Comparison of submersible-survey and hydroacoustic-survey estimates of fish density on a rocky bank

Richard M. Starr*
Sea Grant Extension Program, University of California
Box 440, Moss Landing, California 95039

David S. Fox
Oregon Department of Fish and Wildlife
SE Marine Science Dr., Newport, Oregon 97365

Mark A. Hixon
Department of Zoology, Oregon State University
Corvallis, Oregon 97331-2914

Brian N. Tissot
Marine Science Department, University of Hawaii at Hilo
W. Kawili St., Hilo, Hawaii 96720

Gary E. Johnson
Bonneville Power Administration
P.O. Box 3621, Portland, Oregon 97208

William H. Barss
Oregon Department of Fish and Wildlife
SE Marine Science Dr., Newport, Oregon 97365

Abstract.—Submersible belt-transect surveys along a rocky bottom were combined with acoustic surveys of the water column to estimate depth distribution and density of fishes at Stonewall Bank, Oregon, in the northeastern Pacific Ocean from September through October 1991. The objectives of the study were to determine the proportion of fish in the water column that were not detected by submersible survey techniques and to compare estimates of fish density near the bottom from submersible surveys with density estimates from hydroacoustic surveys. More than 75% of the fishes recorded on acoustic surveys resided in the bottom third of the water column. Rockfishes (family Scorpaenidae) were the predominate fish taxa observed in the study area. Estimates of fish density from submersible surveys were more than six times greater than estimates of fish density near the bottom from hydroacoustic surveys. Submersible and acoustic surveys provided different, but complementary, information regarding the use of rocky banks by fish. Submersible surveys provided estimates of fish density near the bottom and provided valuable ground-truth for acoustic equipment. Hydroacoustic surveys provided estimates of fish density in the portions of the water column not observed on submersible transects and provided additional information on the vertical and horizontal distribution of fishes. The combined use of submersible and acoustic sampling techniques provided a better understanding of how fish use rocky banks than did either technique alone.

Manuscript accepted 14 July 1995.
Fishery Bulletin 94:113–123 (1996).

Large aggregations of fishes are associated with rocky banks along the Pacific coast of North America. Many of these banks are located along the edge of the continental shelf and provide important habitat for commercially and recreationally valuable species (Carlson and Straty, 1981; Nagtegaal, 1983; Pearcy et al., 1989). Fishes harvested from the rocky banks are often associated with bottom habitats, especially fishes in the family Scorpaenidae (rockfishes and their relatives).

Assessment of the distribution and relative abundance of these bottom dwelling fishes is difficult because of the limitations of existing field-sampling techniques. Bottom trawls have been used to assess fishery resources over the continental shelf and along the edge of some offshore rocky banks since the 1970's (Gunderson and Sample, 1980; Leaman and Nagtegaal, 1982; Dark et al., 1983; Weinberg et al., 1984), but rugged topography has precluded the use of trawls for assessing fishes on the tops of the banks. Trawls are also a poor tool for sampling rocky areas (Carlson and Straty, 1981; Butler et al., 1991). A few researchers have successfully sampled rocky areas using

* Affiliated with University of California, Davis, CA 95616.

gill nets but have detected large biases in species and size composition of the catches (Matthews and Richards, 1991).

Acoustic surveys have proven useful in estimating distribution and abundance of many species of fishes in mid-water (e.g. see Karp, 1990), but the techniques require some method of validation (Johannesson and Mitson, 1983). Recently, there has been an interest in developing acoustic methods to survey fishes in rocky areas (Leaman et al., 1990; Richards et al., 1991; Kieser et al., 1993; Phillips, 1994). Assessing fish near the bottom, however, is difficult with acoustic techniques (Mitson, 1983), particularly over rocky habitats. Most echo integrators have difficulty distinguishing between targets near the bottom and bottom echoes in high-relief terrain (Burczynski, 1979). The acoustic shadowing that occurs in high-relief terrain also presents difficulties for echo integrator signal processors. Fishes in the acoustic lee of a rock are often not echo integrated.

In the late 1980's, several investigators began using submersibles to assess fishes inhabiting rocky banks in the northeastern Pacific Ocean (Richards, 1986; Pearcy et al., 1989; Stein et al., 1992; Krieger, 1993; O'Connell and Carlile, 1993; Murie et al., 1994). With the exception of Krieger (1993), these studies were designed to provide information only on fishes closely associated with the bottom. These submersible surveys were successful in assessing fishes associated with bottom habitats but missed an unknown number of fishes swimming above the bottom. For example, Pearcy et al. (1989) noted large schools of fish in the water column that were near the bottom but not counted by the submersible observers.

In this study, we combined submersible and hydroacoustic techniques to estimate more accurately the distribution and relative abundance of fishes on a rocky bank off Oregon. Our objectives were to determine the proportion of fishes in the water column that were not detected with submersibles and to compare estimates of fish density near the bottom from submersible surveys with density estimates generated for the same region from hydroacoustic surveys.

Methods

From 24 September to 3 October 1991, we surveyed fish assemblages on Stonewall Bank, a large (200 km^2), relatively flat, rocky bank located about 22 km southwest of Newport, Oregon (Fig. 1). Stonewall Bank ranges in depth from 41 m to over 75 m and comprises a gently sloping rock bottom with dissected ridges of siltstone and mudstone. We used the research submersible *Delta* to survey fixed stations on the top and side of Stonewall Bank. At three stations, both submersible and acoustic surveys were conducted (Fig. 1).

Submersible surveys

We completed three submersible transects at each of three survey stations. In addition to the nine transect dives, we completed three bounce dives to evaluate large schools in the water column that were detected acoustically. On the bounce dives, the submersible was launched and directed into schools in the middle of the water column. Observers estimated species and size composition of schooling fishes.

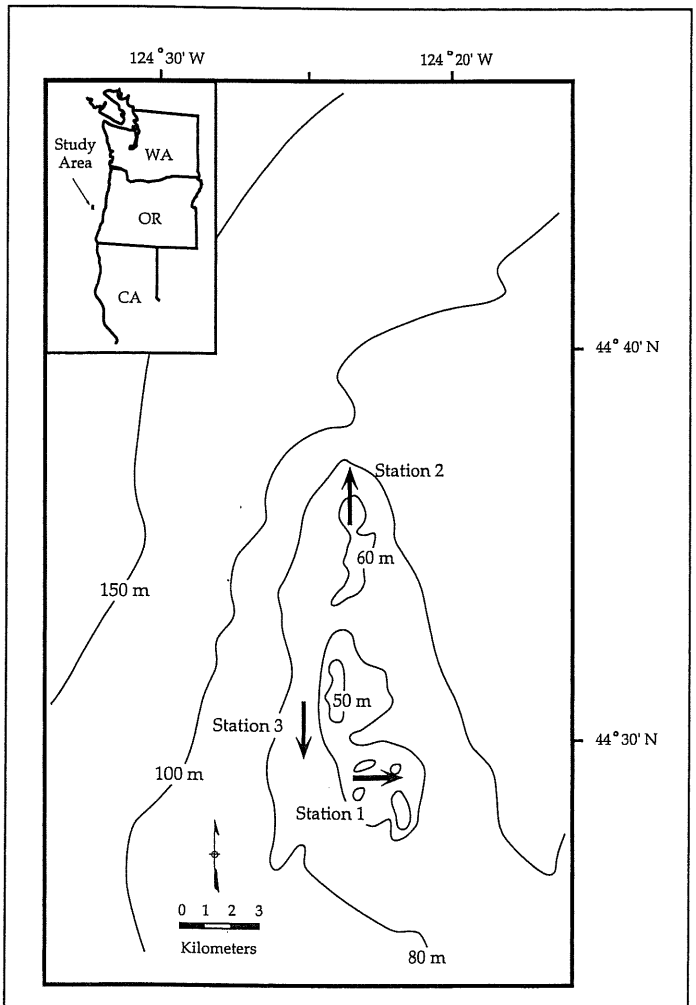

Figure 1

Location of Stonewall Bank off Newport, Oregon, where acoustic and submersible surveys were conducted from September through October, 1991. Arrows indicate the length and direction of transects.

Submersible belt transects followed techniques used in SCUBA surveys (Brock, 1954; Brock, 1982; Ebeling, 1982; Sale and Sharp, 1983; Davis and Anderson, 1989) and in our previous submersible surveys (Pearcy et al., 1989; Stein et al. 1992; Hixon et al.[1]). Each transect consisted of two 30-minute segments, separated by a 10-minute rest period. The submersible started from a preselected location and traveled on a preselected course. Course headings were chosen to keep transects at a uniform depth.

During the transect, the pilot attempted to maintain a constant speed of 3 km·hr^{-1} and a constant altitude of 2 m above the bottom. Actual speed and altitude varied because of the difficulties of piloting the submersible over rough terrain. However, in no case did the submersible observer count fish that were more than 4 m off the bottom. To plot the actual submersible path, the support ship RV *Pirateer* was periodically positioned directly over the submersible by using a Trackpoint II system, and latitude and longitude were recorded with a global positioning system (GPS) receiver.

Submersible observation techniques followed those of Pearcy et al. (1989) and Stein et al. (1992) and are more fully described by Hixon and Tissot.[2] Observers looked forward and downward through a viewing port in the bow of the DSV *Delta* to identify fishes. In addition to identifying fish to species when possible, the observer counted and estimated the sizes of all fish observed to the nearest decimeter. We estimated fish density by dividing the number of fish counted by the area visually surveyed. The area visually surveyed was calculated by multiplying the length of the transect by the width of the average field of view (2.3 m) along the transect.

Acoustic surveys

A total of 14 hours of echo integration and dual-beam target strength data were collected before, during, and after submersible surveys. Acoustic data collected during submersible transects were not usable because of interference from the submersible. Acoustic equipment used in this study included a 120-kHz dual-beam ceramic transducer with nominal beam widths of 10 and 22 degrees deployed in a towed body, a BioSonics Model 101 echosounder with dual 20 log R and 40 log R time-varied-gain receiver board, a Sony digital tape recorder and interface, and a microcomputer used as a signal processor. The microcomputer integrated signals in real time and stored integration values in five-second intervals. Latitude and longitude data obtained from the ship's GPS were automatically written into echo integration files. Dual-beam target strength data were taped concurrently for processing later.

In situ dual-beam methods provide measurements of target strength in the natural environment (Ehrenberg and Lytle, 1977) but can be problematic in surveys of schooling fishes because they require resolution of individual organisms. An alternative method of estimating target strength is to use the mathematical relationship empirically derived by Love (1971, 1977) to relate fish length and intensity of echoes from the dorsal surface of a fish. The relationship, expressed in terms of acoustic frequency, is

$$TS = 19.1 \log (L) - 0.9 \log (f) - 62.0,$$

where TS = target strength in decibels (dB); L = fish length (cm); and f = frequency (kHz).

To avoid the problems associated with dual-beam methods caused by schooling fishes, we chose to use the mean length of fish observed (Love's equation) to scale echo integrator output. Although Love's equation provided the primary method for scaling echo integrator output, we also generated target strength estimates using dual-beam data. We compared target strength estimates obtained from Love's equation (Love, 1971) with those generated by dual-beam acoustic methods by converting the dual-beam estimates of target strength from logarithmic units (decibels) to linear units, using the equation $TS = 10 \log (\sigma)$, where TS = target strength and σ = backscattering cross section, a linear measure of the reflective nature of a target.

Ship speed on transects ranged from 0.5 to 3 m·sec^{-1}; thus integration sequences covered about 3–15 m of linear bottom. In the vertical dimension, we summed echoes in 2-m depth bins from the surface to the bottom. Acoustic surveys provided both areal (fish·m^{-2} over water column sampled) and volumetric (fish·m^{-3}) estimates of fish density.

To compare the submersible and acoustic surveys, we divided the acoustic data into two strata. In one stratum, we summarized the echo integration data collected from the surface to 4 m above the bottom. These data represent fish that were above the area that the submersible surveyed ("above sub" stratum).

[1] Hixon, M. A., B. N. Tissot, and W. G. Pearcy. 1991. Fish assemblages of rocky banks of the Pacific Northwest [Heceta, Coquille, and Daisy Bank]. A final report by the Department of Zoology and College of Oceanography of Oregon State University for the U.S. Department of the Interior, Minerals Management Service Pacific OCS Office, Camarillo, CA.

[2] Hixon, M. A., and B. N. Tissot. 1992. Fish assemblages of rocky banks of the Pacific Northwest [Stonewall Bank]. A final report supplement by the Department of Zoology of Oregon State University for the U.S. Department of the Interior, Minerals Management Service Pacific OCS Office, Camarillo, CA.

As a second stratum, we summarized the acoustic information collected from 4 m above the bottom down to the bottom. These data represent acoustic information collected for the same area that was surveyed by the submersible ("below sub" stratum).

Navigation

The support ship crew navigated using GPS instrumentation with an expected positional accuracy within 100 m (Hurn, 1989). At two stations, submersible observers and pilots saw the same object on subsequent dives. In each case, the object was within a few meters of the intended path of the submersible. Although these observations provided evidence that the navigational precision of the support vessel was better than 100 m, we did not expect the submersible to duplicate the path of a previous dive. Similarly, GPS variation, and wind and sea conditions prevented the support ship from duplicating an acoustic transect. Thus, the acoustic and submersible transects did not cover identical segments of the bottom. Instead, each survey provided three estimates of fish density in a rectangle that was approximately 300 m wide by 2,500 m long (Fig. 2).

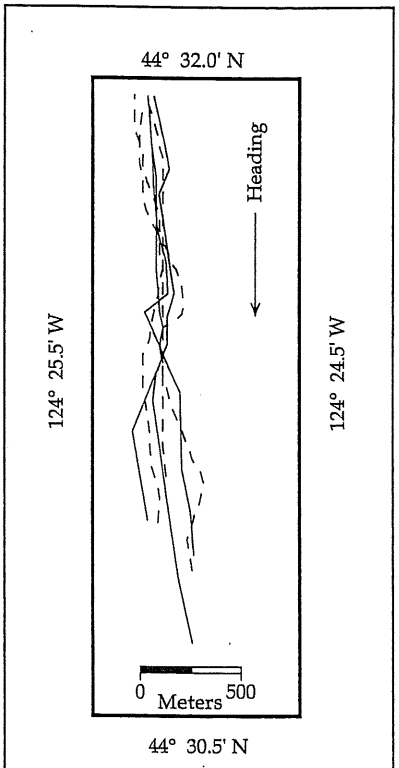

Figure 2

Example of multiple submersible and acoustic transects that occurred at station 3 from September through October 1991, off Newport, Oregon. At this station, submersible and acoustic transects sampled an area 100 m wide by 2,500 m long. Dashed lines indicate acoustic transects. Solid lines represent submersible transects.

Results

Fish species observed

On submersible transects, observers counted a total of 1,928 fish from 28 taxa. Rockfish species accounted for 15 of the taxa observed and 89% of all fishes counted (Table 1). Mean length of fishes observed on submersible transects ranged from 19.3 to 21.0 cm (Table 2). On bounce dives into large schools in the water column, submersible observers saw mixtures of three species: blue (*Sebastes mystinus*), yellowtail (*S. flavidus*), and widow (*S. entomelas*) rockfish. Schools in the middle of the water column all contained large (> 30 cm) adult rockfishes.

Rockfishes observed from the submersible fell into three strata with respect to location in the water column: there were fishes touching the bottom, fishes swimming a short distance (1 m) off the bottom, and fishes schooling well off the bottom. Species such as rosethorn rockfish, *S. helvomaculatus*, were more frequently observed on the bottom or in crevices; species such as redstripe rockfish, *S. proriger*, were more frequently observed swimming singly or in small groups about 1 m off the bottom; and species such as blue and yellowtail rockfish were more commonly observed in small or large schools that extended upward from 1 m off the bottom to past the limit of visibility. Juvenile rockfish of unknown species occasionally occurred in very large schools 1 m or more above the bottom.

Fish density

Estimates of areal density generated by submersible surveys ranged from 76.2 fish·ha^{-1} to 1,101.7 fish·ha^{-1}. Estimates obtained from acoustic surveys of the entire water column ranged from 3.4 fish·ha^{-1} to 5,716.6 fish·ha^{-1} (Table 3). We observed no significant difference in mean fish density between acoustic surveys conducted before and after submersible transects (Wilcoxon paired sample test, n=8, z= –0.14, P=0.89). Mean densities estimated from submersible and acoustic surveys exhibited a significant positive correlation (Kendall Rank Correlation, n =9, τ=0.72, z=2.71, P=0.007).

Table 1

Number of fishes in the ten most abundant taxa observed on submersible dives at Stonewall Bank, Oregon, from September through October 1991.

Scientific name	Common name	Station 1	Station 2	Station 3	Total	Percent	Cumulative percent
Sebastes spp. (juv.)	Rockfish juveniles	103	617	214	934	48.4	48.4
Sebastes mystinus	Blue rockfish	31	0	159	190	9.9	58.3
Sebastes flavidus	Yellowtail rockfish	26	97	64	187	9.7	68.0
Sebastes proriger	Redstripe rockfish	15	56	81	152	7.9	75.9
Sebastes helvomaculatus	Rosethorn rockfish	7	60	59	126	6.5	82.4
Hexagrammos decagrammus	Kelp greenling	15	17	27	59	3.1	85.5
Sebastes pinniger	Canary rockfish	40	2	16	58	3.0	88.5
Sebastes ruberrimus	Yelloweye rockfish	3	21	15	39	2.0	90.5
Rathbunella spp.	Ronquil spp.	1	9	19	29	1.5	92.0
Sebastes entomelas	Widow rockfish	0	0	27	27	1.4	93.4

Table 2

Mean length (cm) of fishes observed from the submersible (sub), target strength (TS in dB) calculated from mean length of observed fishes, and target strengths acoustically measured at Stonewall Bank, Oregon, from September through October 1991.

Station	No. fish observed (sub)	Mean length (cm)	Mean TS[1] (dB)	No. dual-beam targets	Dual-beam TS (dB)	Mean length[2] (cm)
1	280	19.3	–39.4	40	–39.1	19.9
2	902	18.3[3]	–39.8[4]	1224	–36.7	26.6
3	747	21.0	–38.6	1794	–38.7	20.8

[1] Estimated by using Love's equation (Love, 1971).
[2] Calculated by inserting dual-beam TS into Love's equation (Love, 1971).
[3] Mean length of fish estimated from the submersible at station 2 is 11.8 cm if juvenile rockfish from dive 2604 are included in the analysis.
[4] TS equals –43.4 dB if juvenile rockfish from dive 2604 are included in the analysis.

Fish densities estimated acoustically in the "above sub" stratum were on average 15.6 times higher than those in the "below sub" stratum (Table 3). However, submersible surveys indicated that fish density near the bottom was greater than that indicated by acoustic measurements. For the stratum near the bottom, submersible estimates of areal fish density were significantly greater than acoustic estimates of fish density (Wilcoxon paired sample test, n=9, z=–2.67, P=0.008). Fish density estimated from submersible operations was higher in each case than corresponding acoustic estimates (Fig. 3); fish density estimated from submersible transects averaged 6.7 times higher than acoustic density estimates (Table 3).

Fish distribution

At all three stations on Stonewall Bank, more than 75% of the fishes insonified on acoustic surveys were located in the lower third of the water column (Fig. 4). There was no significant difference in depth distribution of fishes between stations (Kruskal Wallis test, df=2, h=0.089, P=0.96). Station 1 was located on the top of Stonewall Bank. The bottom at station 1 was relatively flat bedrock in primarily 50–55 m of water; it contained low relief and few fish. Submersible and acoustic surveys at station 1 exhibited the lowest estimate of fish density generated from the cruise (Table 3). Schools were sparsely distributed (Fig. 5), averaged 11.1 m (SE=1.6) wide, and had a mean vertical thickness of 2.6 m (SE=0.1). Of the fish observed acoustically, 78% were located in the bottom third of the water column (Fig. 4).

Station 2 was located near the north edge of Stonewall Bank, primarily in 60–70 m of water. The bottom at station 2 contained smooth ridges of rock, with occasional scarps 2–3 m high. Submersible observers at station 2 saw few fish, except for occasional

Table 3

Estimates of fish density obtained from acoustic and submersible (sub) surveys of Stonewall Bank, Oregon, from September through October 1991.

	Submersible transects			Acoustic transects	
Station	Max. depth (m)	Density (fish/ha)	Total (fish/ha)	Above sub (fish/ha)	Below sub (fish/ha)
	56	134.0	264.6	227.3	37.3
1	55	76.2	3.4	2.4	1.0
	56	344.3	96.2	55.0	41.2
	69	118.3	32.2	28.7	3.5
2	76	353.9	26.5	15.6	10.9
	73	1101.7	5716.6	5573.5	143.1
	65	418.6	312.9	278.7	34.2
3	59	525.5	1142.1	967.5	174.6
	65	454.1	644.4	563.3	81.1
	Mean	391.9	915.4	856.9	58.5
	Mean[1]	303.1	315.3	267.3	48.0

[1] Mean density without dive 2604 (see text for details).

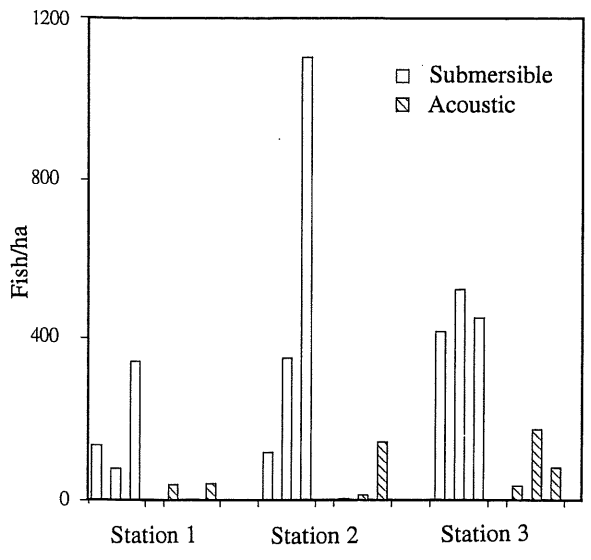

Figure 3

Comparison of submersible estimates of fish density near the bottom with acoustic estimates of fish density from 4 m above the bottom to the bottom for surveys conducted from September through October 1991, off Newport, Oregon.

very large schools of juvenile rockfish. The large schools of juvenile rockfish observed at station 2 created an anomalously high density estimate derived from one submersible transect (Table 3). Similarly, acoustic surveys showed few fish, except for occasional large schools that were situated near the bottom (Fig. 5). Schools were on average 32.2 m (SE=1.8) wide, and had an average vertical thickness of 3.8 m (SE=0.2). Of the fish observed acoustically, 93% were located in the bottom third of the water column (Fig. 4).

Station 3 was located near the west edge of Stonewall Bank in primarily 50–60 m of water. The bottom at station 3 contained more vertical relief than other stations. It comprised numerous rock ridges with 3–4 m high scarps. Submersible observers saw small schools of unidentified juvenile rockfish, and large schools of blue rockfish, yellowtail rockfish, canary rockfish (*Sebastes pinniger*), and widow rockfish. Acoustic transects also recorded more fish at station 3 than at other stations. Schools were on average 34.5 m (SE=1.1) wide, and had an average thickness of 4.1 m (SE=0.2) (Fig. 5). Of the fish observed acoustically, 79% were located in the bottom third of the water column (Fig. 4).

Target strength estimates

Target strength estimated from Love's equation ranged from –38.6 to –43.4 decibels (dB) (Table 2). Target strength estimated from dual-beam analysis ranged from –36.7 to –39.1 dB. Back-scattering cross section estimated from dual-beam analysis were 1.1 and 1.0 times, respectively, that estimated from Love's equation at stations 1 and 3 (Table 4). At station 2, dual-beam methods provided a back-scattering cross section that was 4.8 times higher than the back-scattering cross section estimated from Love's equation.

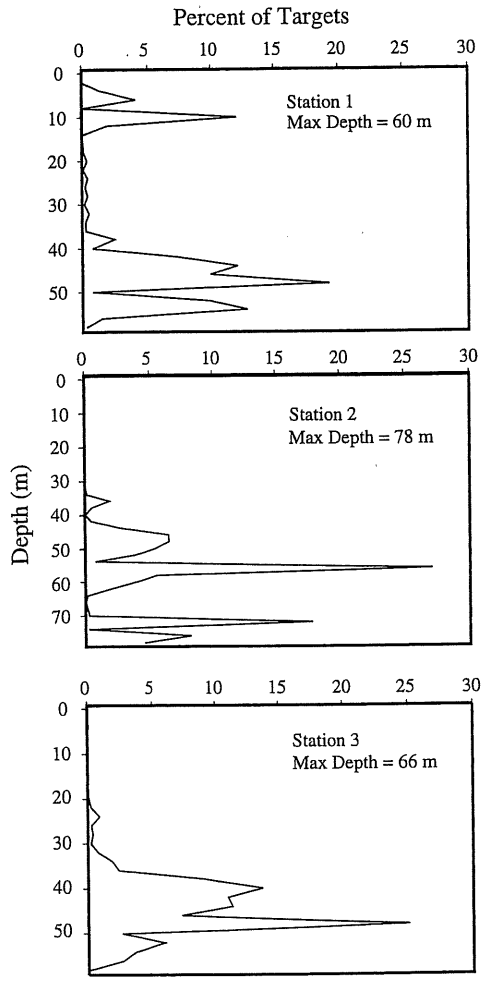

Figure 4

Vertical distribution of fishes insonified at stations 1–3 during acoustic surveys conducted from September through October 1991, off Newport, Oregon.

Table 4

Comparison of backscattering cross section (σ) from dual-beam estimates (DB σ) and from Love's equation (Sub σ). Target strength (TS) was converted to backscattering cross section (σ) by using the equation $TS = 10 \text{ Log } \sigma$.

Station	DB σ	Sub σ	DB σ/Sub σ
1	0.000123	0.000116	1.06 (0.65)[1]
2	0.000214	0.000045	4.76 (2.04)[1]
3	0.000135	0.000138	0.98 (0.56)[1]

[1] Ratio of DB σ/Sub σ using mean lengths of nonschooling fishes only (see text for details).

Discussion

Comparison of submersible and acoustic surveys

On the basis of our previous submersible surveys of rocky banks off Oregon and anecdotal information from sport and commercial fishers, we expected to observe demersal rockfishes from the submersible and to insonify large schools of rockfishes in the water column well above the rocky substrate of Stonewall Bank. Data collected from submersible transects and bounce dives did indicate that rockfishes were the predominate fish taxa inhabiting Stonewall Bank at the time of the surveys. However, most schools appeared to be associated with bottom features and were not isolated in the middle of the water column. Most large schools of fishes extended from the bottom upward for as much as 20 m into the water column, and submersible observers were able to view the lower portions of these schools.

The extension of rockfish schools from the bottom upwards into the water column has been reported from other submersible surveys. Krieger (1993) visually surveyed an area from 0 to 10 m above the bottom and noted that Pacific ocean perch, *Sebastes alutus,* ranged from 0 to 7 m above the bottom. He observed that small groups of rockfishes were close to the bottom, whereas larger groups were higher off the bottom. Krieger observed no rockfish schools higher in the water column than 7 m above the bottom. Researchers in Alaska (O'Connell and Carlile, 1993), British Columbia (Murie et al., 1994), Oregon (Pearcy et al., 1989; Stein et al., 1992), and California (Yoklavich et al., 1995) also observed schools of semipelagic rockfishes above high-relief bottom features.

"Plumes" of rockfish rising above pinnacles are readily apparent on echograms from our acoustic surveys (Fig. 5). Wilkins (1986) described this characteristic shape for widow rockfish schools as tall, narrow columns rising over an irregular bottom. Richards et al. (1991) developed techniques to estimate species composition of rockfishes in the plume from the patterns of acoustic signals. They suggested that computer processing of acoustic signals could lead to a remotely operated technique for species identification of schooling rockfishes. Acoustic identification of rockfish species would improve acoustic surveys and seems possible, given the characteristic acoustic shape of rockfish schools. However, single species aggregations were atypical in our study. Species discrimination based on acoustic pattern recognition would have been difficult, although we were able acoustically to identify aggregations of mixed

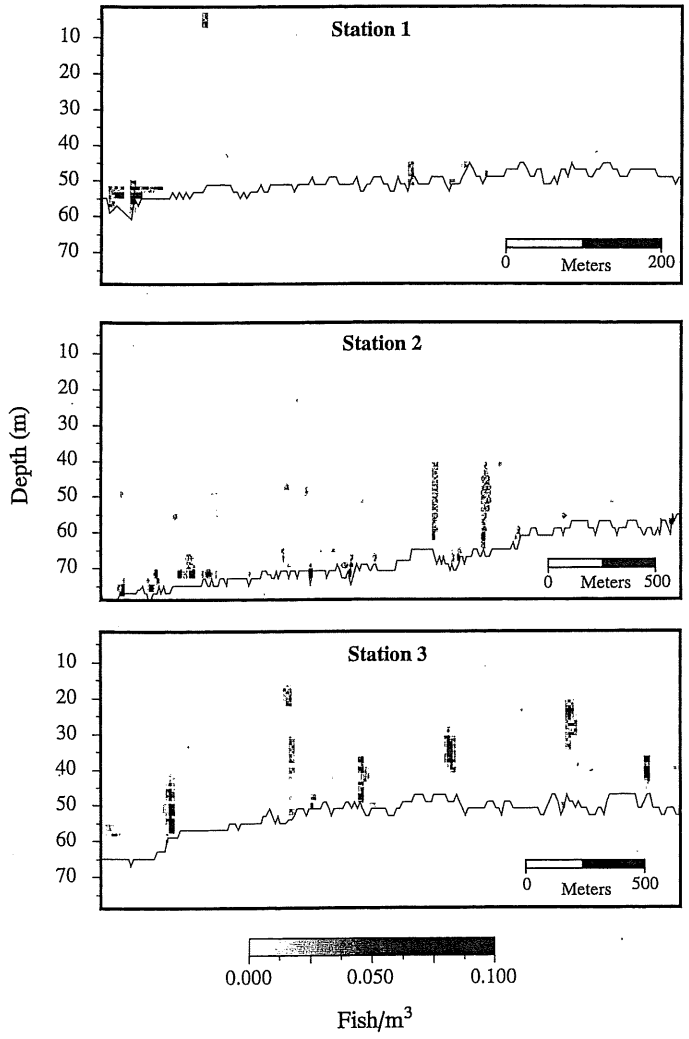

Figure 5

Examples of the density and distribution of fish schools recorded by sonar at stations 1–3 during acoustic surveys conducted from September through October 1991, off Newport, Oregon. Bottom depth is depicted by the solid line and fish densities are indicated by shaded areas.

species of rockfishes. Submersible observations contributed greatly to the acoustic surveys because species composition of large schools could be characterized once they had been located acoustically.

Acoustic surveys enabled us to quantify the vertical distribution of fishes and to determine the proportion of fishes not detected by the submersible surveys. Although several researchers have noticed an avoidance of survey vessels by mid-water fishes (e.g. Olsen et al., 1983; Misund, 1990; Ona and Godø, 1990), we observed no difference between acoustic surveys conducted before and after submersible transects. The affinity that most rockfishes have for bottom features may make them less likely to actively avoid a vessel passing overhead. At all stations, fishes recorded by acoustic equipment were located primarily in the lower third of the water column, often above rock scarps or pinnacles. This pattern occurred in all acoustic transects and is similar to observations of fish density increasing with depth for both shallow and deep water rockfishes (Hallacher and Roberts, 1985; Leaman et al., 1990; Love et al., 1991; Richards et al., 1991; Sullivan, 1991).

The acoustic estimate of mean areal density in the "above sub" stratum was 2.3 times greater than the mean submersible estimate of fish density. Submersible surveys, therefore, accounted for almost one-third of the fishes inhabiting Stonewall Bank during the time of the study. However, the mean density estimates of both submersible and acoustic surveys were each greatly affected by one transect. Submersible and "above sub" acoustic estimates of fish density were more similar when two transects that skewed the mean were removed from analysis (Table 3). On dive 2604 at station 2, the submersible observer recorded several large schools of juvenile rockfishes. Similarly, large, patchy schools were detected on the accompanying acoustic transect. We assumed that the high fish densities associated with these transects were due to the presence of schools of juvenile rockfishes. After removing these data from the analysis, density estimates from the submersible transects were 14% higher than those generated acoustically for the "above sub" stratum, suggesting that the relative abundance of adult rockfishes was approximately equal above and below the level of the submersible.

The estimates of fish density generated from submersible transects were more than six times those from acoustic surveys for the same depth stratum. This difference reflects the inherent limitations of acoustic sampling in rocky, high-relief locations and demonstrates the influence of sampling method on survey results. Pearcy et al. (1989) and Stein et al. (1992) observed rockfish species over a variety of benthic habitats ranging from smooth mud to high-relief rock and also reported schools of rockfishes in the water column. Given the variety of habitats in which rockfishes are located, it appears that several sampling tools are needed to assess their relative abundance.

Trawls have historically been used to assess fish abundance over smooth bottoms. Weinberg (1994),

however, documented high variability in trawl survey estimates of rockfish abundance and implied that trawl surveys may not adequately estimate rockfish abundance. Krieger (1993) compared trawl and submersible estimates of rockfish abundance on flat bottoms and came to the same conclusion. He suggested that on flat terrain, trawl surveys overestimate rockfish abundance because bridles and otter doors herd rockfish into a trawl and bias density estimates. Adams et al. (1995) found remotely operated vehicle (ROV) surveys to be better than trawl surveys for benthic species on flat bottoms. They reported that ROV estimates of fish density were higher and had lower coefficients of variation than did trawl estimates. For rockfishes swimming off the bottom, however, the reverse was true. Trawls yielded better estimates of rockfish density and densities of other species with patchy distributions and off-bottom behavior. Despite the improvement in estimates, Adams et al. (1995) suggested that neither ROV nor trawl methods adequately assessed off-bottom rockfishes. Both Krieger (1993) and Adams et al. (1995) acknowledged that trawls are poor tools for assessing rockfishes on high-relief terrain. Kulbicki and Wantiez (1990) compared trawl surveys with diver observations and determined that trawl surveys and direct observations each have biases that are dependent upon habitat usage by different fishes. In their study, species size, shape, coloration, and swimming habits greatly influenced the ratio of diver to trawl density estimate. Thus, a combination of survey methodologies is probably needed to estimate adequately the abundance of many fish species. A similar conclusion was reached by Uzmann et al. (1977) in comparing submersible, camera sled, and otter trawl techniques.

Acoustic target strength analysis

The target strength of a fish is dependent upon a variety of factors, including the size of the fish, its orientation to the acoustic signal, and its swimbladder characteristics (Ehrenberg and Lytle, 1977). Of particular importance is the orientation of the fish to the acoustic signal. Small changes in the tilt angle of a fish caused by differences in fish behavior can cause large changes in target strength. Traynor and Williamson (1983), for example, estimated a 3-dB difference in target strength of fishes due to day-night differences in behavior. Dual-beam echo processing methods can resolve many of the problems associated with differences in fish orientation (Traynor and Williamson, 1983) but require the resolution of individual targets. Dual-beam methods cannot estimate target strength in the case of overlapping echoes, such as those produced by schooling fish.

We chose to use the mean length of fish observed (Love's equation) instead of dual-beam methods to scale echo integrator output for two reasons. First, the number of individual, nonoverlapping targets needed for dual-beam analysis was relatively small in several of the acoustic transects (Table 2). Second, Traynor et al. (1990) suggested that target strength estimates of schooling fish may not accurately reflect the actual size of fish insonified because the equipment measures fish on the periphery of the schools. Fish on the periphery of schools may not be the same size as fish in the center of the school or may be exhibiting different behavior (orientation).

Although Love's equation was the primary means of scaling echo integrator data, we calculated dual-beam target strength as well. Target strength estimated from Love's equation included schooling fish. Dual-beam analysis, however, included only nonoverlapping echoes, i.e. those fish not in a school. At stations with few schools, the back-scattering cross sections obtained from dual-beam analysis were almost identical to the back-scattering cross sections derived from the mean length of observed fishes (Table 4). At station 2, where large schools of juvenile rockfishes occurred, the back-scattering cross section estimated from dual-beam methods was 4.8 times higher than estimates from Love's equation. When the mean length of only nonschooling fishes was used in Love's equation at station 2, the dual-beam estimate and Love's equation estimate of target strength were more similar.

In this study, a combination of two survey methods provided a better estimate of the distribution and relative abundance of rockfishes than did either method alone. Submersible surveys yielded estimates of fish density near the bottom as well as information used to provide ground truth for acoustic surveys and to scale echo integrator values. Acoustic equipment enabled portions of the water column not observed on submersible transects to be surveyed and provided additional information on the vertical and horizontal distribution of fishes.

Acknowledgments

Funding for submersible work was provided by NOAA's West Coast National Undersea Research Center, Fairbanks, Alaska. We thank the crew of the DSV *Delta* and the crew of its support ship for their work at sea. Bob Hannah, Mary Yoklavich, and two anonymous reviewers provided helpful reviews of the manuscript. This paper was funded in part by a grant from the National Sea Grant College Program, National Oceanic and Atmospheric Administration, U.S.

Department of Commerce, under grant number NA 89AA-D-SG138, through the California Sea Grant College.

Literature cited

Adams, P. B., J. L. Butler, C. H. Baxter, T. E. Laidig, K. A. Dahlin, and W. W. Wakefield.
1995. Population estimates of Pacific coast groundfishes from video transects and swept-area trawls. Fish. Bull. 93:446–455.

Brock, R. E.
1982. A critique of the visual census method for assessing coral reef fish populations. Bull. Mar. Sci. 32:269–276.

Brock, V. E.
1954. A preliminary report on a method of estimating reef fish populations. J. Wildl. Manage. 18:297–308.

Butler, J. L., W. W. Wakefield, P. B. Adams, B. H. Robinson, and C. H. Baxter.
1991. Application of line transect methods to surveying demersal communities with ROVs and manned submersibles. Oceans 91 Conference Proceedings, Vol. 2, p. 689–696.

Burczynski, J.
1979. Introduction to the use of sonar systems for estimating fish biomass. FAO Fish. Tech. Pap. 191, 89 p.

Carlson, H. R., and R. R. Straty.
1981. Habitat and nursery grounds of Pacific rockfish, *Sebastes* spp., in rocky coastal areas of southeastern Alaska. Mar. Fish. Rev. 43(7):13–19.

Dark, T. A., M. E. Wilkins, and K. Edwards.
1983. Bottom trawl survey of canary rockfish (*Sebastes pinniger*), yellowtail rockfish (*S. flavidus*), bocaccio (*S. paucispinis*), and chilipepper (*S. goodei*) off Washington-California, 1980. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-48, 40 p.

Davis, G. E., and T. W. Anderson.
1989. Population estimates of four kelp forest fishes and an evaluation of three *in situ* assessment techniques. Bull. Mar. Sci. 44:1138–1151.

Ebeling, A. W.
1982. Scuba diver observations and statistical analysis. *In* C. M. Dewees (supervising ed.), Guidelines for marine ecological surveys, nekton, p. 6–9. California Sea Grant College Mar. Adv. Prog., Univ. California, Davis.

Ehrenberg, J. E., and D.W. Lytle.
1977. Some signal processing techniques for reducing the variance in acoustic stock abundance estimates. Rapp. P.-V. Reun. Cons. Int. Explor. Mer, Vol. 170, p. 196–204.

Gunderson, D. R., and T. M. Sample.
1980. Distribution and abundance of rockfish off Washington, Oregon, and California during 1977. Mar. Fish. Rev. 42(3–4):2–16.

Hallacher, L. E., and D. A. Roberts.
1985. Differential utilization of space and food by the inshore rockfishes (Scorpaenidae: *Sebastes*) of Carmel Bay, California. Environ. Biol. Fish. 12:91–110.

Hurn, J.
1989. GPS, a guide to the next utility. Trimble Navigation, Sunnyvale, CA, 76 p.

Johannesson, K. A., and R. B. Mitson.
1983. Fisheries acoustics: a practical manual for aquatic biomass estimation. FAO Fish. Tech. Pap. 240, 249 p.

Karp, W. A., ed.
1990. Developments in fisheries acoustics: a symposium held in Seattle, 22–26 June 1987. Rapp. P.-V. Reun. Cons. Int. Explor. Mer, Vol. 189, 442 p.

Kieser, R., R. J. Mulligan, L. J. Richards, and B. M. Leaman.
1993. Bias correction of rockfish school cross section widths from digitized echo sounder data. Can. J. Fish. Aquat. Sci. 50:1801–1811.

Krieger, K. J.
1993. Distribution and abundance of rockfish determined from a submersible and by bottom trawling. Fish. Bull. 91:87–96.

Kulbicki, M., and L. Wantiez.
1990. Comparison between fish bycatch from shrimp trawlnet and visual censuses in St. Vincent Bay, New Caledonia. Fish. Bull. 88:667–675.

Leaman, B. M., and D. N. Nagtegaal.
1982. Biomass estimation of rockfish stocks off the west coast of the Queen Charlotte Islands during 1978 and 1979. Can. Manuscr. Rep. Fish. Aquat. Sci. 1652, 47 p.

Leaman, B. M., R. Kieser, P. Withler, and R. D. Stanley.
1990. *W.E. Ricker* hydroacoustic cruise to study rockfish behaviour off Northern Vancouver Island; 14–23 March 1990. Can. Manuscr. Rep. Fish. Aquat. Sci. 2091, 63 p.

Love, M. S., M. H. Carr, and L. J. Haldorson.
1991. The ecology of substrate-associated juveniles of the genus *Sebastes*. Environ. Biol. Fishes 30:225–243.

Love, R. H.
1971. Dorsal-aspect target strength of an individual fish. J. Acoust. Soc. Am. 49(3):816–823.
1977. Target strength of an individual fish at any aspect. J. Acoust. Soc. Am. 62:1397–1403.

Matthews, K. R., and L. J. Richards.
1991. Rockfish (Scorpaenidae) assemblages of trawlable and untrawlable habitats off Vancouver Island, British Columbia. N. Am. J. Fish. Manage. 11:312–318.

Misund, O. A.
1990. Sonar observations of schooling herring: school dimensions, swimming behavior, and avoidance of vessel and purse seine. Rapp. P.-V. Reun. Cons. Int. Explor. Mer, Vol. 189, p. 135–146.

Mitson, R. B.
1983. Acoustic detection and estimation of fish near the seabed and surface. FAO Fish. Rep. 300, p. 27–34.

Murie, D. J., D. C. Parkyn, B. G. Clapp, and G. G. Krause.
1994. Observations on the distribution and activities of rockfish, *Sebastes* spp., in Saanich Inlet, British Columbia, from the *Pisces IV* submersible. Fish. Bull. 92:313–323.

Nagtegaal, D. N.
1983. Identification and description of assemblages of some commercially important rockfishes (*Sebastes* spp.) off British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 1183, 82 p.

O'Connell, V. M., and D. W. Carlile.
1993. Habitat-specific density of adult yelloweye rockfish *Sebastes ruberrimus* in the eastern Gulf of Alaska. Fish. Bull. 91:304–309.

Olsen, K., J. Angell, and A. Louik.
1983. Quantitative estimations of the influence of fish behavior on acoustically determined fish abundance. *In* O. Nakken and S. C. Venema (eds.), Symposium on fisheries acoustics. Selected papers of the ICES/FAO symposium on fisheries acoustics; 21–24 June 1982, Bergen, Norway, p. 139–148. FAO Fish. Rep. 300, 331 p.

Ona, E., and O. R. Godø.
1990. Fish reaction to trawling noise: the significance for trawl sampling. Rapp. P.-V. Reun. Cons. Int. Explor. Mer, Vol. 189, p. 159–166.

Pearcy, W. G., D. L. Stein, M. A. Hixon, E. K. Pikitch, W. H. Barss, and R. M. Starr.
1989. Submersible observations of deep-reef fishes of Heceta Bank, Oregon. Fish. Bull. 87:955–965.

Phillips, S. (compiler).
1994. Report of the nearshore rockfish management workshop; 1–2 March, 1994, Portland, Oregon. Pacific States Mar. Fish. Comm. Rep., Gladstone, OR, 32 p.

Richards, L. J.
1986. Depth and habitat distributions of three species of rockfish (*Sebastes*) in British Columbia: observations from the submersible *PISCES IV*. Environ. Biol. Fishes 17(1):13–21.

Richards, L. J., R. Kieser, T. J. Mulligan, and J. R. Candy.
1991. Classification of fish assemblages based on echo integration surveys. Can. J. Fish. Aquat. Sci. 48:1264–1272.

Sale, P. F., and B. J. Sharp.
1983. Correction for bias in visual transect censuses of coral reef fishes. Coral Reefs 2:37–42.

Stein, D. L., B. N. Tissot, M. A. Hixon, and W. Barss.
1992. Fish-habitat associations on a deep reef at the edge of the Oregon continental shelf. Fish. Bull. 90:540–551.

Sullivan, P. J.
1991. Stock abundance using depth-dependent trawls and spatially correlated variation. Can. J. Fish. Aquat. Sci. 48:1691–1703.

Traynor, J. J., and N. J. Williamson.
1983. Target strength measurements of walleye pollock (*Theragra chalcogramma*) and a simulation study of the dual beam method. *In* O. Nakken and S. C. Venema (eds.), Symposium on fisheries acoustics: selected papers of the ICES/FAO symposium on fisheries acoustics; 21–24 June 1982, Bergen, Norway, p.139–148. FAO Fish. Rep. 300.

Traynor, J. J., N. J. Williamson, and W. A. Karp.
1990. A consideration of the accuracy and precision of fish-abundance estimates derived from echo-integration surveys. Rapp. P.-V. Reun. Cons. Int. Explor. Mer, Vol. 189, p. 101–111.

Uzmann, J. R., R. A. Cooper, R. B. Theroux, and R. L. Wigley.
1977. Synoptic comparison of three sampling techniques for estimating abundance and distribution of selected megafauna: submersible vs. camera sled vs. otter trawl. Mar. Fish. Rev. 39(12):11–19.

Weinberg, K. L.
1994. Rockfish assemblages of the middle shelf and upper slope off Oregon and Washington. Fish. Bull. 92:620–632.

Weinberg, K. L., M. E. Wilkins, and T. A. Dark.
1984. The 1983 Pacific west coast bottom trawl survey of groundfish resources: estimates of distribution, abundance, age and length composition. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/NWC-70, 376 p.

Wilkins, M. E.
1986. Development and evaluation of methodologies for assessing and monitoring the abundance of widow rockfish, *Sebastes entomelas*. Fish. Bull. 84:287–310.

Yoklavich, M. M., G. M. Cailliet, H. G. Greene, and D. Sullivan.
1995. Interpretation of side-scan sonar records for rockfish habitat analysis: examples from Monterey Bay. *In* Proceedings of workshop on applications of side-scan sonar and laser-line systems in fisheries research, p. 11–15. Alaska Dep. Fish Game, Spec. Publ. 9.