Evaluation of rockfish abundance in untrawlable habitat: combining acoustic and complementary sampling tools

Darin T. Jones (contact author)[1]

Christopher D. Wilson[1]

Alex De Robertis[1]

Christopher N. Rooper[1]

Thomas C. Weber[2]

John L. Butler[3]

Email address for contact author: darin.jones@noaa.gov

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

[2] Center for Coastal and Ocean Mapping
University of New Hampshire
24 Colovos Road
Durham, New Hampshire 03824

[3] Southwest Fisheries Science Center
National Marine Fisheries Service
3333 North Torrey Pines Court
La Jolla, California 92037

Abstract—Rockfishes (*Sebastes* spp.) are an important component of North Pacific marine ecosystems and commercial fisheries. Because the rocky, high-relief substrate that rockfishes often inhabit is inaccessible to standard survey trawls, population abundance assessments for many rockfish species are difficult. As part of a large study to classify substrate and compare complementary sampling tools, we investigated the feasibility of using an acoustic survey in conjunction with a lowered stereo-video camera, a remotely operated vehicle, and a modified bottom trawl to estimate rockfish biomass in untrawlable habitat. The Snakehead Bank south of Kodiak Island, Alaska, was surveyed repeatedly over 4 days and nights. Dusky rockfish (*S. variabilis*), northern rockfish (*S. polyspinis*), and harlequin rockfish (*S. variegatus*) were the most abundant species observed on the bank. Backscatter attributed to rockfish were collected primarily near the seafloor at a mean height off the bottom of 1.5 m. Total rockfish backscatter and the height of backscatter off the bottom did not differ among survey passes or between night and day. Biomass estimates for the 41 square nautical-mile area surveyed on this small, predominantly untrawlable bank were 2350 metric tons (t) of dusky rockfish, 331 t of northern rockfish, and 137 t of harlequin rockfish. These biomass estimates are 5–60 times the density estimated for these rockfish species by a regularly conducted bottom trawl survey covering the bank and the surrounding shelf. This finding shows that bottom trawl surveys can underestimate the abundance of rockfishes in untrawlable areas and, therefore, may underestimate overall population abundance for these species.

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Many fish species associate with and find refuge in high-relief substrate, where bottom trawl surveys are ineffective (O'Connell and Carlile, 1993; Yoklavich et al., 2000; Zimmermann, 2003). The bottom trawl survey of the Gulf of Alaska (GOA) conducted by researchers with the NOAA Alaska Fisheries Science Center (AFSC) (von Szalay et al., 2010) routinely encounters areas that are untrawlable because of rough substrate or known hazards to fishing gear on the seafloor. When untrawlable substrate is located at a designated sampling station, an alternate location with suitable substrate is sought nearby (von Szalay et al., 2010). Mean estimates of species abundance from sampling stations are then extrapolated over the entire management area, including known untrawlable areas. Yet rockfish abundance between trawlable and untrawlable areas can vary considerably (Stein et al., 1992; Jagielo et al., 2003; Rooper et al., 2007) and is often lower in trawlable areas than in untrawlable areas (O'Connell and Carlile, 1993; Rooper et al., 2010). Therefore, extrapolated estimates can be inaccurate.

In habitats that cannot be sampled adequately with trawls, acoustic methods combined with complementary sampling tools may improve rockfish stock assessments by providing more complete and accurate estimates of rockfish populations. Acoustic surveys can cover large areas and much of the water column in a relatively short time, but accurate abundance estimates require consideration of the target species, their diel movements and association with the seafloor, and the type and structure of the substrate. It has been demonstrated that acoustic surveys can be successfully used to assess pelagic rockfish populations in areas of relatively low relief (Wilkins, 1986; Richards et al., 1991; Stanley et al., 2000; Krieger et al., 2001). Cooke et al. (2003) described methods for acoustically sampling fishes in areas of high relief by performing multiple passes at various angles to thoroughly map the seafloor. However, when fish are on or near the bottom in the acoustic dead zone, (i.e., the near-bottom zone where the echo from the seafloor masks acoustic signals from organisms near the seafloor), a large portion of the population may go undetected (Ona and Mitson, 1996), particularly in areas where the bottom terrain is rough or variable.

Besides the problem of resolving fish backscatter within the dead zone, scientists also must consider the problem of determining the species composition and size distribution of fishes that are detected in that zone. Starr et al. (1996) used a submersible in association with acoustics to estimate rockfish distribution and abundance. Krieger (1992), and Krieger and Ito (1998) used visual surveys from manned submersibles to assess rockfish abundance in untrawlable areas and compared their numbers with those from trawl catches. For surveying in large areas, however, manned submersibles are costly, labor-intensive, and inefficient. Williams et al. (2010) demonstrated the feasibility of using stereo-video drop (i.e., lowered) camera systems for assessing rockfish species and size in untrawlable areas. Ressler et al. (2009) and Rooper et al. (2010) successfully used underwater cameras and echo sounding systems to assess rockfish populations in rocky habitat. However, the species of interest in these studies were far enough above the bottom that assessment in the acoustic dead zone was not necessary.

Rockfishes, of the genus *Sebastes*, constitute a large and diverse assemblage within North Pacific marine ecosystems and are important components of this region's commercial fisheries. Of the rockfish species in the GOA, Pacific ocean perch (*Sebastes alutus*), northern rockfish (*S. polyspinis*), and dusky rockfish (*S. variabilis*) are among the most abundant. They are the only rockfish species supporting commercial fisheries (aside from occasional directed fisheries for the demersal shelf rockfish complex in specific areas), and all 3 species have experienced local depletions within the last decade (Hanselman et al., 2007). In our study on Snakehead Bank, dusky, northern, and harlequin (*S. variegatus*) rockfishes were the most abundant species observed during our surveys and the species on which our analyses focused. Determination of precise population estimates for dusky, northern, and harlequin rockfishes is challenging because these species aggregate in rocky, high-relief areas where it is difficult to conduct trawl surveys to estimate abundance.

Dusky rockfish are managed as part of the pelagic shelf rockfish assemblage and are routinely caught by trawlers on the outer continental shelf at depths of 100–150 m. Dusky rockfish also have been observed on banks and near gullies with hard, rocky habitats containing sponges and corals. Commercial catches of dusky rockfish are primarily located on banks near Yakutat in southeast Alaska and to the east and south of Kodiak Island, Alaska (Lunsford et al., 2009).

Northern rockfish are presently managed as a single stock in the GOA (Heifetz et al., 2009). The preferred habitat of adult northern rockfish in the GOA appears to be hard, rocky, or uneven substrate on relatively shallow rises and banks on the outer continental shelf at depths of ~75–150 m. One such rise south of Kodiak Island known as Snakehead Bank accounted for 46% of the northern rockfish catch during the 1990s (Clausen and Heifetz, 2002). Northern rockfish stocks on Snakehead Bank have been depleted, and the commercial fishery is nearly absent compared to past effort in this area (Heifetz et al., 2009).

The primary objective of this work, which formed part of a larger study, was to use acoustic and complementary sampling tools to evaluate the feasibility of improving abundance estimates of rockfish species in an untrawlable habitat in the GOA. Other aspects of the larger study, comparing sampling technologies (Rooper et al., 2012 [this issue]) and investigating the use of acoustics for substrate classification (Weber[1]), are reported elsewhere in this issue of *Fishery Bulletin* or otherwise available. We used a combination of acoustic backscatter measurements, video observations from a stereo-video drop camera (SDC), a remotely operated vehicle (ROV), and catch composition data from a modified bottom trawl to estimate abundances of rockfish species on Snakehead Bank. To establish whether or not rockfishes are disproportionately abundant in untrawlable areas, we compared estimates of rockfish biomass for the dominant species on Snakehead Bank with those obtained from the AFSC biennial bottom trawl survey.

Materials and methods

This study was conducted during the period of 3–12 October 2009 with 2 vessels at a relatively shallow bank, known locally as Snakehead Bank, located at the GOA shelf break about 74.1 km (40 nautical miles [nmi]) south of Kodiak Island (Fig. 1). The acoustic surveys and ROV deployments were conducted aboard the NOAA Ship *Oscar Dyson*. The SDC and bottom trawl were deployed from the FV *Epic Explorer*. This site was selected because of high historical catches of northern rockfish in the commercial fishery and AFSC bottom trawl survey (Clausen and Heifetz, 2002) and an abundance of rough substrate designated as untrawlable by the AFSC GOA bottom trawl survey (Martin[2]).

The Snakehead Bank survey initially consisted of 14 parallel transects 9.3 km (5 nmi) long and spaced 2.2 km (1.2 nmi) apart (Fig. 1). Several transects were extended where significant backscatter continued beyond the original endpoints used during the first pass. A pass, defined as a complete survey of all transect lines, was attempted twice—once during daylight hours and again at night—on 4 consecutive days. The number and length of transects surveyed were similar within each pair of passes (day and night) but varied between pairs because deteriorating weather conditions made it impos-

[1] Weber, T. 2011. Unpubl. data. Center for Coastal and Ocean Mapping, Univ. New Hampshire, Durham, NH 03824.

[2] Martin, M. 2009. Personal commun. Alaska Fisheries Science Center, Seattle, WA 98115.

sible to cover all transects on each successive pass. The core area, or the common area covered on all passes (Fig. 1), was used in further analyses to ensure that similar areas were used in comparisons between passes made on different days and between pairs of passes.

Acoustic equipment and backscatter processing

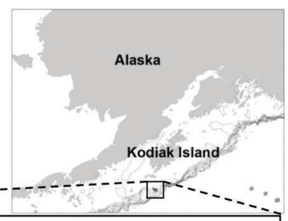
Acoustic measurements were collected with a calibrated Simrad[3] (Kongsberg AS, Horten, Norway) EK60 scientific echo sounding system (Simrad, 2004) with 5 split-beam transducers (18, 38, 70, 120, and 200 kHz) and a Simrad ME70 multibeam echo sounder (Trenkel et al., 2008). The split-beam transducers were mounted on the bottom of a retractable centerboard, positioning the transducers 9.15 m below the water surface during survey activities. A pulse length of 0.512 ms and ping rate of 1.0 s were used for all EK60 data collections. Nominal half-power beam widths were 7° for the 38-, 70-, 120-, and 200-kHz transducers and 11° for the 18-kHz transducer. Acoustic instruments on the *Oscar Dyson*, other than the split-beam and multibeam systems, were turned off (e.g., the navigational fathometer, Doppler speed log) during acoustic data collections. Data processing and analyses of the acoustic data were performed with Echoview software, vers. 4.70.48 (Myriax Software, Hobart, Tasmania, Australia). The 38-kHz echo sounder was the primary source for the quantitative rockfish backscatter measurements presented here. To measure performance of the EK60 system, acoustic system calibrations with a standard target were conducted by following the methods of Foote et al. (1987).

The echo sounders estimated the distance to the bottom with the amplitude-based algorithm (with a threshold of –36 dB re 1 m^{-1}) implemented in the echo sounder software (Simrad ER60, vers. 2.1.2). The mean of the sounder-detected bottom from all 5 frequencies of the EK60 echo sounder was used as the bottom discrimination line in further data processing (Jones et al., 2011). Acoustic measurements were integrated from 16 m below the surface to the bottom discrimination line. All echograms were examined for bottom integrations. Acoustic backscatter was averaged at 2 resolutions: 185 m (0.1 nmi) horizontal by 1) 0.5 m vertical down to 0.5 m above the bottom discrimination line and 2) 0.25 m vertical from 0.5 m to the bottom discrimination line. All data were exported using an S_V integration threshold of –70 dB re 1 m^{-1}.

Based on calculations from Ona and Mitson (1996), the near-bottom acoustic dead zone calculated with the current system configuration was about 0.3 m at a depth of 100 m. With an additional zone of partial integration (where part of the sampled volume is in the dead zone) equivalent to ~0.2 m and a backstep of 0.25 m (to ensure that backscatter from the seafloor is excluded), the total integrator dead zone at a depth of 100 m was ~0.7 m above the sounder-detected bottom.

Backscatter was designated to a category (i.e., rockfishes on the bank, deep rockfishes, bubbles, or zooplankton mix) based on backscatter morphology, location on the bank, depth in the water column, and frequency response. Backscatter attributed to rockfishes was assigned to 2 categories based on location in the water column and whether the rockfishes were located on the shallow bank or deeper adjacent shelf break (i.e., bank flanks). Thus, backscatter in one category, hereafter referred to as *rockfishes*

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



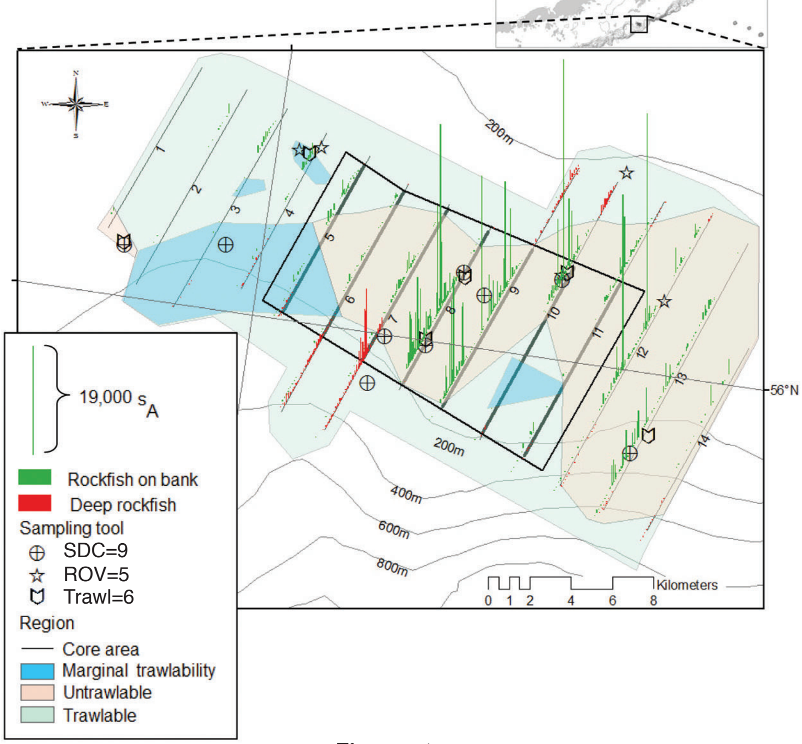


Figure 1

Location of the survey site on Snakehead Bank in the Gulf of Alaska near Kodiak Island, Alaska. Parallel lines represent the full extent of transects surveyed and the core area is represented by the rectangle outlined in black in the middle of this bank. Other colored polygons represent *trawlability*, which was determined with multibeam acoustic backscatter. Symbols indicate sites where the stereo-video drop camera (SDC), remotely operated vehicle (ROV), or bottom trawls were deployed. Green bars depict acoustic backscatter (s_A; m^2 nmi^{-2}) attributed to rockfishes (species mix) on the bank. Red bars depict rockfishes (e.g., Pacific ocean perch [*Sebastes alutus*]) detected at depths >150 m along the bank flanks. The height of the scale bar for acoustic backscatter represents 19,000 s_A.

on the bank, indicated rockfishes located on top of the relatively shallow bank (<150 m) within ~5 m of the bottom and represented the dominant species observed by SDC and ROV and captured by trawl. Backscatter in the other category, hereafter referred to as *deep rockfishes*, indicated rockfishes located at depths >150 m and generally >10 m off the bottom over the bank flanks. The deep rockfish backscatter over the bank flanks was attributed to Pacific ocean perch because that was the only species observed in an SDC deployment in that vicinity.

Several areas on the bank contained backscatter that resembled bubble plumes rising from the seafloor. Such backscatter was characterized by comparing the frequency response relative to 38 kHz. The expected volume backscattering strength from rockfishes at 18, 70, 120, and 200 kHz is within 5 dB of the volume backscattering strength at 38 kHz (De Robertis et al., 2010). Any backscatter resembling bubble plumes with a frequency response that differed from the response at 38 kHz by more than 5 dB was classified as bubbles; otherwise, backscatter was classified as rockfishes on the bank or as deep rockfishes over the flanks.

Differences in mean rockfish backscatter for all 8 passes were evaluated with ANOVA. Tests were performed on natural log-transformed data because of unequal variances in the raw data. Differences in rockfish backscatter within pass pairs (between night and day) were evaluated with a paired *T*-test. All tests were considered significant at an alpha level of 0.05.

The mean height above the seafloor of the seafloor, or height off bottom (m), for backscatter attributed to rockfishes on the bank was calculated for each pass with the following formula:

$$\textit{Mean height off bottom} = \sum(s_{Ai} \times h_i) / \sum s_{Ai},$$

where s_{Ai} = the nautical area scattering coefficient (MacLennan et al., 2002) in each bin with a resolution of 185×0.5 m (except in the bin closest to the bottom, which was 0.25 m high and offset from the bottom by an additional 0.25 m); and

h_i = the height off bottom of each respective bin.

For rockfish backscatter and height off bottom, each pass was considered a sample unit because data for adjacent transects were not independent. In addition, transects differed in length, and, if transects were used as sample units, the contribution of the shorter transects would be disproportionate compared to the contributions of other transects because shorter transects would receive the same weight as longer ones. Because of these conditions, estimates of sampling variance were expressed as coefficients of variance (CV) with passes as the sample unit, rather than as standard deviations derived from transects as the sample units, and, for that reason, we do not show error bars in our figures.

Stereo-video drop camera

The SDC (for a full description, see Williams et al., 2010) was used to identify and count fish species. Paired still images from 2 video cameras were used to estimate fish length and height off bottom. All SDC deployments were conducted in locations where fish aggregations were identified acoustically. The SDC was maintained at a constant height off bottom by using a live video feed to the surface. The paired cameras were oriented at 30° off horizontal (forward and slightly down), allowing the field of view to extend vertically from the seafloor to ~3 m off bottom. The horizontal field of view surveyed by the cameras (W) was ~2.4 m. The distance the SDC covered along the seafloor (L) was approximated by using the GPS on the *Epic Explorer*. The area swept during each SDC deployment was calculated as $W \times L$ and the catch per unit of effort (CPUE) for each species was calculated as the number of fish observed per area swept.

All fishes observed in a camera deployment were counted and identified to species when possible. Height off bottom was measured from the seafloor to 2.0 m off the bottom and grouped in 0.5-m increments. Height off bottom was estimated from a single camera for 2 deployments because a malfunction of one of the cameras did not allow stereo measurements of fish length or height off bottom. Height off bottom was compared for single- and stereo-camera counts from deployments where both cameras functioned properly.

Remotely operated vehicle

A Phantom DS4 ROV (Deep Ocean Engineering, Inc., San Jose, California) was used to collect data to verify substrate type, identify species, measure length of dominant rockfishes, and determine species–substrate relationships (for a full description, see Rooper et al., 2012). All measurements were made with a pair of parallel lasers 20 cm apart and a third laser that crossed each parallel laser at specified distances from the cameras. Height off bottom for fishes observed in ROV deployments was estimated as either on the bottom, up to 2.0 m off the bottom, or >2.0 m off the bottom. The ROV was not maintained with a constant field of view above the seafloor; therefore, we did not calculate the area swept and a CPUE for this survey tool.

Modified bottom trawl

Trawl deployments were conducted to collect rockfish specimens for species and size composition for comparison with SDC data (for a full description, see Rooper et al., 2012). The trawl was a modified 4-seam Poly-Nor'Eastern bottom trawl similar to those trawls used by the AFSC in the GOA bottom trawl survey (Stauffer, 2004). The major modifications to the net were heavier netting material in the belly of the net, a footrope with tire gear through the center, and continuous roller gear through the sweeps. Estimates of rockfish densities were not calculated from these trawl deployments because they were conducted in locations where fish aggregations were acoustically detected and therefore the level of catches would be biased high. Because our trawl deployments were not done at random locations, catch estimates from them could not be compared with results from regular bottom trawl surveys designed to provide estimates of rockfish density and biomass.

Abundance estimation

Fish abundance was estimated for the 3 most abundant rockfish species encountered in the core area covered in our study on Snakehead Bank: dusky, northern, and harlequin rockfishes. Abundance estimates above the acoustic dead zone were calculated for each species and depth layer. These estimates were then combined with abundance estimates from the acoustic dead zone, which were calculated by using 2 different methods (described later in this section), to obtain estimates of total species abundance.

Length-frequency distributions and species compositions were derived from SDC, ROV, and trawl deployments. Length-frequency distributions, backscatter measurements, species compositions, and a target strength (TS) regression (described later in this section) were used to estimate the total number of fish in 1-cm length bins, by following Simmonds and MacLennan (2005). Length-weight relationships obtained from catch data for each species, from AFSC bottom trawl surveys conducted in the summer in the GOA, were used to estimate a biomass for each species and depth layer above the acoustic dead zone.

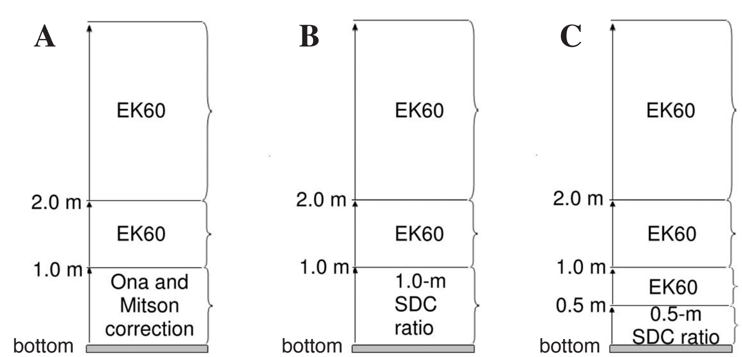


Figure 2

Diagram of depth layers used in calculations of abundances for the dead zone in 2 methods: (**A**) Ona and Mitson (1996) dead zone correction, as well as (**B**) extrapolation of abundance from the depth layer of 1.0–2.0 m to the depth layer of 0–1.0 m using the ratio of fishes observed in counts from images collected with the stereo-video drop camera (SDC) and (**C**) extrapolation of abundance from the depth layer of 0.5–1.0 m to the depth layer of 0–0.5 m by using the ratio of fishes observed in SDC counts. EK60 refers to abundance estimation by using backscatter collected with a Simrad EK60 scientific echo sounder. A dead zone is a near-bottom area where the echo from the seafloor masks acoustic signals from organisms near the seafloor.

It was not possible to obtain an estimate of rockfish TS during this study, and no published estimates for the primary species encountered are available. Therefore, the regression described for generic physoclist fishes, $TS=20\log_{10}L-67.5$, where L is fork length (cm) (Foote, 1987), was used as an approximation. Stanley et al. (2000) used this TS relationship for widow rockfish (*S. entomelas*) because it was shown to also agree with several studies on deepwater redfish (*S. mentella*). Rooper et al. (2010) also used the same TS regression for a combination of *Sebastes* species in the Bering Sea. Furthermore, Kang and Hwang (2003) examined *ex situ* TS of Korean rockfish (*S. schlegelii*) and obtained a similar relationship of $TS = 20\log_{10}L - 67.7$.

Biomass in the 0.7-m acoustic dead zone was calculated by 2 methods to account for the binning of the video observations in 0.5-m increments. The first method used the correction proposed by Ona and Mitson (1996). This correction extrapolates backscatter to the dead zone from a designated zone above the dead zone. The resulting backscatter within the dead zone was apportioned to species based on species composition data from the SDC. The second method for calculating abundance in the dead zone used 2 combinations of depth layers and species ratios from SDC counts (i.e., "1.0-m SDC ratio" and "0.5-m SDC ratio", Fig. 2, B and C). This method, where a constant, weight-specific TS across species and size classes is assumed, used the ratio of species relative abundance from SDC counts in adjacent depth layers to extrapolate abundance from a depth layer above the dead zone to a layer within the dead zone with the following equation:

$$A_{z,j} = (C_{z,j} / C_{z+1,j}) \times A_{z+1,j},$$

where $A_{z,j}$ = the abundance in metric tons of species j in depth layer z;
$C_{z,j}$ = the relative abundance of species j in depth layer z (from the camera data);
$C_{z+1,j}$ = the relative abundance of species j in the depth layer $z+1$ (also from the camera data); and
$A_{z+1,j}$ = the abundance in metric tons (derived from acoustic measurements) of species j in depth layer $z+1$.

For the "1.0-m SDC ratio," z represents the depth layer of 0–1.0 m and $z+1$ represents the depth layer of 1.0–2.0 m. For the "0.5-m SDC ratio," z represents the depth layer of 0–0.5 m and $z+1$ represents the depth layer of 0.5–1.0 m. Abundance estimates for all depth layers were combined for total biomass values by species and method.

Trawlability index

Multibeam acoustic data collected with an ME70 echo sounder were processed to characterize parameters that could potentially be used as an index for *trawlability* (Weber[1]). SDC and ROV images were used to verify substrate typing from these multibeam data. The trawlability index was mapped along with EK60 backscatter by using ARCMAP software, vers. 9.3.1 (ESRI, Redlands, California) to determine the amount of area designated to each substrate type and the association between substrate type and fish backscatter.

Results

The core area of the acoustic survey comprised parts of 7 transects (numbers 5–11, Fig. 1) totaling ~59 km (32 nmi) for each of 8 passes. Bottom depths ranged from 63 to 233 m (mean 118 m) over all transects and 63 to 171 m (mean 101 m) within the core area.

Backscatter designation and height off bottom

Most (63%) of the backscatter attributed to rockfishes on the bank was observed within the core area, primarily along the 3 eastern transects (numbers 8–10, Fig. 1). The variation in rockfish backscatter among passes was relatively low (CV=0.27, N=8, Fig. 3A), and no significant difference was observed in mean rockfish backscatter between day and night passes (P=0.29, Fig. 3A).

Counts of fishes off bottom, determined from deployments with only one functional camera, were verified by comparing them with counts from the stereo-video camera deployments where both cameras functioned properly. With the single-camera deployments, ~10% of dusky rockfish and 25% of northern rockfish were closer to the bottom than those same speicies observed with the stereo-cameras during the same delployments. No harlequin rockfish were seen during the deployments from which single- and stereo-camera comparisons were made. When the deployments during which images were collected from only one camera were not included in analysis, overall abundance estimates decreased ~40% for dusky rockfish and increased 350% for northern rockfish. These differences in abundance estimates resulted from a change in the relative species abundance: 83% of all dusky rockfish and 79% of all harlequin rockfish encountered on all SDC deployments were observed during the 2 single-camera deployments. Because of the relatively minor change in assignments of height off bottom and the large change in species composition and abundance that would result if these data were not included, estimates of height off bottom from single-camera deployments were included in our analyses.

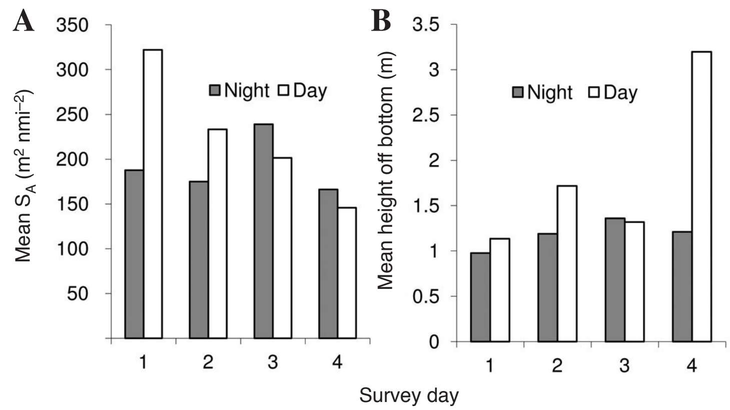


Figure 3

(**A**) Mean rockfish backscatter ($s_{A;}$ m^{2}nmi^{-2}) and (**B**) mean height off bottom (m) of rockfish backscatter in the core area of surveys conducted on Snakehead Bank by survey day for each pair of passes (one during the day and one at night for each day of the surveys).

The mean height off bottom for backscatter attributed to rockfishes over all passes in the core area was 1.5 m (Fig. 3B). Height off bottom for rockfish backscatter was variable among passes (CV=0.47, N=8) largely because the height off bottom of backscatter was greater on the last daytime pass of the survey than on other passes.

Species composition

Relatively similar species compositions of the major rockfish species (dusky, northern, and harlequin rockfishes) were observed with the different sampling tools. For all sampling tools, the dusky rockfish was more abundant (40% of individuals for SDC, 51% for ROV, and 67% for trawl) than all other species, and the harlequin rockfish was the second-most observed species (12% of individuals for both SDC and ROV, and 28% for trawl). Aside from juvenile Pacific ocean perch observed with the ROV (12%), northern rockfish was the third-most abundant species (3% of individuals for ROV, 4% for trawl, and 12% for SDC). The SDC observed the highest number of unidentified juvenile (22%) and adult (8%) rockfishes, and the ROV observed the largest number (10) of species identified (for full details, see Rooper et al., 2012).

Stereo-video drop camera

In total, 9 deployments of the SDC were conducted (Fig. 1). More than 3 times as often as any other species, dusky rockfish were observed at heights >0.5 m off the bottom with the SDC (Fig. 4). Although dusky rockfish composed only ~10% of all fishes identified at heights <0.5 m off the bottom (Fig. 4), 56% of all observed dusky rockfish were seen in this depth layer (Fig. 5). Surveyed with the SDC, unidentified juvenile rockfishes composed the largest group (43%) that was observed at heights <0.5 m off the bottom (Fig. 4).

Northern rockfish made up 20% of all fishes encountered at heights >0.5 m off the bottom with the SDC but were a small percentage (3%) of all fishes observed <0.5 m off the bottom (Fig. 4). However, the majority of northern rockfish (39%) were encountered <0.5 m off the bottom (Fig. 5).

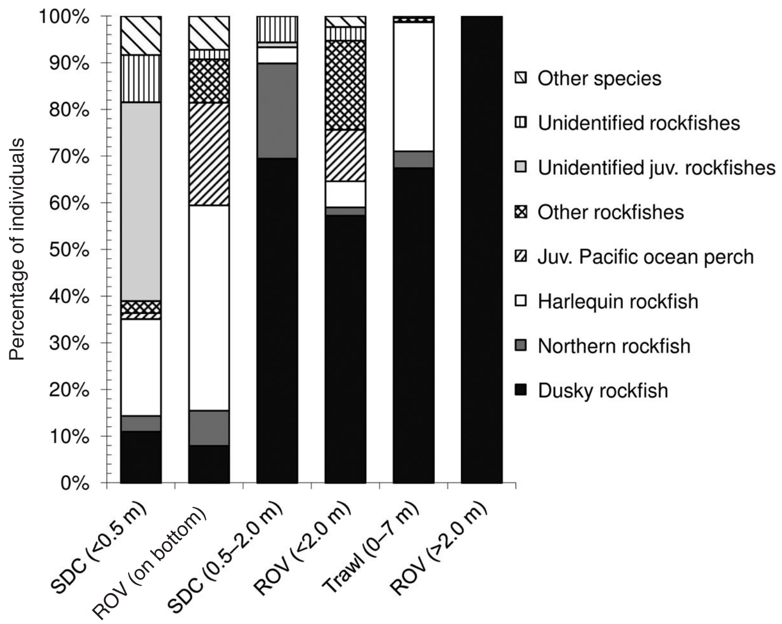


Figure 4

Relative species composition observed by depth layer for each type of sampling tool: stereo-video drop camera (SDC), remotely operated vehicle (ROV), and bottom trawl. Note that the depth layers for each tool are of different heights off the bottom and that there are 3 layers for the ROV, 2 for the SDC, and one for the trawl.

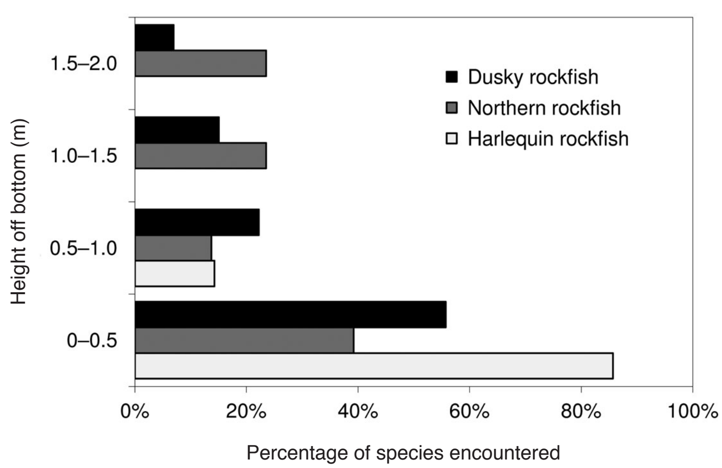


Figure 5

Percentage of each major rockfish species—dusky (*Sebastes variabilis*), northern (*S. polyspinis*), and harlequin rockfish (*S. variegatus*)—encountered with the stereo-video drop camera by half-meter bins of height off the bottom. Note that harlequin rockfish were absent 1–2 m off the bottom.

Harlequin rockfish composed 21% of the fishes observed at heights <0.5 m off the bottom with the SDC (Fig. 4). Harlequin rockfish were observed only <1.0 m off the bottom with the SDC and were most prevalent (86%) <0.5 m off the bottom (Fig. 5).

Remotely operated vehicle

The ROV was deployed at 5 sites during the survey (Fig. 1). Of the dusky rockfish observed with the ROV, ~3% were found on the bottom and 11% were seen >2.0 m off the bottom. In contrast, ~65% of harlequin rockfish and ~50% of the northern rockfish observed with the ROV were on the bottom.

Bottom trawl

Trawl deployments were conducted at 6 locations (Fig. 1). More than 98% of the individuals caught in the bottom trawl were from the 3 major rockfish species (dusky, northern, and harlequin rockfishes).

Trawlability and abundance estimates

The trawlability index derived from the multibeam sonar (Weber[1]) suggested that the majority (73%) of the core area covered in our survey consisted of untrawlable habitat. Additionally, the majority of the rockfish backscatter (95%) from the core area was located in that untrawlable habitat (Fig. 1).

Only dusky rockfish were found >2.0 m off the bottom on the bank; therefore all rockfish backscatter >2.0 m off the bottom was attributed to that species. The resulting biomass estimate for dusky rockfish observed within the core area >2.0 m off the bottom was 262 metric tons (t).

Both dusky and northern rockfishes were observed 1.0–2.0 m off the bottom; therefore, backscatter in that depth layer was split between these species based on their relative abundance in SDC counts (56% and 33%, respectively). The resulting biomass was 331 t for dusky rockfish and 103 t northern rockfish in the depth layer of 1.0–2.0 m off the bottom.

The majority of all fish species were <0.5 m off the bottom according to SDC counts and ROV observations (Fig. 4). Although the 3 major species considered here composed <40% of all fishes observed <0.5 m off the bottom (Fig. 4), the majority of the observed individuals from these 3 species were encountered in this depth layer (Fig. 5).

The abundance estimates determined by using the Ona and Mitson (1996) dead zone correction for fishes observed <1.0 m off the bottom resulted in an additional 2082 t of dusky rockfish (43% of all fishes in that depth layer) for a total water-column biomass of 2676 t. Harlequin rockfish (13% of all fishes in that depth layer) were the second-most abundant species <1.0 m off the bottom, but their biomass amounted to only 79 t because of their small size. Biomass of northern rockfish <1.0 m off the bottom (8% of all fishes in that depth layer) was 217 t, based on the Ona and Mitson correction method, and total water-column biomass was 321 t (Fig. 6).

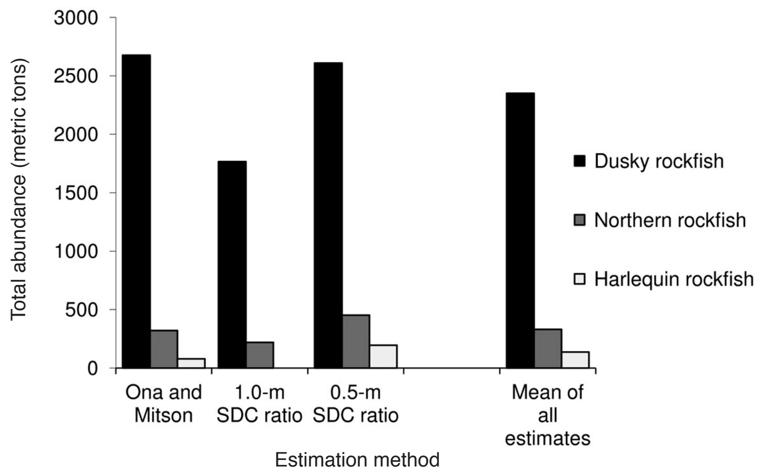


Figure 6

Total abundance values (measured in metric tons of observed fish) for dusky (*Sebastes variabilis*), northern (*S. polyspinis*), and harlequin (*S. variegatus*) rockfishes in the core area of the surveys conducted on Snakehead Bank and calculated with the Ona and Mitson (1996) dead zone correction, 1.0-m and 0.5-m SDC ratios, and with the mean of all of these abundance estimation methods combined.

The abundance estimate for rockfishes <1.0 m off the bottom determined using the approach of the 1.0-m SDC ratio resulted in an additional 1171 t of dusky rockfish (3.5 times the estimate for the 1.0–2.0-m depth layer) and 117 t of northern rockfish (1.1 times the estimate for the 1.0–2.0-m depth layer). Combining all depth layers resulted in total water-column estimates of 1765 t of dusky rockfish and 220 t of northern rockfish (Fig. 6). Because no harlequin rockfish were observed >1.0 m off the bottom, it was not possible to estimate their biomass with this method.

Abundance estimates determined with the 0.5-m SDC ratio and camera counts in the 0.5–1.0 m depth layer resulted in 574 t of dusky rockfish (70% of all fishes in that depth layer), 90 t of northern rockfish (12% of all fishes in that layer), and 28 t of harlequin rockfish (11% of all fishes in that depth layer). For rockfishes encountered <0.5 m off the bottom, the following estimates were calculated: an additional 1441 t of dusky rockfish (2.5 times the estimate for the 0.5–1.0-m depth layer); 258 t of northern rockfish (2.9 times the estimate for the 0.5–1.0-m depth layer estimate); and 167 t of harlequin rockfish (6 times the estimate for the 0.5–1.0-m depth layer). Summing over all depth layers resulted in total water-column estimates of 2609 t for dusky rockfish, 452 t for northern rockfish, and 195 t for harlequin rockfish (Fig. 6).

The total abundance estimates that resulted from these 3 approaches were within 34% of one another for dusky rockfish, 30% for northern rockfish, and 40% for harlequin rockfish (Fig. 6). Because no specific approach to estimate biomass was clearly superior, the estimates were averaged, and an overall biomass for each species was calculated. The resulting mean biomass estimates were 2350 t for dusky rockfish, 331 t for northern rockfish, and 137 t for harlequin rockfish (Fig. 6).

Backscatter attributed to bubbles

Backscatter at numerous sites within our Snakehead Bank study area resembled rising bubble plumes. These backscatter patterns were visible at all 5 EK60 frequencies and often extended from the seafloor vertically through the lower half of the water column. An ROV deployment in the vicinity of these backscatter verified the presence of bubbles seeping from the seafloor (Fig. 7). Most of the backscatter attributed to bubbles (62%) in the entire survey was recorded within untrawlable areas. At the base of several areas of bubble backscatter, we observed aggregations that appeared to be fish based on echo morphology and frequency response. It was difficult to classify backscatter as either bubbles or fishes. However, the total amount of backscatter attributed to bubbles was <7% of the backscatter attributed to rockfishes. Additionally, most of the backscatter attributed to rockfishes (pass average: 78%) occurred in areas without bubble plumes.

Rock formations, presumably calcium carbonate pavements, and bubbles emanating from the substrate often co-occurred. Subsequent water collections near the bubble seeps verified methane levels in the water column up to 40 times those of atmospheric equilibrium conditions at ambient temperature and salinity (Lilley[4]).

[4] Lilley, M. 2010. Unpubl. data. School of Oceanography, Univ. Washington, Seattle, WA 98195.

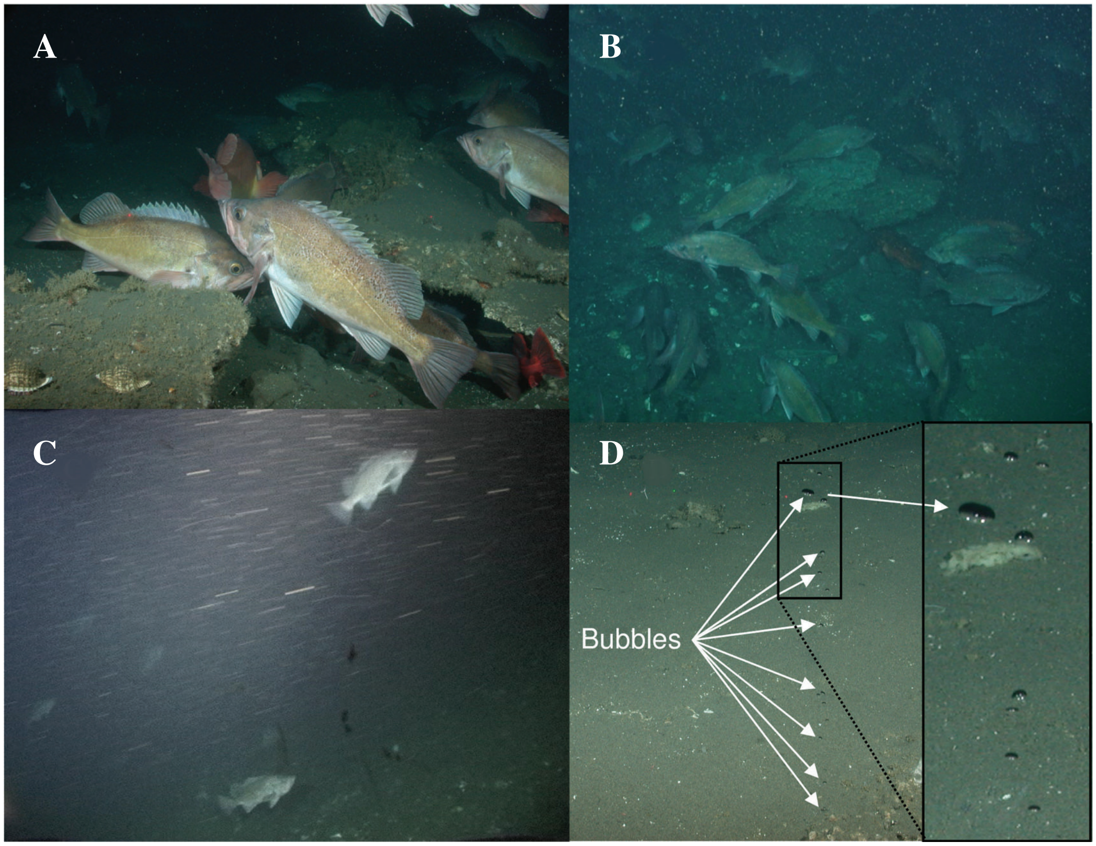


Figure 7

Images captured during our study on Snakehead Bank: (**A**) several rockfish species above carbonate pavement as seen from the remotely operated vehicle (ROV); (**B**) mixed rockfishes in untrawlable habitat as seen from the ROV; (**C**) dusky rockfishes at various heights off the bottom as seen from the stereo-video drop camera and (**D**) bubbles emanating from the substrate (with inset of bubble close up) as seen from the ROV.

Underwater observations by ROV of areas with hard substrate and bubble plumes in the northwest corner of our study region confirmed that rockfishes were also present in these areas. Underwater video also showed numerous species of rockfishes taking refuge in rocky crevices and under carbonate ledges (Fig. 7).

Discussion

Several sampling tools were used during an acoustic survey to assess the species and abundance of rockfishes on a predominantly untrawlable bank in the GOA. Each tool has advantages and limitations, but, when used together, they can give a more complete picture of habitat and species abundances. Acoustic surveys are excellent means for enumerating midwater organisms of known target strength. However, species that are strongly bottom-oriented are difficult to assess with sonar because of the acoustic dead zone. In addition, this problem is exacerbated in high-relief or sloped terrain where rockfishes are abundant because the upper extent of the dead zone is determined by where the acoustic beam first encounters the seafloor within the beam footprint (i.e., the shallowest point within the beam). Furthermore, acoustic sampling alone is often insufficient to differentiate between species if multiple species are aggregated or have similar frequency-response or backscattering characteristics. In areas of rough terrain, or for species that are bottom-oriented or aggregated densely, video images can provide a better mechanism to quantify relative species abundance.

Differences observed in the amounts of the rockfish species between the other 3 sampling tools (SDC, ROV, and modified bottom trawl) could be partly explained by the deployment procedures for the different tools. The SDC was lowered to the seafloor and drifted along transects at a consistent height off bottom without altering the camera angle. Because we surveyed in this manner, the SDC sampling effort remained constant for the different depth layers and was viewable up to about 2.0 m off the bottom. The ROV, because it was powered, did not drift with the *Oscar Dyson* and was capable of observing specific objects of interest and identifying more fishes to species. The added control capability allowed greater flexibility to observe and identify fishes or features of particular interest, such as bubble plumes. Indeed, if not for the precise control of the ROV, the presence of bubble seeps would not have been confirmed. However, when specific objects are investigated, standardization of the viewing field and effort becomes more difficult. Bottom trawl surveys allow for complete species identification and length measurement of captured individuals but do not facilitate allocating catch to specific depth layers. Other aspects of the sampling procedures, such as time to deploy equipment and process samples, difficulty of operation, and cost, have been considered by Rooper et al. (2012).

Generally, northern and harlequin rockfishes observed with the SDC and ROV were smaller than the rockfishes of those species observed with the bottom trawl, indicating size selectivity in the bottom trawl surveys (Rooper et al., 2012). Although the mesh size of the net may allow escape of juveniles and smaller adults, some of the difference in the estimated size distributions between the video and trawl equipment also could be a result of different reactions to the gear by juveniles compared to reactions by adults. Darting into cracks and crevices, juvenile rockfishes appeared to react differently to the ROV (and to a lesser degree to the SDC) than did adults. In contrast, most near-bottom adult rockfishes on the bank did not appear startled or exhibit obvious avoidance behavior to the ROV or SDC, although there was the potential for avoidance or attraction of adult fish to the ROV or SDC outside a camera's field of view (Stoner et al., 2008). If this hiding behavior of juveniles also occurs in response to an approaching trawl and adults show less avoidance behavior, a disproportionate capture of larger fishes may occur.

Despite a locally patchy distribution, abundance in the core area of our survey did not change significantly between passes, indicating that fishes were relatively stable in their geographic distribution over the limited duration of this study. Although most of the backscatter was located in habitat designated as untrawlable, dusky and northern rockfishes also were observed in trawlable areas. Juvenile rockfishes were much more prevalent in untrawlable areas than in trawlable areas, and the harlequin rockfish, which is smaller than the dusky and northern rockfishes, was not seen at all in the trawlable areas. This finding is likely a result of the shelter requirements of juvenile rockfishes and agrees with the observations of Krieger (1992) on unidentified, small (<25 cm fork length) rockfishes in southeast Alaska.

The AFSC GOA bottom trawl survey is conducted biennially to assess the distribution and abundance of the principal groundfish species (von Szalay et. al., 2010). Snakehead Bank lies primarily within the Kodiak International North Pacific Fisheries Commission (INPFC) statistical area. Results from the AFSC bottom trawl survey conducted in 2009 indicate that 94% of dusky rockfish observed in the Kodiak INPFC statistical area were found in the depth stratum of 100–200 m that covers an area of 43,333 km^2 (12,634 nmi^2) (von Szalay et al., 2010). The density estimate for dusky rockfish was 8.8 kg/ha in the depth stratum of 100–200 m from the 2009 bottom trawl survey in the Kodiak INPFC statistical area. Our estimate for dusky rockfish from surveys on Snakehead Bank was 167.1 kg/ha, almost 19 times the value of the estimate from the 2009 bottom trawl survey in the Kodiak INPFC statistical area. The difference between our density estimates for Snakehead Bank and the AFSC estimates from the 2009 bottom trawl survey for the entire statistical area is likely attributable to rockfishes being observed predominantly within untrawlable habitat on Snakehead Bank. About 3% of the substrate in the depth stratum of 100–200 m within the Kodiak INPFC statistical area has been designated as untrawlable by the AFSC for its bottom trawl surveys. It is important to note that the designation of trawlability in the AFSC bottom trawl survey does not necessarily equate to our multibeam trawlability index because, unlike our index, the bottom trawl survey's designation is applied to a grid consisting of cells of predefined size. When the higher densities of dusky rockfish from Snakehead Bank were applied to the untrawlable portion of the Kodiak INPFC statistical area in the depth stratum of 100–200 m, the total abundance within that stratum increased by nearly 60% from 38,000 t to 60,000 t. Similar patterns existed for the other 2 rockfish species. The results from the 2009 bottom trawl survey indicated that the majority of northern (54%) and harlequin (97%) rockfishes were observed in the depth stratum of 100–200 m in the Kodiak INPFC statistical area. The density estimate for northern rockfish on Snakehead Bank was 5 times the estimate from the 2009 bottom trawl survey (depth stratum: 100–200 m), and the estimate for Snakehead Bank harlequin rockfish was nearly 60 times greater.

The high rockfish abundances on Snakehead Bank indicate that a substantial quantity of fishes could be overlooked when trawl catches from trawlable areas are extrapolated to larger areas containing untrawlable habitat. Methods for near-bottom measurement are vital to determine accurate estimates of abundance for bottom-oriented species, but quantification becomes particularly difficult when fishes are in complex habitat inaccessible to both sonar and trawls. For the most accurate population assessments, adjustments must be made that account for the bottom-oriented proportion of the stock residing in these complex habitats.

In our study, 2 methods were applied for estimating near-bottom abundance in complex habitat, one of which is applied in 2 different combinations of depth layers. All of the estimation methods use counts from video images to partition backscatter to species and depth layers. The Ona and Mitson (1996) correction essentially calculates the portion of the water column that lies within the dead zone and extrapolates the amount of backscatter in a specified area above the dead zone into that unknown area. This method assumes similar densities in both the depth layer above and in the dead zone, along with a flat seafloor over the beam width. Yet, as documented in this study, densities can vary within very small distances from the seafloor, and untrawlable areas are, by definition, not flat.

The other method used for estimating abundance in the dead zone relies more on the relative abundance of each species in the dead zone compared to that in the zone above the area where backscatter can reliably be measured. The backscatter was then extrapolated to the dead zone by using the estimated ratio of species relative abundance. This method is much more reliant on estimation of ratios of species relative abundance and the depth layer used in ratios. In our present example, no estimate could be made for harlequin rockfish when the 1.0-m depth layer was used because this species was not present above 1.0 m for extrapolating data down for the dead zone. However, an estimate for harlequin rockfish was possible when the 0.5-m depth layer was used because this species was present in both the depth layers of 0–0.5 m and 0.5–1.0 m.

Abundance estimates calculated in our study rely heavily on video estimates of relative species counts and height off bottom. For that reason, original project plans were to deploy the SDC, ROV, and trawl in the same location successively to obtain a more accurate comparison of their performance. More frequent deployments also were planned, but additional sampling tool deployments and comparisons were not possible because of weather and logistical difficulties.

Rockfishes were associated with carbonate pavements and encountered in the vicinity of bubble seeps (Fig. 7). It is not clear whether this apparent relationship is a result of the particular substrate type in the vicinity of the plumes or the bubble plumes themselves. To help determine the importance of carbonate pavements as rockfish habitat, more observations are needed to characterize this association and describe the geographical distribution of this habitat type in the GOA.

Conclusions

We examined the complexity of methods for obtaining accurate abundance estimates for species that are bottom-oriented and have an affinity for complex habitat. This study shows that an adequate survey of dominant species in untrawlable terrain can be performed with acoustic instruments in conjunction with an SDC-based sampling system. Expanding such a survey to a geographic area larger than the one used in our study would be reasonable once suitable descriptors for substrate habitat classification are employed to characterize an area and enable untrawlable locations to be specifically targeted. Because of the patchy nature of the schooling behavior of fishes and their attraction to specific topographical features, additional targeted camera effort would improve allocation of species distribution and counts. Combined biomass estimates from the trawlable and untrawlable areas would then provide a picture of species abundances that is much more representative over the entire management area than current practice estimates in which only data from trawlable areas are used.

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