DEVELOPMENT AND EVALUATION OF METHODOLOGIES FOR ASSESSING AND MONITORING THE ABUNDANCE OF WIDOW ROCKFISH, *SEBASTES ENTOMELAS*

MARK E. WILKINS[1]

ABSTRACT

Rapid expansion of a new fishery for widow rockfish, *Sebastes entomelas*, stocks off the Pacific coast of the United States began in 1979. Within 3 years, landings rose from <1,000 t to almost 30,000 t of a species for which little information on abundance or life history was available. It was known that widow rockfish occurred in irregularly distributed, dense, midwater, and semidemersal schools primarily during the night, which posed problems in directly assessing this resource. Therefore, a project was designed to further investigate the habits and distribution of the species and develop an adequate assessment methodology.

Line transect survey methods, using sector scanning sonar to estimate the number of schools per unit area and standard hydroacoustic echo integration techniques to estimate school biomass, were used in study areas off Washington and Oregon. The applicability of this methodology will depend on our ability to resolve technical problems and minimize the effects of distributional variability by refining survey design. The need for more sophisticated sonar equipment to improve data collection and processing, the extreme temporal and spatial variability of widow rockfish school size and location, and the difficulty of identifying the species composition of observed schools are matters of special concern.

The rockfish (genus *Sebastes*) of the Pacific Ocean are comprised of over 65 species exhibiting a wide array of colors, sizes, body forms, behavior, and life history characteristics. Members of this family are generally demersal or semidemersal and school over hard substrate on the continental shelf and slope. The widow rockfish, *Sebastes entomelas*, is atypical. As an adult it aggregates in dense midwater schools during the night.[2] These schools tend to disappear from established fishing grounds at dawn or shortly thereafter, becoming less vulnerable to the fishery.

The role of this species in the Pacific coast groundfish fishery changed from an undesirable incidental catch in 1978 to a major target species by 1980. Advances in fishing technology and product handling and marketing, as well as new vessels seeking alternative fisheries, promoted an increase in landings from 1,107 t in 1978 to 28,419 t in 1981 (Table 1).

By 1981, schools were becoming more difficult to locate and there was concern that the resource was being overharvested. The fishery began expanding into new areas to maintain profitable catch rates. During late 1981 and early 1982, most of the widow rockfish were being taken from the vicinities of Bodega Bay and Monterey, CA, though fishing was taking place as far north as Cape Flattery, WA.

The rapid growth of this new fishery resulted in large catches from a resource about which little was known. Research on this species prior to 1979 was limited to general descriptions of distribution, habitat, and biological characteristics (Hitz 1962; Phillips 1964; Pereyra et al. 1969). Scientists began gathering data in 1978 to determine the impact of the fishery on the condition of the stock, to define the distribution and size of the stock, and to establish a baseline of biological characteristics of the species. Commercial landings have been sampled by State

TABLE 1.—Landings of widow rockfish by state for years 1973-83 in metric tons.

Year	Washington	Oregon	California	Total
1973	81	15	29	125
1974	18	7	47	72
1975	13	11	57	81
1976	51	55	147	253
1977	277	34	267	578
1978	428	472	207	1,107
1979	1,697	1,960	636	4,293
1980	6,632	8,718	4,808	[1]20,677
1981	7,211	14,689	6,519	28,419
1982	6,030	9,262	10,270	25,562
1983	3,293	3,151	3,455	9,899

[1]This also included 519 t of joint venture and foreign catch.

[1]Northwest and Alaska Fisheries Center Seattle Laboratory, National Marine Fisheries Service, NOAA, 7600 Sand Point Way N.E., Building 4, BIN C15700, Seattle, WA 98115.

[2]Groundfish Management Team. 1981. Status of the widow rockfish fishery. Unpubl. manuscr., 41 p. Pacific Fishery Management Council, 526 S.W. Mill Street, Portland, OR 97201.

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and Federal agencies in Washington, Oregon, and California for information on size and age composition, sex ratio, maturity, feeding habits, morphometrics, meristics, and fecundity.

Widow rockfish abundance was estimated by the Groundfish Management Team (fn. 2, 1982[3]) of the Pacific Fisheries Management Council, using cohort and stock reduction analyses (SRA) (Kimura and Tagart 1982). These stocks were found to have been fished down from their virgin level and were thought to be approaching a biomass level which would, under prudent management, produce a maximum sustainable yield of about 12,000 t in the INPFC (International North Pacific Fisheries Commission) Columbia and Eureka areas.

Research surveys were needed to complement these analyses by providing independent estimates of abundance, describing the distribution, and collecting biological information not available from fishery data (for example, data on prerecruits and fish in areas which will not support a profitable fishery). Widow rockfish present special problems to those seeking to estimate their abundance through research surveys. The species is not usually available to bottom trawls, precluding traditional "area-swept" trawl surveys, and its tightly clustered distribution and inconsistent schooling behavior reduce the effectiveness of traditional hydroacoustic surveys.

In 1980, the Northwest and Alaska Fisheries Center (NWAFC) began developing a practicable method to survey widow rockfish stocks. Scientists needed to understand the distribution and behavior of widow rockfish to determine which survey methods might be most appropriate to measure the size of the resource. The first objective of the project, therefore, was to study aspects of the behavior, distribution, and biology of the species. The distribution of its characteristic nighttime aggregations relative to features of submarine topography was of particular interest. The distribution of this species is highly variable both on a diel basis and over longer periods, and the reasons for this variability were also of interest. Another question concerned what proportion of the total resource is present in detectable schools and how that proportion changes in space and time. Clark and Mangel (1979) described a theoretical situation in yellowfin tuna stock dynamics wherein detectable, fishable schools are constantly being replenished from an undetectable portion of the population. They discussed the implications of this behavior in a fishery. If such a phenomenon could be confirmed in widow rockfish, determining the detectable proportion of the population might enable us to estimate the absolute size of the resource.

The second objective of the project was to investigate methodologies with potential for estimating widow rockfish stock size, considering the species' behavior and distribution patterns. The final objective was to evaluate the effectiveness of the chosen technique when actually implemented.

The project was conducted in three phases: 1) an examination of the biology and behavior of widow rockfish on commercial fishing grounds, 2) the development of a practical survey method for assessing distribution and abundance, and 3) an evaluation of the feasibility and effectiveness of applying such assessment methodology to widow rockfish on a routine coastwide monitoring basis. Field studies were initiated in March 1980 and concluded in April 1982. Behavior studies were conducted during August 1980 and April 1981. Field work focusing on methodology development took place during late March 1980 and mid-March 1981, and the trial assessment survey took place during mid-March to early April 1982. All field work was conducted off Oregon and southern Washington (Fig. 1).

The purpose of this report is to document the work done to date on the development of widow rockfish assessment methodologies, to evaluate the utility of those methods for routine assessment and monitoring of widow rockfish stocks and other species exhibiting a similar behavior, and to recommend means of enhancing future assessment efforts.

BEHAVIOR STUDIES (1980-81)

The nature of the fishery made it apparent that the behavior of widow rockfish differed from that of other commercially important species of the genus *Sebastes*. Extremely large widow rockfish catches were taken by midwater trawlers operating almost exclusively at night and fishing on very dense midwater schools in only a few small areas along the coast.

The first phase of the project studied the behavior and habits of widow rockfish to determine their distribution patterns, using demersal and midwater trawls and hydroacoustic observations. This included determining where the fish go when the dense, midwater schools disperse; whether there are components of the stock other than the typical midwater aggregations; and at what period in their daily cycle

[3]Groundfish Management Team. 1982. Status of the widow rockfish fishery. Unpubl. manuscr., 22 p. Pacific Fishery Management Council, 526 S.W. Mill Street, Portland, OR 97201.

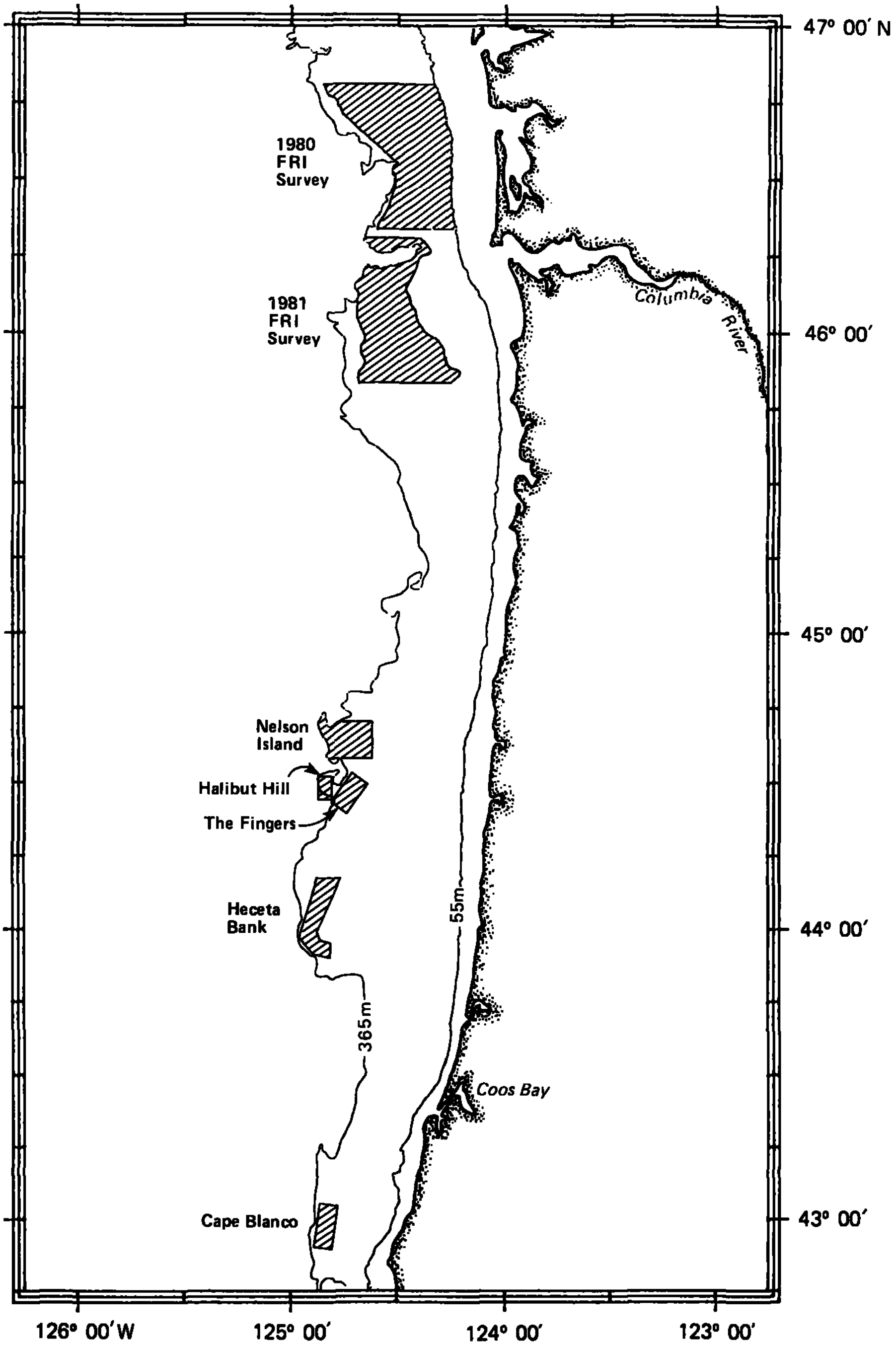


FIGURE 1.—Widow rockfish survey areas off the coasts of Washington and Oregon occupied during field work conducted between 1980 and 1982.

their availability is most stable. Other objectives were to investigate the possible causes of their diel aggregation habits and to develop an ability to distinguish widow rockfish schools from those of other species on the basis of echosign[4] characteristics and test fishing.

Methods

The behavior study was initiated 11-13 August 1980 aboard the chartered trawlers *Pat San Marie* and *Mary Lou*. Concurrently, scientists aboard the NOAA RV *Miller Freeman* conducted a conventional echo integration survey in the study area and made four midwater tows to identify the species composition of the schools sighted. The survey was repeated during 10-26 April 1981 aboard the NOAA RV *Chapman* and included 7 d of hydroacoustic and sonar observations.[5] Descriptions of the vessels, trawls, and hydroacoustic equipment employed appear in Tables 2, 3, and 4, respectively.

Demersal trawl stations were located around a seabed rise known as Nelson Island off Newport, OR, to determine if significant quantities of widow rockfish occurred on or near the bottom in an area where they were known to form dense midwater aggregations. A 4 × 4 station grid with interstation distances of 4.6 km (Fig. 2) was established between the depths of 110 and 360 m with the rise at the center. Two trawl hauls were attempted at each station: one during daylight and one during darkness. When significant midwater fish schools were observed, they were sampled with midwater trawl gear for species composition.

The contents of each trawl haul were sorted by species, weighed, counted, and recorded. Otoliths were removed from samples selected for age determination and stage of maturity was recorded for some individuals. Stomach sample collections, stratified by fish length, were also taken and preserved for feeding studies.[6] No meaningful description of age and length composition was possible because of the small catches.

Consultations with fishermen, observation trips aboard commercial trawlers, and observations during research operations provided further information about school characteristics and diel behavior patterns of widow rockfish and other species on and around widow rockfish fishing grounds.

Results

Twenty-seven demersal tows were completed during the August 1980 widow rockfish behavior study, including 12 at night and 15 during the day. The trawl was damaged during two night hauls. The widow rockfish catch was small, with 1 or 2 specimens in six hauls and 20 specimens in one of the night hauls during which the trawl was damaged (Fig. 3, 1980). Therefore, no conclusions about diel movement patterns were possible from the 1980 study.

The *Miller Freeman* transected the Nelson Island area during the same study period and found one

[4]"Echosign" can be defined as the echo return output (paper echograms, video chromoscope displays, etc.) of an echo sounder aimed at targets in the water column.

[5]Thomas, G. L., C. Rose, and D. R. Gunderson. 1981. Rockfish investigations off the Oregon coast, annual report. Unpubl. manuscr., 20 p. Univ. Wash., Fish. Res. Inst., FRI-UW-8119.

[6]Adams, P. B. 1984. The diet of widow rockfish (*Sebastes entomelas*) in northern California. Unpubl. manuscr. Southwest Fisheries Center Tiburon Laboratory, National Marine Fisheries Service, NOAA, 3150 Paradise Drive, Tiburon, CA 94920.

TABLE 2.—Vessels used during the widow rockfish assessment project.

Vessel	Length (m)	Main engine (hp)	Survey type	Agency[1]	Dates
Muir Milach	26	800	Hydroacoustic sonar	FRI	19 Mar.-2 Apr. 1980
Pat San Marie	31	765	Behavior	NWAFC	11-13 Aug. 1980
Mary Lou	26	700	Behavior	NWAFC	11-13 Aug. 1980
Miller Freeman	66	2,200	Behavior and hydroacoustic	NWAFC	11-13 Aug. 1980
Alaska	30	600	Hydroacoustic sonar	FRI	12-23 Mar. 1981
Chapman	39	1,165	Behavior and hydroacoustic sonar	NWAFC	7-26 Apr. 1981
Ocean Leader	36.5	1,125	Hydroacoustic sonar	NWAFC	14 Mar.-7 Apr. 1982

[1]FRI = Fishery Research Institute; NWAFC = Northwest and Alaska Fisheries Center.

TABLE 3.—Fishing gear used during the widow rockfish assessment project.

Trawl type	Vessels	Doors and accessory gear	Approximate fishing dimensions
Bottom trawl			
Nor'eastern	*Pat San Marie* and *Mary Lou*	1.5 × 2.1 m steel V-doors, 55 m triple dandylines, 32 mm mesh cod end liner, roller gear	9.1 m headrope height, 13.4 m wingspread
	Muir Milach and *Chapman*	Same as above but with 1.8 × 2.7 m steel V-doors 2,500 lb	6.10 m headrope height, 16.7 m wingspread (Wathne[1])
	Alaska	Same as above but with 1.6 × 2.9 m aluminum V-doors	(not measured)
Midwater trawl			
Alaska Diamond	*Chapman*	1.8 × 2.7 m steel V-doors, 55 m double dandylines with 4 sets of 5.5 m bridles, 125 kg weights attached to the bottom of each wingtip, 32 mm mesh cod end liner	11.0-14.6 m vertical opening 15.2 m wingspread
	Alaska	Same as above but with 1.6 × 2.9 m aluminum V-doors	Same as above
Norsenet	*Miller Freeman*	6 m^2 Waco doors, 75 m double dandylines, 46 mm mesh cod end covered with a double braided 144 mm mesh bag	18-20 m vertical opening
No. 7 Gourock rope wing	*Muir Milach*	4.6 m^2 Suberkrub doors, 73.2 m double dandylines, 114 mm mesh cod end (no liner)	18.3 m vertical opening, wingspread not measured
No. 8 Gourock rope wing	*Ocean Leader*	4.5 m^2 Suberkrub doors, 100 m dandylines 200 kg weights attached to the bottom of each wing, 32 mm mesh cod end liner	21.3 m vertical opening, wingspread not measured

[1]Wathne, F., Northwest and Alaska Fisheries Center, 2725 Montlake Blvd. E., Seattle, WA 98115, pers. commun. June 1981.

TABLE 4.—Hydroacoustic equipment used during widow rockfish behavior and assessment surveys, 1980-82. FRI = Fisheries Research Institute; NWAFC = Northwest and Alaska Fisheries Center.

Vessel:	*Muir Milach* (FRI)	*Miller Freeman* (NWAFC)	*Alaska* (FRI)	*Chapman* (NWAFC)	*Ocean Leader* (NWAFC)
Dates used	19 March-2 April 1980	11-13 August 1980	12-23 March 1981	21-26 April 1981	14 March-7 April 1982
Echo sounder and transducer	Simrad[1] EK-38 11° beam at −3dB	Simrad EK-38 12° beam at −3dB	Simrad EK-38 11° beam at −3dB	Simrad EK-38 11° beam at −3dB	Biosonics 101 7° beam at −3dB
Towed V-fin transducer housing	2-ft Braincon	2-ft Braincon	2-ft Braincon	2-ft Braincon	2-ft Braincon
Tape recorder	TEAC 3440A reel-to-reel	cassette	TEAC 3440A reel-to-reel	TEAC 3440A reel-to-reel	cassette
Chart recorder	Simrad wet paper	Simrad dry paper	Simrad wet paper	Simrad wet paper	EPC 1600 dry paper
Portable echo integrator	Biosonics 120	NWAFC acoustic research container system	Biosonics 120	Biosonics 120	Biosonics 120
Computer	Not used	NWAFC acoustic research container system	Not used	Not used	Radio Shack TRS-80
Sonar system	C-Tech LSS-68 68 kHz sector scanning	Not used	C-Tech LSS-68 68 kHz sector scanning	Simrad SQ searchlight beam	Furuno FSS-75 75 kHz sector scanning
Video camera and recorder	RCA C004 camera Panasonic recorder	Not used	RCA C004 camera Panasonic recorder	RCA C004 camera Panasonic recorder	RCA C004 camera Panasonic recorder

[1]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

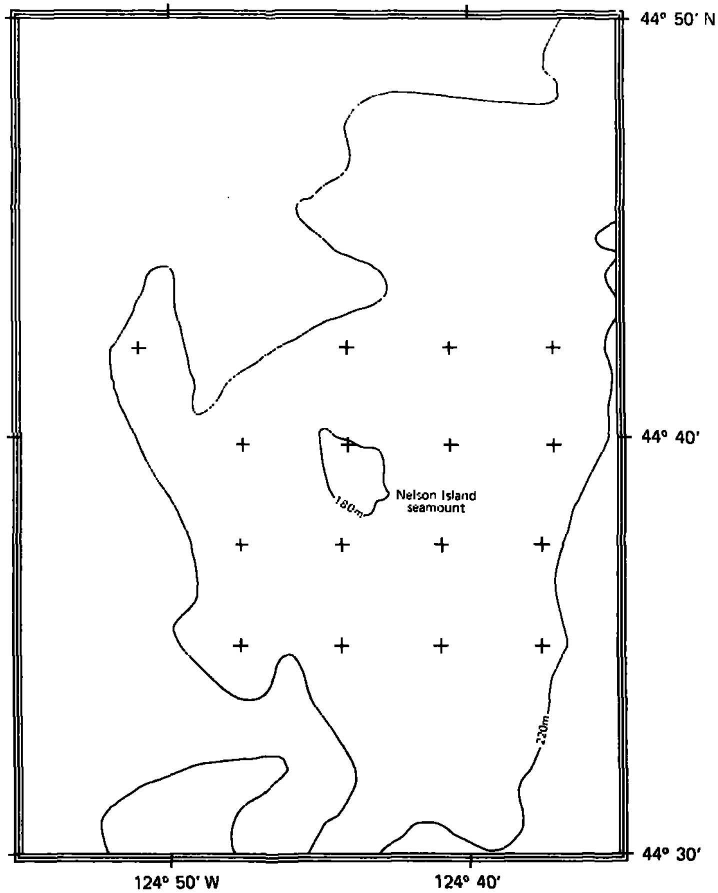
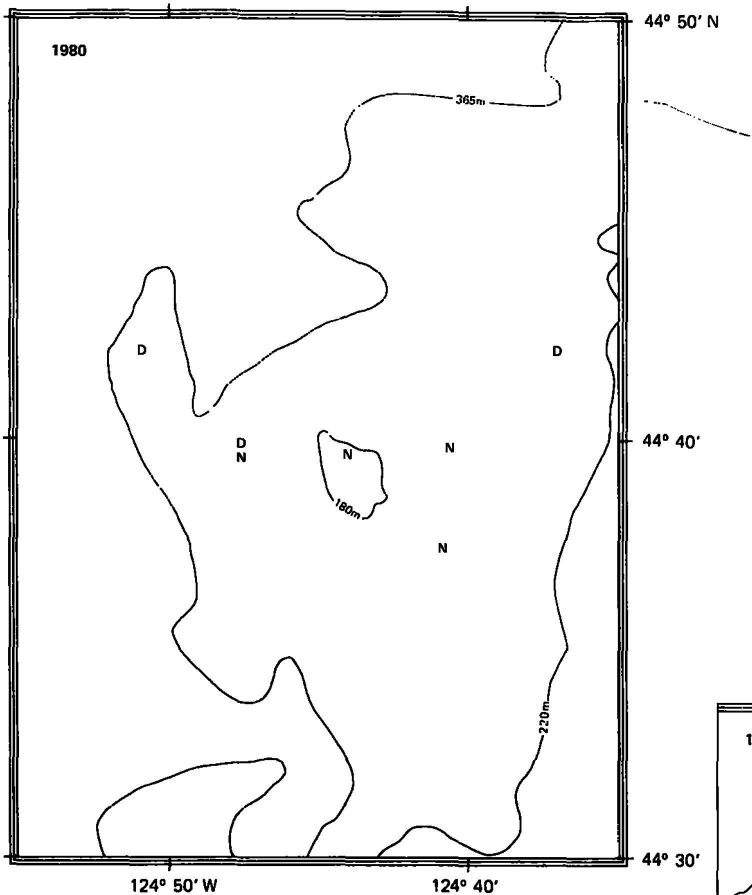


FIGURE 2.—The demersal trawl station grid occupied during 1980 and 1981 widow rockfish behavior studies on the Nelson Island ground off Newport, OR. The 16 trawl stations are marked with a (+).

school of widow rockfish, which was sampled with midwater trawl gear (Fig. 4). It was not possible to stay in contact with the school long enough to observe diel changes in behavior.

When the study was repeated in April 1981, only 4 of 20 demersal tows contained widow rockfish. Two of these tows contained only a single specimen each, while the others contained 20 and 28 specimens. Results again indicated that widow rockfish were relatively unavailable to demersal trawl gear and that their distribution was somewhat more closely associated with Nelson Island during the night than during the day (Fig. 3, 1981).

It is important to be able to distinguish widow rockfish from other species on the basis of echosign in order to draw conclusions about their behavior, distribution, and abundance. Commercial fishermen targeting on this species have shown that this can be done. We characterized the echosign produced by widow rockfish and other species occurring on widow rockfish grounds using echograms obtained aboard research and commercial vessels and through discussions with commercial fishermen on echograms and corresponding catches. Widow rockfish schools most frequently appeared on echograms as tall, slender columns suspended over an irregular bottom (Fig. 5). These were often accompanied by less dense layers probably composed of salps and other zooplankton. Widow rockfish were sometimes present during evening and morning in smaller schools high in the water column (Fig. 6). Shortbelly rockfish, *Sebastes jordani*, and redstripe rockfish, *S. proriger*, have similar echosign characteristics and are most likely to be confused with widow rockfish off the Oregon coast (Figs. 7, 8). Other midwater targets in the area were identified as layered schools of



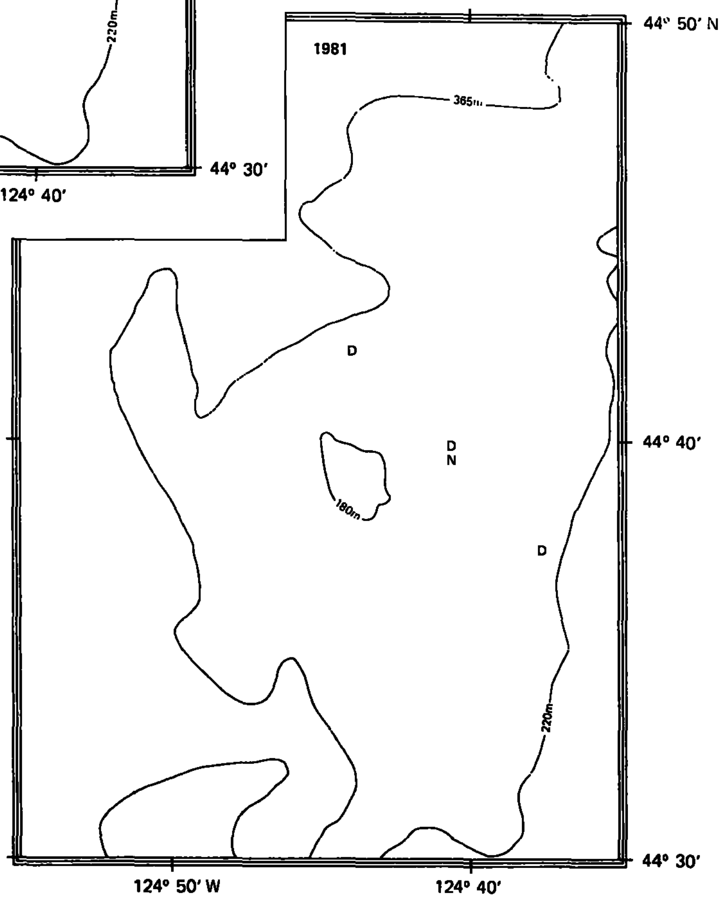


FIGURE 3.—Locations of demersal tows which contained widow rockfish during day (D) and night (N) sampling during the 1980 and 1981 behavior studies.

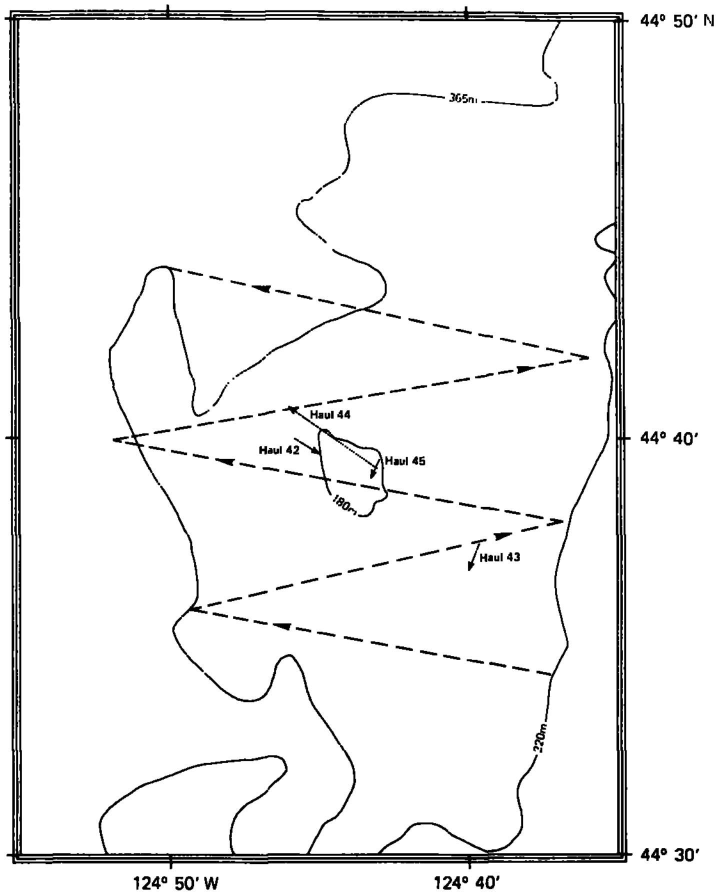


FIGURE 4.—Hydroacoustic transects (dashed lines) and midwater trawl hauls (solid arrows) conducted by the RV *Miller Freeman* during the 1980 behavior study. Only haul 43 contained widow rockfish (1,247 kg).

Pacific whiting, *Merluccius productus*, (Fig. 8) or less dense layers of zooplankton.

The formation and dispersal of widow rockfish aggregations was observed during the research cruises. During a typical night, small schools would appear in late evening (from 2000 to 2400) either near bottom or high in the water column. As the night progressed, these schools tended to grow and those high in the water would settle toward the bottom. Peak school size and density usually occurred between 0200 and dawn. Shortly after daybreak, most schools would separate into smaller schools and rise off the bottom. The schools would sometimes move over deeper water while maintaining their nighttime configuration.

Departures from the typical behavior patterns have been reported. For example, while observing widow rockfish schools over the continental shelf (not aggregating around a seamount), Gunderson et al.[7] noted a progressive offshore shift in the location of the schools during one night. By sunrise most of the schools were located near the edge of the shelf. Most of these schools dispersed after dawn, but some remained on the bottom in the area (in one case as late as 1037 when observations were terminated). This apparent shift may have been related to diurnal vertical migration behavior (Pereyra et al. 1969).

METHODOLOGY DEVELOPMENT (1980-81)

The methodology development was conducted by

[7]Gunderson, D. R., G. L. Thomas, P. Cullenberg, and R. E. Thorne. 1981. Rockfish investigations off the coast of Washington and Oregon. Final report. Unpubl. manuscr., 45 p. Univ. Wash., Fish. Res. Inst., FRI-UW-8125.

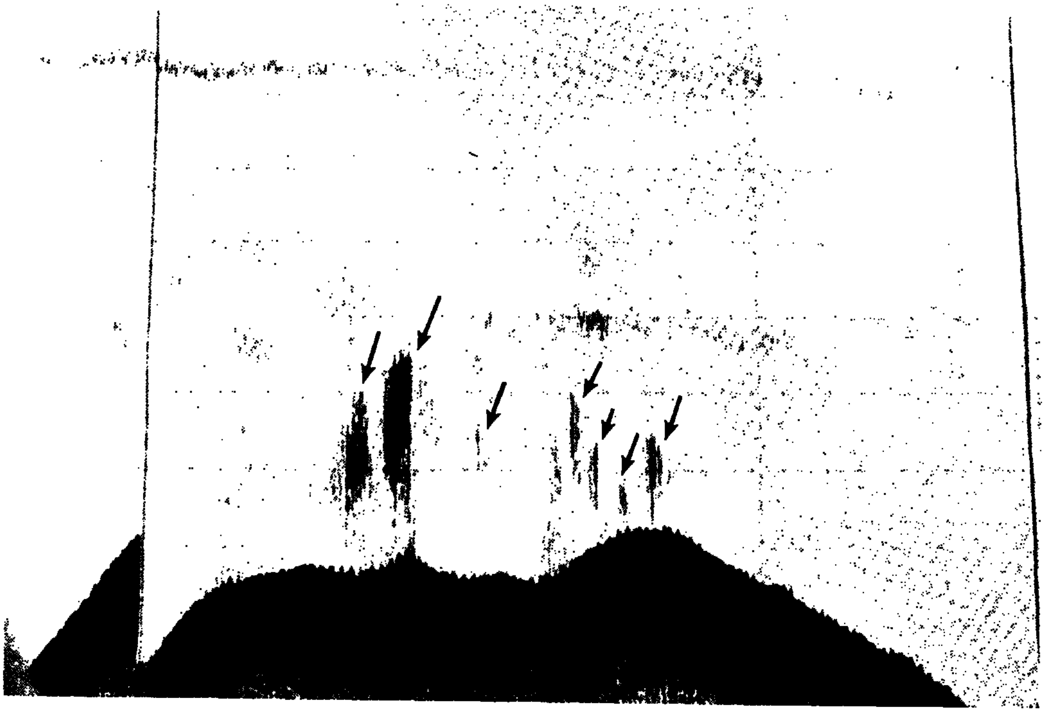


FIGURE 5.—Echogram showing the typical configuration of widow rockfish schools at night (arrows).

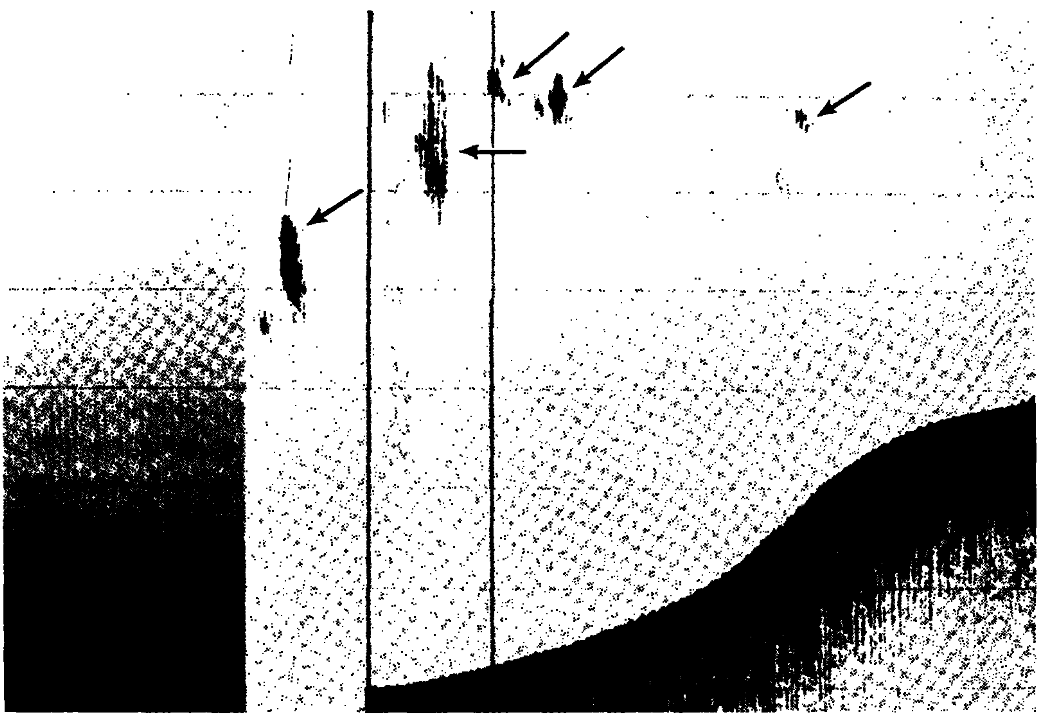


FIGURE 6.—Echogram showing the configuration of "evening and morning" widow rockfish schools (arrows).

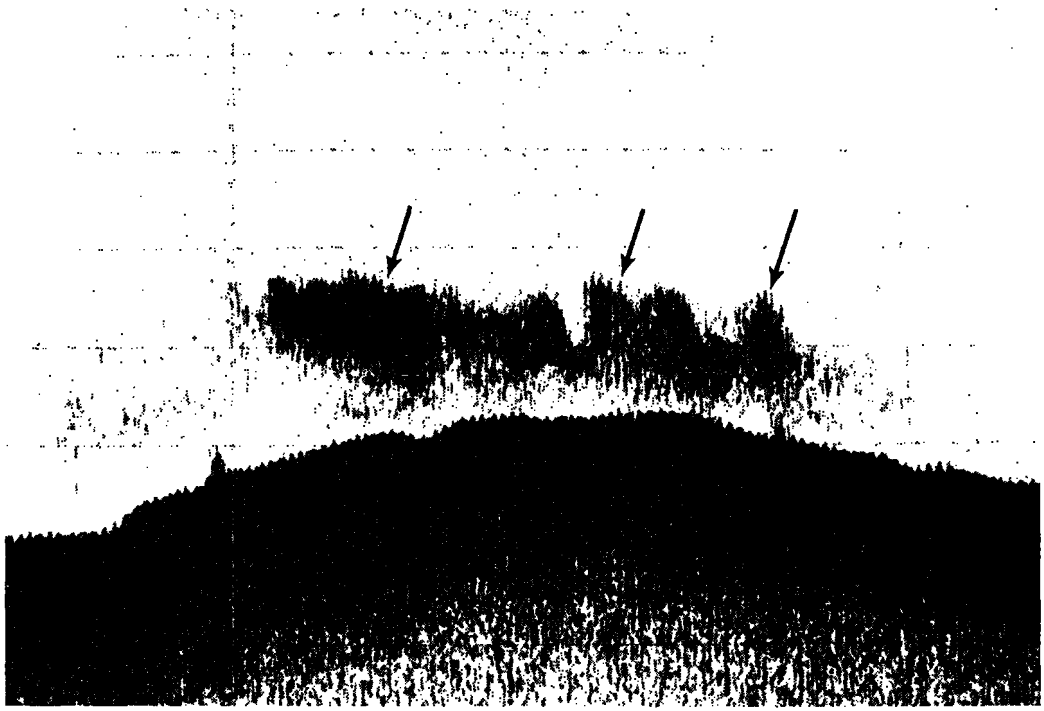


FIGURE 7.—Echogram showing the typical configuration of shortbelly rockfish schools (arrows).

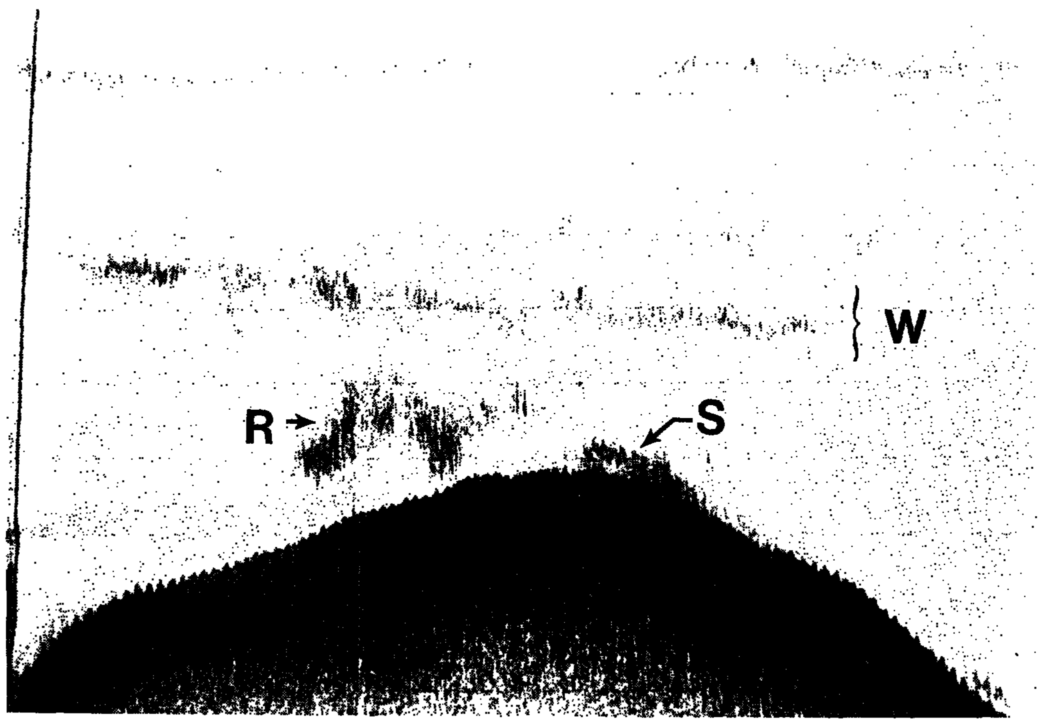


FIGURE 8.—Echogram showing configuration of Pacific whiting (W), redstripe rockfish (R), and shortbelly rockfish (S) schools.

the University of Washington's Fishery Research Institute (FRI) under contract with the NWAFC (Gunderson et al. fn. 7, 8). The objectives of the work were to evaluate the applicability of several resource assessment techniques and refine the most promising approaches. In particular, it involved a comparison of three methods of quantifying widow rockfish abundance in small areas off southern Washington and northern Oregon: conventional echo integration, line transect survey theory (Burnham et al. 1980; Seber 1980), and line intercept survey theory (Seber 1973, 1980).

Methods

This study involved three research cruises off southern Washington and northern Oregon. Tables 2-4 present the dates of these cruises and specifications of the vessels, fishing gear, and hydroacoustic equipment employed. The field work entailed systematically transecting the survey areas, simultaneously recording data from quantitative echo integration equipment and sector scanning sonar. Data were collected on the number of fish schools, their perpendicular distance from the transect, their depth below sea surface, the size and density of selected schools, and the distribution of schools in relation to various features of submarine topography. The echo integration system was used in a conventional manner to obtain a measure of the density of fish within a relatively narrow acoustic beam of 10°-11° directly below the vessel (Fig. 9). Sector scanning sonar cannot measure fish density, but by employing an array of transducers radiating an acoustic signal over a 200° × 9° semicircular wedge perpendicular to the path of the vessel (Fig. 9), it can be used to count schools within about 100-200 m to each side of the vessel, measure their dimensions, and determine their perpendicular distance from the transect. The sonar's transducer array was aimed straight downward for these studies. The entire wedge was

[8]Gunderson, D. R., G. L. Thomas, P. Cullenberg, D. M. Eggers, and R. E. Thorne. 1980. Rockfish investigations off the coast of Washington. Annual report. Unpubl. manuscr., 68 p. Univ. Wash., Fish. Res. Inst., FRI-UW-8021.

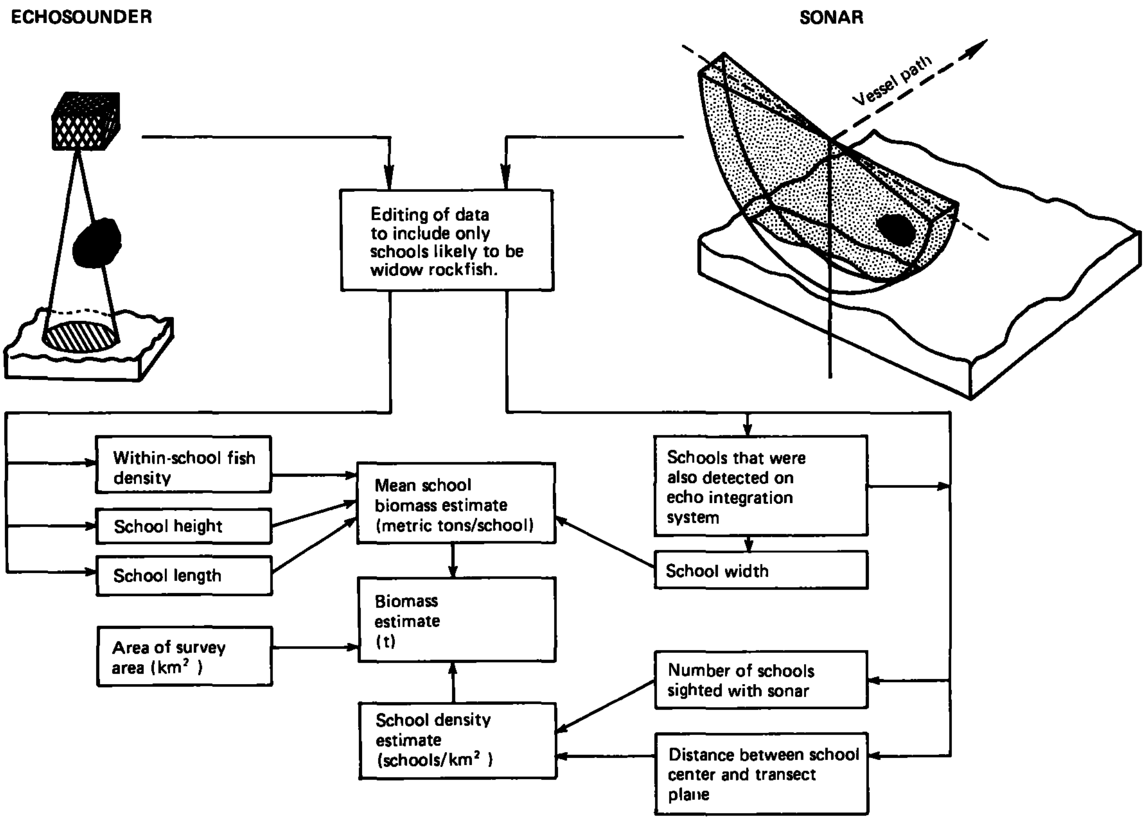


FIGURE 9.—Schematic diagram depicting the analysis of echo sounder and sonar data collected during hydroacoustic line transect surveys.

displayed simultaneously on a 10-in diameter cathode ray tube (CRT) screen which provided information on the location and size of fish schools within its 200-400 m wide path (Fig. 10).

Data was collected electronically during the echo integration and sonar surveys. Echo sounder return signals were processed by an echo integrator capable of measuring voltages in variable-sized depth intervals. The echo integrator produced periodic printouts of summed integrated voltage values which corresponded to relative fish densities along the transect in various depth intervals. Analog data (receiver output voltages) were recorded onto magnetic tape as a back-up procedure and for further processing. The sonar CRT display screen was video-taped for playback and data reduction in the NWAFC laboratory.

Survey design of the 1980 and 1981 FRI studies off southern Washington was generally similar, though some aspects differed. In 1980, preselected tracklines were run and were between lat. 46°20′N and 46°48′N and between 55 and 183 m isobaths at intervals of of 3.7 km. When a significant aggregation of fish was encountered, its bounds were determined by making several mapping runs perpendicular to the main trackline. Trawling followed to determine the species composition of the aggregation and to collect biological samples. Most of the 1980 work was done during daylight with the intent of mapping and measuring yellowtail rockfish, *Sebastes flavidus*, schools. After encountering numerous widow rockfish schools at night, it became apparent that this species' schooling behavior was better suited for evaluating this methodology. Thereafter, three nights were spent transecting a smaller "widow rockfish subarea". Diel behavior and distribution were examined by making several repetitions of three selected tracklines. Near the end of this cruise an area occupied by a dense aggregation of widow rockfish schools was encountered. A short nonrandom transect was run to obtain comparable line intercept and line transect results.

In 1981, tracklines spaced every 3.7 km were transected between the depths of 128 and 220 m off northern Oregon between lat. 45°50′N and 46°18′N.

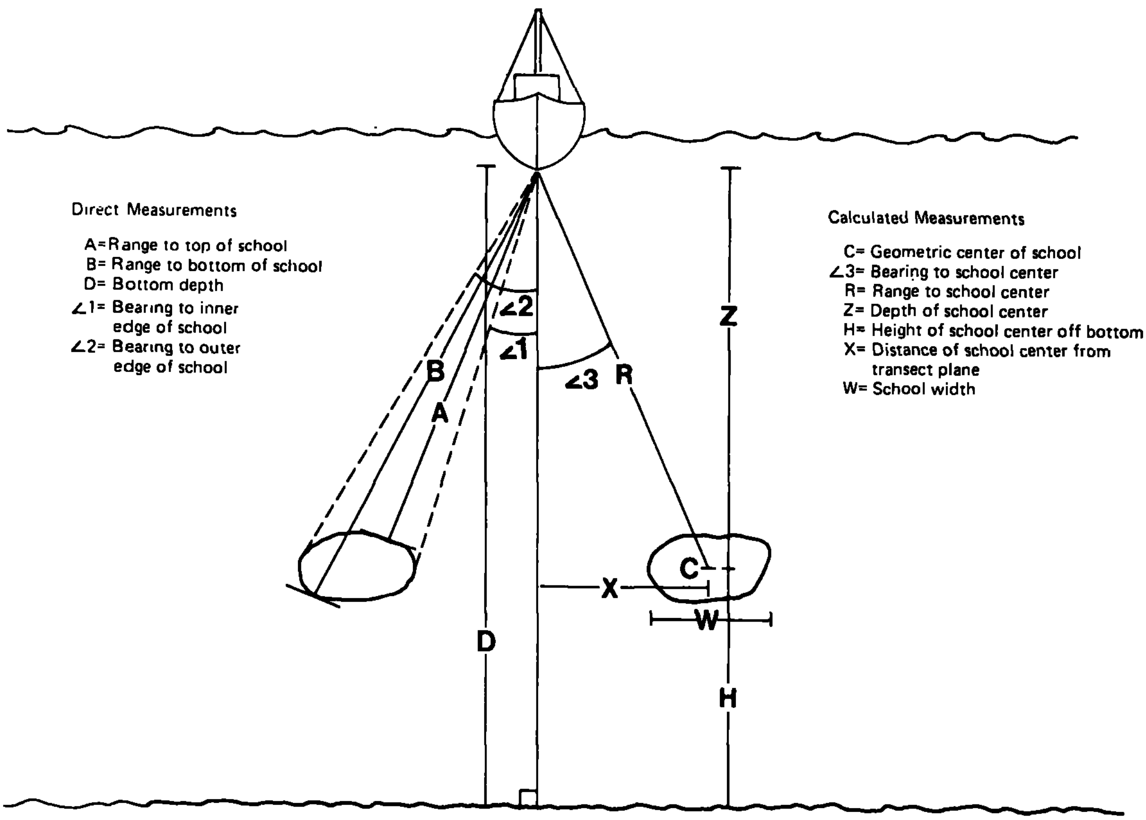


FIGURE 10.—Measurements and calculated dimensions of fish schools from videotaped sonar records.

The same procedures were used as in 1980 except that nearly all operations were conducted after dark and no mapping runs were made to define the bounds of school groups. A diel variability study was conducted on 20 March 1981 between the hours of 0153 and 1037, consisting of 13 replicates of trackline 21.

The conventional analysis of echo sounder data (integration) is based on the principle that the acoustic intensity of a signal reflected from fish targets is proportional to the density of fish in the region irradiated by the echo sounder. Detailed descriptions of the technique can be found in Moose and Ehrenberg (1971), Forbes and Naaken (1972), and Thorne (1977). During the 1980 and 1981 surveys, density estimates from this method were obtained by averaging returning acoustic signals over a series of transmissions (25 transmissions over 12.5 s during the *Muir Milach* cruise and 40 transmissions over 50 s during the *Alaska* and *Chapman* cruises). These averages were then converted from relative to absolute densities (kg/m^2) for various depth intervals using calibration data and a scaling factor based on an average target strength of −35 dB/kg.[9] Absolute abundance (biomass) was estimated by extrapolating absolute density estimates to the survey area.

Each survey area was systematically transected using the echo sounder and sonar to search for fish schools and, thereby, to derive line intercept and line transect estimates of school abundance (schools/km^2). Data on school dimensions and density were collected from those schools sighted. With the line intercept method, only the presence of a school (as detected by the echo sounder) and its width were used to estimate school abundance. This technique is based on the theory that, for systematically located transects, the probability of intersecting school i equals w_i/W, where w_i is the width of school i and W is the distance between adjacent transects. The number of schools per unit area (D) can then be estimated by

$$\hat{D} = \sum_{j=1}^{n} \frac{1}{w_j L} \qquad \text{(Seber 1980)}$$

where n = number of schools measured on a transect of length L

w_j = width of j^{th} school.

[9]The target strength value used in these analyses (−35 db/kg) was not derived during work on widow rockfish. Since accurate target strength estimation was not necessary for evaluating the utility of the methodology, we used a value which had been estimated for Pacific whiting (Dark et al. 1980) which has a similar scattering cross section.

The line intercept method was applied only to data collected from the nonrandom run made on the night of 27-28 March 1980. The data from this line were subdivided into two artificial transects of unequal length and the jackknife method (Seber 1980) was used to estimate D and its variance. This technique is described fully by Gunderson et al. (fn. 8).

Line transect theory is based on the premise that the probability of sighting a given object (or school) is a function of its perpendicular distance from the transect. A "detection function" is derived from school sighting data which relates the probability of a school being sighted to its distance from the transect. This function is used to expand the number of schools actually sighted to obtain an estimate of school abundance. The advantage of this method is that not all schools within sighting range need to be detected in order to estimate the number of schools in the area.

Using line transect estimation, the school abundance (schools per unit area) was estimated by

$$\hat{D} = \frac{n\hat{f}(0)}{2L}$$

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

n = number of schools sighted

L = length of transect

$\hat{f}(0)$ = "detection function"—a parameter estimated from probability function for the perpendicular distances off transect of schools sighted.

The assumptions necessary for the use of this method are

1) Schools directly on the transect plane will always be sighted.
2) Schools are sighted in the position they occupied prior to the approach of the vessel, i.e. there is no avoidance of or attraction to the vessel.
3) Perpendicular distances off transect are measured precisely, particularly near the transect plane.
4) The detection function remains constant.

The computer program TRANSECT (Laake et al. 1979) was used to estimate the probability density function of the perpendicular distance of schools from the transect. The estimator model used is based on a nonparametric Fourier series expansion fit to data sets of observed perpendicular distances of schools off the transect plane. Quinn (1979) and Burnham et al. (1980) showed that this model is robust and flexible and provides the best fit to the detection function in most applications. This estimator, at zero distance, is

$$\hat{f}(0) = \frac{1}{w^*} + \sum_{k=1}^{m} \hat{a}_k$$

where w^* = truncation width, or the effective limit of the range of detection, beyond which all observations are discarded and

$$\hat{a}_k = \frac{2}{nw^*}\left[\sum_{i=1}^{n} \cos\left(\frac{k\pi x_i}{w^*}\right)\right] \text{(Burnham et al. 1980)}$$

where 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 (m) is determined by a stopping rule in the computer program TRANSECT].

TRANSECT also computes the school abundance estimate $\hat{D}$ and its variance which is estimated by the equation:

$$\hat{\text{var}}(\hat{D}) = (\hat{D})^2 \left[\frac{\hat{\text{var}}(n)}{n^2} + \frac{\hat{\text{var}}[\hat{f}(0)]}{[\hat{f}(0)]^2}\right].$$

Mean school biomass estimates were derived from density information (from echo sounder data), school dimension information (from sonar data), and an assumed target strength of −35 dB/kg. These estimates were used in the line transect and line intercept analyses. All information on schools detected by the hydroacoustic systems was edited to discriminate widow rockfish from other species using judgments based on school form, density, location, and test trawl records. Data on each school identified as widow rockfish were then integrated to obtain mean within-school density. The CRT display of the sector scanning sonar provided representations of the size, shape, and position of fish schools within its range of detection. The dimensions of all schools identified as widow rockfish were measured on the screen of a video monitor using the slow motion and freezeframe features of the video recorder-player. Dimensions measured directly included depth of school from the surface, distance off bottom, width, thickness, radial distance from vessel, and bearing to the right or left of a vertical line below the vessel (Fig. 10). The perpendicular distance of the school from the vertical plane of the vessel's path ("distance off transect") was calculated from the radial distance and bearing. All distances were measured or calculated to the apparent geometric center of each school (Burnham et al. 1980). The length of each school was calculated from the product of vessel speed and the duration that the school was being detected by the sonar, and was corrected to account for the variable sonar beam width parallel to the vessel's path due to depth.

The biomass of individual schools was estimated by the formula

$$\hat{b}_i = t_i\, l_i\, w_i\, d_i$$

where $\hat{b}_i$ = estimated biomass of school i
t_i = average thickness of school i, top to bottom (echo sounder data)
l_i = length of school i, parallel to transect (sonar data)
w_i = average width of school i perpendicular to transect plane (sonar data)
d_i = mean integration density for school i (g/m^3) assuming a target strength of −35 dB/kg (see footnote 9) (echo sounder data).

The mean school biomass (MSB) was estimated from the individual school biomass estimates; its variance was determined from

$$\hat{\text{var}}(M\hat{S}B) = \sum_{i=1}^{N} \frac{(\hat{b}_i - M\hat{S}B)^2}{N(N-1)}$$

where N = number of schools averaged for MSB.

Total biomass estimates from the line transect and line intercept methods were calculated for each survey area using the formula

$$\hat{B} = A\,\hat{D}\,(M\hat{S}B)$$

where $\hat{B}$ = estimated total biomass for the survey area, and
A = total area (km^2) of the survey area.

The variance of these estimates was determined from

$$\hat{\mathrm{var}}\ \hat{B} = A^2\ [(\hat{D})^2\ \hat{\mathrm{var}}(\hat{MSB}) + (\hat{MSB})^2\ \hat{\mathrm{var}}(\hat{D}) - \hat{\mathrm{var}}\ (\hat{MSB})\ \hat{\mathrm{var}}\ (\hat{D})] \quad \text{(Goodman) 1960)}$$

Results

Twenty one trawl hauls were made during the 1980 FRI survey aboard the *Muir Milach*; 6 with bottom gear and 15 with midwater gear. Widow rockfish were caught only in midwater hauls and comprised 99% of those catches. The most abundant species in the bottom tows were spiny dogfish, *Squalus acanthias*, and black rockfish, *Sebastes melanops*. The acoustic survey consisted of 22 systematic transects covering about 550 km and employed sonar and echo integration equipment. Twenty six schools were sighted and measured to provide data for a line transect estimate of school abundance. During the nonrandom transect run on the night of 27-28 March 1980, 73 schools were sighted and measured for use in developing line transect and line intercept estimates of school abundance in a small subarea.

Only four trawl hauls were attempted during the 1981 FRI survey due to severe gear damage. Redstripe rockfish, *Sebastes proriger*, comprised 90% or more of the two catches which contained fish (one midwater haul and one bottom haul). The midwater haul was made quite close to bottom near midnight and contained small quantities of sharpchin rockfish, *Sebastes zacentrus*; widow rockfish; and greenstriped rockfish, *S. elongatus*, suggesting an association of these species in nearbottom schools at night. Fifteen systematic transects were covered during this survey (about 400 km) during which 49 schools were sighted and measured. One of the transects was replicated 13 times during one night to observe the behavior of a group of schools over the continental shelf just south of the Columbia River. These schools were not gathered around a prominent bottom feature. As the night progressed they moved deeper and further offshore, reaching the shelf break about sunrise. After sunrise most of the schools dispersed, though some remained on bottom at least until observations ceased at 1037 (Gunderson et al. fn. 7).

During the 1981 NMFS cruise, quantitative hydroacoustic data were collected from 21 transects on the Nelson Island, The Fingers, Heceta Bank, and Cape Blanco grounds (Fig. 1, Table 5) using echo integration (Thomas et al. fn. 5). The searchlight-beam sonar available on the *Chapman* was inadequate to identify school types or provide estimates of school density. This is because it employed only a single transducer programmed to sweep back and forth and did not provide continuous coverage of the area within its range. Therefore, all density and biomass figures for this survey refer to total nekton rather than widow rockfish.

TABLE 5.—The mean fish and nekton density (g/m^2) and biomass (metric tons) by location, date, and transect estimated by a conventional echo integration survey performed aboard the NOAA RV *Chapman*, 21-26 April 1981.[1]

Location	Date	Transect	Transect length (km)	Density	Mean density $\bar{D}$	$\hat{\mathrm{Var}}\ \bar{D}$	Area (km^2)	Biomass $\hat{B}$	$\hat{\mathrm{Var}}\ \hat{B}$
Crater	4/21	1	18.56	1.78					
	4/22	2	17.11	5.86	2.82	2.45	228.87	646	1.28×10^5
	4/22	3	15.02	0.66					
Cape Blanco	4/23	4	4.19	16.17					
	4/23	5	4.35	26.22					
	4/23	6	4.67	4.50					
	4/23	7	5.32	1.12	6.47	11.31	200.81	1,301	4.56×10^5
	4/23	8	6.11	1.79					
	4/24	9	2.44	1.63					
	4/24	10	3.87	0.34					
	4/24	11	3.87	0.06					
Heceta Bank	4/24	12	17.59	4.67					
	4/25	13	18.37	0.12	4.89	9.44	87.15	427	7.17×10^4
	4/25	14	15.30	10.88					
The Fingers	4/25	15	14.74	1.78					
	4/25	16	14.74	1.01	1.73	0.19	75.11	130	1.07×10^3
	4/25	17	12.22	2.54					
Crater	4/26	18	5.57	0.00					
	4/26	19	6.96	0.00	1.79	2.83	34.78	62	3.43×10^3
	4/26	20	6.28	6.75					
	4/26	21	5.63	0.26					

[1]Thomas, G. L., C. Rose, and D. R. Gunderson. 1981. Rockfish investigations off the Oregon coast, annual report. Unpubl. manuscr., 20 p. Univ. Wash., Fish. Res. Inst. FRI-UW-8119.

The results of echo integration, line intercept, and line transect analyses were compared using data collected during the 1980 and 1981 FRI cruises (Gunderson et al. fn. 7, 8). Large differences were seen between echo integration and line transect estimates in a situation where schools were relatively small and scarce (1980 transect data, Table 6). The principal reason for this is that the threshold echo voltage required to trigger the sonar CRT display was higher than that needed to detect a school on the echo integration system, so many of the sparser schools detected by the echo sounder were not detected with the sonar. In situations where schools were larger and more plentiful (1980 nonrandom runs and 1981 transects) all three methods produced similar estimates. The precision of abundance estimates generated by line transect and line intercept methods is usually comparable to that of conventional echo integration methods and can exceed it in some cases (Gunderson et al. fn. 7). The major factors which led us to concentrate our efforts on line transect surveys were the ability to cover large areas rapidly and the ability to expand the number of schools sighted by a detection function, yielding more accurate estimates of school abundance.

APPLICATION OF ASSESSMENT METHODOLOGY

By 1982 the aforementioned studies had provided a foundation of information on which to expand developmental research. The behavioral observations suggested that widow rockfish aggregations were most stable and susceptible to assessment during the night. Line transect estimation of school abundance through the use of sonar and echo integration equipment was found to be the most effective of the techniques compared, especially when school abundance was likely to be low. The next step in the project was to evaluate the feasibility of applying the line transect survey method in a comprehensive survey to assess and monitor widow rockfish stocks.

Methods

The trawler *Ocean Leader* was chartered to survey five areas off Oregon (Fig. 1) where widow rockfish had been caught consistently between 1980 and 1982. Specifications of the vessel, fishing gear, and hydroacoustic equipment used appear in Tables 2-4. The proximity of alternative grounds was important for the success of the survey, should widow rockfish not be found in one or more of the areas. At each of the grounds the survey procedure was as follows:

1) The ground was systematically surveyed with hydroacoustic equipment during the night to determine whether fish schools were in the area. The locations of schools suspected to be composed of widow rockfish, or species likely to be confused with widow rockfish, were noted. The final boundaries of the study area were then delineated.
2) The study area was surveyed at night along parallel tracklines about 1 km apart using the line transect survey technique. The tracklines were replicated as many times as practical throughout

TABLE 6.—Summary of estimates of school abundance (D), mean school biomass (MSB), and total biomass (B) for widow rockfish. Coefficients of variation (CV) are given for each estimate.[1]

	$\hat{D}$ (schools/ nm^2)	CV	$M\hat{S}B$ (t)	No. of schools	CV	$\hat{B}$ (t)	CV
1980							
Transect data							
26 schools, 2 transects							
Line transect estimate	69.5	0.84	0.12	15	0.20	204	0.84
Echo integration estimate						778	0.16
Nonrandom run data							
73 schools, 1 transect							
Line transect estimate	242.2	0.19	0.85	16	0.50	5,003	0.53
Line intercept estimate	248.9	0.10	0.85	16	0.50	5,139	0.51
Echo integration estimate						6,453	—
1981							
Transect data							
29 schools, 3 transects							
Line transect estimate	12.1	0.24	0.62	27	0.33	342	0.40
Echo integration estimate						342	0.77

[1]Gunderson, D. R., G. L. Thomas, P. Cullenberg, and R. E. Thorne. 1981. Rockfish investigations off the coast of Washington and Oregon. Final report. Unpubl. manuscr., 45 p. Univ. Wash., Fish. Res. Inst. FRI-UW-8125.

the night to provide information on variability of abundance and distribution within a given night. Selected study areas were again surveyed after an interlude of several days to study variability over longer periods.

3) Fish aggregations noted during transecting were sampled with midwater trawls for species identification. This was done on alternate nights so as not to impede the progress of the acoustic assessment portion of the survey. Biological data (e.g., size composition, maturity, stomach contents) were collected from widow rockfish in the catches.

Results

About 725 km of transects were covered in the five study areas during the 12 nights of hydroacoustic data collection. Ten midwater trawl hauls were made to identify species present in various schools. Widow rockfish schools were seen in all areas, but were sparse on the Cape Blanco, Heceta Bank, and The Fingers grounds. The Halibut Hill ground, only recently exploited, contained the highest density of widow rockfish schools and also the largest average school size. After editing videotaped sonar records, 127 schools were identified as widow rockfish; data from 37 of these were integrated on the echo sounder system and used to calculate school biomass estimates. Ideally, a mean school biomass would have been derived for each ground, but because few schools were observed there, school biomass estimates were pooled and averaged for the Nelson Island, The Fingers, and Heceta Bank grounds. No measurable widow rockfish schools were seen during surveys of the Cape Blanco ground. School abundance was estimated for each area by treating each pass through the area as a replicate and pooling data from all replicates within the area. School abundance (excepting Cape Blanco) ranged from 0.6035 schools/km^2 on The Fingers ground to 1.4810 schools/km^2 on the Halibut Hill ground. Area biomass estimates are summarized in Table 7. The total estimated biomass for the five survey areas was about 830 t; 50% at Halibut Hill ground, 30% at Heceta Bank, 11% at The Fingers, and 9% at Nelson Island.

Sampling was concentrated on the Halibut Hill ground, where widow rockfish schools were largest and most plentiful, in order to investigate the diel and night-to-night variability in school abundance. The survey of this ground was repeated seven times; three times each night on 26-27 March and 31 March-1 April and once on 30 March. Separate sighting functions for each night were estimated by pooling observations. Corresponding school abundance and mean school biomass estimates were then calculated for each night. School abundance ranged from 0.39 schools/km^2 on 26-27 March to 4.50 schools/km^2 on 30 March. Mean school biomass tended to decline as school abundance increased, however, so biomass estimates for each of the sampling periods changed less than either school abundance or mean school biomass (Table 8). It was not possible to analyze the Halibut Hill data on a replicate-by-replicate basis because few schools were sighted during any single replicate. The number of sightings per replicate ranged from 4 to 34. Burnham et al. (1980) cautioned that such stratification procedures for line transect surveys should be "severely limited to those few surveys where the number of objects seen on replicate lines is fairly large (perhaps at least in the 20 to 30 range)".

TABLE 7—Summary of estimates of school abundance (D), mean school biomass (MSB), and biomass (B) in each of four study areas covered during the 1982 widow rockfish assessment feasibility survey.

Study area	$\hat{D}$ (schools/km^2)	$\hat{Var}(\hat{D})$	$M\hat{S}B$ (t/school)	$\hat{Var}(M\hat{S}B)$	Area (km^2)	$\hat{B}$ (t)	$\hat{Var}(\hat{B})$	$CV(\hat{B})$ $[\hat{Var}(\hat{B})]^{1/2}/\hat{B}$
Heceta Bank	0.9490	0.0305	1.968 (6 schools)	0.656	68.60	245.76	6,758.37	0.335
The Fingers	0.6035	0.0711	6.409 (4 schools)	5.486	40.47	92.20	2,212.03	0.510
Nelson Island	0.7587	0.3010	3.924 (2 schools)	9.514	27.44	78.59	3,467.75	0.749
3 above areas pooled[1]			3.775	1.151				
Halibut Hill	1.4810	0.2028	9.639 (25 schools)	21.668	28.81	411.27	51,758.47	0.553

[1]School biomass data from Heceta, The Fingers, and Nelson Island were pooled to provide a mean school biomass which was used to calculate total biomass in each area.

TABLE 8.—Summary of estimates of school abundance (D), mean school biomass (MSB), and biomass (B) of widow rockfish on the Halibut Hill ground during replicates on 26-27 March, 30 March, and 31 March-1 April 1982.

Sampling period	No. of repli-cates	No. of schools sighted/ replicate	$\hat{D}$ $\left(\frac{\text{schools}}{\text{km}^2}\right)$	$\hat{Var}(\hat{D})$	$\hat{MSB}$ $\left(\frac{\text{t}}{\text{school}}\right)$	$\hat{Var}(\hat{MSB})$	Area (km²)	$\hat{B}$ (t)	$\hat{Var}(\hat{B})$	$CV(\hat{B})$ $\frac{[\hat{Var}(\hat{B})]^{1/2}}{\hat{B}}$
26-27 March	3	9	0.394	0.1264	21.674	153.878	28.81	245.96	52,852.69	0.935
		14			(MSB based on 8 schools)					
		13								
30 March	1	34	4.499	0.8908	0.729	0.160	28.81	94.49	2,962.75	0.576
					(MSB based on 7 schools)					
31 March-1 April	3	9	1.325	0.1687	0.935	0.088	28.81	35.69	238.52	0.433
		11			(MSB based on 9 schools)					
		11								

Variations in the pattern of school abundance over the course of a night were common. Echograms recorded during the seven replicates of one transect on the Halibut Hill ground (Fig. 11) illustrate one case when abundance was high early in the night and decreased toward dawn (26-27 March). The opposite trend of low abundance increasing toward dawn is illustrated (31 March-1 April) in the same figure.

DISCUSSION

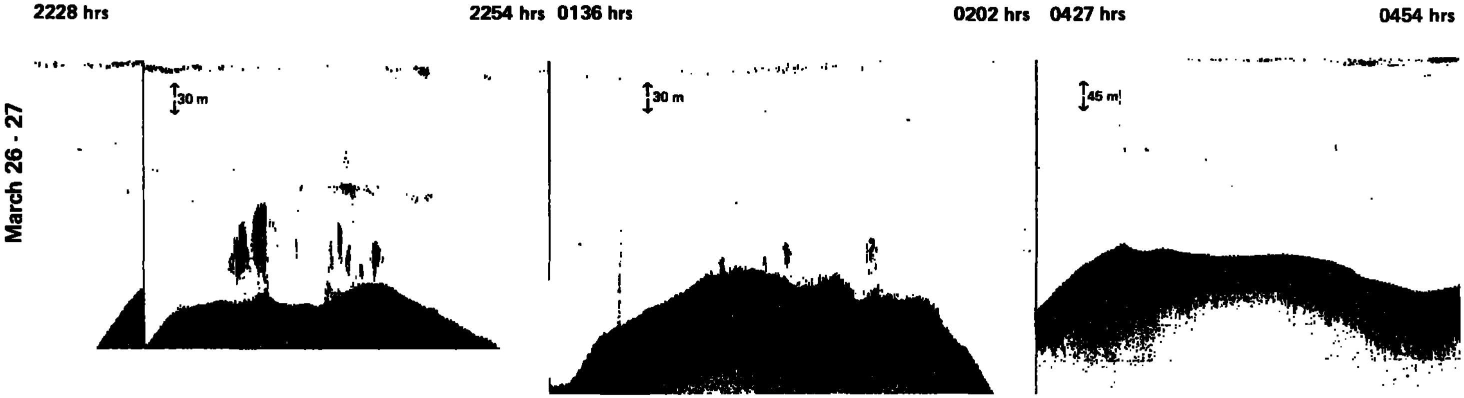
The objectives of this 3-yr project were to study the schooling behavior of widow rockfish to provide the background needed to design effective abundance estimating surveys; then to develop an appropriate survey methodology for the species; and, finally, to test the feasibility of implementing such a survey. Substantial progress was made toward satisfying these objectives. The studies of widow rockfish habits and distribution have provided a base for designing surveys which cover its range and produce the best likelihood of encountering the exploitable population at a time when it will be most available.

Understanding the schooling and dispersal behavior of widow rockfish was important to develop an appropriate survey approach for estimating abundance. The nighttime aggregations which are the targets of the commercial fishery tend to disperse about daybreak, perhaps scattering throughout the water column or seeking shelter near the bottom. If the latter had been the case, more conventional survey methods (i.e., bottom trawl or conventional echo integration surveys) might have been more appropriate.

Although daytime concentrations of widow rockfish were observed, bottom trawl catches during the 1980 and 1981 surveys showed that this species is relatively unavailable to bottom trawls in an area where widow rockfish are known to aggregate at night.[10] This is substantiated by low incidences of widow rockfish in catches of other bottom trawl surveys during periods when midwater trawlers were making large landings. Consequently, when midwater schools disappear during the day, it is unlikely that they disperse along the bottom. In recent years, skippers of midwater trawlers have commented that widow rockfish are becoming more evasive and dive below their nets to avoid capture. Some skippers have taken advantage of this behavior by purposely driving the schools toward bottom with engine noise where they capture them with bottom trawls equipped with roller gear. Although these are classified as bottom trawl landings, the fishermen are, in a sense, capturing midwater schools. Fishermen have also reported encountering daytime aggregations of this species over the continental slope in waters deeper than they are usually found at night (>500 m) and some have been able to catch them on or near the bottom during the day. Thus the distribution of widow rockfish relative to the sea bottom is quite unpredictable during the daytime. These schools are also not as large as those that occur at night. The appropriate time to survey this resource thus appeared to be at night. The line transect survey method, adapted for use with sector scanning sonar and echo integration equipment, was chosen over conventional echo integration and the line intercept method because of its ability to survey areas more quickly and thoroughly.

Application of the method exposed several problems affecting the precision and accuracy of the abundance estimates. The estimation of school abundance was hampered primarily by limitations of the sonar equipment and by small samples. We were not

[10]Observations of midwater echosign and landing information from commercial vessels fishing in the area confirmed that the usual dense midwater widow rockfish aggregations were present in the area at night during the 1981 bottom trawl survey.



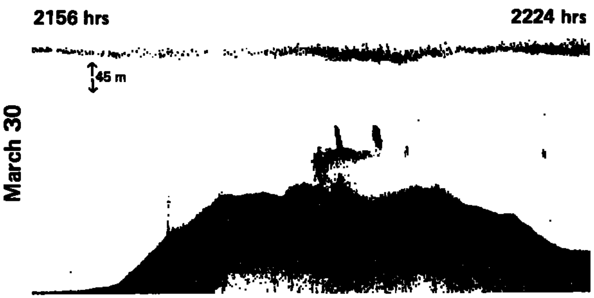
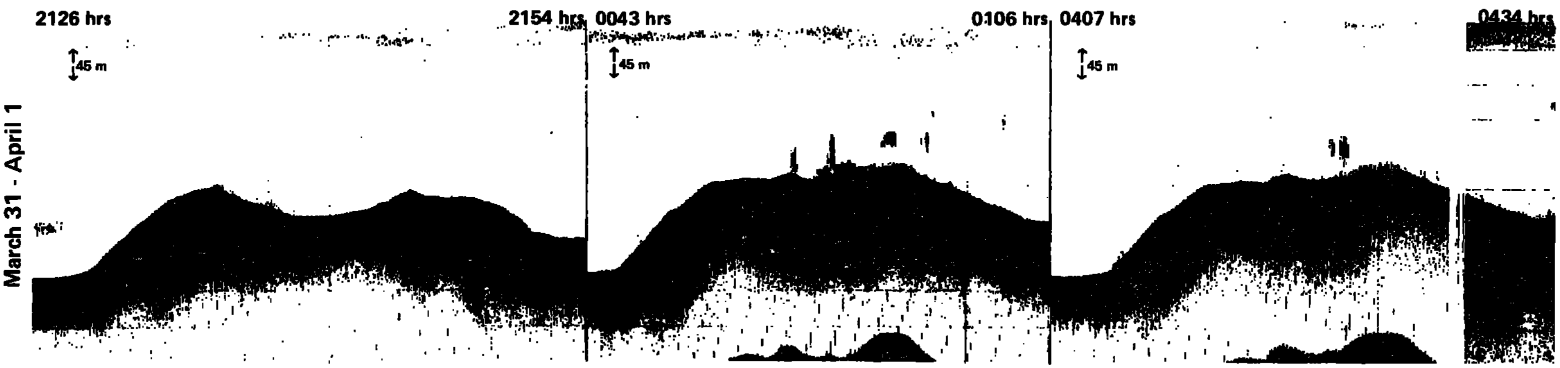


FIGURE 11.—Echograms of Halibut Hill Transect No. 4, which was replicated seven times during the three separate sampling periods. Each row of echograms represents all replicates made in a given night. Columns roughly correspond to the time of night that the transect was run. Sunrise occurred at about 0610. Temporal variability can be seen in the pattern of abundance of widow rockfish schools in the area.



able to calibrate the sonar systems so that the sensitivity of all transducers in the array were equal. Hence, the probability of detecting a given school in one sector of the sonar display was not necessarily the same as detecting it at an equal distance in another sector. The inability to calibrate the transducers may have compromised our ability to detect all schools directly below the transect. This is the most important assumption of line transect surveys; school abundance estimates will be biased downward if it is violated. Intercalibration of the transducers would also help establish a more accurate detection function which would apply throughout the sonar's range.

The limited lateral resolution of sector scanning sonar hampers the accurate measurement of school width, an important value for determining mean school biomass. Each transducer in the fan-shaped array acts as an independent echo sounder and if any portion of a school enters the radiation pattern, the entire width of the 9°-10° sector sampled by that beam will be displayed as a reflective target (Fig. 12). This results in an overestimation of school width and a distortion of the school's size and location, yielding overestimates of biomass and inaccurate measures of distance from the transect plane. The detection function will be altered by these inaccuracies and may modify estimates of school abundance depending on the magnitude and the direction of the errors. The distortion may be aggravated by interference of side lobes in the directivity pattern of individual transducer beams (Fig. 13). Even these lower power lobes can produce echo signals if very dense targets are encountered and may interfere with the acoustic signals from adjacent transducers.

Another weakness of sector scanning sonar in this application is insufficient detection sensitivity. This weakness became apparent during calculations of the lengths of individual schools. Lengths were calculated twice for each school, once based on echo sounder data and again based on sonar data. The theoretically correct method would employ the sonar data because schools could be detected further to each side of the vessel. The echo sounder could only detect the portion of the school within the 10°-11° beam directly below the vessel. Consequently, if a large part of the school was outside the beam, its length was underestimated. In practice, however, the length estimates based on sonar detections were usually shorter than those based on echo sounder data (Table 9) due to the lower sensitivity of the sonar system. The sonar-based lengths were chosen, however, because they measured the dimensions of the part of the school having densities above the threshold required to trigger the sonar. This is probably

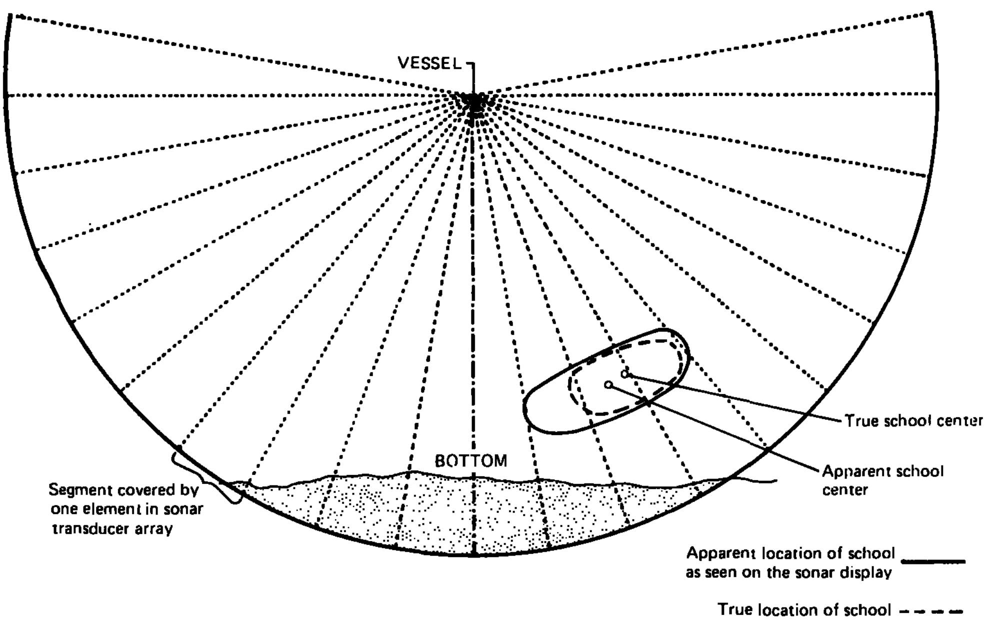


FIGURE 12.—A facsimile of the sector scanning sonar output display exemplifying biases in apparent school locations resulting from the limited resolution of the instrument.

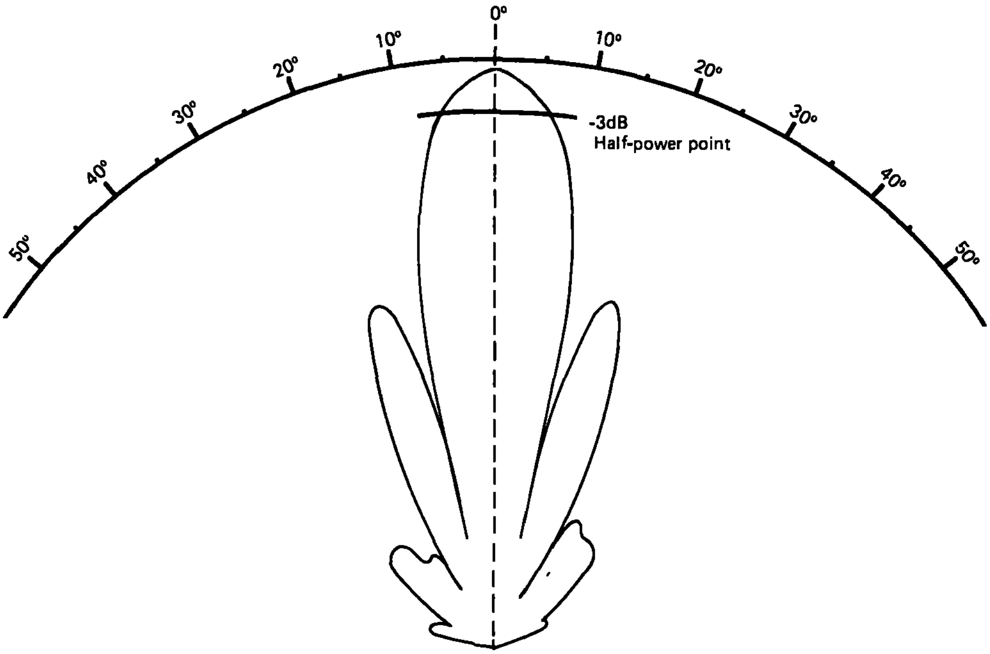


FIGURE 13.—The theoretical directivity pattern of one transducer element of the sector scanning sonar showing side lobes which may interfere with the signals received by adjacent transducers.

a more proportional measurement of school length than the echo sounder-based lengths. The accuracy of school dimension measurements could be improved by using more sensitive and specialized sonar equipment.

These problems with the limitations of sector scanning sonar should not be difficult to overcome. More sensitive quantitative sonar equipment is now available or relatively easy to develop. Lateral resolution may remain a problem because of the difficulty and expense of producing narrow-beam transducers, but the errors it causes are relatively unimportant.

The accuracy of mean school biomass estimates would be improved by target strength studies specific to widow rockfish. Calculation of average fish density within each school was relatively straightforward but involved assuming a target strength of −35 dB/kg. Ideally, the target strength should be calculated specifically for widow rockfish but such specialized work was beyond the scope of this study.

The ability to distinguish widow rockfish schools from those of other species using hydroacoustic equipment is an important element of this technique. Through these studies, our ability to correctly identify widow rockfish echo sign has been improved. The accuracy of species identification varies depending on the nature of the species complex in the survey area. Where shortbelly and redstripe rockfish are present, the potential for misidentification increases. Technological improvements in sonar equipment may help to reduce this problem. The density of a school is an important criterion for distinguishing widow rockfish from other species and newer sonar equipment includes density-graded color video displays. Other techniques, such as underwater photography or remote video camera vehicles, might also improve our ability to identify species. I believe, however, that test fishing will always be a necessary component of hydroacoustic resource assessment surveys.

Surveys of widow rockfish resources must be designed with the behavior and distributional variability of the species in mind. The diel behavior of the species indicates that the most effective sampling period is at night, but even then unpredictable behavior places special demands on survey design. Observations from hydroacoustic transects which were replicated on several nights (Fig. 11) show that long-term variability in abundance (e.g., night-to-night or week-to-week) is even more marked than that over a shorter time. These results are substantiated by other surveys (see footnotes 5, 7, and 8) and illustrate the difficulty of estimating widow rockfish abundance. Long-term variability is also a factor in area-swept bottom trawl surveys. The

TABLE 9.—Comparison of school length measurements (m) derived from echo sounder versus sector-scanning sonar data collected aboard the FV *Ocean Leader*, 14 March-7 April 1982.

School	Density (kg/m^2)	Length from echo sounder	Length from sonar
1	0.1292	48.5	45.0
2	0.0265	85.8	2.1
3	1.4860	66.2	5.8
4	1.6996	51.8	19.2
5	0.6374	37.4	74.0
6	0.3559	37.4	79.6
7	1.2415	59.9	52.3
8	0.7513	93.2	66.5
9	0.2119	117.5	118.1
10	0.7567	81.9	236.2
11	0.0686	526.9	497.5
12	0.0453	45.0	31.9
13	0.0490	96.9	353.1
14	0.0068	138.0	18.7
15	1.1400	511.9	393.2
16	0.6089	189.7	64.2
17	0.3055	76.6	18.4
18	0.4564	84.6	70.6
19	0.2154	27.8	93.0
20	0.0080	62.5	116.6
21	0.0487	103.0	16.9
22	0.1057	130.3	49.3
23	0.0936	147.5	28.5
24	0.1730	27.4	9.9
25	0.0103	46.8	39.6
26	0.1262	53.6	40.9
27	0.0182	67.7	43.9
28	0.1013	30.1	124.9
29	0.0830	67.7	84.2
30	0.0430	67.7	189.4
31	0.0208	48.9	33.5
32	0.0117	23.8	41.4
33	0.0128	22.4	14.8
34	0.1808	106.4	50.2
35	0.1809	292.2	216.7
36	0.0424	81.0	66.4
37	3.3097	158.3	101.6
	$\bar{x}$ 0.3990	105.8	94.8
	s 0.6587	113.5	112.2

assumption is that the variability has a strong random component and catch per unit effort values are consequently unbiased. The same situation may well be true here, in which case an important component of the survey design would be multiple replication to obtain good estimates of both long- and short-term variance.

Burnham et al. (1980) reported that good results from line transect surveys require observation of a minimum of about 40 objects per replicate. Fitting the observed perpendicular sighting distances to a detection function becomes less reliable with a smaller number of objects. Widow rockfish abundance is now low on all major grounds and the recommended minimum number of schools was not observed during any single replicate in the 1982 survey, but by pooling replicates a sufficient database was constructed. Sample sizes could be increased through more intense sampling. A time-stratified analysis of the data would be desirable to define within-night variability, but this would place even further demands on a sampling program.

Surveys of the type used for widow rockfish must cover the geographic range of the species of interest more thoroughly than most other survey methods. The dynamic behavior of widow rockfish suggests that the survey method should cover large areas in a relatively short time in order to survey a given fishing ground at least once during the night. Because of day-to-day variability, surveys should include sampling each area during several nights over a 1- or 2-wk period. Most areas containing fishable widow rockfish concentrations have probably been identified and there are a limited number of these grounds (probably 12-20); nearly all are characterized by ridges or rises on the outer continental shelf or upper slope and are relatively small in area. Intensive sampling of widow rockfish, therefore, is more feasible than for most other groundfish species inhabiting less well-defined areas.

Because widow rockfish schools are continually forming and breaking up, there may be a significant portion of the population which is not schooling at any given time and is therefore not susceptible to these survey techniques. This project did not answer whether this is so, but nothing was found to suggest that widow rockfish are significantly detectable by trawl or hydroacoustic surveys in any form other than midwater schools. Until more is learned about the proportion of the stock occurring as schools, surveys must be considered as yielding minimum biomass estimates. Clark and Mangel (1979) proposed a study of rates of school formation and dispersal to explain and evaluate a similar relationship between overall stock size and the proportion of a yellowfin tuna stock occurring as schools. Such a technique should receive further consideration in this situation, but present low widow rockfish school abundance (schools/km^2) and lack of a consistent pattern of school formation and dispersal would probably make its application in widow rockfish assessment difficult. This question is analogous to that of defining catchability coefficients (i.e., what proportion of those fish in the path of a net are actually captured) for quantitative trawl surveys. Changes in relative abundance can be monitored by such surveys without knowing the catchability if one assumes that the available proportion of the population is constant.

Results of other analyses of widow rockfish behavior and stock size should be used to evaluate survey methodology. The groundfish management team of the Pacific Fisheries Management Council (see footnotes 2 and 3) used stock reduction and cohort analyses to estimate the abundance of this species. In an area comparable to our 1982 survey area, the widow rockfish biomass was estimated to be 21,664 t at the begining of 1982. This estimate is based in part on commercial landing information and, consequently, the definition of the grounds to which it applies is somewhat vague. The fishery-based estimates are much higher than those derived from the 1982 survey data (about 830 t). The relatively low sensitivity of the sonar systems used would result in underestimating biomass and is undoubtedly responsible for much of this difference. The discrepancy is also partly due to the fact that our survey methods only estimate the portion of the stock present as detectable schools and are therefore a measure of relative, rather then absolute, abundance. This is true to some extent for most types of surveys.

Innovations are also needed to resolve the technical problems related to data collection, identification of school species composition, and survey design. Some suggestions include

1) a two-vessel survey to improve the efficiency of data collection—such a technique would separate the chore of delineating areas of widow rockfish aggregations, estimating school abundance, and test fishing from that of estimating mean school biomass (Gunderson et al. fn. 7);

2) a means of recording a time base on both the audio and video tape records of the echo sounder and sonar to simplify finding the same school on each system for school dimension measurements; and

3) a method of estimating all school dimensions and the density within the school from a single data collection system—this would entail development of a sophisticated, quantitative sonar-integration system with the capability of recording the output onto videotape (Ehrenberg 1979).

Such refinements could probably be implemented with relative ease. The methodology should be reevaluated when these technological and sampling improvements have been made. Widow rockfish management could have been significantly improved with the knowledge of stock size from an effective resource assessment survey. There are also other species which exhibit similar behavior and which, although presently unexploited, need to be assessed (e.g., shortbelly, redstripe, and black rockfish). This methodology could probably be easily adapted for surveying these resources.

CONCLUSIONS

Based on the results of research conducted during this project, the line transect survey method using a sector scanning sonar and a quantitative echo sounder appears to be the best means of assessing widow rockfish abundance with research surveys. A weakness of this method is that it only measures the portion of the population existent as distinguishable schools and that portion may be quite variable. It also relies heavily on subjective experience for identifying the species composition of schools. Its strengths are that large areas can be covered quickly and it is not necessary that all schools within sighting range be detected in order to estimate school abundance. It appears that this could be a useful assessment method for widow rockfish and for several other Pacific coast groundfish species which are not yet being seriously exploited. The effectiveness of the technique could be enhanced by employing or developing more sensitive and specialized quantitative sonars and by improving the methods of data collection. The technological and survey design problems encountered should be relatively easy, though somewhat costly, to resolve. The method should then be reevaluated to determine its utility. As the technique is used, scientists will gain a better understanding of the behavior and habits of the target species.

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