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ABSTRACT: Rockfish *Sebastes* spp. abundances were assessed acoustically using echo integration and compared to rockfish catch rates using a bottom trawl. Twenty-three sites were assessed acoustically and trawled simultaneously at depths of 177–294 m in the eastern Gulf of Alaska. The acoustics sampled depths from 0.5 to 25.5 m above the seafloor, whereas the bottom trawl sampled depths from the seafloor to 10 m above the seafloor. Rockfish were the primary species caught in the trawls, and 93% of the rockfish consisted of 4 species: Pacific ocean perch *S. alutus* (53%), redstripe rockfish *S. proriger* (18%), silvergray rockfish *S. brevispinis* (12%), and sharpchin rockfish *S. zacentrus* (10%). Rockfish catch rates were 1,524–17,493 kg/h at 6 sites with rockfish schools and were 10–1,153 kg/h at 17 sites with solitary rockfish and no schools. A significant relationship between rockfish catch rates C and acoustic indices A was best explained by the multiplicative model $C = 4.32\ A^{0.83}$ ($r^2 = 0.69$, $P < 0.001$), indicating that acoustics can be used to assess rockfish abundance.

INTRODUCTION

At least 30 rockfish species of the genus *Sebastes* inhabit waters of the Gulf of Alaska (GOA; Eschmeyer et al. 1983). The most abundant rockfish species concentrate on the outer continental shelf at depths of 150–300 m and are fished commercially, mainly with bottom trawls. Pacific ocean perch *S. alutus* is the most abundant species and has provided most of the commercial catch. The GOA rockfish fishery was exploited heavily in the 1960s by the Soviet and Japanese trawl fleets; catches peaked in 1965 at 350,000 t. By the late 1970s rockfish catches had declined to less than 10,000 t and catch per unit effort (CPUE) had decreased by 80% (Balsiger et al. 1985). The rockfish fishery in the GOA is currently managed for a domestic catch of approximately 30,000 t based on stock assessments that partially rely on biomass estimates derived from bottom-trawl surveys (Heifetz et al. 1999).

Current assessment of rockfish in the GOA is controversial because of uncertainty in survey results (Quinn et al. 1999). For example, biomass estimates for Pacific ocean perch from bottom-trawl surveys were 214,800, 138,000, 460,800, 778,700, and 727,000 t in 1987, 1990, 1993, 1996, and 1999 (Heifetz et al. 1999). The variability in these estimates probably does not reflect changes in abundance because these rockfish grow slowly and have low mortality rates. In addition, some of these estimates are associated with wide confidence limits. Leaman and Nagtegaal (1986) noted their dissatisfaction with rockfish bottom-trawl surveys because of wide confidence intervals associated with biomass estimates and because the biomass estimates may be grossly in error. Because bottom trawls appear to be an effective method of sampling rockfish over trawlable substrates (Krieger and Sigler 1996), the inaccurate and imprecise estimates from trawl surveys is likely due to the patchy and dynamic distribution of rockfish and their changing availability to the sampling gear as a function of location and time (Kieser et al. 1992). Consequently, methods other than bottom-trawl surveys are needed for stock assessments of offshore rockfish.

In this study we evaluate the use of a calibrated sonar echosounding system combined with echo integration to quantify rockfish abundance. Such a sys-

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tem could improve rockfish assessments because it is not substrate-limited and can sample large geographical areas. Echosounding has been used by fishermen and scientists for many years to monitor rockfish populations. Fishermen used echosounding to locate and qualitatively map rockfish schools on chart recordings before 1970 (Major and Shippen 1970). Scientists used a combination of sonar echograms and trawl surveys throughout the northeastern Pacific Ocean during 1963–1966 to investigate the distribution and abundance of rockfish, and the high catch rates that commonly exceeded 4,500 kg/h were due in part to trawling on sonar-detected fish (Westrheim 1970). Leaman and Nagtegaal (1986) estimated rockfish abundance by mapping rockfish aggregations with sonar and then subsampling the aggregations using trawl nets.

Calibrated echosounding systems combined with echo integration (acoustics) have been used extensively since the 1960s to quantify fish abundance (Misund 1997). Acoustics have been used in a few rockfish studies to distinguish among rockfish species (Richards et al. 1991), to quantify the above-bottom rockfish that could not be quantified from a submersible (Starr et al. 1996), for exploratory surveys of rockfish on the western coast of Canada (Kieser et al. 1993; Hand et al. 1995), and to explore the effect of diel behavior on biomass estimates of rockfish (Stanley et al. 1999). Acoustics have been used sparingly to assess rockfish abundance for several reasons: (1) rockfish distribute both on the seafloor (undetectable with sonar) and above the seafloor; (2) species other than rockfish may be abundant above the seafloor; (3) reliable population estimates of rockfish were not available for calibrating acoustic data; and (4) the reflection properties (target strengths) of rockfish used for converting acoustic backscatter to absolute biomass were not known.

In this study we acoustically quantified near-bottom fish targets for comparison to bottom-trawl catch rates in the eastern GOA. Based on previous in situ studies of rockfish in the eastern GOA, we assumed that most near-bottom fish are rockfish and that bottom trawling effectively sampled the rockfish (Krieger 1993; Krieger and Sigler 1996). The main objective was to determine whether acoustic backscatter from near-bottom fish targets is related to bottom-trawl catch rates of rockfish.

MATERIALS AND METHODS

This study was conducted in August 1993 on the outer continental shelf between lat. 54°N and 56°N in the eastern GOA (Figure 1). Trawl sites ($n = 23$) were selected randomly from a bottom-trawl survey conducted every 3 years. Bottom trawling and acoustic sampling were completed simultaneously from the NOAA ship *Miller Freeman*. Because the trawl sampled approximately 500 m behind the vessel and the acoustics sampled directly below the vessel, acoustic sampling began when the trawl gear was deployed so that the same path was sampled with acoustics and trawling. Rockfish probably react to trawl gear by diving to the seafloor (Krieger and Sigler 1996), but how close to the trawl gear they react is unknown. To determine whether rockfish beneath the vessel had reacted to the trawl gear 500 m away, they were acoustically sampled before trawling and compared to acoustic samples during trawling using a 2-sided paired t test. Trawling was during daylight, between 0800 and 2000 hours.

Bottom Trawling

A high-opening, polyethylene Nor'eastern trawl was used for bottom trawling. This trawl had a 27.2-m headrope, a 24.9-m footrope, mesh that stretched to 12.7 cm, and a codend liner with mesh that stretched to 3.2 cm. Triple dandy lines on each side, 54.9 m long, connected the net to a pair of steel "V" doors measuring 1.8 m by 2.7 m and weighing 998 kg. Rubber bob-

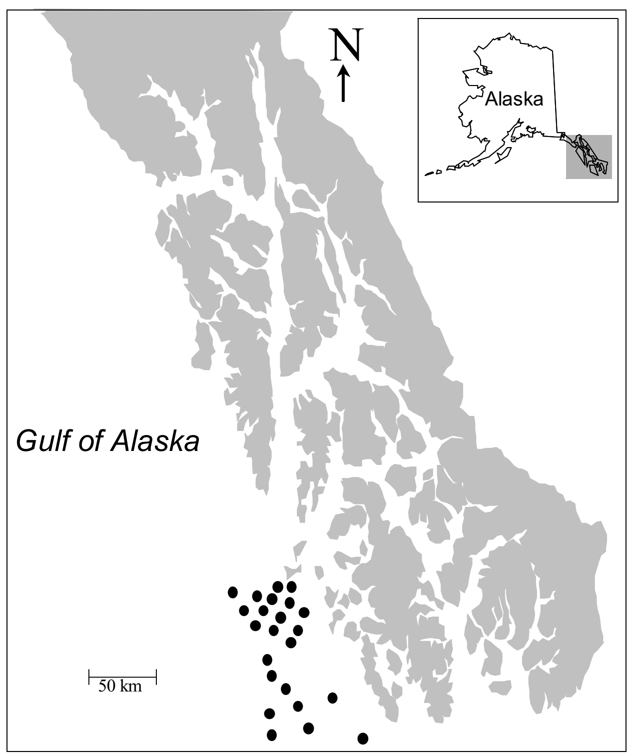

Figure 1. Location of 23 sites sampled with bottom trawls and acoustics in the eastern Gulf of Alaska, August 1993.

bins 36 cm in diameter and separated by 10-cm diameter rubber disks were attached to the footrope. A net-mensuration system was attached to the wingtips of the trawl; the net width for individual hauls ranged from 13 to 18 m. The net height, measured from footrope to headrope in previous studies, ranged from 8 to 10 m (NMFS 1997). Trawl duration was measured from the time the net reached bottom until the net departed the seafloor during retrieval; a sonar net-sounder attached to the trawl was used to monitor the location of the net with respect to the seafloor. Standard trawl times were 30 min, or less if the ship's echosounder indicated rough bottom or large quantities of fish. Trawl hauls of at least 10-min duration were compared to acoustics if the trawl gear was retrieved intact (no tears in the net or broken cables). Trawl distances and trawl speeds were calculated from global positioning system fixes. Trawl catches were processed for total number of fish and weight by species, and the catch rate (kilograms per hour) of each species was calculated.

Acoustic Sampling

Acoustic data were collected with a 38-kHz Simrad EK500 quantitative sonar system (Bodholt et al. 1989). The transducer was mounted on the vessel's centerboard, placing the transducer at 9-m depth. An acoustic value was computed for each transmitted ping that represents the mean volume backscattering (S_v) from all targets within a 25-m depth interval. This interval began 0.5 m above the seafloor to exclude integration of the seafloor and extended to 25.5 m above the seafloor to include the off-bottom range of Pacific ocean perch observed from a submersible (Krieger 1993). Backscatter values that exceeded a minimum threshold were summed and then divided by the total number of values to produce relative indices of abundance; the threshold value excluded backscatter from zooplankton. The acoustic indices were compared directly to bottom-trawl catch rates. Quantitative, colored echograms provided visual presentation of the density and distribution of fish targets. The relationship between acoustic indices and rockfish catch rates was examined using regression analysis (Sokal and Rohlf 1981).

RESULTS

Rockfish Reaction to Trawling

Seven of the 23 sites were sampled acoustically before and during trawling. Echograms of the off-bottom distribution of rockfish before and during trawling were not significantly different (2-sided paired *t* test, $P = 0.89$; Table 1). These comparisons indicate that rockfish beneath the vessel probably had not yet responded to bottom-trawl gear that was 500 m away. Some variation of acoustic indices within sites was expected because survey paths could not be duplicated exactly due to tides and winds.

Table 1. Acoustic indices of rockfish abundance before trawling and during trawling in the eastern Gulf of Alaska, August 1993.

Site	Acoustic Indices	
	Before Trawling	During Trawling
3	6,190	5,690
4	1,330	3,580
9	290	100
10	340	170
14	900	220
15	67	80
20	430	62

Catch Composition

The depths ranged from 177–294 m at the 23 sites where catch data and acoustic data were compared (Table 2). Eighteen sites were trawled for 30 min, and 5 for less than 30 min because of high-density echo signals (sites 1 and 3) or rugged substrates (sites 2, 18, and 20). Trawl speeds averaged 5.2–6.8 km/h, and trawl distances ranged from 0.9 km for a 10-min trawl to 3.4 km for a 30-min trawl. Rockfish were captured at all sites, and catch rates ranged from 10 to 17,493 kg/h (Table 2). Rockfish biomass was 77% of the total fish biomass from the 23 trawl hauls and averaged 89% of the fish biomass at the 11 sites where rockfish catch rates exceeded 200 kg/h. Four rockfish species accounted for 93% of the rockfish catch: Pacific ocean perch (53%), redstripe rockfish *S. proriger* (18%), silvergray rockfish *S. brevispinis* (12%), and sharpchin rockfish *S. zacentrus* (10%; Table 2). All sites contained either solitary rockfish or schools of rockfish and solitary rockfish (Figure 2).

Comparison of Catches and Acoustics

Acoustic indices of relative abundance ranged from 10 to 19,850 (Table 3). Solitary fish were the only acoustic targets at 17 sites, whereas both solitary fish and schools of fish were acoustic targets at 6 sites (Table 3). Regression analysis indicated a significant relationship between catch rates *C* and acoustic indi-

Table 2. Catch rate (kg/h) of rockfish and other fish at 23 sites sampled with bottom trawls and acoustics in the eastern Gulf of Alaska, August 1993.

		Rockfish (kg/h)						
Site	Depth (m)	All Rockfish	Pacific Ocean Perch	Red-stripe	Silver-gray	Sharp-chin	Other Rockfish	Other Fish
1	196–196	17,493	13,339	3,074	797	0	283	649
2	241–250	5,074	1,141	1,100	74	1,379	1,380	425
3	212–212	4,264	0	2,169	159	1,287	649	493
4	215–216	2,688	109	231	1,854	200	294	371
5	237–255	1,561	831	7	92	602	29	192
6	251–255	1,524	1,205	0	291	0	28	236
7	233–255	1,153	904	15	170	44	20	404
8	236–240	807	610	7	80	68	42	309
9	231–233	661	445	82	77	1	56	428
10	217–217	481	190	194	57	20	20	519
11	177–197	308	1	0	307	0	0	229
12	219–213	188	84	1	87	0	16	717
13	244–255	155	117	1	24	3	10	255
14	205–215	142	112	0	28	0	2	264
15	195–195	133	128	0	2	0	3	612
16	244–256	136	112	0	11	5	8	1,182
17	212–215	122	29	0	83	0	10	802
18	289–291	81	75	0	6	0	0	388
19	209–218	81	29	0	39	0	13	529
20	266–275	74	66	0	0	0	8	908
21	277–294	73	66	0	6	0	1	233
22	208–210	35	16	0	19	0	0	673
23	284–285	10	10	0	0	0	0	548

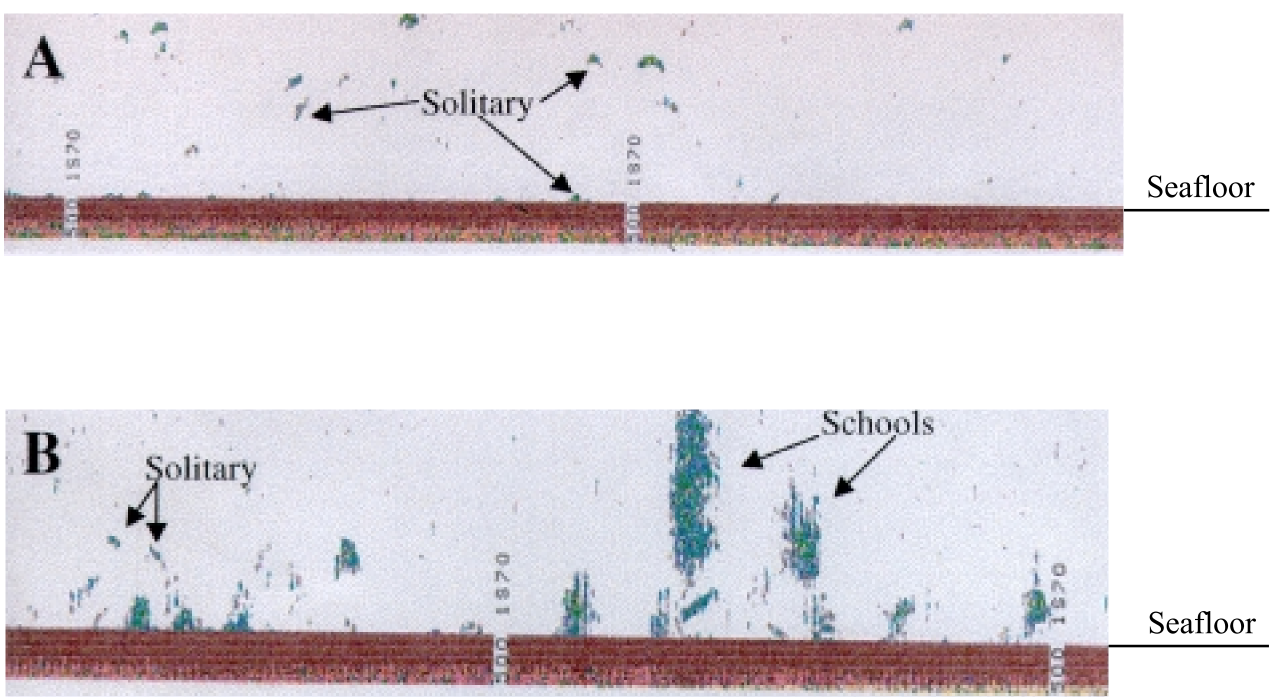

Figure 2. Sonar echograms of solitary rockfish (A) and both solitary rockfish and schools of rockfish (B) at sites that were sampled with acoustics and bottom trawls in the eastern Gulf of Alaska, August 1993.

ces A (Figure 3), and the relationship is best explained by the multiplicative model $C = 4.32A^{0.83}$ ($r^2 = 0.69$, $P < 0.001$).

Based on the catch rates of rockfish, 4 sites were classified as high abundance (>2,600 kg/h), 7 sites as moderate abundance (300–1,600 kg/h), and 12 sites as low abundance (<200 kg/h). Of the 4 high-abundance sites, 3 contained dense schools that resulted in acoustic indices exceeding 3,500 and ratios (expressed as a quotient) of acoustic indices to rockfish catch (*A:C*) of 1.1, 1.3, and 1.3 (Table 3). The acoustic index for the remaining high-abundance site (site 2) was 460, resulting in an *A:C* ratio of only 0.1. This site contained 9 rockfish schools, but all the schools were low density. Acoustic indices ranged from 100 to 470 at the 7 moderate-abundance sites, and they had similar *A:C* ratios: 0.2–0.4 at 6 of these sites and 0.7 at the seventh site (Table 3). Solitary rockfish were the only sonar targets at 5 of the sites, whereas solitary rockfish and rockfish schools were the targets at the 2 sites with the highest catch rates (Table 3). Acoustic indices ranged from 10 to 330 at the12 low-abundance sites, and their *A:C* ratios ranged from 0.1–5.1. The wide range of *A:C* values was caused by other fish species inflating the acoustic values at the 6 sites where *A:C* exceeded 0.6. These fish were layered as individual targets in distinct horizontal layers, unlike the vertical domes or spikes of rockfish groups. The acoustic indices included the lower part of these layers, which ranged from 15–50 m above the seafloor. Two species that distribute in these type of layers are walleye pollock *Theragra chalcogramma* and Pacific hake *Merluccius productus*, and these species averaged 24% of the total catch and exceeded the rockfish catch at the 6 sites with layers, whereas they never exceeded the rockfish catch and averaged <1% of the catch at the other 17 sites.

DISCUSSION

The unexpected gadids within 25 m of the seafloor resulted in inflated acoustic indices at 6 sites. Fortunately, gadids aggregate in distinct horizontal layers that can be distinguished from rockfish aggregations. Backscatter from the gadids could have been removed from the acoustic indices if the acoustic data had been collected in 1-m depth intervals instead of a single 25-m

Table 3. Acoustic indices, bottom-trawl catch rates of rockfish, acoustic/catch quotient, and numbers of rockfish schools and solitary rockfish targets at 23 sites in the eastern Gulf of Alaska, August 1993.

				Rockfish Schools/3 km			Solitary Rockfish/3 km		
Site	Acoustic Indices	Catch Rate (kg/h)	Acoustic/ Catch	Total	High Density	Low Density	<10	10–40	>40
1	19,850	17,493	1.1	24	6	18		X	
2	460	5,074	0.1	9		9		X	
3	5,690	4,264	1.3	12	4	8		X	
4	3,580	2,688	1.3	3	3			X	
5	280	1,561	0.2	3		3			X
6	390	1,524	0.3	3		3	X		
7	470	1,153	0.4					X	
8	330	807	0.4				X		
9	100	661	0.2					X	
10	170	481	0.4					X	
11	230	308	0.7					X	
12	330[a]	188	1.7				X[a]		
13	20	155	0.1						X
14	220[a]	142	1.5					X[a]	
15	80	133	0.6					X	
16	80	136	0.6						X
17	40	122	0.3						X
18	30	81	0.3						X
19	120[a]	81	1.5					X[a]	
20	60[a]	74	0.8						X[a]
21	10	73	0.1						X
22	180[a]	35	5.1					X[a]	
23	20[a]	10	2.0						X[a]

[a] Includes walleye pollock and Pacific hake layered 15–50 m above the seafloor.

interval. If gadid targets were excluded from the 6 sites, our acoustic indices would have been accurate predictors of high, medium, and low rockfish abundance levels at 22 of the 23 sites. Acoustics did not detect the high abundance of rockfish caught at one site, possibly because most rockfish were within 0.5 m of the seafloor (and not available to acoustic assessment), or the rockfish in the 9 schools at this site were oriented more vertically with respect to the seafloor, thus decreasing their backscattering properties. Westrheim (1970) noted that occasional hauls yielded substantial Pacific ocean perch catches even though no schools were detected by the echosounder.

Pacific ocean perch were expected to dominate the rockfish catches, based on previous trawl surveys and observations from the submersible. Although they totaled 52% of the rockfish catch, 3 other rockfish species were caught in higher abundance at 9 of the 23 sites. *A:C* ratios did not reflect differences in the rockfish species, indicating that all 4 species had similar proportions distributed off-bottom. Rockfish schools were detected acoustically at the 6 sites with the highest catch rates, and perhaps enumerating rockfish schools can improve acoustic indices of rockfish abundance.

The significant relationship between acoustic indices and rockfish catch rates indicates that quantitative acoustic data can be used to estimate rockfish abundance. Acoustic sampling could improve rockfish assessments because it is not substrate-limited and can sample large geographical areas. However, additional comparisons are needed to refine the equation that defines the relationship, especially at high-density rockfish sites. Additional comparisons are also needed to determine which rockfish species can be indexed acoustically and the importance of the number of rockfish schools as a predictor of rockfish abundance. If trawl surveys continue as a main sampling tool for assessing rockfish, perhaps qualitative acoustic data could be used in conjunction with the trawl surveys. For example, Everson et al. (1996) described a sampling design known as the Trawl and Acoustic Presence/Absence Survey (TAPAS) developed for mackerel icefish *Champsocephalus gunnare*, which have similar distribution patterns to those of offshore rockfish in our study. The schools of both species are patchy, mobile, unpredictable in location, close to the seafloor, and recognizable using echosounding. The TAPAS design uses qualitative acoustic data to indicate presence or absence of a dense concentration of fish, and trawl hauls are then made in the low-density habitat at randomly selected sites and in each high-density habitat located with acoustics. The size of the fish concentration is also defined using acoustics. Trawl data from randomly

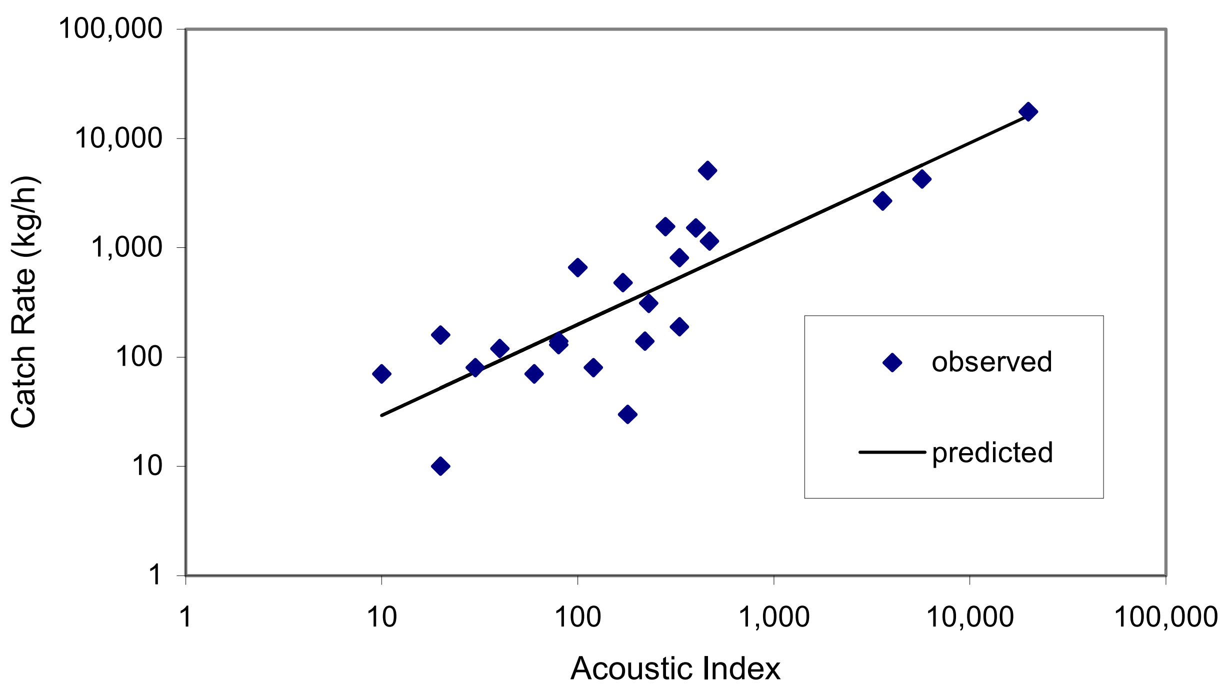

Figure 3. Relationship (log scale) between acoustic indices A and bottom-trawl catch rates C for rockfish in the eastern Gulf of Alaska, August 1993. The relationship is best explained by the nonlinear regression model $C = 4.32\,A^{0.83}$ ($r^2 = 0.69$, $P < 0.001$).

selected sites are then combined with the trawl data from fish concentrations of defined sizes. Everson et al. (1996) reported that this method provided an efficient estimate of overall abundance using only slightly more ship time than would be needed for a pure trawl survey with the same number of hauls.

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