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DEVELOPMENT OF A COMBINED HYDROACOUSTIC AND VISUAL SURVEY TO DETERMINE REGIONAL POPULATION SIZE OF NEARSHORE ROCKFISH IMPORTANT TO RECREATIONAL AND COMMERCIAL WEST COAST FISHERIES

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Executive Summary

Grant NA17NMF4270223 gave us the opportunity to determine if a combination of hydroacoustic and visual methods could be used to survey Oregon's nearshore semi-pelagic rockfish resources. First, we determined that the combination of our suspended camera system is and hydroacoustics can provide population estimates for these species. Further they are a relatively efficient tool that provide additional benefits to stock assessors and managers by the nature of their design. This work has been published in the ICES Journal of Marine Science. Second, working with the ROV team we also assessed the impact of the near bottom acoustic deadzone on our population estimates. Overall we found that the majority of the semi-pelagic fish are located above the near bottom acoustic deadzone. Further, the addition of a downward facing camera on our suspended stereo camera system allows us to correct for fish located in the near bottom deadzone which are unavailable to the acoustics. A draft manuscript of this work is in preparation and will also be submitted to ICES Journal of Marine Science. Finally, after completing this work, some funds remained which were used in concert with funds from the Oregon Department of Fish and Wildlife's Restoration and Enhancement board to operationalize the hydroacoustic and suspended camera system for a statewide survey of nearshore semi-pelagic rockfish. Despite difficulties due to Covid-19, the survey was completed in December of 2021 and results are forthcoming. These data will be combined into a report and presented to the Pacific Fisheries Management Council's Scientific and Statistical Committee.

The results of this work were presented at local Oregon coast research venues. However, a presentation is yet to be made at the Western Groundfish Society as these meetings have been on hiatus since 2017. We also conducted Facebook livestreams, Instagram takeovers and used other forms of social media presence to heighten the awareness of our work. Overall, the reception of the work by the general public and fishing communities was positive. Finally, this work allowed early career scientists to obtain publications, which ultimately culminated in their attaining a full time career.

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Background from initial submission

The purpose of the proposed project was to further the development of a novel nearshore fishery-independent survey to improve assessment and sustainable management of nearshore rocky reef fish stocks off of Oregon. The specific goal was to gather detailed data to inform the selection of the optimal combination of visual survey tools and hydroacoustic data collection for quantifying nearshore rocky reef fish abundance and biomass, with a focus on the semi-pelagic rockfish species that are most critical to Oregon's coastal communities. There are two specific objectives for this project.

Objective 1: Assess the effectiveness of paired acoustic and pelagic drop-camera surveys for documenting semi-pelagic rockfish density and biomass.

The Oregon Department of Fish and Wildlife's Marine Resources Program has developed a pelagic drop-stereo camera system specifically to provide species and length compositions to compliment acoustic data collection. However, specific deployment strategies to accurately assess these compositions throughout the water column have not yet been evaluated. This objective tested multiple deployment strategies of the pelagic drop-camera by targeting schools of semi-pelagic rockfishes and compare species compositions and length distributions from each deployment strategy.

Objective 2: Assess the importance of near-bottom fish (including target species and non-target species) for interpretation of acoustic-based abundance estimates. Evaluate the ability of three visual survey tools (drop-camera, lander, ROV) to quantify the contribution of these fish to total abundance for target species.

While the pelagic drop-camera has been developed specifically for use with the acoustic system, there is strong potential for bias in its sampling frame, as it is geared towards mid-water column data collection, and therefore may underestimate abundance and bias species compositions by not sampling near-bottom species that are acoustically detected. Additionally, an inherent feature of acoustic data collection is the presence of a near-bottom "dead zone" in high relief habitat. Oregon Department of Fish and Wildlife's Marine Resources Program has an ROV that is capable of capturing species composition and length distributions of benthic fish, including those adjacent to or within the acoustic dead zone. By evaluating the ROV, in concert with the acoustic and pelagic drop-camera combination, a more complete picture of the species present will be provided and would quantify the importance of regularly sampling the benthos during a nearshore survey. To evaluate this objective, multiple reefs were surveyed. Densities of near-bottom fish were be compared, and sampling area population estimates produced.

Anticipated Benefits/Outcomes

Taken together, results from these two objectives would inform the design and implementation of a wide-scale nearshore fishery-independent survey. The first objective will provide information on the optimal deployment strategy for the pelagic drop-camera, and if that deployment strategy might need to be modified in different locations along the Oregon coast due to differing species compositions or semi-pelagic school structure. The second objective will provide information on whether an additional tool that evaluates the benthic component, both within the acoustic dead zone and outside the scope of the pelagic drop-camera, is needed. This will provide information on how critical this benthic component is to regularly sample as part of a comprehensive, wide-scale nearshore survey, and would provide information if the importance of the benthic component may vary by location or site characteristics. Finally, comparisons between the two benthic tools will provide support for the most appropriate tool to use with the acoustic and pelagic drop-camera combination, if necessary. This objective will also allow for evaluation of the size and importance of the acoustic dead zone, and how that feature might vary in multiple types of terrain present off the Oregon coast.

The information provided from this pilot study would allow ODFW to effectively plan and implement a comprehensive nearshore fisheries-independent survey in the near future. In the short term, this project would directly increase knowledge of nearshore fish behavior and habitat associations, and particularly provide additional information about nearshore species that are currently extremely data-limited. Eventually, the full implementation of a nearshore fishery-independent survey would provide unbiased estimates of abundance and biomass for multiple nearshore species, including those critically important to the coastal community. This fishery-independent survey will be especially important for the most heavily fished species, such as the semi-pelagic black, blue and deacon rockfishes. Improvement of nearshore stock assessments will provide benefits to both commercial and recreational fishermen, and to coastal communities that rely on those industries, by promoting the long-term, sustainable management of these species, and increase public confidence in stock assessments, which is key to successful management.

Objective 1

Objective 1 was examined using a test survey at Seal Rock Reefs. Results of that mock survey were published in ICES Journal of Marine Science (https://academic.oup.com/icesjms/article/79/1/100/6470671). The text from this article are recreated below for ease.

Combined video-hydroacoustic survey of nearshore semi-pelagic rockfish in untrawlable habitats.

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Abstract

New survey technologies are needed to survey untrawlable habitats in a cost effective and nonlethal manner with minimal impacts on habitat and nontarget species. Here we test the efficacy of integrating data from a suspended underwater camera with acoustic data to generate population estimates for nearshore Black (*Sebastes melanops*), Blue (*Sebastes mystinus*) and Deacon Rockfish (*Sebastes diaconus*). We surveyed Seal Rock Reef near Newport, Oregon, and compared our results to population estimates derived from a mark-recapture study conducted at the same reef. We compared fish density estimates from video deployments to those calculated from applying published target strength to length regression models to our acoustics data. Densities derived from the acoustics, using a generalized physoclist target strength to length model, were significantly

different from densities derived from video; conversely, a rockfish-specific target strength to length model generated densities that were not statistically different from video densities. To assess whether, and how, fish behaviour was influenced by the presence of an underwater camera, we deployed our camera under the acoustic transducer. No statistical difference was observed in the acoustic density of fish before, during, or after camera deployment. Our work suggests that combining acoustic and stereo video data provided a similar population estimate to historic survey results, but an accurate acoustic density estimate was dependent on using the proper acoustic target-strength model. We contend that combining camera data with hydroacoustic data is effective for surveying rockfish in untrawlable habitats.

1. Introduction

Fisheries independent surveys provide an important unbiased data input into fisheries stock assessments (Hilborn and Walters, 1992). Fisheries independent surveys are often time consuming and costly, making their implementation difficult for all but the most economically important fisheries. Bottom trawls are currently the most commonly used fishery independent survey tool for groundfish (Gunderson, Donald R., 1993); however, research continues to demonstrate that trawls may not be effective in rugose habitats, which may significantly impact the survey data products as well as the tool being a relatively destructive way to sample (Zimmermann, 2003; Pirtle *et al.*, 2015). Alternatively, other methodologies and technologies are being considered to survey "untrawlable habitats" (Tolimieri *et al.*, 2008; Williams *et al.*, 2010). Technologies, such as hydroacoustic and underwater video, are being examined as potentially more efficient and cost-effective than traditional survey methods.

In Oregon's nearshore waters, Black Rockfish (*Sebastes melanops* Girard 1856), Blue Rockfish (*Sebastes mystinus* Jordan & Gilbert 1881) and Deacon Rockfish (*Sebastes diaconus* Frable et al. 2015) are the primary target of the recreational bottomfish fishing fleet (Cope *et al.*, 2015). These species are known to occur off the bottom in schools, as well as near the bottom and are often deemed semi-pelagic. These species also represent an important component of commercial nearshore hook and line, and longline fisheries. Despite their economic importance, there are currently no fishery independent surveys conducted in Oregon's waters that target nearshore rockfish. Historically, a mark-recapture passive integrated transponder (PIT) tagging study for Black Rockfish was conducted at a single reef on the central Oregon coast (Krutzikowksy *et al.*, 2019). However, this study only provided a population estimate of one reef, making the data difficult to use as a stock assessment model input because it is not representative of the entire stock, which is distributed across multiple reefs.

An accurate estimation of stock size is an integral component of sustainable fisheries management (Maunder and Punt, 2013), and this estimation has been hindered by a lack of fishery independent data (Cope *et al.*, 2015; Dick *et al.*, 2017). Hydroacoustic population estimates are attractive to stock assessors because they provide numerical estimates of fish abundance rather than a relative abundance index which can better inform the size of the stock. However, for hydroacoustics to be effective, the fish must be detectable by the acoustics (Ona and Mitson, 1996; Kotwicki *et al.*, 2015) and a proper target-strength to length model needs to be available (Love, 1971; Foote, 1987). Detectability, for semi-pelagic fishes, requires the fish to be high enough off the seafloor to allow their acoustic signature to be differentiated from the seafloor (Mello and Rose, 2009; Rasmuson, 2021). Fish whose backscattering signature cannot be differentiated from the seafloor are said to be located within the near bottom acoustic dead zone. While the presence of the acoustic dead zone makes population estimates of benthic rockfish species difficult, previous studies have shown hydroacoustic surveys to be well suited for semi-pelagic rockfish (Parker *et al.*, 2008). Previous studies on the congeneric Widow (*Sebastes entomelas* Jordan and Gilbert 1880) and Yellowtail Rockfish (*Sebastes flavidus* Ayres 1862), off the coast of Oregon and British Columbia, suggested that hydroacoustic surveys are a viable method for these species (Stanley, 1999, 2000). Hydroacoustic surveys of Black Rockfish in Alaska and Washington also provided accurate and repeatable population estimates (Boettner and Burton, 1990; Tschersich, 2015). This suggests hydroacoustic surveys may be an effective survey method for Oregon's semi-pelagic nearshore rockfish.

In order to convert the acoustic backscattering data into fish densities, hydroacoustic data is paired with species composition and length data (McClatchie *et al.*, 2000). Traditionally, this data comes from midwater trawls (Williams *et al.*, 2010; Jones *et al.*, 2019); however, midwater trawls are difficult to operate in highly rugose areas, and lethally sample fish. In environments where trawling is difficult, and lethal sampling is not desirable, alternative sampling tools are necessary. Underwater video tools are becoming an increasingly common non-lethal alternative for producing both species composition and length data (Rooper, 2010; Bacheler *et al.*, 2017). The advent of stereo camera technology allows scientists to measure lengths of fish observed by the camera (Langlois *et al.*, 2012; Hannah and Blume, 2016). Combining species composition and length data from stereo video with hydroacoustic data has been shown to be an effective survey combination, producing accurate fish densities (Starr *et al.*, 1996; Jones *et al.*, 2012; Boldt *et al.*, 2018). To date, combining species composition and length data with hydroacoustic data has never been done for Black Rockfish. In the case of Tschersich (2015), species composition data were obtained from a single camera and no lengths were obtained. In the case of Boettner and Burton (1990), a midwater trawl was used. Advancements in how species composition and length data can be obtained from, and combined with, acoustic surveys of Black Rockfish are necessary. Further, wWhen selecting athe sampling tool, it is essential to account for the fact that all sampling tools have some form of sampling bias error associated with them. The effect of sampling error associated with each tool and how those assumptions influence both length and species composition data and the effect of this error must be considered.

Here, we tested the efficacy of combining hydroacoustic data and underwater stereo video data (length and species composition data) to generate a population estimate of three of Oregon's nearshore rockfish species (Black, Blue and Deacon Rockfish). We created a novel camera system that is uniquely designed for semi-pelagic rockfish species found in rocky reef habitat. This system was designed to be paired with hydroacoustic data. One concern with all survey tools, is the catchability of a species by the tools (Koslow *et al.*, 1995; Stoner *et al.*, 2008; Somerton *et al.*, 2017). For acoustic surveys, catchability is the ability of the acoustics, as well as the ability of the trawl (or in our case, video sampling tool), to detect fish. For video and acoustic survey tools, where fish are not actually caught, catchability is known as detectability. In this manuscript we use detectability to refer to the ability of acoustic and video sampling tools to accurately provide a representative sample of the focal population(s) (Arreguin-Sanchez, 1996). Hydroacoustic detectability may be reduced due to the near bottom dead zone, and video detectability may be reduced due to fish avoidance of the video tool, as well as poor underwater visibility. We address detectability of the hydroacoustic and video tools by examining the potential impact the acoustic dead zone and camera deployment may have on the abundance estimate.

2. Methods

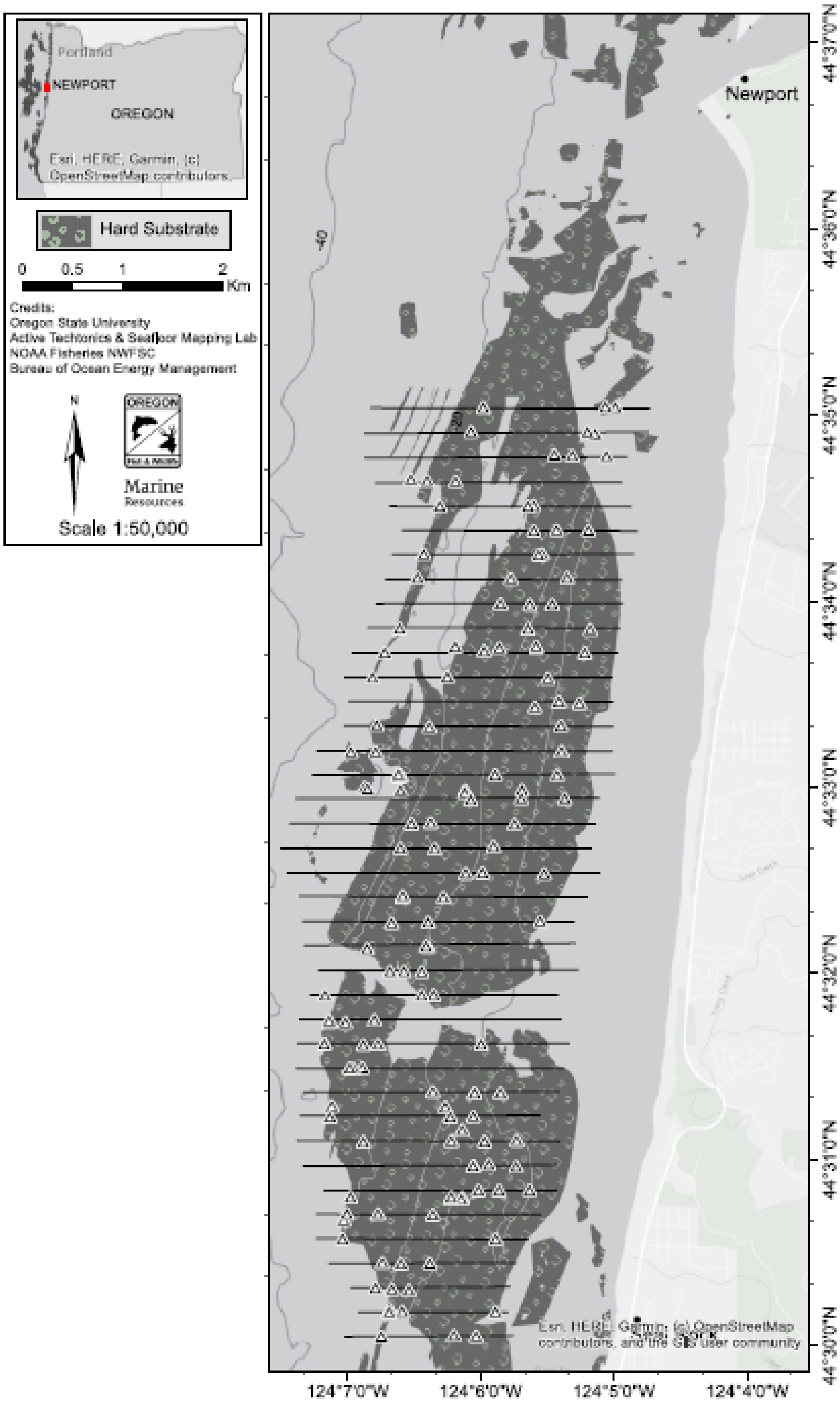

Figure 1. Map of survey transects (black lines) overlaid on the known hard substrate. Triangles denote deployment locations of the BASSCam. Transect lines extended 500 m offshore and shoreward of the known hard bottom substrate.

2.1 Field Work

We conducted a pilot survey to test the integration of hydroacoustic data with suspended stereo camera data to generate a population estimate of midwater rockfishes. The survey was conducted from September 25-29, 2017 at Seal Rock Reef, just south of Newport, Oregon (**Fig. 1**). This reef was chosen due to the presence of historic data from this location, and its nearness to research facilities. The goal of this study was not intended to provide a regional population estimate, but to assess the utility of the survey method. All surveys were conducted from a 15.25 m long charter passenger fishing vessel operating at an average speed of 9.25 kph. Thirty-eight parallel transects were established and spaced 0.5 km apart (in the North/South direction). Transects began 500 m offshore of known hard bottom habitat and extended 500 m inshore of the hard bottom, or to a water depth of 5 m, whichever occurred first. To minimize the effect of ocean swell, acoustic data were collected while the vessel traveled from offshore to inshore, using a 201 kHz BioSonics DT-X transducer. The transducer was calibrated 6 months prior to the survey and immediately following the survey at the BioSonics factory. The transducer was pole mounted in a downward facing orientation on the starboard side of the vessel. The beam width of the transducer was 6.5° and the unit transmitted 0.3 ms pulses at a ping rate of 5.0 pings per second.

On each transect, while collecting the acoustic data, three fish schools were identified from the acoustics and marked on a GPS for later sampling with a suspended camera system. Previous work demonstrated rockfish schools remain at relatively the same locations on the reef for days to weeks, making it possible to return to schools to deploy the camera after the acoustic data was collected for the entire transect (Rasmuson unpublished data). Video sampling of each school occurred within one hour of the transect being ensonified. At each transect, three fish schools were selected for video deployments . If less than three schools were observed, the camera system was deployed on high relief rocky habitat, identified in the acoustics, for a total of three video deployments per transect. If more than three fish schools were observed, schools were selected haphazardly for video sampling.

The suspended camera data was collected with our Benthically Anchored Suspended Stereo Camera system (hereafter BASSCam). The BASSCam was equipped with a pair of forward-looking GoPro Hero4 Black Edition cameras in a calibrated stereo configuration, with illumination from two Big Blue VL7500P LED lights. The cameras were calibrated using a 3-dimensional calibration cube, developed by SeaGIS, and calibration coefficients were generated using the SeaGIS CAL software. In addition to the forward-looking stereo cameras, the platform also had one GoPro Hero4 Black Edition camera looking downward from the forward plane at an angle of 22 degrees, illuminated by two Big Blue VL2800P LED lights. Based on height of the camera system off bottom, and the angle of the downward facing camera, we know that 78% of the volume viewed by the downward camera is within 1 m of the bottom (what we define as the near bottom acoustic dead zone in this paper). The platform was equipped with a Star-Oddi DST tilt sensor that recorded the 3-dimensional orientation of the camera system as well as depth and temperature. The BASSCam was designed to remain upright and orient into the current (**Fig. 2**). A 2 m tether was attached to the bottom of the camera with an 18 kg piece of scrap iron as an anchor, which was designed to break-away if caught on the rocky bottom habitat.

Prior to each deployment, the video system was turned on while onboard, and a synchronizing video frame was generated using a video clapper board. The captain then positioned the vessel over (or near) the fish school and the camera deployed so it drifted into the target fish school. The camera system was tended at the surface while tethered by an armored umbilical (2.57 mm). One camera (left) was connected to the umbilical and sent live video signal to the vessel for real-time viewing. The live camera was used to determine if the fish school was successfully sampled, if it was not, to the camera was re-deployed. The camera was retrieved using an electric motor and spool after a minimum of two minutes from the time the camera's anchor reached the bottom.

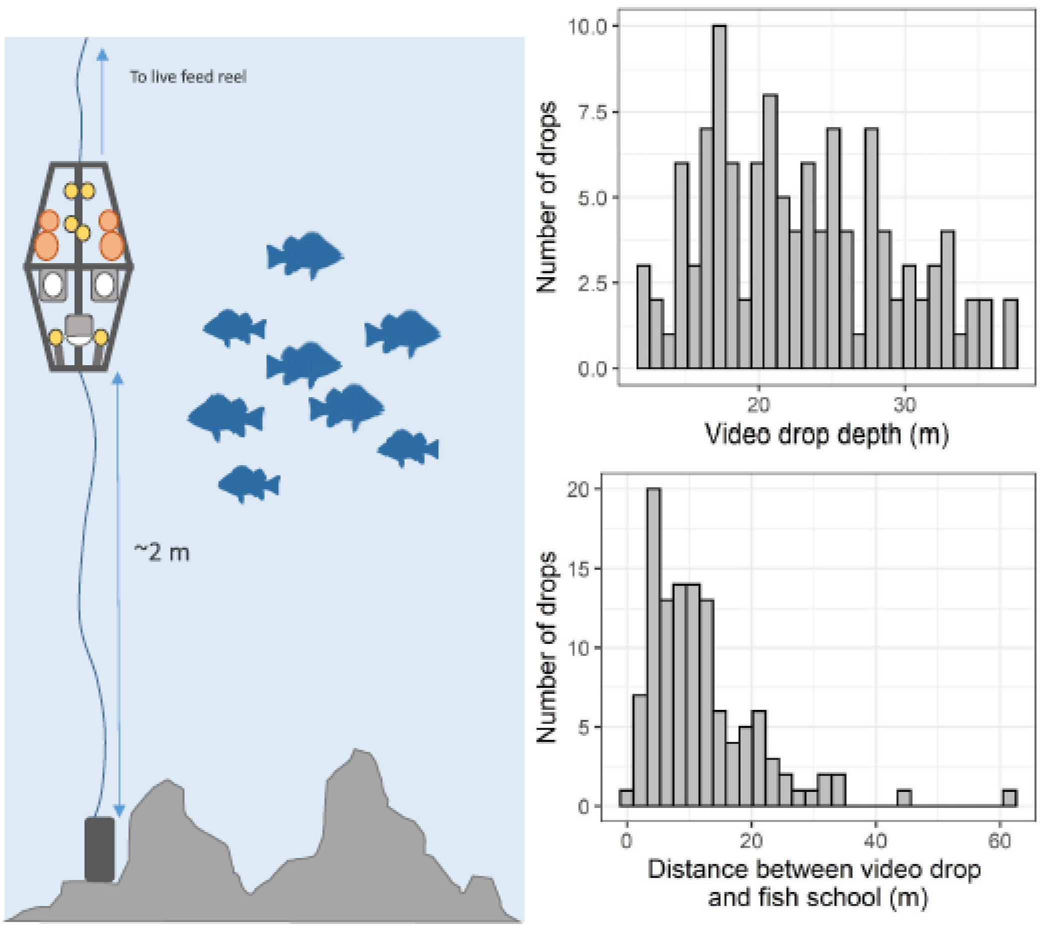

Figure 2. Schematic of BASSCam deployed in a school of fish (left) and number of BASSCam deployments by water depth (upper right) and the distance from the BASSCam deployment location to the fish school identified by the hydroacoustics (lower right). On the left, the white and grey boxes denote the location of the three video cameras, the orange circles denote non-compressible trawl floats used to provide buoyancy and the yellow circles denote the locations of the underwater lights.

Bottom time was determined with a stopwatch. Two minutes of bottom time was shown to be enough time to provide accurate size and length data (Rasmuson unpublished data).

2.2 Analysis

All statistical analyses were conducted using R version 3.6.3 Holding Windsock (R Core Team, 2020). Distances from the targeted fish schools to the BASSCam deployment locations were calculated using the Geosphere package. Our analysis required us to combine acoustic and video data in multiple ways to answer the hypotheses we generated; to aid the reader, a flow chart is included to assist in understanding which data were used to answer each question **(Fig. 3).**

2.2.1 Video Analysis

Videos were reviewed using the EventMeasure software developed by SeaGIS. Only the first two minutes of video, after the camera reached the bottom, were reviewed. All species were identified to the lowest taxonomic unit possible. Blue and Deacon Rockfish were scored as a single species complex because they are routinely difficult to differentiate due to poor water visibility. There is considerable debate in the literature about the best way to review stationary underwater video.

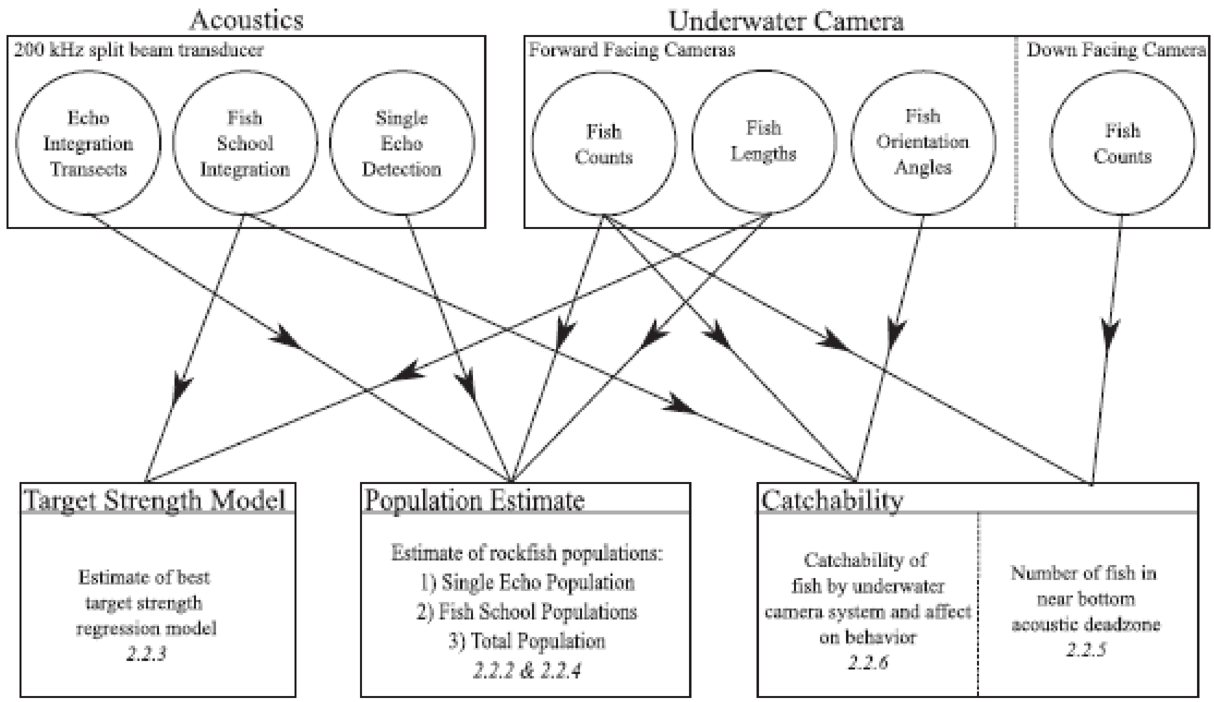

Figure 3. Flow chart depicting the relationship of acoustic and video inputs for each component of the analysis process.

Therefore we reviewed videos from the BASSCam's forward cameras using both a MaxN and a MeanCount approach (Schobernd *et al.*, 2014). The results of this analysis are available in the online supplement.

We found the MeanCount method to be the most statistically robust and efficient way to review video. MeanCount was conducted by enumerating all fish in each of the five randomly selected frames from the two-minute bottom time. Fish were counted in the left forward-facing stereo camera only. No attempts were made to ascertain whether fish being counted in each of the five frames were the same fish. In the downward facing camera, fish were counted in the same frames that we counted in the forward camera. Of the fish counted in the left camera, we attempted to measure each fish, which is only possible if the fish's head and tail are observed in both forward-facing cameras. To do this, reviewers tracked each fish both forwards and backwards in the video to find a frame where they were best able to identify and measure the fish. Due to the rarity of some species, we aggregated non-focal species into functional groups. Black Rockfish were kept as a single species group and Blue and Deacon Rockfish were kept as a congeneric cryptic species group. Yellowtail Rockfish, Widow Rockfish and Canary Rockfish (*Sebastes pinniger* Gill 1864) were all categorized as non-focal semi-pelagic rockfish, and all remaining rockfish were categorized as demersal rockfish. Black and Blue/Deacon Rockfish < 20 cm in length (as measured using EventMeasure stereo software) were classified as juvenile Black/Blue/Deacon Rockfish. This cut off was based on genetic identification of hook and line caught fish, which suggested fish < 20 cm in length are difficult to positively identify visually, even when in-hand (Rasmuson *et al.*, 2021b).

To generate a volumetric density of fish (number of fish per m^3) for each video deployment, we followed the methods of Williams et al. (2018) to convert the viewable area into a volume. We then used the average number of each species identified in all 5 frames to generate an average density of rockfish for each video deployment conducted.

2.2.2 Acoustic Analysis

Acoustic data were processed in Echoview v9.0 using a combination of echo counting and echo integration methods. We defined the near bottom acoustic dead zone from 0-1 m off bottom, and the nearfield dead zone from 2.5-0 m from the transducer face; both areas were excluded from all analyses (Ona and Mitson, 1996). Our acoustic data had a large amount of noise from zooplankton and other acoustic scatterers, so masking procedures were used to reduce noise (**Fig. 4).**

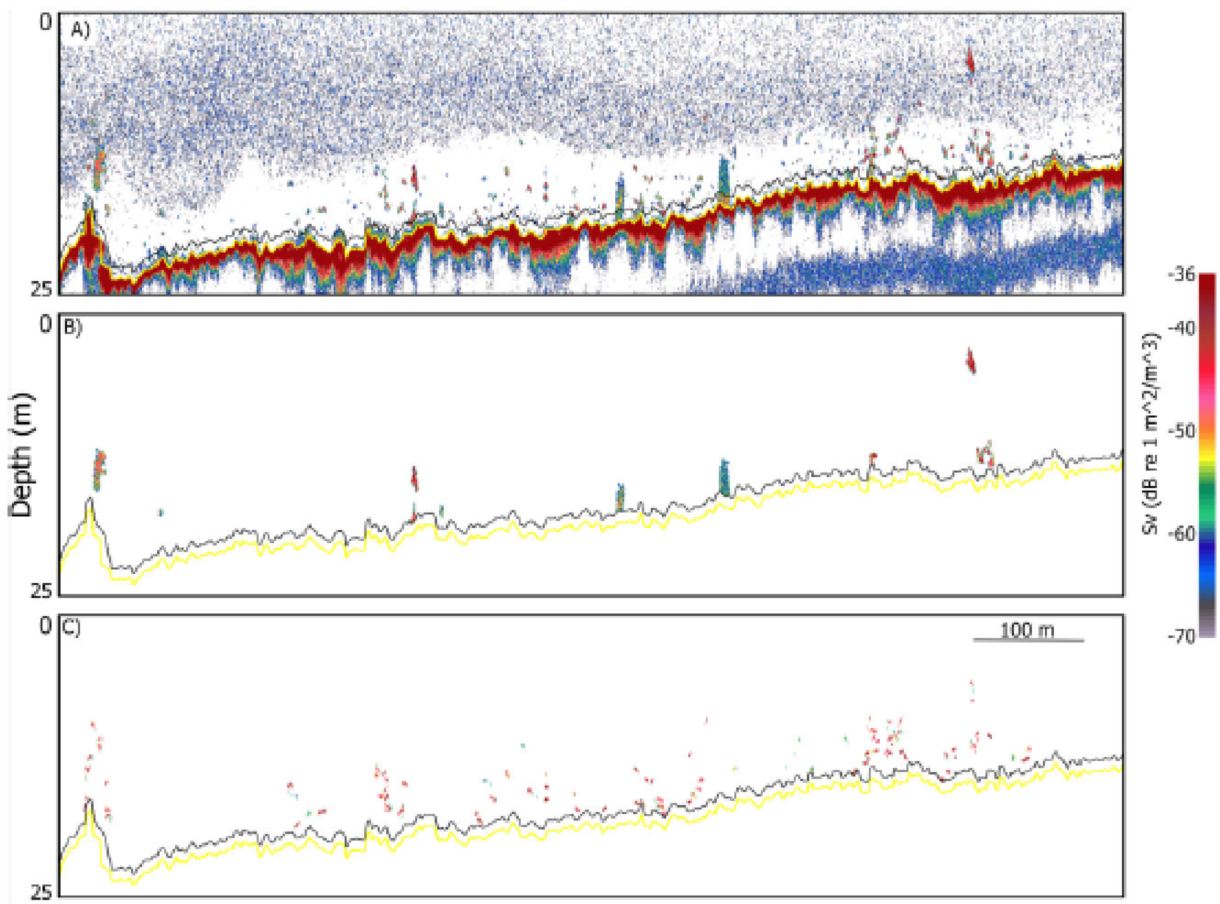

Figure 4. (a) Uncorrected echogram with the bottom detection line (yellow line), and the near bottom acoustic dead zone exclusion line (black line), (b) echogram displaying only the fish schools identified by the school detection algorithm; all other data have been masked, (c) single targets identified in the echogram that were used in conjunction with the fish tracking algorithm; all other data have been masked. In panels (b) and (c), data from the near bottom acoustic dead zone were masked by the processing algorithms.

2.2.2.1 Echo integration

Regions for echo integration were identified using the Sawada index as well as the ratio of multiple echoes (Sawada *et al.*, 1993). Regions where the Sawada index values were < 0.04, and the ratio of multiple echoes value was < 0.7, were used for single target analysis. Both methods allow the research to identify areas where the density of fish is too large to count individuals. In regions where densities of fish were too large, data were analyzed using echo integration. Schools were identified on echograms, smoothed with a 3x3 median filter, and defined using the school detection algorithm described by Barnage (1994), Haralabous (1996), and Nero and Magnuson (1989). The algorithm used a series of thresholds and criteria to define regions as a school of rockfish, which were then edited by the reviewer (**Table 1**). The unfiltered backscattering data were then masked to only display the regions defined as schools by the school detection algorithm. The raw total backscatter (NASC) was exported for each transect as a whole, to be used for population estimations, as well as exported for individual schools, to be used in the selection of a target strength model. Backscattering cross-section data were calculated in 1 cm bins, and scaled for relative abundance of each species, or species group, following methods of Robertis et al. (2014). Backscattering cross-section data (σ_{bs}) were calculated using the standard target strength to length equation given as:

$$TS=20\log_{10}(L)-b_{20} \qquad E.1$$

where TS is the fish target strength, L is the fish length in cm, and b_{20} is a species-specific constant. See section 2.2.3 below for how b_{20} was determined for this study. Length data were obtained from a survey-wide distribution of stereo measurements from the BASSCam. Mean back scattering cross-section was calculated as

$$\overline{\sigma_{bs}} = \sum\nolimits_{i,g} \left(P_{i,g} * \sigma_{bs,i}\right) \qquad E.2$$

Where $\overline{\sigma_{bs}}$ is the mean back scattering coefficient, $P_{i,g}$ is the proportion of a group of rockfish (g) at length i and $\sigma_{bs,i}$ is the back scattering cross-section at length i. The proportion of each species group by length was calculated as

$$P_{i,g} = \frac{NCamFish_{i,g}}{\sum NCamFish_i} \qquad E.3$$

Where $NCamFish_{i,g}$ is the number of fish in a length bin (i) for a given species group (g) observed in by the BASSCam, and $\sum NCamFish_i$ is the sum of all rockfish groups in a length bin i observed by the BASSCam. Mean back scattering cross-section was converted to number of fish using

$$EIdens_{i,g,t} = \left(\left(\frac{NASC_t}{4\pi\sigma_{bs}}\right) * P_{i,g}\right) * \left(\frac{1}{3.43 * 10^6}\right) \qquad E.4$$

Where $EIdens_{i,g,t}$ is the density of fish in a length bin i for each species group (g) in number of fish per meter square on given transect t. $NASC_t$ is the nautical areal scattering coefficient provided as an output from the acoustic software for transect t.

Table 1. Parameter settings for school detection, single target detection and fish tracking in Echoview acoustic software. Note: dB values in this table are dB re. 1 m^2/m^3.

School Detection

Parameter	*Value*
Minimum school length	5.00 m
Minimum school height	2.00 m
Minimum candidate length	3.00 m
Maximum vertical linking distance	5.00 m
Maximum horizontal linking distance	2.00 m

Single Target Detection

Parameter	*Value*
Compensates target strength threshold	-60.00 dB
Pulse length determination level	6.00 dB
Minimum normalized pulse length	0.30
Maximum normalized pulse length	2.00
Maximum beam compensation	12.00 dB
Maximum standard deviation exclusion of minor axis angles	4.00 degrees
Maximum standard deviation exclusion of major axis angles	4.00 degrees

Fish Tracking (collected for 4d data)

Parameter	*Value*
Alpha major axis	0.800
Alpha minor axis	0.800
Alpha range	0.800
Beta major axis	0.100
Beta minor axis	0.100
Beta range	0.100
Target gate major axis exclusion distance	1.00 m
Target gate minor axis exclusion distance	1.00 m
Target gate range exclusion distance	0.20 m
Target gate major axis missed ping expansion	50.00 %
Target gate minor axis missed ping expansion	50.00 %
Target gate range missed ping expansion	100.00 %

2.2.2.2 Echo Counting

For regions analyzed by echo counting, we follow the protocol outlined in Tschersich (2015) for identifying single targets. Echoes within these regions were identified using the Echoview single target identification algorithm described by (Soule, 1997; Ona, 1999) which differentiates single fish signals from multiple fish signals. However, multiple detections are often made of the same fish so a fish tracking algorithm (Balk and Lindem, 2000; ICES, 2000), was then applied to identify where groups of single targets were in fact a single fish (**Table 1**). Following (Tschersich, 2015) fish density was computed from individual fish tracks using:

$$ECdens_t = \frac{1}{l_t}\sum_{f=1}^{f_n}\left(\frac{1}{2\tan(\theta) * z_n}\right) \qquad E.5$$

ECdens is the summed density contributions (number of fish per m^2) of all single fish tracks on a specific transect (denoted by *t*), *l* is the length of the transect in meters, θ is half of the full angle beam width of the transducer (3.25° in this case), and *z* is the depth, in meters, of each individual fish track (denoted by *f*) from the face of the transducer.

2.2.3 *Target Strength Model- Used for Echo Integration*

Echo integration requires a target strength to length relationship (E.1). In previous acoustic studies of rockfish in the Northeast Pacific Ocean, the generalized regression model for physoclist fish (b_{20}= -67.4, reported by Foote (1987)) has been used to convert backscattering data to abundance estimates (Stanley, 2000; Rooper, 2010; Jones *et al.*, 2012). However, recent work in the Northwest Pacific has provided target strength regression models for the congeneric Korean Rockfish (*Sebastes schlegeli* Hilgendorf 1880) (b_{20}=-70.93), and Dark-banded Rockfish (*Sebastes inermis* Cuvier 1829) (b_{20}=-72.8) (Kang and Hwang, 2003; Hwang, 2015). In an attempt to confirm our selection of a target strength model, we converted backscatter values into a volumetric density of fish for each school identified in the acoustics using each of the three existing target strength regression models (Foote, 1987; Kang and Hwang, 2003; Hwang, 2015). Based on morphological examination of Korean and Dark-banded Rockfish, we hypothesized that a model "in-between" these two species may be more representative of Black, Blue and Deacon Rockfish. We took the arithmetic mean of the b_{20} values from these two target strength regression models, providing an average *Sebastes spp.* model (b_{20}=-71.9). Backscattering data for individual schools was converted into densities using the length distribution derived from video deployments conducted within 10 m of an ensonifed fish school. We then used a one-way Analysis of Variance (ANOVA) with a Tukey-HSD post hoc test to compare the volumetric fish densities from the acoustics; to the volumetric densities of fish from the camera deployments.

2.2.4 *Population Estimate*

No attempts were made to use a modeling or geostatistical approach to generate a population estimate. Further, no attempts were made to estimate or correct for the component of the population that resided within the near bottom acoustic dead zone. Only a very simple design-based approach was used. BASSCam data from all video deployments were combined to determine the ratio of each species abundance relative to total fish abundance as well as to generate a distribution of lengths for each species. Species specific ratios by size (1 cm bins) from the BASSCam were used to convert the hydroacoustic data into a survey level density estimate of Black Rockfish and of Blue/Deacon Rockfish. Densities were generated independently for the echo counting and echo integration data. Average echo integration density of each group of rockfish for Seal Rock was calculated as the total density for each group at each transect averaged by the total number of transects sampled:

$$\overline{EIdens_g} = \frac{\sum_t(\sum_i EIdens_g)}{n_t} \qquad E.6$$

$$EIstdev_g = \sqrt{\frac{\sum\left(EIdens_{g,t} - \overline{EIdens_g}\right)^2}{n_t}} \qquad E.7$$

Where $\overline{EIdens_g}$ is the average echo integration density in number of fish per m^2 of each group of rockfish (*g*) for the entire reef, and n_t is the total number of transects (n = 38). $EIstdev_g$ is the standard deviation of average echo integration density for each group of rockfish. Average echo counting density and standard deviation was calculated as:

$$\overline{ECdens_g} = \frac{\sum ECdens_t}{n_t} \qquad E.8$$

$$ECstdev_g = \sqrt{\frac{\sum\left(ECdens_t - \overline{ECdens_g}\right)^2}{n_t}} \qquad E.9$$

Where $ECdens_g$ is the average echo counting density for each rockfish group (g) in number of fish per m^2, $ECstdev_g$ is the standard deviation of echo counting density, and n_t is the total number of transects (n = 38). These densities and standard deviations were then multiplied by the total survey area (m^2) to generate an average abundance and standard deviation of rockfish at Seal Rock. Survey area (m^2) was calculated by drawing a polygon around the outer edges of all transects. Abundance estimates from the single target and echo integration methods were summed to generate a total abundance.

2.2.5 Near bottom fish population

While it would be ideal to know exactly how many fish were located only within 1 m of the bottom (the near bottom acoustic dead zone), our downward camera includes fish counts from both the near bottom dead zone (78% of volume viewed) and those above the near bottom dead zone (22% of volume viewed). To determine if our focal species are located above the bottom 1 meter of the water column, we examined the ratio of fish counted in downward facing camera to the total number of fish counted in both the forward and downward facing cameras for Black, Blue/Deacon Rockfish and juvenile Black/Blue/Deacon Rockfish using the following formula;

$$BottomCameraRatio = \frac{nfish_d}{nfish_d + nfish_f} \qquad E.10$$

Where BottomCameraRatio is the ratio of fish counted in the down camera ($nfish_d$) relative to the number counted in the forward ($nfish_f$) and down combined.

2.2.6 Length data

We compared our camera-derived length data to fish length data from the recreational hook and line fleet. Also, Black Rockfish lengths from the camera were compared to length measurements from an eleven-year-long PIT tagging study of Black Rockfish conducted at the same reef complex as our present study (Krutzikowksy *et al.*, 2019). Due to the inequality in sample sizes between video data and hook and line data, quantitative comparison was not possible, rather, analysis was limited to a visual comparison.

2.2.7 Fish orientation and behavior

Orientation of a fish's swim bladder, and consequently the fish's overall orientation, has the potential to influence acoustic backscattering cross-section values, and therefore alter the final abundance estimate. Underwater stereo cameras provide us with the ability to study the three-dimensional underwater orientation of our focal species. For each camera deployment, we determined the average orientation of the camera system relative to a flat horizontal plane with data from a tilt sensor. Using the three-dimensional coordinates of the head and tail of each measured fish, obtained during the measurement process in EventMeasure, we applied trigonometric functions to determine the orientation of the fish relative to a plane parallel with a hypothetical horizontal seafloor. These data were not used in this study to correct the acoustics due to the lack of tilt corrected target strength models for *Sebastes spp.* Future work hopes to incorporate orientation data into population estimates.

To assess how deploying the BASSCam influences the behavior of a fish school, we compared the acoustic backscattering values of three schools of fish. Deployments occurred in approximately 30 m of water depth, where the area sampled by the acoustic beam had an approximate sample area of 33 m^2. Each school was observed: before the camera was deployed, while the camera was deployed in the school, and after the camera was removed. To do this, the camera was deployed (to the seafloor) directly below the acoustic transducer while a fish school was ensonified. The buoys on the camera provide an acoustic signal that was visible during the deployment, the only deployments used were those where the camera was visible under the transducer for the entire test period. For the duration of the two-minute deployment, the captain positioned the vessel over the top of the camera and school, using both of the vessel propellors. The captain then kept the vessel over the school while the camera was retrieved, and for an additional two minutes after the camera was removed. Upon review of this data, the estimated backscattering value attributable to the camera was subtracted from the school. Corrected backscattering values of the fish school for each time-period were compared using an ANOVA.

3. Results

Thirty-eight acoustic transects were completed for a total sampled distance of ~120 km which encompassed 24.1 km^2 of reef (**Fig. 1**). From the acoustics, the school identification algorithm identified 1,018 schools of fish presumed to be Black, Blue or Deacon Rockfish. The echo counting algorithms identified 2,077 fish tracks presumed to be Black, Blue and Deacon Rockfish (**Fig. 5**).

One hundred twenty video deployments were conducted at depths ranging from 12 to 38 m (**Fig. 6**). Most deployments occurred within 15 m of the target fish school identified during the acoustic transect. Of the 120 video deployments, fish were observed on 81 deployments. Blue/Deacon Rockfish were the most frequently observed species followed by Black Rockfish. Of the 3,383 fish identified from video, 2,514 were observed by the forward cameras, and 869 in the downward camera (**Table 2**). The majority of Black and Blue/Deacon Rockfish were observed in the forward cameras rather than in the downward facing camera. Of the rockfish observed in the downward facing camera, 17% of the total observed were Blue/Deacon Rockfish, 36% Black Rockfish, and 42% juvenile Black/Blue/Deacon Rockfish.

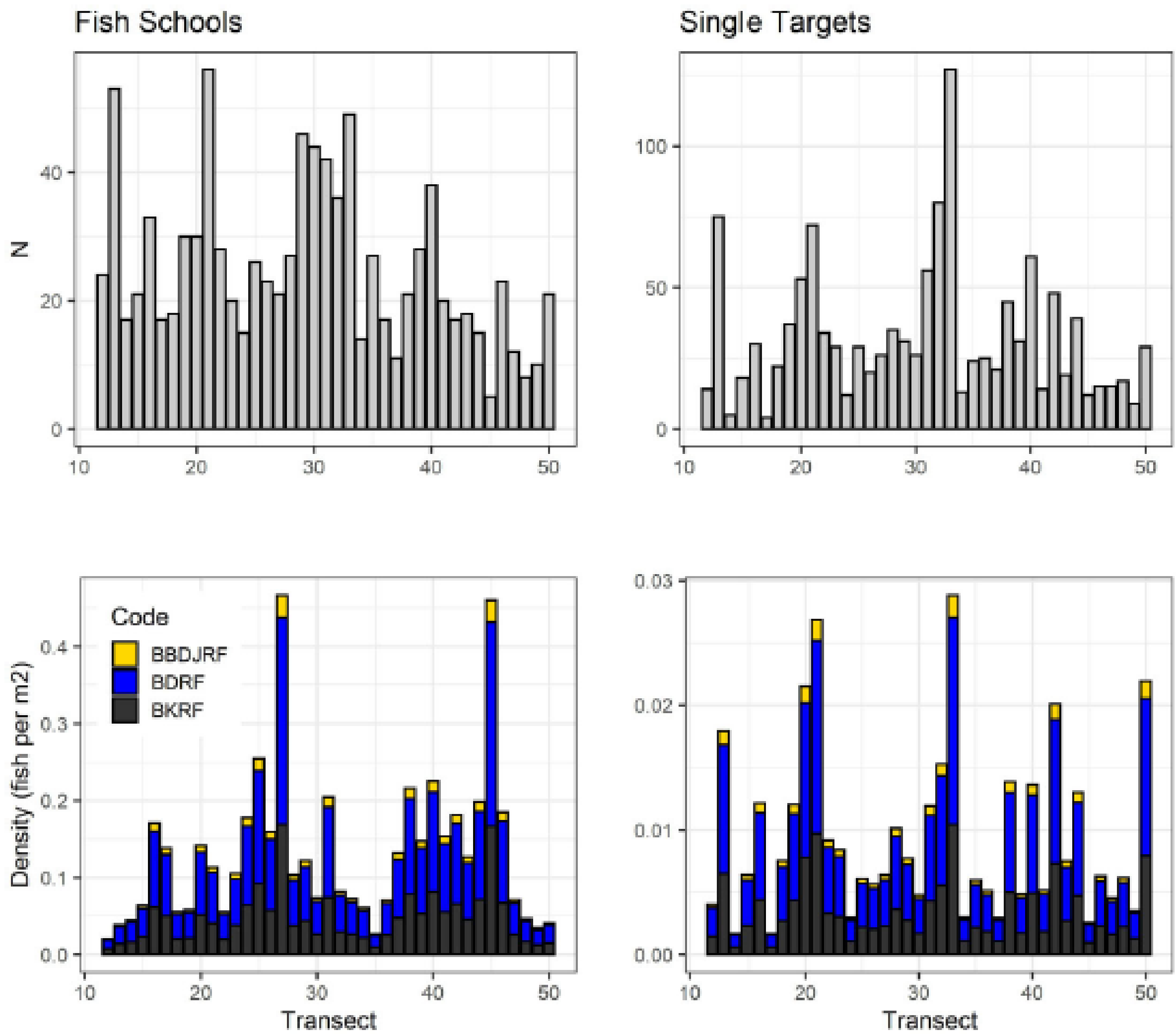

Figure 5. Number of schools (top left) and their conversion to density (number of fish per m^2) for the three focal species groups (bottom left). Number of single echoes (top right) and their conversion to density (number of fish per m^2) for the three focal species groups (lower right). BBDJRF are juvenile Black/Blue/Deacon Rockfish, BDRF are Blue/Deacon Rockfish, and BKRF are Black Rockfish.

Table 2. Number of each species or species group counted in the forward or downward facing cameras on the suspended BASSCam.

	Forward Facing Camera	Downward Facing Camera	Total Number of Fish Counted
Juvenile Black/Blue/Deacon Rockfish	155	114	269
Blue/Deacon Rockfish	1,429	283	1,712
Black Rockfish	899	452	1,351
Fish Without a Swim Bladder	6	12	18
Fish With a Swim Bladder	21	3	24
Unidentified Rockfish	4	5	9
Total Number of Fish Counted	2,514	869	3,383

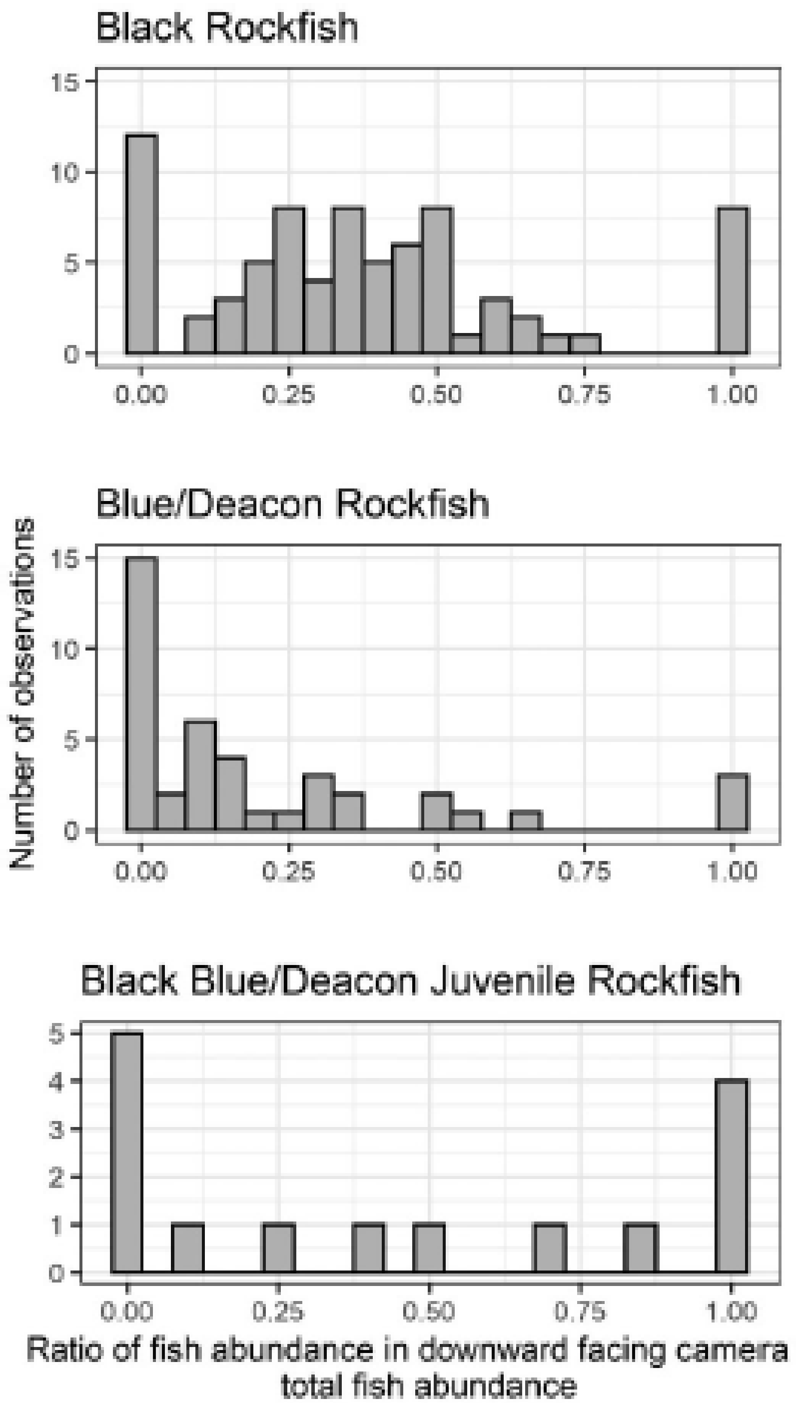

Figure 6. Histogram displaying the ratio of Black, Blue/Deacon, and juvenile Black/Blue/Deacon Rockfish abundance in the downward facing camera relative to the total abundance of fish (forward + downward). A value of 1 denotes fish observed only in the downward facing camera, a value of 0 denotes fish were only observed in the forward camera, and 0.5 indicates 50% of the fish were in the forward camera and 50% were in the downward facing camera.

Of the 25 deployments where Blue/Deacons were observed, in only one instance were they solely present in the downward facing camera (**Fig. 6**). Of the 36 deployments where Black Rockfish were observed, in only three instances were they solely present in the downward facing camera. Of the 15 deployments where juvenile Black/Blue/Deacon Rockfish were observed, in only four instances were they solely present in the downward facing camera (**Fig. 6**). Further, in 23 of 25 deployments (92%), >50% of Blue/Deacon Rockfish were observed in the forward cameras, and in 29 of 36 deployments (80.5%), >50% of the Black Rockfish were observed in the forward cameras. In 9 of 15 deployments (60%) >50% of juvenile Black/Blue/Deacon Rockfish were observed in the forward cameras.

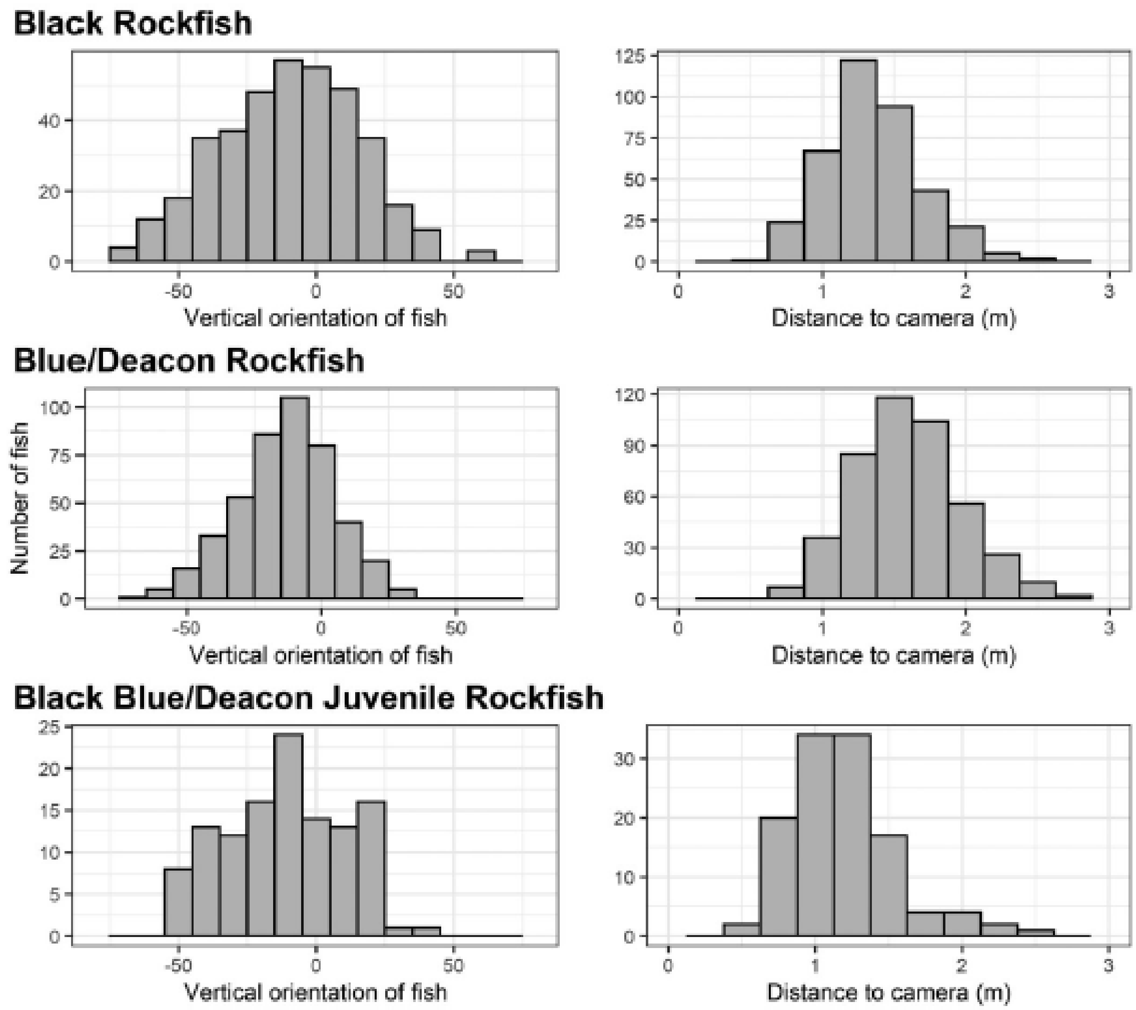

Figure 7. The measured distance of Black, Blue/Deacon, and juvenile Black/Blue/Deacon Rockfish to the BASSCam (Left) and vertical orientation of Black, Blue/Deacon, and juvenile Black/Blue/Deacon Rockfish relative to a hypothetical horizontal plane extending out from the stereo cameras (Right). Left—only fish that were measured contributed to the distance data. Right—positive values denote the fish's head was tilted upwards towards the water surface, and negative values denote the fish's head was tilted down towards the seafloor. All vertical fish orientations were corrected for tilt of the BASSCam.

Black Rockfish were observed at a slightly closer distance to the BASSCam than Blue/Deacon Rockfish (**Fig. 7**) and juvenile Black/Blue/Deacon Rockfish were the closest. On average, all species and size classes were observed at distances ranging from 0.5 m to approximately 2.5 m from the BASSCam. On average, Blue/Deacon Rockfish (mean: 267 ± 41 mm) were smaller than

Black Rockfish (mean: 349 ± 50 mm, **Fig. 8**). Length data of juvenile Black/Blue/Deacon Rockfish were bimodal with an average length of 161 ± 30 mm. A comparison of Black Rockfish lengths from our video to lengths of fish caught and retained in the recreational fishery (mean: 386 ± 40 mm), and by the fishery independent PIT tagging project (mean: 372 ± 38 mm), show similar size distributions, although the camera system observes a larger number of smaller fishes than those captured by fishing. For Blue/Deacon Rockfish, the camera system observed much smaller fish than those retained by the recreational fleet (mean: 321 ± 38 mm). For all species, the largest size classes captured by the recreational fleet were also observed by the camera system, though the relative abundance of these larger fishes was reduced in the video data due to the high abundance of smaller fish.

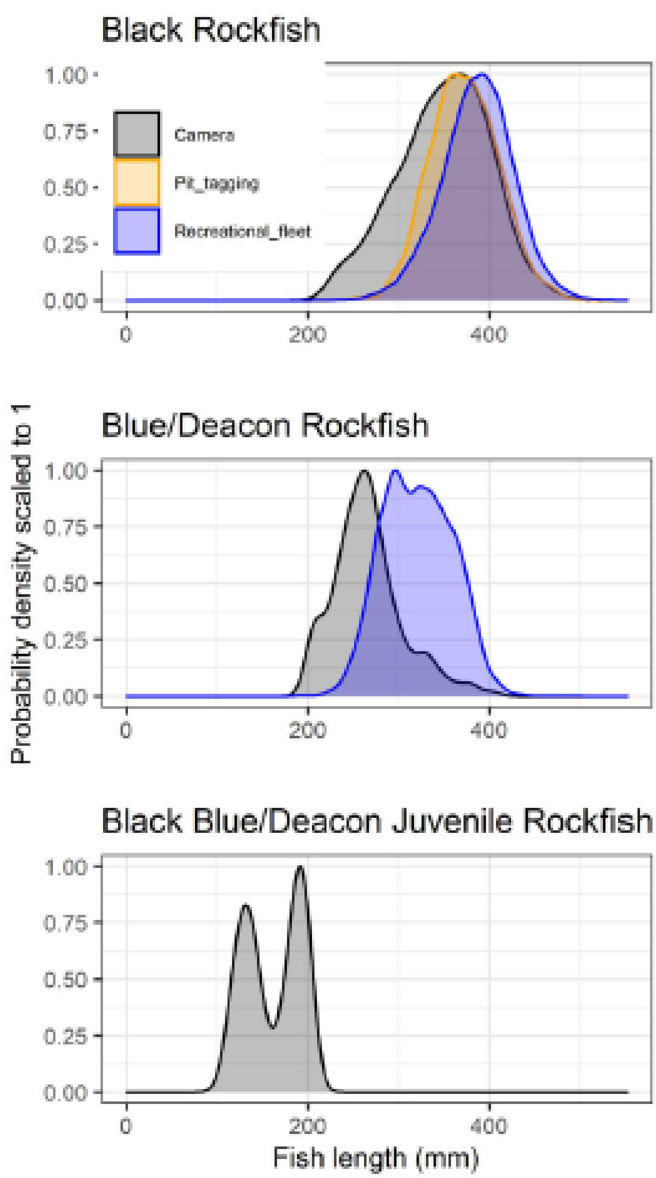

Figure 8. Scaled size distributions of Black, Blue/Deacon, and juvenile Black/Blue/Deacon Rockfish, observed by the BASSCam (gray area), caught by the recreational fleet (blue area), and caught as part of a fisheries independent PIT tagging project (gold area).

Blue/Deacon Rockfish heads were oriented below a horizontal plane located at the location of camera deployment at 13.5 ± 18.0 degrees, on average. Black Rockfish were also oriented downwards at 9.6 ± 25.3 degrees (**Fig. 8)**. Juvenile Black/Blue/Deacon Rockfish heads were oriented upwards at 5.2 ± 21.5 degrees. The distribution of Blue/Deacon Rockfish orientations was much narrower than for Black Rockfish, while juvenile Rockfish distribution has more uniform shape than that of adult Black and Blue/Deacon Rockfish.

For the three test deployments of the BASSCam below the transducer used to test for fish behavioral response to the camera (a measure of the tool's detectability), there was no significant change in the backscattering values of the school before, during, or after deployment of the BASSCam ($F(2,6)=0.052$, $p=0.95$; **Fig. 9**).

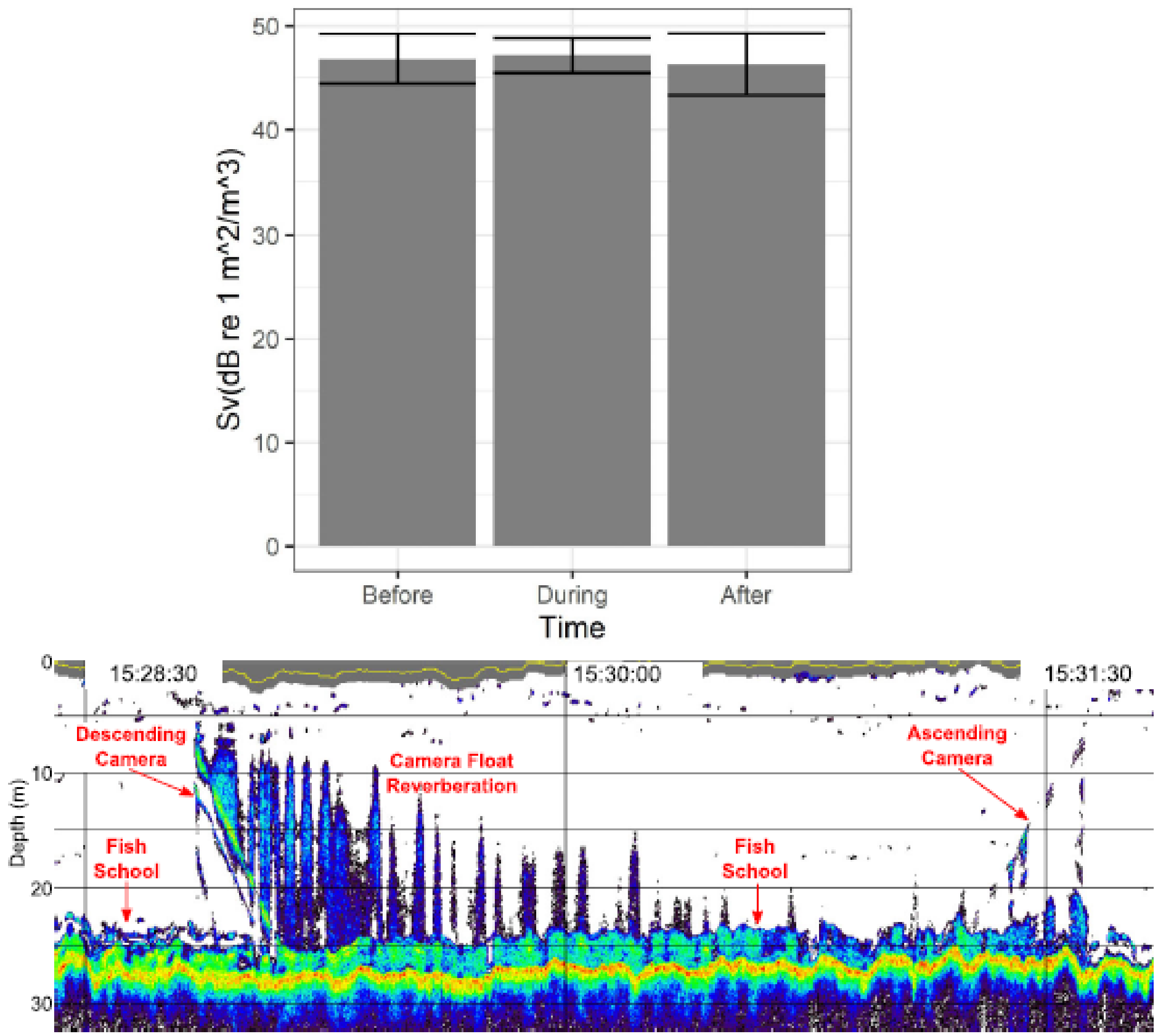

Figure 9. Changes in average backscattering values before, during, and after the deployment of the BASSCam into a school of fish (upper), and an example echogram of the camera deployment into a school of fish, during observations of the school, and retrieved from a school of fish (lower).

Forty-three camera deployments were conducted within 10 m of an ensonified school of fish. Average volumetric density of individuals schools of rockfish calculated from the video data was 0.47 rockfish per m^3 (**Fig. 10**). The density estimates from the video data differed significantly from the acoustic density estimates generated using the Foote model, but did not differ significantly from the other three models (**Fig. 10;** $F(4,210)=6.142$, $p<0.001$). Although all acoustic densities generated with rockfish-specific target strength models did not statistically differ from camera derived densities; our b_{20} averaged model provided fish densities (0.46 fish per m^3) most similar to video derived densities. Therefore, going forward, all echo integrations were conducted using the b_{20} value of -71.9 dB re. m^2/m^3.

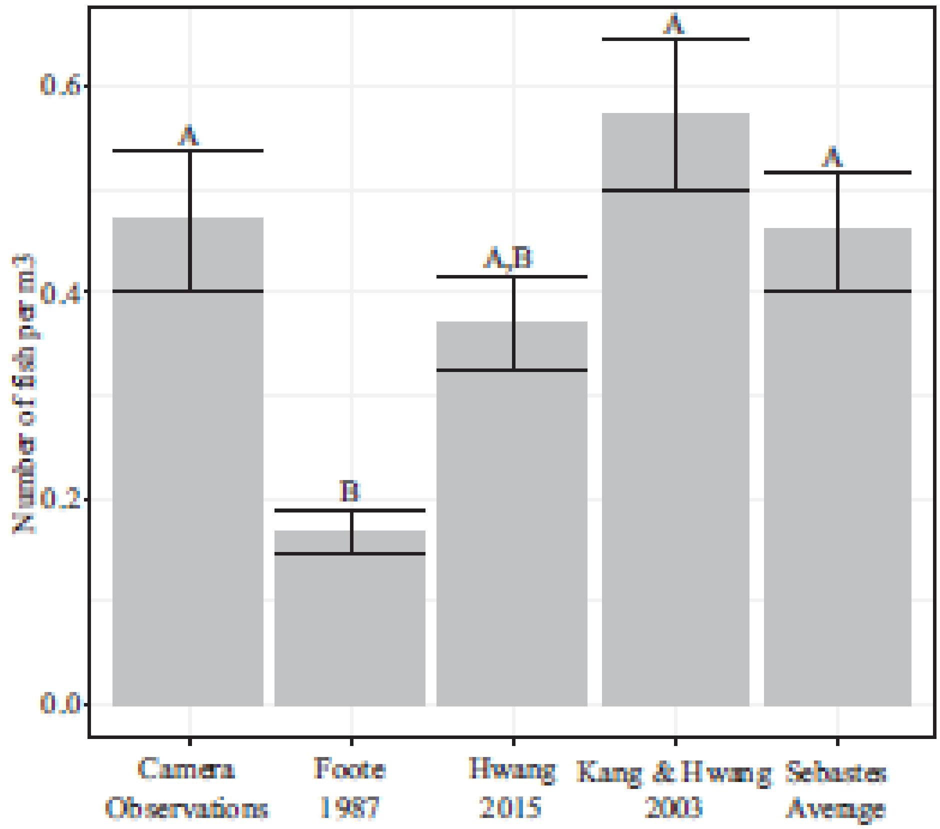

Figure 10. Volumetric densities (number of fish per m^3) generated from our camera system observations and fish schools identified in the acoustics. Acoustics were converted from backscattering values to densities using length data from the closest video deployment to that school. Only camera deployments occurring within 10 m of fish schools are reported here. Letters over bars denote significant statistical differences between datasets, as identified with a Tukey-HSD test.

On average, there were 25.4 ± 12.4 (mean ± standard deviation) schools of fish and 33.4 ± 24.7 single target echoes identified per acoustic transect (**Fig. 5**). The following estimates are generated from combining the acoustic data with species composition and length data from the stereo video.

For Black Rockfish, the average density of schooling individuals was 0.04 ± 0.03 fish per m^2 and for single echoes the average density was 0.003 ± 0.003 fish per m^2. For Blue/Deacon Rockfish, the average density of schooling individuals was 0.08 ± 0.06 fish per m^2, and 0.005 ± 0.004 fish per m^2 for single echoes. For juvenile Black/Blue/Deacon Rockfish, the average density of schooling individuals was 0.008 ± 0.006 fish per m^2, and 0.0005 ± 0.0004 fish per m^2 for single echoes. Extrapolated to the reef area, this results in a total population of 1,188,222 ± 601,249 Black Rockfish; 1,888,731 ± 955,712 Blue/Deacon Rockfish; and 204,866 ± 103,663 juvenile Black/Blue/Deacon Rockfish (**Table 3)**. Our coefficient of variation for these estimates was 50.6%.

4. Discussion

The benefit of this survey method is not only the ability of the tool to work in untrawlable habitat during rougher ocean conditions than most other survey techniques, but to also work on chartered vessels, of a variety of sizes, with a small scientific crew. These methods could easily be implemented with a crew of three. In a separate study, these same tools were also operated off a 7.5 m trailer-able boat, which allowed for application in shallow waters near wash rocks and shorelines, areas known to be important habitat for nearshore rockfish (Love *et al.*, 2002). The versatility and cost-effective nature of this survey method is in contrast with other common

Table 3. Design-based estimate of fish abundance at Seal Rock. Values are number of fish plus and minus the standard deviation.

	Single Targets	Fish Schools- Echo Integration	Combined
Black	80,161 ± 58,610	1,108,061 ± 848,272	1,188,222 ± 601,249
Blue/Deacon	127,420 ± 93,164	1,761,312 ± 1,348,366	1,888,731 ± 955,712
Juvenile Black/Blue/Deacon Rockfish	13,821 ± 10,105	191,045 ± 146,254	204,866 ± 103,663
Combined	221,402 ± 161,879	3,060,417 ± 2,342,891	3,281,819 ± 1,660,624

methods of nearshore rockfish methods such as PIT tagging and hook and line sampling, which require a captain, deckhands, and multiple anglers; often resulting in a crew of 10 + individuals. Oregon's ocean is notoriously rough and difficult to work on, so developing tools and methods that require relatively few days at sea are ideal. The biggest drawback of this survey method is the extensive post processing required for both the video and acoustic data. However, the use of pre-developed workflows in both the acoustic software and the video processing software significantly decreased processing time.

For survey data to be incorporated into a stock assessment or used to produce an independent abundance estimate, the "catchability" coefficient, must be estimated or measured (Arreguin-Sanchez, 1996; Kotwicki *et al.*, 2018). Catchability for a survey tools that don't actually catch fish is deemed detectability. Detectability of fish by an acoustic transducer is more influenced by the general behavior of the fish rather than the fish's response to the tool (Lawson and Rose, 1999; Stanley, 1999). In the case of Black Rockfish, high resolution telemetry work suggests that as long as operations are conducted during daylight hours, fish should be detectable by the acoustics (Parker *et al.*, 2008). Using similar telemetry data, we have shown that Deacon Rockfish have a distinct diel cycle (Rasmuson *et al.*, 2021a). Telemetry data demonstrated Black and Deacon

Rockfish lie directly on the substrate at night making them undiscernible from the acoustic return from the bottom. Combining these data with other high resolution acoustic telemetry data for nearshore rockfish, we demonstrated that Deacon and Black Rockfish should be available to hydroacoustics during daylight hours (Rasmuson, 2021). In a previous exploratory study, we routinely collected acoustic data, during daylight hours, on four transects at Seal Rock over the course of two months, and found that regardless of time of day, sea state, and tidal cycle, fish schools were always present, and frequently observed at the same locations along the transect (Rasmuson unpublished data). Similarly, detectability of rockfish with video tools is affected by time of day (Rooper *et al.*, 2020), indicating video operations should be conducted during daylight hours as well.

The detectability of fish by cameras has received a lot of attention in the last decade (Stoner *et al.*, 2008). Our survey vessel consistently deployed the BASSCam very close to the intended target, and fish were observed in a majority of deployments. Further, when the camera was deployed directly below the transducer there was little, or no avoidance or attraction behavior observed. Fish can either be attracted to, or repelled by the camera, due to sounds, lights, or simply the presence of the camera on the seafloor (Koslow *et al.*, 1995; Somerton *et al.*, 2017). In this study, we saw no change in the acoustic signature of the school of fish throughout camera deployment, and we found no trend in the number of fishes, of either species, observed for the duration of the video. Overall, our suspended camera design and deployment method does not seem to repel or attract fish. While we cannot fully discount detectability issues in our survey method, we hypothesize that the effects are minimal.

The remaining component of the detectability discussion is the effect of fish inhabiting the near bottom acoustic dead zone, temporarily or permanently. While there have been many advances in methods to correct for, or estimate, fish abundances in the acoustic dead zone (Ona and Mitson, 1996; Mello and Rose, 2009), exclusion of data from the near bottom region, as we have done in the present study, remains the most common methodology. Other work on *Sebastes spp.* suggests a general pattern of the fish moving out of the dead zone during the day and into the dead zone at night (Stanley, 1999; Rooper, 2010). In our survey, the use of the downward facing camera allowed us to estimate the ratio of our focal species in the near the bottom region. Our finding of a similar ratio of Black Rockfish located 0-1 m above the seafloor to those located <1 m above the seafloor, and fewer Blue/Deacon Rockfish in 0-1 m than in <1 m, suggests our focal species are located above the near bottom dead zone, and are therefore available to the acoustic signal during daylight sampling. At our deepest survey depth of 36 m, the dead zone was calculated to be 0.33 m thick (following Ona and Mitson 1996), therefore excluding data within 1 m of the bottom from our data analysis is extremely conservative. Such a conservative approach was taken because there is considerable debate about how large of a contribution to a population estimate fish within 1 m represent. Despite this conservative exclusion, our population estimate for Black Rockfish was similar to population estimates generated by the PIT tagging project, further supporting our hypothesis that most semi-pelagic fishes are located above the near bottom acoustic dead zone during daytime sampling. The combined effects of the dead zone on survey design and survey results are currently being studied by pairing a larger scale hydroacoustic/video survey with data from a remotely operated vehicle (ROV) (Rasmuson In Preparation). Although not done in the present study, data from the downward facing camera could be used to provide measured correction indices to estimate the abundance of fish in the near bottom dead zone. Modeling population estimates within the near bottom dead zone will be possible in future studies when the survey is implemented at a statewide level resulting in a larger dataset. Nevertheless, based on the results of this pilot study, we confidently conclude that a combined acoustic and suspended camera survey method is an effective sampling methodology for Oregon's nearshore rockfish and can be used conservatively by excluding data in the near bottom dead zone, or less conservatively by expanding the population estimate into the near bottom dead zone. In future studies we suggest the exclusion zone can and should be reduced from 0-1 m off bottom to 0-0.5 m .

Studies continue to show that fishery independent surveys are critical to effective fisheries management (Hilborn, 2007; Dennis *et al.*, 2015) and, as mentioned, trawls are currently the primary survey tool used throughout the world's oceans. However, while rockfish assemblages differ widely between trawlable and untrawlable areas, trawls are inoperable in rugose habitats (Matthews and Richards, 1991; Zimmermann, 2003). Further, trawls lethally sample fish which can potentially create social concerns and impact benthic habitats. The use of cameras and acoustics are an attractive alternative or complement to trawl surveys because of their ability to operate in these regions, and because they have been proven to be effective for a variety of rockfish species (Williams *et al.*, 2010; Jones *et al.*, 2012). Jones et al. (2012) demonstrated that density estimates from trawl and acoustic surveys differed by as much as 5-60 times, signaling potential for a significant underestimation of population size when applying trawl data to untrawlable habitats. As both acoustics and cameras provide volumetric densities of fish, there is an ability to relate the data from the two tools. A point which we illustrate here by using our video-derived volumetric densities to help inform which target strength to length regression model to use.

Another unique benefit of using a stereo camera system is the ability to generate fish orientation data, a variable which can strongly influence a population estimate derived from acoustics (Huse, 1996; McClatchie, 1996). While it is worth noting that a video reviewer only measures a fish when the fish is oriented close to parallel with the camera faces, the orientation of the fish, relative to a horizontal plane extending from the cameras (i.e., head tilted towards the surface or bottom), does not influence the reviewer's choice to measure a fish. Therefore, bias in our fish orientation data based on our method for measuring fish is assumed to be minimal. The use of cameras to provide tilt data has proven effective for krill and mackerel (Kubilius *et al.*, 2015; Fernandes *et al.*, 2016). Kang and Hwang (2003) demonstrated that for *Sebastes schlegeli,* the tilt of the fish changed the target strength of the fish by as much as 30 dB re. m^2/m^3. In the current study, we have not applied any orientation corrections to our data because target strength models have not been developed for our focal fish species (Frouzova *et al.*, 2005). We are in the process of developing models of the swim bladders for future use. These new swim bladder models, used in combination with the orientation of the fish, will increase the precision of the population estimates generated by the combination of underwater video and acoustics data.

Our stereo camera system targets semi-pelagic rockfish more completely than other survey tools. It provides a more complete representation of the length distributions of our focal species than survey gear such as trawls and hook and line. Hook and line suffers from hook selectivity and trawls suffer from mesh size dependent selectivity as well as net avoidance (Campbell *et al.*, 2014; Kuriyama *et al.*, 2019). While behavioral avoidance is common with underwater camera systems, our work demonstrated no change in school size with the deployment of our camera system, which suggests minimal behavioral impacts. The greater density of small fishes in our length distributions also suggests we are sampling across the size distribution of nearshore rockfish. Especially in acoustics, where length data are directly used to calculate biomass, this strongly demonstrates the benefit of using a benthically anchored buoyant camera system in combination with hydroacoustics. Overall, the novelty of our camera system, over other tools used in conjunction with acoustics, is the addition of both the downward facing camera and the tilt sensor. Both tools make the camera system uniquely well adapted to working with rockfish in highly turbid and productive waters because they provide the opportunity to apply corrections to the population estimate. Here, we did not apply tilt corrections or near bottom dead zone corrections from the downward facing camera due to several limitations that will be addressed in subsequent studies.

The combined methodology of our study produces comparable population estimates to previous survey results. The resulting population estimate from our combined video and acoustic survey suggest a population of ~1.2 million ± 600,000 (mean ± 1 SD) Black Rockfish within the survey area. An eleven-year-long PIT tagging study that encompassed our study area, and a few additional small reefs, reported an abundance of 1-2 million Black Rockfish (Krutzikowksy *et al.*, 2019). The similarity between the two studies, suggests that the combination of acoustics and underwater cameras can provide an accurate population estimate. We offer that when used in combination, hydroacoustic data and data from our suspended stereo camera system, create a robust survey method for nearshore rockfish. In the future, combining this methodology with hook and line sampling to provide age and maturity samples should create a robust nearshore fisheries-independent survey. In the short-term, this would provide stock assessors with an estimate of biomass for this particular year, which could be used in the assessment to inform absolute stock size (i.e., help to reduce uncertainty in the estimation of population scale). Population size is the most uncertain parameter in Black Rockfish, and most other nearshore species stock assessments, which creates extremely high levels of uncertainty associated with quotas and has implications for sustainable fisheries management. This method could be used iteratively over time to create an index of abundance for Black Rockfish which fills a critical need for west coast nearshore species, as identified by regional management councils.

Overall, we propose the survey method outlined here is an efficient and effective way to survey Oregon's nearshore rockfish. To be effective this survey should be extended throughout Oregon's nearshore waters so as to provide a complete estimate of nearshore rockfish abundance. Increasing the habitat coverage of fishery independent surveys is a necessary addition to the stock assessment process, and the method described here may serve as a relatively low-cost, high return survey for the rugose and untrawlable nearshore environment. The acknowledged drawback of video and acoustic tools is the amount of post-processing required for the data collected. However, we have demonstrated that development of a standardized analysis process can reduce processing time significantly. Further, as automated approaches continue to advance, the requirement for human hours to process these data will decline (Richards *et al.*, 2019). Another flaw of this survey method was the coefficient of variation was quite high (~50%). Going forward, a stratified survey design (adjusting effort allocations based on bottom hardness) combined with a geostatistical or model-based abundance estimation may allow for a reduction in variance. A preliminary attempt to model the population size of these same data using a geostatistical approach resulted in a coefficient of variation of ~19% and very little change in the population estimate, further supporting the theory that a larger, more robust survey design, combined with species specific target strength models, will allow generation of accurate population estimates for Oregon's economically and ecologically important nearshore rockfish.

Data availability

The data underlying this article will be shared on reasonable request to the corresponding author.

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Supplement to accompany: Combined video-hydroacoustic survey of nearshore semi-pelagic rockfish in untrawlable habitats.

Videos were reviewed using both the MeanCount approach and the MaxN approach. We then examined these data to assess 1) how size frequency of focal species differed between the methods, 2) how the ratio of individual species abundance relative to total abundance differed between the two methods, and 3) which method was the most efficient. Size and species ratio data are used in echo integration to convert acoustic data into number of fish.

1) Size Frequency of Target Species:

For each species/species group we compared the size distributions between the two video review methods using a Kolmogorv-Smirnov test. The size distributions were not statistically different between the MaxN and MeanCount video processing methods (Fig S1, Black Rockfish: D=0.05, p=0.98; Blue Deacon Rockfish: D=0.08, p=0.43; Black Blue Deacon Juvenile Rockfish D=0.25, p=0.22). Based on these results, either video review method will generate similar distributions.

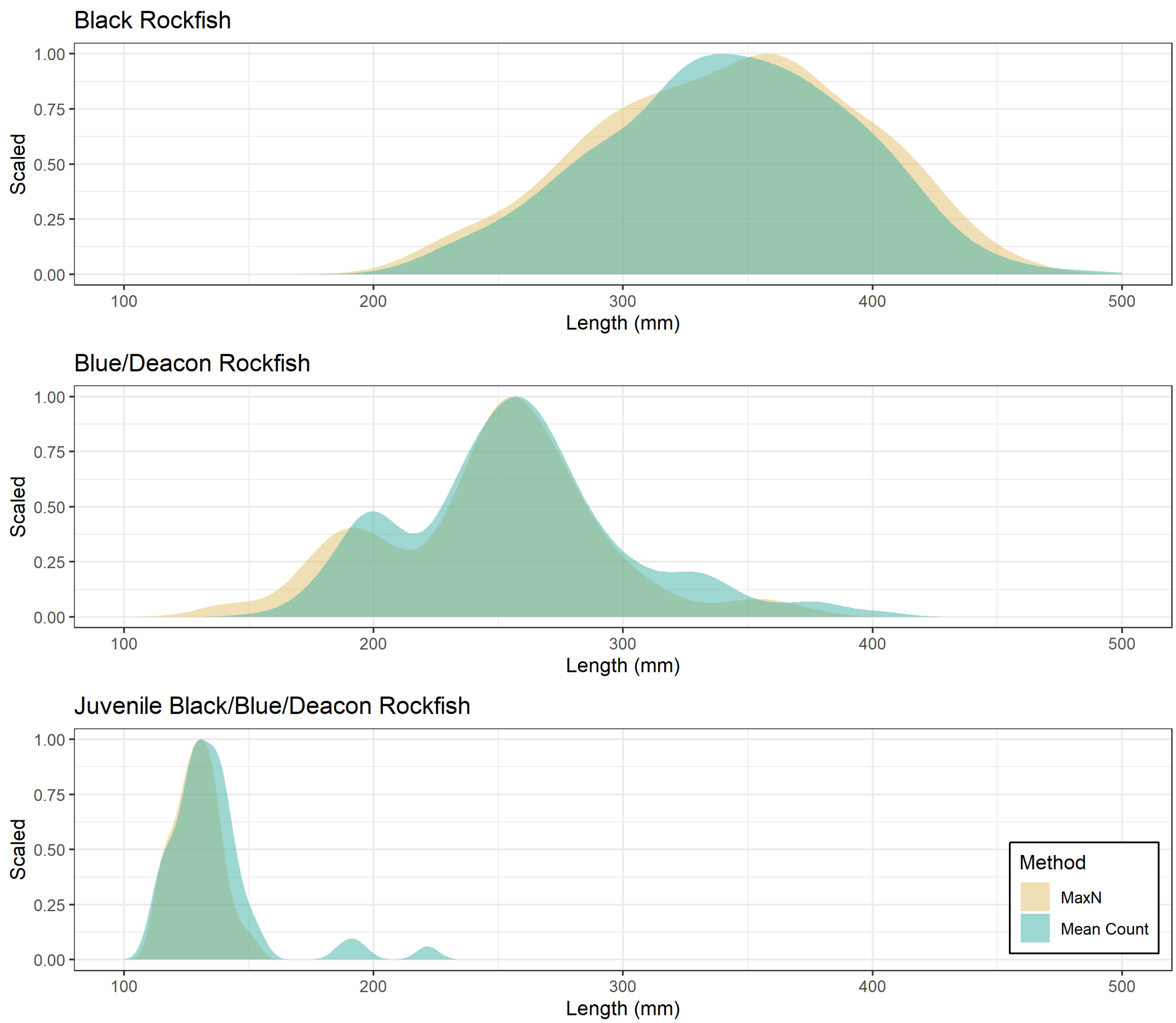

Fig. S1. Scaled size distribution of Black (top), Blue/Deacon (middle) and Juvenile Black/Blue/Deacon Rockfish (bottom) using the MaxN and MeanCount approach to video review.

2) Ratios of Target Species:

To determine if the ratio of Black to Blue/Deacon Rockfish differed between the two methods we used a generalized linear model with binomial distribution to compare species proportions. The proportions of Black and Blue/Deacon Rockfish did not differ significantly between the MaxN and MeanCount methodologies (Fig S2, Table S1). Based on these results, either video review method will generate similar species proportions.

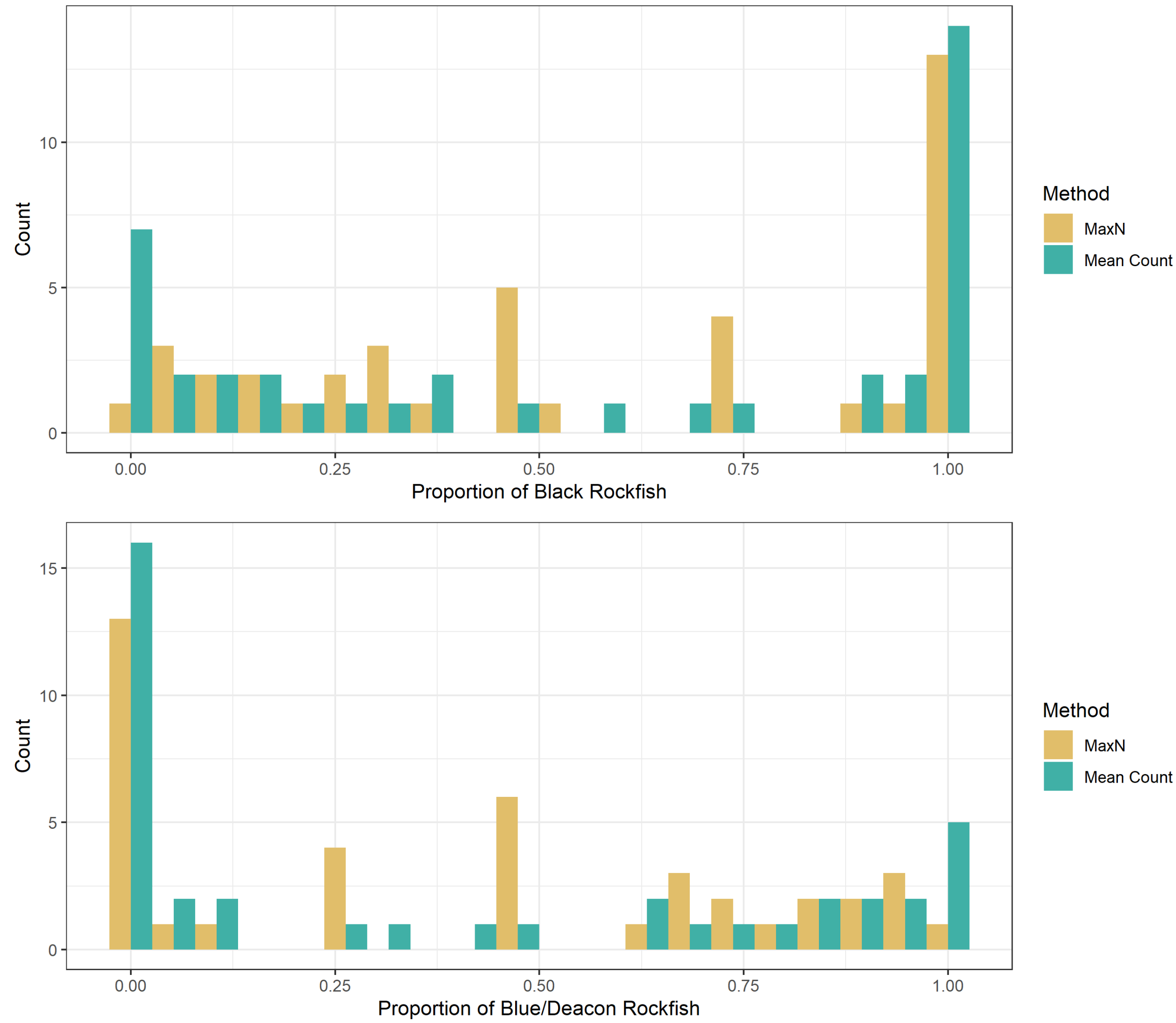

Fig. S2. Summary of number of video drops with proportions of Black versus Blue/Deacon Rockfish for each of the two video review methods.

Table S1: Results of binomial generalized linear model comparing species proportions between the methods for Black and Blue/Deacon Rockfish.

Black Rockfish Proportions

	Est.	**S.E.**	**z val.**	**p**
(Intercept)	-0.37	0.32	-1.14	0.25
MeanCount	-0.13	0.45	-0.29	0.77

Blue/Deacon Proportions

	Est.	**S.E.**	**z val.**	**p**
(Intercept)	-0.37	0.32	-1.14	0.25
MeanCount	-0.07	0.46	-0.16	0.87

3) Efficiencies of the MaxN vs. MeanCount Video Processing:

Given that the above evidence suggests there is no difference in the resultant size and species proportion data with either review method, we examined the review efficiencies using simulations. We first examined the distribution of sampling times to process the videos using each method. These data were best described by a gamma distribution. We then simulated 1,000 video drops using the rgamma function in R. We repeated this 2,000 times to see how long it would take to process all 1,000 videos on average. The MeanCount video methodology proved to be a more time efficient method (Fig. S3). This finding combined with the evidence of no statistical differences in species proportions or sizes is the reason we elected to conduct our video review using the MeanCount approach.

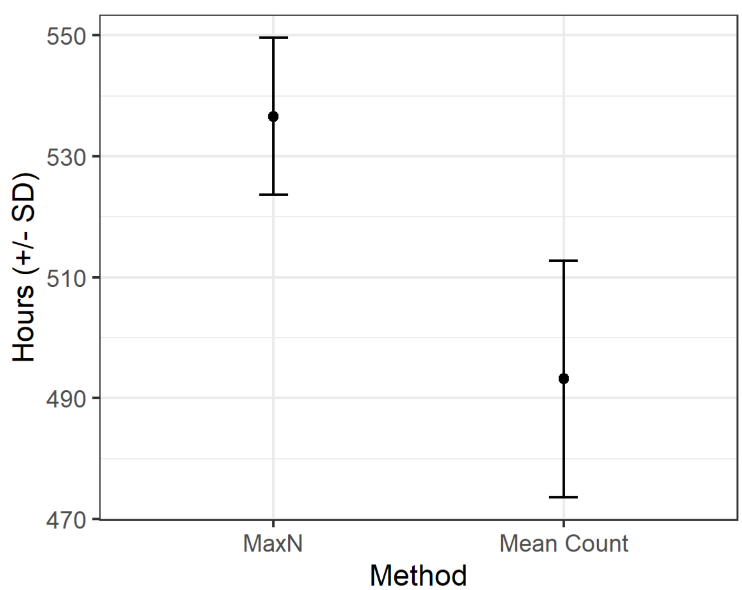

Fig. S3 Average number of hours required to review 1,000 video drops using the MaxN and MeanCount video review methods.

Objective 2

Objective 2 was examined using surveys at multiple reefs throughout Oregon. These data are in being developed for a manuscript in ICES Journal of Marine Science.

Influence of near bottom habitat use on the efficacy of a combined hydroacoustic video survey for nearshore midwater rockfish.

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Abstract

Fisheries independent surveys are an important for effective fisheries management. However, nearshore rugose habitats are under surveyed. An effective, non-destructive tool is combining hydroacoustics and underwater video. This method has proven effective tool for semi-pelagic rockfish in the Northeastern Pacific. Acoustics can struggle to differentiate fish in the near bottom acoustic deadzone. Multiple methods have been proposed to correct for the deadzone. Here we compare a combined hydroacoustic visual method to a ROV. We first established that despite sampling frame differences, there is agreement in the observations. We find that the method of extrapolating fish schools observations above the deadzone into the deadzone is effective for Black but not for Blue/Deacon Rockfish. We also show that despite the great diversity of rockfish, most demersal rockfish remain within the near bottom acoustic deadzone ultimately not contaminating the acoustic data. We also establish that fish densities reach a minima at distances >35 m from a fish school and calculate background densities to be used as population estimate corrections. Finally, we compare population densities finding higher densities of Black and Blue/Deacon's than estimates from the ROV, ultimately suggesting that most of the population resides above the near bottom deadzone. Using the results of this paper corrections for the near bottom acoustic deadzone will be possible in future surveys.

1. Introduction

Effective fishery management benefits from rigorous and systematic fishery independent surveys to provide fish abundance estimates (Hilborn and Walters, 1992). Fisheries independent surveys can take many forms including hook and line, bottom trawl, and acoustics. For acoustic surveys to be effective they need to be paired with another tool that can provide species and length composition data (Misund, 1997; McClatchie *et al.*, 2000). Regardless, acoustic surveys are cost effective because large areas can be survey relatively quickly with few staff. As such these methods have proven extremely effect for many pelagic and midwater stock, and even more importantly for stocks that occupy deep high relief environments like Acadian Redfish (*Sebastes fasciatus*), Orange Roughy (*Hoplostethus atlanticus*) and Walleye Pollock (*Gadus chalcogrammus*) (Kloser *et al.*, 2002; Gauthier and Rose, 2005; Robertis *et al.*, 2014). Although acoustic methods are well developed for species occupying continental shelfs and slopes as well as the abyssal plain, there has been limited research on the utilization of acoustics in nearshore high relief environments.

Regardless of sampling depth, for midwater species that spend some component of their time on or very near the bottom, acoustics may struggle to differentiate a fishes signal from the signal of the bottom (Rasmuson, 2021).

The area directly above the bottom is often called the near-bottom acoustic deadzone (Ona and Mitson, 1996; Totland *et al.*, 2009; Kotwicki *et al.*, 2018). This deadzone occurs because there is an overlap in the return of fish echoes that occur at a certain height off bottom. This height off bottom where the bottom and fish echoes overlap is influenced by the settings of the transducer, water depth and the rugosity of the bottom. Due to the strength of the bottom return (especially hard bottoms) an integration of the bottom, even if very small, can dramatically inflate a population estimate (Mello and Rose, 2009; Tušer *et al.*, 2013; Kotwicki *et al.*, 2018). Therefore, it is common to exclude a band of water extending from the bottom upwards a certain height. In relatively shallow water, the thickness of the thickness of the exclusion zone can be relatively thin relative due the depth of the water column (Ona and Mitson, 1996). However, for midwater fish that occupy the region directly above the bottom exclusion of even a fraction of the population could dramatically reduce the population estimate (Mcquinn *et al.*, 2005). Thus, some surveys use alternative survey methods to determine the density of fish in the near-bottom acoustic deadzone and combine these data into a single population estimate (Kloser, 1996; Jones *et al.*, 2012; Kotwicki *et al.*, 2018).

The effect of the near-bottom acoustic deadzone on a population estimate can be further exacerbated inter and intra species vertical segregation (Stanley, 1999; Gauthier and Rose, 2005; Thorson *et al.*, 2016). In the case of a single species, size and or sex based vertical segregation can lead to incorrect estimates of population density since density estimates from acoustics are directly affected by length composition. In the multi-species segregation the problem is even further confounded, especially in highly diverse genera like Sebastes (Rooper *et al.*, 2012). Therefore, sampling both above and within the near-bottom acoustic deadzone is important to ensure population estimates reflect true population dynamics. Combining bottom and midwater trawls is an effective, albeit destructive, way to do this. However, for midwater species that occupy highly rugose habitats, deployment of trawls is often not possible. Underwater cameras continue to be advanced as a good tool to samples these areas (Jones *et al.*, 2012). Further, with the invention of stereo camera stereo camera technology, the length data estimates have become much more precise (Denney *et al.*, 2017).

Acoustics have been shown to be an effective tool for rockfish, genus Sebastes (Boettner and Burton, 1990; Stanley, 2000; Gauthier, 2002; Tschersich, 2015). Early work showed that the tool was effective for the shelf stocks of Yellowtail (*Sebastes flavidus*) and Widow Rockfish *(Sebastes entomelas*) (Stanley, 2000). In these studies, length and species composition data came from midwater trawls. More recently acoustics have been used in Alaska with underwater cameras to assess how much of the rockfish population resides within areas untrawlable with a standard bottom trawl. Jones et al. (2012) found that these untrawlable rocky reefs were important rockfish habitats and for accurate population estimates need to be surveyed. Further, they compared the utility of using a stereo drop camera to estimate the population size of rockfish in the near-bottom deadzone to the extrapolation method of Ona and Mitson (1996). Regardless of method they demonstrated that the near-bottom acoustic deadzone contains many of their focal species. In contrast, nearshore midwater rockfish have received relatively little attention for the development of fisheries independent surveys despite the fact that species like Black Rockfish (*Sebastes* *melanops*) are the primary catch of the recreational fleet in Oregon. Historically, Tschersich (2015) and Boettner and Burton (1990) demonstrated that acoustics would be a viable tool for Black Rockfish. However, Tserchich (2015) was able to just do echo counting and did not require length composition. Boettner and Burton (1990) used a midwater trawl to sample, which while effective, is not considered acceptable in the nearshore. Thus, Rasmuson et al. (2021) combined a suspended stereo camera system with hydroacoustics to estimate nearshore midwater rockfish densities. They suggest that this combination is effective and efficient way to survey. However, the effect of the nearbottom deadzone was only summarily considered and the relative contribution of other rockfish species to the backscattering in the acoustics was unconsidered.

Therefore, our goal was to assess whether the near-bottom deadzone influences the utility of an acoustic survey to provide a population estimate Black, Blue (*Sebastes mystinus*), and Deacon Rockfish *(Sebastes diaconus*). Further, we ascertained if acoustics observed demersal (non-focal) rockfish and if so if population estimates needed to account for their presence when apportioning backscattering data To answer these questions, we compared belt transect data from a remotely operated vehicle (ROV) to point estimates from our suspended camera and acoustics data. The resulting data was used to address four questions; 1. Does the size distribution of each species differ between tools as a result of differences in sampling method, 2. Do the tools observe the same fish in the same locations, 3. How does abundance of and species composition within the acoustic dead zone directly below schools change with sampling method, 4. What is the background density of species not collocated with schools and 5. How do population estimates for each species differ with tool.

2. Methods

2.1 Field Work

Surveys were conducted in the spring and fall of 2018. Surveys were conducted at the rocky reefs near Cascade Head, Cape Arago, Bandon, Orford Reef and Redfish Rocks. At each reef, transect centroids were randomly placed within the mapped area of rocky reef, defined as areas mapped as having cobble or larger substrates, between 20 m and 50 m depth. These survey boundaries reflected the shallow end of the ROV's safe working range and the deep end of the expected depth distribution for Black Rockfish. All transects were oriented in a NW-SE direction, anticipating the likely direction of predominant winds and waves. Transects conducted in the spring were 300 m long, but this was determined to be inefficient and fall transects were lengthened to 500 m. Transects were separated by at least 50 m. Randomly placed transects that did not intersect sufficient rocky habitat or traversed unsafe features (e.g. shallow pinnacles) were either rejected or slightly repositioned or re-oriented.

2.1.1 Acoustics and BASSCam

Except for Cascade Head, surveys were conducted aboard a 15.25 m charter passenger fishing vessel. At Cascade Head surveys were conducted 7.6 m aluminum vessel. Operations and settings were the same regardless of vessel. Transects were first ensonified using a Biosonics 200k kHz split beam transducer with a beam width of 6.9 degrees. Data were collected using a ping rate of 5 pings per second and a pulse duration of 0.3 ms. While ensonifying the transect, 3 fish schools were selected for camera drops. In the event, that no school were identified, rugose habitat was targeted.

Camera drops were conducted using the benthically anchored stereo suspended camera (BASS Cam) described by Rasmuson et al. (2021). Briefly, the camera consists of a pair of stereo Go Pro Hero 4's facing forward and a single Go Pro Hero 4 facing downward at an angle of 22 degrees. The camera was anchored to the bottom using an 18.15 kg anchor. The anchor is located 2 m below the camera. The camera is positively buoyant and, unlike in previous work where the unit provided a live feed, attached to line which went to surface floats. After the camera was on the bottom for two minutes it was retrieved by the vessel.

2.1.2 ROV

ROV surveys were conducted using a Deep Ocean Engineering Phantom HD2+2 ROV. The primary fish abundance data were gathered using a high definition video camera (Black Magic Micro Cinema with an 8mm wide-angle lens) housed in a custom pressure tube with a dome port mounted on the front of the ROV at an angle of 30° below horizontal. A pair of parallel red lasers (Deep Sea Power & Light SeaLaser 100) spaced 10 cm apart were mounted on the camera housing to provide a scale reference. Time data from a Horita PG2100 time code generator located within the video housing was recorded onto the camera's audio track for later synchronization of video observations with ROV position data. Imagery from the HD camera was captured internally on SD cards for later processing, and also transmitted via the umbilical to the boat for piloting purposes. A live view from a forward-facing DeepSea Power & Light Multi SeaCam was also transmitted for piloting purposes. Altitude above the seafloor was recorded with the aid of two ranging altimeters, one mounted on the forward-looking camera housing and one mounted vertically. A second Black Magic HD camera, paired with a pair of 10 cm scaling lasers, pointed straight down in front of the ROV. Two Nuytco 200-watt HMI lights provided illumination for the forward-looking camera. Two down-facing SeaLite Matrics LED lights illuminate the substrate for the down-facing camera.

A calibrated stereo video system provided accurate measurements of fish length and fish height of bottom. Two GoPro Hero4 Black cameras were mounted in custom dome-port housings (Sexton Corporation) on the front of the ROV with a 47 cm separation and 6-degree toe-in angle. The stereo cameras were oriented forward-facing to maximize the ability to measure fish height off bottom for this project. Objects in view of both cameras (e.g., fish, invertebrates, benthic structures) can be sized with sub-centimeter accuracy. Stereo video was captured internally on SD cards, and not transmitted in real time to the surface.

The ROV was navigated using an acoustic tracking system (ORE Offshore Trackpoint III), high-precision GPS heading sensor (Hemisphere VS100), motion reference unit (ORE Offshore), and Hypack software. Raw ROV positions were determined at 4 s intervals and subsequently smoothed using a 7-point moving average to minimize any positional artifacts. This equipment and processing typically yield a positional accuracy of ± 4 m.

Video transects were conducted with the ROV between 0.5 and 1.5 m above the bottom, depending on vertical relief of the substrate, at a target speed of 0.5–1 knot. Speed varied as wind and seas affected the survey vessel. The resulting view angles typically produce a transect width of 1-4 m as the ROV navigates bottom features.

2.2 Data Processing

2.2.1 BASSCam

BASS Cam video was reviewed following the methods described by Rasmuson et al. (2021). Briefly, videos were reviewed using Event Measure. Five frames were selected at random. In each of these frames all fish were identified to the lowest taxonomic unit possible. Fish were counted and assigned to the forward or downward facing camera. If a fish in the forward camera was oriented approximately parallel to the cameras it was measured.

BASS Cam counts were turned into densities using a modified version of Williams et al. (2018). Assuming no obstructions and using the average distance fish we measured the planar area view straight out from the forward cameras and also the planar area of the downward camera on the bottom. Two-dimensional areas were used instead of volumes to allow comparison with the ROV.

2.2.2 Acoustics

Processing of the acoustic data followed the methods outline by Rasmuson et al. (2021). All analyses were conducted in Echoview version 11. Detection algorithm settings were identical to those defined by Rasmuson et al. (2021). Acoustic data were analyzed using both echo integration and echo counting. Echogram were apportioned into each analytical method using the Sawada index and the ratio of multiple echoes (Sawada *et al.*, 1993). Both of these indices identify regions of the echogram where fish densities are so high such that they cannot be analyzed using echo counting. In regions analyzed with echo integration the school detection algorithm was used to identify schools in a median 3x3 filter smoothed echogram and defined using a school detection algorithm that applies user defined thresholds and algorithms to identify fish schools in the echogram (Nero and Magnuson, 1989; Barange, 1994; Haralabous, 1996). The regions defined as schools by the algorithm were then visually checked for accuracy. To convert the acoustic backscattering data into densities, the Sebastes average target strength to length model described by Rasmuson et al. (2021) was used. Length data was provided by the BASSCam. Back scattering cross-section data were calculated in 1 cm bins and scaled for functional groups.

The echogram was then examined visually to define regions with individual echoes. In these regions, the single target algorithm in Echoview was used to differentiate single echoes attributable to a single or multiple observable fish. Since it is common for multiple targets to represent a single observed fish, we then used Echoview's fish tracking algorithm defined by (Balk and Lindem, 2000; ICES, 2000) to adjust multiple single targets that are attributable to a single fish into a single fish track. Each fish track was turned into a density by taking into account its depth in the water column and the area surveyed by the acoustic beam at that depth (Tschersich, 2015).

2.2.3 ROV

Digital video files were reviewed using Adobe Premier Pro. The audio track containing time stamp data was directed to a Horita TCW-50 time code wedge which provided text input to an Xkeys programmable data entry keyboard. This allowed reviewers to use single keystrokes to enter observations along with associated times of observation into a Microsoft Access database. The times of observation were later merged with time-stamped ROV navigation files to geolocate each observation along a transect at 1 s intervals.

A trapezoidal screen overlay was used to define the review frame, an area of usable video extending from the full width at the bottom of the screen to a line at 80% of screen height, tapering toward the top. This overlay excluded areas too distant or marginal to allow reliable species identification. Within the review frame, multiple variables were each interpreted from video in separate passes. First, ROV Status review applied a threshold criterion to exclude problematic sections of video with respect to identifying fish. Segments were defined as a "Fish Gap" if the reviewer estimated that a 20 cm fish could be obscured in more than 20% of the review frame for any reason, including poor visibility, terrain obstructions, or ROV maneuvering. Fish Gaps were also invoked if the ROV was not making relatively linear forward progress (e.g. during stops or rapid turns). Fish Gap segments were excluded from later quantitative analyses of fish abundance and from comparisons with data derived from acoustics and BASS Cam.

Fish were identified to species where possible for 24 target species, and otherwise were recorded in higher level taxonomic groupings. Size of individual fish was estimated where possible (broadside near lasers) within the following categories: < 10 cm, 10 – 30 cm, 30 – 60 cm, > 60 cm. Sex was recorded for Kelp Greenling (*Hexagrammos decagrammus*), which exhibit distinct coloration by sex.

Transect width was calculated at 30 s intervals by measuring the on-screen distance between scaling laser contact points with the sea floor. Camera calibration measurements conducted prior to the survey were used to relate measured laser width to review frame width. Transect width was interpolated for each 1-sec interval, allowing calculation of survey area for different portions of each transect (e.g. each non-gap segment, or areas in proximity to BASS Cam drops) by multiplying the transect width by the along-transect distance derived from the smoothed tracking data for each 1-sec interval.

Stereo imagery was reviewed using SeaGIS software. Total length was measured for each appropriately positioned and oriented fish, and height off bottom was measured by estimating and measuring to the nearest visible rock, where appropriate. Fish visibly resting on the seafloor were assigned a height of zero

2.3 Statistical Analysis

All statistical analyses were conducted using R version 4.1.2 Bird Hippie (R Core Team, 2020).

2.3.1 Length Data Comparison

To determine if the ROV and BASS Cam observed fish of the same length, we compared the length distribution of Black, Blue/Deacon and juvenile rockfish at each of the different reefs. Not enough individuals of the other functional groups were measured to provide data for the analysis. Due to differences in sample size plots were developed using scaled densities. Data were statistically compared using a Kolmogorov-Smirnoff test.

We also used the selectivity ratio defined by Kotwicki et al. (2017) to determine if either the ROV or the BASS Cam observed a greater number of fish of a certain size class. The selectivity ratio was calculated and applied using SCMM approach and the mgcv package in R (Wood, 2006, 2011). Lengths were aggregated into 2 cm bins as this was greater than the error of our stereo camera systems. Predicted selectivity ratios two stage resampling methods and 1000 bootstrap resamples.

2.3.2 Spatial Overlap

In order to address the joint questions of whether the two tools were seeing schools of fish at similar places along transects, and whether the tools' assessments of high-density and low-density regions along transects corresponded with each other, fish density data for the acoustic sampling and the ROV sampling were spatially compared. Transect data were spatially overlaid and segmented into approximately 50 m long segments, creating sample units for comparison within transects. To minimize any mismatch in data among tools due to segment split points that might be located by chance within a school of fish, we established the transect segment split points using an algorithm that located along-transect minima in acoustically-estimated fish density. The algorithm first established along-transect split zones within which each successive segment boundary might fall, thereby ensuring a minimum and maximum length for all segments, then placed the split point either at the center of the zone (if no fish were locally present) or at the minimum fish density within the zone.

To restrict the dataset to those portions where both tools acquired valid data, we first filtered the data according to the lateral distance between the actual tracks of the two sampling tools. For example, in some situations the ROV deviated from the planned sampling line to accommodate variations in the boat's track. Data were discarded where the two sampling tracks were separated by greater than X m. Within each segment the total non-gap ROV survey area and the non-gap ROV fish density were calculated. Segments with less than X m^2 of surveyed area were discarded. Fish density estimates were compared between ROV and acoustics for the remaining segments.

To determine how much spatial agreement there was in the presence and absence of fish between the ROV and acoustics we generated a confusion matrix. A confusion matrix compares whether or not there is agreement in the presence or absence of an organism (Visa *et al.*, 2011). These were generated for the Black, Blue/Deacon, Midwater and Demersal Rockfish categories. Data from Cascade Head were excluded from this analysis due to the extreme low numbers of fish observe by both tools. A confusion matrix effectively operates as an error matrix that classifies data into 4 conditions: both tools saw fish, neither tool saw fish, only the ROV saw fish and only the acoustics saw fish. These data could then be used to calculate a relative amount of agreement in the tools by diving the number of agreements (both tools saw fish and neither tool saw fish) by the total number of observations. We also calculated the Pearson's correlation coefficients between the densities derived for each tool.

2.3.3 Fish School Deadzone Densities

To test whether the BASSCam's downward facing camera provided an accurate count of fish in the near bottom deadzone we compared ROV data collected within 20 m of each BASSCam drop. These data were then summed to provide total counts above and within the near bottom deadzone for each transect. Models were developed with the response variable being the proportion of fish above the deadzone relative to the total number observed fish. This was done to standardize differences in viewed areas between the different tools. Explanatory variables were tool, species group, and reef. Data from Cascade Head were excluded from this analysis due to the extreme low numbers of fish observe by both tools.

For the BASSCam to determine which fish were above and which were within the near bottom deadzone, we used the field of view measurements for the forward and downward facing camera and trigonometry. As the goal was to determine how many fish were in the acoustic deadzone, we also calculated the volume of water observed by the downward facing camera and determined that 78% of the observed volume occurred from 0-1 m off bottom. Therefore, counts from the downward facing camera were multiplied by 0.78 to correct the counts to represent only what was counted within the near bottom deadzone. All fish viewed in the forward camera were considered above the near bottom deadzone. The proportion for the BASS Cam was generated by dividing the number of fish counted in the forward camera by the number counted in the forward plus the corrected number from downward facing camera

For the ROV we used the measured height off bottom data from our stereo pairs to determine a proportion of fish that were located within the 0-1 m off bottom deadzone and the proportion above. Proportion was calculated as number above 1 m divided by number below 1 m plus number above 1 m.

Summing our data allowed to the transect level and analyzing proportions allowed us to model our data. Data were modeled using a binomial distribution. Models were fit using the *glm* function in the base *stats* package. Covariates included in the model were Species, Reef, and Camera. All possible model iterations were fit and a best fit model selected using the Aikake Information Criterion (AIC). Relative strength of model selection considered using Akaike weights and log likelihood.

2.3.4 Background Fish Densities

To assess the mean density of fish in the deadzone in areas away from schools (i.e. the "background density" of fish that would otherwise be undetected in an acoustic-only survey of schools), we split the ROV data into near-school and away-from-school categories, and calculated the mean density in each category, restricting the ROV data to the density within the deadzone only (0-1 m off bottom). To determine the appropriate distance threshold for the away-from-school category, we first created a series of concentric spatial buffers in 5 m increments around the acoustically-detected schools. The acoustic data provided a centroid location and school width measurement for each school, and we placed the first circular 5 m buffer around the outer edge of the school and incremented outward to 50 m. Where schools were found in close proximity, some of the larger diameter buffers overlapped and were merged together, such that no fish were double-counted in the buffers for multiple schools. The ROV data were spatially overlaid on the buffers and the total viewed area and total counts of each fish species were summed within each 5 m distance increment.

To determine how far from fish schools we could safely assume we were at background fish densities we used generalized additive models to visualize the reduction in density with distance from schools. Each species/functional group was modeled independently. Response data were counts per 5 m distance bin, with viewed area per bin provided as a model offset. Explanatory variables were distance from school and reef. Categorical distance bins were made continuous by selecting each bin's maximum distance from the school to represent the distance. In other words counts from the 0-5 m bin were coded as 5 m. Counts within the school were coded as 0 m. All possible model formulations including reef and distance were considered. Models were fit with a negative binomial distribution with an offset for total area within each distance bin. Models were selected using AIC and relative strength of model selection considered using Akaike weights and log likelihood.

We selected a threshold value to define the away-from-schools category in the ROV data based on the GAM plots of abundance with distance from schools. We were conservative about the threshold selection, as there was no need to use data from areas potentially influenced by schools. We spatially filtered all ROV main camera data beyond the threshold distance and calculated the mean ("background") density in the deadzone for that area for each transect. This was accomplished by multiplying the ROV main camera-derived density for the away-from schools region by the proportion of total fish seen in the ROV's stereo cameras that were within the 0-1 m zone, for each species.

Table 1. Fish species and counts observed by the ROV and BASSCam. BASS/ROV denotes the ratio of fish observed in the BASSCam to the ROV. BASSCam counts are counts from only one randomly selected observation frame per deployment.

Common Name	Scientific Name	Functional Group	ROV	BASS	BASS/ROV
Black Rockfish	*Sebastes melanops*	Black	1,770	1,111	0.63
Black/Blue/Deacon Juvenile Rockfish	Sebates melanops/mystinus/diaconus	Black/Blue/Deacon Juvenile	NA	159	NA
Blue Rockfish	Sebastes mystinus	Blue/Deacon	25	NA	NA
Blue/Deacon Rockfish	Sebastes mystinus/diaconus	Blue/Deacon	3,022	2,325	0.77
Brown Irish Lord	Hemilepidotus spinosus	NA	5	0	0
Cabezon	Scorpaenichtys marmoratus	NA	86	1	0.01
Canary Rockfish	Sebastes pinniger	Non-Focal Midwater	689	95	0.14
China Rockfish	Sebastes nebulosus	Demersal	211	8	0.04
Copper Rockfish	Sebastes carnatus	Demersal	44	8	0.18
Deacon Rockfish	Sebastes diaconus	Blue/Deacon	2,980	NA	NA
Kelp Greenling	Hexagrammos decagrammus	NA	883	3	0.01
Lingcod	Ophiodon elongatus	NA	332	15	0.05
Longfin Gunnel	Pholis clemensi	NA	41	0	0
Northern Ronquil	Ronquilus jordani	NA	333	0	0
Painted Greenling	Oxylebius pictus	NA	20	1	0.05
Pile Perch	Rhacochilus vacca	NA	43	1	0.02
Poachers	Agonidae	NA	1	0	0
Puget Sound Rockfish	Sebastes emphaeus	Demersal	54	0	0
Quillback Rockfish	Sebastes maliger	Demersal	338	9	0.03
Ratfish	Hydrolagus colliei	NA	1	0	0
Red Irish Lord	Hemilepidotus hemilepidotus	NA	2	0	0
Rosethorn Rockfish	Sebastes helvomaculatus	Demersal	25	0	0
Shiner Perch	Cymatogaster aggregata	NA	2	0	0
Starry Skate	Raja stellulata	NA	3	0	0
Stripped Surf Perch	Embiotoca lateralis	NA	5	2	0.4
Tiger Rockfish	Sebastes nigrocinctus	Demersal	14	0	0
Vermilion Rockfish	Sebastes miniatus	Demersal	81	11	0.14
Widow Rockfish	Sebastes entomelas	Non-Focal Midwater	88	6	0.07
Wolf Eel	Anarrhichthys ocellatus	NA	21	0	0
Yelloweye Rockfish	Sebastes ruberrimus	Non-Focal Midwater	142	17	0.12
Yellowtail Rockfish	Sebastes flavidus	NA	183	38	0.21
Unidentified Surf Perch		NA	0	1	1
Unidentified Juvenile Rockfish		NA	NA	12	NA
Unidentified Fish		NA	31	35	1.13
Unidentified Flatfish		NA	879	0	0
Unidentified Rockfish		NA	5,292	330	0.06
Unidentified Sculpin		NA	112	0	0

2.3.5 Population Estimate

Data from the acoustic population estimates were generated for each transect. Echo integration data (backscattering) was exported for each transect and converted in to density data (see section 2.2.2). Echo counting density data from each fish track were summed to generate an average density per transect. The echo integration and echo counting densities were summed together for each transect. Densities were then averaged for each reef and species group individually.

ROV count data from the main forward camera were used to generate mean densities per species per reef. For each species, each transect' s density was calculated as the total count within non-gap portions of the transect divided by the non-gap surveyed area. The reef-level mean density was calculated as the weighted mean +/- weighted standard deviation of the transect densities, using the non-gap survey area for each transect as the weight.

3. Results

A total of 157 paired transects were sampled with both the ROV and the Acoustics/BASSCam survey methods (see online supplement for maps of each reefs transects). On these transects, 37 species or species groups were identified and 38,656 fish being counted (**Table 1**). The ROV observed more species and individuals than the BASSCam. In the acoustics 340 schools of fish and 1403 of fish tracks were identified. Due to the focus of this paper being on the efficacy of the acoustic/BASSCam tool to sample the nearshore midwater rockfish (Black, Blue and Deacon) we aggregated other species for analysis. Yellowtail, Widow, Puget Sound and Canary Rockfish were classified as non-focal midwater rockfish and all other rockfish species were classified as demersal rockfish (**Table 1**). All other species and species groups were excluded from additional analysis. Based on genetic work, all Black, Blue and Deacon rockfish <20 cm in length were classified as juveniles.

Table 2. DeltaAIC, Log Likelihood and Akaike Weight values for every model iteration used to determine if the number of fish in the near bottom acoustic deadzone differed. Reef- Study reef, Camera- ROV vs BASSCam, Species- Which functional group (Table 1). Models were run on the proportion of fish above the near bottom deadzone to the total number counted.

Formula	Delta AIC	Log Likelihood	Akaike Weight
Camera*Species*Reef	26.09	0	0
Species*Reef	29.74	0	0
Camera *Reef	41.86	0	0
Camera *Species	0	1.00	1.00
Species	16.22	0	0
Reef	80.72	0	0
Camera	34.31	0	0
1	79.67	0	0

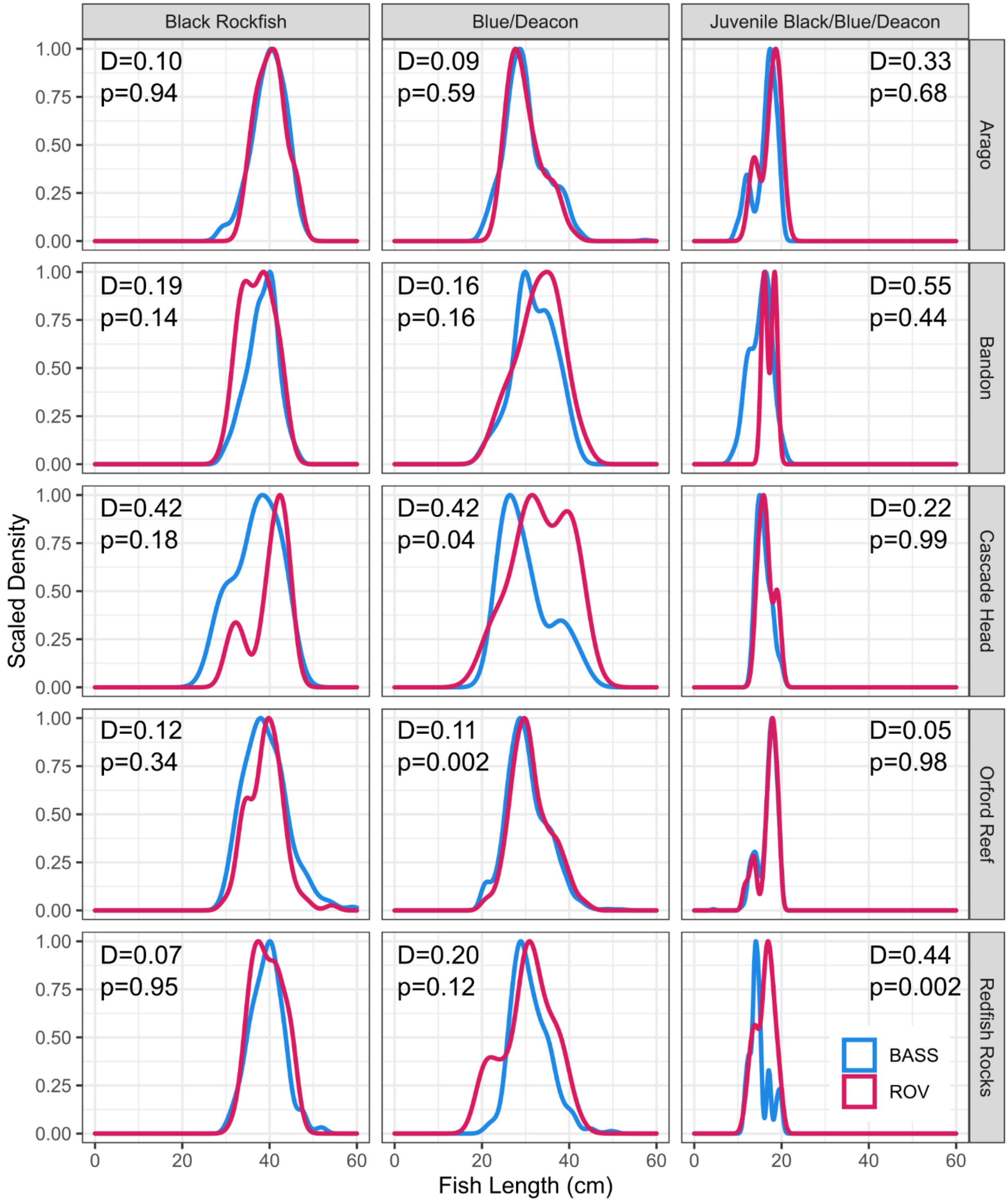

Fig. 1 Scaled density plots of length distributions for the three focal species (species groups) at each reef. Values in the plot represent the results of a statistical comparison of the two densities using a Kolmogorov-Smirnov test.

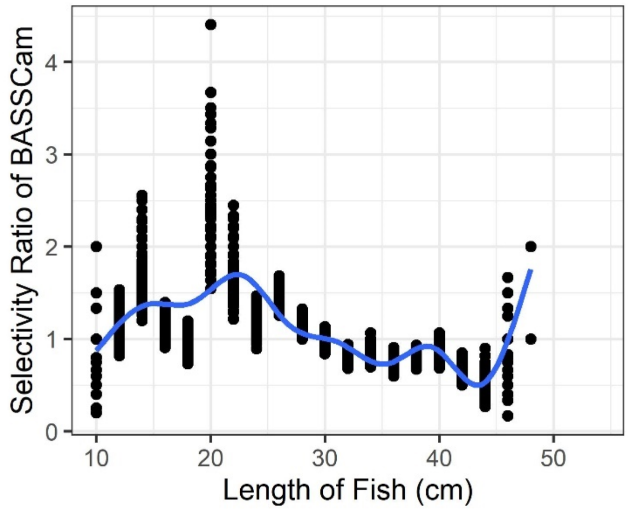

Fig. 2 Relative length selectivity of the BASSCam to the ROV. Value above 1 indicate greater selection by the BASSCam and values less than 1 indicate greater selection by the ROV. Black dots denote each estimate of selectivity from 1000 sampling iterations and the blue line denotes the best estimate of selectivity estimated using a generalized additive model. The blue line is surrounded by a shaded area representing the 95% confidence interval.

3.1 Length Data Comparison

On average there was no difference in length distribution for each of the tools at each reef (**Fig. 1**). The exceptions to this Blue/Deacon's at Cascade Head and Orford Reef and Juvenile Black, Blue Deacon's and Redfish Rocks. Despite the fact that statistically these three species and reef combinations were different from one another, overall the distributions are visually quite similar.

The selectivity analysis demonstrated that on average from lengths of 12 – 30 cm the BASSCam observed slightly more fish than the ROV and above this the ROV observed more fish (**Fig. 2)**. However, the selectivity ratio was very small suggesting that although there was evidence of selectivity in length by each tool the magnitude of the effect was very small.

3.2 Spatial Overlap

In general there was spatial overlap in where the ROV and the acoustics/BASSCam observed fish. The accuracy for Black Rockfish was 72%, for Blue/Deacon Rockfish was 77%, for non-focal midwater rockfish was 71% and for demersal rockfish was 65%. Further the density estimates for Black and Blue/Deacon Rockfish were moderately well correlated with one another (**Fig. 3**). For the non-focal midwater and demersal rockfish the correlations were non-significant and poor (**Fig. 3**).

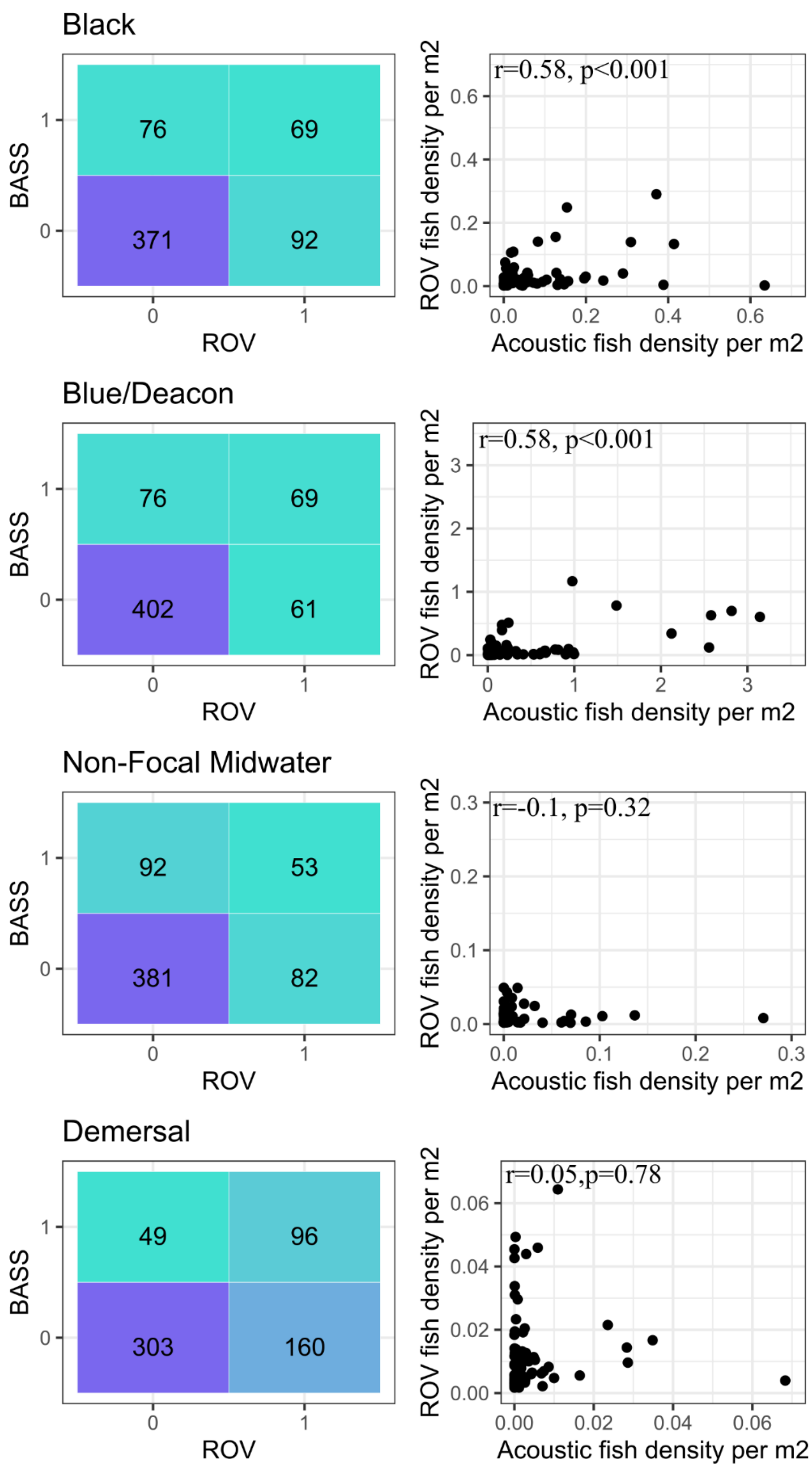

Fig. 3 Confusion matrices of spatial observations of each species group (left) and density correlation plots between the BASSCam and ROV. In the confusion matrices 1 denotes fish were observed and 0 denotes no fish were observed. Statistics values in the correlation plot denote the results of Pearson's correlation coefficient.

3.3 Fish School Deadzone Densities

Our best fit model included an interaction between species and tool (**Table 2,** see online supplement for summary of best fit model). The next best fit models had AIC values ~ 15 units higher than the best fit model suggesting strong consensus in model selection. This as corroborated by Akaike weight and log likelihood values of 1. In general for non-demersal fish the BASS Cam observed more fish above the deadzone than the ROV did (**Fig. 4**). However, the difference in proportions above and within were quite similar for Black Rockfish. The BASS Cam did not observe any demersal rockfish and the ROV found that most were within the near bottom deadzone. Blue/Deacon Rockfish were primarily above the near bottom deadzone regardless of tool.

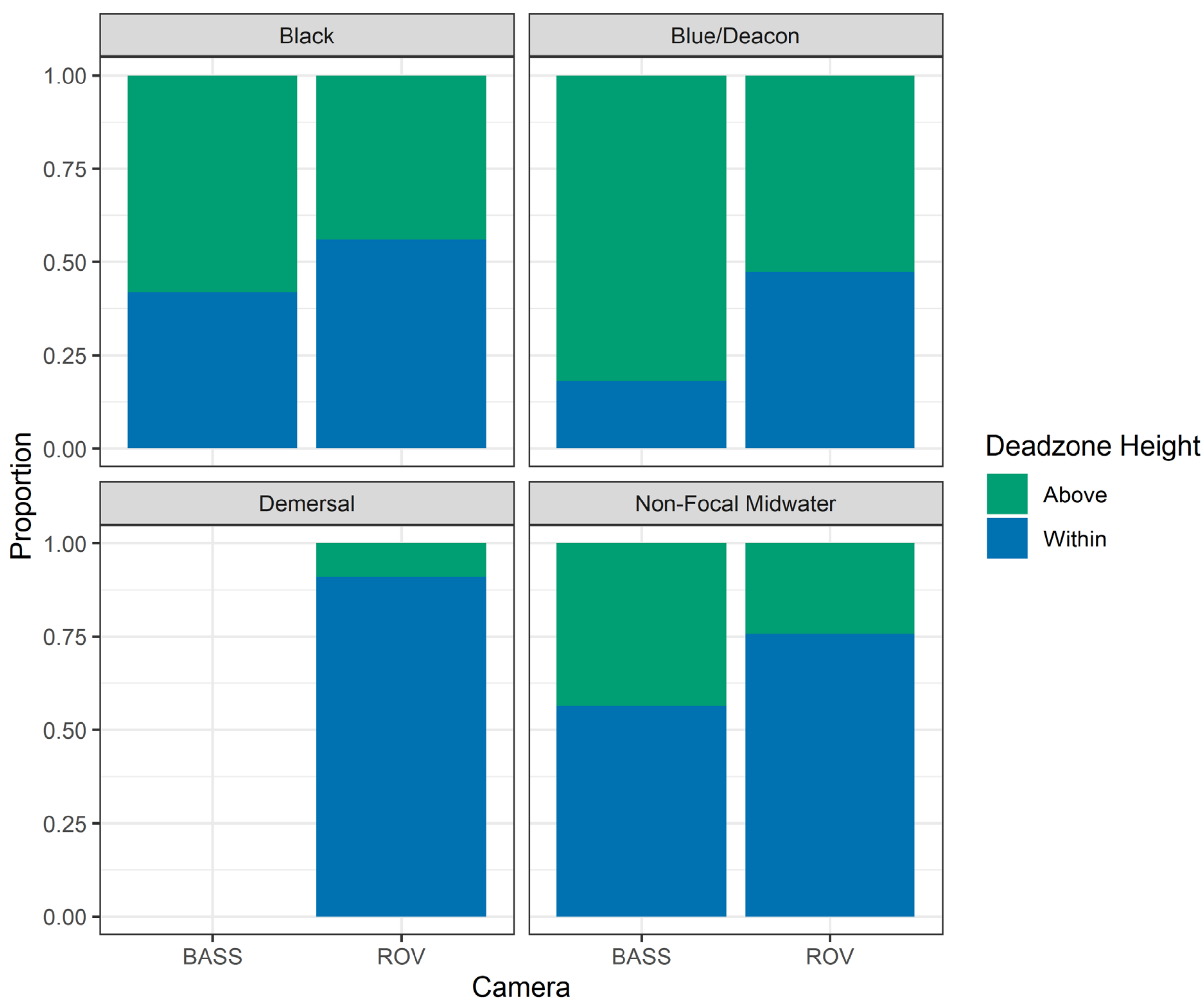

Fig. 4 Proportion of fish above and within the near bottom deadzone for each of the four focal study groups observed by each camera. No demersal fish were observed by the BASS Cam. Model selection suggested there was no effect of reef (see Table 2).

3.4 Background Fish Densities

Our best fit model of fish abundance with distance from school included an interaction between reef and distance and reef as an independent factor (**Table 3,** see online supplement for summary of best fit models). The best fit model for each species except demersals was well supported (high Akaike weights). Models of demersal were relatively poor fits. Examination of the GAM smooths suggested fish counts at distances > 35 m from the school edge could be considered background densities (**Fig. 5**). Background densities were calculated for each species group at using all data from > 35 m from the school edge (**Table 4**). Background densities were relatively consistent with each species commonly having a single reef with a larger than average density.

Table 3. DeltaAIC, Log Likelihood and Akaike Weight values for every potential model assessing the relationship between ROV-derived density and distance from the edge of each acoustically-detected school. Distance- Distance from the edge of each fish school. Reef- Study reef.

Black

Formula	Delta AIC	Log Likelihood	Akaike Weight
Distance*Reef+Reef	0	1.00	0.92
Distance*Reef	4.84	0.09	0.08
Distance+Reef	13.99	0	0
Distance	38.29	0	0
Reef	42.48	0	0
~1	71.71	0	0

Blue/Deacon

Formula	Delta AIC	Log Likelihood	Akaike Weight
Distance*Reef+Reef	0	1.00	1.00
Distance*Reef	44.96	0	0
Distance+Reef	10.83	0	0
Distance	43.26	0	0
Reef	26.85	0	0
~1	53.23	0	0

Demersal

Formula	Delta AIC	Log Likelihood	Akaike Weight
Distance*Reef+Reef	0	1.00	0.47
Distance*Reef	1.62	0.44	0.21
Distance+Reef	3.65	0.16	0.08
Distance	2.08	0.35	0.17
Reef	5.97	0.05	0.02
~1	4.53	0.10	0.05

Non-Focal Midwater

Formula	Delta AIC	Log Likelihood	Akaike Weight
Distance*Reef+Reef	0	1.00	1.00
Distance*Reef	10.96	0	0
Distance+Reef	14.49	0	0
Distance	18.63	0	0
Reef	21.89	0	0
~1	26.74	0	0

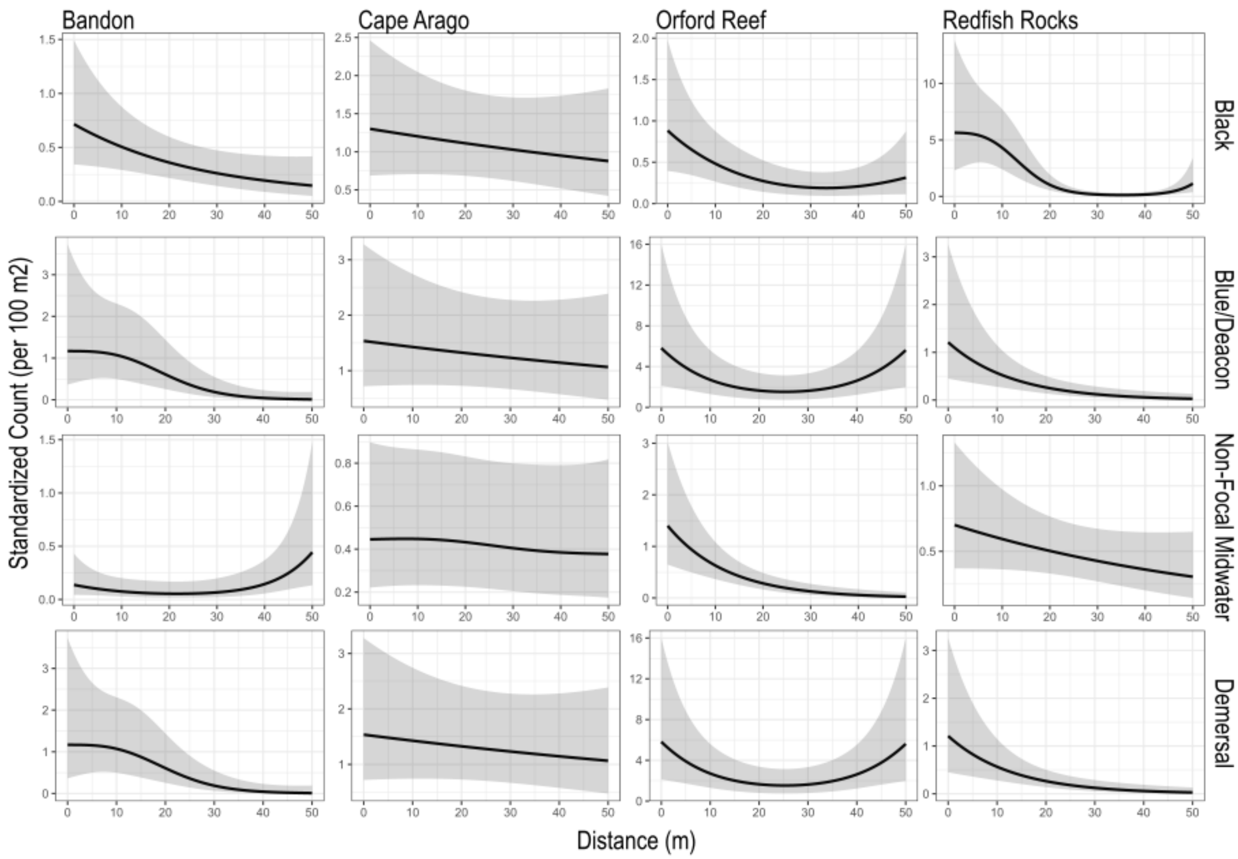

Fig. 5 Generalized additive models of number of fish counted by the ROV within fish schools observed by the acoustics and outwards to a distance of 50 m. Although distances were modeled as a continuous variable, counts were aggregated into bins. E.g. 0-5 m from the school (5 m on the rug plot), 5-10 m from the school (10 m on the rug plot). 0 denotes the counts within the school. See Table 3 for model selection.

3.5 Population Estimate

The total reef density estimate for Black Rockfish from the acoustics/BASSCam was higher than that from the ROV (**Fig. 6**). There density estimate for Blue/Deacon Rockfish, with a dramatic difference in density at Cape Arago, was higher in the acoustics/BASSCam than the ROV. The density estimates were higher for demersal rockfish in the ROV than the acoustics/BASSCam and there was variability in the results for the non-focal midwater rockfish. Regardless of tool the CV estimates for both tools were quite high (**Table 5**).

Table 4. Background ROV density (individuals per 100 m^2) and standard deviation at each reef for the study's four species groupings. Background densities were calculated for the entire region further than 35 m from the outside edge of schools observed in the acoustic sampling. Raw density: the mean transect density assessed by the ROV main camera; SD: the standard deviation of the raw density among transects; Adjusted density in deadzone: the raw density multiplied by the proportion of fish in the 0 – 1 m deadzone in the ROV's stereo cameras, out of the total fish within 2 m of the bottom; N: number of transects.

Species	Reef	Raw density	SD	Adjusted density in deadzone	Adjusted SD	N
Black	Bandon	0.193	0.317	0.141	0.233	17
Black	Cape Arago	0.449	0.866	0.324	0.624	13
Black	Orford Reef	0.193	0.331	0.130	0.223	18
Black	Redfish Rocks	0.311	0.357	0.120	0.138	17
Black	All Reefs	0.275	0.487	0.170	0.301	65
Blue Deacon	Bandon	0.123	0.362	0.070	0.207	17
Blue Deacon	Cape Arago	0.380	0.630	0.191	0.317	13
Blue Deacon	Orford Reef	0.981	1.357	0.476	0.658	18
Blue Deacon	Redfish Rocks	0.108	0.266	0.037	0.091	17
Blue Deacon	All Reefs	0.408	0.867	0.197	0.418	65
Demersal	Bandon	0.289	0.299	0.278	0.288	17
Demersal	Cape Arago	0.530	0.555	0.505	0.528	13
Demersal	Orford Reef	0.324	0.243	0.304	0.228	18
Demersal	Redfish Rocks	0.174	0.168	0.165	0.159	17
Demersal	All Reefs	0.317	0.343	0.300	0.325	65
Non-Focal Midwater	Bandon	0.550	1.832	0.523	1.742	17
Non-Focal Midwater	Cape Arago	0.263	0.389	0.222	0.328	13
Non-Focal Midwater	Orford Reef	0.186	0.218	0.136	0.160	18
Non-Focal Midwater	Redfish Rocks	0.143	0.247	0.108	0.186	17
Non-Focal Midwater	All Reefs	0.285	0.961	0.228	0.766	65

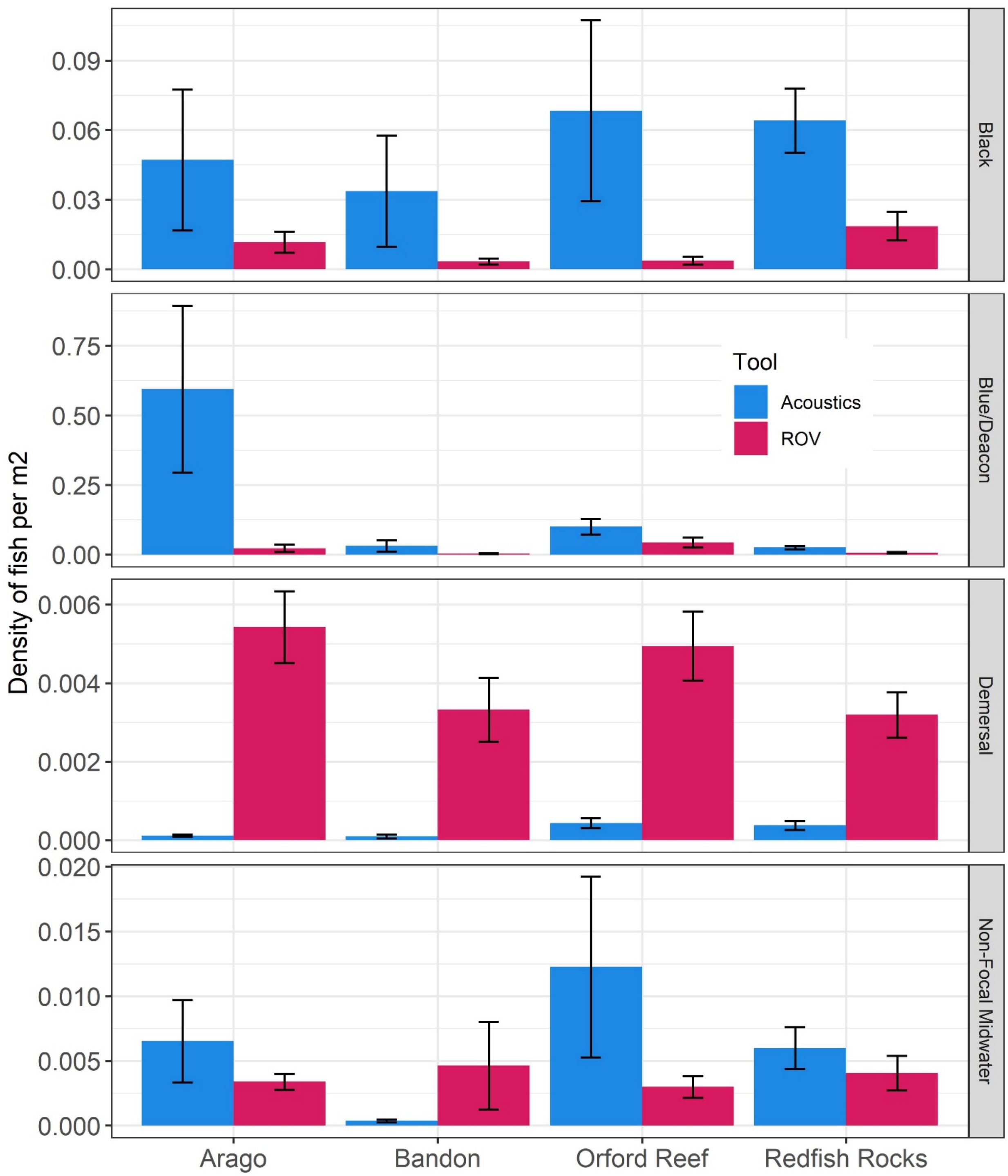

Fig. 6 Mean population density estimates from each of the two sampling tools for each reef and species group. Error bars denote standard deviation

4. Discussion

In this paper we set out to determine if the near bottom acoustic deadzone made an acoustic survey for Oregon's nearshore midwater rockfish feasible. To address the question, we paired our acoustic/video sampling with an ROV to determine the relative contribution of the near bottom acoustic deadzone. In order for us to answer this question we first had to assess whether or not there were catchability (detectability) differences between our tools (Arreguin-Sanchez, 1996; Lawson and Rose, 1999). In general, we found that there was strong spatial coherence in the observations between our two tools and that the densities of observed fish were well correlated.

Table 5. Coefficient of variation estimates for the population estimates for each of the focal groups for each tool at each reef and for all reefs on average.

Reef	Black		Blue/Deacon		Non-Focal Midwater		Demersal	
	Acoustics	ROV	Acoustics	ROV	Acoustics	ROV	Acoustics	ROV
Arago	0.43	0.72	0.54	0.48	0.56	1.50	1.25	1.64
Bandon	0.39	0.74	0.42	0.63	1.06	0.37	0.62	1.13
Orford Reef	0.45	0.59	0.95	0.66	0.46	0.95	1.03	1.50
Redfish Rocks	1.28	0.84	1.37	0.65	1.12	0.83	0.99	1.53
Average	0.63	0.72	0.82	0.61	0.80	0.91	0.97	1.45

Further, the length distributions of our focal species did not differ between the tools and we found little evidence of size selectivity (Kotwicki *et al.*, 2017). Thus, we hypothesize that by combining these two survey methods we were able to accurately assess the relative importance on the near bottom acoustic deadzone to nearshore midwater rockfish and the utility of a combined hydroacoustic video survey to survey them. Our work suggests that the combination of acoustics and our suspended BASSCam create a great survey tool for nearshore midwater rockfish.

The nearbottom acoustic deadzone has been shown to greatly influence the population estimates of species (Ona and Mitson, 1996). As such multiple methods have been proposed to correct for the near bottom deadzone (Tušer *et al.*, 2013; Kotwicki *et al.*, 2018). In this paper we considered correction of the near bottom acoustic deadzone as two components. First, correction of school observations into the region directly below the school that occupied the near bottom deadzone. A common way to correct acoustic data is to extrapolate the acoustic backscaterring data above the near bottom deadzone into the deadzone (Kloser, 1996). While this method is often applied and the assumption left unvalidated, here we are able to confidently state that an extrapolation of acoustic backscattering data into the near bottom acoustic deadzone provides a realistic correction to the acoustic data. In our study, we found that the proportion of Black Rockfish was not very different above and within the deadzone regardless of tool. Suggesting we could use this method for Black Rockfish. Alternatively, Blue/Deacon Rockfish were much more prevalent above the near bottom deadzone suggest and extrapolation of this species would artificially increase our population estimate. We made no attempts were made to apply these correction methods and correct our population estimates due to the relatively short length of our transect which resulted in high uncertainty in our population estimates. The data here suggest that either a extrapolation based method on the acoustics or a observational method from our BASSCam both should be viable for Black Rockfish but a reduction in the extrapolation is needed for Blue/Deacon. Further very few of the non-focal midwater and demersal rockfish were observed above the near bottom deadzone suggesting minimal contamination of the backscattering or echo counting data. These methods should be assessed more fully when the survey is implemented at a regional level.

The second correction needed is for the fish located within the near bottom deadzone but not collocated with a fish school. We consider this background densities of fish. Since the ROV samples using a belt transect we were able to assess the background density of our focal species. No difference in background density was observed between reefs suggesting that a correction from the ROVs near bottom observations could be applied to these non-school regions.

Another concern with species groups like rockfish is the differentiation of species. While target strength methods have been applied elsewhere to differentiate species (McClatchie *et al.*, 2000; Korneliussen *et al.*, 2009) these methods have not been tested yet for the Northeastern Pacific Sebastes genus. Our finding that demersal rockfish remained within 1 m of the bottom implies that despite the great diversity of rockfish in Oregon's nearshore, many of these species occur outside of the observational scope of the acoustics and therefore do not contaminate the population estimate. As such the population estimate is ultimate only contaminated by an additional 3-4 species (Canary, *Sebastes pinniger*, Widow and Yellowtail Rockfish). Therefore, the difficulty of differentiation is reduced and further simplified by the ease of detection of these species with the BASSCam. Further, these non-focal midwater species have been shown to be good candidates for acoustic surveys (Stanley, 1999, 2000) and the methods we describe here could easily be adapted to the continental shelf to provide population estimates for the valuable stocks.

An additional potential concern of our BASSCam as a tool to provide species and length composition data to apportion backscattering data into density and ultimate population estimates is that it takes point estimates from fish schools. As the ROV conducts a belt transect we are able to assess if our point estimates are missing species and or size classes of fish. As discussed above and based on the species composition data, it is obvious that there is little difference in which species are observed. Further, when there are differences, it is often the ROV observing rare non-rockfish species and demersal rockfish species. The first are excluded from analyses based on our schools detection algorithm and the latter are excluded since, as discussed above, are almost exclusively located in the near bottom acoustic deadzone. Therefore, this suggests point estimates from the BAS Cam do provide accurate insight into species composition for a reef. It is worth noting that the total number of fish counted by the ROV is much higher than with the BASSCam, however, since the conversion of acoustic backscattering data into density only requires proportions, this has little affect. The length distribution observed by the ROV and BASSCam did not differ in most instances. Since the ROVs length data were taken from the entirety of the transect and the BASSCam from schools, this suggests that there is no size fractionation between schools and individuals not located within schools. Ultimately, we hypothesize that these data suggest point estimates taken within schools provide accurate species and length composition data.

Our population estimates were much larger for the focal species using the acoustics and BASSCam than the ROV. Previously Rasmuson et al. (2021) demonstrated there was strong coherence between the population estimate from combining acoustic and the BASSCam and a previous PIT tagging study. Our work further confirms that this tool is well designed for these species. Similar to the findings of Rooper et al. (2020) the choice of camera tool is dependent on habitat and species. In our, case we hypothesize the suspended camera is better designed to sample nearshore midwater fish. Further, there is reduced contamination from demersal rockfish in the data. One thing to note is that the CVs for both survey tools were high. In the case of the acoustics, the transect were very short 3-500 m which greatly increased the variability in the data. When this survey tool is implemented, survey transect should be much longer, spanning multiple kilometers which will ultimately reduce this variance. Further, these data demonstrate that for both the ROV and acoustics modeling based approaches to population estimates are likely the best way forward.

While these methods are specifically designed for nearshore species they can very easily be adapted to work with the important midwater shelf rockfish stocks. Our work demonstrate that the near bottom acoustic deadzone does not negatively affect the ability of the tool to sample our focal species. In reality it actually enhances the utility of the tool by reducing the number of species that need to be considered since the majority of rockfish are demersal and therefore not detectable by the acoustics. Further, targeting schools provides an accurate estimate of species composition and length data. In an area where the visibility is characteristically bad, deploying cameras into large schools greatly increases the chance of collecting data. In short we find that acoustics and suspended cameras are a good survey tool for midwater rockfish.

5. Acknowledgments

We thank captain Dave DeBelloy of the CPFV Enterprise and captain Bob Pedro of the RV Miss Linda for their assistance in this project. We thank Alison Whitman, Greg Krutzikowsky and David Fox for their assistance in obtaining the grant funding. Funding for this project was made available from the NOAA Saltonstall-Kennedy grant program grant number NA17NMF4270223.

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Supplement to accompany: Influence of near bottom habitat use on the efficacy of a combined hydroacoustic video survey for nearshore midwater rockfish.

The following maps show the individual transects sampled at each reef overlaid on the best available multibeam bathymetry.

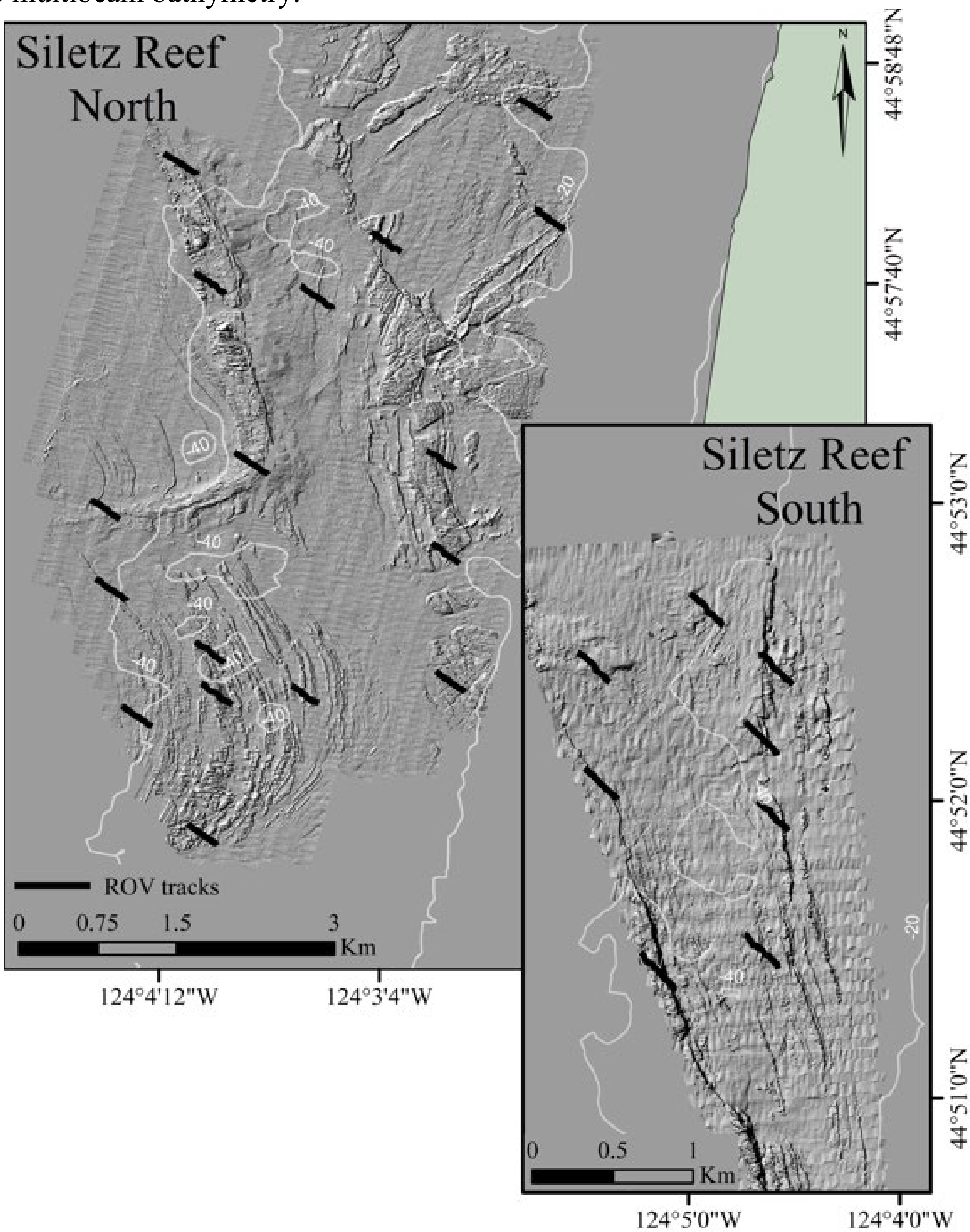


Fig. S1 Cascade Head (Siletz reef) survey areas. Black lines are the transects sampled by the ROV and acoustics. On each transect 3 BASS Cam drops were conducted (not depicted here due to figure resolution). These data were only analyzed in the length data due to the relative infrequence of fish.

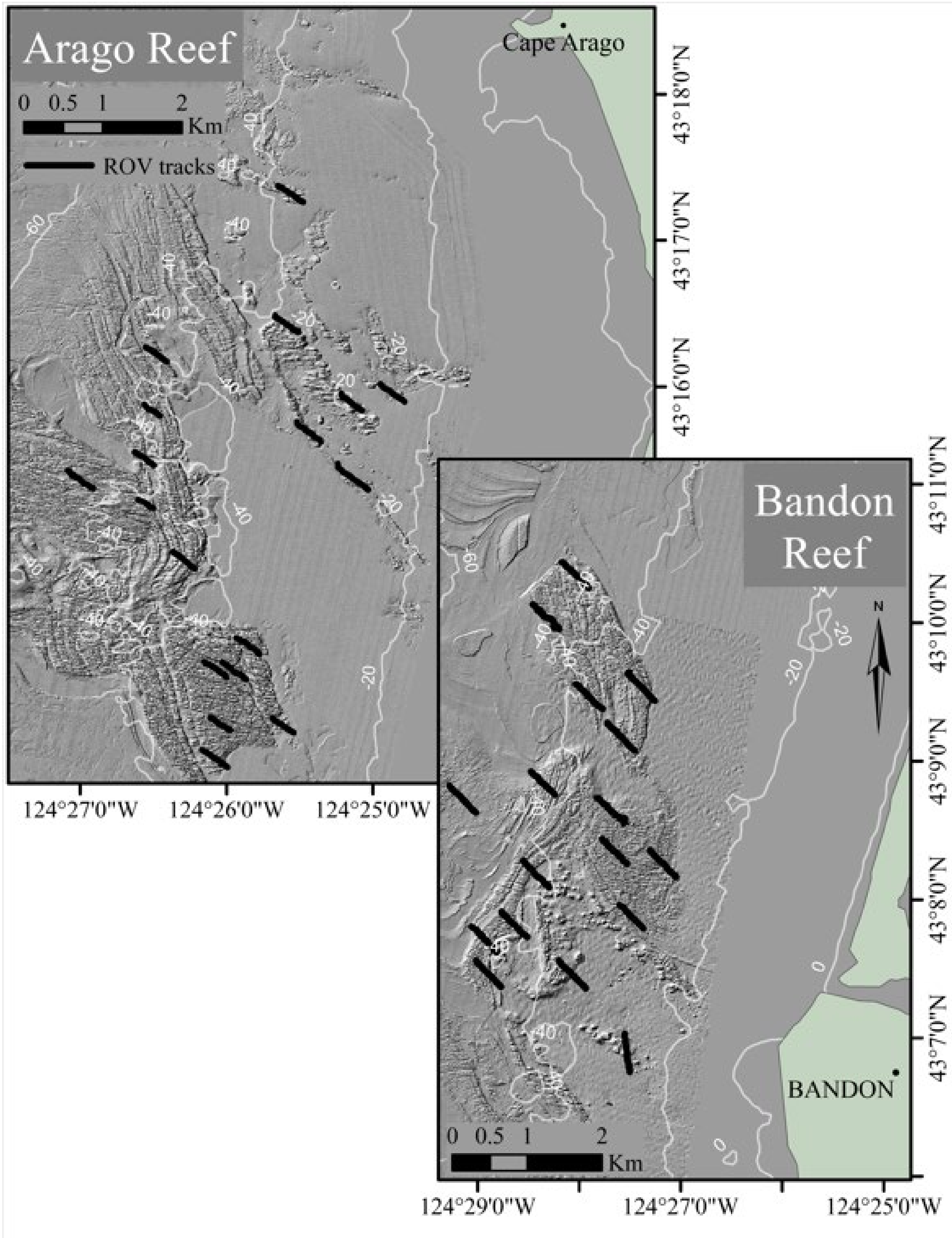


Fig. S2 Arago and Bandon survey areas. Black lines are the transects sampled by the ROV and acoustics. On each transect 3 BASS Cam drops were conducted (not depicted here due to figure resolution). These data were only analyzed in the length data due to the relative infrequence of fish.

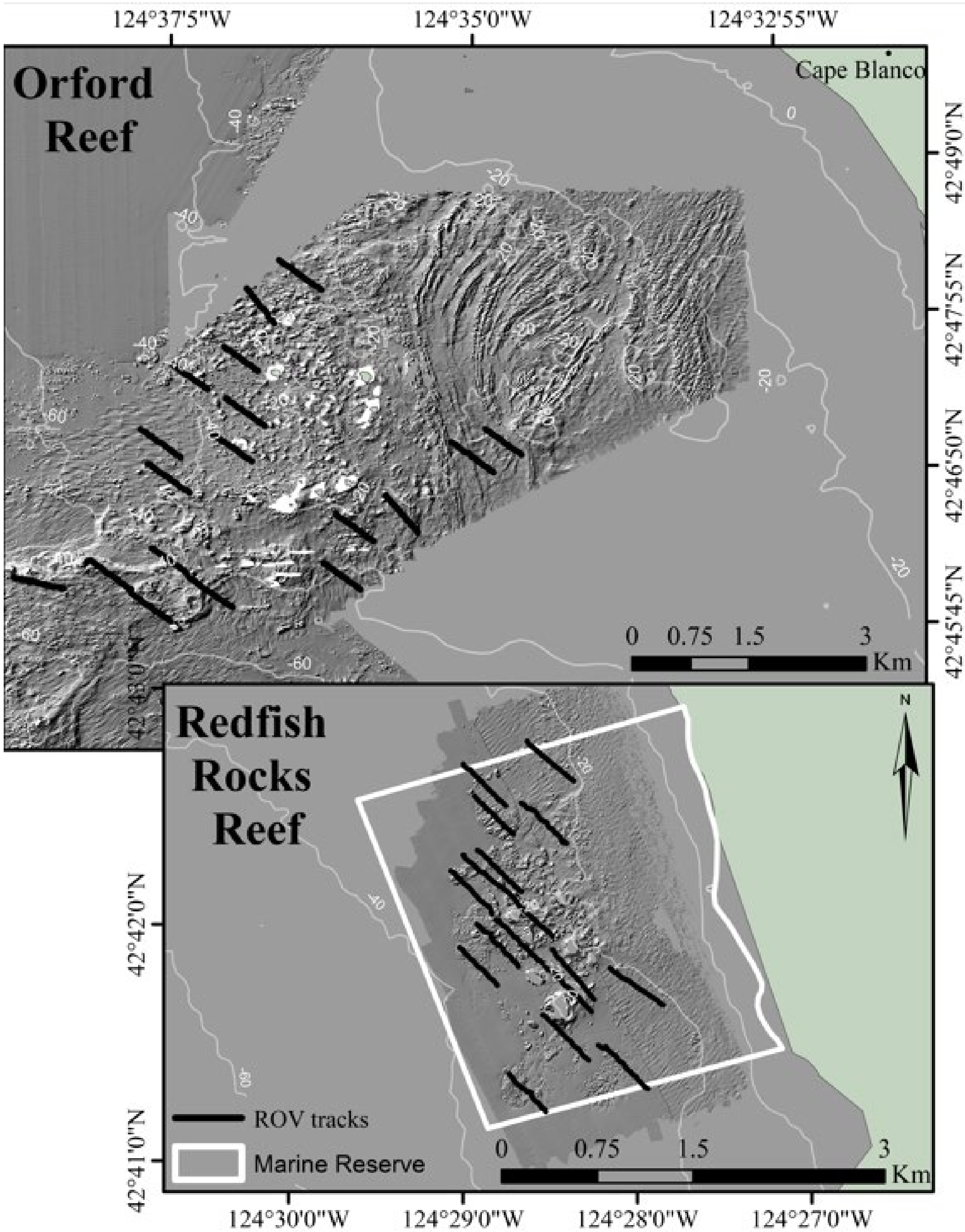


Fig. S3 Arago and Bandon survey areas. Black lines are the transects sampled by the ROV and acoustics. On each transect 3 BASS Cam drops were conducted (not depicted here due to figure resolution). These data were only analyzed in the length data due to the relative infrequence of fish.

Table S1 Model summary output for the best-fit GAM to examine the effect of Camera, reef and species on proportion of fish in the near bottom deadzone (section 2.3.3 and 3.3 in the primary manuscript).

glm(formula = Proportion ~ Tool * Species, family = binomial, data = Trans1)

Deviance Residuals:

Min	1Q	Median	3Q	Max
-1.3212	-0.4334	-0.1655	0.3748	2.1964

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	0.3318	0.4323	0.767	0.44281
Camera=ROV	-0.5718	0.5856	-0.976	0.32888
Species=Blue/Deacon	1.1837	0.6213	1.905	0.05676
Species=Demersal	-2.0782	0.6642	-3.129	0.00175
Species=Non-Focal Midwater	-0.5917	0.8764	-0.675	0.49955
Camera = ROV & Species=Blue/Deacon	-0.8313	0.8031	-1.035	0.30061
Camera = ROV & Species=Demersal	NA	NA	NA	NA
Camera = ROV & Species=Non-Focal Midwater	-0.3015	1.0643	-0.283	0.77696

Null deviance: 147.957 on 196 degrees of freedom
Residual deviance: 94.042 on 190 degrees of freedom

Number of Fisher Scoring iterations: 5

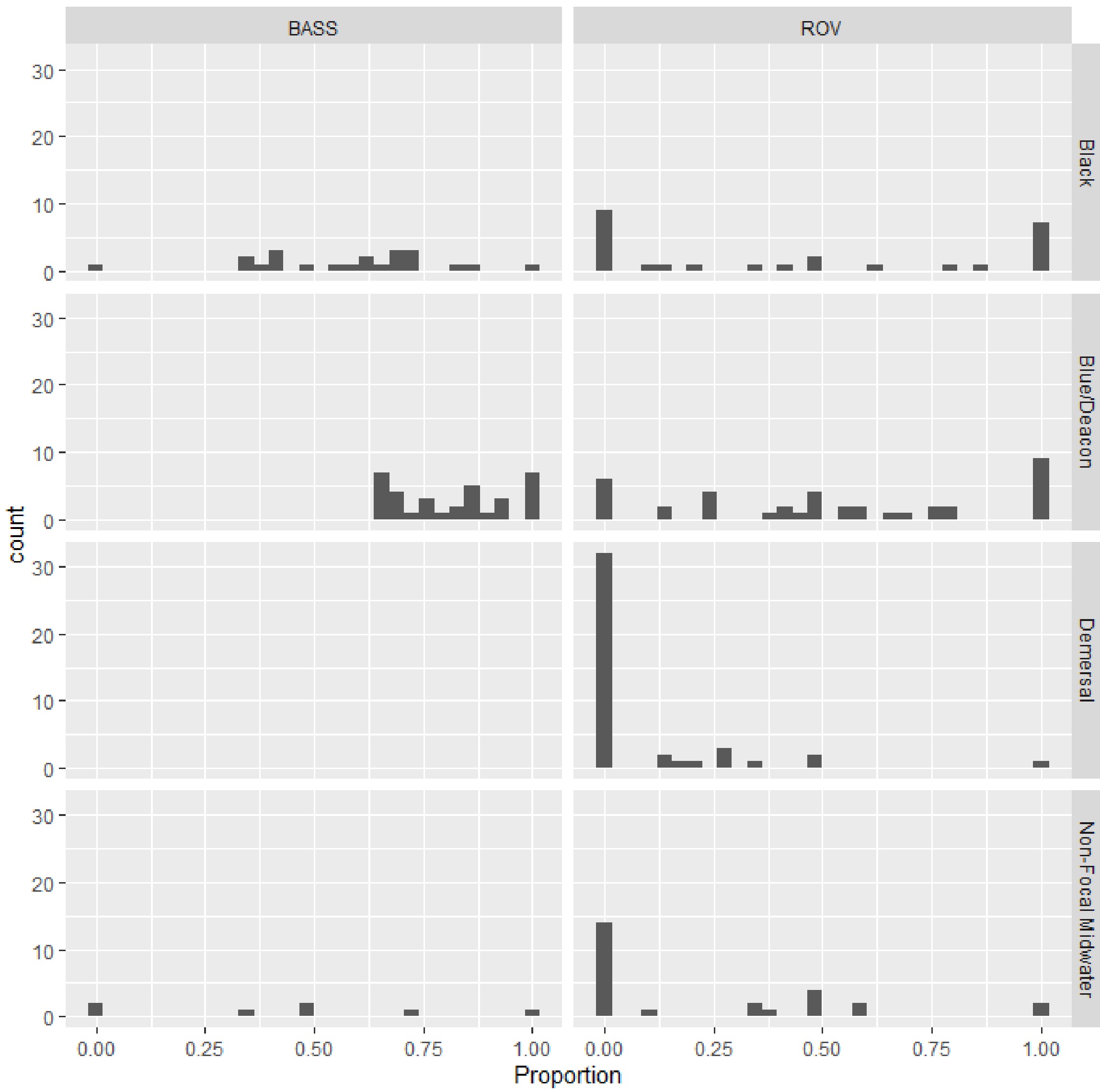


Fig S4. Histogram of proportion observations by tool and species.

Table S2. Model summary tables for the best-fit GAMs to examine the effect of distance on fish abundance (section 2.3.4 and 3.4 in the primary manuscript). Each species was modeled independently.

Black Rockfish

Family: Negative Binomial(0.28)
Link function: log

Formula: Fish_n ~ s(Dist, by = Location, k = 4) + Location

Parametric coefficients:

	Estimate	Std. Error	z value	Pr(>|z|)
Bandon	-5.76366	0.26278	-21.933	< 2e-16
Cape Arago	1.22560	0.36210	3.385	0.000712
Orford Reef	0.02068	0.35588	0.058	0.953661
Redfish Rocks	1.00997	0.34177	2.955	0.003125

Approximate significance of smooth terms:

	edf	Ref.df	Chi.sq	p-value
Distance * Bandon Reef	0.9043	3	4.981	0.0154
Distance * Cape Arago	0.4201	3	0.631	0.2202
Distance * Orford Reef	1.5574	3	6.785	0.0123
Distance * Redfish Rocks	2.6900	3	42.482	<2e-16

R-sq.(adj) = 0.518 Deviance explained = 29.6%
-REML = 494.9 Scale est. = 1 n = 520

Blue/Deacon Rockfish

Family: Negative Binomial(0.133)
Link function: log

Formula: Fish_n ~ s(Dist, by = Location, k = 4) + Location

Parametric coefficients:

	Estimate	Std. Error	z value	Pr(>|z|)
Bandon	-6.1411	0.4440	-13.831	< 2e-16
Cape Arago	1.7823	0.5388	3.308	0.00094
Orford Reef	2.5274	0.5136	4.921	8.61e-07
Redfish Rocks	-0.1681	0.5748	-0.292	0.76995

Approximate significance of smooth terms:

	edf	Ref.df	Chi.sq	p-value
Distance * Bandon Reef	1.7230	3	11.109	0.001351
Distance * Cape Arago	0.2957	3	0.504	0.191436
Distance * Orford Reef	1.5484	3	4.748	0.047082
Distance * Redfish Rocks	0.9258	3	11.376	0.000455

R-sq.(adj) = 0.421 Deviance explained = 27.9%
-REML = 499.97 Scale est. = 1 n = 520

Demersal Rockfish

Family: Negative Binomial(0.802)
Link function: log

Formula: Fish_n ~ s(Dist, by = Location, k = 4) + Location

Parametric coefficients:

	Estimate	Std. Error	z value	Pr(>|z|)
Bandon	-5.49192	0.18122	-30.305	<2e-16
Cape Arago	0.48794	0.28703	1.700	0.0891
Orford Reef	0.07113	0.24605	0.289	0.7725
Redfish Rocks	-0.25444	0.25706	-0.990	0.3223

Approximate significance of smooth terms:

	edf	Ref.df	Chi.sq	p-value
Distance * Bandon Reef	0.000198	3	0.000	0.8403
Distance * Cape Arago	0.130716	3	0.156	0.2886
Distance * Orford Reef	1.238448	3	4.232	0.0343
Distance * Redfish Rocks	1.359661	3	5.985	0.0130

R-sq.(adj) = 0.646 Deviance explained = 5.04%
-REML = 433.61 Scale est. = 1 n = 520

Midwater Rockfish

Family: Negative Binomial(0.271)
Link function: log

Formula: Fish_n ~ s(Dist, by = Location, k = 4) + Location

Parametric coefficients:

	Estimate	Std. Error	z value	Pr(>|z|)
Bandon	-6.8524	0.3599	-19.038	< 2e-16
Cape Arago	1.3682	0.4800	2.851	0.004362
Orford Reef	0.5957	0.4824	1.235	0.216886
Redfish Rocks	1.4794	0.4197	3.525	0.000423

Approximate significance of smooth terms:

	edf	Ref.df	Chi.sq	p-value
Distance * Bandon Reef	1.7168	3	5.594	0.0345
Distance * Cape Arago	0.2503	3	0.256	0.3425
Distance * Orford Reef	0.9487	3	16.733	2.73e-05
Distance * Redfish Rocks	0.6976	3	2.137	0.0800

R-sq.(adj) = -0.926 Deviance explained = 17.4%
-REML = 336.69 Scale est. = 1 n = 520

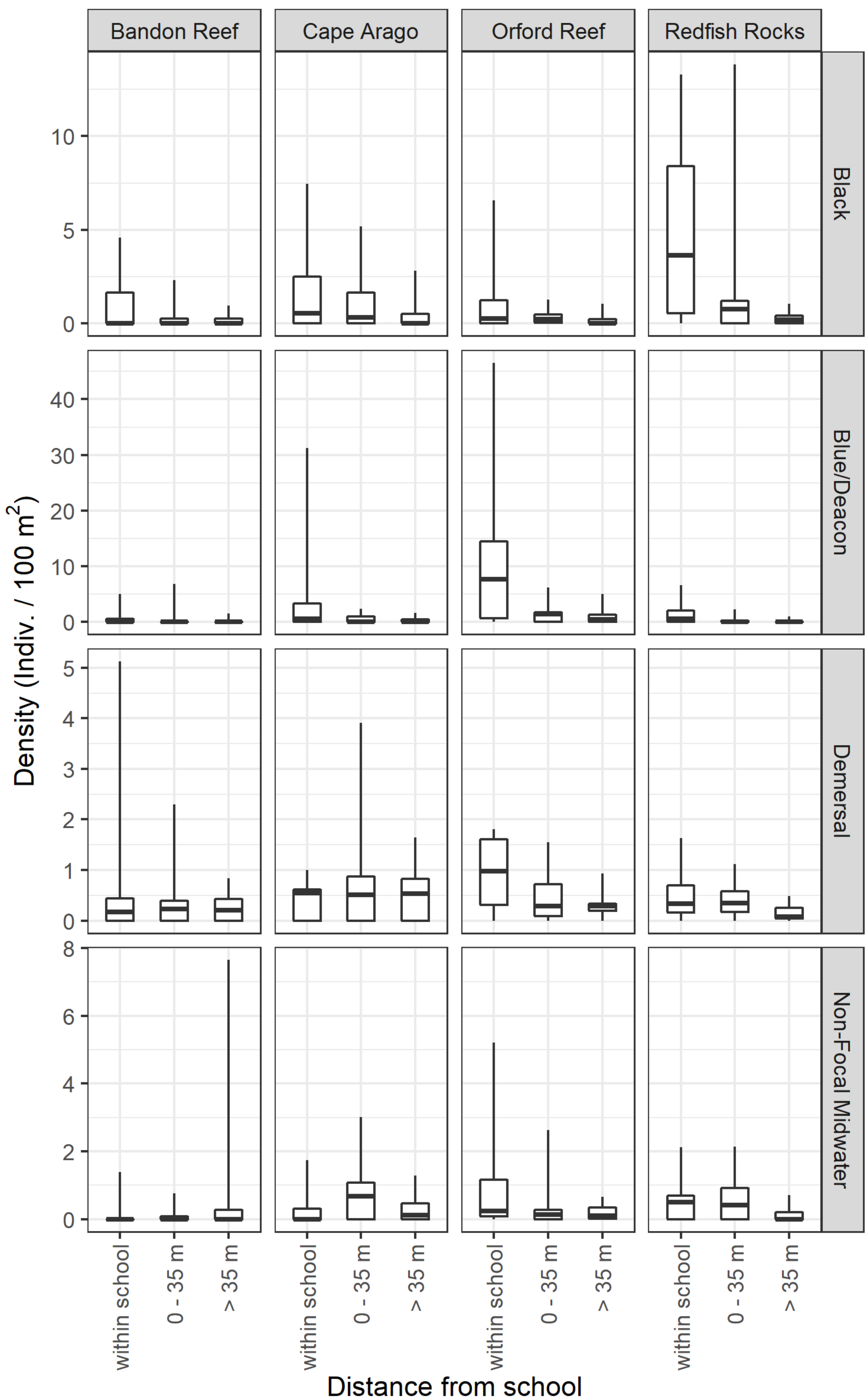


Fig S5. Boxplots of fish densities wihtin fish schools, in the transition zone (0-35 m from the school) and at distances >35 m from the school. Whiskers are extended to the full extent of the data range.

Additional Research Conducted

In objective 1 and objective 2 we demonstrated that the combination of video and hydroacoustics was an effective tool to survey nearshore semi-pelagic rockfish. Thus, additional funding was obtained from the Oregon Department of Fish and Wildlife Restoration and Enhancement Board to conducted a survey. The survey was conducted in the late summer/fall of 2021. Transects were conducted from the Washington to California border. Video drops were conducted throughout the study range and twice daily hook and line sampling was conducted to provide age and maturity samples. CTD casts were also conducted to map and measure oceanographic conditions.

A total of 44 days were spent at sea collecting data from 595 transects over a distance of 3,570 km. 507 video drops were conducted, 229 CTD casts, 48 fishing stations and 580 fish were caught. Initial review of the data demonstrated that severe hypoxia affected the northern extent of our survey range. Therefore, an additional pass of the highly important northern coast was conducted. These sample sizes are not reported here.

These data are in the process of being reviewed and will be presented to the Pacific Fisheries Management Council's Scientific and Statistical Committee during their December 2022 meeting. The information developed from this grant and described in Objective 1 and 2 above will be pivotal in getting these data incorporated into future stock assessments.

Outreach and Education

Objective 1 was published in ICES Journal of Marine Science and Objective 2 is in preparation for ICES Journal of Marine Science and we hope to submit by April, 2022. Presentations describing the results of the grant were made to the Oregon Department of Fish and Wildlife's Restoration and Enhancement Board, NOAA Oregon Cooperative Research Institute, Hatfield Visitor Center, Oregon Chapter of the American Fisheries Society, Pacific Fisheries Management Council Scientific and Statistical Committee, and the Alaska Fisheries Science Center. A presentation at a more formal scientific conference will occur when Western Groundfish starts again. A walk through of the vessel used for the statewide survey completed with additional funds was streamed on facebook live and posted to YouTube https://www.youtube.com/watch?v=nf6PXMJCwsU. And following the survey a presentation was made at the Oregon State of the Coast which was recorded and made available on their website https://seagrant.oregonstate.edu/state-coast/program.

Underwater video collected during the grant were featured on the ODFW Instagram Page https://www.instagram.com/odfwmarine/?hl=en and ODFW Conservation Facebook Page https://www.facebook.com/ODFWConservation/.

A spotlight highlighting the work is posted on the Oregon Nearshore Strategy's website.

Nearshore Strategy Website: https://oregonconservationstrategy.org/oregon-nearshore-strategy/
Strategy Spotlight Link: https://oregonconservationstrategy.org/strategy-species/black-rockfish/

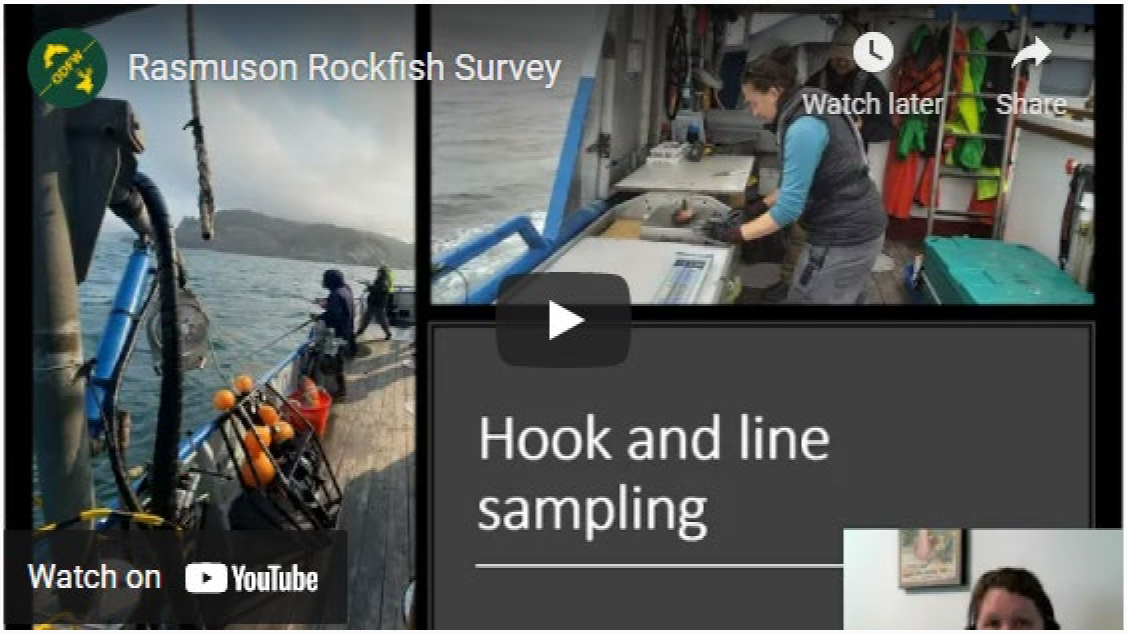
Copy of the strategy spotlight. Go to website to view videos.

Strategy spotlight: Nearshore survey of semi-pelagic rockfish

Oregon's nearshore semi-pelagic Black, Blue and Deacon Rockfish all lack statewide fisheries independent surveys. These fish all live in subtidal rocky habitat and are important to both the ecosystem and Oregon fisheries. Rocky reef habitat has proven to be a difficult place to sample, especially over larger areas in a short period of time. Semi-pelagic means that these schooling rockfish species are usually found up above the rocky reefs and they are often found in big schools with the species sometimes mixed together. After being selected for funding by the competitive federal Saltonstall-Kennedy grant program administered NOAA Fisheries, ODFW researchers demonstrated that combined data collected with a scientific fish finder and a suspended underwater camera was an effective survey tool to accomplish this goal. Even better, these combined technologies were able to do so without killing any of the fish or destroying their habitat. ODFW's marine fisheries research team also worked with ODFW's underwater Remotely Operated Vehicle team to determine that using these methods didn't miss fish right on or near the bottom. Thus, this great project suggested that the scientific fish finder and underwater camera combination was effective at counting Oregon's nearshore semi-pelagic rockfish. To learn more details see the report **available here**.

ODFW staff then set out to conduct the first ever statewide survey to estimate the populations of these three fish species in Oregon's nearshore waters. With funding from ODFW's Restoration and Enhancement fund, the survey began on August 1, 2021. The video below provides a walk through of how the boat was set up for this work just before they started the survey.

While conducting the survey ODFW staff encountered low oxygen (hypoxia) conditions from the Washington border to approximately Heceta Head. Therefore, in order to assess how low oxygen conditions influence fish abundance, staff redid the survey from Three Arch Rocks to Waldport. A summary of the survey work can be seen in the video below.



During this survey the team also captured some fish with hook and line to provide additional data on ages and weights that is needed for stock assessments. These data, together with the fish finder and video data will be available for stock assessment scientists to use after the results are finished and should help provide better estimates of the population sizes of these economically and ecologically important species.

Data Sharing

A description of the metadata from each of the objectives is posted on the Oregon Department of Fish and Wildlife's data clearinghouse. As processing of data from the statewide survey (see additional research conducted) is completed an additional reference will be made available.

Clearing house: https://nrimp.dfw.state.or.us/DataClearinghouse/default.aspx?p=1

This grant: https://nrimp.dfw.state.or.us/DataClearinghouse/default.aspx?p=202&XMLname=42073.xml

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