Estimating species and size composition of rockfishes to verify targets in acoustic surveys of untrawlable areas

Christopher N. Rooper (contact author)[1]
Michael H. Martin[1]
John L. Butler[2]
Darin T. Jones[1]
Mark Zimmermann[1]

Email address for contact author: Chris.Rooper@noaa.gov

[1] Alaska Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
7600 Sand Point Way NE
Seattle, Washington 98115

[2] Southwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
8604 La Jolla Shores Dr.
La Jolla, California 92037

Abstract—Rockfish (*Sebastes* spp.) biomass is difficult to assess with standard bottom trawl or acoustic surveys because of their propensity to aggregate near the seafloor in high-relief areas that are inaccessible to sampling by trawling. We compared the ability of a remotely operated vehicle (ROV), a modified bottom trawl, and a stereo drop camera system (SDC) to identify rockfish species and estimate their size composition. The ability to discriminate species was highest for the bottom trawl and lowest for the SDC. Mean lengths and size distributions varied among the gear types, although a larger number of length measurements could be collected with the bottom trawl and SDC than with the ROV. Dusky (*S. variabilis*), harlequin (*S. variegatus*), and northern rockfish (*S. polyspinis*), and Pacific ocean perch (*S. alutus*) were the species observed in greatest abundance. Only dusky and northern rockfish regularly occurred in trawlable areas, whereas these two species and many more occurred in untrawlable areas. The SDC was able to resolve the height of fish off the seafloor, and some of the rockfish species were observed only near the seafloor in the acoustic dead zone. This finding is important, in that fish found exclusively in the acoustic dead zone cannot be assessed acoustically. For these species, methods such as bottom trawls, long-lines, or optical surveys using line transect or area swept methods will be the only adequate means to estimate the abundance of these fishes. Our results suggest that the selection of appropriate methods for verifying targets will depend on the habitat types and species complexes to be examined.

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Rockfishes (*Sebastes* spp.) are a group of species with a predilection for high-relief, rocky habitats, where biomass estimation from traditional bottom-trawl survey data is difficult or impossible. However, many of these rockfishes also occur semipelagically, so that acoustic biomass assessments are possible (Wilkins, 1986; Demer et al., 2009; Ressler et al., 2009; Rooper et al., 2010). Acoustically estimating fish abundance requires accurate target verification of species composition and size distribution—verification that is typically achieved with midwater or bottom trawls. Because bottom trawling is hampered in high-relief areas, so too are acoustic abundance estimates from these habitats, owing to inadequate information describing species-specific abundance and size composition for fishes on or near the seafloor. Therefore, habitat-specific rockfish distribution patterns have the potential to affect the accuracy and precision of survey biomass estimates when traditional bottom trawl or combination acoustic-bottom trawl survey methods are used (Cordue, 2006).

Evidence suggests that untrawlable areas can support different species assemblages than those found in trawlable areas (Matthews and Richards, 1991; Jagielo et al., 2003; Zimmermann, 2003). Untrawlable areas can also have different size classes or abundances of the same species (Matthews, 1989; Stein et al., 1992; O'Connell and Carlile, 1993; Rooper et al., 2007). The primary species thought to inhabit untrawlable areas in high abundance in Alaska are northern rockfish (*Sebastes polyspinis*), dusky rockfish (*S. variabilis*), juvenile Pacific ocean perch (*S. alutus*), and black rockfish (*S. melanops*; Clausen and Heifetz, 2002; Rooper et al., 2007). Additionally, some rockfish species that occur in Alaska are rarely encountered in bottom trawl surveys (e.g., tiger rockfish [*S. nigrocinctus*]), possibly because of their preference for rough, rocky, and therefore untrawlable habitat. For these reasons, there is a clear need for alternative assessment methods to accurately and precisely estimate rockfish distribution and abundance over untrawlable areas, so that, in conjunction with similar estimates from trawlable areas, rockfish stock assessments can be improved.

Critical for an accurate acoustic assessment of rockfishes is determining the vertical distribution of species and sizes and their relation to the seafloor. Some size classes of the population may occur exclusively near the bottom (<1 m), where they cannot be acoustically differentiated from the seafloor (Ona and Mitson, 1996; Rooper et al., 2010). Therefore, the ability to estimate the distance of fishes off the seafloor is important in determining which species and size classes are acoustically observable.

We evaluated the ability of gear types to discriminate species and size compositions of fish for the purpose of determining the best methods for target verification for acoustic surveys for rockfishes in untrawlable habitats. We compared the body lengths and species diversity of rockfishes from a modified bottom trawl with two optical methods—a remotely operated vehicle (ROV) and a stereo drop camera (SDC). For the SDC, the vertical distributions among species were compared. The proportion of rockfish species inhabiting trawlable and untrawlable areas was compared. We also compared the time and cost to employ each survey method in order to make recommendations for efficient and cost-effective methods for target verification in acoustic surveys.

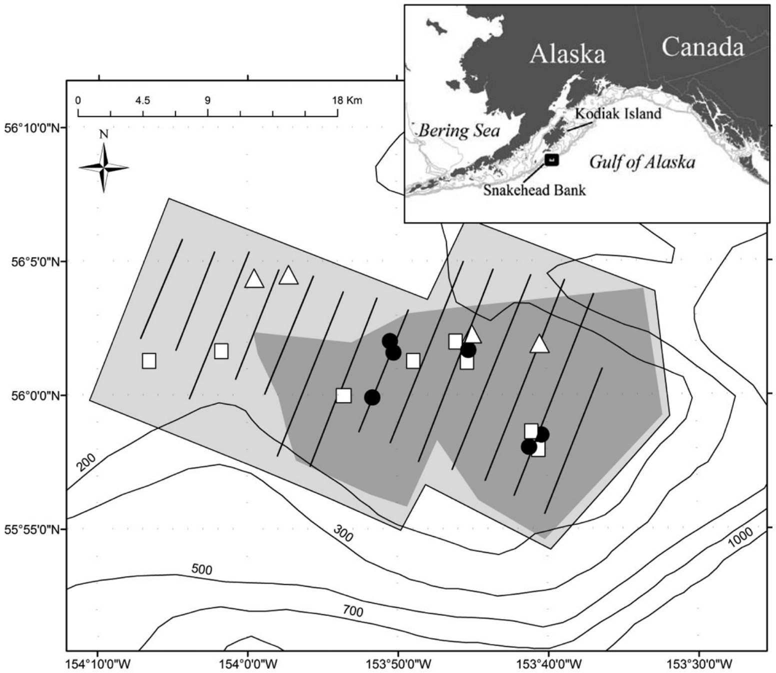

Figure 1

Map of study area showing the Snakehead Bank southwest of Kodiak Island, Alaska (indicated by black outline in inset). Deployment locations of remotely operated vehicle (triangles, $n=4$ deployments), stereo drop camera (squares, $n=8$ deployments), and bottom trawl (filled circles, $n=6$ deployments). Acoustic transect lines and depth contours (m) are also shown. Trawlable areas are shown in light gray and untrawlable areas are shown in dark gray.

Materials and methods

The research was conducted southwest of Kodiak Island, Alaska, at an offshore bank locally known as the "Snakehead Bank" from 3 to 12 October 2009 (Fig. 1). The continental shelf of the Gulf of Alaska near Kodiak has been shaped by past glacial and seismic activity and generally comprises sedimentary bedrock covered with glacially deposited sediments overlying most of the shelf (Hampton, 1983). Much of the shelf south of Kodiak Island is a series of flat underwater banks with deep troughs carved by glaciers that separate adjacent flat banks. The Snakehead Bank is a relatively small (~210 km^2), shallow bank on the outer continental shelf that protrudes from the shelf and abuts the continental slope. At its shallowest point, the bank rises to within ~65 m of the surface and deeper water (>150 m) is found on the continental shelf to the north. Much deeper water (200–2000 m) is located on the continental slope to the south and east. The depths of the Snakehead Bank are inhabited by a distinct assemblage of continental shelf rockfishes that typically extends to about 180 m depth (Rooper, 2008). The Snakehead Bank has long been a productive area for commercial rockfish fisheries (Clausen and Heifetz, 2002; Hanselman et al., 2007), and Gulf of Alaska bottom trawl survey tows conducted at the Snakehead Bank often have high catches of northern rockfish and dusky rockfish (e.g., von Szalay et al., 2010).

The research was conducted aboard two vessels, the NOAA ship *Oscar Dyson* and a chartered commercial fishing vessel, the FV *Epic Explorer*. The *Oscar Dyson* is a 64-m length overall stern trawler equipped for fisheries and oceanographic research. The *Epic Explorer* is a 39.6-m house-forward stern trawler active in commercial fisheries in Alaska. Both vessels were present in the study area simultaneously. Researchers aboard the *Oscar Dyson* collected acoustic data using Simrad EK60 scientific echosounders operating at five frequencies and a Simrad ME70 multibeam echosounder (Simrad, Horten, Norway[1]). The ROV was also deployed from the *Oscar Dyson*. The modified bottom trawl and stereo drop camera were deployed from the *Epic Explorer*. During the survey with the *Oscar Dyson,* acoustic data were collected on a grid of parallel transects (Fig. 1). Eight individual passes of the parallel tracks were carried out (4 were completed during nighttime hours and 4 during daytime hours). From these acoustic data, researchers aboard the *Oscar Dyson* identified areas of fish aggregation and directed the deployment of the ROV, bottom trawl, and SDC to verify the species and length compositions of acoustic targets at those locations. Then the acoustic survey data were used to estimate abundance of fish species identified by the target verification meth-

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[1] Mention of trade names or commercial companies is for identification purposes only and does not imply endorsement by the National Marine Fisheries Service, NOAA.

ods (Jones et al., 2012 [this issue] for details of the acoustic assessment).

Remotely operated vehicle

Target verification was conducted with a Phantom DS4 ROV (Deep Ocean Engineering, Inc., San Jose, CA) nicknamed "*Sebastes*" that is owned and operated by the NOAA Southwest Fisheries Science Center (further details on this ROV and its capabilities can be found at http://swfsc.noaa.gov/textblock.aspx?Division=FRD&id=8784, accessed February 2012). Video footage from the ROV was recorded with a forward-looking color camera (Sony FCB-IX47C module with 468×720 lines of horizontal resolution and 18× optical zoom, Sony Corp., Tokyo, Japan). High-resolution still images were also collected with a Scorpio digital camera (Nikon Coolpix 995 with 4× zoom, Nikon Corp., Tokyo, Japan) to aid in species identifications. Speed of the ROV was measured by a downward facing Explorer Doppler velocity logger (DVL, Teledyne RD Instruments, San Diego, CA) which was also used to calculate transect length. This DVL was calibrated over a known distance and was accurate to ±0.07% (J. Butler, unpubl. data). The average speed of the ROV during deployments was 1.32 km/h (standard error [SE]=0.65) and the average altitude was 2.31 m (SE=0.75), although a constant speed, altitude, and heading was generally not maintained during deployment.

We used Canadian grid projections (Wakefield and Genin, 1987) calculated with 3-Beam software (Green Sky Imaging, Vero Beach, FL) to estimate the field of view for the ROV. This system uses 3 lasers on the ROV, the altitude of the vehicle and the pitch of the camera to calculate the field of view (Pinkard et al., 2005). The 3 high-intensity lasers were mounted parallel to the horizontal axis of the video camera: 2 parallel red lasers on either side of the video camera spaced 20 cm apart and 1 green laser that crosses the left parallel laser at 0.99 m and the right parallel laser at 2.72 m from the camera lens. The position of the green laser to the red lasers was used to calculate the distance from the camera lens to the seabed (i.e., slant range), and the parallel lasers provided a reference distance used to determine the field of view and fish length. For 3 of 4 transects with relatively flat seafloor, the field of view was calculated every 2 seconds. The average field of view, 2.61 m (SE=0.20), was used as an estimate of the search area for the remaining transect.

The ROV was deployed from the starboard side of the *Oscar Dyson* when weather permitted (Beaufort sea state <6) and was equipped with an acoustic transponder that provided its location relative to the ship. The position of the ROV on the sea floor was corrected in real-time by using WinFrog survey software (Fugro Pelagos, Inc., San Diego, CA). All other navigational data (e.g., water depth, temperature, heading, course over ground, etc.) were collected at 1–2 s intervals, synchronized, and logged by using WinFrog. The ROV tether was attached with a swivel to a clump weight, which was connected by a cable to a winch onboard the vessel. The ROV and clump weight were lowered in unison to ~10 m above the seafloor at which point the cable to the clump weight was secured, monitored, and adjusted to maintain a clump-weight-elevation of >10 m (to avoid hitting the seafloor), while the ROV more closely approached the seafloor for identification of rockfishes and substrate type.

General locations for investigation were provided to the bridge from scientists operating the fisheries acoustics equipment and the ship's position was adjusted to drift or slowly navigate over a site where fish targets had been identified. However, the ROV did not transit specific transects and instead the seafloor was searched in one general direction, sometimes diverting from a straight-line to allow identification of rockfish targets or explore boulder patches more closely: this approach resulted in variable headings, speeds, and areas searched within a single deployment. For this reason, densities of rockfish were not computed from these transects. However, we did calculate the area swept by the ROV (distance traveled multiplied by the field of view) for comparison with the other gear types.

Bottom trawl

The bottom trawl used was a modified version of the Poly Nor'Eastern bottom trawl currently used by the Alaska Fisheries Science Center (AFSC) for bottom trawl surveys of the Gulf of Alaska and the Aleutian Islands (Britt and Martin, 2001; Stauffer, 2004). The net modifications included replacement of the standard footrope with rockhopper gear, the addition of heavier bridles (1.9 cm), and double meshes in the belly of the net. The center section of the rockhopper gear consisted of 61 cm rockhopper discs spaced approximately 46 cm apart. The rockhopper discs were spaced at about 61 cm on the wings and gradually tapered from 61 to 46 cm diameter on the wing extensions. All rockhopper discs were separated by solid sections of 2- cm (10-in.) discs. The bottom trawl was fished with 5-m^2 Fishbuster trawl doors each weighing 1089 kg (NET Systems Inc., Bainbridge Island, WA). The bottom trawl modifications were designed to improve the ruggedness of the net and allow the net to sample seafloor considered untrawlable with the standard survey net. The net width and height of the bottom trawl were ~17 m and 7 m respectively. The bottom trawl was towed at an average speed of 5.87 km/h (3.17 knots) ranging from 5.24 to 6.32 km/h and was generally deployed against the prevailing current. The area swept by the bottom trawl was estimated as the distance fished multiplied by the net width.

Stereo drop camera

The stereo drop camera system and deployment winch are described in Williams et al., (2010). The system consisted of two parallel-mounted cameras that collected simultaneous underwater video at a resolution of 720×480 pixels. Each of the cameras was calibrated to correct for intrinsic optical parameters. Lengths of individual targets in the two cameras were calculated by identifying the position of individual points (such as a fish's head and tail) in each of the paired images and calculating their relative position using triangulation. The lens of each camera was keyed to its port so that the camera fit in only one position in the housing. This ensured consistent relative positioning of the cameras among deployments. Illumination was provided by two 50-watt, high-intensity discharge lights mounted above the camera housings inside an aluminum frame. The lighting system was powered by 4 rechargeable 4 Ah 12 V nickel-metal hydride batteries.

For calibration, the SDC was suspended in the water while the research vessel was dockside. The cameras were calibrated underwater by using images of a target plate with a printed 10×10 square checkerboard pattern of 50×50-mm squares (Williams et al., 2010). The approximate depth of the camera was 1 m and the approximate distance from the target was 1–2 m. The checkerboard target was lowered into the water along the vessel until it was plainly visible in both cameras. The target was then slowly moved horizontally and vertically through the field of view of both cameras and up to 15 minutes of calibration video were collected. Progressive scan video images were collected at 29.97 frames/s in each camera, and the videos from each camera were aligned by using a light-emitting diode (LED) synchronization light flashed in front of both cameras at the beginning of deployment. This LED synchronization was repeated at the end of the deployment to confirm that the video frames from the paired cameras were still aligned.

For the calibration procedure, still frame images were extracted from the aligned videos at 1-s intervals with Adobe Premiere software (Adobe Systems, Inc., San Jose, CA). Twenty paired images in which the target checkerboard was visible in both cameras were randomly selected for the calibration of the camera system. The calibration parameters were estimated with the camera calibration toolbox in Matlab (Mathworks, Inc., Natick, MA; Bouguet, 2008). For each image pair, the position of the corner points of the checkerboard pattern were identified by clicking on the images. The location of these points in the still images was computed by the calibration software to determine the focal parameters of each camera. Intrinsic camera parameters were used to correct the individual images for optical distortion resulting from the camera lenses.

The SDC was deployed and retrieved by an electric winch with 4-conductor electromechanical armored cable. The camera system was suspended 1–2 m off the seafloor at an angle of approximately 30° from horizontal to the seafloor. This position allowed a viewing path width of 2.43 m (SE=0.14) and under normal lighting conditions the field of view extended ~3 m in front of the SDC, although this varied with the distance of the SDC off the seafloor and the volume of light scattering particles in the water. The SDC traveled over the seafloor at a target speed of 1.9–3.7 km/h (1–2 knots) for transects lasting up to about 1 hour. The overall mean speed of the SDC during field deployments was 2.26 km/h (SE=0.15). Some steerage of the camera was possible by towing the system gently with the vessel, and during slack water or low current periods the unit was sometimes towed to maintain a constant low speed. However, the direction of drifting and towing was with the prevailing current, and therefore directed transects were generally not possible. The area swept by the SDC was calculated as the path width multiplied by the distance traveled during a transect.

Classification of trawlable and untrawlable substrates

The substrata observed in the underwater video transects were classified by using the seafloor substrate classification scheme of Stein et al. (1992) and Yoklavich et al. (2000). It consists of a two-letter coding of substrate type denoting a primary substrate (>50% coverage of the seafloor bottom) and a possible secondary substrate (20–49% coverage of the seafloor bottom). In this classification scheme, there are seven substrate types: mud (M), sand (S), pebble (P, diameter <6.5 cm), cobble (C, 6.5< diameter<25.5 cm), boulder (B, diameter >25.5 cm), exposed low-relief bedrock (R), and exposed high-relief bedrock and rock ridges (K). For example, a section of seafloor covered primarily in sand, but with boulders over more than 20% of the surface, would receive the substrate code sand-boulder (Sb), where the secondary substrate is indicated by the lower-case letter. Because the SDC and ROV provided a continuous display of substrata, the substrate code was only changed if a substrate encompassed more than 10 consecutive seconds of video.

For the purposes of this study, we further classified substrata as either untrawlable or trawlable with reference to the standard Poly-Nor'Eastern 4-seam bottom trawl used by the AFSC in biennial bottom trawl surveys of the Gulf of Alaska and Aleutian Islands (Stauffer, 2004). To define trawlability we used video captured from the ROV and SDC. The untrawlable areas were defined as any substrate containing boulders extending higher than ~20 cm off bottom or with exposed jagged bedrock that was rugose enough that the standard bottom trawl footrope would not pass easily over it. The heights of individual boulders and rocks were estimated by using the relative positions of the lasers from the ROV and measured with the SDC. The trawlable grounds, in contrast, were mostly composed of small cobble, pebble, sand, and mud without interspersed boulders or rocks. A single experienced observer conducted the substrate classification for both the ROV and SDC video transects.

Identification and measurements of fish

All rockfish caught with the bottom trawl were identified to species. Fish were identified and counted by species where possible for the optical methods (ROV and SDC). Fish were counted up to a maximum of 4 m in front of the ROV and consistently out to 3 m in front of the SDC. *In situ* identification of fish with the optical methods was more difficult than with the bottom trawl and resulted in some fish that could not be positively identified to species. Many of these were smaller rockfish (<150 mm) that could not be positively identified to species with the ROV and SDC. Double counting of individual fish was assumed not to be an issue for the SDC because the camera drifted with the current in a relatively uniform direction and generally passed by fish as they were observed. For this vehicle, only fish that appeared in front of the camera were counted. In some cases during ROV deployments the vehicle was stopped so that an individual fish could be identified, and this brief pause could have resulted in double counting as fish milled around the stationary vehicle. An attempt was made to minimize double counting of individual fish in these cases by not counting fish that moved into the frame while the ROV was stationary; however, some double counting of fish probably occurred during these occasional stationary moments during ROV deployments. A single experienced observer identified the fish to species for both the SDC and ROV, and the habitat where each fish was observed was classified as either trawlable or untrawlable.

The Canadian grid projection (Wakefield and Genin, 1987) calculated with the 3-Beam software system was used to estimate fish length with the ROV. This limited the ability of the ROV to measure fish that were not in the same plane as the seafloor (i.e., above the seafloor). Additionally, the height of individual rockfish off the seafloor could not be measured.

For the bottom trawl, each catch was sorted to species and weighed. A random subsample of up to approximately 150 fish from each rockfish species identified in the catch was dissected to determine sex, and individual fork lengths were measured to the nearest centimeter. Because the bottom trawl integrates the catch spatially in both the vertical and horizontal planes, the height above the seafloor could also not be estimated for fish captured with the bottom trawl.

For the SDC, fish lengths were measured by using stereo triangulation functions supplied with the camera calibration software package (Bouguet, 2008) and the protocols identified in Williams et al. (2010). Images were extracted from the two video feeds at 1-s intervals, as with the calibration video. The videos from each camera were synchronized at the beginning and end by using the LED synchronization light. Length measurements were obtained by identifying the pixel coordinates of corresponding pixel locations (i.e., fish snout and fork of tail) in the left and right still frames of the camera. These points were used to solve for the 3-dimensional coordinates of the points in the images by triangulation, and by using the calibration-derived parameters. Once the 3-dimensional coordinates of the fish snout and tail were obtained, the length was measured as the simple Euclidian distance between the points in real space. This measurement method underestimated length for fish whose bodies were curved. However, fish in the video and still camera rarely exhibited body curvature and the few individuals that did were excluded. All individual fish that could possibly be measured or a random sample of 200 fish per species (where more than 200 were possible) were measured for each deployment of the SDC.

For each fish that was measured with the SDC, the distance of the fish off bottom when it was first observed was also measured. These distances were then summarized into 0.5-m bins for each species. Because the SDC was deployed ~1 to 2 m off the seafloor, the vertical field of view was approximately 2 m off the seafloor and rarely extended above 3 m off the seafloor. This obviously limited the observed fish height off bottom.

Data analysis

Species diversity among the ROV, bottom trawl, and SDC samples was determined by examining the number of species observed with the 3 verification methods. The total number of species observed was compared among gear types by using analysis of variance (ANOVA) with video transects and bottom trawl hauls as replicates. The proportion of fish that were unidentified on each transect was also tested by using ANOVA to compare the ability of each of the gear types to allow identification of observed rockfishes to species. The proportion of unidentified fish by transect was the dependent variable for comparisons among the categorical variable of gear type. The proportion data were arcsin square-root–transformed before the tests to best approximate normality. Statistical significance for all tests was determined at $\alpha<0.05$.

The fish-length distributions for major species were compared among gear types by using pairwise Kolmogorov-Smirnov tests to determine whether the length distributions from different gear types could have been drawn from the same sample. Fish-length composition was compared by using ANOVA to test for significant differences in mean length within major species for the 3 gear types. Owing to small overall sample sizes, individual fish lengths were used as replicates in this analysis and were combined across transects. The mean length of two rockfish species (northern rockfish and dusky rockfish) that occurred in both trawlable and untrawlable habitat were also compared to determine if fish were smaller in one habitat than in the other.

The percentage of rockfish that could be measured out of the total number of rockfish observed per transect for the major species was also calculated for each gear type. We used a *t*-test to determine whether the proportion of rockfish that could be measured was significantly different between the ROV and the SDC. For this analysis, the overall proportions of rockfish measured on each transect were used as the replicates. The proportion data were arcsin square-root–transformed before the *t*-test to improve normality. We did not consider this comparison for the rockfish captured in bottom trawl hauls because all the fish captured in the trawl could potentially be measured.

The acoustic dead zone is the area near the seafloor where fish targets cannot be resolved from the seafloor echo. At the Snakehead Bank, it was found to be depth dependent but generally extended to 0.7 m above the seafloor (Jones et al., 2012 [this issue]). Therefore, we calculated the proportion of each rockfish species that was observed in the acoustic dead zone (<1 m off the seafloor) and compared this proportion to a random vertical distribution of fish using a chi-squared statistic. This analysis was conducted only for fish whose height off the seafloor was measured with the SDC and was used to test the hypothesis that rockfish were randomly sorting themselves into heights off the seafloor, regardless of species.

The distribution of rockfish species between trawlable and untrawlable areas was also compared to a random distribution over the two habitats by using a chi-squared test. Additionally, the proportion of each of the major rockfish species and a combined "other" species group that occurred in untrawlable habitat was calculated along transects and compared to determine whether individual species were found in significantly different proportions in either trawlable or untrawlable habitats. For these analyses the replicates were transects where the species (or species group) occurred and where both trawlable and untrawlable areas occurred along that transect. Thus, the distribution of a rockfish species was tested as to whether it was found predominantly within trawlable or untrawlable habitat along a transect. The proportion data were arcsin square-root–transformed before the *t*-test to improve normality.

To produce a target verification map of backscatter from fish targets for acoustic analysis, we then assumed that the height of rockfish off the seafloor would have been the same for the fish observed in the ROV and captured in the bottom trawl (where this aspect of rockfish distribution was not measured) as was observed with the SDC. The proportions of each rockfish species <1 m off bottom and >1 m off bottom from the SDC were thus applied to the fish observed by the ROV and captured by the bottom trawl. The resulting proportions were shown graphically across the area of the acoustic survey where target verification transects and bottom trawl tows were conducted in order to show the spatial distribution of fish species, as well as their vertical distribution as either within or above the acoustic dead zone.

Finally, the amount of time needed to deploy and retrieve each gear type and process the data to completion was estimated. The amount of time for each task was summed by each gear type for comparisons. The approximate cost for building, deploying, and maintaining each of the gear types was also compared.

Results

Classification of substrate

The most common seafloor substrates observed in the ROV and SDC video data from the Snakehead Bank were combinations of cobble, pebble, and sand. These 3 substrates comprised the primary substrate in 70.7% of the total seafloor area observed in the ROV videos and 89.8% of the seafloor observed in the SDC videos. However, 23.6% of these otherwise trawlable substrates observed in the ROV videos and 71.7% of these substrates in SDC videos were judged to be untrawlable because of the presence of large boulders or rocks. In total, 46.0% of the substrate observed by the ROV was designated as untrawlable, whereas 74.6% of the substrate observed by the SDC was designated as untrawlable. The untrawlable observations came predominantly from the eastern half of the study area. Acoustic data confirmed that the eastern half of the study area was mostly untrawlable and the western half of the bank was predominantly trawlable (Fig. 1; Weber et al.[2]). However, some patches of trawlable ground occurred at transects in the area designated as predominantly untrawlable and vice versa.

Identification of fish

The ROV was deployed at four locations, the bottom trawl was deployed at six locations, and the SDC was deployed at eight locations where acoustic backscatter attributed to fish was observed near the seafloor and in the water column (Fig. 1). During two of the SDC deployments only a single camera collected images and during one deployment at a trawlable location, no rockfish were observed. At 5 of the SDC sites, the bottom trawl was deployed at the same location immediately after SDC deployment. One of the ROV deployments was at the same location as that of a SDC deployment and two of the ROV deployments were at the same location as that of a bottom trawl (Fig. 1). However, all of the target verification deployments used in this analysis occurred between depths of 65 and 150 m on the top of the Snakehead Bank, and all were conducted within a 210-km^2 area.

Twelve different species of rockfishes were identified at the Snakehead Bank study area. Nine species were identified by using the ROV, 9 with the bottom trawl, and 7 with the SDC. Six species were observed in common by all 3 gear types. The most common rockfish captured in the bottom trawl and recorded by the ROV and SDC was dusky rockfish (Table 1). These were followed by harlequin rockfish (*S. variegatus*), northern rockfish, and Pacific ocean perch. Analysis of variance revealed there were no significant differences in the number of species observed among the three gear types (P=0.31, F=1.27, n=16 deployments). The total numbers of fish observed were almost equal for the ROV and SDC (1251 and 1176, respectively). The number of fish captured by the bottom trawl (6993) was much higher. The total amount of seafloor observed by the optical methods was

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[2] Weber, T., C. N. Rooper, J. L. Butler, D. T. Jones, and C. D. Wilson. 2012. Seabed classification for trawlability using the Simrad ME70 multibeam echosounder on Snakehead Bank in the Gulf of Alaska. In review.

Table 1

Number of deployments, rockfish species observed or caught, percentage of rockfish not identified to species, total area swept, and percentage of area that was untrawlable for each gear type: remotely operated vehicle (ROV), modified bottom trawl (trawl), and stereo drop camera (SDC). Trawlability was defined in reference to the standard Poly-Nor'Eastern 4-seam bottom trawl used by the Alaska Fisheries Science Center in biennial bottom trawl surveys of the Gulf of Alaska and Aleutian Islands (Stauffer, 2004), not the modified bottom trawl used during our study.

		ROV	Trawl	SDC
Deployments		4	6	8
Rockfish observed				
Pacific ocean perch	*Sebastes alutus*	107	9	10
Dusky rockfish	*S. variabilis*	700	4733	500
Northern rockfish	*S. polyspinis*	31	254	148
Dark rockfish	*S. ciliatus*	7	40	8
Harlequin rockfish	*S. variegatus*	166	1942	151
Redbanded rockfish	*S. babcocki*	5		
Tiger rockfish	*S. nigrocinctus*	3		
Redstripe rockfish	*S. proriger*	80	2	
Pygmy rockfish	*S. wilsoni*		1	
Silvergrey rockfish	*S. brevispinis*		4	
Rosethorn rockfish	*S. helvomaculatus*			3
Yelloweye rockfish	*S. ruberrimus*	36	8	5
Unidentified rockfish	*Sebastes* spp.	116		351
Total rockfish species		9	9	7
Total rockfish observed		1251	6993	1176
Percentage unidentified		9.3%	0.0%	29.8%
Total area swept (ha)		2.70	4.66	2.62
Percentage untrawlable		46.0%	100.0%	74.6%

similar (~2.7 and 2.6 ha) and the amount of seafloor swept by the bottom trawl was much greater (4.7 ha).

There were significant differences in the percentages of fish identified to species with the 3 gear types by using ANOVA (P=0.002, F=10.45, n=16). The percentage of fish not identified to species was low for the ROV (9.3%), where control of the camera allowed individual fish to be followed and examined for species identification (Table 1). Fish identification was complete with the bottom trawl because all individuals could be closely examined and unambiguously identified. The high percentage of unidentified rockfish (29.8%) with the SDC reflects our inability to finely control the position and attitude of the drop camera system to closely examine fish for identification.

Measurement of fish length

Length distributions of dusky rockfish and harlequin rockfish were not significantly different (P=0.71 and P=0.34) between the ROV and SDC (Fig. 2). The length distributions were significantly different between the bottom trawl and the two optical methods (ROV and SDC) for dusky rockfish (P=0.018 and P=0.013) and for harlequin rockfish (P=0.003 and P=0.002). Length distributions for Pacific ocean perch were significantly different (P=0.03) between the ROV and bottom trawl (there were not enough samples from the SDC to conduct statistical tests). Length distributions of northern rockfish from each of the gear types were significantly different (P<0.01).

Analysis of variance revealed that mean lengths of the major rockfish species collected in this study varied significantly among gear types (Fig. 3). Tukey's *post hoc* tests for 3 species of rockfishes (dusky rockfish, harlequin rockfish, and Pacific ocean perch) indicated there were no significant differences in mean length measured with the 2 optical gear types (P>0.05). Tukey's *post hoc* tests indicated that the mean length of northern rockfish from the ROV was significantly shorter than those estimated by the SDC, and northern rockfish measured by both the optical methods were significantly shorter than those measured from the bottom trawl. Mean lengths of harlequin rockfish from the ROV and SDC were significantly shorter than those from the trawl. Dusky rockfish and Pacific ocean perch mean lengths were the same for all 3 methods. In general, more shorter fish were observed with the optical methods than with the bottom trawl. Interestingly, the mean length of northern rockfish from untrawlable areas was shorter than that from trawlable areas (Fig. 4), although no differences in length by habitat (trawlable or untrawlable) were observed for dusky rockfish. Because of the confounding of gear types for northern rockfish (all the small northern rockfish were measured by using the ROV in untrawlable areas and only one northern rockfish was measured in an untrawlable area with the SDC), these differences could not be tested for statistical significance.

The percentages rockfish observed on a transect that could be measured varied between the ROV and SDC, although this difference was not statistically significant when a *t*-test was applied (P=0.056, t=–2.3, df=7). For the ROV an average of 9.9% (SE=0.054) of the dusky rockfish, northern rockfish, harlequin rockfish, and Pacific ocean perch observed on a transect could be measured. On average 41.9% (SE=0.184) of these species captured in a trawl haul were measured, higher than the percentage with the optic methods (Fig. 5). With the SDC, 35.6% (SE=0.100) of the rockfish species observed on a transect could be measured (Fig. 5).

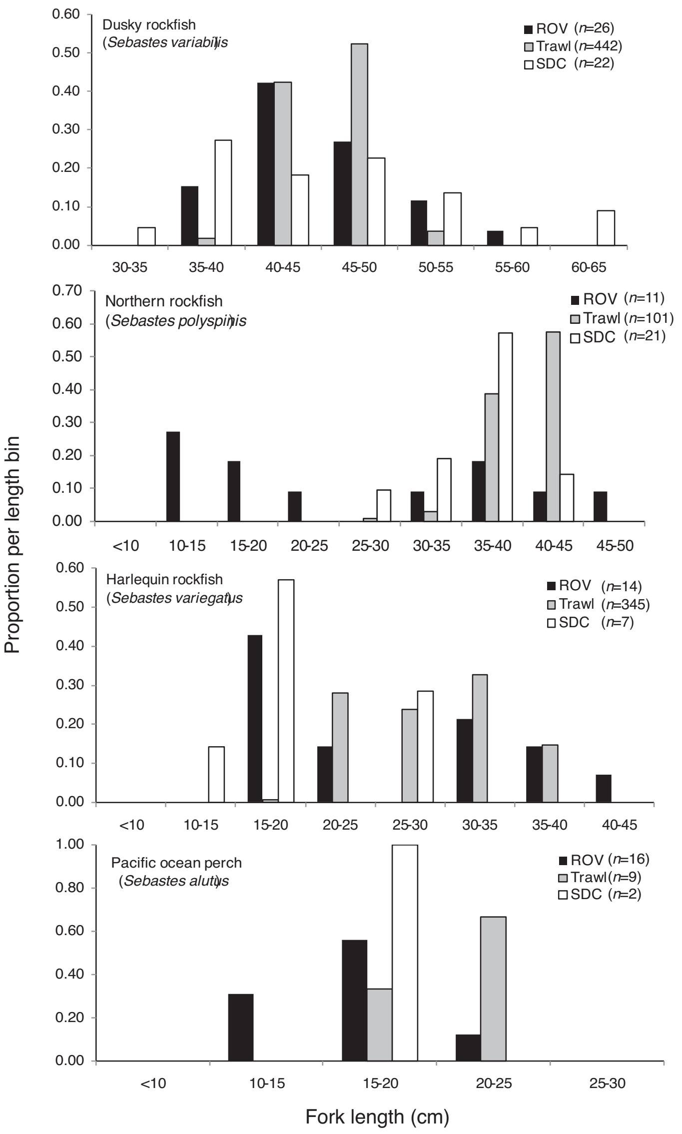

Figure 2

Length-frequency data for each gear type (ROV=remotely operated vehicle, Trawl= bottom trawl=Trawl, and SDC=stereo drop camera) for dominant rockfish species observed at the Snakehead Bank, Alaska, in 2009. n=the number of fish measured for each species and gear type.

Vertical distribution of fish and comparisons between trawlable and untrawlable areas

The results of the acoustic survey indicated that the majority of rockfish were near the seafloor because the mean height off bottom of rockfish from all 8 acoustic survey passes was 1.5 m (Jones et al., 2012 [this issue]). Mean height off bottom during each of the 8 survey passes ranged from 1 to 3.25 m, a range that allowed most of the rockfish biomass to be observed with the ROV or SDC or captured in the trawl. The observed height off the seafloor, as measured with the SDC, varied significantly among rockfish species from a random distribution according to a chi-squared test (Table 2). Harlequin rockfish, Pacific ocean perch, rosethorn rockfish (*S. helvomaculatus*), dark rockfish (*S. ciliatus*), and yelloweye rockfish (*S. ruberrimus*) were observed exclusively within 1 m of the seafloor (Fig. 6). The rockfish species found in the water column (>1 m off the seafloor) were dusky and northern rockfish, although these species were also found within the acoustic dead zone as well. The bottom trawl integrated rockfish catch from approximately 0 m to 7 m (the height of the net opening) off the seafloor and the ROV laser system does not allow for measurement of distance off the seafloor on a fine scale; therefore the depth distributions of various rockfish species could not be precisely determined with these gear types.

With a chi-squared test, we also detected a significant nonrandom distribution of rockfish species by habitat type; either trawlable or untrawlable (Table 3). The proportion of fish in untrawlable areas was higher than in trawlable areas for the individual fish species (Fig. 7), as well as for the combined other rockfish group (yelloweye rockfish, redstripe rockfish (*S. proriger*), redbanded rockfish (*S. babcocki*), dark rockfish, tiger rockfish, and rosethorn rockfish). *T*-tests indicated some of these differences were insignificant, because the proportion of dusky rockfish (P=0.10, t=–1.83, n=10), northern rockfish (P=0.33, t=–1.07, n=6), and Pacific ocean perch (P=0.07, t=–2.12, n=8) was not significantly higher in untrawlable areas than in trawlable areas. All the harlequin rockfish and the rockfish grouped into the "other species" category were observed exclusively in untrawlable areas, with the exception of one redbanded rockfish (Fig. 7). This division resulted in a significantly higher proportion of the "other species" group being found in untrawlable areas than in trawlable areas ($P<0.0001$, $t=-40.09$, $n=12$).

Together, the differences in both vertical (height off the seafloor) and spatial (trawlable versus untrawlable habitat) distributions of the rockfish, resulted in a complex picture of the verification of fish species potentially observed in acoustic data during the survey of Snakehead Bank (Fig. 8). Rockfishes within the acoustic dead zone (<1 m) over trawlable areas were dominated by dusky rockfish and northern rockfish (Fig. 8). In the untrawlable areas, the acoustic dead zone contained dusky, harlequin, and northern rockfishes in greatest abundance. Fish in the water column (>1 m off bottom) that were likely to be observed by using the vessel acoustics comprised mostly dusky and northern rockfish in both trawlable and untrawlable areas, although as shown in Figure 7, the higher proportion of these two species was observed in untrawlable areas.

Data analysis, processing time, and cost

The ROV required both the highest level of expertise and the longest time to deploy (Table 4). The bottom trawl required the least amount of time to deploy, retrieve, and process samples (Table 4). The level of expertise required to deploy and retrieve the gear was high, but other tasks associated with the bottom trawl required moderate expertise. The level of expertise required to deploy and retrieve the SDC was also high, although it could be done in relatively short time. The level of expertise to process the SDC video footage into data required for acoustic surveys was also high, and the time required to collect and process one sample (1 h of video) was large (7 h). Once the ROV video was collected, processing it into data required for verification of target species in the acoustic surveys was comparable to that required with the SDC, although more time was necessary to measure the lengths of fish with the lasers than with the stereo cameras. The initial costs of purchasing the ROV and constructing the bottom trawl were quite high. The SDC was the cheapest of the 3 equipments to purchase and construct. The cost per unit of area surveyed during this project was cheapest with the bottom trawl and most expensive with the ROV.

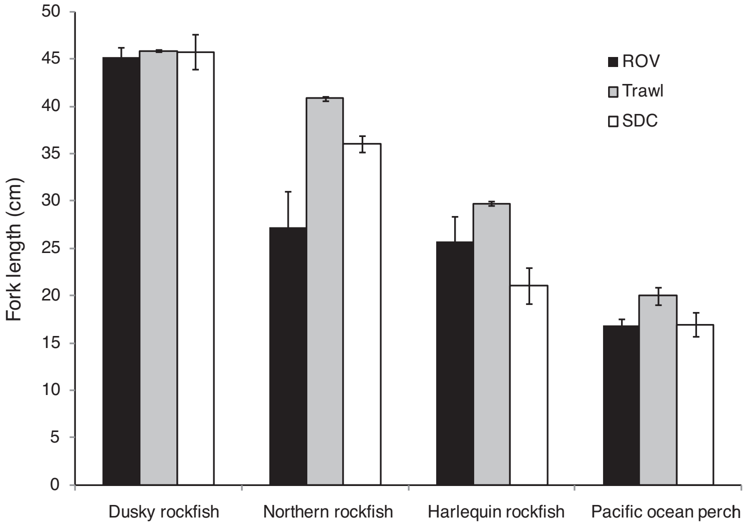

Figure 3

Mean (and standard error) fork length (cm) for dominant rockfish species observed with the 3 gear types (ROV=remotely operated vehicle, Trawl=bottom trawl, and SDC=stereo drop camera) at the Snakehead Bank, Alaska, in 2009. Sample sizes for length measurements are the same as those shown in Figure 2.

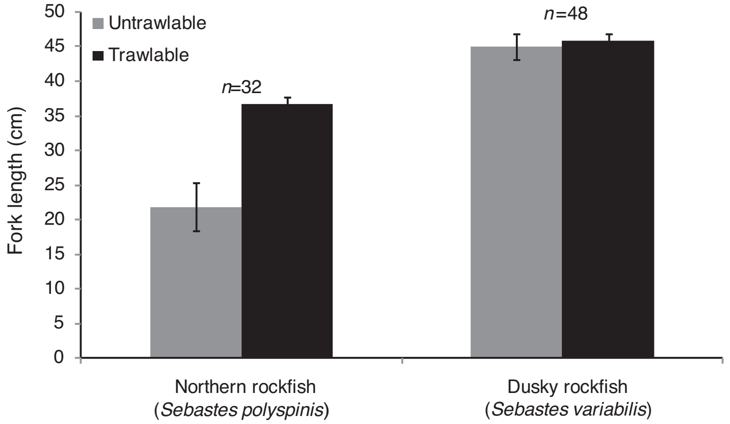

Figure 4

Mean (and standard error) fork length (cm) for rockfish species observed and measured in both trawlable and untrawlable regions of the Snakehead Bank, Alaska in 2009. Data from the remotely operated vehicle and stereo drop camera are combined. n=number of fish measured for each species.

Discussion

In this study, the rockfish species observed in the water column were similar between trawlable and untrawlable areas, which is encouraging for the potential to assess the biomass of these species acoustically in both types of habitats. However, clear differences

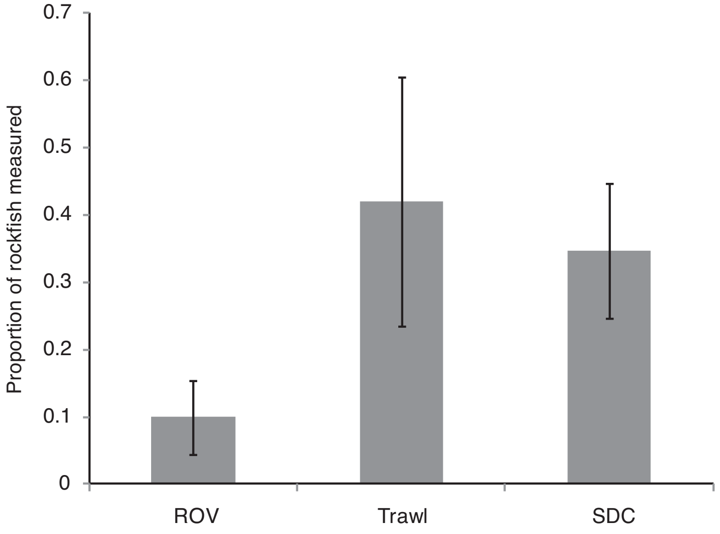

Figure 5

Average proportion (and standard error) of rockfish that were measured out of the total number of dusky rockfish (*Sebastes variabilis*), northern rockfish (*S. polyspinis*), harlequin rockfish (*S. variegatus*), and Pacific ocean perch (*S. alutus*) observed. Proportions were calculated for the 4 species from each transect surveyed with the remotely operated vehicle (ROV; $n=4$ deployments), bottom trawl haul (trawl; $n=6$ deployments) and stereo drop camera transect (SDC, $n=5$ deployments) conducted at the Snakehead Bank, Alaska, in 2009 where length data were collected. The average proportions were computed by using transects as replicates.

Table 2

Chi-squared test for random distribution of each rockfish species at <1 m height off the seafloor. The observed frequency and expected frequency of each rockfish species <1 m off the seafloor are shown for data from stereo drop camera deployments where both cameras were functional and rockfish were observed during the deployment ($n=5$ deployments).

Species	Observed frequency <1 m off bottom Species	Expected frequency <1 m off bottom
Dusky rockfish (*Sebastes variabilis*)	7	11
Northern rockfish (*Sebastes polyspinis*)	3	11
Harlequin rockfish (*Sebastes variegatus*)	7	4
Other rockfish: Pacific ocean perch (*Sebastes alutus*), rosethorn (*S. helvomaculatus*), yelloweye (*S. ruberrimus*), and dark rockfishes (*S. ciliatus*)	18	9
Total number of fish observed/χ^2	68	19
χ^2 (critical value, $P=0.05$, df=4)		9.49

in rockfish species composition on the seafloor in trawlable and untrawlable areas were observed during this study. Other studies of untrawlable habitats have revealed similar differences in rockfish species composition near the seafloor when compared with trawlable areas (Matthews and Richards, 1991; Matthews, 1989; Rooper et al., 2007). Our observations highlight the potential that a considerable proportion of the rockfish biomass (in this case harlequin, northern, and dusky rockfish) will be unavailable to the standard bottom trawl survey in untrawlable areas, potentially negatively biasing population abundance estimates. Although at least some of these species may be available for acoustic biomass estimation, the abundance of species that are found in the acoustic dead zone in untrawlable areas will be more difficult to estimate

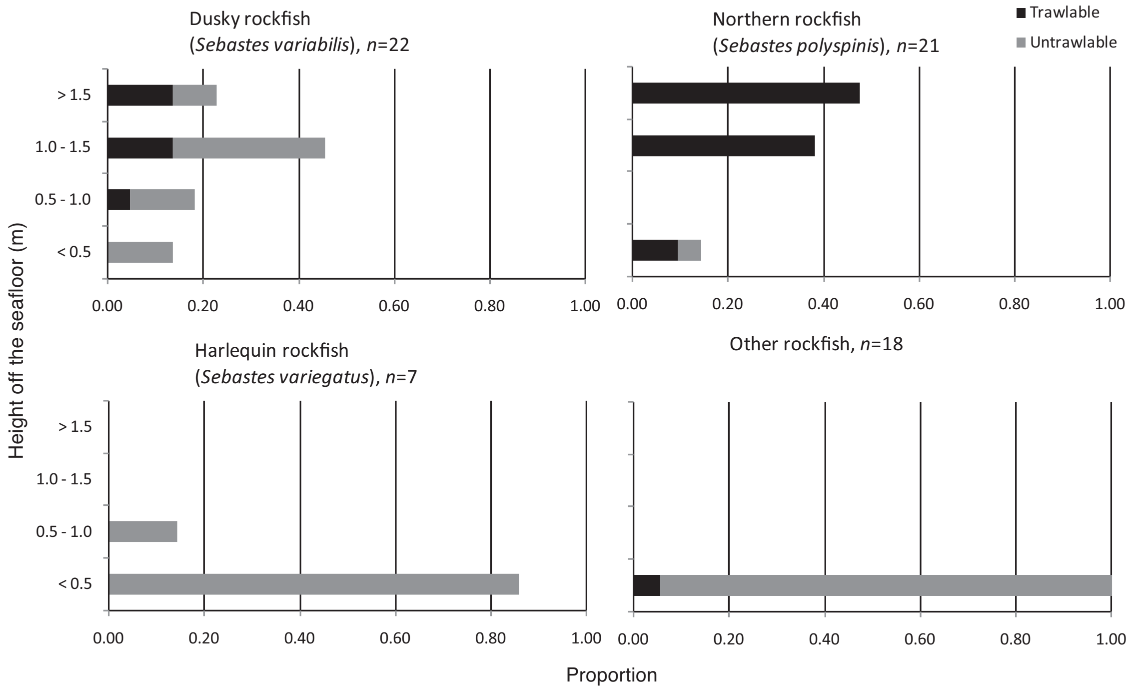

Figure 6

Distribution of rockfish species by height off the seafloor (m) at the Snakehead Bank, Alaska, in 2009. These data were available only from the five stereo drop camera transects where both cameras were functional and where rockfish species were observed. The data for each depth and species are split into trawlable and untrawlable proportions based on the seafloor characteristics where the individual fish were observed. Other rockfish include Pacific ocean perch (*Sebastes alutus*), rosethorn rockfish (*S. helvomaculatus*), yelloweye rockfish (*S. ruberrimus*), and dark rockfish (*S. ciliatus*). *n*=no. of fish in sample.

Table 3

Chi-squared test for the random distribution of rockfish species between trawlable and untrawlable habitats. Data from stereo drop camera (SDC) and remotely operated vehicle (ROV) deployments (*n*=12). Shown are the observed frequency and expected frequency of rockfish for each species that occurred in trawlable areas, based on the amount of trawlable area surveyed with the SDC and ROV are shown.

Species	Observed frequency in trawlable areas	Expected frequency in trawlable areas
Dusky rockfish (*Sebastes variabilis*)	157	479
Northern rockfish (*Sebastes polyspinis*)	130	71
Harlequin rockfish (*Sebastes variegatus*)	0	127
Pacific ocean perch (*Sebastes alutus*)	1	46
Other rockfish: yelloweye (*Sebastes ruberrimus*), redstripe (*S. proriger*) redbanded (*S. babcocki*), dark (*S. ciliatus*), tiger (*S. nigrocinctus*), and rosethorn rockfishes (*S. helvomaculatus*)	1	59
Number of fish observed/χ^2	1960	366
χ^2 (critical value, *P*= 0.05, df=11)		19.68

because these species are unavailable to both acoustic and bottom trawl surveys.

Temporal and spatial variability in species distribution may have influenced the results of comparisons of species distribution by gear types in this study. Although each of the gear types was deployed at a slightly different combination of sites over the same relatively small area of the Snakehead Bank, each gear type was deployed in reasonably close proximity in space over the same time period. We observed uniformity of species composition within trawlable and untrawlable habitats when sampling with the two optical gear types. For example, dusky rockfish and northern rockfish were the dominant species observed with both optical gear types in trawlable areas, whereas additional rockfish species such as harlequin rockfish were found with the optical gear types (as well as the trawl) in untrawlable areas. This result would not be expected if we were sampling substantially different communities in the small area the Snakehead Bank. The acoustic information showed that the biomass of fish in the Snakehead Bank area was relatively stable between eight successive day and night passes (~2800 t, coefficient of variation [CV]=0.27; Jones et al., 2012 [this issue]), indicating it was unlikely that substantial fish movement into or out of the study area would have influenced the results.

The spatial scale of the effort varied also with each gear type in this study. The bottom trawl covered a wide area, whereas the two optical technologies covered only small swaths of the seafloor. This difference in spatial scale probably affected the catchability of the gear types. The substrate type also affected the catchability. In the more rugose substrate, the ROV and SDC allowed rockfish to be observed in individual cracks and crevices although identifying individuals partially hidden in crevices was more difficult with the SDC. The modified bottom trawl undoubtedly did not capture all the fish species that occurred in the most rugose areas. The modifications to the footrope were designed to allow the net to bounce over large rocks and probably led to some fish in rocky areas not being captured.

Fish length differed between the 3 gear types. The smallest fish were observed only with the

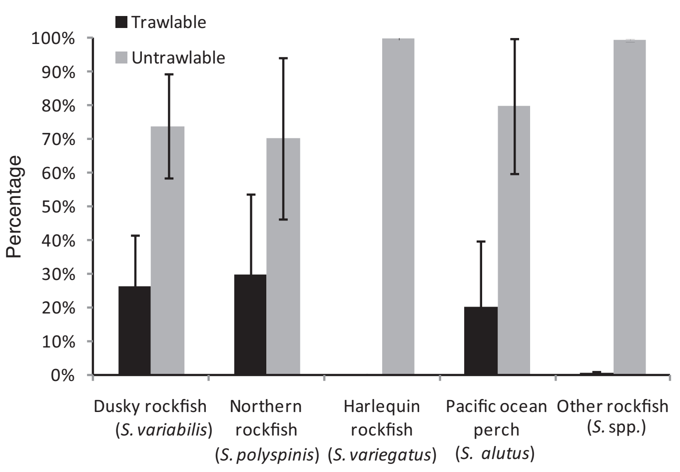

Figure 7

Mean percentage (and standard errors) of rockfish by species observed in trawlable and untrawlable areas as estimated with the stereo drop camera and remotely operated vehicle along the transects. Only transects that included both trawlable and untrawlable areas and transects where the rockfish species occurred were used to calculate the mean percentages. The other rockfish species group includes yelloweye rockfish (*Sebastes ruberrimus*), redstripe rockfish (*S. proriger*), redbanded rockfish (*S. babcocki*), dark rockfish (*S. ciliatus*), tiger rockfish, (*S. nigrocinctus*), and rosethorn rockfish (*S. helvomaculatus*).

Table 4

Estimated total hours spent deploying each gear type to collect one bottom trawl sample from a 5–15 minute tow and one hour of underwater images from either the remotely operated vehicle (ROV) or the stereo drop camera (SDC). Each major data collection task (identifying, counting, and measuring all species of fish) and data entry is listed, as well as the relative level of expertise required to complete the task. Underwater video was used for substrate classification, fish counting, and identification for the ROV and SDC. Still images were used for determining fish length for the ROV and SDC, and still images were used to aid fish identification with the ROV.

	ROV		Bottom trawl		SDC	
Task	Estimated time required (person hours)	Level of expertise required	Estimated time required (person hours)	Level of expertise required	Estimated time (person hours)	Level of expertise required
Deployment and retrieval of gear	2.5	High	1	High	1.5	High
Classification of substrate	0.5	High	—	—	0.5	High
Fish count and identification	2	High	0.5	Medium	2	High
Determination of fish length	3	High	0.5	Low	2	High
Data entry and formatting	1	Medium	0.5	Medium	1	Medium
Total	9		2.5		7	
Initial cost of equipment	>$100,000		$66,000		$18,308	
Operational cost (per ha of seafloor)	$1,393		$139		$262	

optical gear types and therefore they were either unavailable to or not retained by the bottom trawl; the smallest rockfish (<150 mm) could probably escape more readily through the bottom trawl. Escapement of this kind has been observed in the Gulf of Alaska and Aleutian Islands bottom trawl surveys where the smallest (<100 mm) rockfish are often not captured (von Szalay et al., 2010, 2011). Because juvenile fish and smaller species, such as harlequin rockfish were observed primarily in untrawlable areas, it is also possible that the smallest fish seek out shelter among the rocks and are not available to the bottom trawl. The accuracy of the fish length measurements also differed by gear type. The fish captured in the bottom trawl are generally assumed to be measured with only a minimal amount of error because each measured fish is individually handled, measured, and recorded. However, fish caught by bottom trawl are only measured to the nearest cm. The error rates for the SDC in measuring the size of known targets have previously been estimated to be less than 8.2%, or less than 2.5 cm for a 30-cm fish (Williams et al., 2010). Other stereo video systems have generally produced smaller error rates <1% of length (Harvey et al., 2002, 2003; Shortis et al., 2009). The higher error rates for the SDC are probably due to the need to remove cameras from the housing unit after each deployment, which possibly causes a slight misalignment of the cameras in relation to the position at calibration reducing the precision of measurements (Williams et al., 2010). The accuracy of length measurements from the ROV parallel laser measuring system was not determined; however, previous research with parallel laser systems have indicated length measurements are accurate to 1–5% of the total length of a rigid object (Rochet et al., 2006). Because fish lengths are translated directly into target strength estimates for acoustic biomass estimation, errors and biases in fish length from the target verification tools are important to determine so that the effect on total fish biomass can be known.

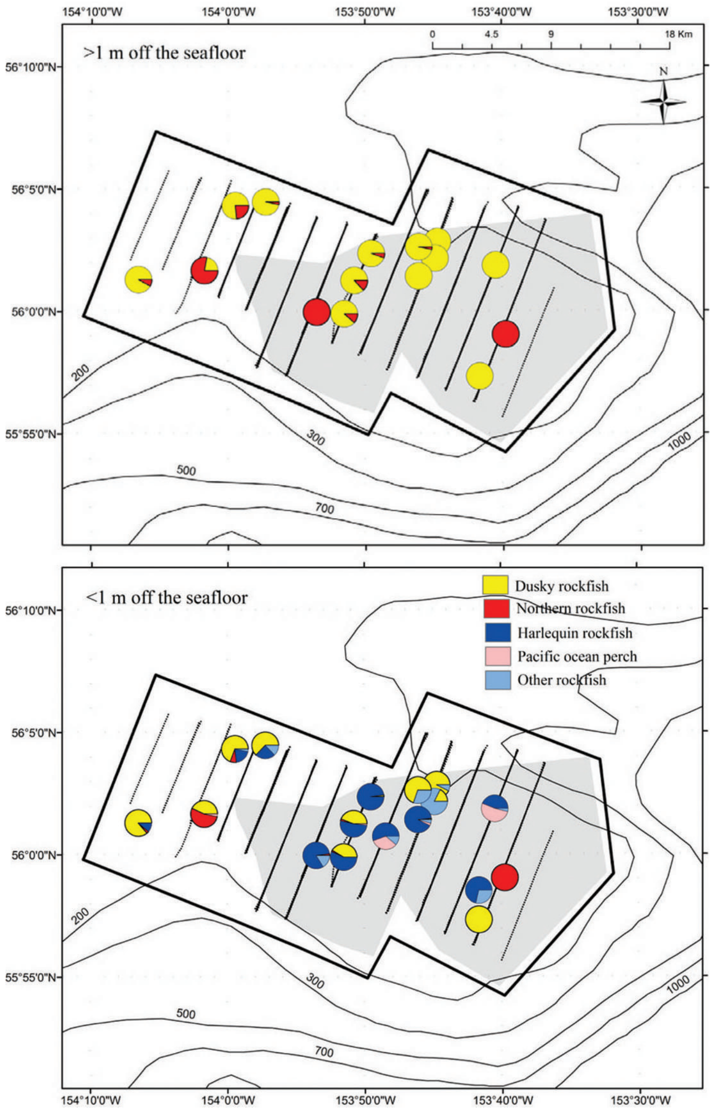

Figure 8

Composition of rockfish (based on percentages from stereo drop camera estimates of height distribution from each species) at stations by height off the seafloor in the categories >1 m off the seafloor and <1 m off the seafloor. Stations were surveyed by remotely operated vehicle, bottom trawl, and stereo drop camera. Some sites have been slightly offset to show species composition charts. Solid line indicates the extent of the acoustic transects, the shaded area shows the area that was considered predominantly untrawlable in the analysis of acoustics (Weber et al.[2]). Dusky rockfish (*Sebastes variabilis*), northern rockfish (*S. polyspinis*), harlequin rockfish (*S. variegatus*), and Pacific ocean perch (*S. alutus*) are shown individually. The other rockfish species group comprises yelloweye rockfish (*Sebastes ruberrimus*), redstripe rockfish (*S. proriger*), redbanded rockfish (*S. babcocki*),dark rockfish (*S. ciliatus*), tiger rockfish (*S. nigrocinctus*), pygmy rockfish (*S. wilsoni*), silvergrey rockfish (*S. brevispinis*), and rosethorn rockfish (*S. helvomaculatus*).

Thus, the results of this study indicate that the method chosen for target verification in acoustic assessments depends on the fish species to be assessed, their size, and the substrate type to be examined. Advantages of the bottom trawl over the optical methods are that it allows identification and measurements of all the rockfish species collected. Specimens collected with the bottom trawl also provide auxiliary information important to stock assessment, such as diet, age, and stage of maturity. The advantage of the optical methods is that they provide data for discriminating species assemblages in untrawlable areas or areas with potentially vulnerable habitats such as deepwater corals and sponges that could be damaged by further trawling (Heifetz et al., 2009). Habitat-specific densities and associations can also be collected by video methods—factors that are masked by the bottom trawl that integrates the catch over a large and unobserved area of the seafloor. Optical methods also allow researchers to collect length information from smaller individuals, but this advantage can be offset by potential inaccuracies in species identification because these small individuals are difficult to identify with optical methods.

There are cost advantages of using the SDC over both the ROV and trawl methods because the initial investment in equipment is smaller. The stereo cameras allow scientists to accurately measure the height of individual fish off the seafloor and the opportunity to measure the length of a higher proportion of observed fish than does the ROV. These are both critical factors for acoustic surveys where it is important to know the size of fish that are observed acoustically in the water column. The major disadvantages of the SDC are the difficulties associated with identifying all fish to species and an inability to finely control the position of the cameras.

For this analysis, we assumed that the distribution of height off bottom for each species was accurately represented by the data collected with the SDC. Any behavioral reactions to this camera system (for example fish diving away from the camera as it approached) would have influenced our ability to perceive the height of fish off the bottom accurately. Errors in this measurement would have serious effects on the acoustic estimates of abundance for any species that reacted to the SDC. For example, if one rockfish species had a tendency to dive to the seafloor before coming into the view of the SDC, as has been observed with manned submersibles (Krieger and Ito, 1999), the species could be underrepresented in the biomass estimate of fish from above the acoustic dead-zone. As the SDC is a relatively small vehicle without a motor that drifts at low speeds with the prevailing current (creating less noise), its potential for eliciting a reaction by fishes is probably less than that of the bottom trawl or ROV. During the analysis of the video from this study, we observed that reactions to the SDC by rockfish were minimal, consistent with a previous study with a SDC (Rooper et al., 2010) and a study where a larger towed camera sled was used (Rooper et al., 2007). Fish reactions to underwater vehicles have generally been found to vary with both the species examined (Krieger and Ito, 1999; Lorance and Trenkel, 2006; Ryer et al., 2009) and the type of underwater vehicle used (Stoner et al., 2008). This is an area where more research should be completed in order to gauge the ability of the SDC and other underwater vehicles to accurately measure the height of rockfishes off the seafloor.

Conclusion

Our overall recommendation for verification of target species in acoustic surveys in areas of patchy untrawlable habitat is that a combination of technically advanced stereo-optic equipment and more rugged bottom trawls be used where species identification is likely to be difficult or where many species are found in the water column. In cases where the rockfish assemblage is dominated by one or two easily distinguishable species, the stereo-optic methods will be the least destructive way to obtain the basic information needed to conduct fisheries acoustic surveys. An important problem highlighted by this research is that species exclusively found in the acoustic dead zone (for example, yelloweye rockfish in this study) will not be able to be assessed acoustically. For these species, alternative methods such as bottom trawls, long-lines, or optical methods using line transect or area swept survey methods will be the only adequate means for estimating the abundance of these fish. Therefore, our results suggest that the selection of appropriate methods for target verification depends on the specific objectives, habitat types, and species complexes being assessed.

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