FRI-UW-8125
December 1981

FISHERIES RESEARCH INSTITUTE
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ROCKFISH INVESTIGATIONS OFF THE COAST OF WASHINGTON AND OREGON

by

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FINAL REPORT

National Marine Fisheries Service
Contract No. 79-ABC-00203

Approved

Submitted December 8, 1981

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INTRODUCTION

Most commercially important rockfish of the genus Sebastes are characterized by a contagious spatial distribution and semi-demersal habits. These characteristics tend to make conventional trawl and hydroacoustic surveys inappropriate for many of these stocks, although the problems involved vary from species to species. Rockfish dominate the landings of groundfish in California, Oregon and Washington, however, and since the data base on the commercial landings (catch by species, effort data, age composition data, etc.) is limited, fisheries surveys are particularly important if these resources are to be managed properly.

As a result NMFS/NOAA entered into a 3-year contract with the University of Washington in July, 1979, to evaluate the usefulness of several new techniques in assessing shelf rockfish stocks. The employment of sector scanning sonar and sonar mapping techniques were among those evaluated. Field surveys were conducted aboard the F/V MUIR MILACH in 1980 (Gunderson et al.1980), and it became apparent that these techniques were most appropriate for widow rockfish, a species which had grown from a minor component of the United States landings in 1978 (1,107 mt) to 19,576 mt in 1980. This species tends to form schools that are further off bottom than most other shelf rockfish in the Washington-Oregon area, and since the near-bottom resolution of the sonar employed turned out to be relatively poor, this species was well-suited to the project′s research. Furthermore, the rapid development of the commercial fishery for widow rockfish has outstripped the ability of management agencies to develop the data base needed for proper management of this species.

Widow rockfish and Pacific whiting are the only species available to the midwater trawl fleet operating along the California-Washington coast, and as such are the target of a highly sophisticated, high volume fishery. In 1981, widow rockfish landings are projected to reach at least 28,000 mt[1] and several scientists have expressed the concern that the stocks could be overfished before an appropriate management plan can be devised for them. As such, the development of techniques that aid in the accurate and timely assessment of widow rockfish abundance have recently assumed a high priority.

During 1981, the emphasis of our investigations consequently shifted to widow rockfish. This involved an increased level of survey effort at night, when widow rockfish tend to school most densely, and a shift in the bathymetric and geographic range surveyed.

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[1] Pacific Fishery Management Council, October 8, 1981 Newsletter.

METHODS

Survey Design

All field work was carried out during March 12-23, 1981 aboard the University of Washington's 100-ft research vessel ALASKA. All midwater and bottom trawling gear used during the survey (Table 1) was on loan from the RACE division, National Marine Fisheries Service.

The survey design was similar to that employed in 1980, with transect lines being laid out perpendicular to the coast at intervals of 2 nautical miles. The region surveyed was changed from that covered in 1980 (Gunderson et al., 1980), to encompass the widow rockfish grounds off Washington and northern Oregon that are most important to commercial fishermen. Based on widow rockfish catch statistics supplied by the Washington State Department of Fisheries and Oregon Department of Fish and Wildlife, the survey area selected extended from 45°50′ (Tillamook Head) to 46°48′ (Cape Shoalwater, Willapa Bay), although time available was not sufficient to survey north of 46°18′ (Cape Disappointment, Fig. 1). The bathymetric range surveyed focused on the continental slope region between 70 and 120 fathoms, but extended out to 200 fathoms in the Astoria Canyon and Willapa Canyon areas. Expendable bathythermograph casts were made at both the inshore and offshore ends of transects 28, 24, 20, 18 and 16 (Table 2).

All research operations were carried out after dark (Tables 3, 4), with the exception of the 0652-1037 replication series made on transect 21. These runs were made as part of a diel series of 13 runs along

Table 1. Vessel characteristics for the ALASKA.

Length:	100 feet
Power:	600 hp Enterprise
Midwater Trawl:	Diamond Midwater Trawl 177′ headrope and footrope 177′ breastline 36′-48′ vertical opening, 50′ horizontal opening (Bill West, personal communication) 3.5" mesh in cod-end, 1.25" liner 180′ dandylines, four sets of 18′ bridles 5′ 4 1/2" x 9′ 8" aluminum doors Furuno netsounder system
Bottom Trawl:	NWAFC "Nor′Eastern" Otter Trawl Construction and rigging similar to that described in Gunderson and Sample (1981), but with three 180′ dandylines, 75" setback on middle bridle, 42" setback on upper bridle 5' 4 1/2" x 9' 8" aluminum doors

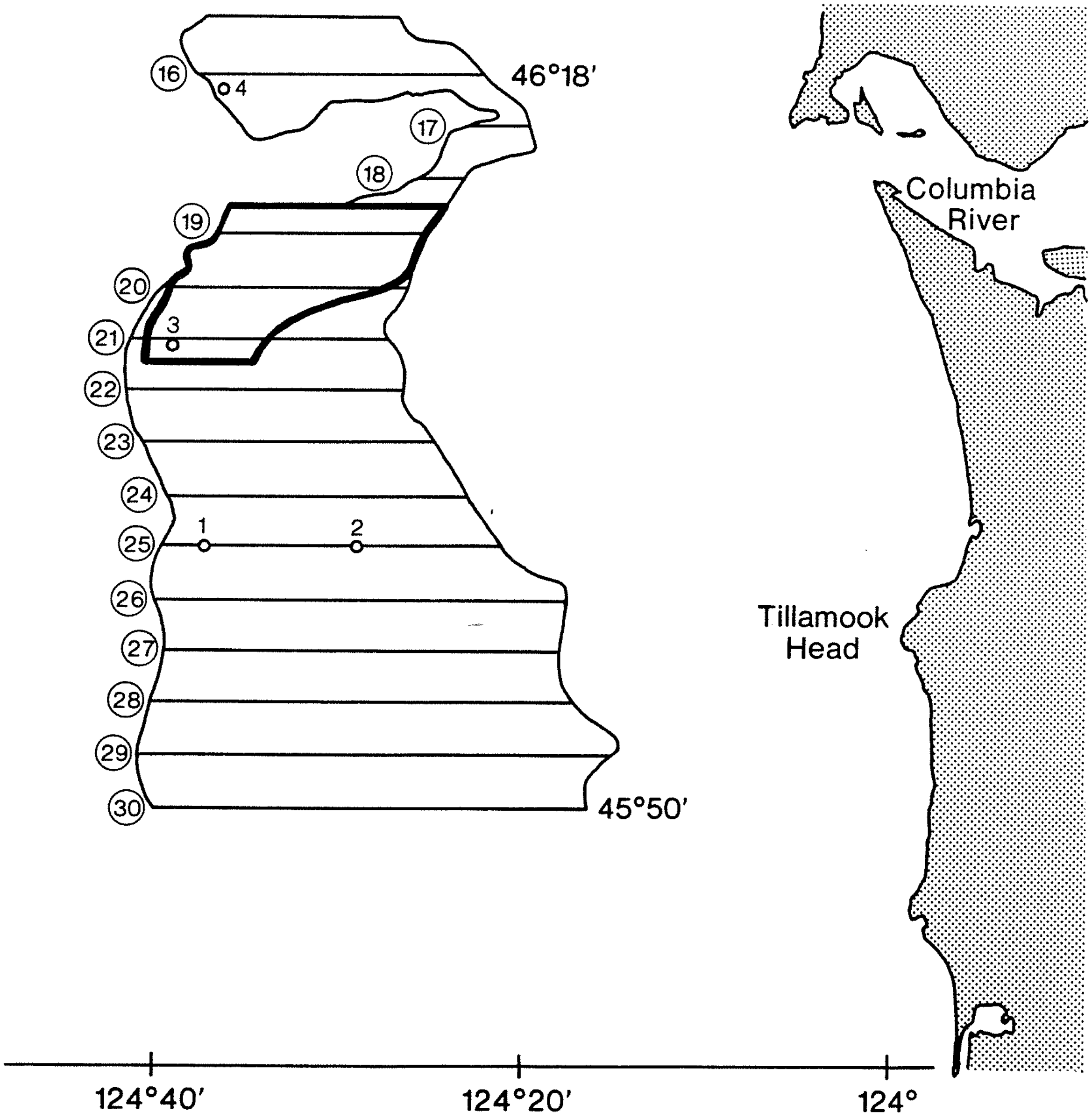

Fig. 1. Chart showing transect lines run during the 1981 ALASKA rockfish survey. The location of each sampling haul is indicated by an open circle, and the "widow rockfish subarea" is delineated by heavy lines.

Table 2. Temperature-depth profiles for 1981 XBT stations. Surface temperatures taken with bucket thermometers are shown in parentheses.

Depth (m)	Transect number										
	28	28	24	24	21*	20	20	18/19	18	16	16
0	10.5	11.1	10.5(10.3)	10.7(10.5)	10.7(10.6)	10.8(10.8)	10.8(10.7)	10.6(10.5)	10.7(10.5)	10.4(10.3)	10.6(10.5)
50	10.8	11.0	10.7	11.0	10.5	10.5	10.7	10.4	10.5	10.4	11.8
100	10.0	9.4	9.0	9.4	9.4	9.2	9.5	9.2	9.3	9.1	10.5
150		8.5		8.5	8.4		8.5		8.5		9.2
200		7.5		7.7	8.0		7.9		8.2		8.5
250					7.4		7.4		7.5		8.0
Bottom temp/bottom depth (m)	8.7/125	7.5/205	8.5/125	7.5/208	7.2/260	8.4/128	**/622	8.4/125	6.2/345	8.6/130	**/366+
Thermocline depth (m)	100	85	92	85	75	95***	85	90***	85	80	83***

* Taken after Haul 3.

** Off scale of XBT recorder. Depth estimated from echosounder.

*** Indistinct.

Table 3. Vessel itinerary for the ALASKA rockfish survey.

3/12	Installed receiver for Furuno netsounder, loaded vessel.
3/13	Checked all electronics, made trial set with Diamond midwater trawl off Shilshole. Left for survey area.
3/14	Arrive Astoria.
3/15-3/18	Ran transects 30-23.
3/19-3/20	Ran transects 22 and 21, with 13 replicates of transect 21 extending from 0153-1037 on 3/20. Put into Astoria.
3/21-3/22	Ran transects 20-16, left for Seattle.
3/23	Arrive Seattle.
3/24	Unloaded vessel.

Table 4. Dates and times of day that transects were run during ALASKA rockfish survey.

Transect	Date run	Time span
16	3/22	0222-0504
17	3/22	0105-0142
18	3/22	0005-0035
19	3/21	2152-2333
20	3/21	1901-2110
21	3/19-3/20	2127-1037
22	3/19	1921-2108
23	3/18	0245-0558
24	3/18	0014-0216
25	3/17	0415-0522,1913-2126
26	3/17	0107-0353
27	3/16-3/17	2158-0037
28	3/16	0427-0616,1901-2126
29	3/16	0118-0404
30	3/15-3/16	2050-0053

transect 21, (Fig. 2), aimed at observing changes in the density and distribution of widow rockfish aggregations over time.

Acoustic sampling was conducted with echosounding and sonar equipment along all tracklines (Fig. 1) until a significant aggregation of fish was detected. Net sampling was then conducted, the Diamond midwater trawl being employed for pelagic concentrations of fish and the Nor'Eastern otter trawl being employed for near-bottom concentrations.

Acoustic Equipment

Echo integration data were collected using the same echo-sounder/data aquisition system used in 1980 (Fig. 3). An EK-38 scientific sounder was used in conjunction with a 38 kHz transducer with a full beam angle of 11° at -3dB. The source level was 121 dB//μbar at 1 m and the receiving sensitivity of the transducer was -73.7 dB//1 volt per μbar. The transducer was housed in a 2-ft Braincon V fin and towed from a boom off the starboard midships. A pulse length of 0.6 ms was used throughout the survey, and the data collection rate was 48 transmissions per minute. The acoustic signal was monitored with an oscilloscope, recorded in real-time on chart paper and stored on magnetic tape with a TEAC 3440A tape recorder for subsequent analysis.

Sonar data were collected using the C-Tech LSS-68 sector scanning sonar under long-term lease for this project. The transducer used in 1980 was found to be defective, and was replaced prior to the 1981 work. The LSS-68 had an operating frequency of 75 kHz, and the pulse length

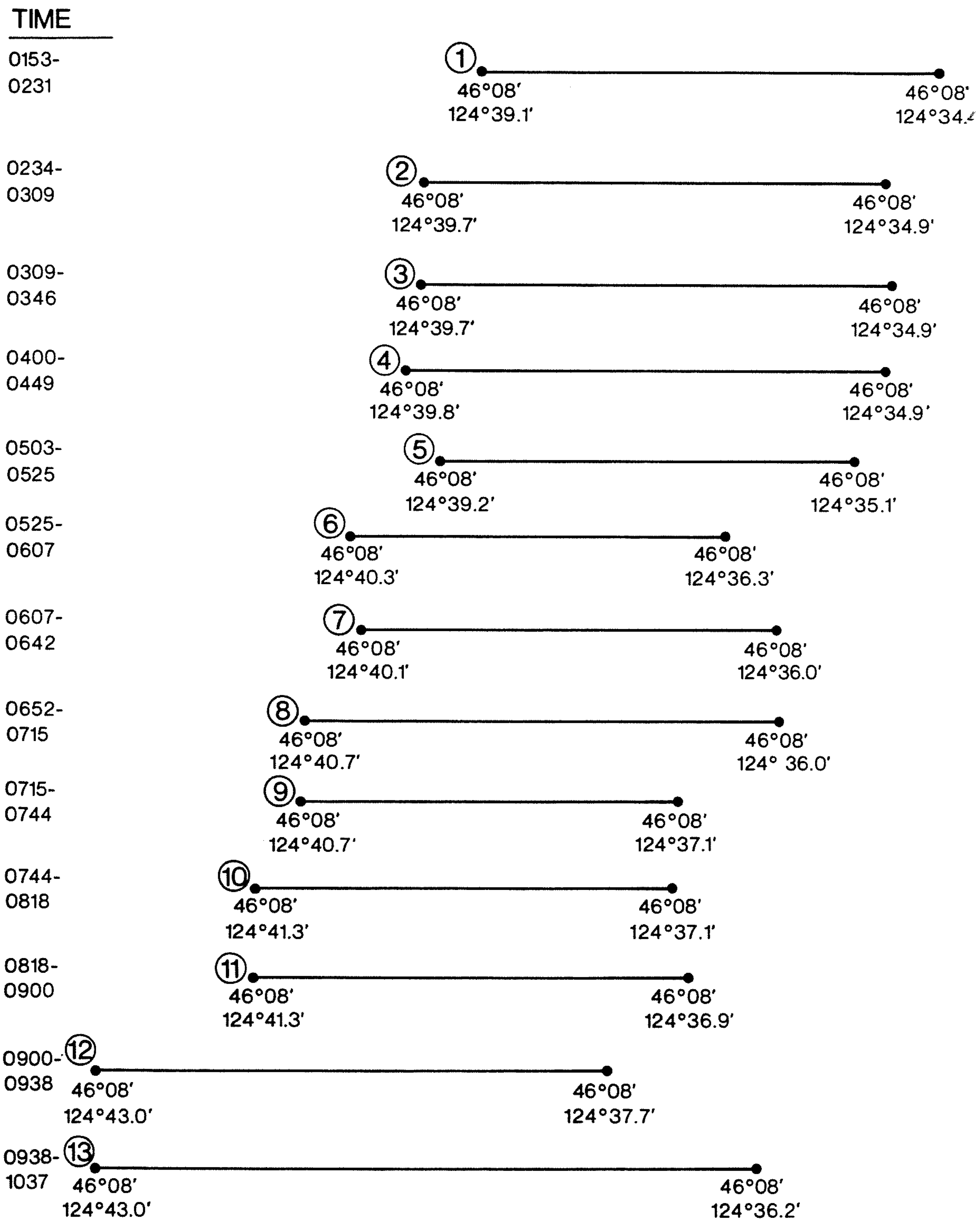

Fig. 2. Location of replicate runs made along transect 21 to observe temporal changes in widow rockfish aggregations, March 20, 1981.

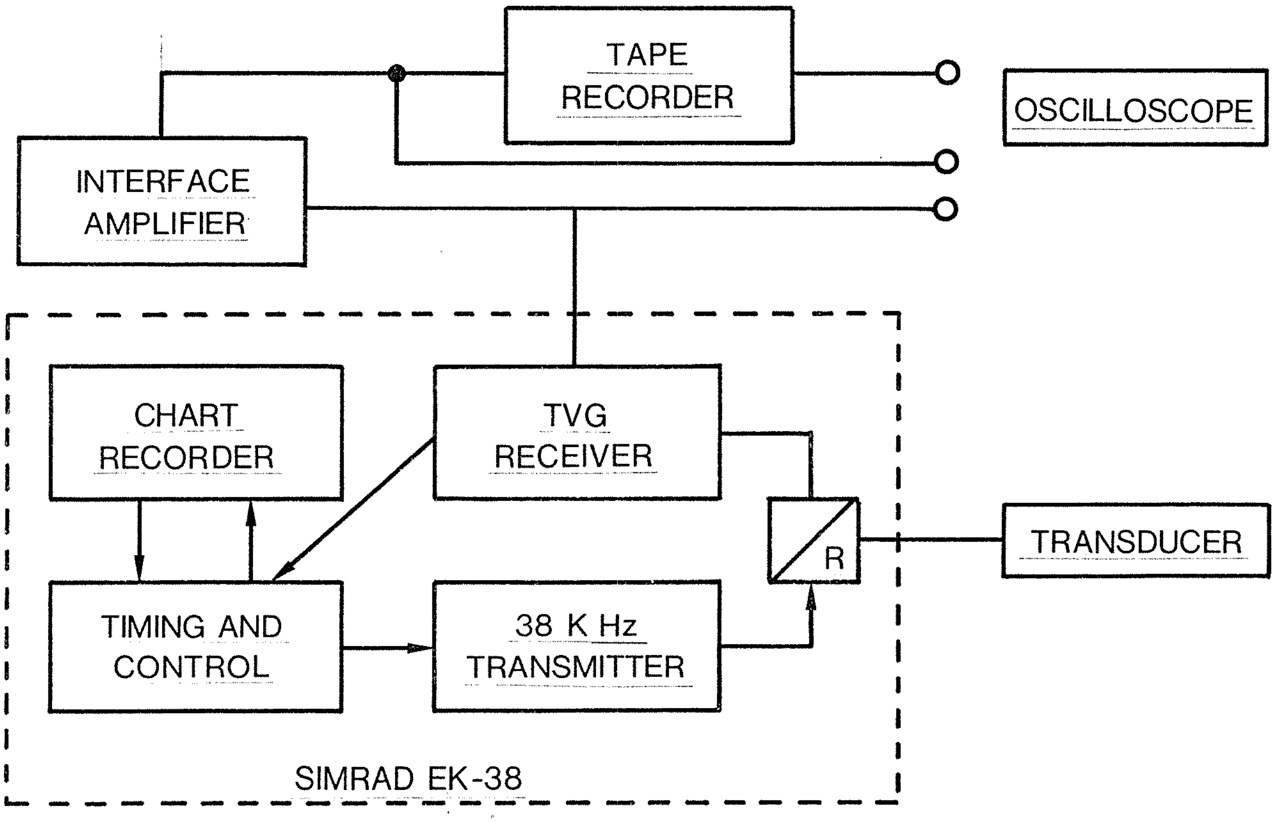

Fig. 3. Block diagram of the echosounder data acquisition system.

employed was usually 1.0-2.0 ms, depending on the depth range selected. Longer pulse lengths (up to 10 ms) were used for brief periods, but the shortest possible pulse length was always used in order to optimize near-bottom resolution of fish targets. Despite this, near-bottom detection of schools was poor due to a "ring" of interference present near bottom on the cathode ray tube (CRT) display (similar to that noted in the 1980 report), and the general quality of the display.

The LSS-68 was deployed at a 90° tilt angle, perpendicular to the bottom, when collecting transect data (Fig. 4). The sonar insonifies a 200° by 9° wedge-shaped field with 10° by 9° angular resolution, and as fine as 15 cm range resolution. Real-time acoustic data are displayed on a 10-inch (CRT) screen giving the range and bearing of all acoustic targets. This information was recorded on magnetic tape using an RCA CC004 video camera and a Panasonic video tape recorder.

The sector scanning sonar gave useful results for pelagic schools, censusing a rectangular area about 200 m wide, and extending from the surface to about 5 m from the bottom. This contrasts sharply with the cone-like region insonified by the echosounder, which was 11-35 m wide (at 30 and 100 fathoms, respectively), near the base (i.e., the sea bed). During the survey, it appeared that the threshold characteristics of the sonar's CRT display seemed to be such that many small or diffuse schools detected by the echosounder were not detected by the sonar. This situation was evaluated in more detail after the survey, by comparing fine-scale integration output data with sonar output on a school by school basis. The data from transect 21, replicate run 7 were

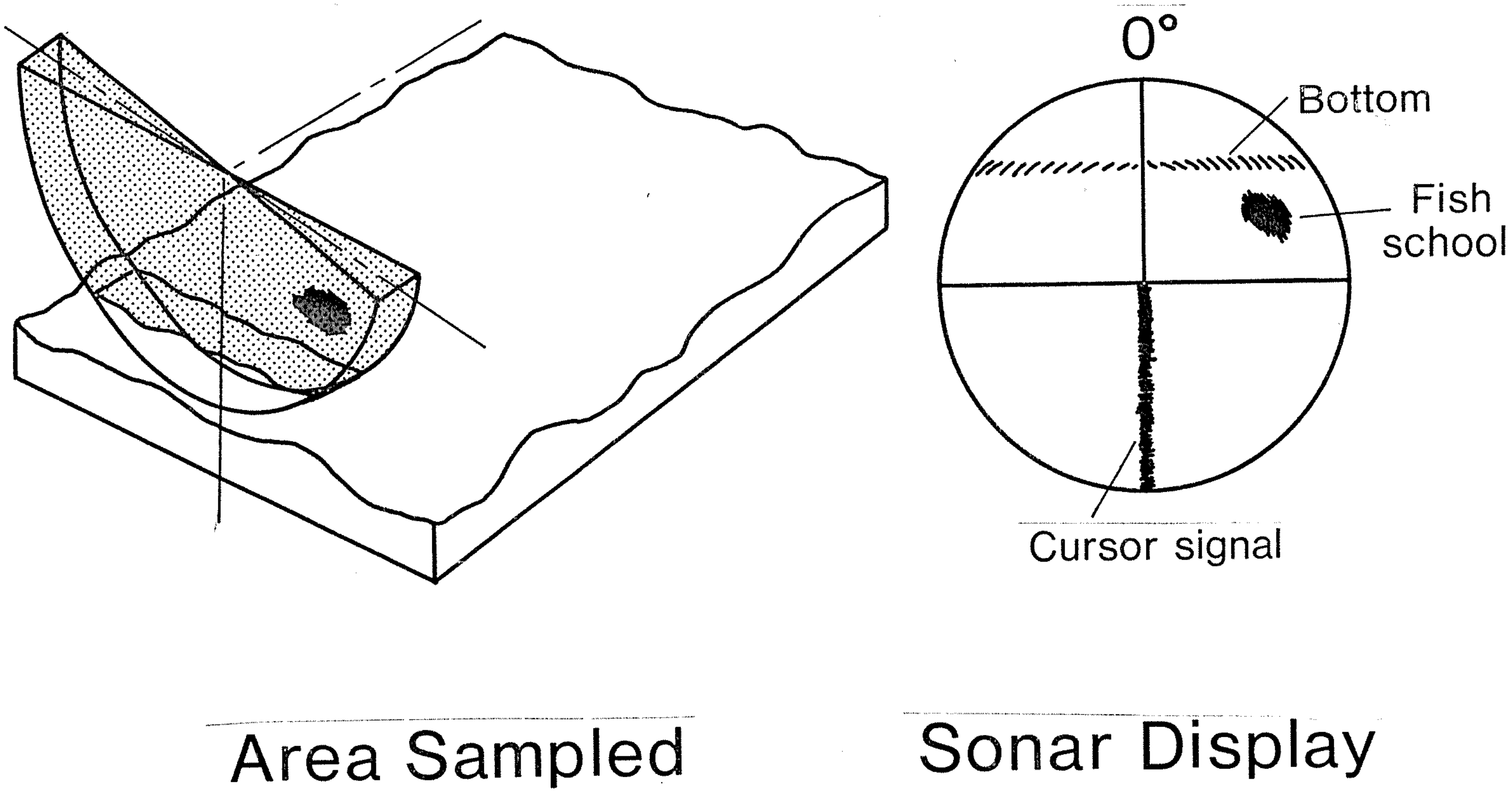

Fig. 4. Area sampled by the LSS-68 sonar, showing the location of a fish school in the beam pattern and the corresponding CRT display for that school.

used to make this comparison, with all integration data being broken down into 2.4 sec (3 transmissions) intervals.

Data Analysis

Echosounder

The technique used to estimate biomass from the echosounder data was based on the principle that the acoustic intensity of a signal reflected from fish targets is proportional to the mean individual scattering cross-section of the targets times the number of targets. Detailed descriptions of the technique can be found in Moose and Ehrenberg (1971) and Thorne (1977).

The echosounder data collected during 1981 were processed with a BIO SONICS Model 120 digital echo integrator. The integrator was set to measure voltages from 5 to 230 m, in the following 10 depth ranges: 5-50, 50-70, 70-90, 90-110, 110-130, 130-150, 150-170, 170-190, 190-210, 210-230. A high proportion of the biomass was located near bottom, and the combination of rapid change in bottom slope and rolling and pitching by the towed body frequently made manual bottom tracking necessary.

For routine transect data the density estimates were averaged over every 40 transmissions (50 sec).Relative densities were converted to absolute values (g/m^2) using calibration data and by assuming a target strength of -35 dB/kg. All calculations were based on the system gain as measured with the calibration oscillator at 150 msec (112.5 m).

Laboratory calibration of the EK-38 performance in 1981 indicated the system was operating in the same manner as in the 1980 pre-survey evaluation. Thorne (1979) demonstrated that the EK-38 time-varied-gain deviations from ideal had an insignificant effect on the estimates of biomass per unit of surface area.

All integration data were keypunched and stored in a permanent SPSS data file on the University of Washington's CYBER 170/750 computer. Each echosounder record included the date, time, transect number and density (g/m^3) at each depth interval. In addition, each aggregation detected by the echosounder was classified as either a school (S), layer (L), or grouped aggregation of schools and layers (G), and a log was created that documented the depths and integration record numbers corresponding to that aggregation.

Any erroneous data points present were then edited from the file, using echograms and integration logs to identify measurements suspected to contain bottom reverberation, surface reverberation, etc. All unusually high density values within 10 fathoms of the bottom were individually examined and edited out if not represented on the echogram. This method constitutes an inescapable bias which underestimates fish density for schools close to the bottom, particularly where the bottom is rough and irregular or the bottom slope changes rapidly.

Sonar data

The LSS-68 sonar display gives a CRT representation of the range and bearing of all targets (Fig.4). Video tapes of the sonar display gave a permanent record of the survey data, which was analyzed on a video monitor using the slow motion and stop action features available with a Panasonic 404 video recorder.

School depth, distance off bottom, width, thickness, radial distance from vessel, perpendicular distance off transect, degrees off transect and bearing (Fig. 5) were measured from the video tape recordings. Measurements were made for all schools identified as widow rockfish which had a length greater than 8 m. School length was calculated by relating the number of pulses received from each target to the number of sonar pulses per minute and the corresponding vessel speed at a particular time.

Perpendicular distance off transect was measured to the center of the school in 1981 (Fig. 5) rather than to the edge of the school as in 1980 (Gunderson et al., 1980). This is the preferred measurement when estimating school densities with the line transect method (Burnham et al., 1980), and the 1980 data on perpendicular distance off transect were re-estimated so that the data for both years were comparable.

Biomass Estimates

Small nocturnal aggregations, some of which could have been widow rockfish, were encountered throughout the survey area. Net sampling and target identification was inadequate for most of these, however. The largest aggregations encountered, and the only ones that were positively identified as widow rockfish, all occurred within a relatively small

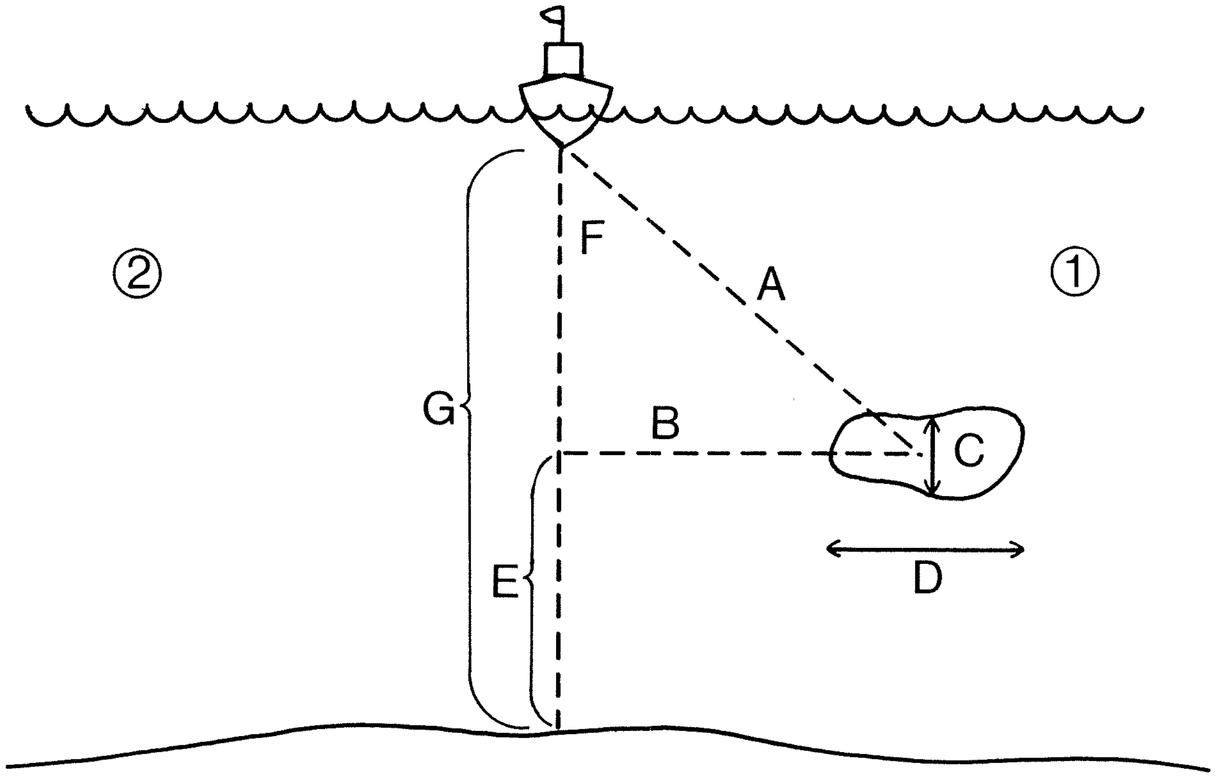

Fig. 5. Data collected from video tape recordings of the sector scanning sonar display: A = radial distance from vessel, B = perpendicular distance off transect, C = thickness at center of school, D = school width, E = distance off bottom, F = degrees off transect, G = bottom depth, 1 = port side bearing, 2 = starboard side bearing.

portion of the survey area (transects 19, 20, and 21). A 45.4 nm^2 "widow rockfish subarea" was delineated to include this area (Fig. 1), and estimates of the widow rockfish biomass present there were obtained from the sonar and echo integration data. The density estimate from the echo integration data was obtained from:

$$\hat{d} = \frac{\sum_{i=1}^{R} l_i \hat{d}_i}{\sum_{i=1}^{R} l_i} = \frac{\sum_{i=1}^{R} l_i \hat{d}_i}{L}$$

where: $\hat{d}$ = density estimate for entire area

l_i = length of transect i

$\hat{d}_i$ = average density estimate (g/m^2) for transect i. Obtained from the average of individual echo integrator outputs (d_B) along the trackline where d_B = g/m^2 of surface area =

$\sum_{i=1}^{n} (R_L - R_u)_i (d_s)_i$ where $(R_L)_i$ and $(R_u)_i$ = the lower and upper boundaries of the i^{th} depth interval between the transducer and the seabed and $(d_s)_i$ = volumetric biomass density (g/m^3) in the i^{th} depth interval.

R = number of transects

L = total transect length for the R transects censused

and biomass was estimated from

$$\hat{B} = \left(\frac{A}{10^6}\right) \hat{d}$$

where $\hat{B}$ = estimated biomass in metric tons

A = total area in widow rockfish subarea = 156,023,193 m^2

The variance of this estimate was determined from:

$$\text{Var}\ (\hat{d}) = \frac{\sum_{i=1}^{R} l_i\ (\hat{d}_i - \hat{d})^2}{L\ (R-1)}$$

and $$\text{Var}\ (\hat{B}) = \left(\frac{A}{10^6}\right)^2 \text{Var}\ (\hat{d})$$

Data collected from the sonar observations were also used to obtain a biomass estimate. Line transect methods were used to estimate school density (schools/nm^2) along the transects, which was then multiplied by an estimate of mean school biomass and extrapolated to the entire "widow rockfish subarea."

The line transect method is based on the fact that the probability of sighting a given school varies with distance from the vessel. Seber (1973) has shown that school density can be estimated from:

$$\hat{D} = \frac{n\hat{f}(o)}{2L}$$

where $\hat{D}$ = estimated number of schools per unit area

n = number of schools sighted

L = length of transect

and $\hat{f}(o)$ = parameter estimated from the probability density function for the perpendicular distances of the schools sighted.

Three main assumptions are necessary concerning data collection to insure a reliable density estimate using the line transect method:

1) Schools directly on the transect plane will always be sighted.

2) Schools are sighted at the position they occupied prior to the approach of the vessel and there is no avoidance of the vessel.

3) Perpendicular distances off transect are measured precisely, particularly near the transect line.

One basic problem in estimation of density using the line transect method is choosing a model for the sighting function f(x). Numerous parametric and nonparametric estimators have been developed to fit the sighting function to a given data set including the exponential, logistic and half-normal. Work by Quinn (1979) and Burnham et al., (1980) suggests that the nonparametric Fourier model is a robust, flexible estimator, and provides the best fit to the sighting function in most applications. Quinn (1979) has shown that there is theoretical justification for pooling the data for several size-classes of schools, even when the sighting function varies with school size. This is because the sighting model that results from the pooled model is self-weighted by the relative abundances of the school size classes.

The Fourier model is based on a Fourier series expansion of the probability density function, f(x). The estimator of the probability density function at zero distance is:

$$\hat{f}(o) = \frac{1}{w^*} + \sum_{k=1}^{m} \hat{a}_k$$

where w* = truncation width, beyond which all observations are discarded. A value of 92 m was used in 1981.

$$\hat{a}_k = \frac{2}{nw^*} \left[\sum_{i=1}^{n} \cos \frac{(k\pi x_i)}{w^*} \right]$$

and n = number of schools observed

x_i = perpendicular distance off transect for the i^{th} school

k = term number = 1, 2, 3, ...m

The number of terms employed (k) was determined by a stopping function in the computer program TRANSECT used in this study. Bias in the estimation of $\hat{f}(o)$ and $\hat{D}$ is reduced by increasing the number of terms employed, but this reduction comes at the cost of reduced precision.

The FORTRAN program TRANSECT (Burnham et al., 1980) was used to estimate $\hat{f}(o)$ and $\hat{D}$, using the Fourier series. This program is documented in Laake et al., (1979) and was made available for use on the CYBER 170/750 computer at the University of Washington. Program output includes frequency histograms of perpendicular distances, together with graphical illustrations of the resulting Fourier model fit to these data (Fig. 6).

The variance of D was estimated by using the equation:

$$\hat{var}\ (\hat{D}) = (\hat{D})^2\ [(\hat{cv}(n))^2 + (\hat{cv}(\hat{f}(o))^2]$$

The squared coefficient of variation for $\hat{f}(o)$ is given by

$$(\hat{cv}(\hat{f}(o)))^2 = \frac{\hat{var}\ \hat{f}(o)}{(\hat{f}(o))^2}$$

and was determined by using equation 2.6 from Burnham et al., (1980) to estimate the sampling variance of $\hat{f}(o)$. The squared coefficient of variation of n = $(\hat{cv}(n))^2 = \frac{\hat{var}(n)}{n^2}$, and was obtained by treating the

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PROGRAM TRANSECT -- LINE TRANSECT DATA ANALYSIS PROGRAM DEVELOPED BY THE UTAH COOPERATIVE WILDLIFE
RESEARCH UNIT.  METHODS AND TESTS FROM BURNHAM ET AL. (1980). PROGRAM VERSION 1.1, 4/1/80.
WIDOW ROCKFISH DATA

ILLUSTRATION OF THE ESTIMATED PDF OF PERPENDICULAR DISTANCES(F) FIT TO THE SHAPE OF THE HISTOGRAM OF THE DATA(*)
CUT POINT SET 1
                      I-----------------------------------------------------------------------------------------------------I
         34.6630      -                                                                                                     I
                      I                                                                                                     I
                      I                                                                                                     I
                      I                                                                                                     I
                      I FFFFFFF                                                                                             I
         30.8116      -        FFFFFFF                                                                                      I
                      I               FFFF                                                                                  I
                      I ******************====**=                                                                           I
                      I                       FF*                                                                           I
                      I                         *FFF                                                                        I
         26.9601      -                         *   FF                                                                      I
                      I                         *     FFF                                                                   I
                      I                         *        FF                                                                 I
                      I                         ***********===***********=                                                  I
 P                    I                         *             FF         *                                                  I
 R       23.1087      -                         *               FF       *                                                  I
 O                    I                         *                 FF     *                                                  I
 B                    I                         *                   FFF  *                                                  I
 A                    I                         *                      FF*                                                  I
 B                    I                         *                        =F                                                 I
 I       19.2572      -                         *                        * FF                                               I
 L                    I                         *                        *   FF                                             I
 I                    I                         *                        *     FF                                           I
 T                    I                         *                        *       FFF                                        I
 Y                    I                         *                        *          FF                                      I
         15.4058      -                         *                        *            FF                                    I
 D                    I                         *                        ***************===*******=                         I
 E                    I                         *                        *                 FF     *                         I
 N                    I                         *                        *                   FFF  *                         I
 S                    I                         *                        *                      FF=                         I
 I       11.5543      -                         *                        *                        *===*********************=I
 T                    I                         *                        *                        *   FFFF                 *I
 Y                    I                         *                        *                        *       FFFFF            *I
                      I                         *                        *                        *            FFFFFFFF    *I
                      I                         *                        *                        *                    FFFF=I
         7.70289      -                         *                        *                        *                        *I
                      I                         *                        *                        *                        *I
                      I                         *                        *                        *                        *I
                      I                         *                        *                        *                        *I
                      I                         *                        *                        *                        *I
         3.85145      -                         *                        *                        *                        *I
                      I                         *                        *                        *                        *I
                      I                         *                        *                        *                        *I
                      I                         *                        *                        *                        *I
                      I                         *                        *                        *                        *I
         .227374E-12  -                                                                                                     I
                      I+---------+---------+---------+---------+---------+---------+---------+---------+---------+---------+I
                                                                                                                                     -01
                  0.                  .993600E-02         .198720E-01         .298080E-01         .397440E-01         .496800E-01
                                                                                                                                    
                            .496800E-02         .149040E-01         .248400E-01         .347760E-01         .447120E-01
                                                            PERPENDICULAR DISTANCE
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Fig. 6. Example of graphical output provided by program TRANSECT.

transect lines as replicates, and using equation 1.23 from Burnham et al. to estimate var(n).

Mean school biomass was determined for all schools detected by both the sonar and echsounder during the period that the line-transect estimates were being made. Echosounder data on school density (g/m^2) and school length were used in conjunction with a school width estimate obtained from the sector scanning sonar. The exact relation used was:

$$\hat{b}_i = t_i n_i v_i w_i d_i$$

where $\hat{b}_i$ = estimated biomass of school i (g)

t_i = duration of integration interval (50 sec in 1981)

n_i = number of intervals integrated for school i

v_i = vessel speed (m/sec)

w_i = mean width (m) of school i as determined from sonar data

d_i = mean integration density (g/m^2) over the n_i intervals integrated.

Mean school biomass ($\bar{b}$) was estimated by averaging the $\hat{b}_i$ values, and the variance of this estimate was determined from:

$$\text{Var}\ (\bar{b}) = \sum_{i=1}^{N} \frac{(\hat{b}_i - \bar{b})^2}{N(N-1)}$$

where N = number of schools $\bar{b}$ is based on.

Total biomass was estimated from school density values using:

$$\hat{B} = A\ \hat{D}\ \bar{b}$$

and its variance (Goodman, 1960) from:

$$\mathrm{Var}\ (\hat{B}) = A^2 \left[(\hat{D})^2\ \mathrm{Var}\ (\bar{b}) + (\bar{b})^2\ \widehat{\mathrm{Var}}\ (\hat{D})\ - \mathrm{Var}\ (\bar{b})\ \widehat{\mathrm{Var}}\ (\hat{D}) \right]$$

In 1980, a single estimate of mean school biomass was obtained from all schools detected at night, regardless of which transects or runs they were seen on (Gunderson et al., 1980). Since it is important to link the mean school biomass estimates as closely as possible to the schools the density estimates pertain to, the 1980 estimates were recalculated. Separate estimates of mean school biomass were obtained for transect and non-random run data, and the estimates of total biomass updated accordingly. An echo integration estimate of biomass from the 1980 non-random run data was also obtained, so as to be able to compare it with the sonar results.

RESULTS

Target Identification

Target identification is a problem with any acoustic survey, and this was certainly the case during the 1981 ALASKA survey. Near bottom layers and small or diffuse schools were seen on most transects, but many of these were probably formed by species other than widow rockfish.

Dense schools were seen in the widow rockfish subarea (transects 19, 20, and 21), and commercial fishermen working in the immediate vicinity (within 0.4-2 nm of the ALASKA) suggested that these schools were made up predominately of widow rockfish. One of these vessels, the F/V IKE, caught 90,000 lb (41 mt) of widow rockfish in the same general area and during the same time the ALASKA was surveying transect 21. Conversations with the captain of the IKE, and the results from haul 3 (Table 5) suggest that dogfish, sharpchin rockfish, redstripe rockfish and yellowtail rockfish were also present in the aggregations, but in small numbers relative to widow rockfish. Dense, but less extensive nocturnal schools were also seen on transects 28, 27, 26, 25, 22 and 16, but usually couldn't be sampled. This was because the schools were too close to the bottom in areas where the bottom was irregular or untrawlable, or because they were too small to justify making a trawl set. Net sampling can be quite difficult where widow rockfish are involved, since they frequently occur over rough bottom that is inaccessable to a bottom trawl. Midwater trawls can be used in this situation, and commercial fishermen frequently fish such gear within a few feet of the bottom.

Table 5. Summary of trawl station and catch data for ALASKA rockfish survey. Trawl type 1 = midwater trawl, type 2 = bottom trawl.

Haul no.	Date	Start position		Trawl type	Time of day	Average depth (fm) gear/bottom	Duration (min)	Catches (kg) of Rockfish									Catches (kg) of other species						
		Lat(N)	Long(W)					Redstripe	Rosethorn	Sharpchin	Greenstriped	Canary	Widow	Yellowtail	Shortbelly	Bocaccio	Petrale sole	Dover sole	Rex sole	Blackcod	Lingcod	Dogfish	Ratfish
1	3/17	46°01'	124°37'	1	0630	52/96	15	Netsounder upside down, ineffective haul															
2	3/17	46°00'	124°29'	2	2223	85/85	21	None															
3*	3/20	46°08'	124°39'	1	2349	99/99	16	510	5	23	16	2	18				5			5	5		
4*	3/22	46°17'	124°36'	2	0614	87/87	35	919	1	16	2		2	3	6	17		1	0.1	5		8	1

*Net badly ripped

This requires considerable skill, however. A group of schools, tentatively identified as widow rockfish, was detected well off-bottom on transect 28, but positive identification could not be made as dawn was approaching and it was concluded that the schools would probably break up by the time a haul could be made.

The catch from haul 4, made to identify a near-bottom school detected on transect 16 in 80-88 fm, underscores the necessity for frequent trawl hauls and target identification. This school was very close to the widow rockfish subarea, and differed little in general appearance from some of the schools seen there. The results from Tow 4 indicated that it was made up predominently of redstripe rockfish, however.

Diel Changes in School Distribution and Abundance

Thirteen replicate runs were made to monitor temporal changes in widow rockfish schools along Transect 21 on the night of March 19/20. Each run was conducted along Transect 21, and terminated when fish aggregations were no longer encountered. The inshore and offshore limits were consequently dependent on the presence of fish, and varied between runs (Fig. 2). There was a progressive offshore shift in the location of the schools (Figs. 7a and 7b) over the course of the night, and by sunrise (0603) most of schools were located near the edge of the continental shelf. Most of the schools dispersed after sunrise, although some

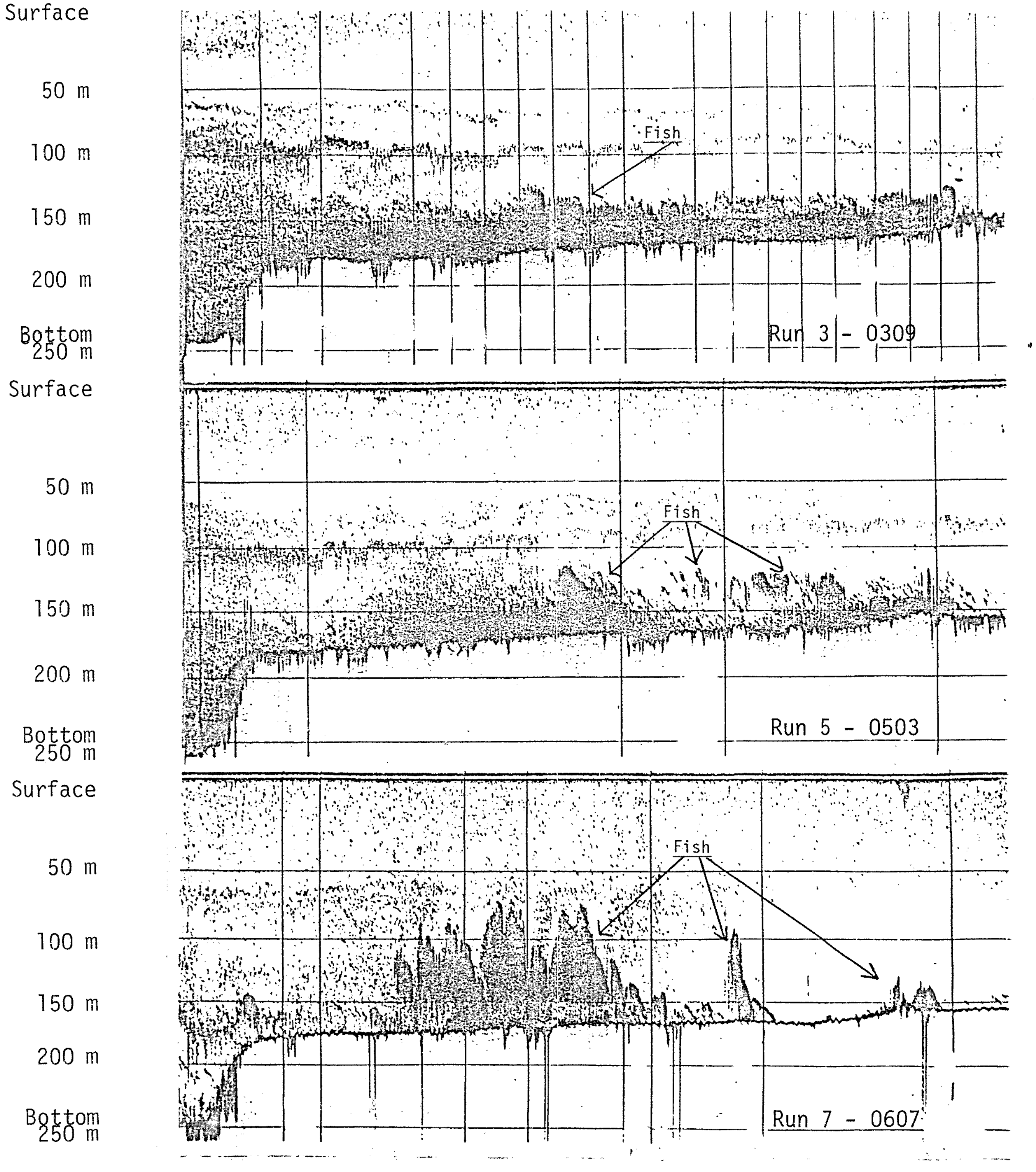

Fig. 7a. Selected repetitions of acoustic track line (transect 21) run on March 20, 1981 showing temporal variability in fish distribution.

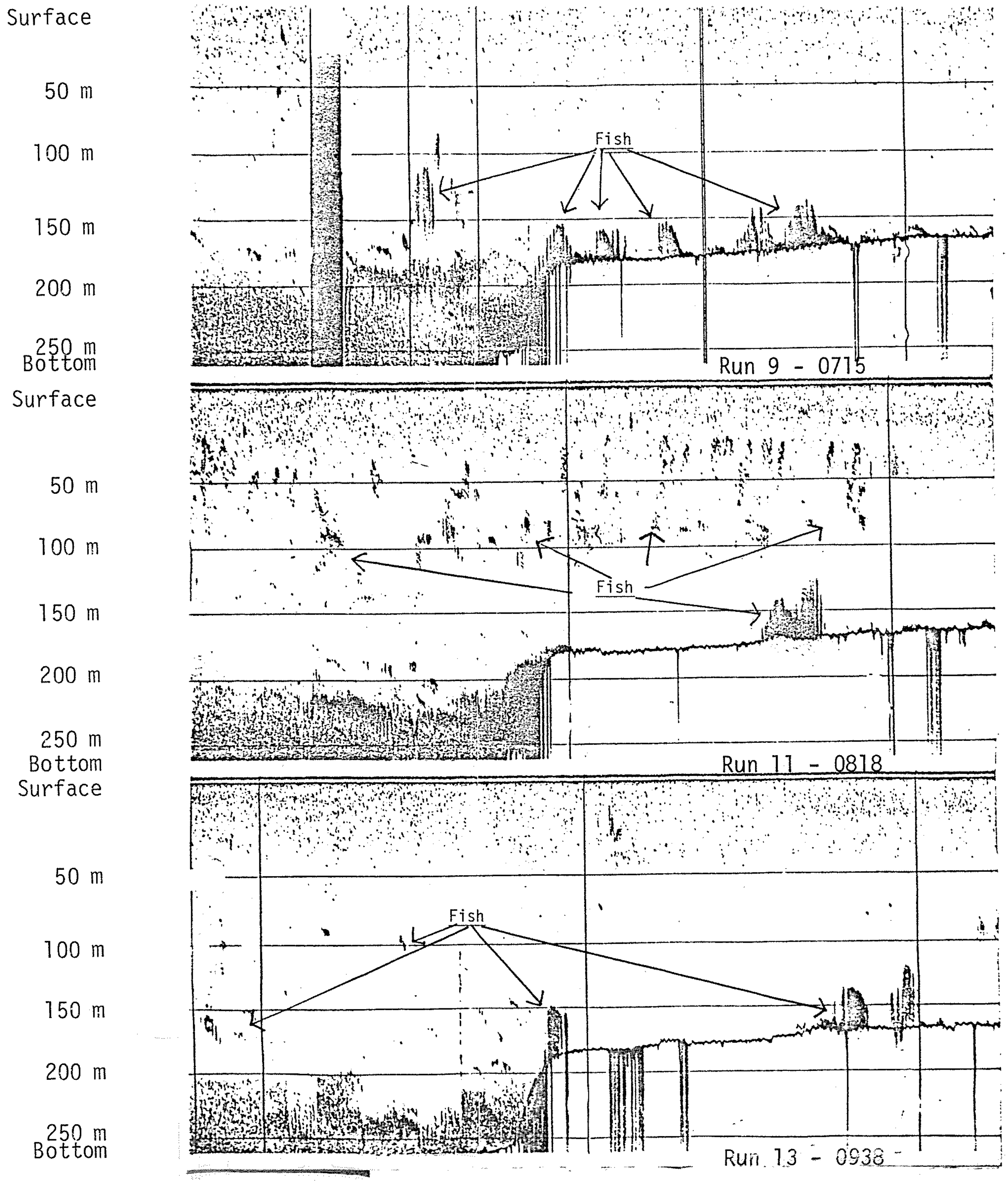

Fig. 7b. Selected repetitions of acoustic track line (transect 21) run on March 20, 1981 showing temporal variability in fish distribution.

remained on the continental shelf at the time when observations were terminated (1037).

A diel trend of layer to school formation was observed during the nighttime runs, while a trend toward school dispersion characterized the daytime runs. Figures 7a and 7b are the echograms from six selected runs which illustrate these phenomena.

The echo integration data on mean density (g/m^2) measured during each run illustrate these trends equally well (Table 6). Variability was high within the nocturnal series, with dynamic changes in school characteristics. Density increased gradually during runs 1-3 (0153-0346), remained relatively stable during runs 4-6 (0400-0607), and increased to a peak value of 23.22 g/m^2 during run 7 (0607-0642). Density fell sharply during run 8 (0652-0715) and remained low during all subsequent daytime runs (0715-1037). A significant portion of this variability probably resulted from the difficulty of differentiating dense near-bottom concentrations of fish from the bottom signal, however. Aggregations of fish were further off bottom during run 7 than they had been during the three preceding runs, for example, and this was at least partially responsible for the high density estimate obtained then.

Sonar observations also reflected changes in school characteristics between daytime and nocturnal series. The number of schools detected on transect 21 fell off only slightly after sunrise (Table 6), but the schools seen after 0642 were smaller than nocturnal schools (Figs. 7a and 7b). Sonar measurements of school volume indicate that this was

Table 6. Mean fish density (g/m^2) and number of schools detected with sonar during replicate runs of transect 21, March 20, 1981.

Run	Time started	Echo integration density (g/m^2)	Schools detected
1	0153	2.68	3
2	0234	2.47	3
3	0309	6.56	5
4	0400	10.37	10
5	0503	14.78	1
6	0525	9.98	5
7	0607	23.22	9
*	--	--	--
8	0652	2.06	4
9	0715	1.45	3
10	0744	.83	6
11	0818	.60	3
12	0900	.79	7
13	0938	1.09	7

*Sunrise 0603

generally the case in 1981 (Table 7), the mean volume of daytime schools (0642 to 1037) being only 46% that of schools encountered at night (1901 to 0642). Data from all schools detected with the sonar were included in Table 7, since there was no significant difference (P = .55 in 1980, P = .09 in 1981) between school size and the distance off transect it is detected (Fig. 8).

Biomass Estimates

Biomass estimates for the widow rockfish subarea delineated in 1981 (Fig. 1) were complicated by the fact that several replicate runs were made on transect 21. Only the nighttime runs were used when making school density and total biomass estimates, and each of these was adjusted to a common length of 4.2 nm. This was the distance between 124° 34.4′ and 124° 40.3′, the innermost and outermost longitudes reached during the seven runs. Since the limits of each run represented that point at which schools were no longer detected, it was assumed that no fish were present in any portion of the 4.2 nm transect not covered during any given run. The average of the seven echo integration density estimates obtained in this manner was used to represent mean density (g/m^2) on transect 21, and this was combined with the density estimates for transects 19 and 20 to obtain the echo integration biomass estimate for the subarea.

Similar adjustments were made in the case of the line transect estimate. School density was obtained by using an estimate for f(o)

Table 7. Morphology of S. entomelas schools as sighted along transects and measured with the sector scanning sonar, 1981.

	Nighttime data N = 45	Daytime data N = 30
Length (m)	$\bar{x}$ = 90.3 s = 124.1 Range = 7.6 - 682.8	$\bar{x}$ = 57.5 s = 54.1 Range = 8.6 - 241.5
Width (m)	$\bar{x}$ = 53.0 s = 34.8 Range = 14.0 - 165.0	$\bar{x}$ = 63.8 s = 48.3 Range = 11.0 - 176.0
Thickness (m)	$\bar{x}$ = 14.4 s = 9.6 Range = 2.0 - 41.0	$\bar{x}$ = 18.4 s = 11.8 Range = 5.0 - 55.0
Volume (m^3)	$\bar{x}$ = 243,678 s = 989,303 Range = 893 - 6,763,647	$\bar{x}$ = 111,542 s = 204,758 Range = 688 - 995,843
School depth (fathoms)	$\bar{x}$ = 89.4 s = 18.9 Range = 51 - 172	$\bar{x}$ = 105.8 s = 37.6 Range = 33 - 176

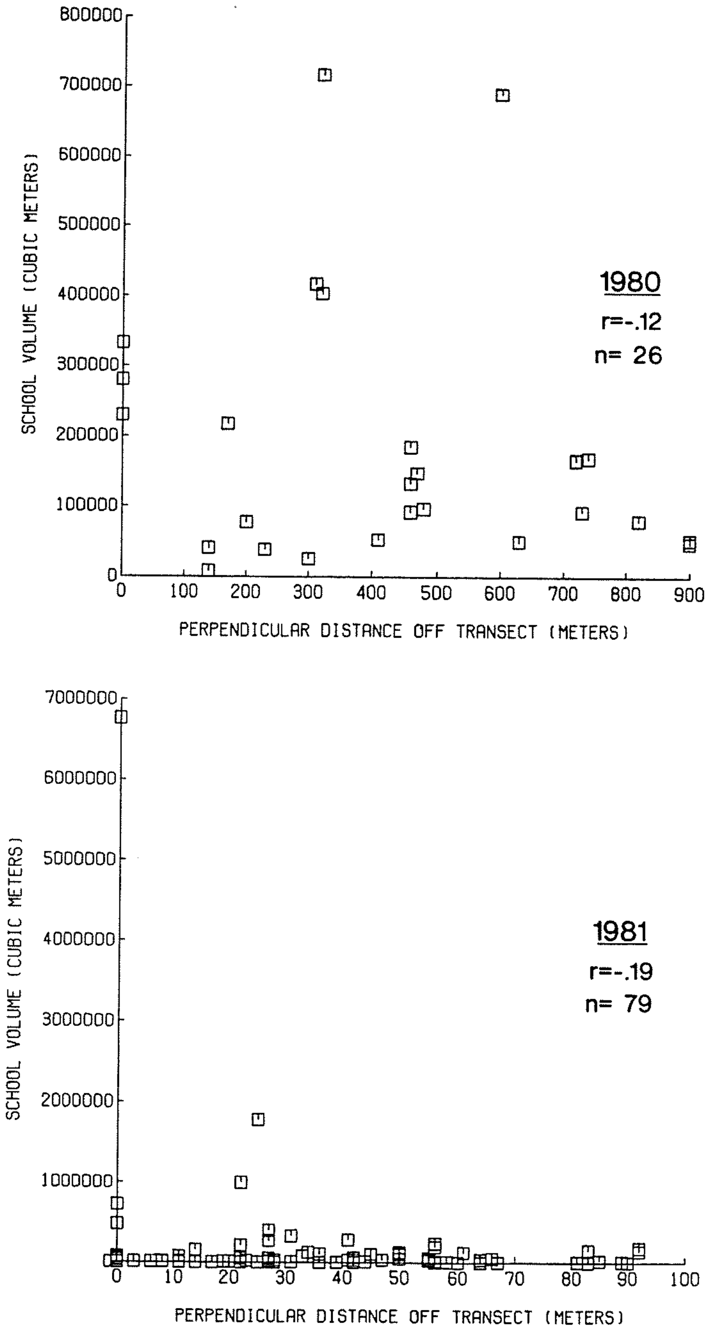

Fig. 8. Relationship between school size (volume in cubic meters) and perpendicular distance off transect for schools detected with the sector scanning sonar in 1980 and 1981.

based on the perpendicular distance data collected on all seven nighttime runs and the two runs made on transects 19 and 20. The n and ℓ_i values used in estimating density were obtained in the normal manner for transects 19 and 20, while a mean value for the number of schools sighted (n) on the seven runs, and an ℓ_i of 4.2 nm was used to represent transect 21.

All estimates of school density, mean school biomass and total biomass obtained during 1980 and 1981 are shown in Table 8. The estimates for 1980 are all based on extrapolations to the 24.3 nm^2 widow rockfish subarea delineated that year (Gunderson et al., 1980). Biomass estimates obtained from the non-random run data are consequently highly biased, and serve only as a means of comparing the results from echo integration, line transect, and line intercept techniques. The estimates from the transect data collected in 1980 and 1981 are biased in a less obvious fashion, since no allowances were made for temporal variability in density. Ideally the entire widow rockfish subarea delineated should have been monitored over the entire night as school densities increased, then the peak values obtained for echo integration density (g/m^2) and number of schools sighted used to develop estimates of biomass. As a result, the estimates in Table 8 should not be used to make inferences about the actual biomass of widow rockfish present, but are meant to be used only for comparative purposes, contrasting the means and variances obtained by using different estimation techniques.

The poorest agreement between methods occurred with the 1980

Table 8. Summary of estimates of school density ($\hat{D}$), mean school biomass ($\widehat{MSB}$), and total biomass ($\hat{B}$) for widow rockfish. Coefficients of variation (CV) are given for each estimate.

	$\hat{D}$ (schools/nm^2)	CV	$\widehat{MSB}$ (mt)	n	CV	$\hat{B}$ (mt)	CV
1980							
Transect data							
26 schools, 2 transects							
Line transect estimate	69.5	.84	.12	15	.20	204	.84
Echo integration estimate						778	.16
Non-random run data							
73 schools, 1 transect							
Line transect estimate	242.2	.19	.85	16	.50	5,003	.53
Line intercept estimate	248.9	.10	.85	16	.50	5,139	.51
Echo integration estimate						6,453	--
1981							
Transect data							
49 schools, 3 transects							
Line transect estimate	12.1	.24	.62	27	.33	342	.40
Echo integration estimate						342	.77

transect data, the line transect estimate being only 26% of the value obtained from echo integration. Analysis of the echosounder data for the two transects the estimate was based on indicated that only about 81% of the biomass present was concentrated in schools. In addition even those schools that were present were quite small (mean school biomass = .12 mt) and it is likely that many small, diffuse schools detected by the echo integration system were not detected by the sonar. The threshold voltage required to trigger the CRT display of the sonar was significantly higher than that detectable by the echo integration system (Table 9) and the sonar gives poor results when mean school biomass is low. Agreement between sonar and echo integration estimates of biomass was much better for the 1980 non-random run data, where mean school biomass was higher (.85 mt).

The best agreement between sonar and echo integration biomass estimates of biomass was obtained during 1981, but the results in Table 8 are somewhat misleading. Echo integration densities (g/m^2) and mean school biomass observations were much higher on transect 21 than on transects 19 and 20, probably due to differences in the time of night they were surveyed (Table 4). The biomass estimates are consequently quite sensitive to the procedures used to weight the data from this transect.

In the case of the echo integration data for example, the estimation procedure used tended to weight the data from transects 19 and 20 the heaviest, since the trackline distance used in the calculations were much

Table 9. Fine scale (2.4 sec data collection intervals) analysis of echosounder data collected on transect 21, replicate 7 during 1981. Those schools detected by the sonar are denoted with an asterisk.

School no.	Time	Maximum density (g/m^3)	Distance off transect (m)	School no.	Time	Maximum density (g/m^3)	Distance off transect (m)
1	0607	0.047	--	16	0620	1.260	--
2	0610	0.024	--	17*	0621	10.873	81
3	0611	0.012	--	18	0622	4.280	--
4	0612	0.071	--	19	0623	1.870	--
5	0612	0.012	--	20	0624	2.406	--
6	0612	0.012	--	21	0625	0.172	--
7	0612	0.059	--	22*	0626	23.212	8
8	0613	0.024	--	23*	0626	22.853	33
9	0613	0.083	--	24*	0627	13.552	36
10	0614	0.272	--	25*	0628	19.762	0
11*	0615	37.708	50	26	0629	9.715	--
12	0616	0.118	--	27*	0631	[1]	92
13	0618	0.344	--	28*	0632	18.188	42
14	0619	2.470	--	29*	0633	20.258	11
15	0619	0.969	--				

[1] Not detected with echosounder.

greater (9.2, and 10 nm, respectively) than that used for transect 21 (4.2 nm). If the echo integration density estimates from the three transects are given equal weight, the resulting biomass estimate becomes 491 mt.

In general however, the data in Table 9 indicate that agreement between sonar and echo integration estimates of biomass are comparable when schools are large and plentiful. The precision obtained when using line intercept and line transect methods to estimate total biomass is usually comparable to that obtained with the echo integration method, and can exceed it under certain circumstances.

DISCUSSION

Several problems posed by the behavior of widow rockfish make fisheries surveys for this species difficult. Two of these, diel variability in density and target identification, have already been mentioned.

Of these, the problem with diel variability is the most severe, since it necessitates close monitoring of a given area over the course of the night and early morning, in order to distinguish the period when density is at a maximum. Improved accuracy of near-bottom echo integration would simplify this task somewhat, and could be achieved by developing a deep-towed, high frequency hydroacoustic system.

Nevertheless, the whereabouts of schooling portions of the widow rockfish during the intervals preceding and following the period of peak abundance is unknown, as is the relationship between total stock size and that portion of the stock which aggregates in detectable quantities. It is obvious that there is still much to learn about widow rockfish behavior, but extrapolations of peak density to the entire "subarea" or "patch" occupied by widow rockfish aggregations should provide a minimum estimate of stock biomass present, and may serve as an index of relative abundance over time. Such an index would be quite useful, since the rapid changes in technology and fishing strategy that characterize midwater trawling for widow rockfish makes traditional measures of catch per unit effort (CPUE) difficult to apply.

One problem area that hasn't been discussed yet pertains to the difficulty of locating "patches" or "subareas" where aggregations of widow rockfish exist. The situation encountered during the 1981 ALASKA survey serves to exemplify this.

Prior to the survey, information on the general location of the commercial fishery, provided by the Washington State Department of Fisheries and Oregon Department of Fish and Wildlife, indicated that widow rockfish were most abundant off Tillamook Head. As a result, the survey was started at the southern end of the survey area. During the 3-4 day period required to reach this area however, the commercial fishery had moved to the north, and the most extensive aggregations encountered during the survey occurred just south of the Astoria Canyon. The area that a given school of widow rockfish ranges over is uncertain and it is not possible to say whether this phenomenon was the result of the migration of a single school, or differential schooling behavior on the part of schools occupying different portions of the geographic range. It could be that fish off Tillamook Head form dense schools only once a week or once a month, for example.

Whatever the cause, the net result from a survey point of view is to make locating these aggregations a significant problem in itself. To effectively survey widow rockfish then, one must be able to determine how many "patches" exist along a given area of the coast, then closely monitor temporal changes within each patch to obtain an estimate of peak density.

Compared to these problems, the target identification problem is a relatively minor one. Few other species form the dense and extensive nocturnal schools that characterize widow rockfish, and the most abundant concentrations should be readily identifiable. An active commercial fleet is usually searching such concentrations out, and when these fishermen are present in the survey area, their catches can be used as an aid in identifying the species composition of these aggregations. Isolated nocturnal schools are difficult to characterize as widow rockfish, since other species (e.g., redstripe rockfish) also tend to form such schools. The technical and logistic problems involved in sampling these isolated schools have already been discussed.

In future surveys of widow rockfish, sonar techniques will probably be most useful in the process of locating and mapping out those areas (or "patches") where large aggregations occur, using line intercept techniques (Gunderson et al., 1980) to estimate how many of these "patches" exist. Monitoring of density within the patches that have been identified can be carried out on a different vessel, using echo integration techniques.

The temporal variability encountered with widow rockfish limits the effectiveness of line transect surveys however, since the method requires a large number of school detections to estimate f(o) and mean school biomass accurately. This limitation could possibly be overcome by multiple replication of transect lines, but if school size changes rapidly over time, such an approach might give misleading results.

Alternatively, sonars that search a much wider area than the LSS-68, and detect a greater number of schools per unit time could be employed for line transect surveys. The cost of such intruments is currently somewhat prohibitive insofar as their use in fisheries surveys is concerned, but the situation could change in the future.

If school detection is the major goal of the sonar survey, the area sampled by the LSS-68 can be significantly increased by using a longer pulse length, and employing a shallower tilt angle during the searching process. Longer range sonars, employing lower frequencies, would be even more useful in this regard. The Krupp Atlas 950 and the Simrad SM600 sector scanning sonars operate at much lower frequencies than the LSS-68 (19.5 and 34 kHz, respectively) and with much higher source levels.

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