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Original Article

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

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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.

Keywords: fisheries independent survey, hydroacoustic survey, rockfish, target–strength model, underwater video.

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, 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*), Blue Rockfish (*Sebastes mystinus*) and Deacon Rockfish (*Sebastes diaconus*) 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*) and Yellowtail Rockfish (*Sebastes flavidus*), 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, when selecting a 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.

Methods

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 to 29, 2017 at Seal Rock Reef, just south of Newport, Oregon (Figure 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. A total of 38 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 1 h of the transect being

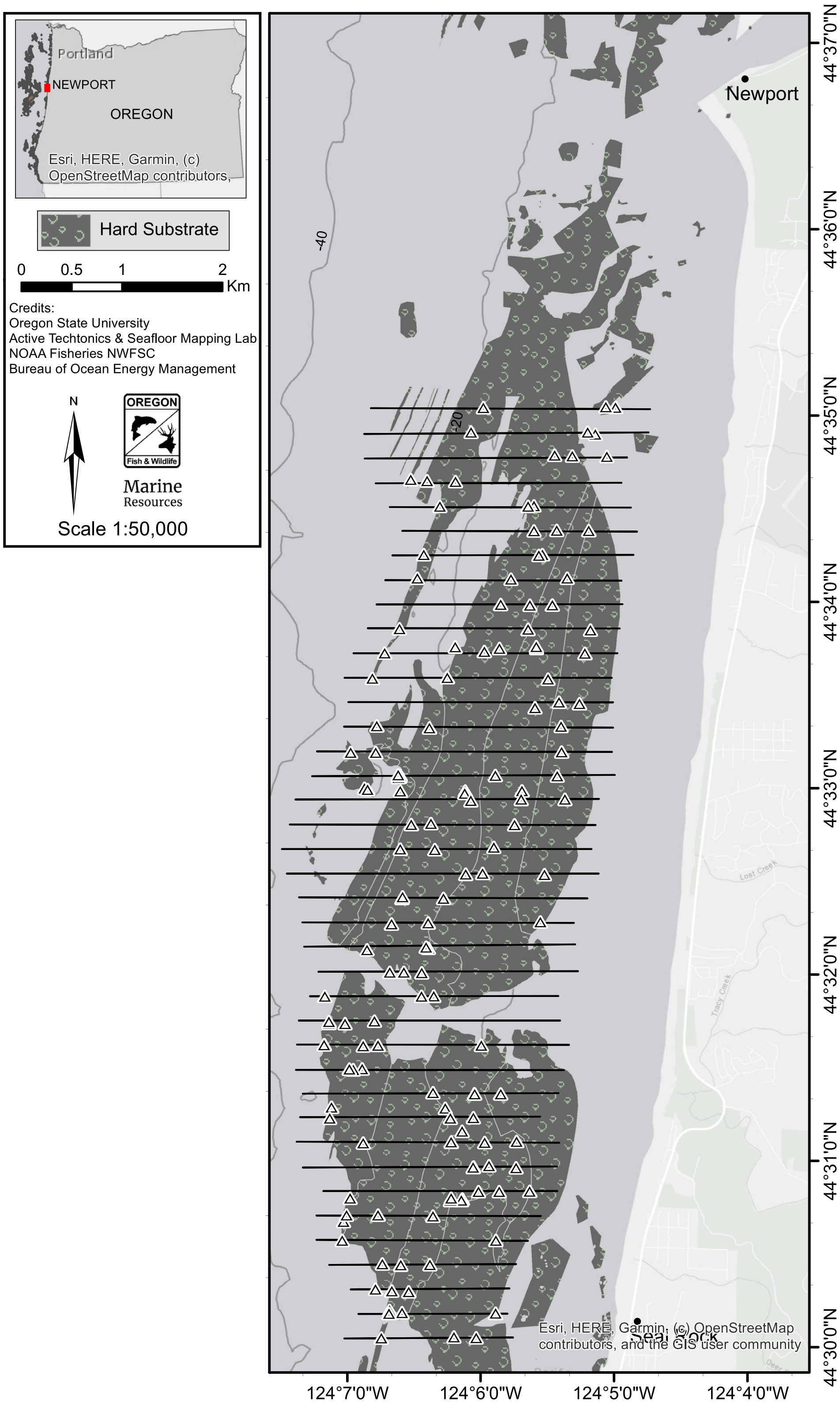

Figure 1. Map of survey transects (black lines) overlaid on the known hard substrate. Triangles denote deployment locations of the BASSCam. Transect lines extended 500 m offshore and shoreward of the known hard bottom substrate.

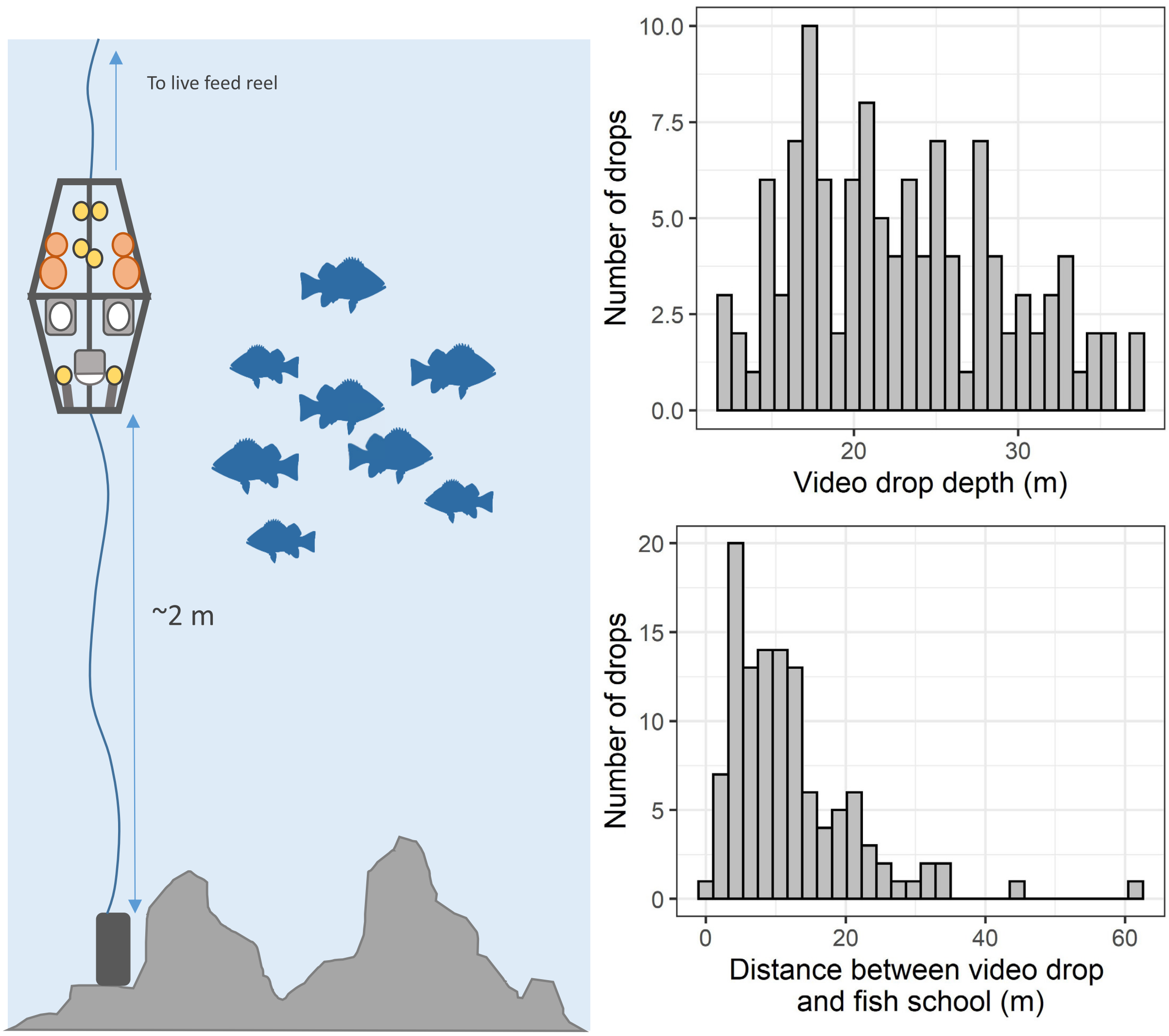

Figure 2. Schematic of BASSCam deployed in a school of fish (left) and number of BASSCam deployments by water depth (upper right) and the distance from the BASSCam deployment location to the fish school identified by the hydroacoustics (lower right). On the left, the white and grey boxes denote the location 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.

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°, 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 (Figure 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

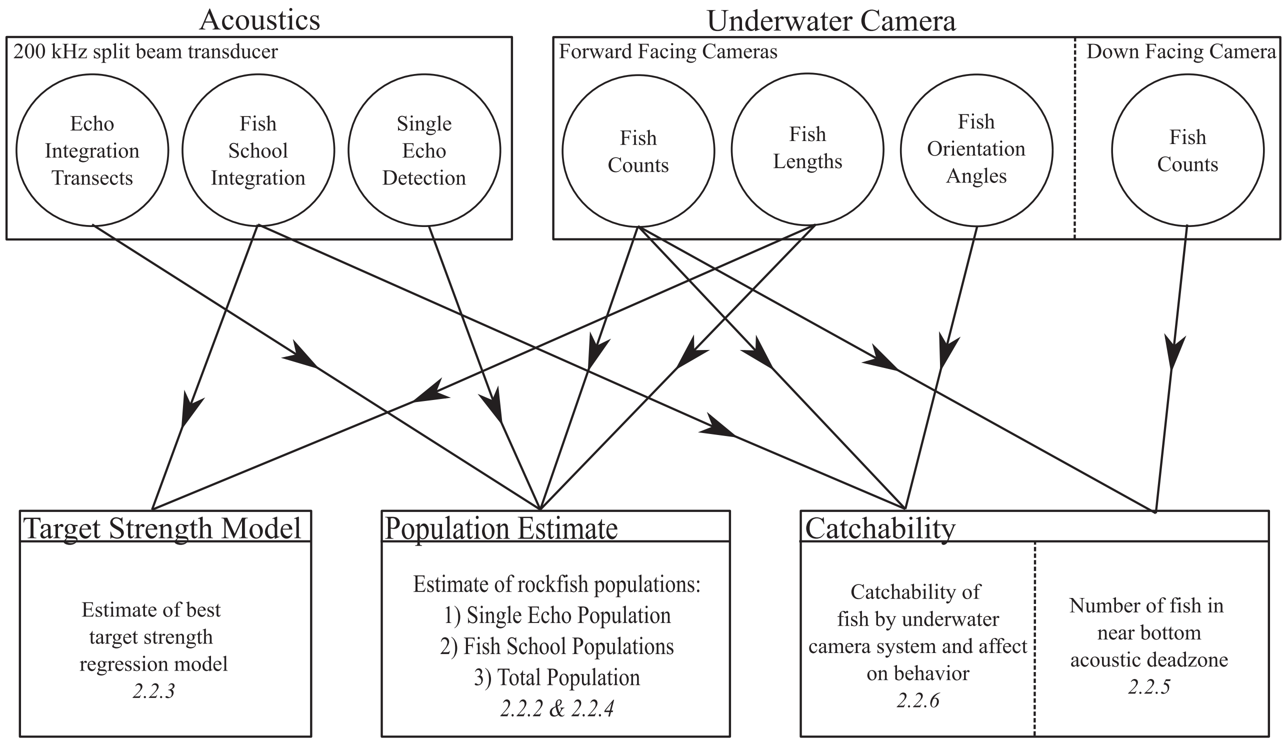

Figure 3. Flow chart depicting the relationship of acoustic and video inputs for each component of the analysis process.

(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 2 min from the time the camera's anchor reached the bottom. Bottom time was determined with a stopwatch. A total of 2 min of bottom time was shown to be enough time to provide accurate size and length data (Rasmuson, unpublished data).

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 (Figure 3).

Video analysis

Videos were reviewed using the EventMeasure software developed by SeaGIS. Only the first 2 min 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. 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 2-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*) 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 five frames

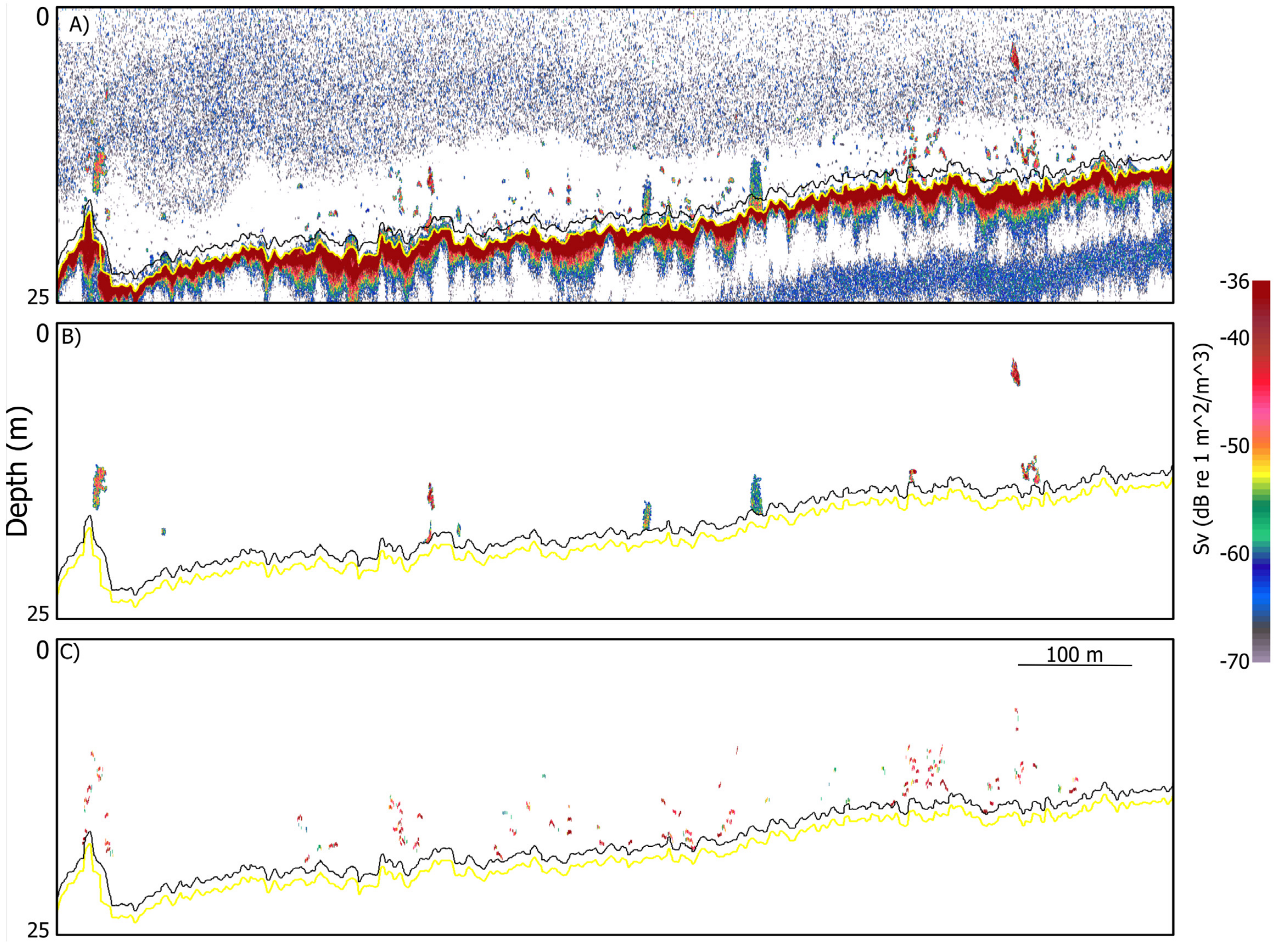

Figure 4. (a) Uncorrected echogram with the bottom detection line (yellow line), and the near bottom acoustic dead zone exclusion line (black line), (b) echogram displaying only the fish schools identified by the school detection algorithm; all other data have been masked, (c) single targets identified 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.

to generate an average density of rockfish for each video deployment conducted.

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 to 1 m off bottom, and the nearfield dead zone from 2.5 to 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 (Figure 4).

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 analysed using echo integration. Schools were identified on echograms, smoothed with a 3×3 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 ($\sigma_{\rm bs}$) were calculated using the standard target strength to length equation given as:

$$\mathrm{TS} = 20\log_{10}(\mathrm{L}) - \mathrm{b}_{20}, \tag{1}$$

where TS is the fish target strength, L is the fish length in cm, and b_{20} is a species-specific constant. See Section *Target Strength Model- Used for Echo Integration* below for how b_{20} was determined for this study. Length data were obtained from

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 4 d 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%

a survey-wide distribution of stereo measurements from the BASSCam. Mean back scattering cross-section was calculated as

$$\overline{\sigma_{bs}} = \sum_{i,g} \left(P_{i,g} * \sigma_{bs,i}\right) \ . \quad (2)$$

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 $\sigma_{\mathrm{bs,\,i}}$ is the back scattering cross-section at length i. The proportion of each species group by length was calculated as

$$P_{i,g} = \frac{NCamFish_{i,g}}{\sum NCamFish_i} \ , \quad (3)$$

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

$$EIden\ s_{i,g,t} = \left(\left(\frac{NASC_t}{4\pi\,\sigma_{bs}}\right) * P_{i,g}\right) * \left(\frac{1}{3.43 * 10^6}\right), \quad (4)$$

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.

Echo counting

For regions analysed 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:

$$ECden\ s_t = \frac{1}{l_t} \sum_{f=1}^{f_n} \left(\frac{1}{2\tan(\theta) * \ z_n}\right). \quad (5)$$

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.

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*; $b_{20} = -70.93$), and Dark-banded Rockfish (*Sebastes inermis*; $b_{20} = -72.8$; 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.

Population estimate

No attempts were made to use a modelling 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:

$$\overline{EIdens_g} = \frac{\sum_t \left(\sum_i EIdens_g\right)}{n_t}, \quad (6)$$

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

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:

$$\overline{ECdens_g} = \frac{\sum ECdens_t}{n_t}, \quad (8)$$

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

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.

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 m 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;

$$BottomCameraRatio = \frac{nfish_d}{nfish_d + nfish_f}, \quad (10)$$

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.

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 11-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.

Fish orientation and behaviour

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 3-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 3-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 behaviour of a fish school, we compared the acoustic backscattering values of three schools of fish. Deployments occurred at a depth of 30 m approximately, 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 dura-

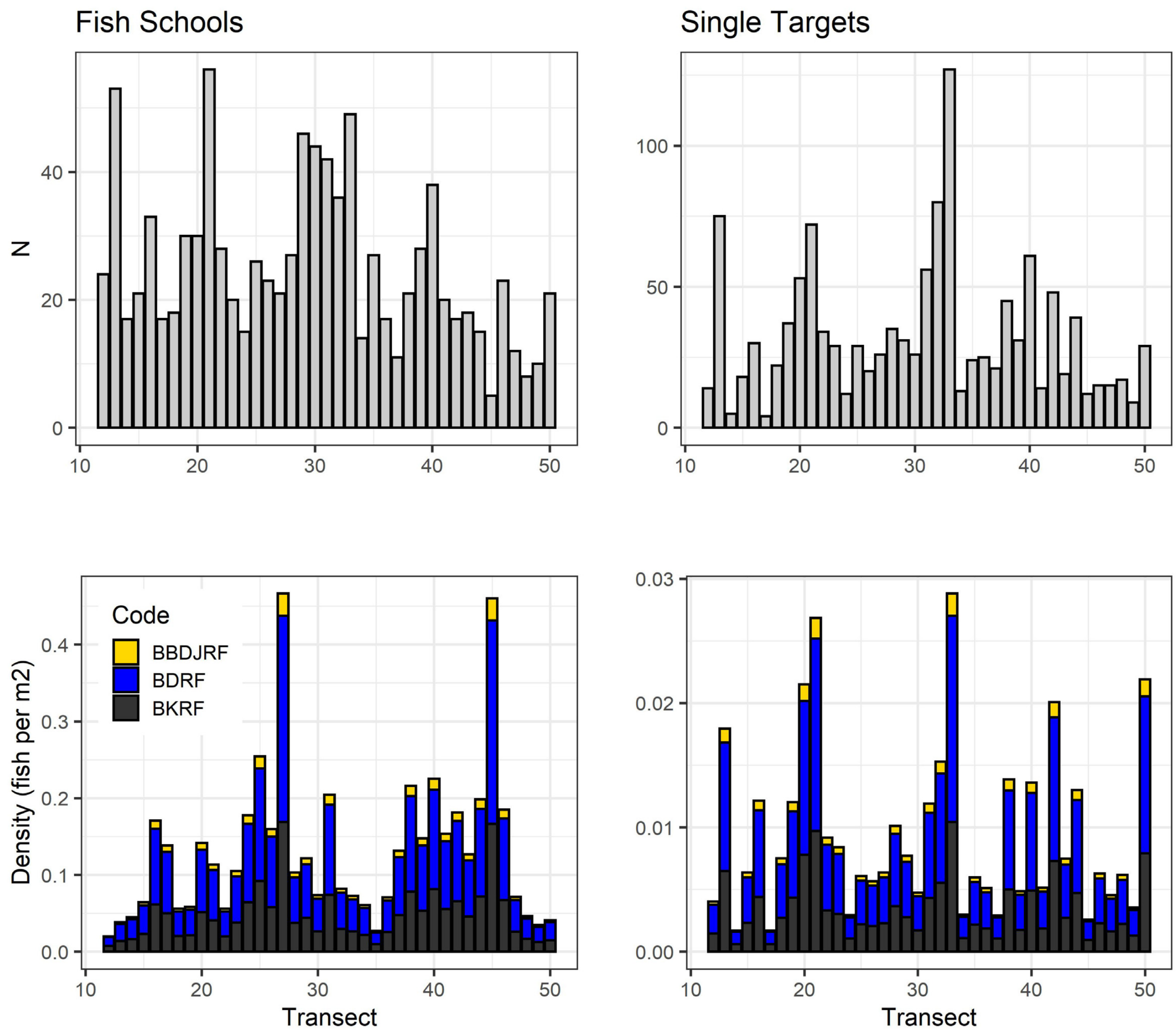

Figure 5. Number of schools (top left) and their conversion to density (number of fish per m^2) for the three focal species groups (bottom left). Number of single echoes (top right) and their conversion to density (number of fish per m^2) for the three focal species groups (lower right). BBDJRF are juvenile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

tion of the 2-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 2 min 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.

Results

A total of 38 acoustic transects were completed for a total sampled distance of ∼120 km, which encompassed 24.1 km^2 of reef (Figure 1). From the acoustics, the school identification algorithm identified 1018 schools of fish presumed to be Black, Blue, or Deacon Rockfish. The echo counting algorithms identified 2077 fish tracks presumed to be Black, Blue, and Deacon Rockfish (Figure 5).

A total of 120 video deployments were conducted at depths ranging from 12 to 38 m (Figure 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 3383 fish identified from video, 2514 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.

Of the 25 deployments where Blue/Deacons were observed, in only one instance were they solely present in the downward facing camera (Figure 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

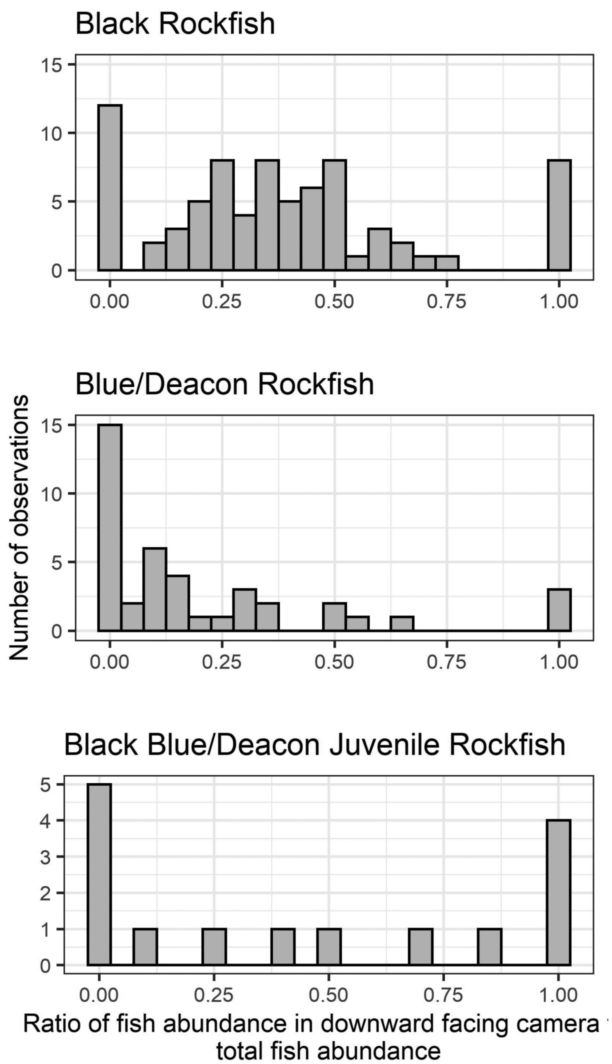

Figure 6. Histogram displaying the ratio of Black, Blue/Deacon, and juvenile Black/Blue/Deacon Rockfish abundance in the downward facing camera relative to the total abundance of fish (forward + downward). A value of 1 denotes fish observed only in the downward facing camera, a value of 0 denotes fish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

Black/Blue/Deacon Rockfish were observed, in only four instances were they solely present in the downward facing camera (Figure 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.

Black Rockfish were observed at a slightly closer distance to the BASSCam than Blue/Deacon Rockfish (Figure 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, Figure 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.

Blue/Deacon Rockfish heads were oriented below a horizontal plane located at the location of camera deployment at 13.5 ± 18.0°, on average. Black Rockfish were also oriented downwards at 9.6 ± 25.3° (Figure 8). Juvenile Black/Blue/Deacon Rockfish heads were oriented upwards at 5.2 ± 21.5°. 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 behavioural 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 ($F(2,6) = 0.052$, $p = 0.95$; Figure 9).

A total of 43 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 (Figure 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 (Figure 10; $F(4210) = 6.142$, $p < 0.001$). 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

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

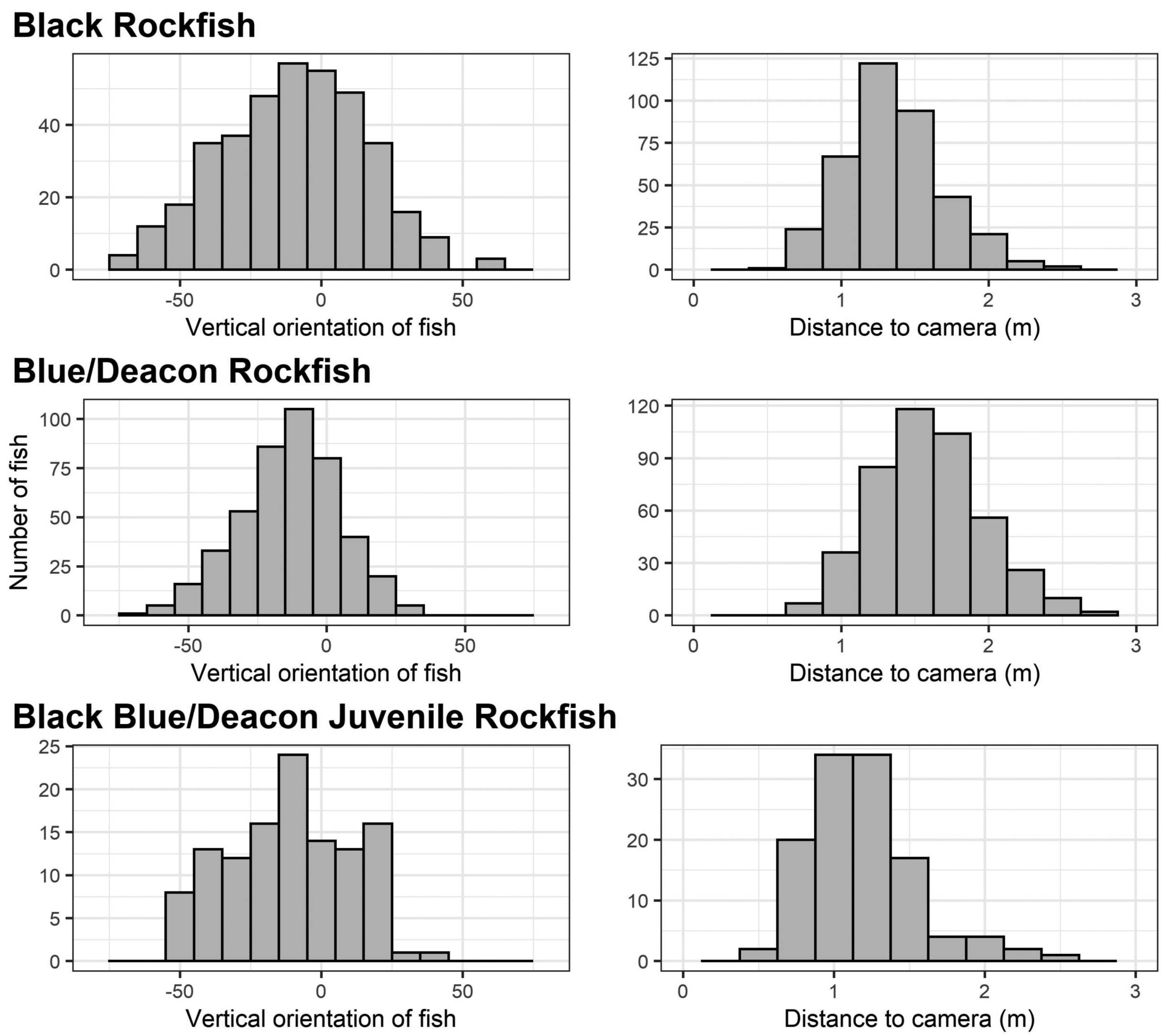

Figure 7. The measured distance of Black, Blue/Deacon, and juvenile Black/Blue/Deacon Rockfish to the BASSCam (Left) and vertical orientation of Black, Blue/Deacon, and juvenile Black/Blue/Deacon Rockfish relative to a hypothetical horizontal plane extending out from the stereo cameras (Right). Left—only 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.

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}.

On average, there were 25.4 $\pm$ 12.4 (mean $\pm$ standard deviation) schools of fish and 33.4 $\pm$ 24.7 single target echoes identified per acoustic transect (Figure 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 $\pm$ 0.03 fish per m^2 and for single echoes the average density was 0.003 $\pm$ 0.003 fish per m^2. For Blue/Deacon Rockfish, the average density of schooling individuals was 0.08 $\pm$ 0.06 fish per m^2, and 0.005 $\pm$ 0.004 fish per m^2 for single echoes. For juvenile Black/Blue/Deacon Rockfish, the average density of schooling individuals was 0.008 $\pm$ 0.006 fish per m^2, and 0.0005 $\pm$ 0.0004 fish per m^2 for single echoes. Extrapolated to the reef area, this results in a total population of 1,188,222$\pm$ 601,249 Black Rockfish; 1,888,731$\pm$ 955,712 Blue/Deacon Rockfish; and 204,866 $\pm$ 103,663 juvenile Black/Blue/Deacon Rockfish (Table 3). Our coefficient of variation for these estimates was 50.6%.

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 trailerable 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 methods of nearshore rockfish methods such as PIT tagging and hook and line sampling, which require a captain, deckhands,

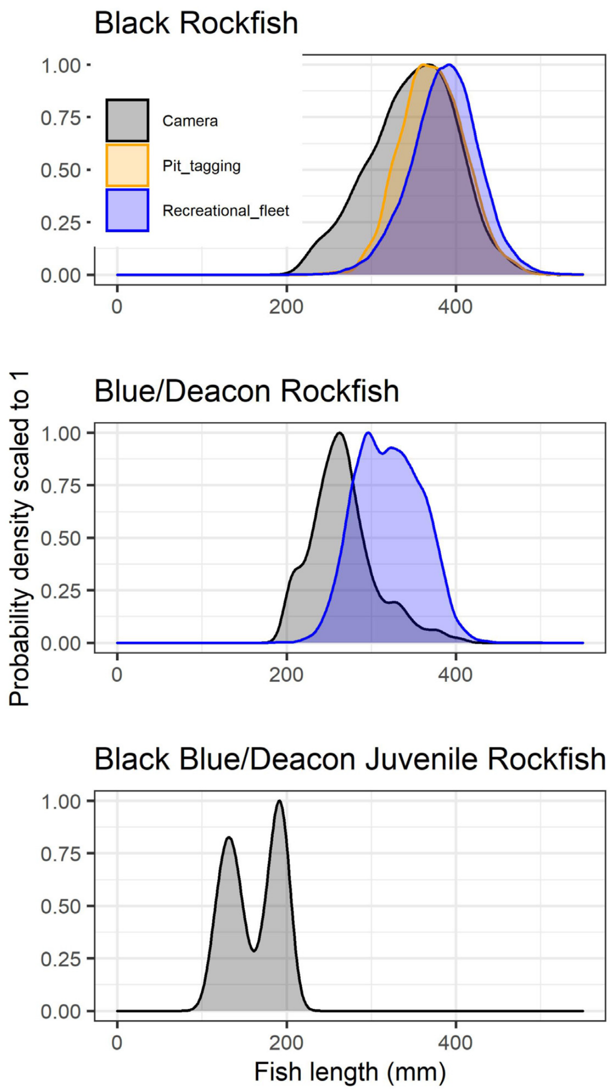

Figure 8. Scaled size distributions of Black, Blue/Deacon, and juvenile Black/Blue/Deacon Rockfish, observed by the BASSCam (gray area), caught by the recreational fleet (blue area), and caught as part of a fisheries independent PIT tagging project (gold area).

and multiple anglers; often resulting in a crew of ten or more 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 do not actually catch fish is deemed detectability. Detectability of fish by an acoustic transducer is more influenced by the general behaviour 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 2 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 behaviour 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

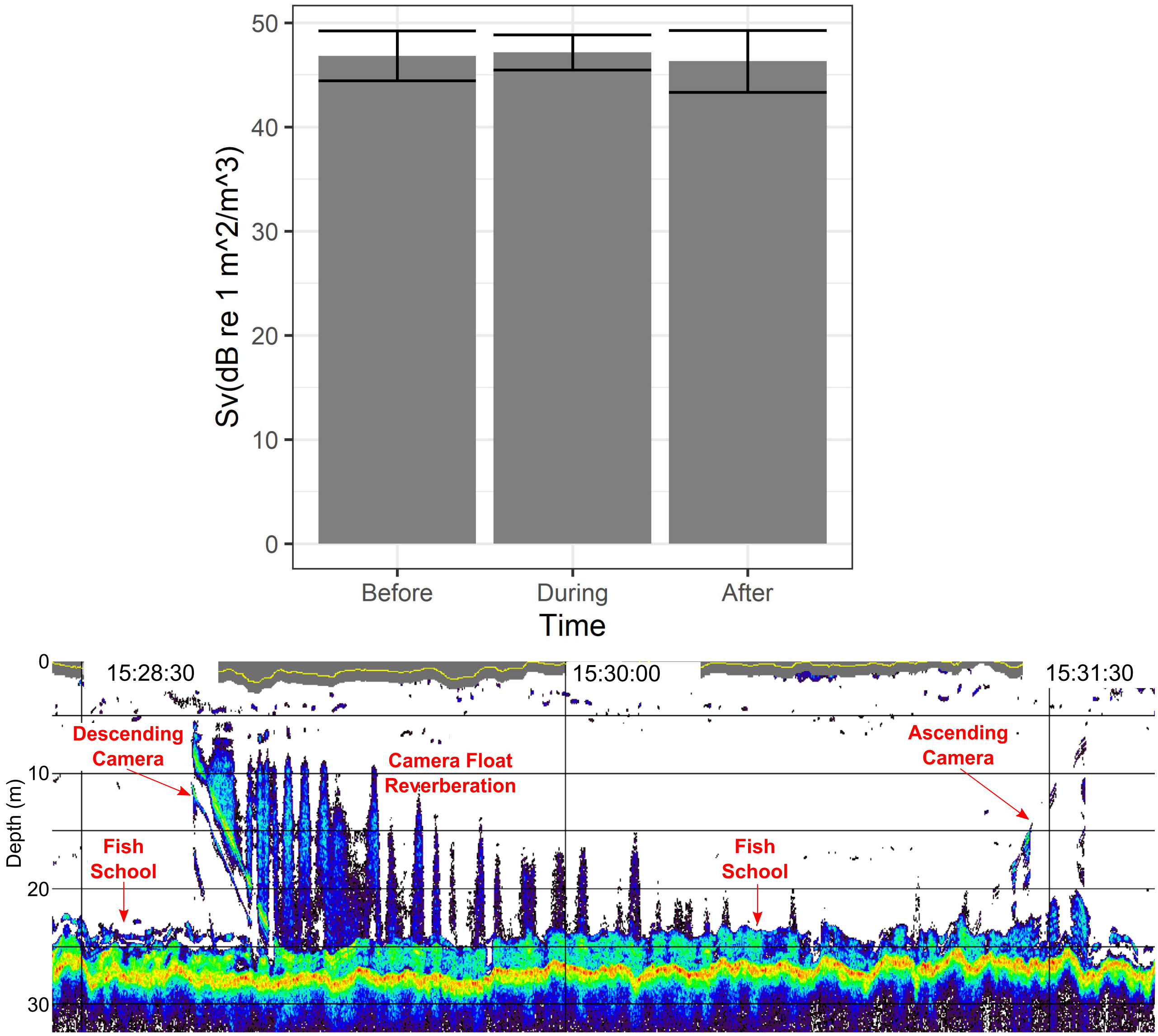

Figure 9. Changes in average backscattering values before, during, and after the deployment of the BASSCam into a school of fish (upper), and an example echogram of the camera deployment into a school of fish, during observations of the school, and retrieved from a school of fish (lower).

being studied by pairing a larger scale hydroacoustic/video survey with data from a remotely operated vehicle (ROV; Rasmuson, in press). 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. Modelling 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

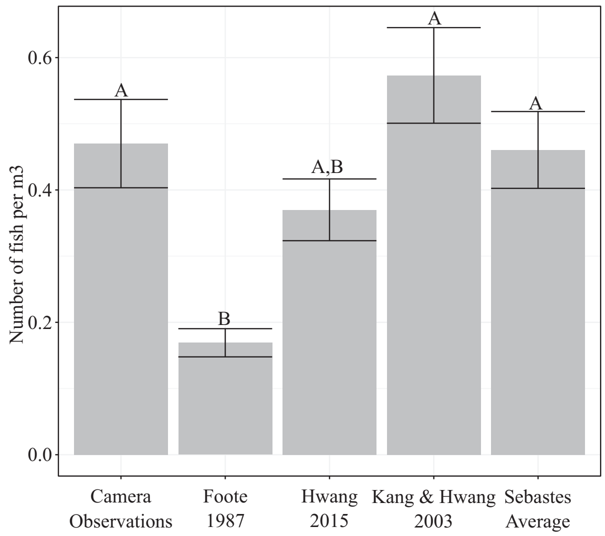

Figure 10. Volumetric densities (number of fish per m^3) generated from our camera system observations and fish schools identified in the acoustics. Acoustics were converted from backscattering values to densities using length data from the closest video deployment to that school. Only camera deployments 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.

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 behavioural 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 behavioural 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 11-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

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

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, and combined with species specific target strength models will allow generation of accurate population estimates for Oregon's economically and ecologically important nearshore rockfish.

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Supplementary data

Supplementary material is available at the *ICESJMS* online version of the manuscript.

Data availability

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

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