

**An evaluation of the Washington coastal Rod-and-Reel Survey's  
ability to detect Black Rockfish (*Sebastes melanops*) population  
abundance changes**

by  
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Submitted in partial fulfillment  
of the requirements for the degree  
of Master of Environmental Studies  
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This Thesis for the Master of Environmental Studies Degree

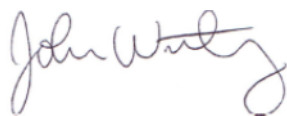
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## Abstract

An evaluation of the Washington coastal Rod-and-Reel Survey's ability to detect Black Rockfish (*Sebastes melanops*) population abundance changes

Lisa K. Hillier

The Washington coastal population of Black Rockfish (*Sebastes melanops*) supports a popular recreational fishery and contributes to the diversity of the nearshore ecosystem. Working through the Pacific Fisheries Management Council process, state fisheries managers at the Washington Department of Fish and Wildlife (WDFW) set annual harvest guidelines for Black Rockfish. Fisheries managers depend on survey data to inform assessment models for coastal bottomfish species, and without reliable, comprehensive, and representative fishery-independent survey data for stock status analysis, harvest limits may be unsuitable for maintaining sustainable fisheries. The WDFW implemented a standardized nearshore coastal Rod-and-Reel Survey in 2019 to address this need, but the survey's ability to detect changes in Black Rockfish abundance had not been evaluated. Here, information from published literature, data from WDFW pilot studies, and data from the Washington Black Rockfish tagging program were used to evaluate the Survey's design and determine the effects of location, gear type, bait type, seasonal timing, and sampling effort on Black Rockfish catch. Results showed that sampling at Rod-and-Reel Survey designated index stations provided representative estimates of the coastal adult Black Rockfish population and that the gear type and terminal tackle used were appropriate for sampling semi-pelagic schooling rockfishes. Spring (March-May) sample timing was biologically suitable for Black Rockfish off Washington and is desirable due to vessel availability, ocean conditions, and budget considerations. Analysis of the 2019 and 2021 Rod-and-Reel Survey data concluded that sampling each of the 125 index stations with 4-drifts per station was adequate for detecting changes in Black Rockfish population abundance. This comprehensive evaluation affirms that the WDFW coastal Rod-and-Reel Survey can produce representative abundance indices that can be utilized by managers and incorporated into Washington Black Rockfish stock assessment models.

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## 1. Introduction

Black Rockfish (*Sebastes melanops*) is an important component of the nearshore ecosystem off the Washington coast and a highly desirable species in the coastal recreational *bottomfish* (see Glossary) fishery. Their ecological importance and high targetability make careful management of the *stock* (see Glossary) essential. Washington's coastal Black Rockfish stock is managed through the Pacific Fishery Management Council (PFMC) process which relies on the best available scientific information to meet the national standards of the Magnuson-Stevens Fishery Conservation and Management Act (16 U.S.C. § 1801-1891(d) (2014)). Working through the PFMC process, state fisheries managers at the Washington Department of Fish and Wildlife (WDFW) set annual harvest guidelines for recreational bottomfish fisheries. For the PFMC management process to function well, the scientific data available for stock status analysis must be reliable, comprehensive, and representative of the fish population.

The Washington coastal Black Rockfish population was last fully assessed through the PFMC process in 2015 (Cope et al. 2016). From this assessment review the PFMC Stock Assessment Review (STAR) panel report stated that the base model would be greatly improved by using existing data to derive an index, or by collecting coastwide *fishery-independent* (see Glossary) survey data (Advisors 2015). These statements were based on concerns about the geographic limitations of the WDFW Black Rockfish tagging program data and a misunderstanding that all data from the tagging program were *fishery-dependent* (see Glossary). The STAR panel recommended future research that included definition and measurement of Black Rockfish habitat, the development of a coastwide fishery-independent survey for nearshore stocks, and improved catch-per-unit-effort (CPUE) standardization protocols. These

recommendations prompted the WDFW to initiate the development of a standardized coastal nearshore survey that targeted multiple bottomfish species.

The WDFW has contributed to the PFMC process by conducting both fishery-dependent and independent surveys since the 1980s to assess Black Rockfish populations. Historically, studies have produced estimates of abundance, growth, survival, and mortality for the proportion of the Black Rockfish stock found in coastal waters off the central Washington coast between Grays Harbor and Sea Lion Rock just north of Cape Elizabeth (Wallace et al. 2010). The 2007 coastal Black Rockfish population dynamics model utilized abundance trends from these surveys to assess the Washington stock and fishery-independent data from the WDFW Black Rockfish tagging program were used in the 2015 Washington Black Rockfish assessment stock synthesis (SS) model (Wallace, Cheng, & Tsou 2008; Methot & Wetzel 2013; Cope et al. 2016). In 2019, the WDFW implemented a fishery-independent coastal Rod-and-Reel Survey to assess multiple nearshore bottomfish stocks. However, this Survey's ability to detect changes in abundance of Black Rockfish for use in the Washington assessment's base model has not been evaluated.

Prior to the implementation of the 2019 coastal nearshore Rod-and-Reel Survey, the WDFW completed multiple pilot studies to address issues highlighted in the 2007 and 2015 Black Rockfish assessment reviews. Although the WDFW had been monitoring Black Rockfish populations through the WDFW Black Rockfish tagging program surveys, and the design allowed for the collection of both fishery-independent (tag release efforts) and fishery-dependent (fishery tag recovery) data, the survey design needed adjustment to incorporate multiple bottomfish stocks and cover a wider geographic range. Targeted species expanded to include China Rockfish (*Sebastes nebulosus*), Copper Rockfish (*Sebastes caurinus*), Quillback Rockfish (*Sebastes maliger*), Blue Rockfish (*Sebastes mystinus*), Deacon Rockfish (*Sebastes diaconus*),

Vermilion Rockfish (*Sebastes miniatus*), Yelloweye Rockfish (*Sebastes ruberrimus*), Kelp Greenling (*Hexagrammos decagrammus*), and Cabezon (*Scorpaenichthys marmoratus*) in addition to Black Rockfish. Several pilot studies were developed to address tagging program survey design inconsistencies, limitations for targeting multiple bottomfish species, and to delineate coastal rocky habitat suitable for rockfishes (T. Tsou WDFW, personal communication). In the fall of 2015, a pilot study to evaluate the effectiveness of rod-and-reel surveys to capture bottomfish in comparison to a set-line survey was initiated. This pilot study was conducted over three seasons at several locations off the Washington coast. Additionally, the WDFW conducted a pilot study to evaluate terminal tackle limitations for capturing schooling rockfish species. A main goal of this study was to address the issue of consistent and effective terminal tackle in a rod-and-reel survey for capturing a targeted set of bottomfish. The WDFW also prioritized efforts to map rocky habitat distribution and quantify abundance off the coast. Information gained from these pilot studies was used to inform the design of the 2019 standardized coastal nearshore Rod-and-Reel Survey.

When designing the Survey, the WDFW made efforts to address the concerns of the STAR panel, but a comprehensive evaluation of the design is needed ensure that survey data can be used to calculate abundance indices for the Washington Black Rockfish stock assessment model. The Rod-and-Reel Survey must be representative of the adult portion of the Washington stock, provide a measure of abundance, and be able to detect changes in abundance. If the Rod-and-Reel Survey meets these objectives, it may be incorporated into the Black Rockfish base model in 2023 and in future assessments, improving fishery management. If it does not meet the objectives, the survey design will be modified by WDFW to ensure that future data collected can detect abundance changes and an index may be incorporated into later stock assessments.

This thesis evaluated the WDFW coastal nearshore Rod-and-Reel Survey to determine whether it can detect changes in Black Rockfish abundance trends by answering the following questions:

- 1.) Are abundance indices derived from surveys at the Rod-and-Reel Survey index station locations representative of the Washington coastal adult Black Rockfish population?
- 2.) Does the Rod-and-Reel Survey use terminal tackle and sampling gear that consistently captures pelagic adult Black Rockfish?
- 3.) Does the Rod-and-Reel Survey sample at a suitable time of year to consistently capture Black Rockfish?
- 4.) Is the Rod-and-Reel Survey effort sufficient to detect changes in population abundance of Black Rockfish using CPUE estimates?

To address the first question, Rod-and-Reel Survey index station locations were evaluated to determine if the fish captured at these locations were representative of the Washington coastal population based on CPUE data from the historic WDFW Black Rockfish tagging program from 1998-2014. The second question was addressed by comparing Black Rockfish CPUE estimates for terminal tackle trials during the 2014 and 2015 WDFW terminal tackle pilot study. Survey sampling technique (gear type) was evaluated using information collected during the 2015-2017 WDFW pilot study designed to compare set-line sampling efficiency with rod-and-reel sampling. Seasonal timing evaluation considered catch rates of Black Rockfish during a WDFW pilot study conducted from 2010-2013, survey vessel availability, and funding constraints. Finally, survey effort was evaluated to determine if time spent at each index station was adequate for capturing a

representative sample and a power analysis was done to determine if the survey design included enough locations to be able to detect an informative change in CPUE.

By addressing these four questions this thesis provides fisheries managers with the information needed to confirm that the WDFW coastal Rod-and-Reel Survey can produce representative abundance indices for incorporation into the next stock assessment model.

Recommended improvements for abundance indices estimates will be discussed for future Black Rockfish stock assessments.

## **2. Literature Review**

A well-designed survey capable of providing a useful abundance estimate must integrate information from the target species management and exploitation history, biology, and lessons learned from research (Walters 2003; Thorson, Stewart & Punt 2012; Kuriyama et al. 2019). This literature review will begin with a brief synopsis of the management and harvest history of Black Rockfish in Washington, followed by an overview of the species biology, life history, and movement behavior. The next section will summarize relevant pilot studies conducted by the WDFW that were used to inform the Rod-and-Reel Survey design. Finally, there will be a review of other nearshore survey methods, limitations of these surveys, and information about the use of CPUE for the development of abundance indices. The design of the WDFW Rod-and-Reel Survey will be discussed in detail to conclude this section. This review of relevant literature, pilot studies, and the Rod-and-Reel Survey will provide the framework for conclusions drawn from the analysis of the Survey design.

### **2.1 Coastal Management and Exploitation History**

Washington's coastal Black Rockfish stock is managed through the PFMC process. The PFMC is tasked with sustainable fisheries management of approximately 119 species of fish on the West Coast of the United States and relies on information from committees, advisory panels, subpanels, and the public (PFMC 2020). The PFMC's Science and Statistical Committee reviews fishery stock assessments and helps the Council evaluate the available scientific information. For bottomfish management, advice is provided to the PFMC by the Groundfish Management Team and advisory subpanels which include representatives from fishing industries, the public, and conservation interests (PFMC 2020). Public meetings to share scientific and management information and receive comments from stakeholders are also an essential step in the

management process. Working through the PFMC process, the WDFW and its partners set annual harvest guidelines for Black Rockfish for the Washington coastal stock.

Historically, coastal Black Rockfish have been harvested by a variety of methods including bottom trawl, set-line, trolling, and rod-and-reel (Parker et al. 2000). In 1999, the WDFW managers closed commercial harvest for all gear types in State waters (0-3 miles offshore) to increase year-round recreational fishing opportunities for bottomfish (Wallace, Cheng, & Tsou 2008; Cope et al. 2016). Since then, the recreational fleet, which is comprised of chartered vessels and independently owned boats, has been responsible for all targeted Black Rockfish landings. Black Rockfish are managed as part of a rockfish species complex. Coastal rockfish recreational fishing opportunities were available year-round in Washington until 2017 when the season was truncated to a March through October opening (WDFW 2017). Prior to 2017, managers adjusted the daily *bag limits* (see Glossary) as a management tool to stay within annual harvest guidelines. From 1961-1991 recreational harvesters could retain 15 rockfish per day. This bag limit decreased to 12 fish per day from 1992-1994 and decreased again to 10 fish per day from 1995-2015, with additional restrictions on the retention of Canary and Yelloweye rockfish. To help limit encounters of Yelloweye and Canary Rockfish, managers implemented fishing depth restrictions in 2006. *Marine Area* 4-Neah Bay (see Glossary), east of the Bonilla-Tatoosh Line, has been limited to 6 rockfish fish per day since 2010, while the western portion of *Marine Area* 4-Neah Bay has had a daily bag limit of 10 from 1995 through 2017. In 2017, in addition to seasonal restrictions, the bag limit was reduced to 7 rockfish (with a limit to the number of Canary Rockfish retained until 2019) in *Marine Areas* 1-4 west of the Bonilla-Tatoosh line and continued the prohibition of Yelloweye Rockfish retention. There are no size restrictions for the retention of Black Rockfish (WDFW 2021).

In 2020, an estimated 137.75 metric tons of Black Rockfish were landed by the recreational fleet, which was much lower than the past 5-year average of 281.47 metric tons per year (RecFin 2021). Reduced harvest during 2020 can be attributed to the closure of the coastal recreational fishery by state managers on March 25, 2020, because of the coronavirus pandemic. Recreational harvest was re-opened for Black Rockfish on May 26, 2020, but charter vessels were capacity limited, the halibut fishery opening was delayed, and several ports deferred opening or have yet to re-open. The Black Rockfish recreational fishery continues to be extremely popular and must be actively managed to ensure annual harvest guidelines are not exceeded.

Fisheries with regulations influence species distributions (Schroeder & Love 2002; Currie et al. 2019). In Washington, the recreational fleet accesses coastal fisheries from a limited number of primary ports: Neah Bay, La Push, Westport, and Ilwaco. The location of these ports influences rockfish harvest because of accessibility to rockfish habitat. In addition to fishery removals, spatial and temporal distributions of Black Rockfish are influenced by species specific life-history parameters and habitat requirements (Love, Yoklavich, & Thorsteinson 2002; Johnson et al. 2003; Miller & Shanks 2004). Researchers developing a survey design for Black Rockfish must consider fisheries impacts when determining spatial sampling coverage, in addition to species-specific biology, life-history characteristics, and movement patterns.

## **2.2 Black Rockfish (*Sebastes melanops*)**

### **2.2.1 Biology**

The genus *Sebastes* includes at least 124 species distributed in temperate zones of the Pacific and Atlantic oceans (STRI 2015). Black Rockfish are considered a semi-pelagic schooling species with a range that extends from Amchitka and Kodiak Islands in Alaska to

Huntington Beach in Southern California (Love, Yoklavich & Thorsteinson 2002). As adults, Black Rockfish school in the water column and are generally found above complex rocky habitats at depths less than 40 fathoms. (Love 2011). In a habitat association study done off the Oregon coast, researchers found that Black Rockfish showed a relationship with reef structure and a negative correlation with sand habitats (Easton, Heppell & Hannah 2015). Juveniles of this species are entirely pelagic, feeding largely on amphipods and copepods and shifting toward a closer association with the bottom as they age (Miller & Shanks 2004; Studebaker & Mulligan 2009; Studebaker, Cox & Mulligan 2009). As they grow their diet expands to include zooplankton, isopods, shrimp, octopuses, sand lance, and other fish, including juvenile rockfish (Love, Yoklavich & Thorsteinson 2002). Age estimates for this species are a maximum of 56 years with a size maximum of 69 cm (27.2 in) and 6 kg (13.3 lb), with females growing larger than males (Love 2011). In Washington, the state record for the largest Black Rockfish is 4.86 kg (10.72 lb) for a fish caught in May of 2016 (WDFW 2020).

### *2.2.2 Life History Parameters*

As a large nearshore rockfish species, the biology and life history of Black Rockfish has been relatively well studied and documented. Like all members of the genus *Sebastes*, Black Rockfish bear live young and produce hundreds to thousands of embryos in increasing quantities as they age (Bobko & Berkeley 2004). Berkeley, Chapman, & Sogard (2004) found that older Black Rockfish females produce embryos that grew faster and were better at resisting starvation than embryos from younger females. Female maturity is estimated to be at 50% at about 6-8 years (25-30 cm) and females grow 3-5 cm larger than males (Love 2011; Cope et al. 2016). A status report from WDFW documents some life history parameters for Black Rockfish off the Washington coast but highlights unresolved problems with natural and fishery mortality

estimates. Natural mortality is challenging to estimate because it can be mixed up with fishing mortality and is a very important parameter because of its effects on population dynamics (Wallace, Cheng, & Tsou 2008). Natural mortality estimates were explored during the 2015 Black Rockfish assessment (Cope et al. 2016), but more work may need to be done to consider how climate change impacts this species (Schwartzkopf et al. 2021; Markel & Shurin 2020).

### *2.2.3 Movement Patterns*

Tagging studies for Black Rockfish indicate that adults tended to have small home ranges (Parker et al. 2007; Green & Starr 2011). Parker et al. (2007) concluded that during a full year of monitoring of tagged Black Rockfish, home ranges were  $55 \pm 9$  ha with no seasonal variability. The WDFW Black Rockfish tagging program summary report for 1981-2008 also concluded that the largest proportion of tagged fish were recovered near the area of release and that there was a declining tagged fish recovery with increasing distance from the release area (Wallace et al. 2010). For adult fish with small home ranges, and a high association with rugose rocky habitats, only a few sampling methods can adequately capture adult fish. Additionally, understanding the home range of a species, what they eat as adults, and general movement patterns, inform researchers on how to conduct a survey both spatially and temporally to capture a representative sample of the population.

## **2.3 WDFW Surveys and Pilot Studies**

### *2.3.1 Coastal Black Rockfish Tagging Program (1981-2014)*

In 1981, the WDFW initiated the Black Rockfish tagging program with objectives focused on producing estimates of abundance, growth, survival, and natural mortality (Wallace et al. 2010). Wallace et al. (2010) described how Black Rockfish were tagged and released off

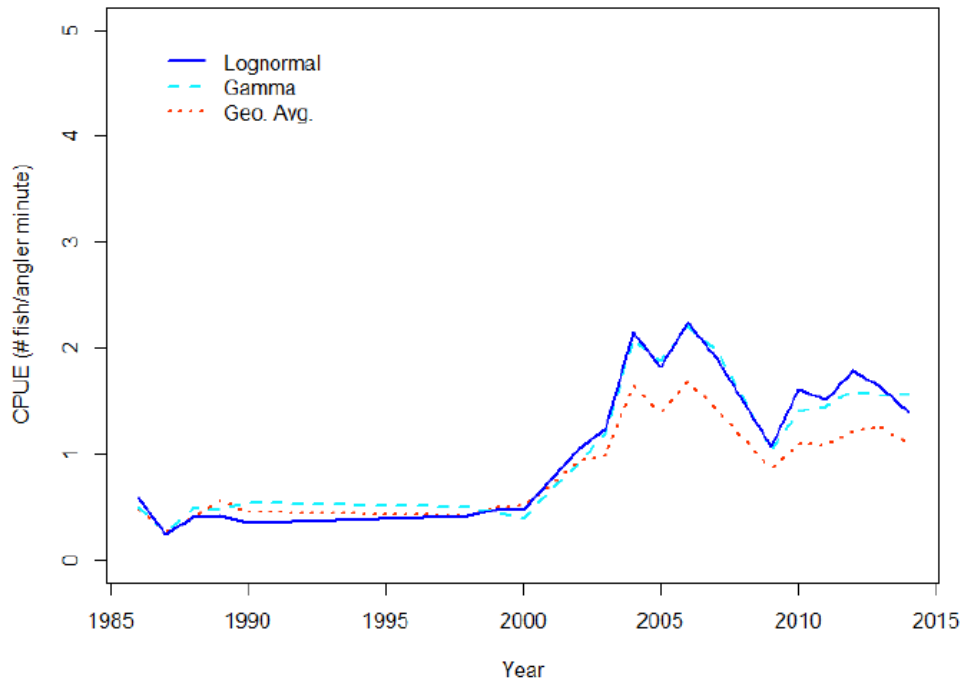
the Washington coast in four *Catch Record Areas (CRA)* (see Glossary), with the program releasing and recovering the highest number of fish (65,714 and 4,783 respectively) in CRA 2 from 1981-2007. Changes to this tagging program happened over time with large modifications occurring in 1998, including changing the tag type from external to internal. Wallace et al. (2010) noted that with this tag type modification recovery of tagged fish changed from voluntary fishery recovery to only dockside fishery recovery by samplers as the tags were no longer visible. Over the course of the program many vessels (research and recreational charter fleet) were used as tagging platforms with the WDFW staff onboard following survey sampling protocols. Data collected for the duration of the program included length, sex (when possible), and fishing time. Additionally, throughout the program, anglers were always targeting Black Rockfish although sampling locations were inconsistent and limited (Wallace et al. 2010).

Rocky habitat is not evenly distributed along the Washington coast which hinders uniform tagging efforts. Because of this patchy habitat distribution, sampling methodology for the WDFW tagging program changed from ‘local knowledge’ pre-2001, to a more formal distribution of effort starting in 2001 (Wallace et al. 2010). In 2001, researchers used georeferenced rocky habitat to create a study area divided into 2° latitudinal blocks, which were then weighted by proportion of habitat and used to distribute tagging effort (Wallace et al. 2010). In 2010, the WDFW expanded the traditional tagging program to include additional sites and added a fall tagging period (WDFW Marine Fish Science Unit 2017). Changes to the program resulted in increased tag deployments and increased geographic distribution of Black Rockfish tags from 2010 through 2013. In 2014 a shift in funding stopped tagged Black Rockfish releases, but dockside tag recovery work for Black Rockfish continued until 2017 (WDFW Marine Fish Science Unit 2017).

The 2015 Black Rockfish assessment (Cope et al. 2016) for the Washington portion of the stock used the WDFW Black Rockfish tagging program release data from 1986 through 2014 to calculate abundance indices to inform the SS model. In this model, the indices derived from the tag release portion of the program were based on CPUE of anglers and was calculated by the angler fishing minutes, by month, and by CRA.

$$CPUE = \frac{Catch \text{ (\# of Fish)}}{Effort \text{ (Angler Fishing Minutes)}}$$

Assessment authors limited the dataset to the most consistent time for tagging fishing trips (spring), and to the area where most trips occurred (CRA 2). Cope et al. (2016) used a modified generalized linear model (delta-GLM; Lo, Jacobson & Squire 1992) to model CPUE where the positive catch component was modeled using the lognormal and gamma distributions. (Figure 1). The use of CPUE data is known to have limitations, but if collected properly, standardized, and used appropriately, CPUE data can be used to create an informative index of abundance (Shono 2008; Maunder & Punt 2004). The 2015 SS model for Washington, specifically the version using the gamma distribution of the abundance indices, was accepted as the best available science on the status of the stock in 2015 (Advisors 2015).



**Figure 1.** Abundance indices derived from the WDFW tagging CPUE analysis and used in the 2015 assessment of the Washington stock of Black Rockfish. The three different lines represent the lognormal, gamma, and geometric averaged distributions used to model the positive catch component (Cope et al. 2016).

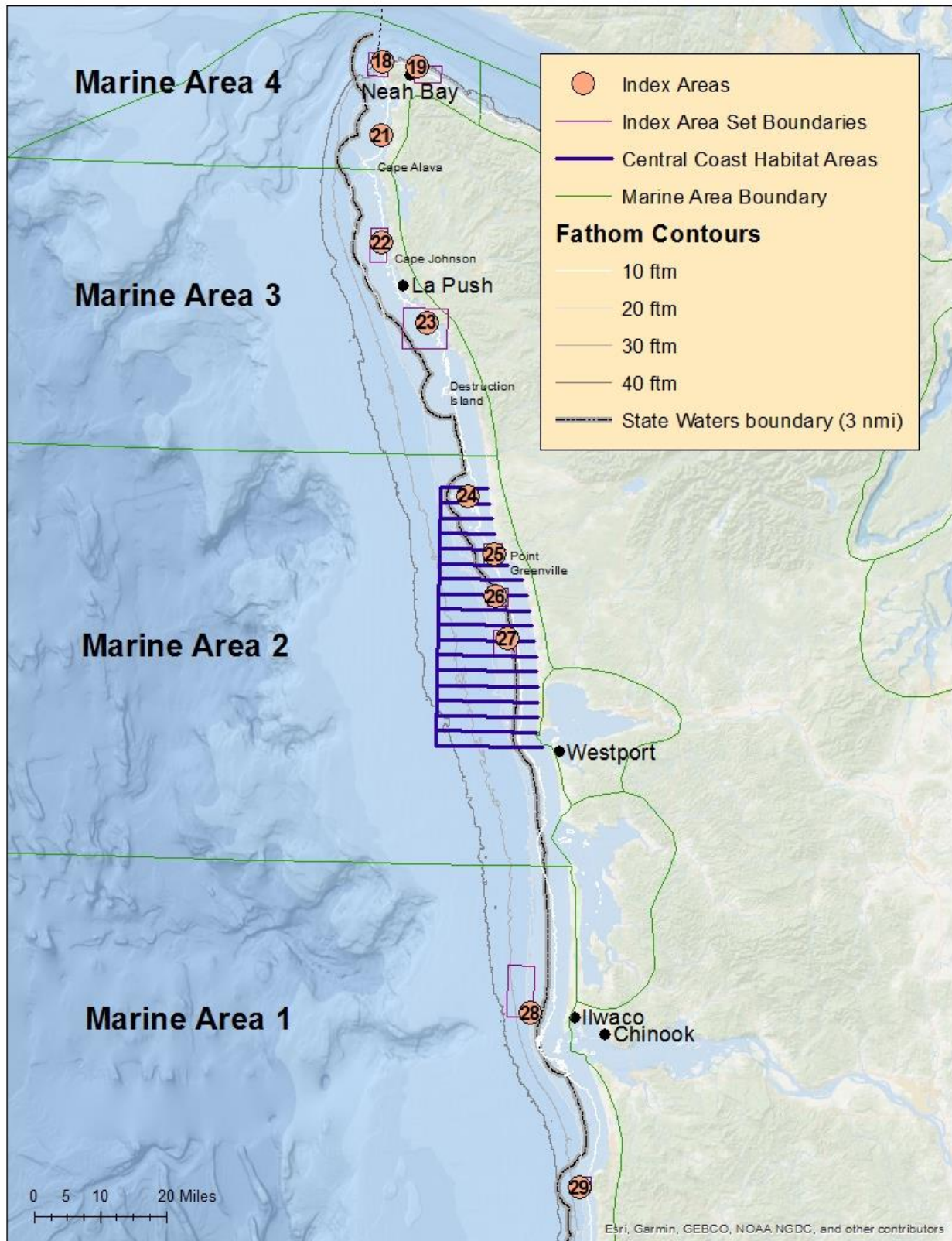
Tagging program data used in the 2015 assessment was provided by the WDFW to the stock assessment authors for model development. For this thesis work, during examination of the tagging data used to create the abundance indices that was used in the 2015 Black Rockfish stock assessment model, an error was found in the calculation of angler fishing minutes. Effort was calculated using boat minutes, which was defined as the amount of time the boat was onsite fishing, instead of angler minutes as stated in the 2015 assessment. The number of anglers varied by boat and by survey. This CPUE calculation error will be discussed further in the results and discussion sections.

Limitations of the data available from the WDFW Black Rockfish tagging program to inform abundance indices for multiple bottomfish species, prompted managers to initiate pilot studies to help inform the design of a new multispecies survey. One of the first components

managers evaluated was survey timing. Budget, ocean conditions, and vessel availability prevent year-round survey effort, so managers initiated the Seasonal Rod-and-Reel Pilot Study (below) to evaluate seasonal effects on bottomfish catch to help identify the optimum time of year to sample.

### *2.3.2 Seasonal Rod-and-Reel Pilot Study (2010-2013)*

In 2010, the WDFW initiated a pilot study with a goal of describing seasonal effects on bottomfish catch during rod-and-reel surveys to address concerns highlighted in the 2007 scientific review of the Northern Black Rockfish assessment (Advisors 2007). Additional details about the pilot study can be found in the unpublished WDFW report *Rod-and-Reel Pilot Study of Washington Coastal Index Areas*, but pertinent information for Black Rockfish is summarized here. Eleven areas from Cape Flattery WA to Cape Falcon OR were sampled and included the eastern portion of Marine Area 4, inside the Strait of Juan de Fuca (Figure 2). Surveys began in the fall of 2010 and occurred in both the spring (March-May) and fall (August-October) seasons in 2011 and 2012 and concluded in the spring of 2013.



**Figure 2.** Coastwide survey areas for the seasonal rod-and-reel pilot study of Washington coastal index areas (unpublished WDFW report). Map provided by Rob Davis, WDFW.

During this seasonal rod-and-reel pilot study, the terminal tackle (bait types) used to catch fish were not standardized, but tackle was selected by experienced boat captains to be the most efficient at catching pelagic rockfishes. Effort at each sampling location was based on a “set” which was thought of as fishing time with no significant change in effort, gear, or location, either anchored or unanchored, and could include multiple drifts (WDFW unpublished report). Data collected for each set included the number of anglers fishing, fishing depth, active fishing time in minutes, species caught, fork length, and tag information (if tag present). Uninjured fish not needed for ancillary research projects were released at the site of capture, using a descending device if warranted. Data analysis and conclusions from this pilot study had not been completed prior to the writing of this thesis, but the raw data was provided by the WDFW for analysis.

Understanding seasonal movement of a species can inform sample timing when developing a survey design. Movement patterns of Black Rockfish evaluated by Parker et al. (2007) showed no seasonal variation, however, females > 39 cm spent more time outside of a monitored area than males during the reproductive season (Nov., Jan., and Feb.) and both sexes had the longest absences from monitored areas from April through July. Variable catch rates based on movement should be considered when designing a survey for abundance estimates. Optimal timing for a survey varies by target species and this pilot study helped inform WDFW on which season had higher catch rates for the largest number of the targeted bottomfish species. In addition to exploring optimal survey timing, WDFW also needed to define the amount of optimal habitat available for targeted bottomfish off the Washington coast.

### *2.3.3 Rocky Habitat Exploration (2014-2015)*

Rocky habitat has a patchy distribution along the Washington coast and complete high precision bathymetric maps have historically been unavailable, hampering nearshore surveys for

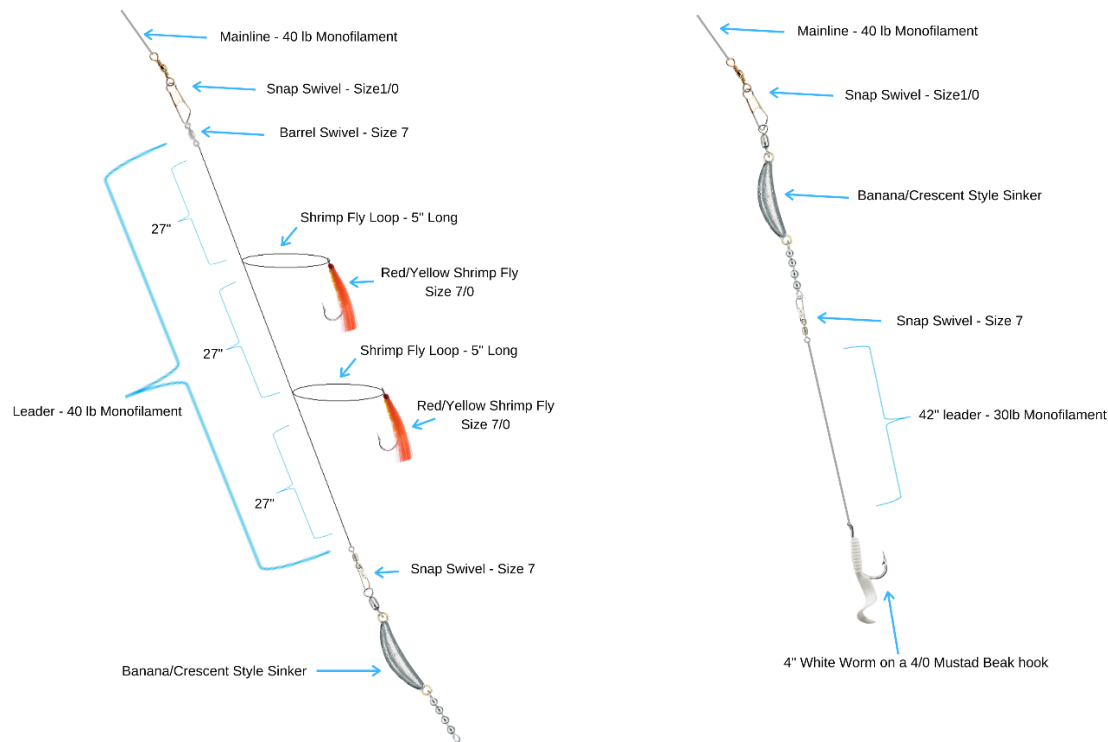
rocky habitat associated species. In 2015, the WDFW developed a systematic survey grid based on extensive habitat exploration work done in 2014 to facilitate geolocation of rocky habitat in CRAs 1-4 off the Washington coast. The WDFW unpublished report - *Washington Coastal Survey Grid Design (Appendix A)* details the extent, creation, and rationale of a survey grid. This grid system breaks the coastal nearshore into 3,000 meter<sup>2</sup> cells for all waters inside the 30-fathom contour with additional cells covering known rocky habitats that extended to 40-fathoms (WDFW unpublished report). By using this grid system WDFW was able to designate grid cells that included, or did not include rocky habitat, essentially quantifying the amount of rocky habitat off the nearshore coast. Based on habitat designation by grid cell, surveys could be stratified by habitat type (WDFW unpublished report).

Rocky habitat in the marine environment includes rocky reefs, boulders, and pinnacles. The Olympic Coast National Marine Sanctuary explains on their website that “structure” is the key to rocky reef habitat which create crevices or shelter, and that off the Washington coast many reefs represent islands of rock surrounded by broad expanses of sand (National Ocean Service 2022). Black Rockfish are associated with structure, as are many of the other bottomfish the WDFW targeted with the Rod-and-Reel Survey (Love 2011). Identifying areas of optimal habitat type helped narrow-down where targeted species were likely to occur off the Washington coast, but the best way to sample these fish in these habitats still needed to be further explored to help inform survey methods.

#### *2.3.4 Terminal Tackle Pilot Study (2014 & 2015)*

The WDFW initiated a pilot study in 2014 with the objective of identifying terminal tackle types that would increase the diversity of bottomfish catch by a rod-and-reel survey without reducing catch rates of Black Rockfish (WDFW unpublished report). Historically,

terminal tackle used during the WDFW surveys targeted semi-pelagic schooling species. For example, the Black Rockfish tagging program used one to three single hook jigs with shrimp flies and/or artificial worms (Wallace et al. 2010; Figure 3). The terminal tackle pilot study focused on catch distribution and catch rate comparisons of both pelagic and demersal species by terminal tackle type. Details about this pilot study can be found in the unpublished WDFW report *Selectivity of Terminal Tackle in Groundfish Rod-and-Reel Surveys Off the Washington Coast*, but pertinent information about this survey as it relates to catch rates of Black Rockfish by terminal tackle type is summarized here. Comparison surveys for terminal tackle types were done in March, April, and May of 2014 and 2015 in coastal CRAs 1-4. The methods used for the terminal tackle surveys conducted in 2014 drastically differed from those done in 2015, making comparisons between the two years difficult. Differences included types of terminal tackle tested and how much time each bait type was fished. Analysis of survey data for Black Rockfish terminal tackle preference was incomplete prior to the writing of this thesis. The WDFW provided data from this pilot study for analysis.



**Figure 3.** Diagram of the standard “shrimp fly” tackle with two hooks that can be baited with artificial worms or squid (left) and a diagram of the “mooching rig” (right). The mooching rig shown here is baited with an artificial worm. (Diagrams courtesy of K. Hinton WDFW).

The effectiveness of terminal tackle used in a hook-and-line survey is entirely dependent on the behavior of the fish, which can be influenced by many factors including currents, light level, temperature, fish density, and prey availability (Stoner 2004). Coghlan et al. (2017) used baited underwater video to find that fish density influenced feeding behavior and noted behavioral differences based on the duration of baited sampling times. A study on catch rates of largemouth bass concluded that size was the strongest predictor of capture, regardless of prey availability (Keiling, Louison & Suski 2020). If behavioral factors are not considered, catch rates could be based more on behavior variation than abundance trends (Stoner 2004; Kuriyama et al. 2019).

Data collected during the terminal tackle pilot study was used to evaluate changes in catch rates of targeted bottomfish species. Following this pilot study researchers further

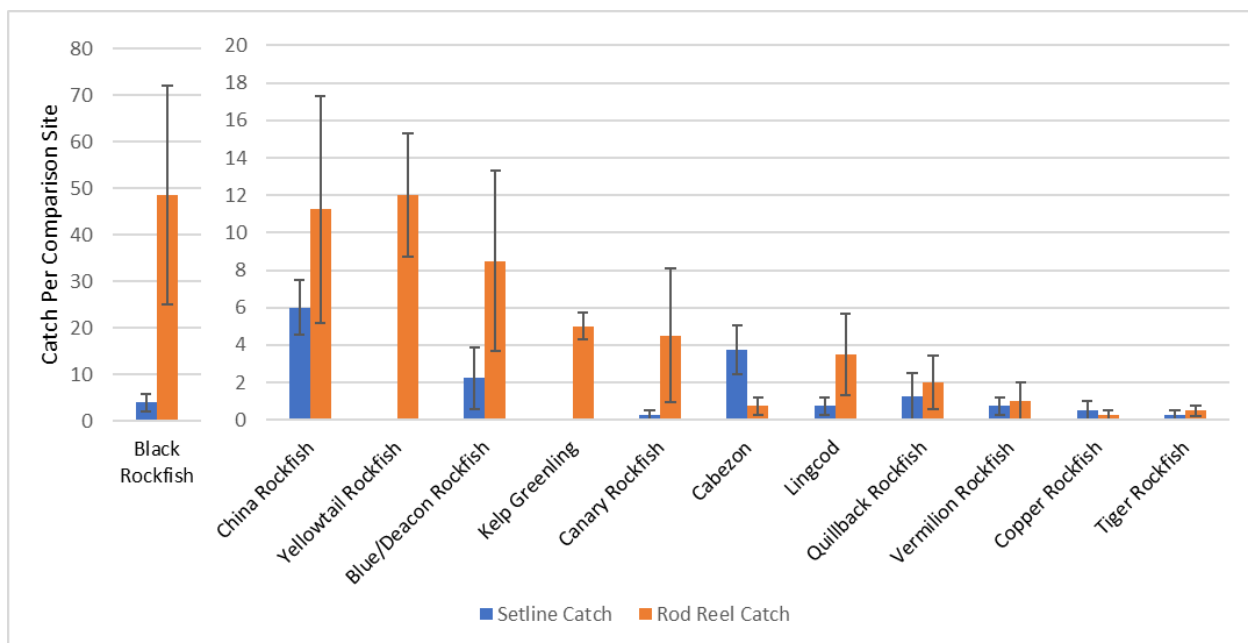
questioned whether rod-and-reel was the most efficient and effective gear to catch targeted bottomfish species (R. Davis WDFW, personal communication). To evaluate this concern a pilot study based on gear type was initiated by the WDFW in 2016.

#### *2.3.5 Rod-and-Reel vs. Set-line Pilot Study (2016-2017)*

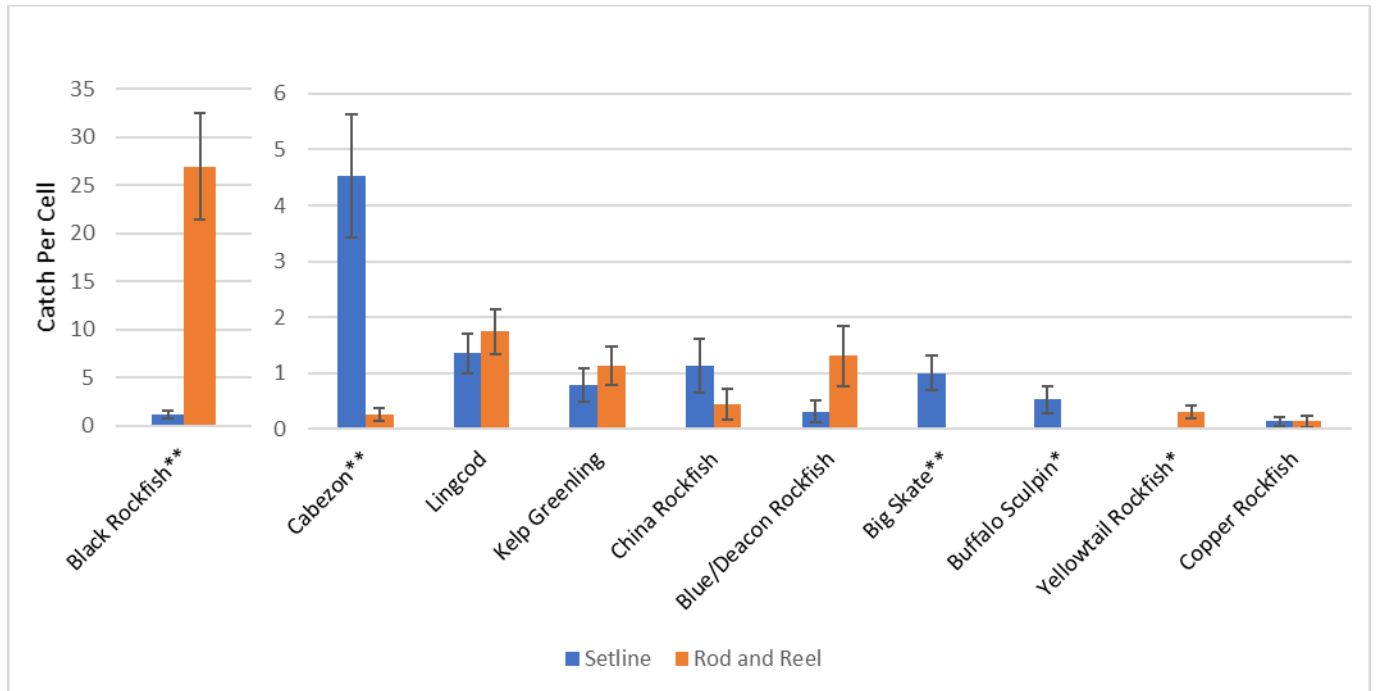
From 2016 through 2017 the WDFW explored the effectiveness of set-line gear to survey nearshore coastal populations of bottomfish (WDFW unpublished report). The primary objective of this pilot study was to develop a survey capable of providing an index of abundance for multiple bottomfish species including, but not limited to, Cabezon, Kelp Greenling, Lingcod (*Ophiodon elongatus*), and rockfishes. Additionally, a second objective was to compare set-line survey catch-rates and species diversity with a traditional rod-and-reel survey. Various set-line gear configurations and hook sizes, adapted from the International Pacific Halibut Commission (IPHC) Fishery-Independent Set-line Survey (IPHC 2017), were used during the study in an attempt to optimize catch rates (WDFW unpublished report).

During this pilot study, a rod-and-reel vs. set-line comparison was done at 5 locations over 5 days in 2016 and another comparison study was done at 31 locations in both spring and fall of 2017. Detailed methods for both studies can be found in the unpublished WDFW report *Set-line Survey of Washington's Nearshore Groundfish Species: Method Development and Gear Selectivity*. Results showed that set-line methods developed for both comparison surveys worked well for highly rugose rocky habitats off the Washington coast. The WDFW also concluded that species composition for set-line gear was significantly different from the traditional rod-and-reel surveys. Normalized fishing effort by gear type showed higher set-line catch rates of demersal species including Cabezon, Big Skate, and Buffalo Sculpin when compared to the rod-and-reel surveys which were dominated by pelagic schooling rockfishes including a significant difference

for Black and Yellowtail rockfish. Black Rockfish catch was significantly higher with rod-and-reel gear in both comparison studies (Figures 4 & 5) however, fish caught with set-line gear had greater mean lengths than those caught with rod-and-reel gear. Results showed that the two survey gear types are not interchangeable but could be considered complementary if attempting to survey both pelagic and demersal species (WDFW unpublished report). Huntington and Watson (2017) also suggest that a combination of a rod-and-reel and set-line surveys would be robust as an abundance estimation program for diverse bottomfish species and would be a preferable survey strategy.



**Figure 4.** Bar graph from an unpublished WDFW report showing the number of individuals caught per comparison site (general location) of species comprising over 1 % of the total catch of the gear comparison study in 2016. Black Rockfish catch was plotted on a different y-axis scale. Error bars represent one standard error of the mean. (WDFW unpublished report)



**Figure 5.** Bar graph from the WDFW unpublished report showing the number of individuals caught per 3-kilometer squared grid cell of species comprising over 1 percent of the total catch of the gear comparison study. Black Rockfish catch was plotted on a different y-axis scale. Error bars represent one standard error of the mean. \* Indicates  $P < 0.05$  and \*\* indicates  $P < 0.01$  from a Wilcoxon rank-sum test (WDFW unpublished report).

## 2.4 Nearshore Survey Considerations and use of CPUE for Abundance Indices

A wide variety of survey gear types are employed to collect fishery-independent data for use in calculating fish population abundance estimates. Surveys utilizing trawl gear, hydroacoustic, visual (e.g., SCUBA, remotely operated vehicles, submersibles), and hook-and-line gear each have advantages and limitations (Koeller 1991; Jagielo et al. 2003; Jones et al. 2012; Keller, Wallace & Methot 2017; Pacunski et al. 2020). For semi-pelagic Black Rockfish off the coast of Washington, several of these survey methods are unviable, due to the species high association with rocky habitat and wide depth distribution. Bottom trawl surveys are not effective in sampling rocky habitats because of gear damage, snags, and habitat impacts. Hydroacoustic surveys also have limitations for assessing this species because of the limited ability of the sonar technology to discern targeted fish from the bottom echo return (Parker et al.

2007; Patel, Pedersen & Ona 2009). Visual surveys using remotely operated vehicles or submarines can sample rocky habitats and collect species information, however biological sampling is lost and behavioral responses to the vehicle may bias results (Stoner et al. 2008; Laidig, Krigsman & Yoklavich 2013; Pacunski et al. 2016). Surveys using SCUBA have depth and time limitations that are too great for fully assessing coastal rockfish populations. Hook-and-line surveys, if designed appropriately, appear to be the best available gear type to sample and assess coastal Black Rockfish populations.

Over time, research has shed light on the many strengths and weaknesses of rod-and-reel surveys (Harms, Wallace & Stewart, 2010; Kuriyama et al. 2019). Although this gear type is well suited for sampling rocky reef habitats and allows for the collection of biological data, other factors need to be considered. Survey locations, hook saturation, and competition can all bias abundance estimates, but these may be mitigated through sampling design (Harley, Myers & Dunn 2001; Kuriyama et al. 2019). Kuriyama et al. (2019) recommended “density-based sampling” (p. 193) for rod-and-reel surveys which is a survey design that samples areas of higher probabilities of high densities but concluded that hook-saturation leading to hyperstability, and competition might be an issue. Hyperstability in rod-and-reel surveys was addressed in Kuriyama’s dissertation where simulations were used to evaluate CPUE abundance trends for patchily distributed fish. They concluded that hyperstability was high for surveys of patchy distribution and affected the relationship between abundance and CPUE. However, hyperstability decreased with preferential sampling surveys (density-based sampling) and increased sample size (Kuriyama 2018). They also concluded that changes to CPUE were detectable with preferential sampling surveys and more sample sites.

A hook-and-line survey conducted in southern California for shelf rockfish since 2003,

through a cooperative effort between NOAA Fisheries, Pacific States Marine Fisheries Commission, and the sportfishing industry, has been used for 14 stock assessments since 2019 (Northwest Fisheries Science Center 2021). An analysis performed on those data in 2010 concluded that when standardized using a Bayesian Generalized Linear Model to account for the effects of location, fishing time, number of anglers and other statistically significant effects, the data were adequate for calculating abundance indices (Harms, Wallace & Stewart 2010). Current sampling protocols for this survey specify that 3 anglers make 5 deployments of a five-hook sampling rig at each of 200 fixed stations in the Southern California Bight to target multiple rockfish species (Harms, Benante & Barnhart 2008; Northwest Fisheries Science Center 2021). Hook saturation and competition was a concern for this survey and researchers stated that they addressed these problems by increasing the number of drops from 3 to 5 with each angler having 5 hooks per line. They concluded that this would reduce the frequency of returning saturated gear (Harms, Benante & Barnhart 2008). Information gained for other research and surveys targeting bottomfish can help to inform survey design. Consequently, the WDFW Rod-and-Reel Survey was evaluated with these considerations in mind.

## **2.5 WDFW Coastal Rod-and-Reel Survey (2019-2021)**

The coastal nearshore Rod-and-Reel Survey was developed to address the need for a fishery-independent method to inform multiple bottomfish assessments for Washington stocks. The following is a synopsis of the survey design, and more specific details can be found in the WDFW unpublished report *Washington Department of Fish and Wildlife's 2019 Coastal Rod-and-Reel Survey Design*. The Rod-and-Reel Survey is designed to occur in spring months (March-May) at 125 index stations in CRAs 1-4 off the Washington coast annually. Index stations were selected using a survey grid schema. The first step in the selection process was to

overlay a one-kilometer squared grid on all waters to 40-fathoms and to identify grid squares (cells) that contained rocky reef habitat. Each cell was assigned a unique number sequentially from south to north and west to east. From these grid cells, 114 cells were random-systematically selected. Selection was done by starting at a random cell and systematically choosing cells at a preset interval to produce the total number that was feasible to sample in a single survey season. Of the original selected cells, 7 were eliminated due to hazards or other known location problems, and 18 were intentionally added to aid in distributing effort more evenly across habitat by CRA. The final number of one-kilometer squared grid cells selected for the Rod-and-Reel Survey was 125. Within each cell a single GPS position based on the center of the known rocky habitat was identified and used as the index station location.

Recreational charter vessels are contracted by WDFW to conduct the survey each year. Survey crews consist of five hired anglers and 3-4 WDFW scientific staff. To complete the full annual survey, approximately 21 fishing day trips are required. Each survey day, the lead biologist and vessel captain work closely to ensure sampling is started at the index station with boat movement tracked using Coastal Explorer™ navigation software. Near each index station a model SBE 19+ V2 conductivity, temperature, and depth instrument (CTD) fitted with a SBE 43 dissolved oxygen sensor and Cyclops-7 fluorescence sensor is deployed to profile the water column. On board the vessel, data are electronically collected on tablets using input interfaces constructed in iForms and Microsoft Access then exported to a Microsoft Access database where it is error checked. Customized queries are used to check for outliers and data isn't finalized until all quality control checks are completed at the end of the annual survey, when it is uploaded to the master survey database.

Standardized fishing rods, reels, and terminal tackle (2 shrimp flies tied on a pre-tied

leader above a dropper weight) are supplied by WDFW to each angler. Each angler is also equipped with a stopwatch, which they start at the beginning of each drift, pause when dealing with landed catch or servicing gear, and stop at the end of the drift. A “drift” is defined as any uninterrupted time span that is spent fishing, beginning when the first angler’s hook enters the water and ending when the last angler’s hook leaves the water for any reason. Drifts last approximately 8 minutes (R. Davis WDFW, personal communication). At each index station, five anglers fish from the vessel for a total of 4 drifts. Anglers target rockfish that typically school above rockpiles. Landed catch is associated to the angler, identified by species, measured, sexed (when possible), scanned for tags, and recorded by index station, depth, and drift number. Catch is measured as fork length in centimeters. Fish that are brought out of the water, but lost at the rail, are documented, and noted as ‘drop off’. Some select bottomfish species receive tags or are retained for age structure sampling. Additional data collected for each day and index station includes environmental and ocean conditions, personnel/boat details, location of angler position on the boat, tag release and recovery, and gear loss. The Rod-and-Reel Survey has been conducted annually since 2019, however not all index stations were surveyed in 2020 because of the coronavirus pandemic.

## **2.6 Considerations**

This thesis asks if the WDFW Rod-and-Reel Survey has the ability to detect changes in coastal Black Rockfish population abundance. The above literature review provides the background information for an evaluation of the design. Historic and current exploitation, biological characteristics, and information gained from pilot studies, assessment reviews, and research were considered during the evaluation and will be further discussed in the conclusion and discussion section.

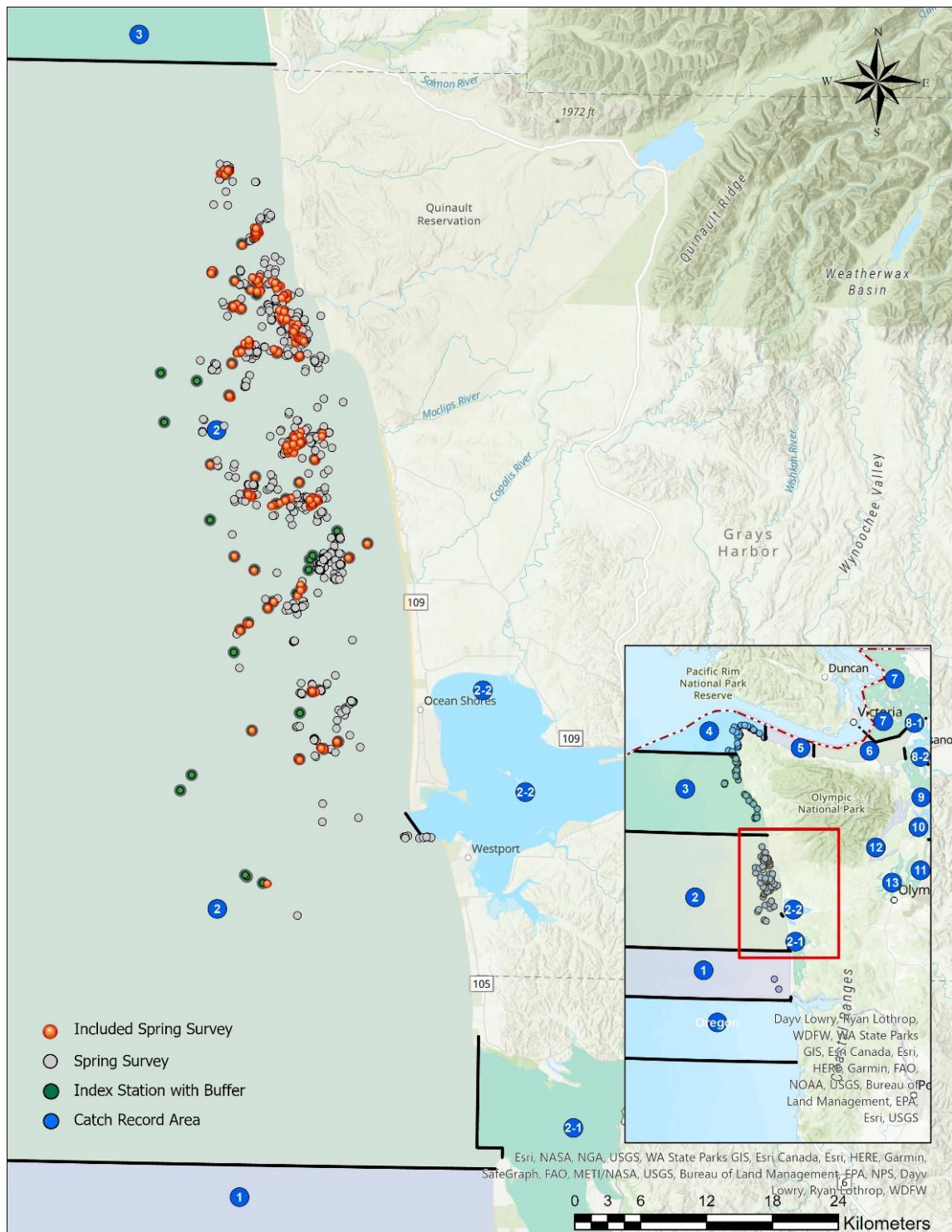
### **3. Methods**

Informative surveys are designed based on target species specific considerations, consider sampling gear limitations, and attempt to mitigate for bias. Therefore, the WDFW Rod-and-Reel Survey design must be considered from multiple perspectives to determine whether it is able to detect abundance changes in the Black Rockfish stock. Evaluation of the WDFW Rod-and-Reel Survey design focused on 4 components: location, terminal tackle and gear type, timing, and effort. All analyses described below were performed in R, the statistical computing language (R Core Team 2021) unless otherwise noted.

#### **3.1 Survey Location**

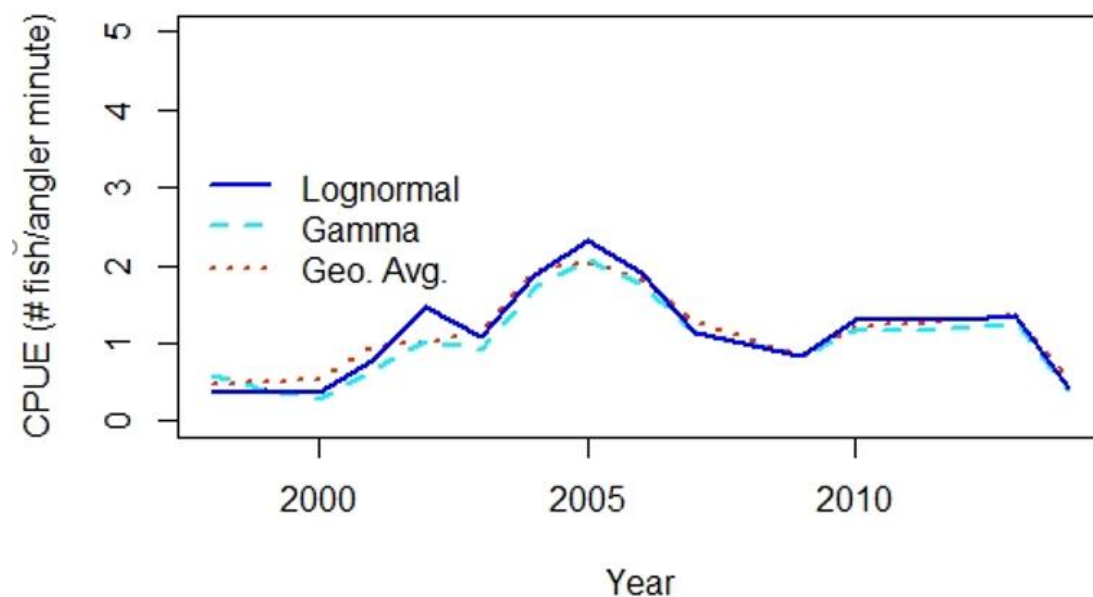
The WDFW Rod-and-Reel Survey limits sampling effort to 125 index stations, of which 66 fall into CRA2 off the Washington coast. To evaluate whether sampling at these selected index stations produces representative abundance indices for Black Rockfish, a comparison of two abundance indices was done. The first abundance indices were created by stock assessment authors from tagging data collected during the WDFW Black Rockfish tagging project (Wallace et al. 2010) and used in the 2015 Washington Black Rockfish SS model (Cope et al. 2016). These indices were compared to a second set of abundance indices created by limiting the same data set to only surveys conducted near index stations. To determine which survey events to include, all WDFW Black Rockfish tagging program surveys from 1986-2014 and the index station locations were mapped using ArcGIS Pro (ESRI 2019) (Figure 6). Spring (February-July) surveys, i.e., tagging or fishing events, that fell within a 500-meter buffer of an index station in CRA2 were selected for inclusion in the calculation of the index station abundance indices. A total of 435 surveys met these criteria. Because selected surveys were very sparse before 1998, and post-1998 no major changes happened in the WDFW Black Rockfish tagging program, only

surveys from years 1998-2014 were used in the calculation of the index station abundance indices. Ultimately, 400 surveys were included in the abundance indices CPUE calculation at index stations.



**Figure 6.** Locations of the historic Black Rockfish tagging program spring surveys (grey dots) off the Washington coast in CRA2. Index Stations are displayed with a 500-meter buffer (green circles), and most are obscured by survey dots. Tagging surveys that fell within the index station buffer are displayed as orange dots and were included in the index station abundance indices CPUE analysis.

Index station abundance indices were calculated using catch of Black Rockfish per boat<sup>1</sup> minute with covariates month and CRA and modeled using a delta-GLM approach (Lo, Jacobson & Squire 1992). This approach was identical to the that used in the 2015 Washington Black Rockfish assessment (Cope et al. 2016) and for ease of comparison was plotted in the same way as in the assessment report to show lognormal, gamma, and geometric average distributions (Figure 7).



**Figure 7.** Abundance indices for index station CPUE for 1998-2014 with lognormal, gamma, and geometric average plotted for ease of comparison to the abundance indices for the WDFW tagging CPUE analysis from the 2015 assessment of the Washington Black Rockfish stock.

Prior to analysis, the tagging CPUE abundance indices used in the 2015 assessment were truncated to only surveys conducted from 1998-2014 for comparison to the index station abundance indices. To determine if the index station abundance indices induced large changes in the 2015 stock synthesis assessment model, the SS model was run using index station abundance indices.

<sup>1</sup> Effort was calculated using boat minutes in the original stock assessment, not angler minutes. Figure labels were left as angler minute to avoid confusion during comparison to the original figures (Cope et al. 2016).

The base model used in the 2015 assessment used SS version V3.24U-safe (Methot 2014; Cope et al. 2016). This version was also used for all new model runs which included: 1) truncation of original tagging abundance indices to years 1998-2014 (with the removal of length composition data prior to 1998), 2) replacing the original indices with the index station abundance indices for years 1998-2014 (including only length composition data from index station surveys), and 3) removal of the entire abundance indices (including all tagging length composition data). The gamma distributions for each set of indices were used to remain consistent with the 2015 assessment model. The model run that included indices from index stations was not re-tuned, and the relative coefficients of variations (CVs) used with the index station abundance indices were not adjusted from the original model, to see the impacts of the index station CPUE abundance indices on the model output. When the entire tagging indices were removed from the model, the model was re-tuned using the methods of Francis (2011). One issue to note when comparing model run output was the addition of extra variance to the Washington CPUE indices in the 2015 SS model, reducing the overall influence of the indices (Cope et al. 2016). In addition to considering model impacts of the index station indices, the relationship between the two indices was also evaluated.

### **3.2 Survey Terminal Tackle and Gear Type**

In the spring of 2014 and 2015 the WDFW conducted a pilot study to determine which type of terminal tackle had the highest catch rates of pelagic schooling species and other recreationally targeted benthic bottomfish (WDFW unpublished report). The survey methodology differed by year and therefore for this analysis each year was analyzed separately. The CPUE of Black Rockfish by angler minute by terminal tackle type for each year of the study was calculated. A Kruskal-Wallis rank sum test with a post hoc Dunn's test (Dunn 1964) was

used to determine which terminal tackle types were significantly different for Black Rockfish.

Concerns over species specific tackle selectivity coupled with rod-and-reel survey standardization issues prompted the initiation of a pilot study to compare set-line vs rod-and-reel survey gear methods (WDFW unpublished report). From 2016 to 2017 the WDFW examined the effectiveness of set-line gear to capture bottomfish in rocky habitats. Analyses using the Wilcoxon rank-sum test, Kruskal Wallis H test, and a two-way analysis of similarity (ANOSIM) were done by the WDFW to determine catch rates by species based on gear type and season (WDFW unpublished report). These analyses performed by WDFW were abridged for only Black Rockfish by gear type and presented in this thesis.

### **3.3 Survey Timing**

Determining the catchability of multiple bottomfish species of ecological and fishery importance was a primary research objective during the seasonal rod-and-reel pilot study conducted from 2010 through 2013 (WDFW unpublished report). During this study 10 areas were surveyed in the spring and fall for three years. To determine if Black Rockfish catchability was higher by season, catch of fish by angler minute, by area, by season, and by year was evaluated using a linear mixed effects model which allowed for nested random effects. For this analysis CPUE at each location was compared by season over three years. The package lme4 was used in R for this modeling (Bates et al. 2015).

### **3.4 Survey Effort**

The Rod-and-Reel Survey design relies on 4 replicate passes or “drifts” at each index station for the station survey to be complete (WDFW unpublished report). Data from the Rod-and-Reel Surveys completed in 2019, 2020, and 2021 were used to assess effort at each index

station. A t-test was used to evaluate the difference in CPUE estimates by the number of drifts conducted by location for three survey years.

To evaluate if the number of index stations surveyed each year in the Rod-and-Reel Survey was high enough to be able to detect changes in Black Rockfish abundance a power analysis was done. A power analysis for a two-sample Z test was done to evaluate the risk of making a type II error (failure to reject the null hypothesis, when it is in fact false) using an online power calculator<sup>2</sup>. Rod-and-Reel Survey data collected in 2019 and 2021 were used for this analysis. Data from 2020 was excluded because not all index stations were surveyed due to the coronavirus pandemic.

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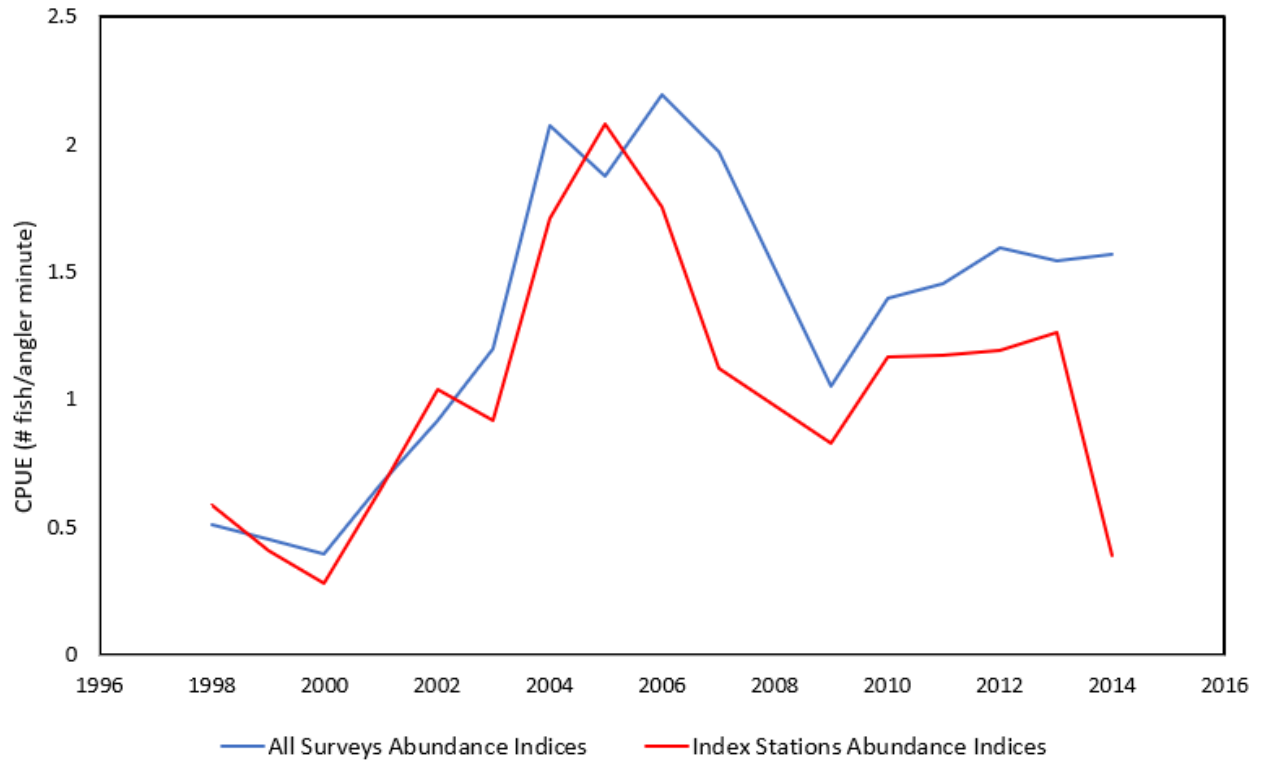
<sup>2</sup> The online power calculator used for this analysis is available at [https://ytliu0.github.io/Stat\\_Med/power2.html](https://ytliu0.github.io/Stat_Med/power2.html).

## 4. Results

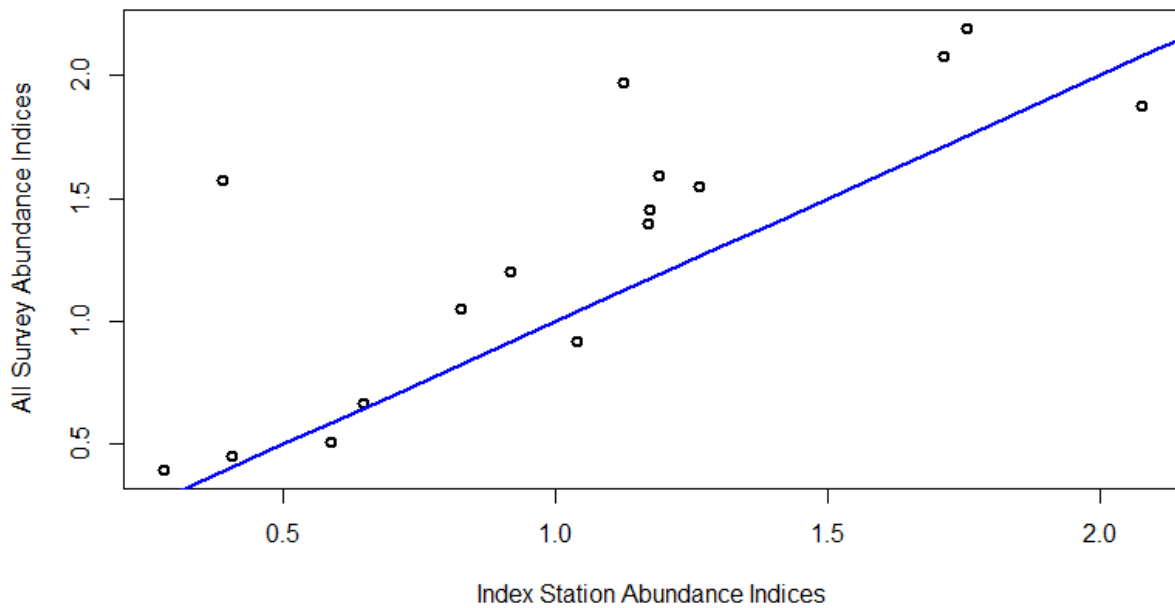
The WDFW nearshore coastal Rod-and-Reel Survey was evaluated to determine whether it can detect changes in Black Rockfish population abundance by analysis of 1) sampling locations, 2) terminal tackle and gear efficacy, 3) survey timing, and 4) survey effort. Each of these components was analyzed using an approach based on the type of available data from historic surveys, pilot studies, and the WDFW Rod-and Reel Survey. All data were provided by the WDFW.

### 4.1 Survey Locations

Abundance indices derived from data collected during the WDFW Black Rockfish tagging program *throughout* CRA 2 was compared to abundance indices calculated from surveys conducted at Rod-and-Reel Survey index stations within CRA 2, for the period 1998-2014. Overall, both abundance indices show similar trends over time (Figure 8). The single largest divergence, in 2014, may be attributed to the lower number of surveys completed near index stations CRA2 as the survey effort that year expanded and was distributed differently along the coast. Comparing individual CPUE estimates from each year to each other showed that the point estimates from *all survey locations* tended to be higher than those for *surveys only conducted at index stations* for Black Rockfish (Figure 9).

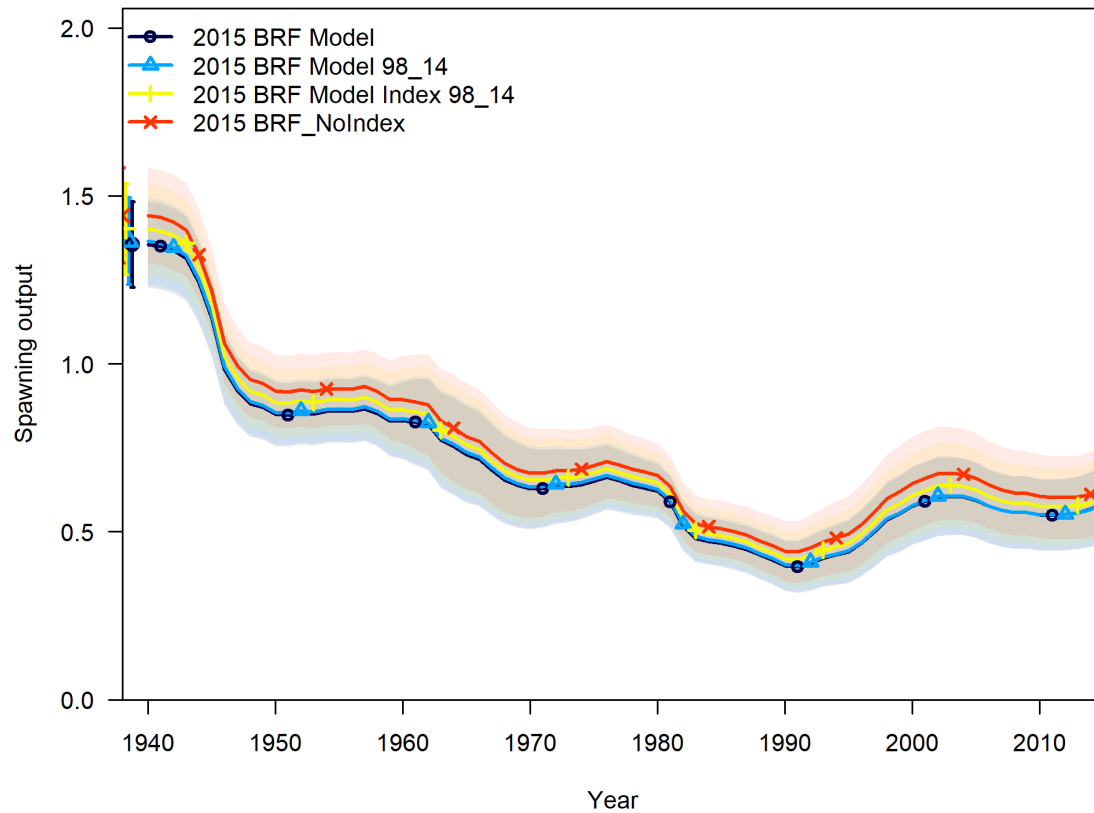


**Figure 8.** The gamma distribution of abundance indices calculated from all surveys and from surveys only conducted at index stations.

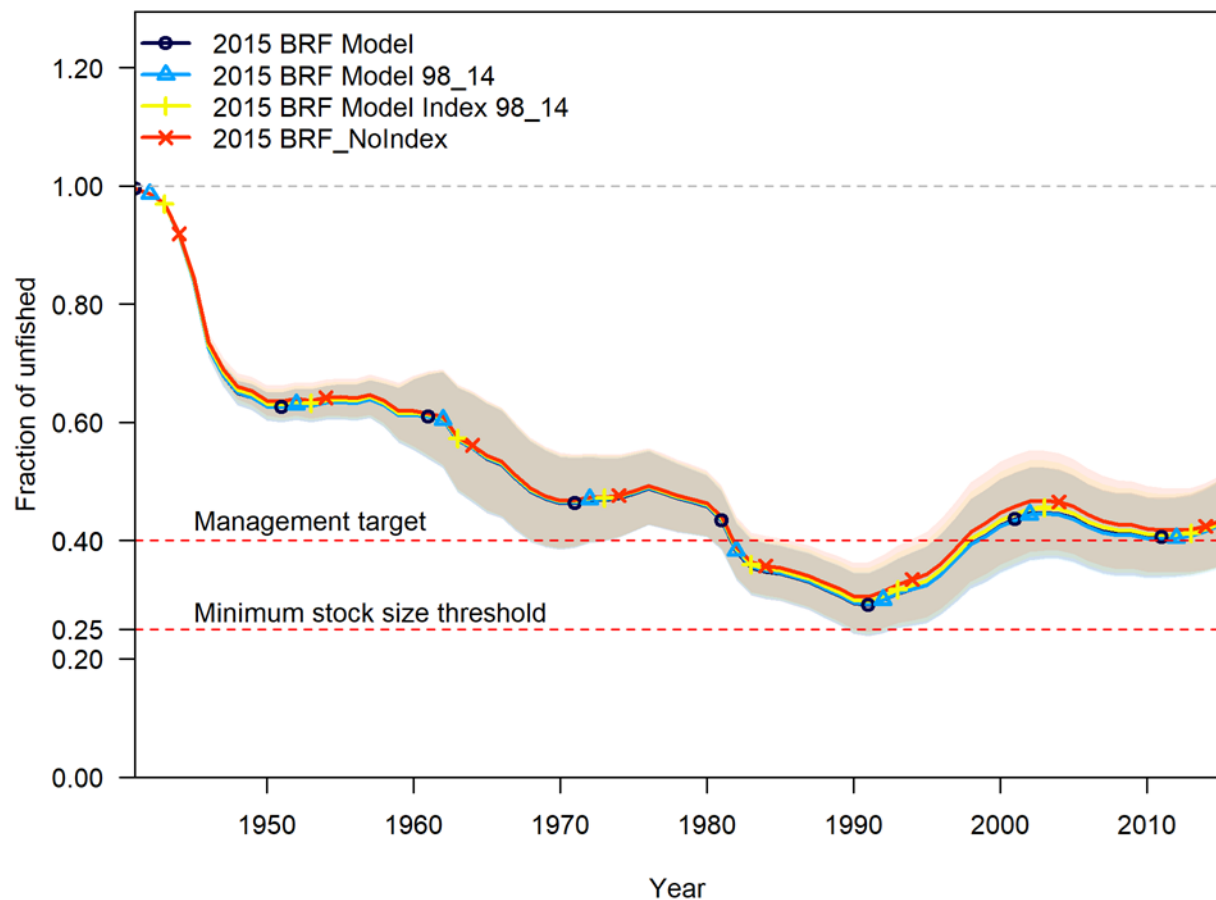


**Figure 9.** A scatter plot (each dot represents one year from 1998-2014) showing a comparison of CPUE abundance indices (using the gamma distributions) of all surveys with surveys at index stations. The blue line is a one-to-one line.

While the two abundance indices followed the same general abundance trends, there could have been a significant difference when informing the stock assessment model. To determine this, the two indices were compared using output from the SS model used in the 2015 Washington Black Rockfish assessment (Methot & Wetzel 2013; Cope et al. 2016). Differences in model output were compared for 4 model runs. Model runs included 1) the base model originally used in the 2015 WA assessment, 2) truncating the tagging CPUE abundance indices to the years 1998-2014 with removal of all length composition data pre-1998, 3) replacing the tagging CPUE abundance indices with the CPUE indices from index stations and including only length composition data from index station surveys, 4) removal of the abundance indices from the base model. No tuning or modifications of the coefficient of variation (CV) error were done with the truncated model run or the index station abundance indices model run. The model run with no abundance indices was tuned using Francis weighting as in the 2015 assessment (Cope et al. 2016). The stock synthesis results for spawning output and stock status are shown in Figures 10 & 11.



**Figure 10.** Time series of spawning output of Black Rockfish in Washington for 4 model runs with ~95% asymptotic intervals. The dark blue circles show the original model run from the 2015 assessment, the light blue triangles show the same data truncated to the years 1998-2014 with pre-1998 length compositions removed, yellow plus signs show the model run with the indices from the Index Stations and length composition data only from Index Stations and the red x line shows the model run with no indices included.



**Figure 11.** Time series of stock status, shown as fraction of unfished, of Black Rockfish in Washington for 4 model runs with ~95% asymptotic intervals. The dark blue circles show the original model run from the 2015 assessment, the light blue triangles show the same data truncated to the years 1998-2014 with pre-1998 length compositions removed, yellow plus signs show the model run with the indices from the Index Stations and length composition data only from Index Stations and the red cross line shows the model run with no indices included.

Stock synthesis model diagnostics were used to evaluate impacts the indices had on the model output. Reference points used for comparison of model runs show a very small change in unfished spawning biomass and the status of stock depletion remained unchanged. A summary of the model diagnostics is shown in Table 1.

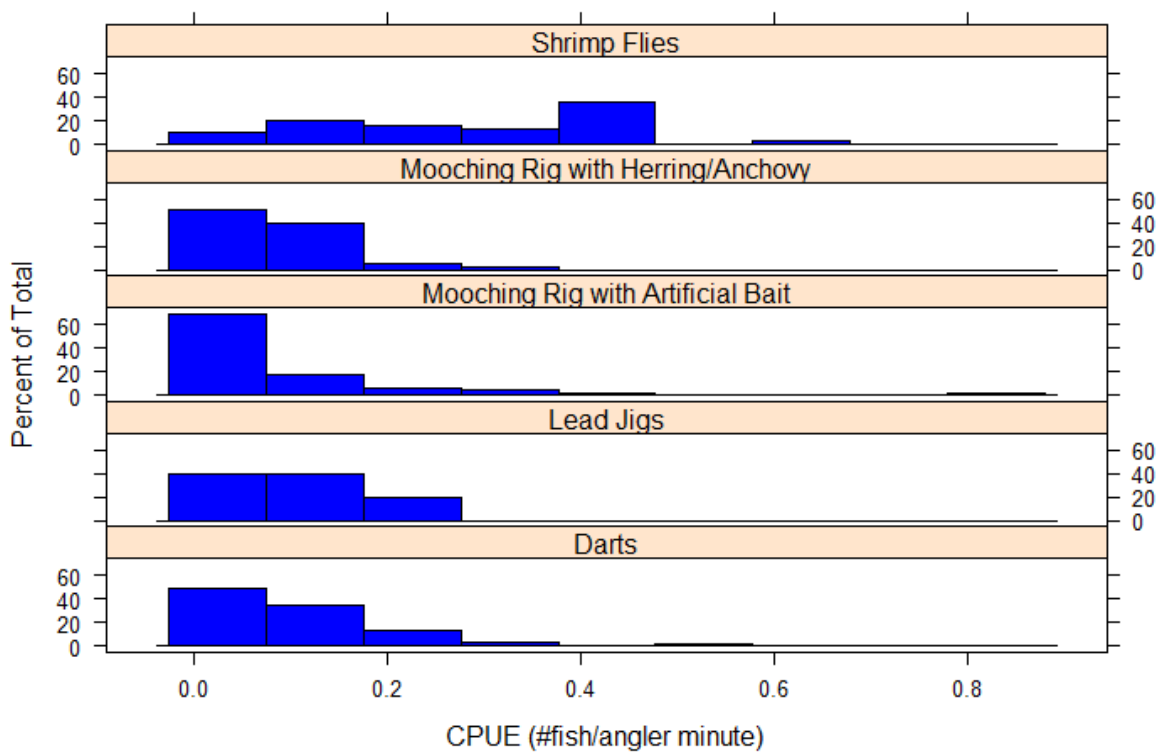
**Table 1.** Table of reference points for a comparison between the 4 Black Rockfish assessment models to show the effects of the indices. The Base Model reference points have no modification and are from the 2015 Washington Black Rockfish accepted stock synthesis model (Cope et al. 2016).

	<b>Base Model</b>	<b>Base 1998-2014</b>	<b>Index 1998-2014</b>	<b>Base No Indices</b>
Unfished Spawning Biomass (mt)	1356	1365	1401	1422
Unfished age 3+ biomass (mt)	9119	9121	9226	9076
Spawning Biomass 2015	582	582	601	584
Unfished recruitment (R0)	2102	2096	2102	1950
Depletion 2015	0.43	0.43	0.43	0.41

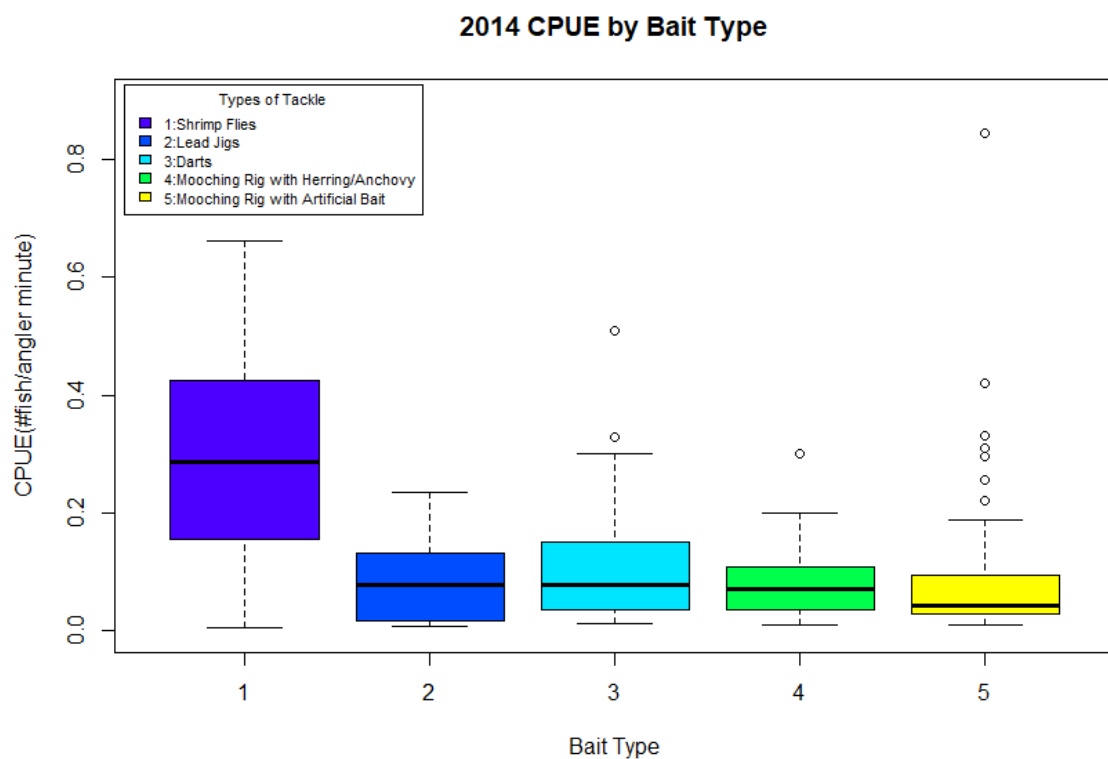
Methodology used to select index stations for the Rod-and-Reel Survey in CRA 2 were also used for selecting index stations in the other three coastal marine areas (CRA 1, 3, and 4). Based on the above analysis, index stations in CRA2 show representative abundance trends of the Black Rockfish adult population and it can be inferred that index stations selected in each of the other three coastal CRA would be representative.

#### **4.2 Survey Terminal Tackle and Gear Type**

The CPUE of Black Rockfish by angler minute by terminal tackle type for each year of the WDFW terminal tackle pilot study was explored. The 2014 pilot study data histogram of CPUE by terminal tackle type (Figure 12) and box plots of CPUE by gear type (Figure 13) were examined. Unfortunately, because large differences in consistent terminal tackle testing in 2014 (different areas fished with different bait type, different fishing times per bait type) were discovered the dataset was not used to statistically evaluate terminal tackle preference by Black Rockfish, but shrimp flies were the preferred terminal tackle by anglers for catching Black Rockfish. Lessons learned from the 2014 pilot study informed the 2015 survey methodology.

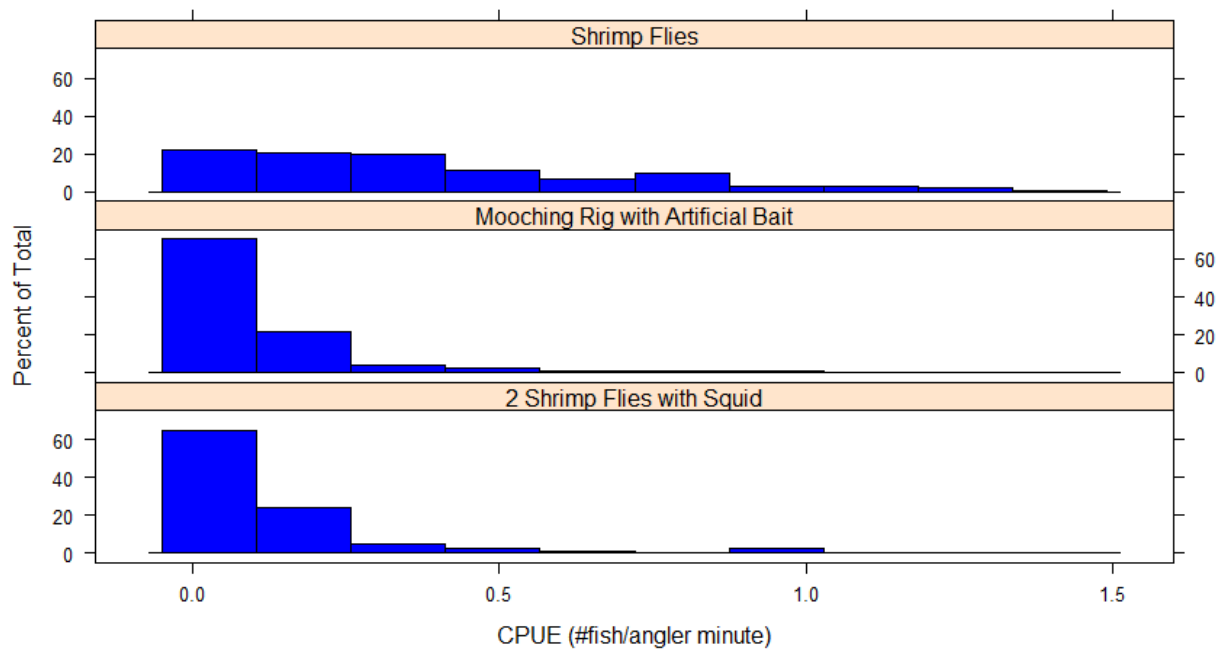


**Figure 12.** CPUE by terminal tackle gear type for survey year 2014.

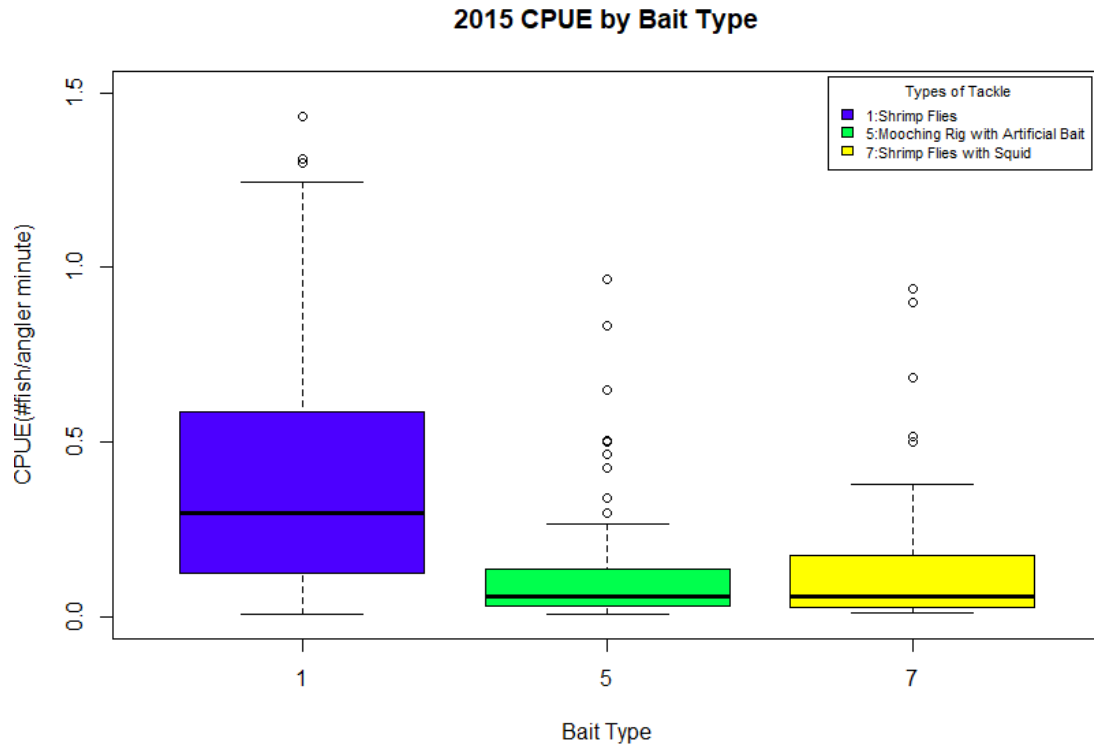


**Figure 13.** CPUE by terminal tackle gear type used in the 2014 WDFW pilot study.

Data from the 2015 survey were explored through a histogram (Figure 14) and box plots of CPUE by gear type (Figure 15). Survey methodology in 2015 included only three terminal tackle gear types: shrimp flies, mooching rigs with artificial bait, and 2 shrimp flies baited with squid. For 2015, there was a significant difference in CPUE based on terminal tackle type (Kruskal-Wallis,  $H_2=113.1$ ,  $P < 0.001$ ). Post-hoc comparison using a Dunn's test showed that CPUE using shrimp flies were significantly different than both mooching rigs with artificial bait ( $P < 0.001$ ) and shrimp flies with squid ( $P < 0.001$ ). There was no significant difference between CPUE with mooching rigs with artificial bait compared to shrimp flies with squid ( $P = 0.807$ ).



**Figure 14.** CPUE by terminal tackle gear type for survey year 2015.



**Figure 15.** CPUE by terminal tackle bait type used in the 2015 WDFW pilot study.

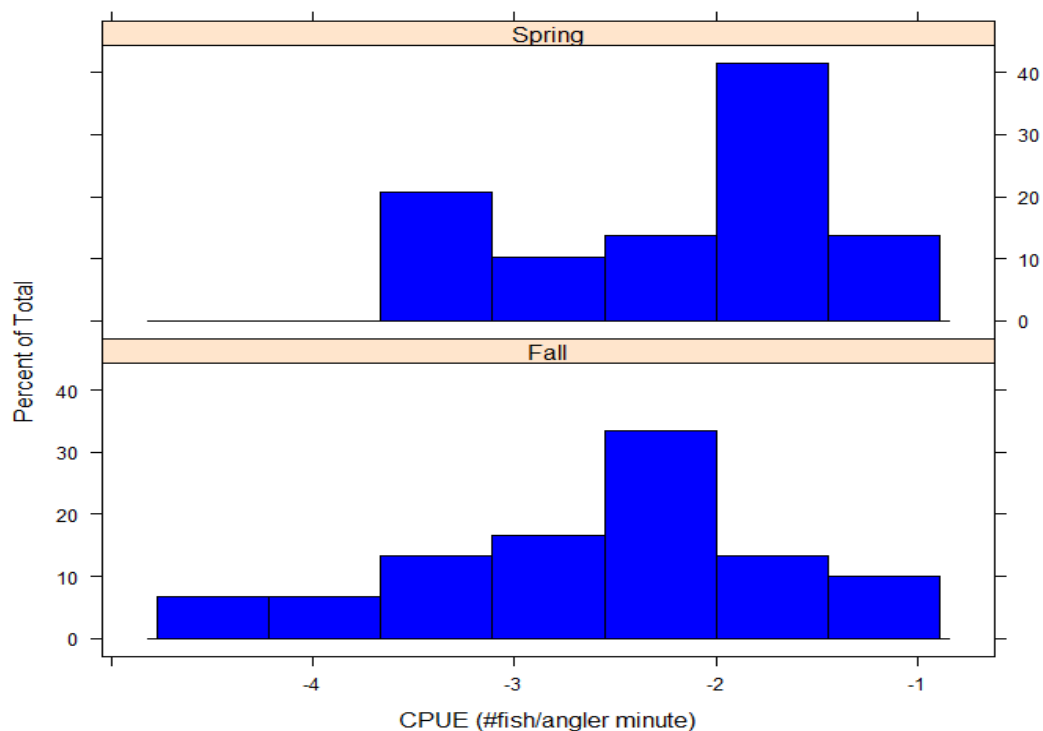
Based on the analysis of Black Rockfish CPUE data from the WDFW terminal tackle pilot study, the most effective terminal tackle for catching Black Rockfish was shrimp flies.

From 2015 to 2017 the WDFW conducted a series of studies to examine the effectiveness of set-line gear to capture bottomfish in rocky habitats. From analysis done on these survey data, WDFW managers concluded highly valuable and abundant Black Rockfish are better monitored with rod-and-reel gear while set-line gear encounters substantially more demersal species (WDFW unpublished data). A cost analysis was also provided by the WDFW for the comparison pilot study. The 5-day comparison study cost approximately \$13K to complete for the rod-and-reel component and \$36K for the set-line effort (R. Davis WDFW, personal communication).

### 4.3 Survey Timing

Data from the seasonal rod-and-reel pilot study were explored through a histogram of

CPUE by season (Figure 16). Seasonal timing based on CPUE of Black Rockfish was analyzed using a linear mixed-effects model (Laird & Ware 1982). This model was chosen because it works well for data that are collected and summarized in groups and have a symmetrical distribution. Analysis evaluated the relationship between CPUE of surveys done in the spring vs. fall at 10 locations over three years. The season in which the surveys were conducted did not have a significant effect on Black Rockfish CPUE (fixed effect of season  $P=0.72$ , accounting for the random effect of year).



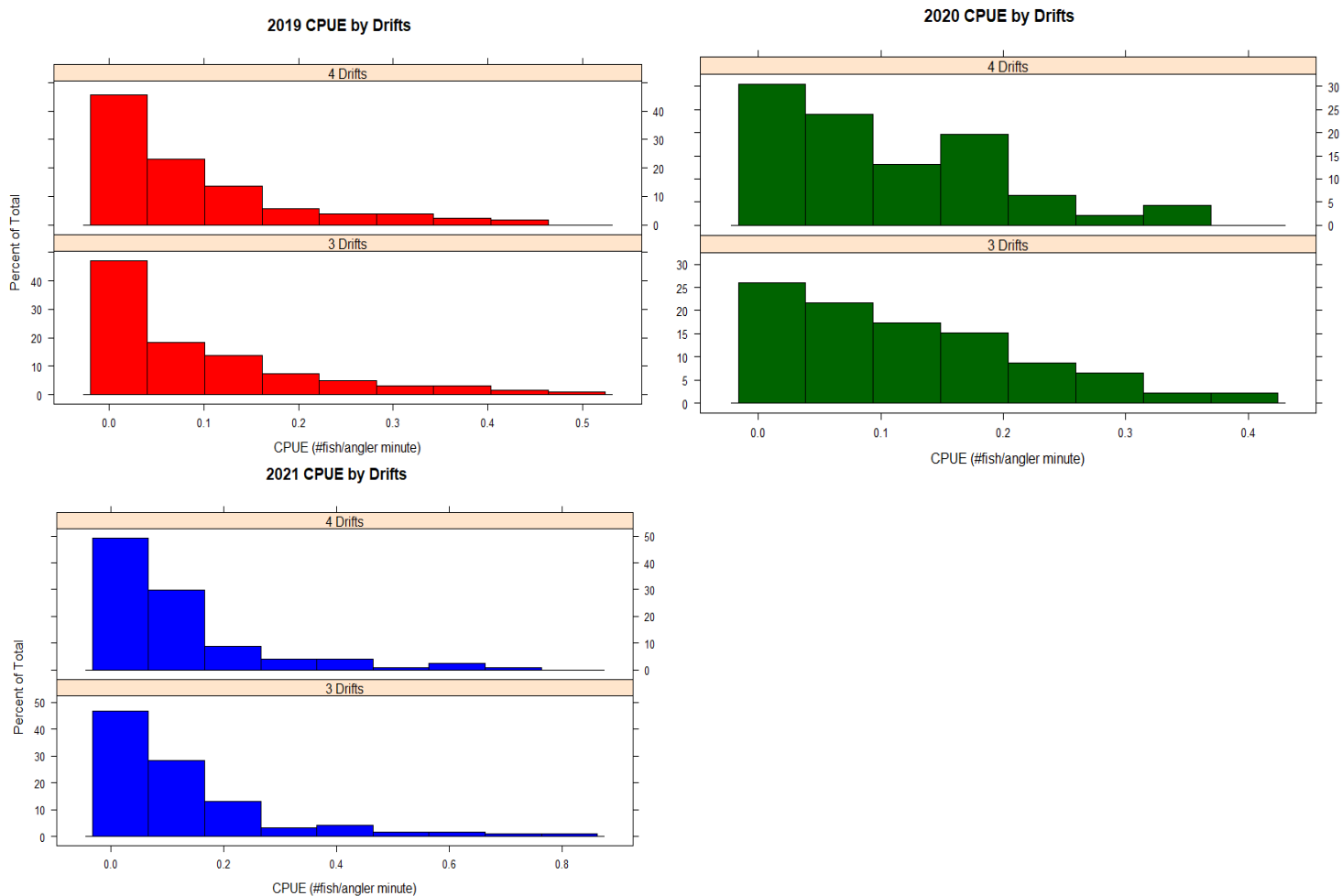
**Figure 16.** Histogram showing CPUE from the fall and spring pilot study surveys from 10 locations over 3 years combined on a natural log scale.

Seasonal survey timing decisions for the Rod-and-Reel Survey were highly dependent on charter vessel availability, ocean conditions, and financial feasibility (T. Tsou WDFW, personal communication). In general, charter vessel operators cater to the recreational fishing fleet and

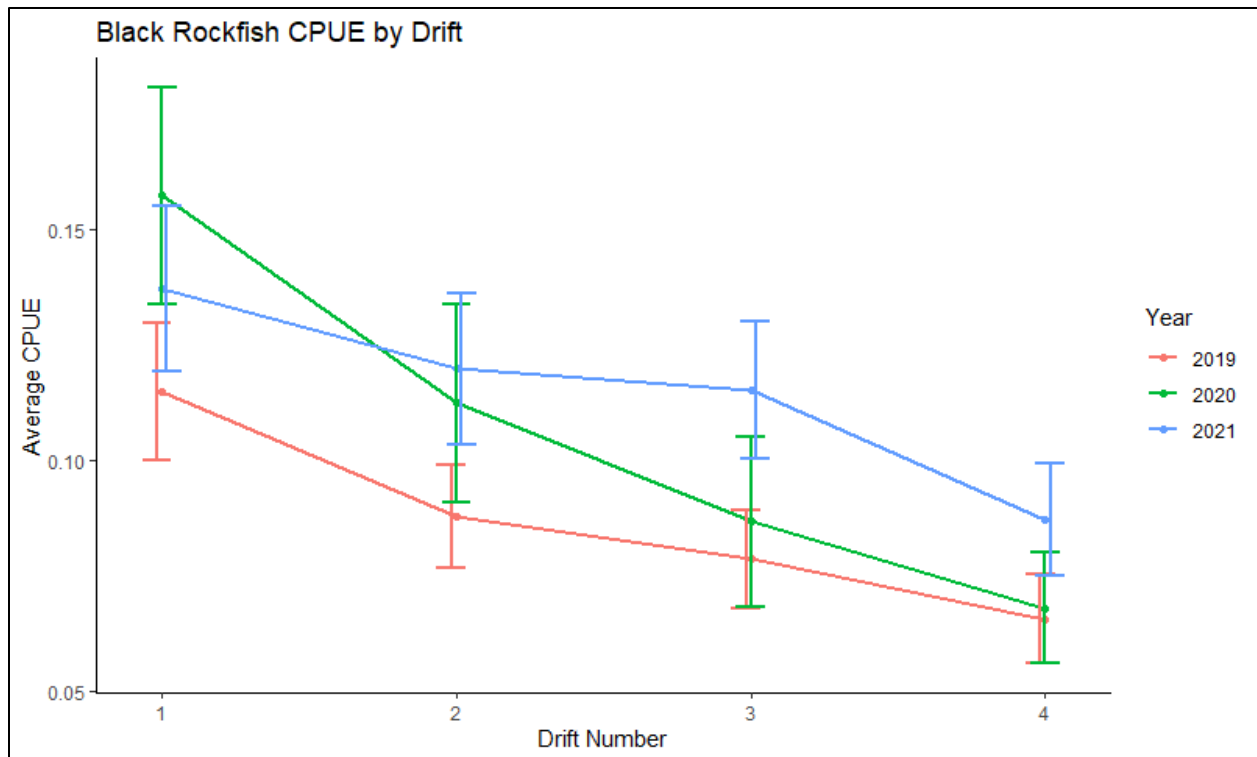
make their income March through October by taking recreational harvesters out to fish. The WDFW contracts with multiple charter vessel operators at the beginning of the bottomfish fishing season to conduct the survey, as the weather is variable, and the demand is lower in the early spring (R. Davis WDFW, personal communication).

#### **4.4 Survey Effort**

The effect of survey effort per index station, with effort defined as the number of drifts conducted (4 vs. 3), was evaluated for data collected during the 2019, 2020, and 2021 Rod-and-Reel Surveys. Survey data was explored by year and by the number of sampling drifts performed at each index station (Figures 17). Current survey design requires 4 drifts across the habitat at each index station. An analysis of the number of drifts at index stations for each survey year was done using a t-test of the difference between the CPUE based on 3 drifts and the CPUE based on 4 drifts. Results showed that the difference between CPUE based on 3 or 4 drifts was significantly different for all survey years 2019, 2020, and 2021 ( $t_{124} = -3.03$ ,  $P = 0.001$ ,  $t_{45} = -3.70$ ,  $P < 0.001$ , and  $t_{123} = -3.57$ ,  $P < 0.001$ , respectively). Average CPUE by drift was plotted to see if there were trends in the data by year (Figure 18). This visual representation of average CPUE for each drift shows that additional drifts yielded less and less CPUE.



**Figure 17.** CPUE based on 4 drifts and 3 drifts (not independent) at each index location for the 2019, 2020, and 2021 Rod-and-Reel Survey.



**Figure 18.** Average CPUE calculated for each drift at Index Stations by survey year.

To evaluate if the number of index stations surveyed each year in the Rod-and-Reel Survey was high enough to be able to detect changes in Black Rockfish abundance a power analysis was done. Rod-and-Reel Survey data collected in 2019 and 2021 were used for this analysis. Data from 2020 was excluded because the survey was not completed due to the coronavirus pandemic. Using a power calculation for a two-sample Z test, sample means from the 2019 and 2021 surveys, a difference in the mean samples for the null hypothesis of zero, and a difference of means in the alternative hypothesis of 0.05, beta was calculated, with sample size of 125 (# of index stations) and standard error of 0.0172 for a two-sided test. From these calculations, the power of the hypothesis test to detect a difference of 0.05 in CPUE was 89%. Alternative differences were explored for the current survey methodology which uses 4 drifts per index station and for the first 3 drifts at each index station. Results from this exploration is shown in Table 2.

**Table 2.** Statistical power (%) with different CPUE effect sizes (0.02-0.05) by number of drifts at the index station for a two-sided two-sample Z test.

	Effect Size				Sample	Standard	SD	SD
	0.02	0.03	0.04	0.05	Size	Error	2019	2021
3 Drifts	21%	42%	64%	83%	125	0.0172	0.11306	0.15509
4 Drifts	25%	48%	72%	89%	125	0.0157	0.103099	0.141542

## 5. Discussion and Conclusions

Designing a survey capable of detecting a change in relative population abundance requires consideration of multiple species-specific factors. In 2019, the WDFW implemented the standardized coastal nearshore Rod-and-Reel Survey which samples 125 index stations annually. Analysis of abundance indices calculated from data from the historic WDFW Black Rockfish tagging program data found no difference between the complete survey data series and surveys conducted only at index stations. Replacing the tagging abundance indices with the indices from index stations in the 2015 SS assessment model had minimal impacts on the stock assessment, with no change to the overall status of stock depletion. However, extra variance was added to the indices by the 2015 stock assessment authors, reducing the impact of the indices to the model. These results indicate that the index station locations selected in CRA 2 for the Rod-and-Reel Survey were representative of the population. Index station selection for the Rod-and-Reel Survey was conducted in the same way for all 4 coastal CRAs, using a grid system over rocky habitat. Selecting locations using the grid system reduced the chance of sampling only easily accessible habitat based on departure port. If index stations selected in CRA 2 represent the population, the same should hold true for CRAs 1, 3, and 4 because they were selected in the same methods.

During exploration of the WDFW Black Rockfish tagging program data that was used in the 2015 Washington Black Rockfish SS model, a notable error was discovered. Assessment authors stated that catches of Black Rockfish were recorded by angler minute, month, and CRA (then referred to as ‘punch card area’) and abundance indices were calculated from this data for 1986-2014 (Cope et al. 2016). However, data referred to as “angler minute” was actually the amount of time a *boat* was at the location for each sampling event with anglers fishing. The

number of anglers fishing from the boat was not included in the data calculation and varied from 2 to 21 anglers. This oversight impacted CPUE estimates, including the CPUE scale and should be corrected if the data series were to be used in the future assessments.

Species-specific characteristics of Black Rockfish, considered a semi-pelagic schooling species with high association with rocky habitat, must be considered when selecting survey gear and terminal tackle. Pilot study data analyzed by the WDFW confirmed that Black Rockfish were better, and more cost effectively, sampled using rod-and-reel gear for fishing shoreward of 40 fathoms along the Washington coast. Results from analysis of data from the 2015 terminal tackle pilot study showed a significant increase in Black Rockfish CPUE using shrimp flies when compared to the 2 other terminal tackle types tested. The 2014 pilot study tested 5 different terminal tackle types for Black Rockfish CPUE, with shrimp flies showing the highest catch rates but results were difficult to interpret statistically.

Gear type and terminal tackle used for the WDFW coastal Rod-and-Reel Survey are similar to those used in the Southern California Bight for the Shelf Rockfish Rod-and-Reel Survey, and that survey data has been used to create abundance indices for use in multiple stock assessment models (Harms, Benante & Barnhart 2008; Harms, Wallace & Stewart 2010). Based on the information presented here, the gear type and terminal tackle specified in the Rod-and-Reel Survey methodology were well suited for sampling Black Rockfish despite modifications to the survey design to increase catch of other targeted bottomfish species. Surveys using rod-and-reel methods have an added benefit of the ability to collect biological samples. Length frequency and age information collected during surveys provide valuable information on growth that can also be used to inform assessment models.

The timing of the spring (March through May) Rod-and-Reel Survey is not solely based

on Black Rockfish catchability. Other factors contributing to designating this time frame included survey vessel availability, seasonal weather conditions, and cost. Through the analysis of data from a pilot study sampling Black Rockfish in the spring and fall, which showed no significant difference in CPUE based on season, it can be concluded that spring is a suitable season for sampling Black Rockfish from both a biological and a cost/feasibility perspective.

The number of index stations included in the survey were initially based on funding and survey capabilities (WDFW unpublished report). To determine whether the number of stations was appropriate for detecting a change in CPUE abundance, a power analysis was completed. The number of index stations included in the design of the survey (125) is adequate for detecting a change in abundance of at least 0.05 CPUE with statistical power of at least 80%, for both 3 and 4 drifts across the station. This effect size (0.05 CPUE) is sufficient to detect a difference of about half a standard deviation (of the CPUE data from index stations, see Table 2).

To determine if the number of drifts conducted at index stations during the Rod-and-Reel Survey are appropriate for capturing a representative sample of Black Rockfish, CPUE by drift was evaluated. Analysis showed that incorporating CPUE estimates from the 4<sup>th</sup> drift at a station lowered the overall CPUE estimate. This reduction was seen in both years with a complete Rod-and-Reel Survey. The post hoc power analysis showed that both 3 and 4 drifts have a power greater than 80% to detect a change of 0.05 in CPUE, however 4 drifts provided a slightly higher power to detect smaller changes in CPUE, due to smaller standard error. These results suggest that the 4<sup>th</sup> drift may not be needed for capturing a representative sample of Black Rockfish and that 3 drifts may accomplish the same task. Hook saturation and competition have been a concern for hook and line surveys (Harms, Benante & Barnhart 2008; Kuriyama et al. 2019; Rodgveller, Lunsford & Fujioka 2008). However, hook saturation does not appear to be a major

concern based on the number of anglers (5) and drifts (4) for the Rod-and-Reel Survey, as CPUE estimates decrease with each drift across the habitat. Additionally, this schooling species, that swims in the water column above rocky habitat (Love 2011), may be able to out compete fish that are more tightly associated with the bottom for descending bait. Because data is collected for this survey by drift, analysis should be repeated after an additional full survey year has been completed to determine if the 4<sup>th</sup> drift can be removed from the survey design allowing for the addition of index stations.

A fishery-independent survey was recommended by the PFMC STAR panel review in 2015 to inform stock assessment models, and the WDFW responded by initiating the coastal nearshore Rod-and-Reel Survey in 2019. By thoroughly evaluating the survey design and answering the four research questions posed, fisheries managers now have the information needed to affirm that the WDFW Rod-and-Reel Survey can produce representative abundance indices for Washington's Black Rockfish stock for incorporation into future stock assessment models.

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## 7. Appendices

### 7.1 Glossary

**Bag limit-** “the maximum number of fish or game animals permitted by law to be taken by one person in a given period” (Merriam-Webster 2022).

**Bottomfish-** As defined by Washington State law these include Pacific cod, Pacific tomcod, Pacific hake (or whiting), walleye pollock, all species of dabs, sole and flounders (except Pacific halibut), lingcod, ratfish, sablefish, cabezon, greenling, buffalo sculpin, great sculpin, red Irish lord, brown Irish lord, Pacific staghorn sculpin, wolfeel, giant wrymouth, plainfin midshipman, all species of shark, skate, rockfish, rattail, and surf perches (excluding shiner perch) (WAC 220-16-340).

**Catch Record Areas (CRA)-** also called **Marine Areas (MA)** and **Punch Card Areas (PCA)** – Areas identified by the Washington Department of Fish and Wildlife to delineate fishing areas throughout the marine waters of the state. Shown on the map below as in white circles. (WDFW 2022) <https://www.eregulations.com/washington/fishing/marine-area-rules-definitions> (Figure 19).

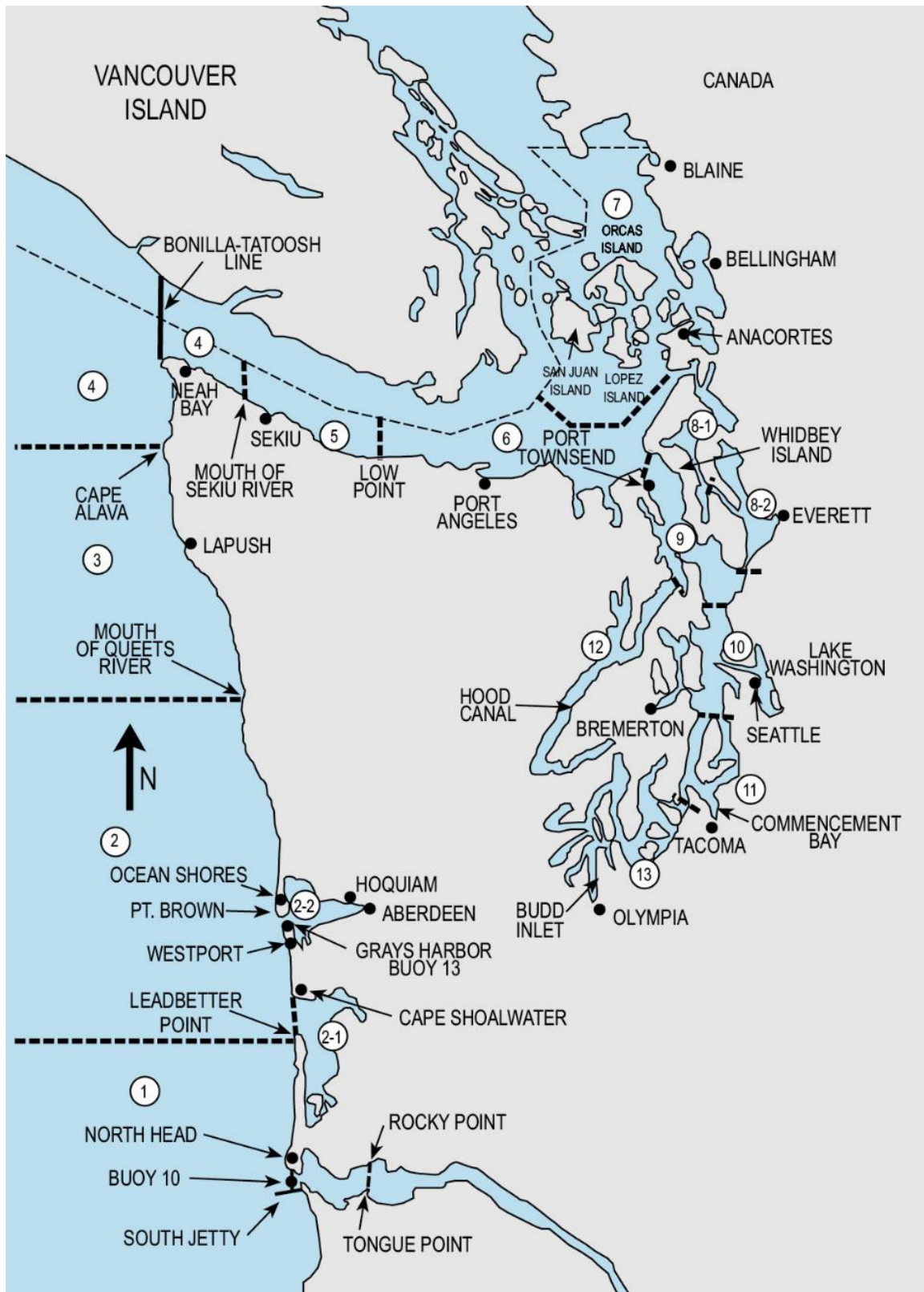
**Fishery-dependent-** “data that are collected from commercial sources (fishermen or dealer reports) and recreational sources (individual anglers, party or charter boats)” retrieved from Atlantic States Marine Fisheries Commission (2022A).

**Fishery-independent-** “data that are collected by scientists conducting resource monitoring projects” retrieved from Atlantic States Marine Fisheries Commission (2022B).

**Groundfish-** “a marine fish (such as cod, haddock, pollack, or founder) of commercial importance” (Merriam-Webster 2022).

**Population-** “a fish population is defined as a group of individuals of the same species or subspecies that are spatially, genetically, or demographically separated from other groups (Wells & Richmond 1995)”. (Pope, Lochmann, & Young 2010, p. 325).

**Stock-** “a fish stock is a management unit grouped by genetic relationship, geographic distribution, and movement patterns” retrieved from Atlantic States Marine Fisheries Commission (2022C).



**Figure 19.** Catch Record Areas identified by the Washington Department of Fish and Wildlife to delineate fishing areas throughout the marine waters of the state.

## 7.2 Glossary References

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