Oregon Department of Fish and Wildlife

SCIENCE BULLETIN

Number 2021-05

Marine Resources Program

Susceptibility of five species of rockfish (*Sebastes spp.*) to different survey gears inferred from high resolution behavioral data.

This report should be cited as:

Rasmuson, L. K, 2021. Susceptibility of five species (*Sebastes spp.*) of rockfish to different survey gears inferred from high resolution behavioral data. Science Bulletin 2021-05. Oregon Department of Fish and Wildlife, Salem.

Susceptibility of five species of rockfish (*Sebastes spp.*) to different survey gears inferred from high resolution behavioral data.

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May 2021

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ABSTRACT

Fisheries independent surveys are an important data input for stock assessments. However, these surveys are expensive to conduct and require precise, well thought out planning to be effective. Although the amount of money allocated to a survey is often dictated by factors beyond the control of the survey development team, surveys must incorporate their understanding of the biology of the focal species or species group into the survey design. Acoustic telemetry data can provide a high-resolution dataset to answer some of these questions. In this study, we reanalyze past acoustic telemetry studies on Black Rockfish (*Sebastes melanops)*, Copper Rockfish (*Sebastes caurinus*), Deacon Rockfish (*Sebastes diaconus*), Quillback Rockfish (*Sebastes maliger*) and Yelloweye Rockfish (*Sebastes ruberrimus*) in order to apply these data to future survey development. We combined the telemetry data with multibeam bathymetry data to 1) understand how the height off bottom of each species changed throughout a day and 2) simply define the habitat utilized by each species. We found, on average, Black, Deacon and Yelloweye Rockfish were all more than 1 m off bottom, whereas Copper and Quillback remained on, or near the bottom throughout the day. Deacon Rockfish were associated with the most rugose bottom, followed by Yelloweye Rockfish. Black, Copper and Quillback Rockfish all utilized low relief habitats. In general, we hypothesize that Black and Deacon Rockfish are good candidates for survey by hydroacoustics, whereas, Copper and Quillback Rockfish appear to be good candidates for survey by bottom trawl. However, our study was only conducted at a single nearshore reef and as such the results should be considered experimental and need validation. Surprisingly, due to the habitat they reside in, Yelloweye Rockfish were available to hydroacoustics, and likely not available to bottom trawl. However, Yelloweye Rockfish have variable behaviors, as reported by the original work, and as such, we are wary to suggest that hydroacoustics are an appropriate survey tool. We do, however, propose that Yelloweye Rockfish potentially contribute to backscattering values of acoustic surveys conducted for midwater rockfish, and that bottom trawls are likely not an effective survey tool for Yelloweye Rockfish.

INTRODUCTION

Groundfish on the West Coast of the continental United States are co-managed by state and federal partners through the collaborative Pacific Fisheries Management Council. One of the primary roles of the Council is to conduct stock assessments of groundfish stocks, which, in turn, are used to provide predictions of stock status. As with all models, these stock assessments are only as good as the data going into them. In nearshore groundfish stock assessment reports, the authors routinely point out the need for fisheries independent surveys. A fisheries independent survey is a survey of the resource that is not affected or directly influenced by commercial or recreational fisheries.

On the Oregon coast, nearshore rockfish are an important component of the recreational and commercial fisheries. Of these nearshore rockfish, the semi-pelagic Black

Rockfish (*Sebastes melanops*) are likely the most economically important recreational rockfish species caught (Research Group, LLC 2015). While semi-pelagic species are not as important to the nearshore commercial fleet, together with high value more colorful benthic rockfish species, they do represent an important component of the fishery. All nearshore groundfish species suffer from a lack of fisheries independent survey data (Rodomsky et al. 2020). Additionally, Yelloweye Rockfish are classified as overfished in Oregon's waters (Gertseva and Cope 2017). Their overfished status results in a reduction of catch quotas, which ultimately constrains the ability of the commercial and recreational fleets to utilize other resources.

While the need for fisheries independent surveys has been acknowledged for quite some time, the development and implementation of fisheries independent surveys is a complex process (Cope et al. 2015; Dick et al. 2017). During survey development one must balance budgetary and time constraints with constraints imparted by the biology of the focal species (Rotherham et al. 2007; Dennis et al. 2015). As survey costs continue to increase, and budgets tend to lag behind inflation, the need to create surveys that are cost effective is more important than ever. An effective way to reduce survey costs is to use technology that allows surveys to be conducted aboard smaller vessels, with fewer scientists going to sea (Meyer-Gutbrod et al. 2012). However, any decisions about survey tools must be made based on the biology of the animal (Stoner et al. 2008; DuFour et al. 2018). For example, although benthic bottom trawls are a common and effective survey tool, they are not, effective for surveying pelagic fish.

A fish's behavior, specifically it's average height above the bottom (hereafter referred to as height off bottom), strongly influences the availability of the fish to different survey gears (Arreguin-Sanchez 1996; Trenkel et al. 2004; Kotwicki et al. 2015). Nearshore rockfish are an extremely diverse group of fish and are known to occupy a large variety of heights off bottom. However, our knowledge of fish height off bottom is considered in a categorical sense (benthic, semi-pelagic etc.) and we do not have numerical values to define the height (Love et al. 2002). Just as height off bottom influences the catchability of a species, the habitat occupied by a species influences which gear types are suitable for surveying that species (Love 2006; Rooper 2010). Habitats where trawls cannot be deployed (untrawlable habitats) are a major example of this; an issue that strongly affects the ability to survey rockfish (Jagielo et al. 2003; Zimmermann 2003; Baker et al. 2019).

In this study we reanalyze high resolution acoustic telemetry studies conducted on Black Rockfish (*Sebastes melanops*), Copper Rockfish (*Sebastes caurinus*), Deacon Rockfish (*Sebastes diaconus*), Quillback Rockfish (*Sebastes maliger*) and Yelloweye Rockfish (*Sebastes ruberrimus*). For each species, we calculated the average height off bottom of that species throughout the day. We also calculated habitat metrics to assess what types of habitats each species was using.

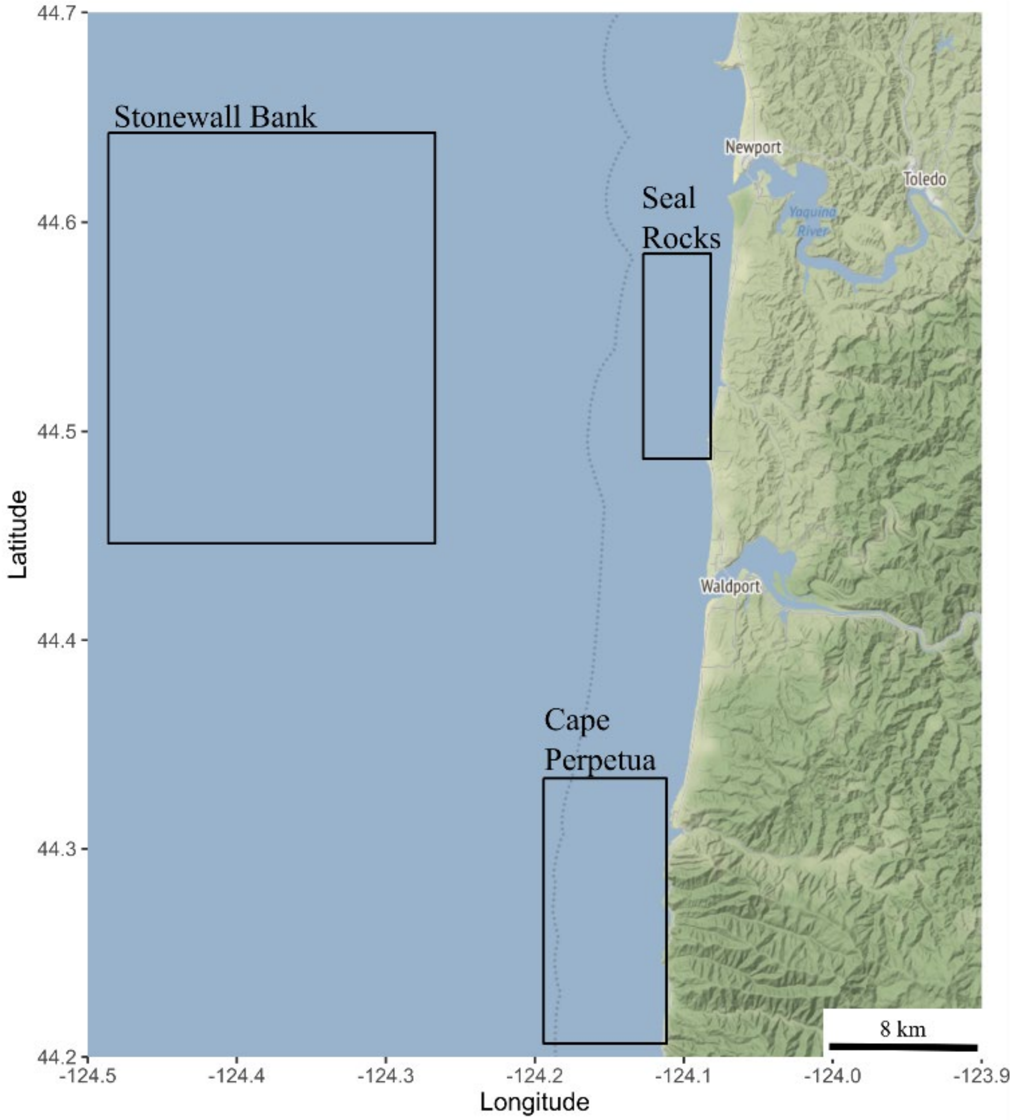

Fig. 1. Overview map of study areas. See table 1 for which fish species were tagged during each study period at each of the three reefs.

METHODS

Acoustic telemetry data were collected for five species of rockfish tagged in Oregon over a 12-year period (Table 1, Fig 1). Study areas were located on the central Oregon coast, but focal reefs differed between species. For more information on the original studies and their design, we refer the reader back to those studies (citations available in Table 1). We utilized the acoustic telemetry data from these studies to characterize fish location (latitude, longitude) and height off bottom. All analyses and mapping were conducted in R 4.0.2 Taking Off Again (R Core Team 2020). Bathymetry data at Seal Rocks and Stonewall Bank had a 2 m resolution and data at Cape Perpetua had a 4 m resolution (Goldfinger et al. 2014).

Location records were used for all fish that had a horizontal position error (HPE) of < 25 m. These data points were then associated with raster values from multibeam bathymetry, in order to extract the bottom depth for each fish location. We then subtracted the fish's depth from the associated bathymetric depth to determine the relative height off bottom of the fish. Data were corrected for tidal signals by correcting the water column thickness for every 5 minute interval. We also calculated the slope and roughness using the Terrain function from the raster package in R (Hijmans 2020) which implements methods described by Wilson et al. (2007). For each fish location, slope and roughness were calculated using the eight neighboring (surrounding) pixels. At the scales we used to calculate them, slope and roughness are exponentially correlated with one another (Fig 2). However, both metrics are used to define untrawlable habitats in the literature and therefore both values are reported.

Height off bottom data were decimated onto a 1 minute temporal resolution for each calendar day. We then fit a generalized additive model (GAM) in the mgcv package (Wood 2006, 2011), with hour of the day as the explanatory variable, and height off bottom as the response variable. Vertical error from the tags incorporated into the model. Each species was analyzed independently. No model selection was conducted as the goal was to understand the average height off bottom throughout the day. The depth of the tag, the roughness and slope of the bottom associated with the tag location were plotted using scaled density plots to assess how habitat utilization differed between species.

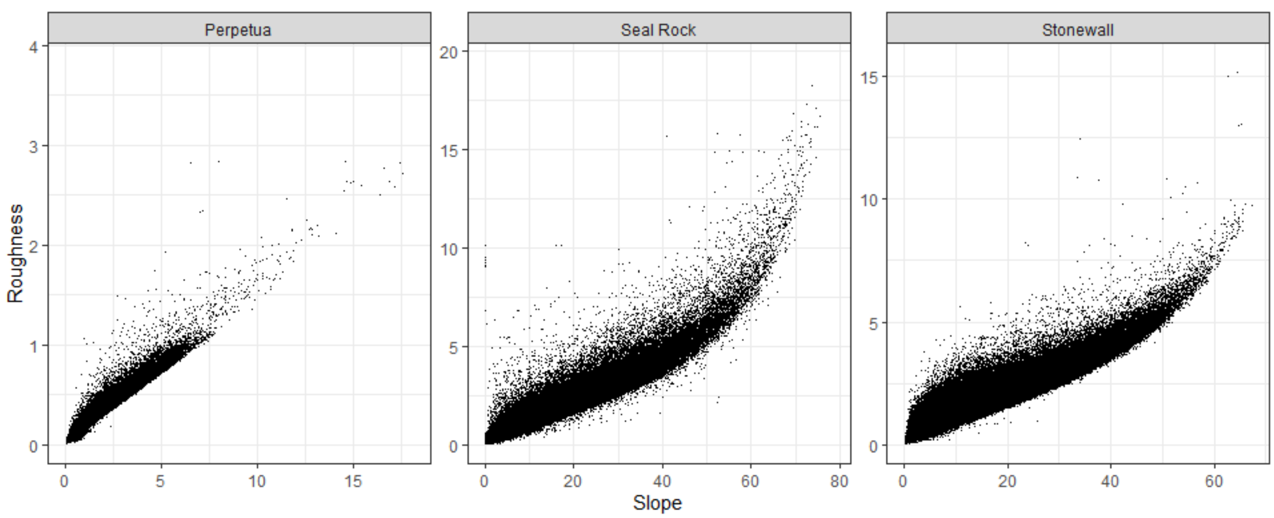

Fig. 2. Relationship between slope and roughness data calculated from the multibeam data for each reef.

Table 1. Study statistics for each of the five focal species.

Common Name	Scientific Name	Date Range	Number of Fish Tagged	Number of Observations with HPE <25	Study Reef	Reference
Black Rockfish	*Sebastes melanops*	08/2004 - 01/2005	26	1,048,575	Seal Rocks	(Parker et al. 2008)
Copper Rockfish	*Sebastes caurinus*	04/2010 - 05/2010	8	5,199	Cape Perpetua	(Rankin et al. 2013)
Deacon Rockfish	*Sebastes diaconus*	05/2016 - 09/2016	11	131,955	Seal Rocks	Rasmuson et al. 2021
Quillback Rockfish	*Sebastes maliger*	05/2010 - 05/2010	9	3,527	Cape Perpetua	(Rankin et al. 2013)
Yelloweye Rockfish	*Sebastes ruberrimus*	04/2012 - 09/2013	18	46,380	Stonewall Bank	(Rankin 2019)

RESULTS

Seal Rock's bathymetry data has an average depth of 21.6 ± 10.5 m, an average roughness estimate of 0.3 ± 0.1, and an average slope of 3.5 ± 5.1 degrees (Fig. 3). Cape Perpetua' bathymetry data set has an average depth of 37.7 ± 12.7 m, an average roughness estimate of 0.1 ± 0.1, and an average slope of 0.6 ± 0.5 degrees (Fig. 4). Stonewall Bank's bathymetry data has an average depth of 62.6 ± 8.9 m an average roughness estimate of 0.6 ± 0.5 and an average slope of 5.9 ± 5.3 degrees (Fig.5).

Black Rockfish and Deacon Rockfish occupied a broader depth range than the other species (Fig. 6). Both Quillback and Copper Rockfish activity was concentrated over a very fine depth range, and Yelloweye occupied a broad depth range, with some individuals even ascending to the surface. For Deacon Rockfish, the depth range equated to an average height off bottom of 5 m during the day and 1 m at night (Fig.7). Black Rockfish remained at an average depth of 3.75 m off bottom. Quillback and Coper Rockfish remained, on average, 0.01 m off bottom. Yelloweye were, on average, 2 m off bottom regardless of time of day.

Deacon Rockfish were associated with the most rugose habitat and habitat with the greatest slope (Fig. 8-9). At Seal Rocks Reef, Black Rockfish occupied far less rugose habitat than Deacon Rockfish. At Cape Perpetua, Quillback was associated with steeper bottoms than Copper Rockfish, but the roughness of the habitat used by the two species was similar. Yelloweye Rockfish used the second most sloped bottom after Deacon's but the roughness of this habitat was not as variable as that of Deacon's preferred habitat.

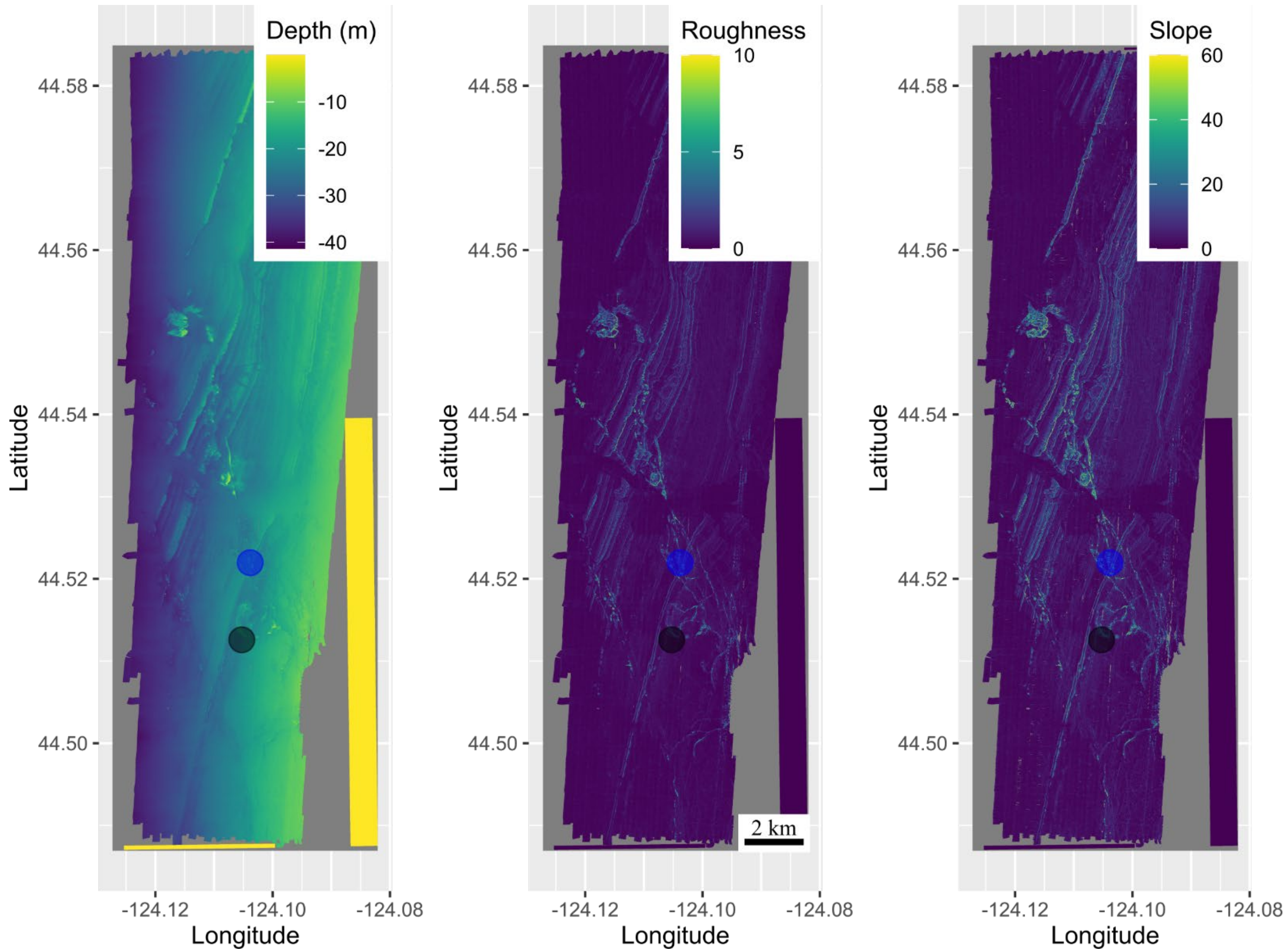

Fig. 3. Depth, rugosity and slope profiles for Seal Rocks Reef. The blue dot denotes the average location Deacon Rockfish were detected and the gray dot denotes the average location Black Rockfish were detected. Bathymetry data were provided by Goldfinger et al. (2014) and converted to rugosity and slope using the Terrain function in R (Wilson et al. 2007; Hijmans 2020).

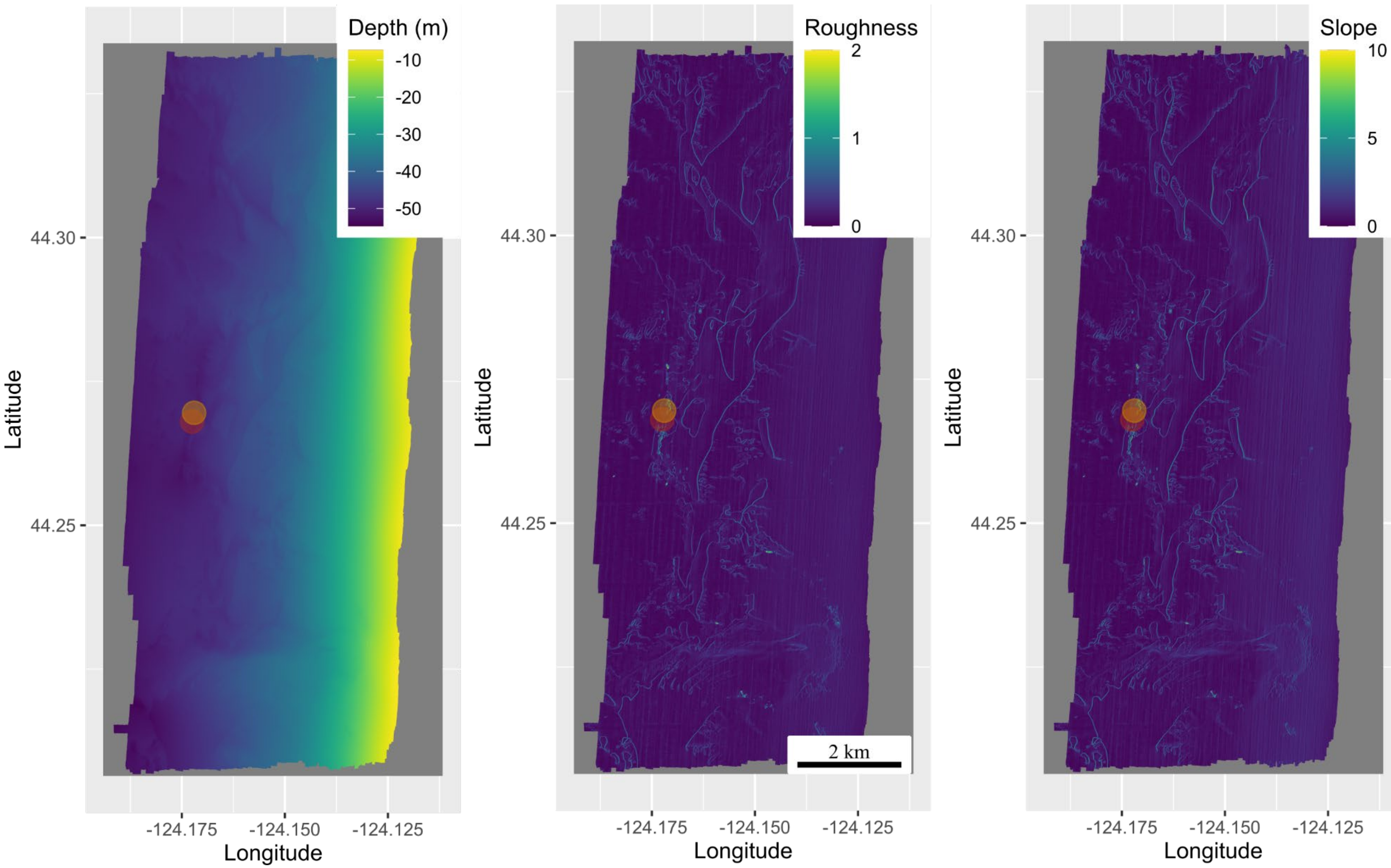

Fig. 4. Depth, rugosity and slope profiles for Cape Perpetua. The orange dot denotes the average location Copper Rockfish were detected and the brown dot denotes the average location Quillback Rockfish were detected. Bathymetry data were provided by Goldfinger et al. (2014) and converted to rugosity and slope using the Terrain function in R (Wilson et al. 2007; Hijmans 2020).

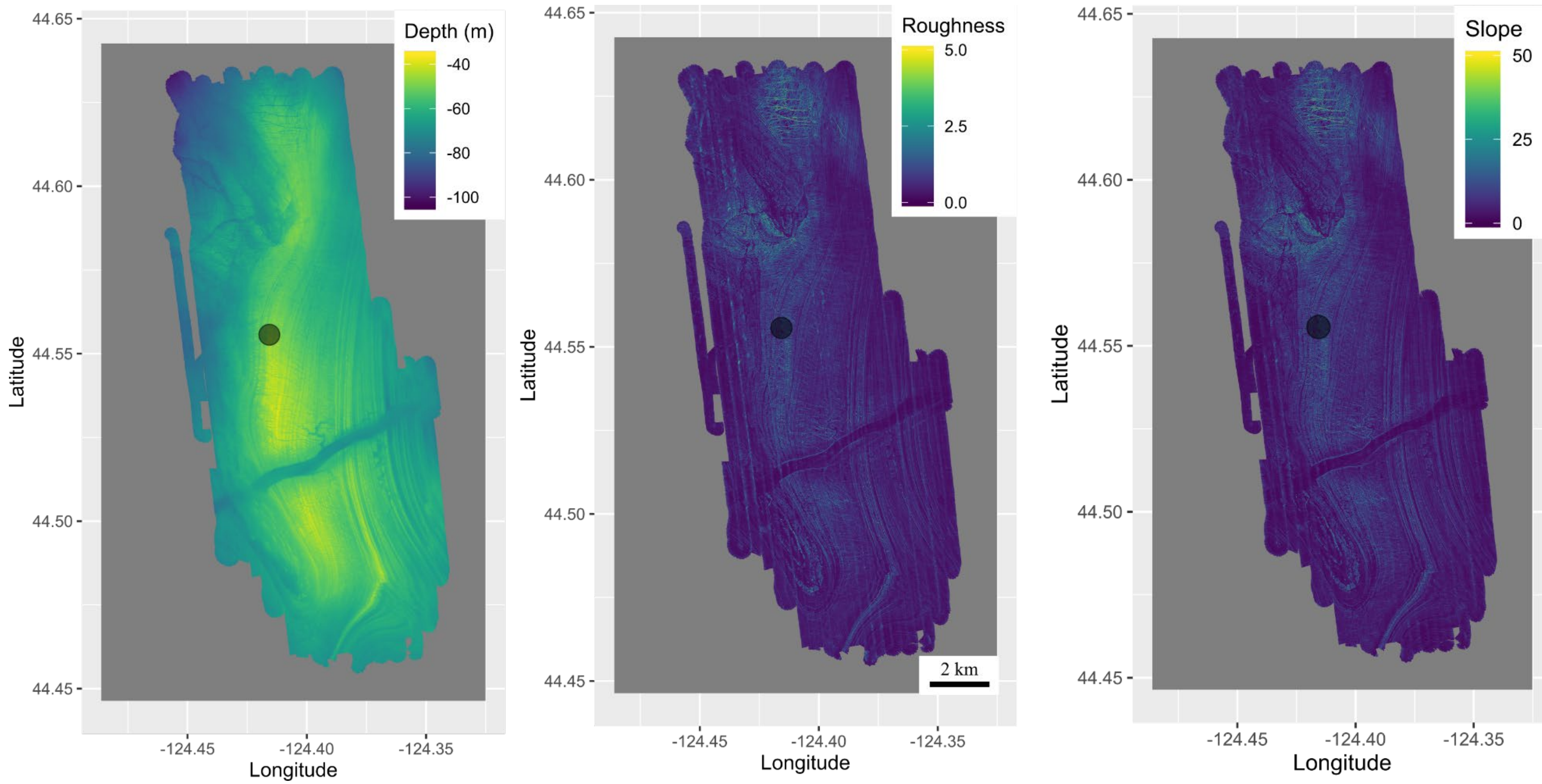

Fig. 5. Depth, rugosity and slope profiles for Stonewall Bank. The gray dot denotes the average location Yelloweye Rockfish were detected. Bathymetry data were provided by Goldfinger et al. (2014) and converted to rugosity and slope using the terrain function in R (Wilson et al. 2007; Hijmans 2020).

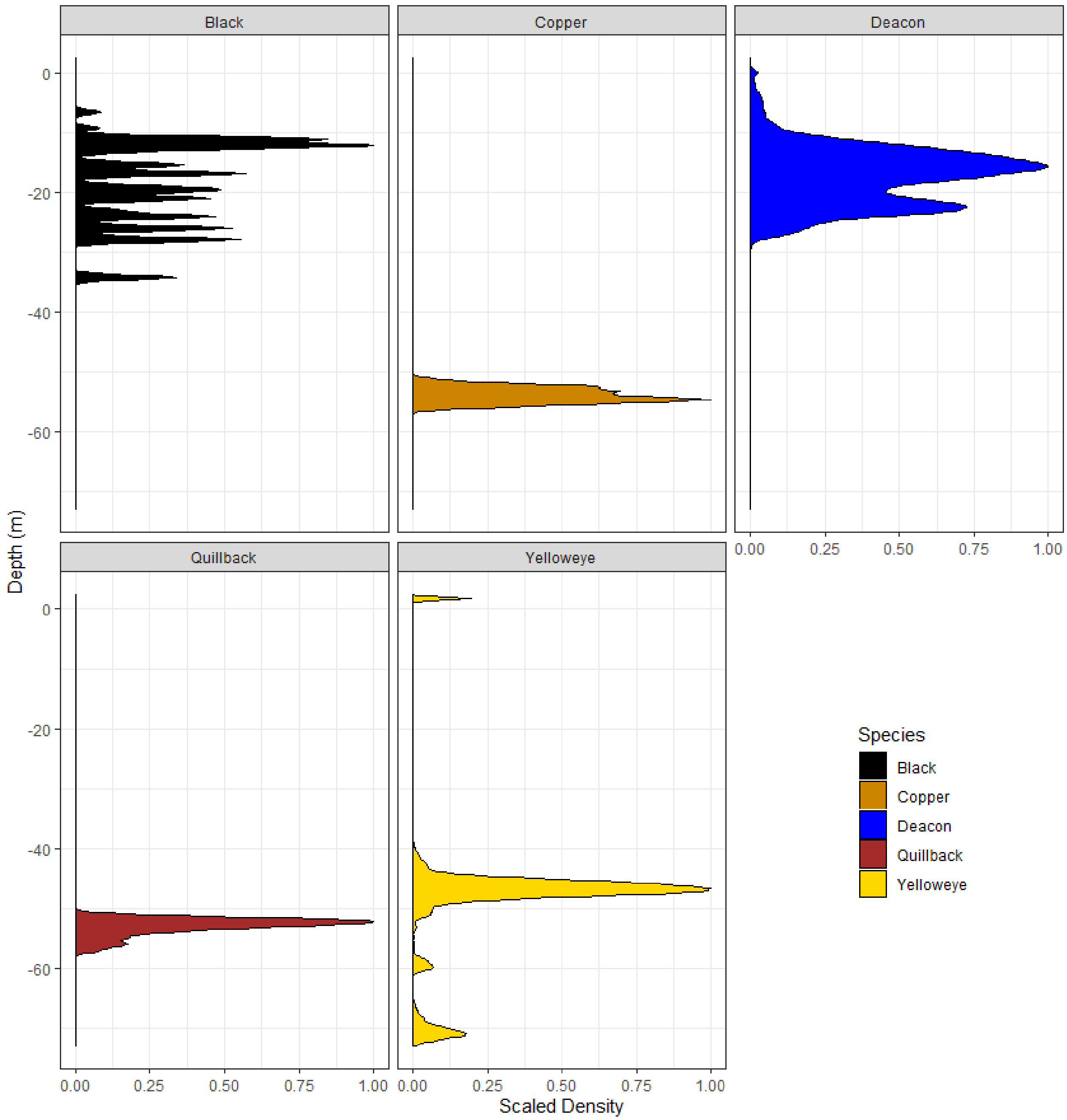

Fig 6. Scaled density plots of depth utilization for each of the five focal species.

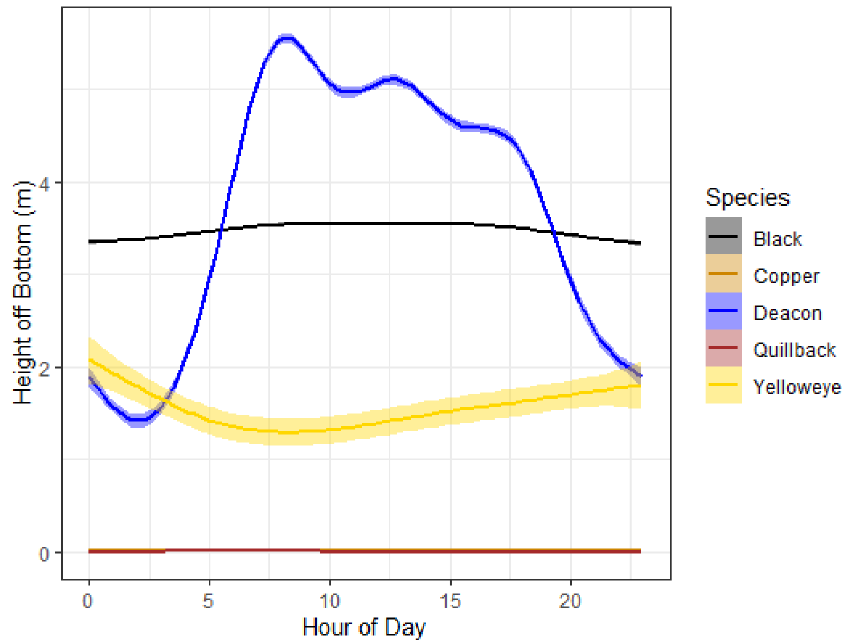

Fig. 7. Average height off bottom throughout a 24-hour period for each of the five focal species. Data from Copper and Quillback Rockfish are both near bottom and make it difficult to see the two different color schemes.

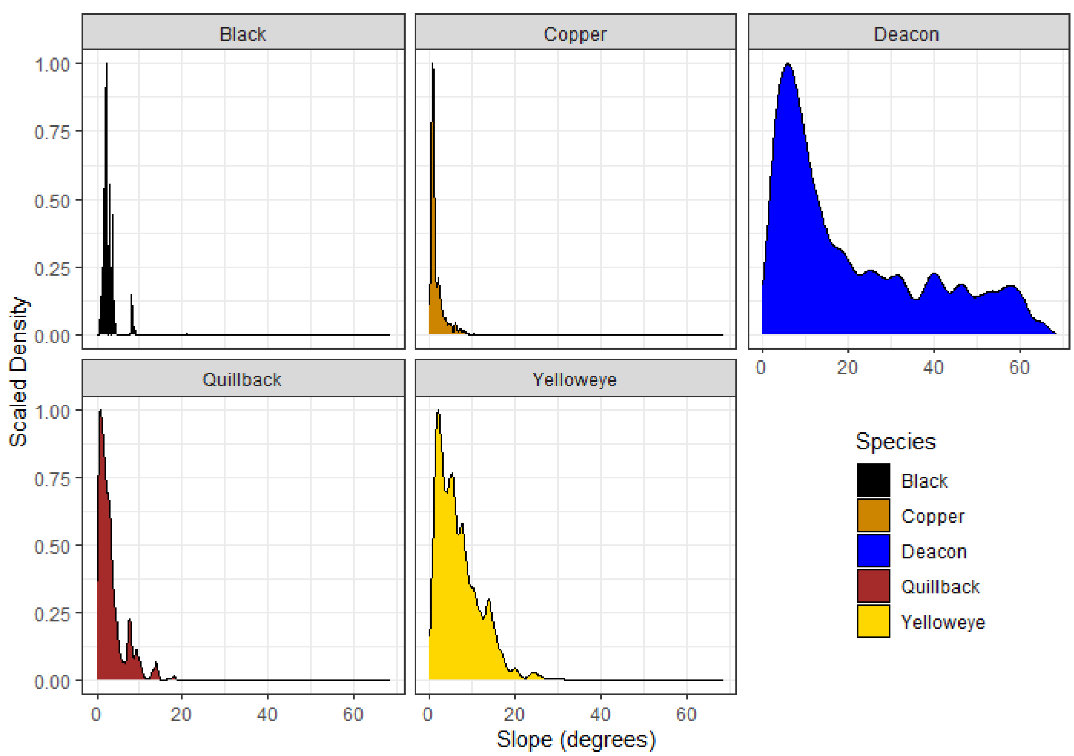

Fig 8. Scaled density plots of the slope of the habitat utilized by each of the five focal species.

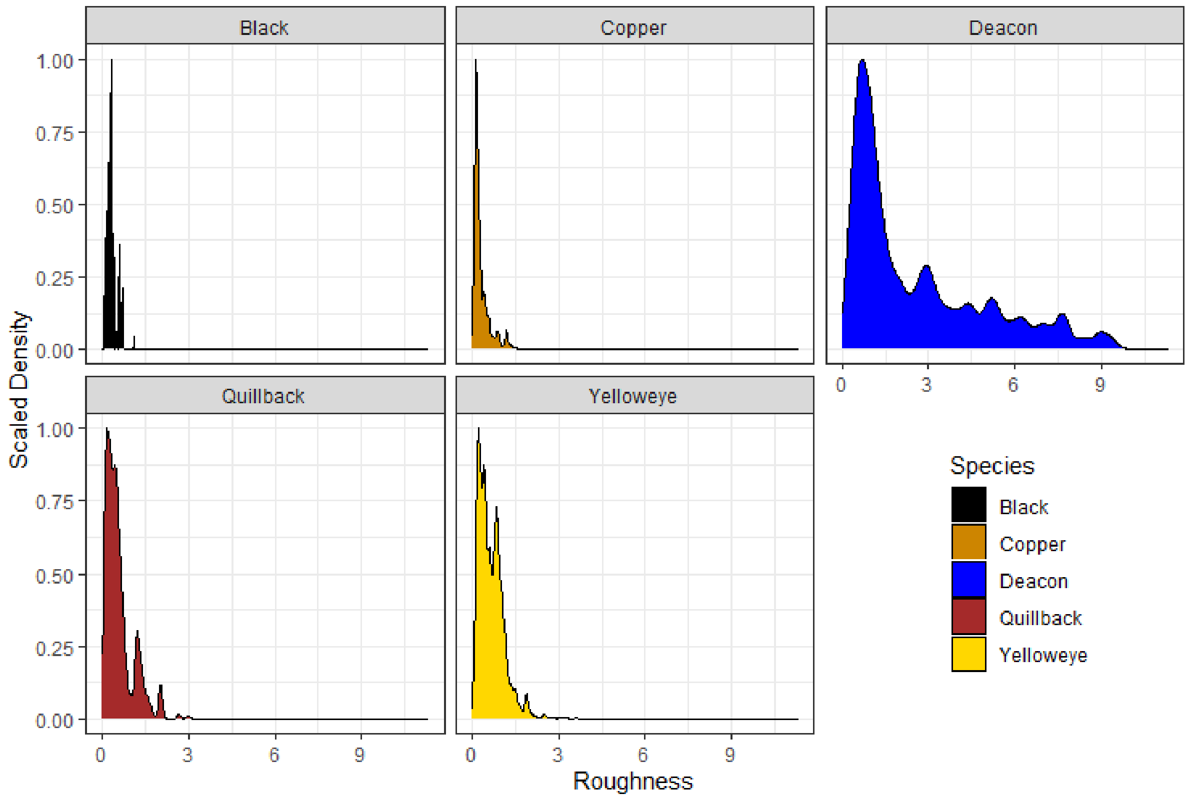

Fig 9. Scaled density plots of the roughness of the habitat utilized by each of the five focal species.

DISCUSSION

These analyses clearly demonstrate that the behavior of rockfish differs dramatically between species. Although, the studies we reanalyze here arrive at similar findings, they often focus their discussion on the variability in individual behaviors of the fish. While individuality occurs and is ecologically important, when designing a survey we survey the population, not the individual (Gunderson, Donald R. 1993). Thus, the understanding of what a species does on average, as provided in this paper, is useful in informing fishery independent population surveys.

Although the current re-analysis provides a temporally robust data set for each of the five species, each species was only studied at one reef and the studies were not always at the same reef. As such, the interpretations should be considered experimental until other studies can be repeated at additional sites within Oregon. Ideally, all of these species should be studied at a single reef to allow for a better intra-reef comparison of behavior and habitat usage.

Based on the findings of our height off bottom analysis, Black, Deacon and Yelloweye Rockfish, should be available to hydroacoustic survey methods. While both Black and Deacon Rockfish live off-bottom, they occupied parts of the reef with different vertical relief and exhibited distinctly different habitat preferences. This may be influenced by the vastly different dietary preferences between the two species (Hobson and Chess 1976; McClure 1982; Doran 2020). Yelloweye Rockfish used somewhat rugose habitat, a trend well established in the literature (Johnson et al. 2003; Mumm 2015).

The discovery that Black and Deacon Rockfish are available to hydroacoustics is not surprising. Both fish are known to school off bottom and Black Rockfish have been surveyed using hydroacoustic methods in Washington and Alaska (Boettner and Burton 1990; Tschersich 2015). However, the telemetry study that generated the data in this paper questioned the utility of hydroacoustics for Black Rockfish based on the presence of individual behaviors that may make those individuals unavailable to traditional acoustic methods (Parker et al. 2008). This demonstrates the importance of assessing the behavior of fish at the species level when considering development of a survey. Deacon Rockfish were also available to hydroacoustics but displayed a distinct diel change in height off bottom (Rasmuson In Press). This suggests that any acoustic operations should be conducted during daytime hours. The relief and slope of the habitat utilized by Deacon's also suggest that trawls would be highly ineffective at providing an accurate estimation of population size.

The finding that Yelloweye Rockfish are available to hydroacoustics is somewhat surprising. Yelloweye Rockfish are characteristically considered a near bottom fish. While the data suggests an acoustic method may be effective for Yelloweye, we propose more research is needed. What is likely more important from our findings is that, surveys of other semi-pelagic continental shelf rockfish (e.g. Widow (*Sebastes entomelas*), Yellowtail *(Sebastes flavidus*) or Pacific Ocean Perch (*Sebastes alutus*), should consider potential presence of Yelloweye Rockfish (Stanley 1999, 2000). Further, it is worth noting that the Yelloweye study occurred on the continental shelf and at greater depths than the other studies. It is unknown if Yelloweye in the nearshore or on the continental slope exhibit these same behaviors and therefore we are unsure how representative our data are of the species as a whole. Finally, as described in Rankin (2019), tagging Yelloweye Rockfish is difficult, with only some fish remaining in the survey array, while others leave the array for long periods of time. In the future, satellite tags may be an effective way to assess where these wandering individuals go, and what their behavior is (Rodgveller et al. 2017). What is not surprising is that based on the habitat use of Yelloweye, a bottom trawl is unlikely to be an effective survey tool (Jagielo et al. 2003; Hannah and Blume 2012, 2014).

Only acoustic survey methods that are resistant to the near bottom acoustic deadzone (e.g. broadband methods or near bottom towed bodies) would be able to differentiate fish echoes from those of the bottom (Kloser 1996), and would useful for Quillback and Copper Rockfish which remain close to the bottom. Contrary to previous publications, these species did use lower relief habitat than Yelloweye and Deacon Rockfish (Richards 1987). This suggests that on average, their bottom tending behavior, combined with their utilization of relatively low relief habitat, should make them available to traditional bottom trawl surveys. Cape Perpetua, where the Copper and Quillback Rockfish were tagged, is relatively low relief compared to the rest of the state's reefs. As such, these species especially would benefit from additional research at a larger higher relief reef. Further, horizontal diel and tidally influenced movements of both of these species have been reported in the literature, and by averaging our data across the entire study diel and tidal behaviors may have been obscured (Tolimieri et al. 2009). Finally, although trawls may be effective, deployment of bottom trawls in nearshore environments comes with concerns about the ecological and social perception concerns suggesting other survey technologies may be better equipped to quantify these species (Watson and Huntington 2016; Huntington and Watson 2017).

Acoustic telemetry data provide deep insight into the availability of rockfish to acoustics and bottom trawl. However, there are some shortcomings of these types of data. First, high resolution acoustic telemetry studies are often only able to tag a relatively small number of individuals. As such, it is possible that the low sample size hides larger trends. Secondly, to provide these high-resolution data, the receiver arrays can only cover a relatively small geographic area. Thus, for species or individuals that move great distances (e.g. some Yelloweye Rockfish), the telemetry data only describes the behavior of those individuals with relatively small home ranges.

Although the data used in this study were collected over a long time period, recent work has shown that fishing pressure can influence individual fishes schooling behavior (Guerra et al. 2020), and that size selective harvesting influences the behavior of the population as a whole (Sbragaglia et al. 2019). Further, the removal of predators by fishing has been demonstrated to increase the boldness of fishes (Rhoades et al. 2019). Thus, these studies and analyses would benefit from re-analysis in the future. Despite our position that we should focus more on the population than the individual for the purpose of surveying fish, we want to acknowledge the importance of the individual. Specifically, the concept of behavioral syndromes should be considered as a potentially important contribution to the effect on fish behavior on fisheries independent surveys being applied to the stock assessment process (Bell and Sih 2007).

In conclusion, our work demonstrates that summarizing high resolution acoustic telemetry data is an effective way to understand how the behavior of different fish species would influence its availability to different survey tools. While in this document we focused on the availability of the different species to hydroacoustics and bottom trawls, these interpretations can easily be extended to other sampling tools like hook and line and underwater video. While highlighting the variability of species behavior has implications for life-history parameters that may contribute to a stock assessment, it is also very informative to the survey development process and helps insure the most appropriate survey tools and methods are being applied.

ACKNOWLEDGMENTS

I thank all of the authors and scientists who conducted all of the hard field work and data analysis outlined in the original manuscripts. Obviously, this work would not have been possible without their hard work. I also thank Kelly Lawrence, David Fox, Katie Pierson, and Scott Malvitch for reviewing this manuscript for me.

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