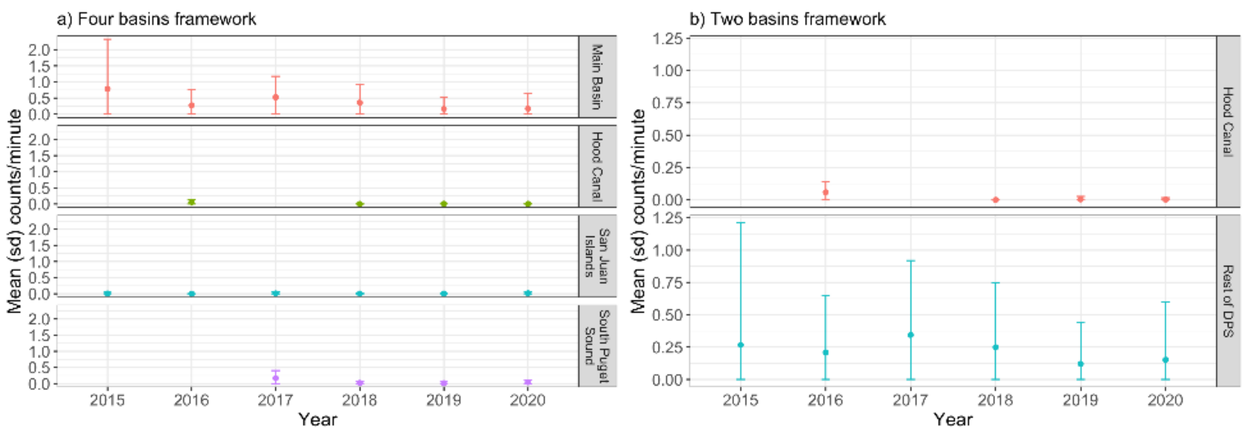

Figure A-1. *Mean (+/-SD) counts of young-of-the-year rockfish per minute surveyed across the (a) four and (b) two management basin frameworks.*

Four-basins management framework

Examination of model diagnostic figures suggests the model: (1) adequately explored the same region of parameter space across multiple chains with a very small proportion of divergences, and converged on parameter values (Figure A-2); and (2) that predicted posterior values adequately captured the observed variation in the raw data (Figure A-3).

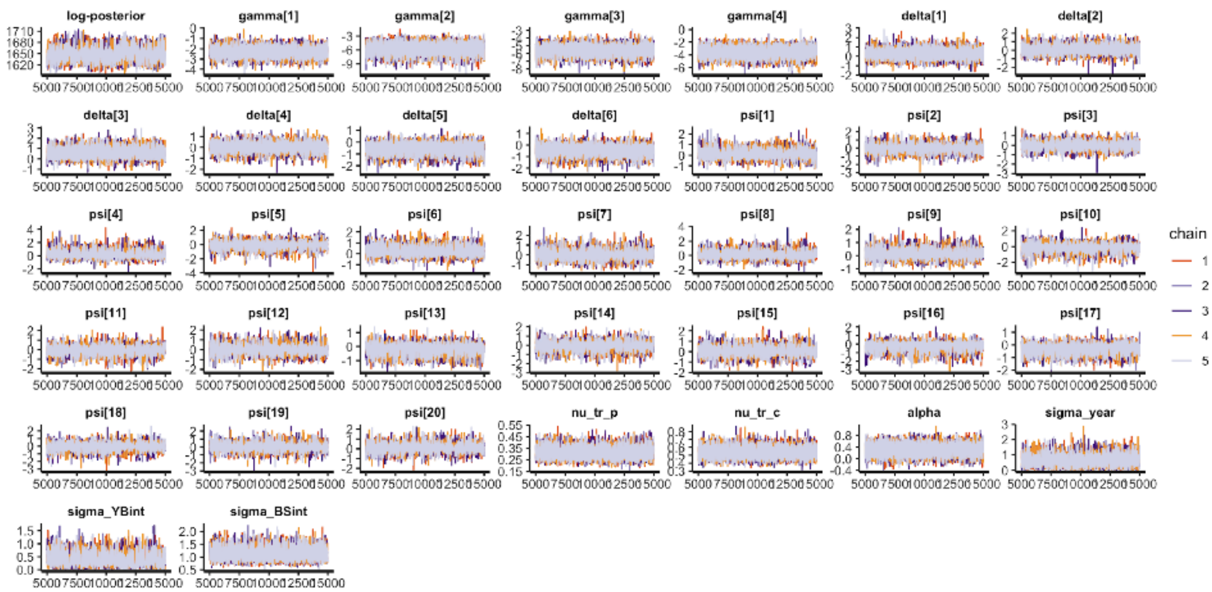

__Figure A-2.__ Trace plot of iterations 5000 – 15000 for each of the primary parameters of the model across five chains after a 5000-iteration warm-up period.

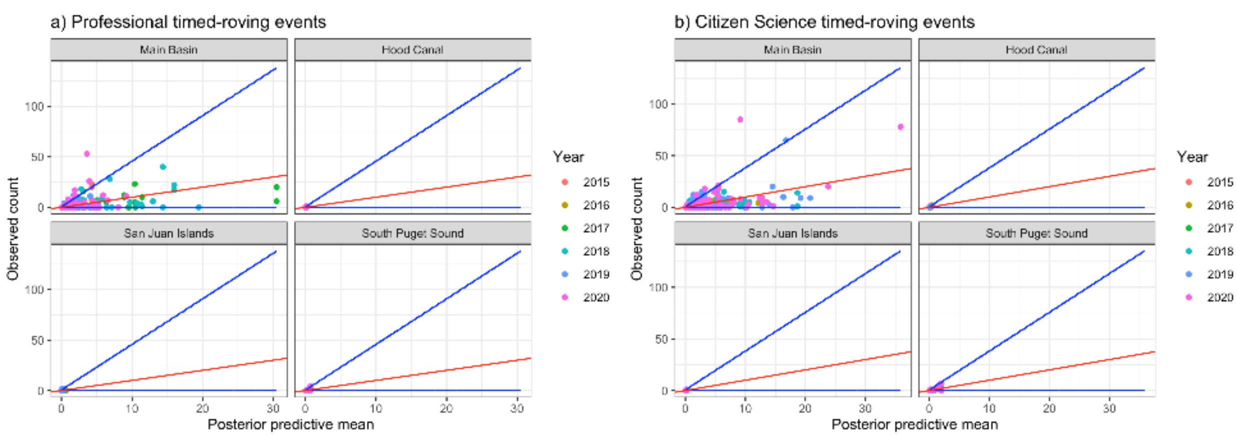

__Figure A-3.__ Comparison of observed counts of YOY rockfish to the corresponding posterior predictive mean across 10,000 iterations for (a) professional (n = 535) and (b) citizen-science (n = 473) sampling event. The red line is the one-to-one line and the blue lines are the 95% confidence interval for which we would expect 95% of the data points to be included.

Final abundance indices suggest YOY abundance was greatest within the Main Basin of Puget Sound, with the highest densities observed in 2017 (Figure A-4). We also found near-zero YOY abundance in the Hood Canal and San Juan Islands management basins across all surveyed years. The log-density plot allows us to explore variation across years for each basin, while the true scale density plot shows the magnitude of difference in YOY densities across all basins. We used the year term to quantify year-to-year variation across all basins throughout the surveyed region – this showed a very similar trend as observed in the Main Basin (Figure A-5). The vast majority of survey effort occurred in this basin and influences the number of opportunities to observe >0 counts of YOY rockfish.

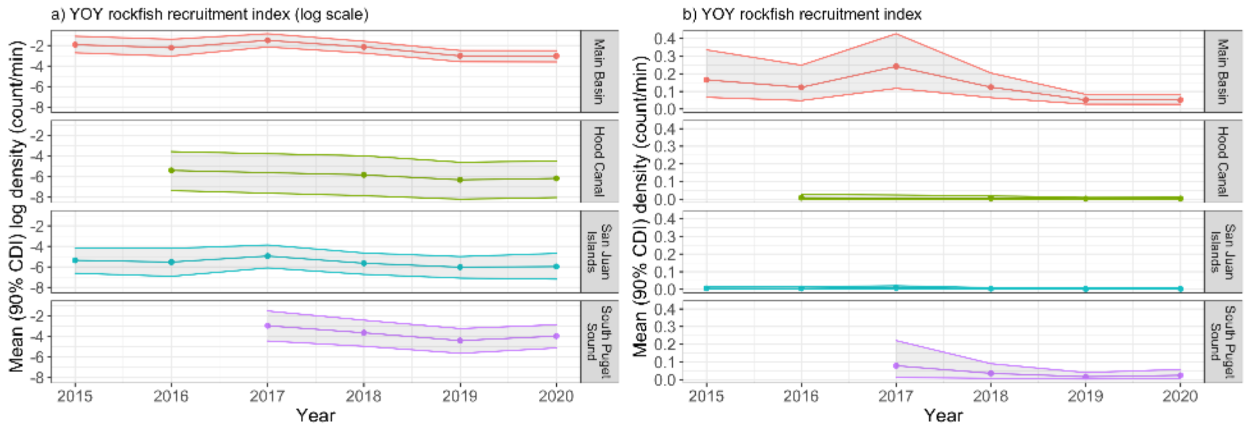

Figure A-4. *Index of YOY rockfish abundance in each management basin from the four management basin framework from 2015 to 2020 on (a) log scale and (b) normal scale.*

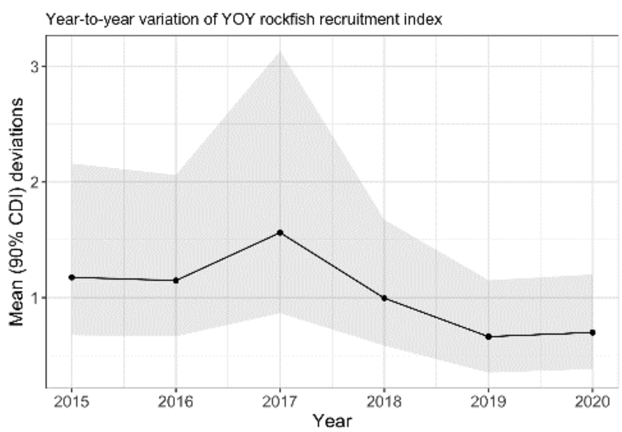

Figure A-5. *Year-to-year deviations in the mean density of YOY rockfish across all sampled basins in the Puget Sound/Georgia Basin DPSs. The deviations are multiplicatively scaled to a value of 1 (e.g., YOY densities were ~1.8 times more abundant in 2017 than the long-term mean across years.*

Spatial variation in YOY rockfish density across all sites showed the highest densities were found in the Main Basin (Figure A-6a). The top 26 (out of 62) highest-density sites were all in the Main Basin, while 8 of the 9 lowest-density sites were found in the San Juan Islands. Similar to patterns observed in SCUBA surveys by the Washington Department of Fish and Wildlife in 2006 (a historically-high rockfish recruitment year), we observed the greatest densities of YOY rockfish at sites along the eastern shores of the Main Basin of Puget Sound, including Keystone (at the entrance to Puget Sound Proper), Edmonds Underwater Park, two sites along the Mukilteo shoreline, and within Elliott Bay at Alki Cove #2. This type of relationship may be correlated with prevailing oceanographic currents, larval supply, and quantity and quality of habitat along this section of the shoreline. Within each basin (Figure A-6b), the magnitude of density values varied with general oceanographic and geographic locations. In the Main Basin, the highest densities were found at the northernmost site (Keystone had 6 times the average density of other Main Basin sites) and along the eastern shoreline, as observed across all sites. The highest densities in South Puget Sound were found along the southeastern shoreline of Fox Island, which is located at the southern end of the Tacoma Narrows, a location of very high currents and turbulent mixing conditions. In Hood Canal, the highest densities were found at the most southern site, which tends to have relatively mild rates of current exchange and very long water residence time. Finally, the highest densities in the San Juan Islands basin were found in two disjunct locations: in the center of the main island archipelago off Shaw Island; and outside and to the southeast of the archipelago at the entrance to Deception Pass and at Smith Island. Importantly, several of the sites with high densities were sites that have been sampled most frequently and may contribute to higher probabilities of observing YOY rockfish simply due to sampling intensity and diver familiarity. Additionally, spatial variation within each basin should be placed in context relative to where sampling has occurred. Each of these cautionary points have been considered in the development of the sampling design (e.g., using index sites paired with random additional sites) and should be lessened over time and with more data, but these will be important considerations of future analyses and modifications to the modeling framework.

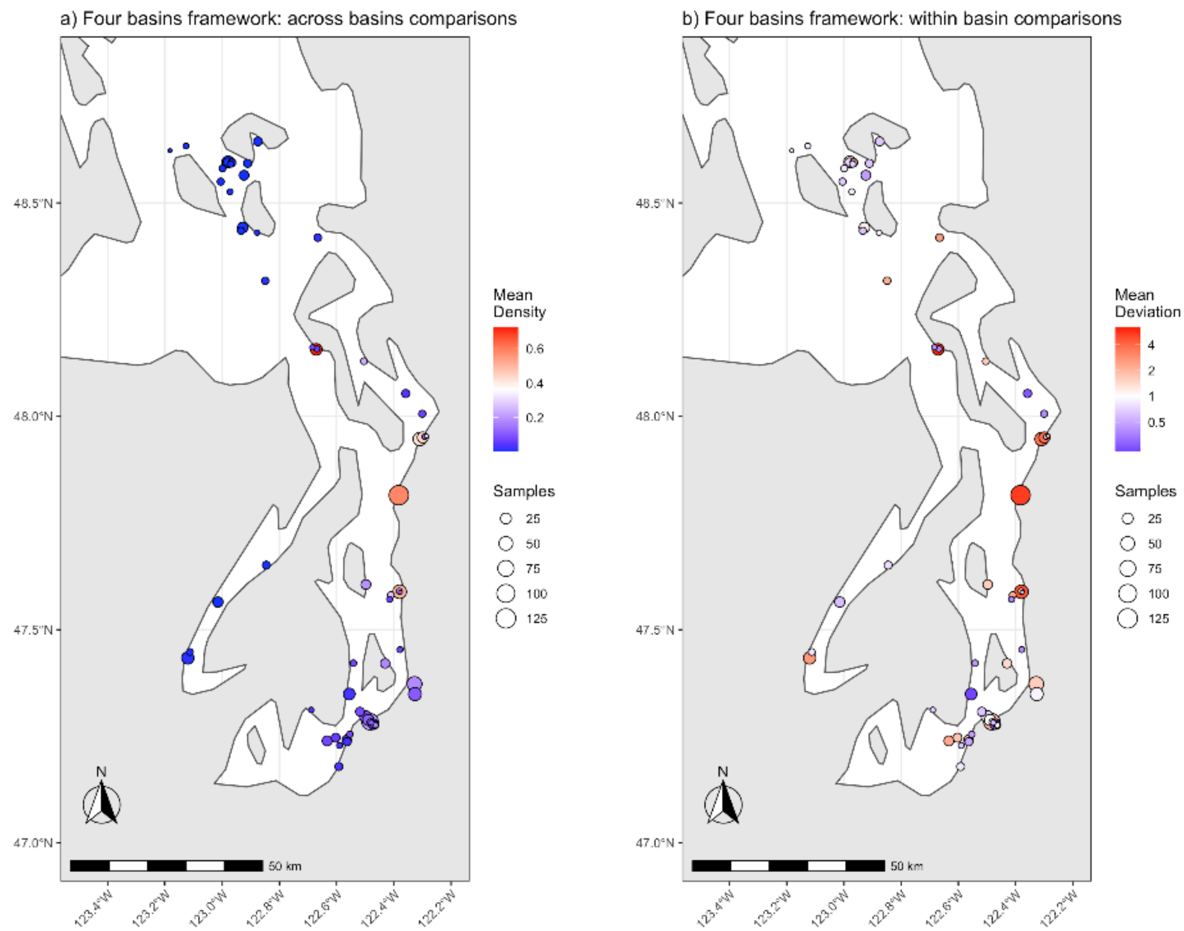

Figure A-6. *Variation in (a) mean density (count/min) of YOY rockfish across all sites in all basins* ($\gamma_b + \kappa_{sb}$) *and (b) mean deviation among sites within individual basins* (κ_{sb}) *in the Puget Sound/Georgia Basin DPSs. Site-to-site deviations are multiplicatively scaled to the mean density (equal to 1) within each basin (e.g., YOY densities at Edmonds Underwater Park were 6.4 times more abundant than the grand mean of sites within the Main Basin).*

Two-basins management framework

Examination of model diagnostic figures suggests the model: (1) adequately explored the same region of parameter space across multiple chains with a very small proportion of divergences and converged on parameter values (Figure A-7); and (2) that predicted posterior values adequately captured the observed variation in the raw data (Figure A-8).

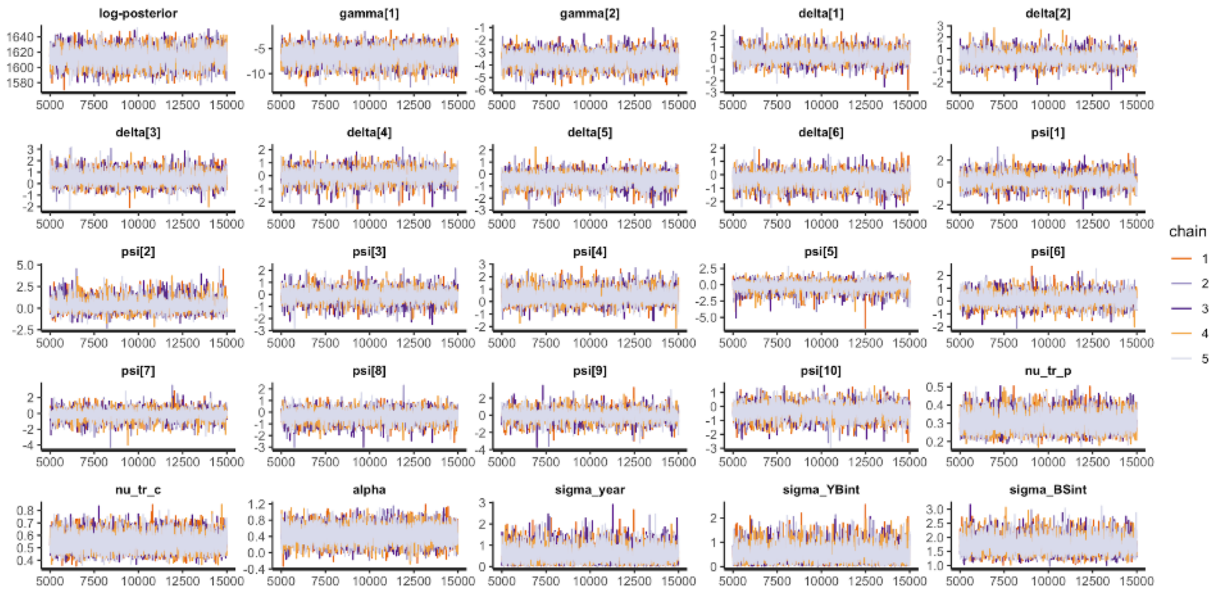

Figure A-7. *Trace plot of iterations 5000 – 15000 for each of the primary parameters of the model across five chains after a 5000-iteration warm-up period.*

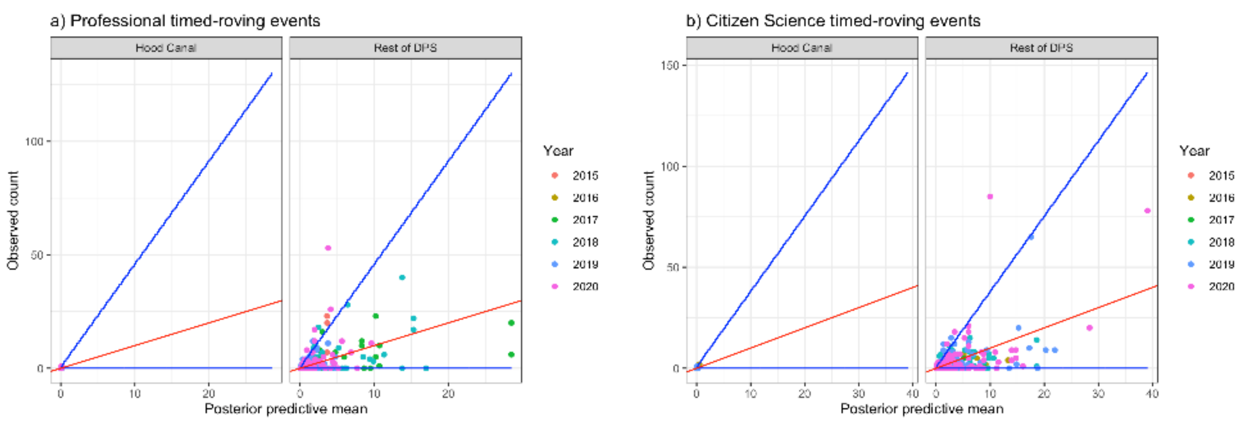

Figure A-8. *Comparison of observed counts of YOY rockfish to the corresponding posterior predictive mean across 10,000 iterations for (a) professional (n = 535) and (b) citizen-science (n = 473) sampling event. The red line is the one-to-one line and the blue lines are the 95% confidence interval for which we would expect 95% of the data points to be included.*

Final abundance indices suggest YOY abundance was greatest within the combined management unit “Rest of DPSs,” which included the Main Basin, San Juan Islands, and South Puget Sound, with the highest densities observed in 2017 (Figure A-9). We also found near-zero YOY abundance in the Hood Canal management basin across all surveyed years, but there was a large amount of variation in the estimates, particularly for 2016. The log-density plot allows us to explore variation across years for each basin, while the true scale density plot shows the magnitude of difference in YOY densities across all basins. We used the year term to quantify year-to-year variation across all basins throughout the surveyed region, which showed a trend very similar to what was observed in the 'Rest of DPS' management basin (Figure A-10). The vast majority of survey effort occurred in the 'Rest of DPS' basin (and largely within Central Sound, within this category) and influences the number of opportunities to observe >0 counts of YOY rockfish.

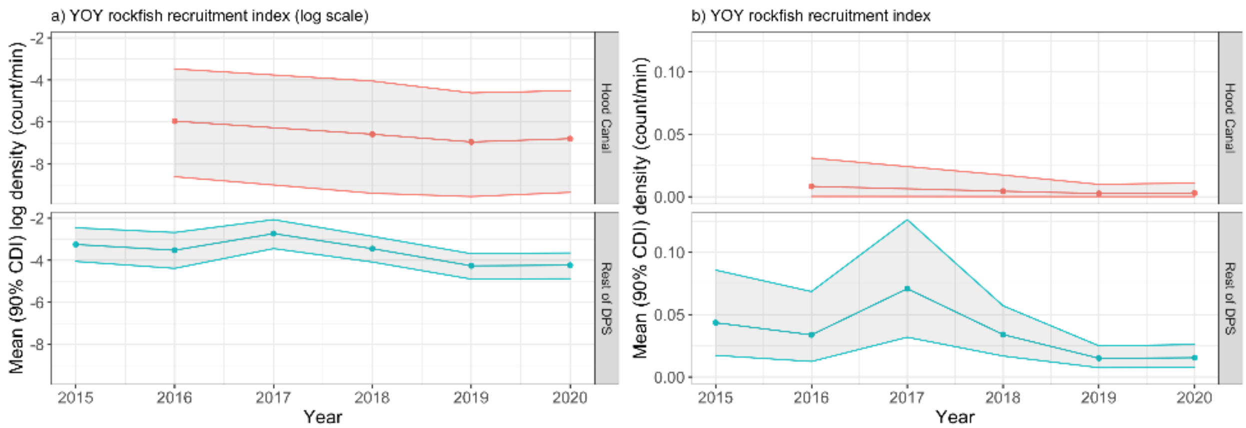

Figure A-9. *Index of YOY rockfish abundance in each management basin from 2015 to 2020 on (a) log scale and (b) normal scale.*

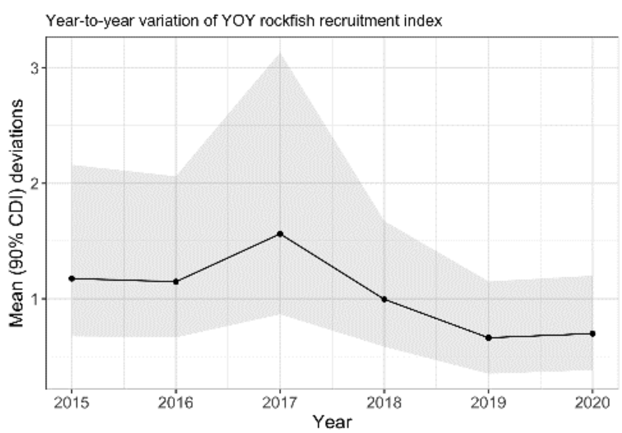

Figure A-10. *Year-to-year deviations in the mean density of YOY rockfish across all sampled basins in the Puget Sound/Georgia Basin DPSs. The deviations are multiplicatively scaled to a value of 1 (e.g., YOY densities were ~1.6 times more abundant in 2017 than the long-term mean across years.*

Spatial variation in YOY rockfish density across all sites showed that the highest densities were found in the 'Rest of DPSs' (Figure A-11a). The top 54 (out of 62) highest-density sites were all in the 'Rest of DPSs' basin, while the four Hood Canal sites were among the lowest eight sites. Expectedly, the overall spatial pattern across all sites is the same as observed in the "Four basins" model. Within each basin (Figure A-11b), the magnitude of density values varies in their general oceanographic and geographic locations. In the 'Rest of DPSs' basin, the highest densities were primarily found within Puget Sound proper. YOY mean density at the northern entrance to Puget Sound proper was 22 times the average density across other 'Rest of DPSs' sites) and densities at four other sites along the eastern shoreline were > 10 times average densities in the basin. In Hood Canal, the highest densities were found at the most southern site, which tends to have relatively mild rates of current exchange and very long water residence time. Importantly, several of the sites with high densities were sites that have been sampled most frequently and may contribute to higher probabilities of observing YOY rockfish simply due to sampling intensity and diver familiarity. Additionally, spatial variation within each basin should be placed in context relative to where sampling has occurred. Each of these cautionary points have been considered in the development of the sampling design (e.g., using index sites paired with random additional sites) and should be lessened over time and with more data, but these will be important considerations of future analyses and modifications to the modeling framework.

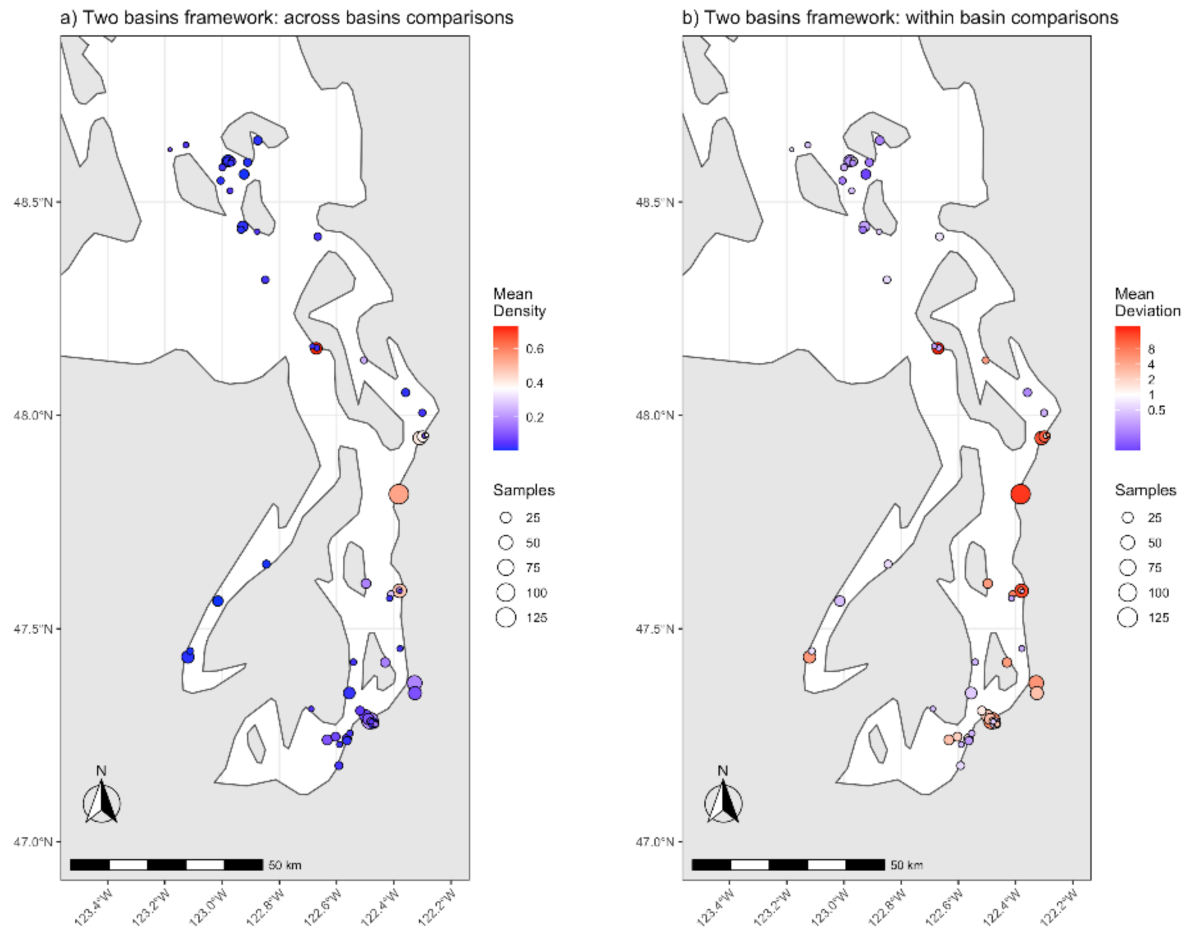

Figure A-11. *Variation in (a) mean density (count/min) of YOY rockfish across all sites in all basins ($\gamma_b + \kappa_{sb}$) and (b) mean deviation among sites within individual basins (κ_{sb}) in the Puget Sound/Georgia Basin DPSs. Site-to-site deviations are multiplicatively scaled to the mean density (equal to 1) within each basin. For example, YOY densities at Edmonds Underwater Park were 17.2 times more abundant than the grand mean of sites across the 'Rest of DPSs' basin.*

Example of future model

We show below an example of how we foresee a fully-developed YOY rockfish recruitment index model for the Puget Sound/Georgia Basin DPSs. This model would include four survey methods across all five management basins (including the Canadian portion of the DPSs) and would add an additional covariate to account for variation across various habitat types that YOY rockfish are observed.

Observation model:

$$Z_{isbym} \sim NegBinom(exp(\lambda_{isbym}), \nu_m)$$

$$\lambda_{isbym} = X_{sby} + log\ E_{im} + \alpha_m + \beta_m$$

Process model:

$$X_{sby} = \gamma_b + \delta_y + \psi_{by} + \kappa_{sb} + \rho_h$$

Fixed effects:

$$\gamma_b \sim Normal(\ -4\ , 8)$$
$$\rho_h \sim Normal(\ -4\ , 8)$$

Random effects:

$$\delta_y \sim Normal(\ 0\ , \sigma^2)$$
$$\psi_{by} \sim Normal(\ 0\ , \omega^2)$$
$$\kappa_{sb} \sim Normal(0, \zeta^2)$$

Offsets for survey methods:

$$\alpha_{m=2,4} \sim Normal(\ -0.5\ , 3)$$
$$\beta_{m=3,4} \sim Normal(-3, 0.5)$$

Priors:

$$\nu_m \sim Gamma(5\ , 5)$$
$$\sigma^2 \sim Normal(0, 1)$$
$$\omega^2 \sim Normal(0, 1)$$
$$\zeta^2 \sim Normal(0, 1)$$