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W. E. RICKER and EASTWARD HO Cruise to Study the Effect of Trawling on Rockfish Behaviour, October 15-27, 1990

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W. E. RICKER AND EASTWARD HO CRUISE TO STUDY THE EFFECT OF TRAWLING ON ROCKFISH BEHAVIOUR, OCTOBER 15-27, 1990

by

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ABSTRACT

Kieser, R., B. M. Leaman, P. K. Withler, and R. D. Stanley. 1992. W.E. RICKER and EASTWARD HO cruise to study the effect of trawling on rockfish behaviour, October 15-27, 1990. Can. Manuscr. Rep. Fish. Aquat. Sci. 2161: 84 p.

A previous cruise collected acoustic observations of undisturbed rockfish behaviour and school structure, over several 24 hour periods (Leaman et al. 1990). The objective of this cruise was to obtain complementary observations on the distribution of rockfish before, during, and after the passage of a trawl net. Additional work investigated the influence of towpoint location and ballast distribution on the stability of the towed body housing the acoustic transducer. The experiments were carried out near the edge of the continental shelf, off Quatsino Sound, British Columbia. The principle rockfish studied was Pacific ocean perch (*Sebastes alutus*).

Direct observation of the trawl warps and the fishing gear by a moving acoustic vessel was unsuccessful. Comparisons of acoustic records from the fishing and acoustic vessels indicate that both the fishing vessel and the fishing gear cause avoidance reactions. Noise from the fishing vessel forces fish schools downward in the water column. This effect diminishes with increasing range from the fishing vessel. The bottom trawl appears to force fish in the lowest portions of the school upward, but fish in the middle and upper segments of the schools display only the downward movement generated by the fishing vessel.

A method to determine the pitch of the towed body from echogram traces was developed. Investigation of towed body stability showed that the towed body can be balanced only for a narrow range of speeds. Several balance configurations may be required to accommodate typical trawling and acoustic survey speeds.

RÉSUMÉ

Kieser, R., B. M. Leaman, P. K. Withler, and R. D. Stanley. 1992. W.E. RICKER and EASTWARD HO cruise to study the effect of trawling on rockfish behaviour, October 15-27, 1990. Can. Manuscr. Rep. Fish. Aquat. Sci. 2161: 84 p.

Une campagne précédente a permis de procéder à des observations acoustiques du comportement de sébastes non perturbés et de la configuration des bancs, sur plusieurs périodes de 24 heures (Leaman et al., 1990). L'objectif de cette campagne était d'obtenir des observations complémentaires sur la distribution des sébastes avant, pendant et après le passage d'un chalut. D'autres recherches ont permis d'étudier l'effet de l'emplacement du trait et de la répartition du lest sur la stabilité de l'engin remorqué, logeant le transducteur. Les expériences ont été effectuées au bord du plateau continental, au large de la baie Quatsino, en Colombie-Britannique. Le principal sébaste étudié était le sébaste à longue mâchoire (*Sebastes alutus*).

L'observation directe des funes et de l'engin de pêche par détection acoustique à l'aide d'un navire en mouvement n'a pas donné de résultats satisfaisants. La comparaison des données acoustiques provenant du bateau de pêche et du navire de détection montrent que le bateau et l'engin de pêche causent tous deux des réactions d'évitement. Le bruit causé par le bateau de pêche fait fuir les bancs de poissons vers le bas de la colonne d'eau. Cet effet va en diminuant à mesure que l'on s'éloigne du bateau. Le chalut de fond semble faire fuir vers le haut les poissons de la partie inférieure des bancs, alors que les poissons des parties moyenne et supérieure des bancs accusent uniquement le mouvement descendant provoqué par le bateau de pêche.

On a mis au point une méthode pour déterminer à partir de l'échogramme le tangage du corps remorqué. L'examen de la stabilité du corps remorqué a montré que ce dernier ne peut être stabilisé que dans un étroit intervalle de vitesses. Plusieurs configurations de stabilisation peuvent se révéler nécessaires pour satisfaire à des vitesses types de chalutage et de détection acoustique.

INTRODUCTION

Trawl surveys to estimate stock biomass of demersal and pelagic marine fishes have been conducted since the early 1900s. However, in recent years the divergence of results between trawl surveys and other methods of stock assessment has raised questions about the validity of the absolute estimates produced by these surveys (Leaman and Stanley 1991). The criticisms of trawl surveys are based on concerns about both the precision and the accuracy of these estimates. The variance of mean catch rates (CPUE), hence biomass estimates, from such surveys can often be >100% of the mean value, and the distribution of CPUE is usually a negative binomial (Taylor 1953, Clark 1974, 1979). Surveys for rockfishes (Sebastes spp.) are typical of this phenomenon. Biologists have tried to compensate for high variance by increasing sample number, but the gains are generally minor and the additional sampling requires excessive resources when the survey areas are large. In addition, the point estimate of biomass often stabilizes at a relatively low sampling density, while major increases in sampling are required to produce meaningful reductions in variance. In many stock assessments, biomass estimates from field surveys may be employed primarily as point estimates, and a reduced variance may be of only limited value in the overall assessment process.

Inaccuracy of the trawl survey estimate of biomass is of far greater concern than its variance. Fishing quotas based on inaccurate survey estimates may have long-term negative effects, particularly for species with long life spans, such as rockfishes. The causes of both inaccuracy and imprecision are the overdispersed and dynamic distribution of the fish and their changing availability to the sampling gear as function of location and time. Over the past decade we have initiated several programs to examine the underlying sources of variance and inaccuracy. Some of these programs have examined the variance caused by fish behavioral patterns on diel, weekly, and fortnightly (tidal cycle) time scales, using standard surveys (Leaman and Nagtegaal 1986, Nagtegaal et al. 1986). We have also used experimental harvest programs to examine the accuracy of trawl survey estimates (Leaman et al. 1988, Leaman and Stanley 1991).

The increased availability of digital acoustic data has afforded new opportunities to examine rockfish behaviour at a high level of resolution (Richards et al. 1991, Kieser et al. 1991). In particular, diel changes in schooling behaviour and the reaction of fish to trawls are of interest. Such data may permit evaluation of whether surveys made at different times of day or using different gears can be standardized or corrected for availability differences. In an earlier report (Leaman et al. 1990), we described diel patterns of aggregation and dispersal for slope rockfishes off the northwest coast of Vancouver Island.

We report here the preliminary results of acoustic observations of rockfish behaviour in response to trawling.

Rockfish aggregations are generally small, relative to the length of a trawl haul, and highly overdispersed. This distribution provides limited opportunity to observe the response of the aggregations to the passage of the fishing vessel and the trawl. We therefore designed our experiment to detect only the major effects which are expected to occur just below and astern of the fishing vessel, and in the vicinity of the trawl doors.

Our objectives were to: locate rockfish aggregations suitable for study, in areas investigated previously (Leaman et al. 1990); standardize observations between the fishing and hydroacoustic vessels; examine the potential for sonar observations of fishing gear; and, to describe the behaviour of fish aggregations before, during, and after the passage of the fishing vessel and the trawl. In addition, we report an analysis and interpretation of the effects of roll and pitch by the towed transducer, on acoustic observations.

MATERIALS AND METHODS

The survey was conducted October 15-27, 1990 aboard the R/V W.E. RICKER (WER), a 58 m, 2500 hp research trawler. The EASTWARD HO (EH), a 33 m, 850 hp fishing trawler was chartered, October 19-24, for concurrent fishing operations.

ACOUSTIC EQUIPMENT

The acoustic instrumentation on the WER included a calibrated echo integration system, a 38 and 50 kHz SIMRAD echosounder, and a 120 kHz WESMAR sonar. The "dry end" of the calibrated echo integration system included a BIOSONICS echo sounder, chart recorder and digital echo integrator, a PCM/VCR tape recording system, and auxiliary equipment. The "wet end" consisted of a towed body, incorporating a SIMRAD ceramic transducer, and an armoured tow cable. The towed body has a torpedo shape, 1.5 m long x 0.5 m diameter, and weighs 70 kg in air (Fig. 1). It consists of an aluminum frame onto which lexan plastic bubbles are bolted. The frame passes through the bubbles to provide towpoints and a tail assembly. The transducer is mounted on the frame between the bubbles. There are two towpoints on top of the body near the widest section, the aft one is slightly recessed. Lead ballast can be mounted near the bow and at two locations aft of the towpoint. This permits control of both total ballast and its distribution.

The echo sounder was operated at 38 kHz, 0.6 ms transmit pulse length, 1000 W power, 1 Hz repetition rate and 20 log R + $2 \cdot \alpha \cdot R$ time varied gain (TVG). The absorption coefficient, α , was 0.0099 dB/m. Calibration of the echo integration system was carried out on March 6, 1990 at the University of Washington, Seattle. Table 1 provides the measured values for transmit level TL, receive sensitivity RS, and other parameters. The overall gain was 20.14 dB.

The calibration was conducted with a new 300 m armoured tow cable. This cable was subsequently shortened to 250 m, however as the decreased cable length resulted in only a negligible gain increase, we used the same calibration values. All recorded echoes exceeded a threshold of 0.2 V and were limited to less than 10 V. Assuming a target strength of -32.0 dB/kg, this corresponds to a density range from 0.00039 to 0.96 kg/m^3.

The echo integrator was programmed to analyze the return echoes for a series of depth strata (range slices) from just below the transducer (towed body) to the bottom. An echo integration sequence was completed every 60 pings (1 minute) and the measured echo intensities were stored on a microcomputer. Kieser (1983), Kieser et al. (1987), and Leaman et al. (1990) provide further details and references on the echo integration system and acoustic data analysis.

Figure 2a shows a typical echogram recorded near the shelf edge during daylight, at a depth range of 350 m. Rockfish aggregations are seen at 140-240 m range. The echogram is annotated with range, sequence, and minute marks and a line that tracks the bottom. Reliable bottom tracking was obtained with a 10 m bottom window. This implies that, on average, our analysis excludes the first 5 m above the bottom.

The chart recorder and echo integrator thresholds were set to the same value to show all data that were analyzed. The relatively low threshold used to record the echo integration data resulted in some noise pulses on the echogram. During normal operation, these contributed a negligible amount to the signal. The weak but persistent surface echo appearing between 15 and 30 m indicates the depth of the towed body. Depth estimates are obtained by adding 25 m to the range shown on the echogram. To avoid inflation of the biomass estimate, the surface echo was excluded from the integration analysis.

A digital colour sonar (WESMAR SS265, 120 kHz) was used to search for fish concentrations in and near the path of the vessel, and to look for the EH's bottom trawl. To gauge the effectiveness of the sonar, initial detection tests for bottom, fish schools and trawl warps were conducted in calmer waters.

The EH used a Simrad Skipper echo sounder with a 50 kHz hull-mounted transducer having a beam angle of approximately 20° between the -3 dB points. The echo sounder uses initial gain suppression rather than a time varied gain (TVG). The echoes were recorded on dry paper (Fig. 2b).

ACOUSTIC OBSERVATIONS

A summary of the vessel activities and acoustic observations is given in Table 2. Event numbers (EVE) are used to identify our acoustic records and to provide unique cross referencing between text, tables and figures. The bridge log and catch data for the hauls made by the WER are presented in Appendix Table A1. Our investigations began in Queen Charlotte Sound, but we were unable to locate aggregations of fish sufficiently large to conduct the experiments. A five transect search pattern near the 200-m contour (Fig. 3) found only scattered schools and effort was re-directed to an area off Quatsino Sound, where rockfish aggregations had been noted on previous cruises (Fig. 4, Leaman et al. 1990). Investigations were broken into several discrete categories.

1. An attempt was made first to acoustically locate the trawl warps and the fishing net, using towed-body and vessel sounders. In addition, observation of the fishing gear using the WER's sonar was also attempted (Fig. 5).

2. The sensitivity and performance of the sounders on the WER and the EH was compared by running the same transect with both vessels in close proximity (Fig. 6).

3. The WER conducted acoustic observations leading and following the fishing vessel. Four hauls were observed in this manner, Figs. 7-10.

4. The WER made observations while steaming closely behind and on either side of the fishing vessel (Fig. 11). This configuration permitted greater precision in tracking over the areas fished, than was possible in configuration 3 when the WER was leading the EH. One tow was observed in this manner.

5. To obtain comparable echograms from both vessels the WER followed the EH at a distance of approximately 0.25 nm (Figs. 12-13). This segment of the experiment was

designed to acoustically observe and fish the same schools.

TOWED BODY STABILITY

The WER's hull-mounted transducer is uncalibrated and picks up excessive background noise. The acoustic observations for the present work therefore depended on the towed body transducer. Thus, assessment of the performance of the towed body at the typical towing speeds of 3-4 kn was important.

At normal survey speeds (8-9 kn) the towed body has a nearly level attitude and is quite stable, however, as speed drops to near 4 kn its attitude and stability deteriorate, especially in poor weather. This results in a distorted echogram and signal loss. Although an investigation of towed body stability was not planned at the beginning of the cruise a period of severe weather (70-95 kn winds) presented an opportunity to investigate the factors influencing towed body pitch and roll in the protected waters of Quatsino Sound. Factors investigated were:

(i) Towpoint location;
(ii) ballast quantity and distribution;
(iii) use of a drogue; and
(iv) towing speed.

Towed body attitude and stability is characterized by both short and long term roll and pitch oscillations. Our investigations were restricted to long-term or mean pitch. Towed body roll is also important but cannot be measured from the echogram. Unlike pitch, mean roll will be independent of speed if a torque balanced cable is used.

TRAWL GEAR AND SAMPLING

The WER was equipped with a Nor'Eastern bottom trawl and a Diamond V midwater trawl. The EH used a Rockhopper, 4-panel box trawl for bottom fishing. The catches from the WER and EH were sorted (or subsampled and sorted) to determine catch weight for each species. Selected rockfish species were sampled for length, sex, and otolith (after Nagtegaal et al. 1986).

Additional tows were made by the WER in Queen Charlotte Sound and off the west coast of Vancouver Island, to obtain yellowtail rockfish (<u>Sebastes</u> <u>flavidus</u>) samples for a coastwide genetics study of this species. Heart, muscle, and liver tissues were obtained from each sampled fish, and frozen for future processing.

RESULTS

RESPONSE OF FISH AGGREGATIONS TO PASSAGE OF VESSEL AND TRAWL

Suitable rockfish concentrations were found west of Quatsino Sound (Fig. 4). The EH conducted eight trawl hauls (Table 4) on aggregations of rockfishes in the 207-265 m depth range, to provide observation opportunities for the acoustic vessel. The bridge log and catch data for these hauls are presented in Appendix Table A2. Common and scientific names for species encountered by the R/V W.E. RICKER and the F/V EASTWARD HO, October 15-27, 1990 are presented in Appendix Table A3.

First trawl response experiment

Set number 1 by the EH ranged from 225-265 m in depth and lasted 168 min. The WER crossed repeatedly near the stern of the fishing vessel to attempt acoustic observation of the trawl cables and the net (Fig. 5). Nine passes were made, with inter vessel distance as close as 30 m, but neither structure was observed. The acoustic records from the WER were also examined for changes in fish distribution and density near the assumed position of the warps or the net, but no significant differences were detected.

A poor weather day was used to compare the echo sounders from the two vessels, by travelling in close proximity along the 200 m isobath (Fig. 6). Quite different echograms were obtained by the WER and the EH (Fig. 2). The differences reflect sounder characteristics (e.g. transducer beam width and pattern, echo sounder gain and TVG, paper speed and definition) as well as variation in vessel paths and motion, and movement of fish between the passage of the two vessels. Both echograms (Fig. 2) showed a haze near the surface and additional layers 20 to 40 m above the bottom. The intensity of these layers is reversed, indicating that the EH's sounder does not adequately compensate for the spreading and absorption losses of the acoustic signal (poor TVG correction). Intermediate depths on both echograms were dominated by small, random spots, indicating noise. Layers of small schools were apparent at 70 m and 180 m below the transducers.

Second trawl response experiment

The EH conducted sets 2 through 5 along the same isobath fished in set 1. Trawling speed and modal depth were approximately 3 kn and 218 m, respectively. The WER executed acoustic transects just ahead or behind the fishing vessel (Figs. 7-10) to observe fish concentrations before and after trawling. As each set started, the WER would sound at a nominal speed of 8 kn ahead of the EH. When a fraction of the planned set had been covered (generally 1/8) the WER turned and travelled to a point well behind the fishing vessel, and then followed it. Each set incorporated several leading and trailing acoustic transects (e.g. Fig. 7).

The following overlapping portions of the echograms from leading and trailing acoustic transects were examined in detail:

Figure	Transect	Time	EVE	Transect	EVE
7	LD01	12:53	73.5-75	TR01	76-80
8	LD03	18:29	97-101	TR03	103.3-106
9	LD04	00:23	111.6-115	TR04	116-119.3
10	LD05	07:40	124-128	TR06	129.3-132.9

Hypothesized effects of a trawling vessel on fish aggregations included depression of fish layers and reduced fish densities. The observations described here however did not detect systematic effects, that could not be attributed to natural changes in the fish distribution between vessel passes.

In addition to the visual echogram examination the echo integration data for the first set of leading and trailing transects, LD01 and TR01, were analyzed to obtain estimates of fish surface density, mean distance of fish from bottom and range from the transducer to the bottom. Figures 14a and 14b show plots of these quantities versus horizontal distance (sequence number) for LD01 and TR01, respectively. Figure 14b has more sequences for the same distance, because the WER slowed while following the EH. The poor bottom depth match between the two transects indicates that TR01 was offset to the deep from LD01. On average, the mean distance of fish from the bottom was quite constant. However, the fish surface density patterns differ dramatically between the first and the second observations. No conclusion regarding the fish's response to the trawl could be made on the basis of these observations.

Third trawl response experiment

Experiments one and two indicated that close proximity between the fishing and acoustic vessel was essential to detect any response of the fish to the trawl gear. Experiment three therefore required the WER to follow the fishing vessel closely astern or to either side (Fig. 11). The corresponding sections of the echograms from the WER were compared visually, for evidence of systematic changes as a function of relative vessel position. No such changes were apparent. Fig. 15 gives an impression of the echograms that were used for visual comparison.

The echograms from this experiment were relatively poor, as the WER was forced to travel at about the same speed as the fishing vessel (3 kn). This led to instability and misalignment of the towed body, hence poor acoustic records. The WER's hull-mounted transducer should have performed well at the prevailing low speeds, however poor weather led to excessive vessel motion and transducer aeration.

Fourth trawl response experiment

During this experiment, the WER trailed the EH at a nominal distance of 0.25 nm. In contrast to the first three experiments, this experiment was based on a comparison of the acoustic records from both vessels. If the major disturbance is from the fishing process, then the echograms from the EH and WER should show undisturbed and disturbed fish concentrations, respectively. We hypothesized that the fish dive in response to fishing, therefore the fish concentrations on the WER's echogram should be closer to the bottom than those on the EH's echogram. To examine this hypothesis transects D01 and D02B were executed.

To examine the trends in the off bottom hight we have measured several distances from the WER and EH echograms. For the lower layer of fish we define L1, L2 and L3 as the distances between the bottom and its lower edge, centre and upper edge respectively. Analogous quantities U1, U2 and U3 are defined for the upper fish layer that appears on most echo grams. Finally index 1 or 2 is added to distinguish between the WER and the EH respectively. Thus $L1_1$ and $L1_2$ gives the off bottom distance for the lower edge of the lower layer for the two vessels. In summary the following distances were measured from the echograms:

$T1_i$	Surface to transducer	
$B1_i$	Transducer to bottom	
$L1_i$	Lower layer:	Bottom to lower boundary
$L2_i$		Bottom to middle
$L3_i$		Bottom to upper boundary
$U1_i$	Upper layer:	Bottom to lower boundary
$U2_i$		Bottom to middle
$U3_i$		Bottom to upper boundary

where i is 1 or 2 for the WER or EH, respectively.

To obtain these measurements corresponding echogram sections were marked (Fig. 15) and three representative locations were selected from each 10 minute sequence. Figures 16a and 16b give the off bottom distances observed along transects D01 and D02B by the WER and EH respectively. Note that the WER echogram for transect D01 did not show an upper layer. The height and position of the layers observed by the two vessels do not agree in detail, but show common trends. We believe that this is caused by differences in the exact paths of the two vessels. This implied that the two vessels will observed different schools or different portions of the same school. Our observations will show average effects but will not be able to follow the vertical movement of individual schools.

Figures 17a gives the off bottom distance ratios for the lower and upper layers, $L1_1/L1_2$ and $U1_1/U1_2$. This ratio is a convenient measure to compare the observations from both vessels. Figures 17b and 17c give the off-bottom distance ratio for the centre and upper edge of the layers respectively. The average off bottom distance ratio is given in Figure 17d for both layers. The results are also summarized in Table 3.

The similarity of the observed echogram bottom profiles (Figs. 2a and 2b) and the close match in mean bottom depths indicate that the path of both vessels was very similar. The measurements for the lower and upper layers show high variability but are consistent with the hypothesis that the fishing process has two major influences on the fish distribution:

1. Fish show a downward, avoidance reaction that diminishes with depth below the fishing vessel. This can be seen for the upper layer (Ux_i), where fish where observed to dive as the fishing vessel passes. Vessel avoidance is strongest for the upper boundary of the midwater layer ($U3_i$).

2. The bottom trawl appears to cause an upward movement of fish nearest the bottom. This is demonstrated by the Lx_i measurements, where the lowest portion of the lower layer moves up as the bottom trawl passes. Net avoidance appears strongest for the lower boundary of the lower layer ($L1_i$), but there is little or no movement of the upper edge of this lower layer.

While our measurements are consistent with this hypothesis, they are insufficient to examine the components of the process. It should also be noted that the trawl catches some of the fish in the lowest portions of the lower layer, and the apparent upward "movement" of the lower school boundary may simply reflect the removal of these fish.

SONAR OBSERVATIONS

Sonar observations were made while following the EH during set 1. Sonar settings for tilt, scan, range, near gain, and far gain were selected to optimize the display of possible targets in the water column and to minimize bottom interference and clutter. The sonar was trained forward and to either side of the vessel to look for fish in the path and around the vessel. While several potential fish traces were detected, none were sufficiently consistent from one sonar sweep to the next, to exclude clutter as a possible source. Finally, the sonar was trained towards the EH's net and trawl cables, but neither structure was observed.

The lack of success prompted us to conduct tests in the calmer waters of Quatsino Sound. The EH deployed ~150 m of trawl cable and then anchored. The WER attempted to find the suspended portion of the cable with the sonar, by passing across the stern of the vessel at varying distances. We could not detect any echo from the cable. We therefore abandoned further investigations with the sonar.

ELECTROPHORETIC SAMPLES

A secondary and independent objective of the trip was to obtain tissue samples of 100 yellowtail rockfish (*S. flavidus*) from both Queen Charlotte Sound and the west coast of Vancouver Island. Samples of 100 fish from each area were obtained and will contribute to a study of stock delineation, to be reported elsewhere.

OCEANOGRAPHIC SAMPLING

We occupied five stations for the Cooperative Plankton Research Program (F1, F2, E1, E2, and E3), following the procedures of Shaw (1988). Each site included a CTD cast and an oblique plankton tow with a bongo net.

TOWED BODY STABILITY

The weight of the towed body in water is the difference between its weight in air and its buoyancy. Weight, cable pull and drag act at different points on the body. Therefore, its pitch depends on the dynamic balance between these forces (Fig. 1). Drag, hence towed body pitch, will depend on speed. Increasing speed will force the nose of the towed body down unless a suitable drogue or ailerons on the tail assembly generate a balancing force.

Towpoint location

With the normal forward towpoint location, the pitch of the towed body was nose-up at low speeds (2-6 kn) and nose-down at high speeds (6-9 kn). When the cable was switched to the aft towpoint, a nose-down pitch was observed at all speeds (3.5-9 kn). This indicated that the pitch is sensitive to small changes in towpoint location.

Ballast quantity and distribution

To compensate for the persistent nose-down pitch when the aft towpoint was used, two 5 kg lead weights were added to the ballast, aft of the towpoint. With this new weight distribution, the towed body flew nose-up at low speed. At 5.6 kn, the body flew level, and flew nose-down with increasing speed.

Increasing aft ballast increased the speed at which the towed body achieved a level pitch in the water. Conversely, increasing ballast in the bow would reduce the speed at which a level pitch will be attained. The effect of total ballast on towed body stability could not be judged from these tests.

Addition of drogue

A final test was conducted using a temporary drogue, which consisted of a 1 l perforated, plastic jar. It was attached by a 1 m tether to the tail of the towed body, 5 cm above the centre-line. The addition of the drogue increased the speed at which the towed body achieved level flight through the water by approximately 1 kn.

Determination of towed body pitch from echograms

a) The inverted V target pattern. Single fish inverted V traces on the echogram are an artifact of the transducer beam pattern (Mitson 1983). A target generally is first detected by the leading edge of the beam, before it passes through the centre and finally the trailing edge of the beam. Assuming a level transducer, edge detections are at greater range than those at the centre of the beam. The apparent target depth first decreases, then increases as the transducer moves past the target. Thus, strong single fish targets appear as inverted V's on the echogram. The target depth is given by the peak of the inverted V.

b) Estimation of pitch and effective beam width from echograms. Assuming that the transducer is mounted level in the towed body, a non-vertical beam orientation will result when the towed body roll and pitch is not level. Information about beam pitch can be derived from single fish traces by noting the range for first target detection, range for last detection and distance travelled by the transducer between first and last detection. A visual examination of the echogram is adequate to determine whether the tow is reasonably level. A level pitch is indicated by single fish traces with arms of equal length. Assuming fish movement is negligible, unequal arm lengths indicate non-level pitch. Effects due to average towed body pitch can be distinguished from those due to short term pitch oscillations and fish movement by the consistency of the distortion among targets. A slightly nose-up transducer, for example, will generate an inverted V trace with a longer and apparently deeper initial arm. When the pitch angle approaches half the effective beam width, the inverted V trace will deteriorate to a simple upward line.

To estimate tow pitch α and effective beam angle β, we analyzed the triangle described by the range at first detection r_1, the range at last detection r_2, and the distance travelled by the transducer between initial and final detection d, (Fig. 18). The quantities r_1, r_2, and d can be measured from the echogram. The effective fore/aft beam width, β, is calculated using the following equation, derived from the cosine rule:

$$\beta = \cos^{-1}\frac{r_1^2+r_2^2-d^2}{2r_1r_2} \qquad (1)$$

Further use of the cosine rule yields the angle, θ, between sides d and r_1. Finally the pitch of the towed body, α, is given by β and θ.

$$\alpha = \frac{\pi}{2}-\frac{\beta}{2}-\theta = \frac{\pi}{2}-\frac{\beta}{2}-\cos^{-1}\frac{r_1^2-r_2^2+d^2}{2r_1d} \qquad (2)$$

Equations (1) and (2) were used to develop a computer program to calculate towed body pitch from single fish echogram traces.

Sensitivity of towed body pitch to speed

Normal towed body towing speed is in the range from 3 to 10 kn, typical survey speeds are 8 to 10 kn. Low speeds are used to obtain detailed acoustic observations of fish or when following a fishing vessel. Properly balanced the towed body flies slightly nose-up at low speed, shifting steadily to nose-down as speed increases. Unfortunately, the range of speed over which the pitch remains near level is only a fraction of the operating range. Inverted V single fish echoes (Figure 2a) are distorted when the pitch exceeds one-half of the -3 dB beam full width of the transducer, approximately ±4° for our transducer.

Single fish echogram traces and the techniques described in the previous section allowed us to examine pitch as a function of towed body ballast and speeds. Table 5 presents typical pitch angles as a function of speed. The towed body was ballasted for level pitch at 3 kn. Pitch was calculated using only strong, well defined single fish traces to reduce the confounding effects of multiple targets and targets too near the periphery of the beam.

CONSIDERATIONS REGARDING FUTURE EXPERIMENTAL DESIGN

The experiments described here are based on observations with one fishing and one acoustic vessel and explore the following configurations:

1. Survey a small area before and after trawling;
2. Cross over the trawl during fishing;
3. Survey the trawl track before and after the passage of the fishing vessel;
4. Follow, then pass trawler;
5. Lead or follow trawler with a fixed distance between vessels.

In options 1-4, the acoustic vessel typically moves 2 or 3 times faster than the trawler. This creates a variable delay between acoustic observation and trawling, thus potential effects will not only be degraded by natural school movement, but also by different recovery periods. Fish may have fully recovered when the acoustic vessel passes. The following additional questions arise:

a. Over how wide a path will the fishing process affect the fish?
b. What is the location of the trawl with respect to the fishing vessel?
c. Can the fishing and acoustic vessels follow the same path?
d. Are the fish affected by the acoustic vessel?
e. Does fishing deplete the observed population?

Considering these difficulties, it is unlikely that experimental configurations 1 through 4 will allow acoustic observations of the same fish that are affected by the fishing process, unless the vessels are very close and the effect of the fishing process is widespread.

These thoughts lead us to suggest the following criteria for a possible future experiment to detect the reaction of fish schools to a fishing vessel:

a. The same fish school must be observed before and after the fishing process. This requires that the positions of the fishing vessel and the trawl are known at all times and can be predicted long enough in advance for the acoustic vessel to preview schools in the undisturbed path, and later in the disturbed path. The stringent requirement that the same fish school must be observed before and after the fishing process can be relaxed if, on average, undisturbed and disturbed schools look very different. In this case, simple observations ahead of the fishing vessel will suffice to establish the average undisturbed school properties. However, to observe disturbed schools the acoustic vessel must be able to follow in the path disturbed by the fishing vessel and the trawl. This task will be very difficult if the width of the disturbed path is small.

b. In order to locate the source or sources of the disturbance, and to study the reaction and recovery of the fish, we must be able to observe the disturbed fish at varying times before and after the disturbance.

Ideally such a response experiment will require two acoustic and one fishing vessel, unless the observations are done in two parts, or the fishing vessel is also used for acoustic observations. In the latter case the fishing vessel should have functionally equivalent acoustic gear and a towed body that can be deployed in front of, over, and behind the trawl.

ECHOSOUNDER AND SONAR REQUIREMENTS

During previous research cruises, we had noted that under favourable conditions a stationary echosounder can provide images of another vessel's fishing gear. Our failure to observe the charter vessel's net may have been caused by poor echo sounder performance, greater depth, sloped bottom, uncertainty in locating the net in the acoustic beam, and/or poor weather. Although the observations were carried out with a scientific echo sounder, its performance was severely limited by instability of the towed body and excessive noise from the WER's transducer. This indicates that acoustic equipment with excellent overall performance is required to observe the fishing gear at typical towing speeds, and under less than ideal weather conditions.

Our unsuccessful efforts to detect either the fishing gear or the fish with the WESMAR sonar may have been due to the low sensitivity of the sonar, and the relatively small size of the target. The WESMAR sonar we used is a very simple instrument, designed to observe major fish schools and other large underwater targets, at relatively close range. To detect small scattered rockfish schools at typical depth requires a more sensitive sonar. The fish we are studying are often near rugged bottom and a sonar with a well-defined acoustic beam, that can be scanned about an axis parallel to the keel of the vessel, is needed. This type of scanning would allow examination of a swath on either side of the vessel with minimum bottom interference, as the orientation of the beam would be nearly perpendicular to the bottom, for at least part of the scan. A sonar of this kind could expand the range of our underwater 'vision' dramatically, with obvious benefits for survey work and fish behaviour studies.

USE OF TOWED BODY AND HULL MOUNTED TRANSDUCERS

At normal survey speeds, a towed body generally provides a better acoustic signal than a hull-mounted transducer. The low speeds that are required for observations near a fishing vessel may reverse this performance. As speed decreases a towed body will lose its stability and alignment, while a hull mounted unit will experience less motion and aeration. As the transducer must pass over the disturbed schools for a trawl avoidance experiment, the towed body also must be accurately located with respect to the vessel. This may be a difficult task, even if specialized instruments are available. In this light, a good hull-mounted transducer is essential.

DISCUSSION

Experienced fishermen and an increasing number of research projects (Olsen 1971; Olsen et al. 1983a, b; Engas and Ona 1987; Ona and Eger 1987; Ona and Godo 1987) confirm an often substantial impact of the fishing operation on the behaviour of the target species. Fish have been shown to avoid the fishing vessel at ranges of several hundred meters, to react to the overhead passage of the fishing vessel, and to respond to the trawl warps, doors and the net opening. Our observations on rockfish schools are consistent with published results for other species, they also indicate that major disturbance of the fish is from the fishing vessel and the trawl. Once a disturbance is created it may require minutes or tens of minutes to establish a new, quasi-undisturbed distribution. In contrast, fish are seldom disturbed by an acoustic vessel if simple precautions, such as turning the deck lights off at night, are observed.

When echo sounding techniques are used to study fish behaviour we are forced to deduce three dimensional fish distributions and movements from the two dimensional section through the water column given by the echo gram. It obviously will be difficult to reconstruct three dimensional movement and its timing. In addition fish may be affected by ambient conditions such as light regime, current patterns, food supply, etc. Lastly, the effect of the capture of fish by the trawl, on subsequent observation of the school, is not well understood. More detailed fishing and acoustic observations are required to clarify the contribution of fish movement and fish capture to the apparent movement of fish from the area swept by the net. It follows that a very simple biological questions must be asked to lead to a successful experiment.

SUCCESSFUL OBSERVATION OF TRAWL AVOIDANCE

During our fourth experiment the WER trailed the EH by 0.25 nm while following the same path as nearly as possible. With one exception echo grams from both vessels showed an upper and a lower fish layer. A detailed comparison of echograms from the WER and EH indicated that fish in the upper layer show a downward avoidance reaction that diminishes with depth below the fishing vessel, on average fish where observed to dive as the fishing vessel passes. Vessel avoidance is strongest for the upper boundary of this layer.

Downward avoidance of the upper layer is contrasted by an upward movement of the lower layer after the passage of the fishing vessel and trawl. Fish appear to avoid the bottom trawl by moving upward. Movement for the near bottom edge of the lower layer is strongest.

TOWED BODY STABILITY TESTS

A clear echo record is essential for accurate acoustic observations of fish distributions and behaviour, and to monitor the fishing operation. Good acoustic observations depend on a stable, vertically aligned transducer. Even relatively small misalignments and oscillations in roll, pitch, and possibly yaw will significantly distort the fish echoes and the bottom signature. They also lead to a reduction of the average echo intensity, or the corresponding fish density estimate. This is caused by a decline of the average fish TS when observations are not from the dorsal aspect (Love 1971 and 1977). In extreme cases, the reorientation of the transducer between its transmit and receive operations leads to a further reduction of the received echo (Shibata 1987).

The pitch of the towed body was found to depend critically on, towpoint location, amount and distribution of ballast, and the presence of a drogue attached to the rear fin. The effects of these changes were found to be speed dependent. Hydrodynamic forces generated by the towed body and drogue increased steadily with speed, consequently ballast distribution was most influential at low speeds.

Our observations indicate that towed body balance is influenced by several factors and is highly dynamic. As a compromise, at least two balance configurations should be developed. One for low-speed behavioral observations such as those described here, and the other for the more common high-speed biomass survey applications. As a simple solution the towed body may be fitted with several tow points. Level pitch at a given speed then is obtained by selecting the correct tow point.

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Table 1. Echo integration systems parameters. All values are in dB units unless otherwise noted.

TL	220.30	Transmit level, BioSonics echo-sounder BS 101-85
RS	-133.71	Receive sensitivity, dB V/μP at 1 m
RC	-12.0	Receiver gain setting
BG	-0.8	Receiver bandpass gain, see Kieser et al. 1987
SG	-0.6	Towed body shell gain, (calibration 24 March 1982, plot 3717, 3718)
BF	-17.55	Beam factor, Simrad transducer # 4899, 7x13°
CT	-3.50	Pulse width factor (1490 m/s 0.0006 s)/2
TS	-32.0	Target strength, dB/kg

Table 2. Summary of activities W.E. RICKER 15-27 Oct. 1990. Event numbers (EVE) are used to identify our acoustic records and to provide unique cross referencing between text, tables and figures.

EVE	DATE	TIME	TRA	Fig	Comment
1	16	13:45			Calibrate system
4		19:49	A01	2	Queen Charlotte Sound, look for fish aggregations
	17				Severe storm, jog in Goletas Channel
	18				RICKER set 1 to catch S. flavidus, rip net
	19				Meet EH off Port Hardy
16-26	20	04:54	B01	3	Off Quatsino Sound, scout fishing location, zig zag transects
32		07:20	B15	4	EH set 1, cut across stern of EH
47		09:04	B26		Brief test of hull transducer
54		17:53	C01		Test sonar in Quatsino Sound(QS), look for trawl warp
66	21	11:27	CAL01	5	Note bot buf 10 m, bot isol 2 m Compare vessel sounders following each other
72		12:53	LD01	6	EH set 2, lead then trail EH
86		15:05			Test ship's transducer
91		15:18	TR02		Trail EH
97		18:29	LD03	7	EH set 3, lead EH
110-120		23:09	LD04	8	EH set 4
124-141	22	07:40	LD05	9	EH set 5
142-165		12:00	TR07	10	EH set 6
	23				Severe storm, test towed body in QS
167-179	24	09:37	D01		EH set 7, follow EH, ≈.25 nm apart
182-198		13:04	D02A		EH set 8, follow EH, ≈.5 then ≈.25 nm
	25	9:00			RICKER set in Queen Charlotte Sound
	26	7:30			RICKER set off Nootka
	27	16:30			Arrive at PBS

Table 3. Summary of off bottom distance and distance ratios measured from WER and EH echograms. The first row gives the mean bottom depth (m) observed by the WER and EH. The following rows give the off-bottom distance (OBD) for the lower and upper layers. The WER/EH column gives the ratio of the OBD observed by the two vessels. If fish dove, the OBD ratio would be less than one. The LM_i row uses the mean OBD based on $L1_i$, $L2_i$ and $L3_i$. The number of measurements used in each calculation is given in the last column.

		WER		EH		WER/EH		
		Mean	Std	Mean	Std	Mean	Std	#
Bot depth		229.3	8.7	230.1	7.7	0.997	0.024	75
OBD:	$L1_i$	20.5	9.9	17.1	11.0	1.579	1.164	73
	$L2_i$	31.8	11.0	30.6	13.5	1.163	0.469	75
	$L3_i$	43.1	13.7	44.3	15.8	1.033	0.320	75
	LM_i					1.140	0.421	75
OBD:	$U1_i$	67.9	16.0	71.5	18.0	0.984	0.255	42
	$U2_i$	82.8	16.1	93.8	19.2	0.906	0.207	42
	$U3_i$	98.9	16.3	118.9	22.4	0.857	0.195	42
	UM_i					0.900	0.195	42

Table 4. Summary of EASTWARD HO sets 20-24 October 1990.

Date	Time	Set	EVE	TRA	Comment
20	04:54	-	16-26	B01	EH scouts fishing location, zig zag transects
	07:20	1	34-53	B15	WER cuts across stern of EH
21	12:53	2	72-95	LD01	WER leads EH
	18:29	3	97-109	LD03	WER leads EH
	23:09	4	110-120	LD04	WER leads EH
22	07:40	5	124-141	LD05	WER leads EH
	12:00	6	142-165	TR07	WER leads EH
24	09:37	7	167-179	D01	WER follows EH, ≈.25 nm apart
	13:04	8	182-198	D02A	WER follows EH, ≈.5 then ≈.25 nm

Table 5. Tow pitch α and effective fore/aft beam width β as a function of speed. r_1, r_2, and d_1 are defined in Figure 18. With increasing speed towed body pitch goes from a nose up to nose down.

Speed kn	r_1 m	r_2 m	d_1 m	β °	α °
2.80	61.81	60.27	17.06	16.0	5.1
3.00	68.85	68.85	19.21	16.0	0.0
3.40	141.67	143.15	29.85	12.0	-2.8
3.90	78.37	79.37	21.90	15.9	-2.5
4.50	62.60	63.74	18.59	16.9	-3.4
6.20	126.69	129.81	28.18	12.5	-6.3

Table 6. Total catch and percentage of total catch by species, F/V EASTWARD HO, October 15-27, 1990. Others includes all species comprising less than 1% of the total catch.

Species	Catch kg	Percent of total
Sebastes alutus	31,956	55.47
S. paucispinis	4,524	7.85
Pacific hake	4,400	7.64
S. reedi	3,060	5.31
S. diploproa	3,035	5.27
Arrowtooth flounder	2,867	4.98
Sablefish	1,796	3.12
Lingcod	1,677	2.91
S. brevispinis	1,278	2.22
S. zacentrus	1,100	1.91
Others	1,914	3.32
	------	------
	57,607	100.00

Table 7. Total catch and percentage of total catch by species, R/V W.E. RICKER, October 15-27, 1990. Others includes all species comprising less than 1% of the total catch.

Species	Catch (kg)	Percent of total
Arrowtooth flounder	426	22.82
Sebastes alutus	267	14.30
S. paucispinis	256	13.71
Walleye pollock	218	11.68
S. brevispinis	157	8.41
Lingcod	99	5.30
S. flavidus	88	4.71
S. proriger	42	2.25
S. babcocki	41	2.20
Pacific hake	26	1.39
S. pinniger	19	1.02
Others	228	12.21
	1867	100.00

Table 8. Catch rates by set (kg/h) for the major species captured by the F/V EASTWARD HO, October 15-27, 1990.

Set	Species	Catch rate
1	Sebastes alutus	1363.2
	S. diploproa	981.4
	Pacific hake	295.3
	Arrowtooth flounder	171.4
2	S. alutus	2001.4
	S. paucispinis	383.2
	S. reedi	223.5
	S. zacentrus	191.6
3	Pacific hake	446.0
	S. alutus	382.5
	Arrowtooth flounder	325.7
	S. reedi	233.8
	Sablefish	212.5
4	Arrowtooth flounder	446.8
	S. alutus	335.9
	Pacific hake	172.5
	S. reedi	106.1
5	S. alutus	2054.0
	Pacific hake	493.6
	S. paucispinis	314.3
	Sablefish	101.2
6	S. alutus	2404.9
	S. paucispinis	257.8
	Lingcod	103.3
	S. brevispinis	72.3
	S. diploproa	72.3
7	S. alutus	1814.9
	S. paucispinis	262.6
	S. brevispinis	125.9
	S. reedi	83.9
8	S. alutus	706.5
	Lingcod	295.0
	S. paucispinis	260.5
	S. reedi	199.0
	S. brevispinis	178.5

Table 9. Catch rates by set (kg/h) for the major species captured by the R/V W.E. RICKER, October 15-27, 1990.

Set	Species	Catch rate
1	*Sebastes alutus*	176.0
	Walleye pollock	144.0
	Arrowtooth flounder	84.7
	S. paucispinis	82.0
2	Arrowtooth flounder	314.7
	S. paucispinis	140.0
	Spiny dogfish	85.3
	S. brevispinis	83.2

Table 10. Summary of length frequency and maturity for Sebastes alutus sampled on the F/V EASTWARD HO, October 15-27, 1990.

Area	Quatsino							
Date	Oct 20		Oct 20		Oct 21		Oct 21	
Depth (m)	125		125		214		214	
Set	1		1		2		2	
	M	F	M	F	M	F	M	F
Length (cm)								
26	-	-	-	-	-	-	-	-
27	-	-	1	-	1	1	-	-
28	-	-	0	-	0	0	-	-
29	-	-	0	-	0	0	-	-
30	-	-	0	-	0	0	-	-
31	-	-	0	-	0	0	-	-
32	2	-	1	-	0	0	1	-
33	1	1	0	-	3	1	0	1
34	6	2	2	2	3	1	3	1
35	7	1	4	2	8	3	3	1
36	6	4	5	7	5	6	6	0
37	3	6	3	2	1	11	1	1
38	4	4	3	2	-	4	3	6
39	0	0	4	4	-	2	1	1
40	1	1	3	7	-	0	1	3
41	-	0	1	3	-	1	1	0
42	-	2	0	3	-	0	-	4
43	-	0	-	4	-	1	-	2
44	-	0	0	2	-	3	-	3
45	-	5	1	1	-	0	-	1
46	-	1	-	1	-	1	-	1
47	-	1	-	-	-	-	-	1
48	-	0	-	-	-	-	-	-
49	-	1	-	-	-	-	-	-
Total	30	29	28	40	21	35	20	26
Maturities								
1	2	2	-	-	2	2	-	-
2	28	19	-	-	19	20	-	-
3	0	8	-	-	0	13	-	-
4	0	0	-	-	0	0	-	-
5	0	0	-	-	0	0	-	-
6	0	0	-	-	0	0	-	-
7	0	0	-	-	0	0	-	-
8	0	0	-	-	0	0	-	-
9	0	0	-	-	0	0	-	-

Table 10 (cont'd). Summary of length frequency and maturity for *Sebastes alutus* sampled on the F/V EASTWARD HO, October 15-27, 1990.

Area			Quatsino			
Date	Oct 21		Oct 21		Oct 21	
Depth (m)	216		216		218	
Set	3		3		4	
	M	F	M	F	M	F
Length (cm)						
26	-	-	-	-	-	1
27	-	-	-	-	1	0
28	-	-	-	-	0	1
29	-	-	-	-	0	1
30	-	-	-	-	0	0
31	-	-	-	-	1	0
32	-	1	-	-	2	2
33	-	1	1	-	1	1
34	2	2	3	1	5	0
35	0	4	3	2	7	2
36	0	8	3	3	1	4
37	1	8	-	2	3	3
38	-	6	-	3	1	1
39	-	2	-	1	0	0
40	-	1	-	0	0	2
41	-	3	-	4	1	4
42	-	1	-	3	1	3
43	-	1	-	1	0	4
44	-	4	-	2	1	1
45	-	2	-	0	1	6
46	-	2	-	3	-	9
47	-	1	-	-	-	3
48	-	-	-	-	-	2
49	-	-	-	-	-	-
Total	3	47	10	25	26	50
Maturities						
1	1	2	-	-	-	-
2	2	33	-	-	-	-
3	0	12	-	-	-	-
4	0	0	-	-	-	-
5	0	0	-	-	-	-
6	0	0	-	-	-	-
7	0	0	-	-	-	-
8	0	0	-	-	-	-
9	0	0	-	-	-	-

Table 10 (cont'd). Summary of length frequency and maturity for *Sebastes alutus* sampled on the F/V EASTWARD HO, October 15-27, 1990.

Area			Quatsino			
Date	Oct 22		Oct 22		Oct 22	
Depth (m)	219		218		218	
Set	5		6		6	
	M	F	M	F	M	F
Length (cm)						
26	-	-	-	-	-	-
27	-	-	-	-	-	-
28	-	-	-	-	-	-
29	-	-	-	-	-	-
30	-	-	-	-	-	-
31	2	-	-	-	-	-
32	0	-	-	-	-	-
33	1	2	1	-	-	4
34	4	6	4	1	3	5
35	14	12	3	4	3	9
36	15	16	3	5	10	6
37	2	8	3	3	5	2
38	3	9	3	4	4	0
39	2	7	2	3	2	3
40	1	3	1	1	1	0
41	1	4	1	2	3	1
42	1	3	1	0	1	1
43	-	2	0	0	2	-
44	-	4	1	2	1	-
45	-	1	-	0	1	-
46	-	1	-	1	-	-
47	-	1	-	1	-	-
48	-	-	-	-	-	
49	-	-	-	-	-	-
Total	46	79	23	27	36	31
Maturities						
1	-	-	0	1	-	-
2	-	-	23	20	-	-
3	-	-	0	6	-	-
4	-	-	0	0	-	-
5	-	-	0	0	-	-
6	-	-	0	0	-	-
7	-	-	0	0	-	-
8	-	-	0	0	-	-
9	-	-	0	0	-	-

Table 10 (cont'd). Summary of length frequency and maturity for Sebastes alutus sampled on the F/V EASTWARD HO, October 15-27, 1990.

Area	Quatsino				Grand total	
Date	Oct 24		Oct 24			
Depth (m)	229		225			
Set	7		8			
	M	F	M	F	M	F
Length (cm)						
26	-	-	-	-	-	1
27	-	-	-	-	3	1
28	-	-	-	-	0	1
29	-	1	-	-	0	2
30	-	0	-	-	0	0
31	-	0	1	-	4	0
32	-	0	0	-	6	3
33	3	0	1	1	12	12
34	5	3	3	4	43	28
35	14	10	2	3	68	53
36	6	10	5	0	65	69
37	6	12	3	5	31	63
38	3	8	2	4	26	51
39	1	2	1	3	13	28
40	3	1	2	5	13	24
41	0	1	1	6	9	29
42	0	3	2	3	6	26
43	1	1	1	6	4	22
44	-	1	1	4	4	26
45	-	1	-	7	3	24
46	-	1	-	11	-	32
47	-	-	-	4	-	12
48	-	-	-	2	-	4
49	-	-	-	-	-	1
Total	42	55	25	68	310	512
Maturities						
1	-	-	-	-	5	7
2	-	-	-	-	72	92
3	-	-	-	-	0	39
4	-	-	-	-	0	0
5	-	-	-	-	0	0
6	-	-	-	-	0	0
7	-	-	-	-	0	0
8	-	-	-	-	0	0
9	-	-	-	-	0	0

Table 11. Summary of length frequency for <u>Sebastes diploproa</u> sampled on the F/V EASTWARD HO, October 15-27, 1990.

Area	Quatsino	
Date	Oct 20	
Depth (m)	125	
Set	001	
	M	F
Length (cm)		
20	-	2
21	-	1
22	5	3
23	28	2
24	12	23
25	13	11
26	7	10
27	6	9
28	4	8
29	1	1
30	2	0
31	1	0
32	0	1
33	0	1
34	2	0
35	1	1
36	-	1
Total	82	74

Table 12. Summary of length frequency for Pacific hake sampled on the F/V EASTWARD HO, October 15-27, 1990.

Area	Quatsino	
Date	Oct 22	
Depth (m)	219	
Set	5	
	M	F
Length (cm)		
44	1	3
45	4	8
46	8	4
47	7	8
48	4	8
49	5	5
50	5	11
51	2	1
52	2	6
53	0	2
54	0	2
55	1	4
56	1	3
57	0	4
58	0	0
59	1	3
60	-	0
61	-	1
Total	41	73

Table 13. Summary of length frequency and maturities of Sebastes flavidus sampled on the R/V W.E. RICKER, October 15-27, 1990.

Area	Cape Scott Spit				Total for Area	
Date	Oct 18		Oct 25			
Depth (m)	100		96			
Set	1		3			
	M	F	M	F	M	F
Length (cm)						
33	-	-	-	1	-	1
34	-	-	-	0	-	0
35	-	-	-	0	-	0
36	-	-	-	0	-	0
37	-	1	-	0	-	1
38	1	0	-	1	1	1
39	0	1	2	0	2	1
40	0	0	0	1	0	1
41	1	0	5	0	6	0
42	0	0	4	0	4	0
43	1	1	5	1	6	2
44	3	0	7	1	10	1
45	8	0	6	1	14	1
46	5	1	6	0	11	1
47	2	1	4	2	6	3
48	1	1	2	0	3	1
49	2	2	3	2	5	4
50	-	1	0	1	0	2
51	-	1	0	0	0	1
52	-	3	1	0	1	3
53	-	3	-	1	-	4
54	-	1	-	-	-	1
55	-	2	-	-	-	2
Total	24	19	45	12	69	31
Maturities						
1	0	3	0	3	0	6
2	24	2	45	5	69	7
3	0	14	0	4	0	18
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	0	0

Table 13 (cont'd). Summary of length frequency and maturities of Sebastes flavidus sampled on the R/V W.E. RICKER, October 15-27, 1990.

Area Date Depth (m) Set	Nootka 261090 79 004		Total for Area		Grand total	
	M	F	M	F	M	F
Length (cm)						
33	-	-	-	-	-	1
34	-	-	-	-	-	0
35	-	-	-	-	-	0
36	-	-	-	-	-	0
37	-	-	-	-	-	1
38	-	-	-	-	1	1
39	1	-	1	-	3	1
40	2	-	2	-	2	1
41	1	1	1	1	7	1
42	4	0	4	0	8	0
43	5	0	5	0	11	2
44	8	3	8	3	18	4
45	5	3	5	3	19	4
46	8	6	8	6	19	7
47	7	10	7	10	13	13
48	3	11	3	11	6	12
49	4	9	4	9	9	13
50	1	3	1	3	1	5
51	-	1	-	1	0	2
52	-	1	-	1	1	4
53	-	1	-	1	-	5
54	-	1	-	1	-	2
55	-	1	-	1	-	3
Total	49	51	49	51	118	82
Maturities						
1	0	1	0	1	0	7
2	49	29	49	29	118	36
3	0	21	0	21	0	39
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	0	0

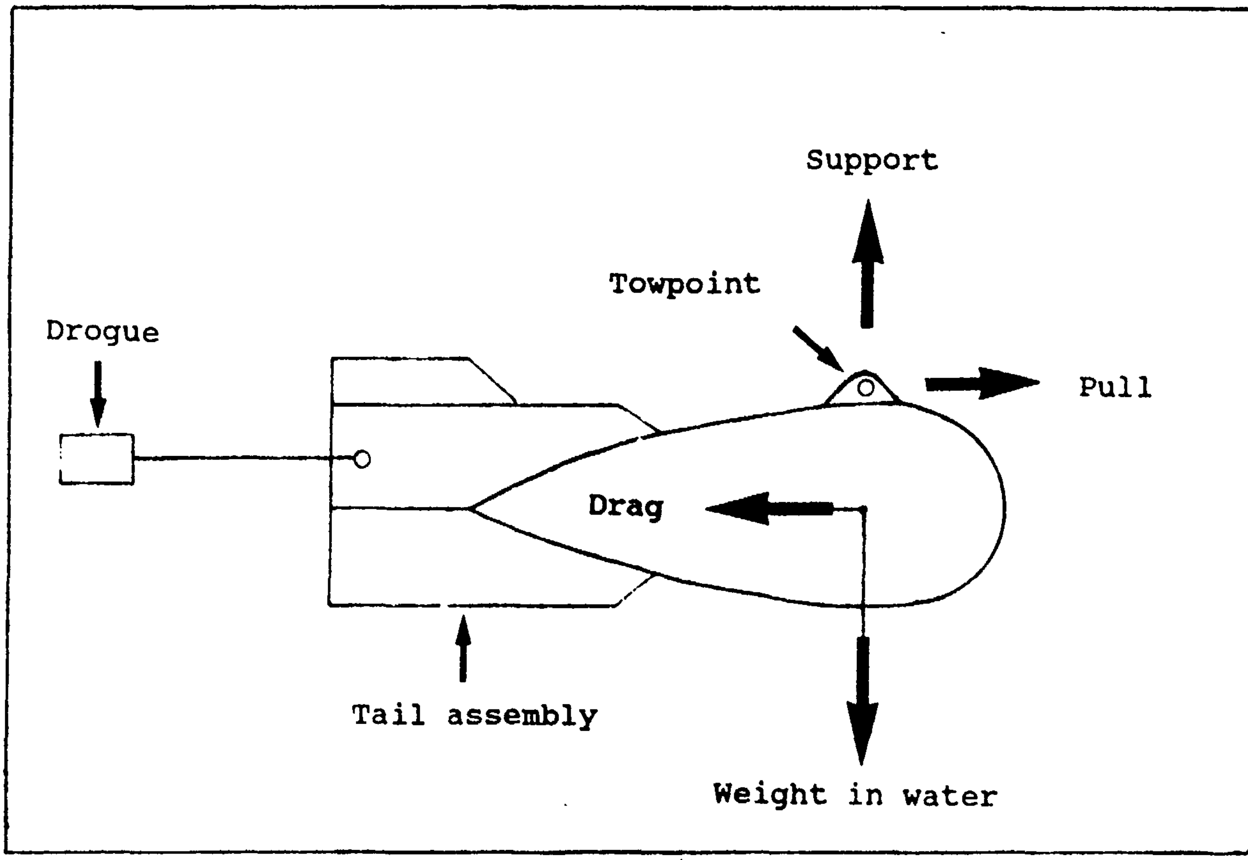


Fig. 1. Outline of towed body showing dominant force vectors affecting pitch.

Fig. 2. Typical echograms showing shelf-slope break and fish concentrations in the 140-240 m range. The echograms were recorded along the same transect, RICKER trails EASTWARD HO by approximately 0.25 nm. a. RICKER, b. EASTWARD HO.

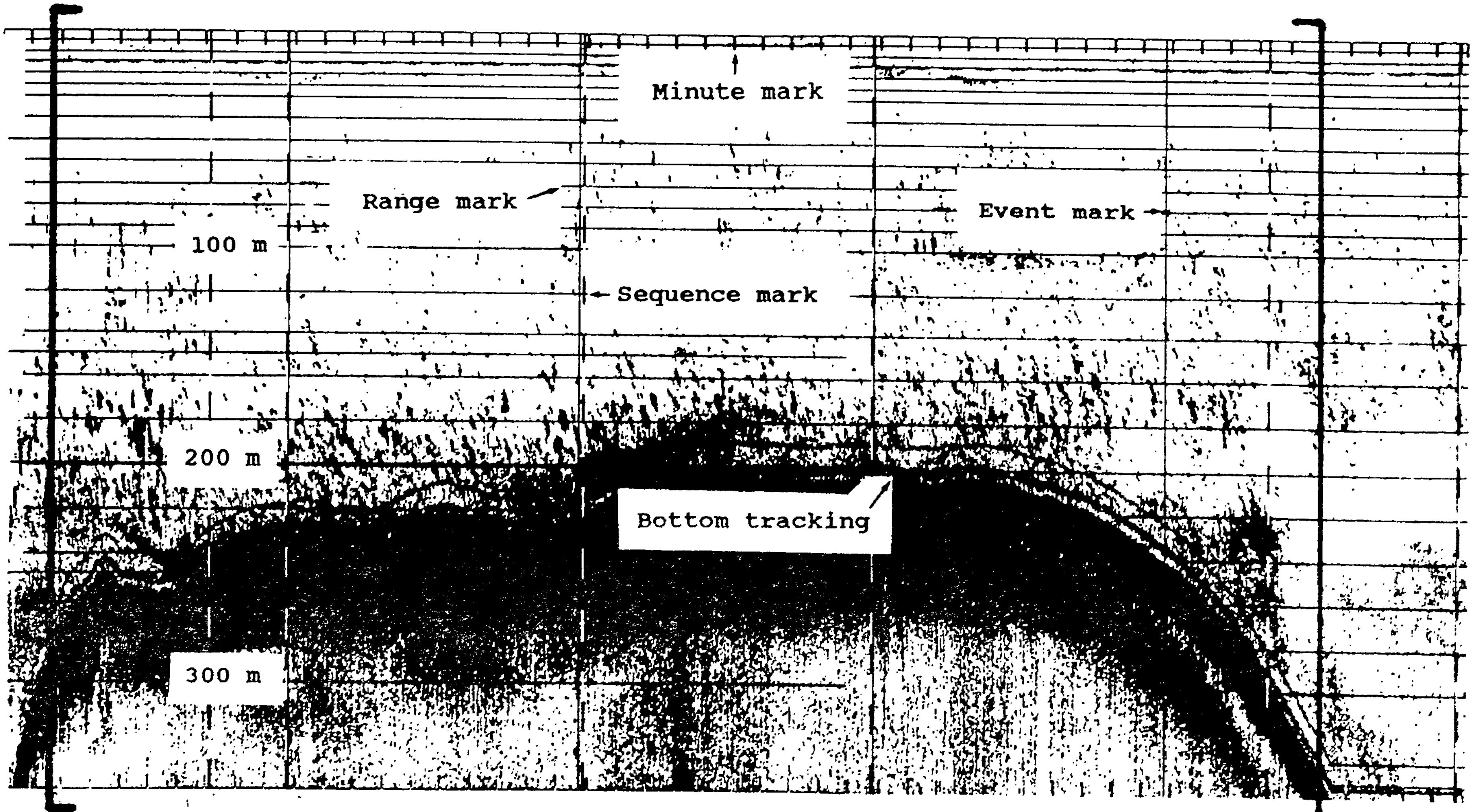
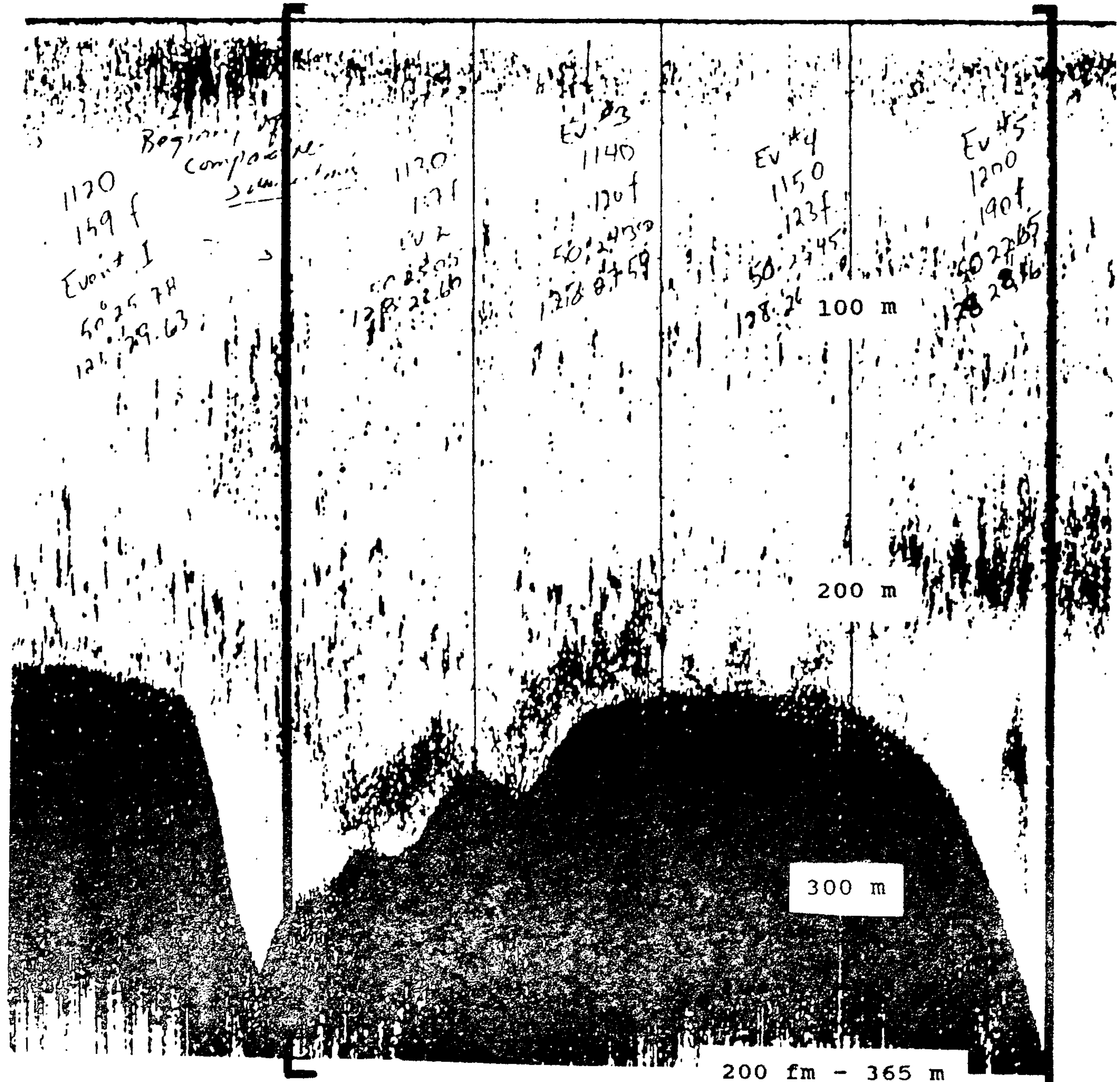

Minute mark
Range mark
Event mark
100 m
Sequence mark
200 m
Bottom tracking
300 m

Fig. 2a.


100 m
200 m
300 m
200 fm - 365 m

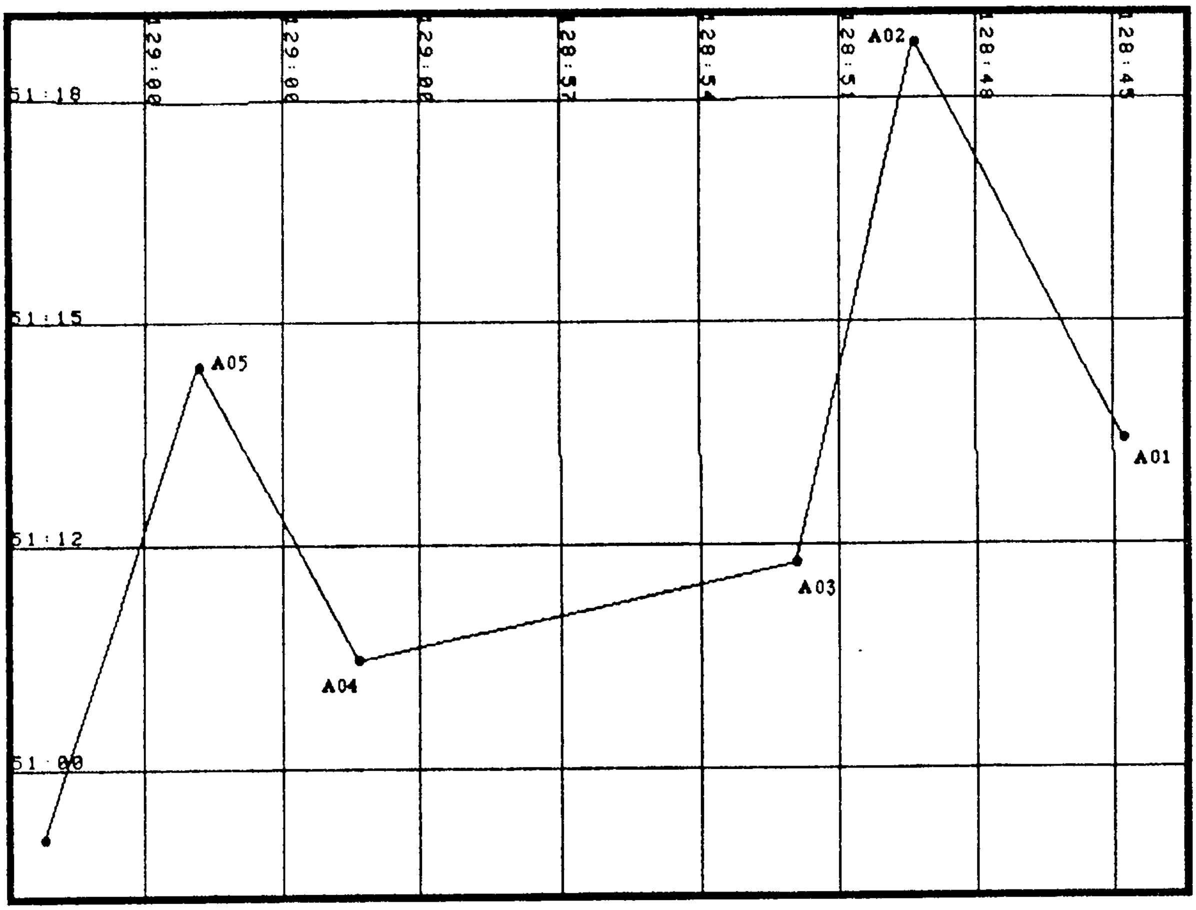


Fig. 3. Transects in Queen Charlotte Sound searching for suitable rockfish concentrations. RICKER A series transects, A01-A06, EVE 4-12, 16/10/90, 19:49.

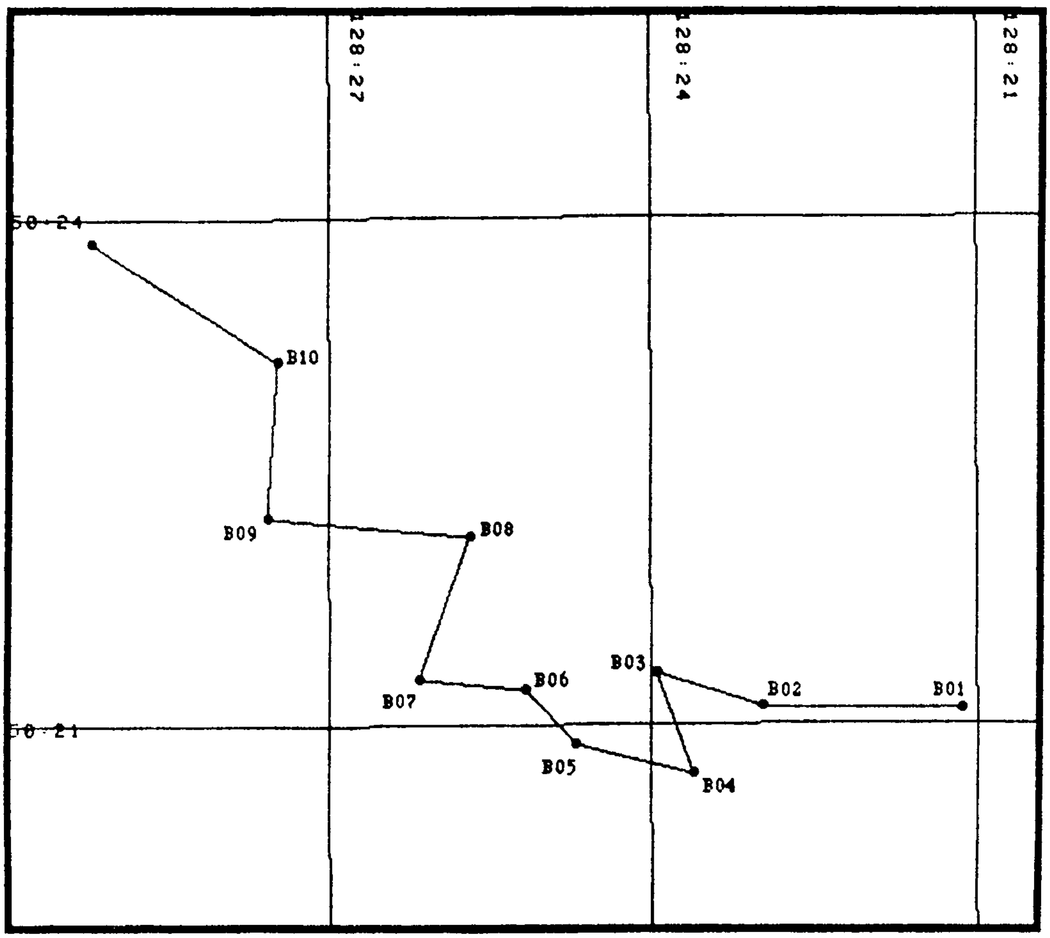


Fig. 4. Exploratory transects off Quatsino Sound. RICKER B series transects, B01-B10, EVE 16-26, 20/10/90, 04:54. Transect names are at the beginning of each transect.

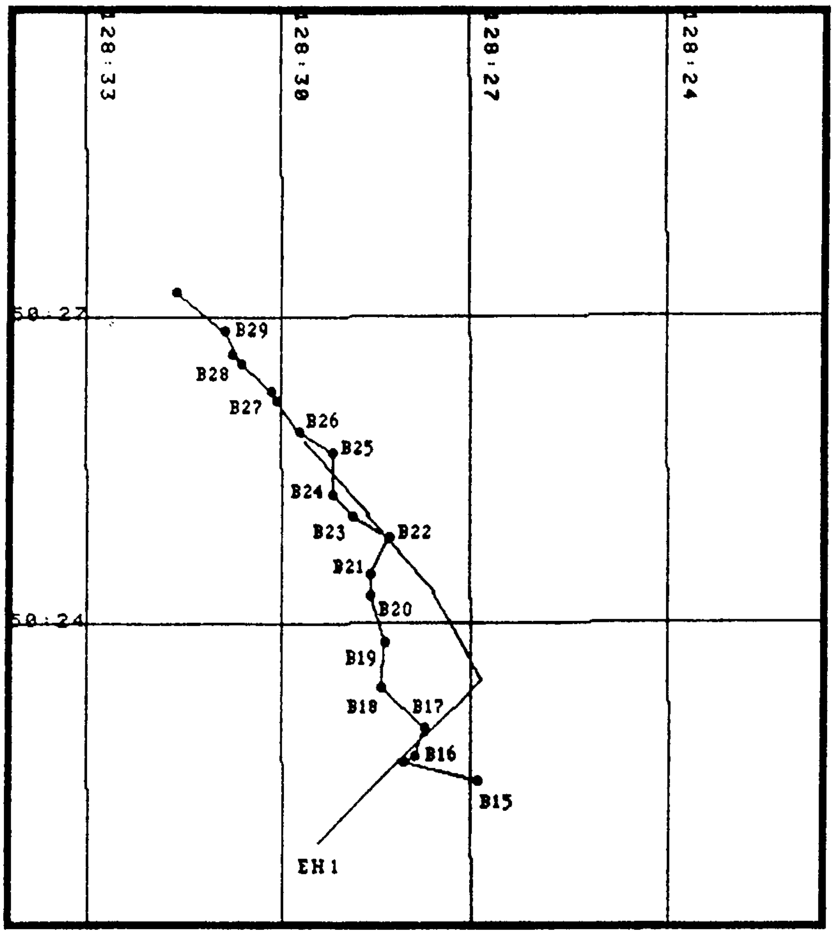


Fig. 5. Cross-over transects, sonar search for trawl warps and net. RICKER B series transects, B15-B29, EVE 34-52, 20/10/90, 07:45. EASTWARD HO set 1, EVE 1-6.

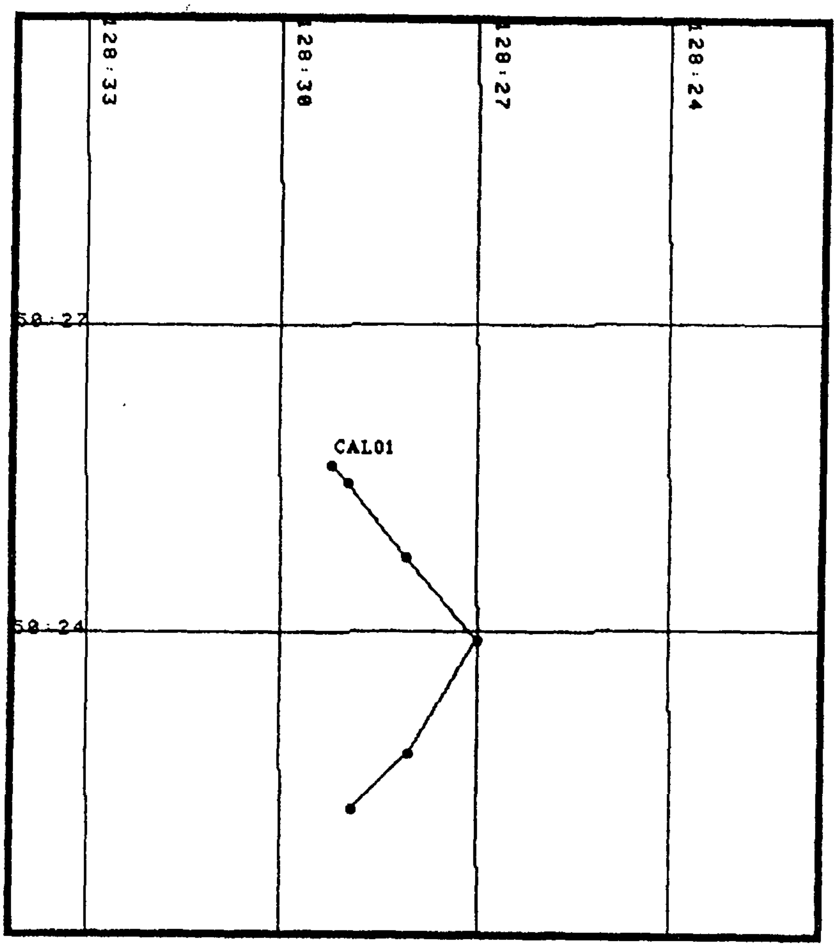


Fig. 6. Echo sound calibration transects, RICKER trailing EASTWARD HO.
RICKER CAL01, EVE 66-71, 21/10/90, 11:27.

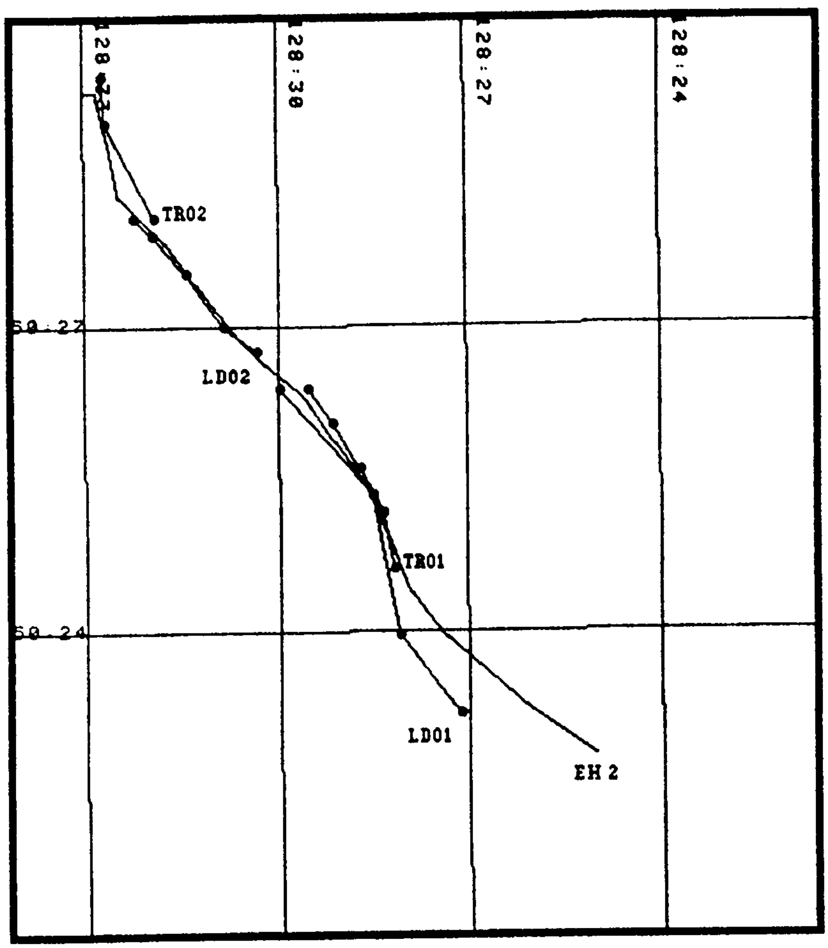


Fig. 7. Leading and trailing transects. RICKER LD01-TR02, EVE 72-95, 21/10/90. EASTWARD HO set 2, EVE 7-23.

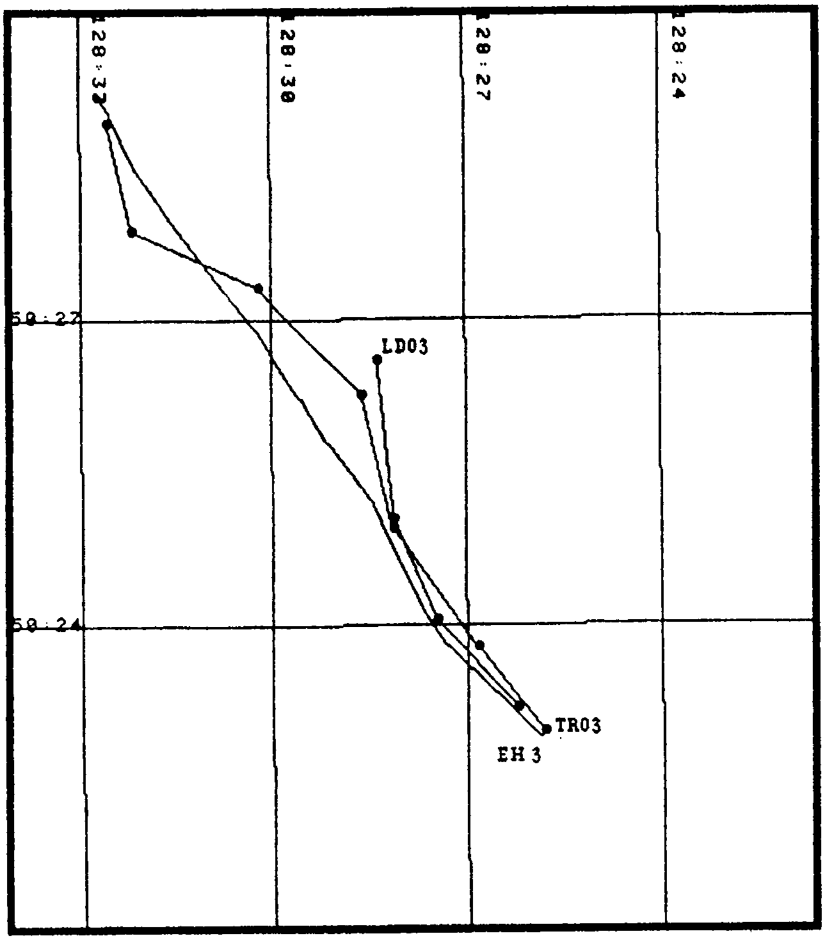


Fig. 8. Leading and trailing transects. RICKER LD03-TR03, EVE 97-109, 21/10/90. EASTWARD HO set 3, EVE 24-37.

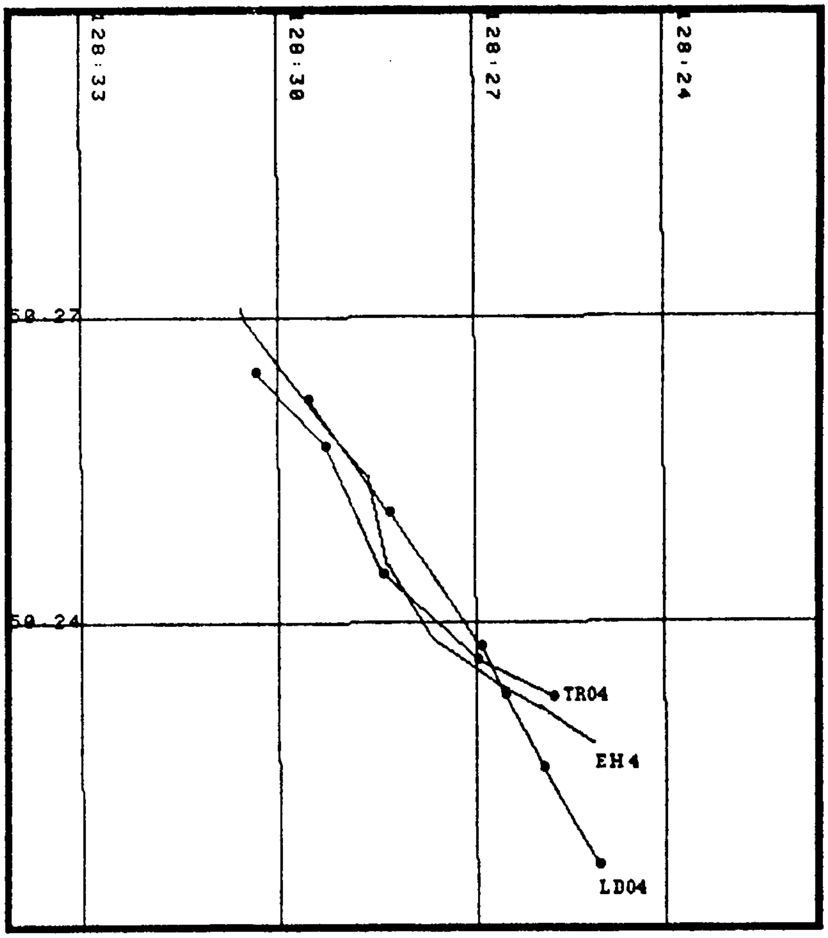


Fig. 9. Leading and trailing transects. RICKER LD04-TR04, EVE 110-120, 21/10/90. EASTWARD HO set 4, EVE 38-46.

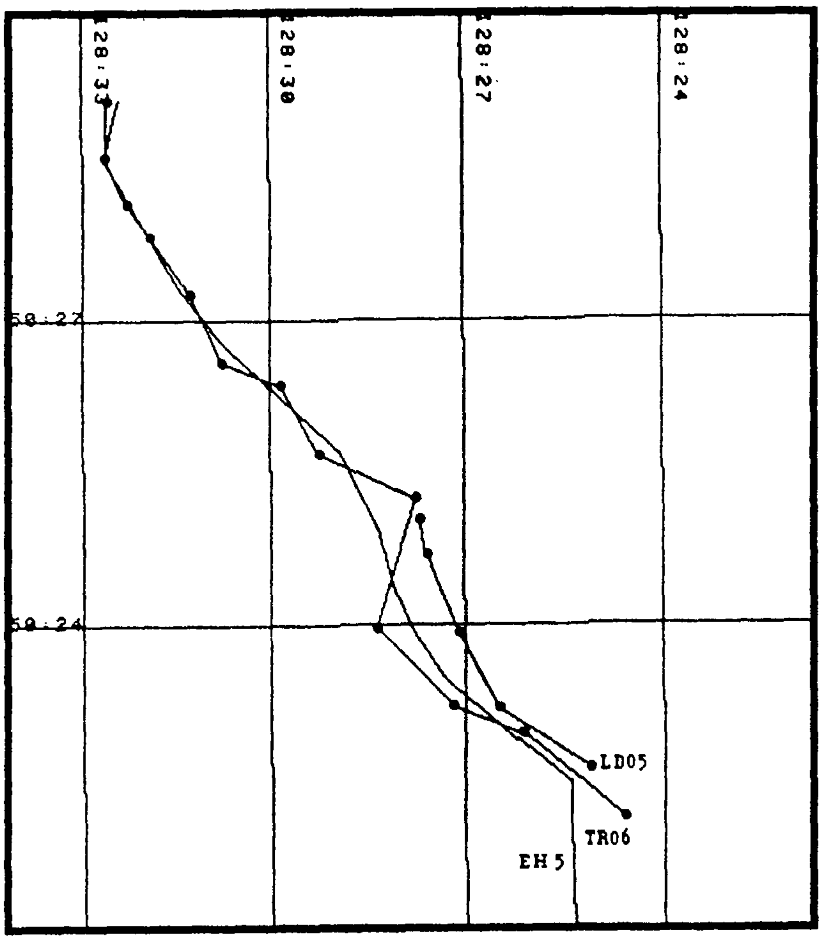


Fig. 10. Leading and trailing transects. RICKER LD06-TR06, EVE 124-141, 22/10/90, 07:40. EASTWARD HO set 5, EVE 47-59.

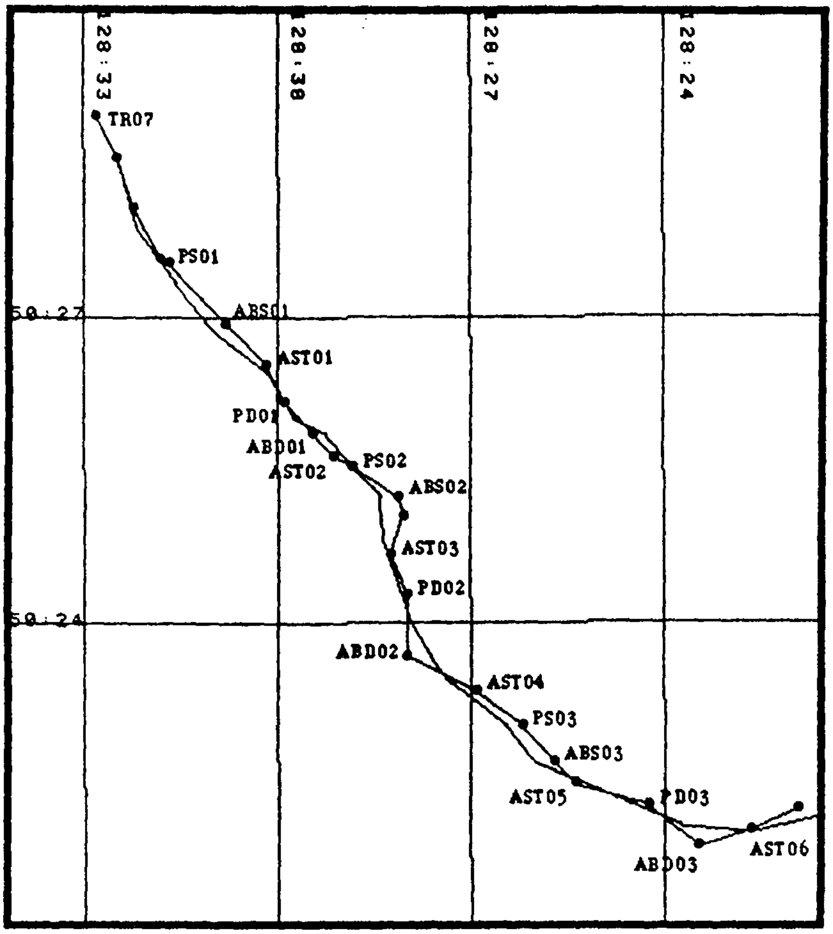


Figure 11. Transects of RICKER following EASTWARD HO on stern and sides. RICKER TR07-AST06, EVE 142-165, 22/10/90, 12:00. EASTWARD HO set 6, EVE 60-77. The following codes are used to denote the relative position of the two vessels were:

ASTxx	WER astern of EH
PSxx	Pass to shallow
ABSxx	Abeam shallow
PDxx	Pass to deep
ABDxx	Abeam deep.

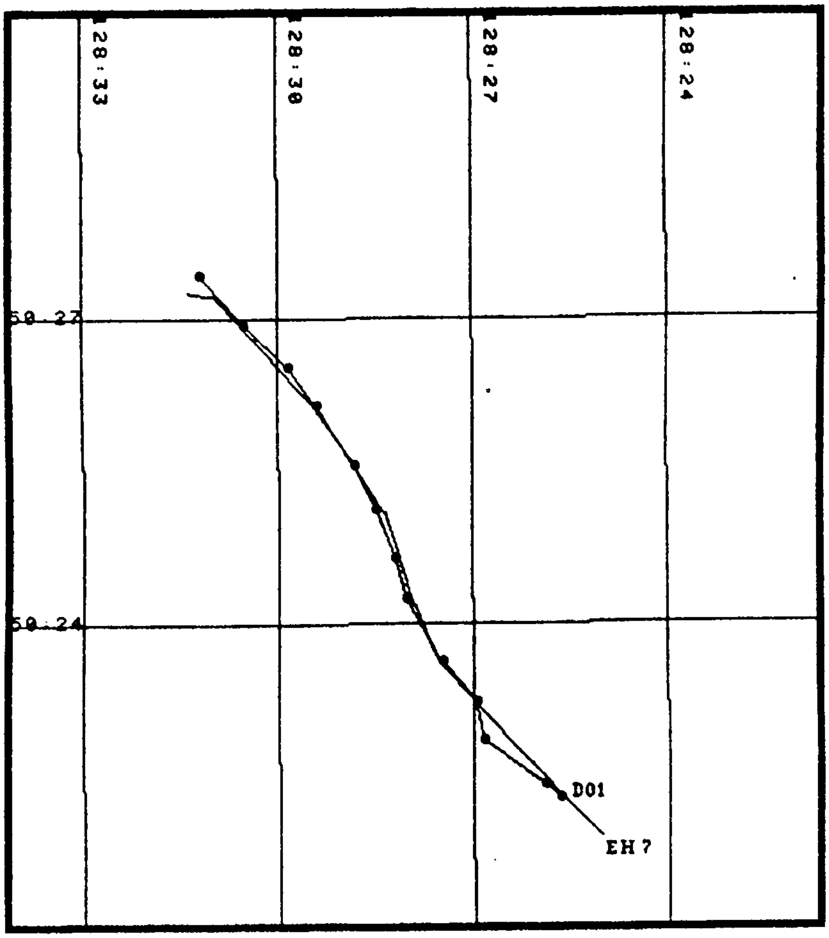


Fig. 12. Transect of RICKER trailing EASTWARD HO. RICKER D01, EVE 167-179, 24/10/90, 09:37. EASTWARD HO set 7, EVE 100-112.

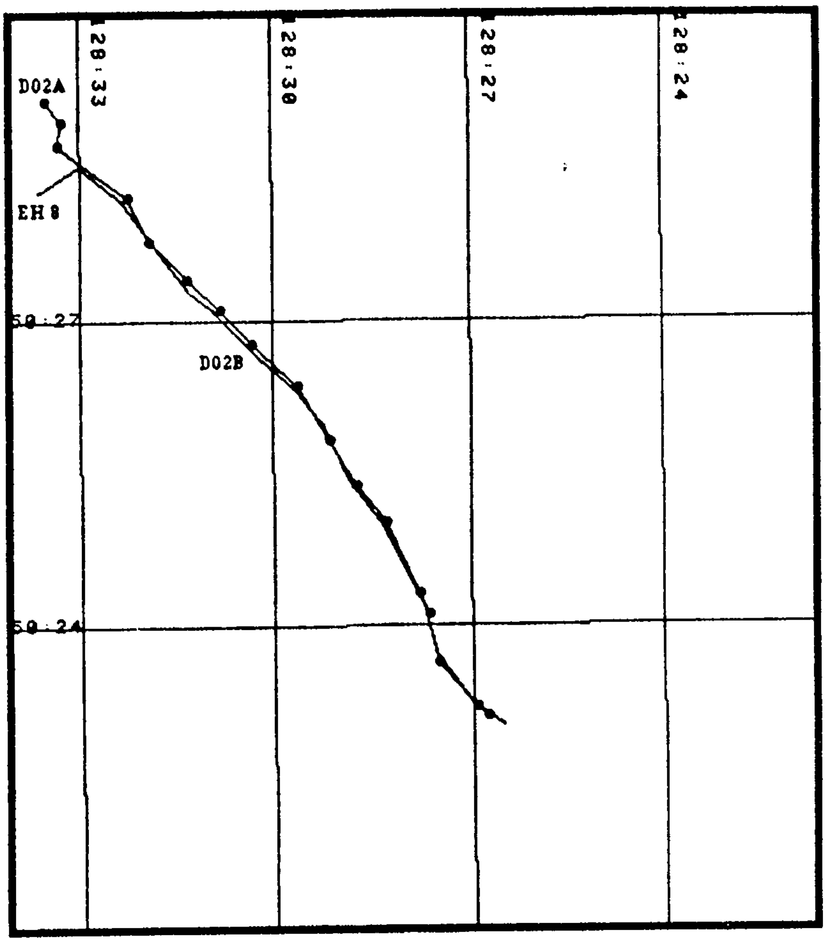
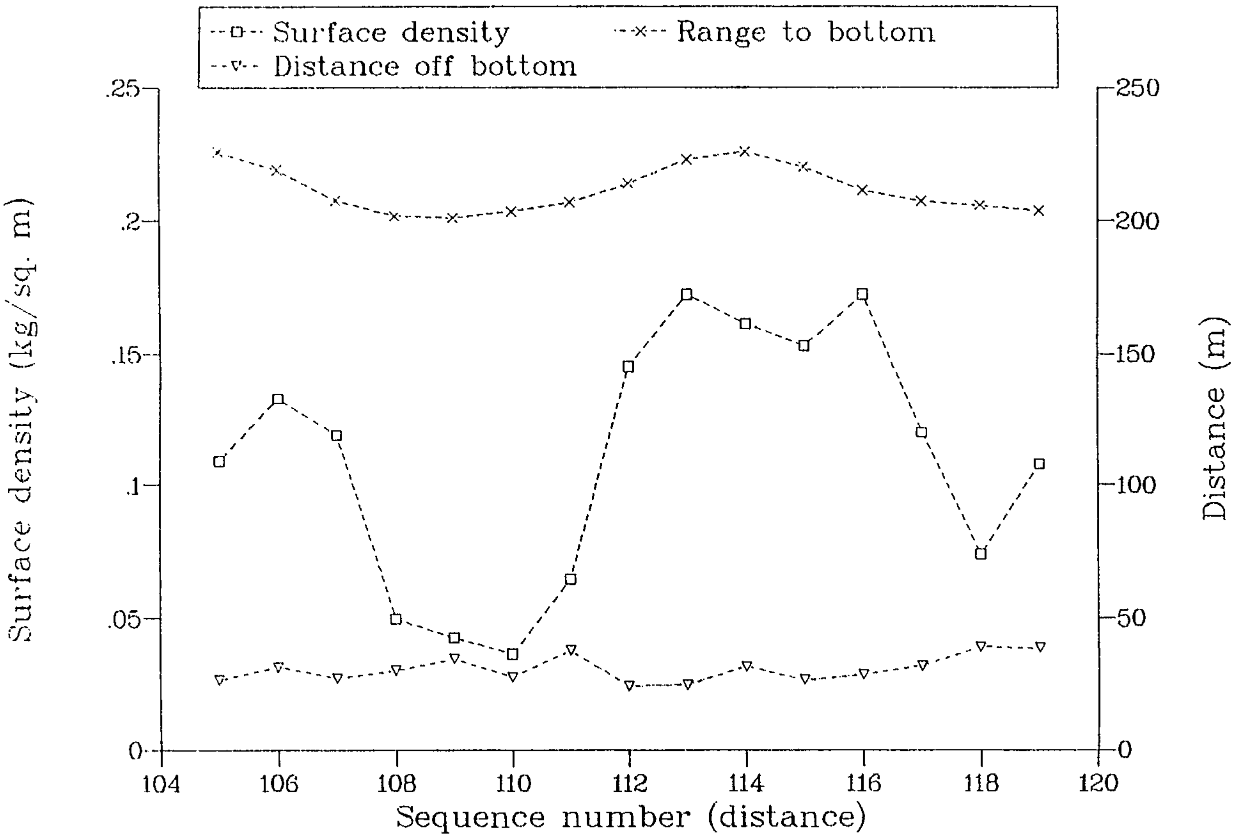
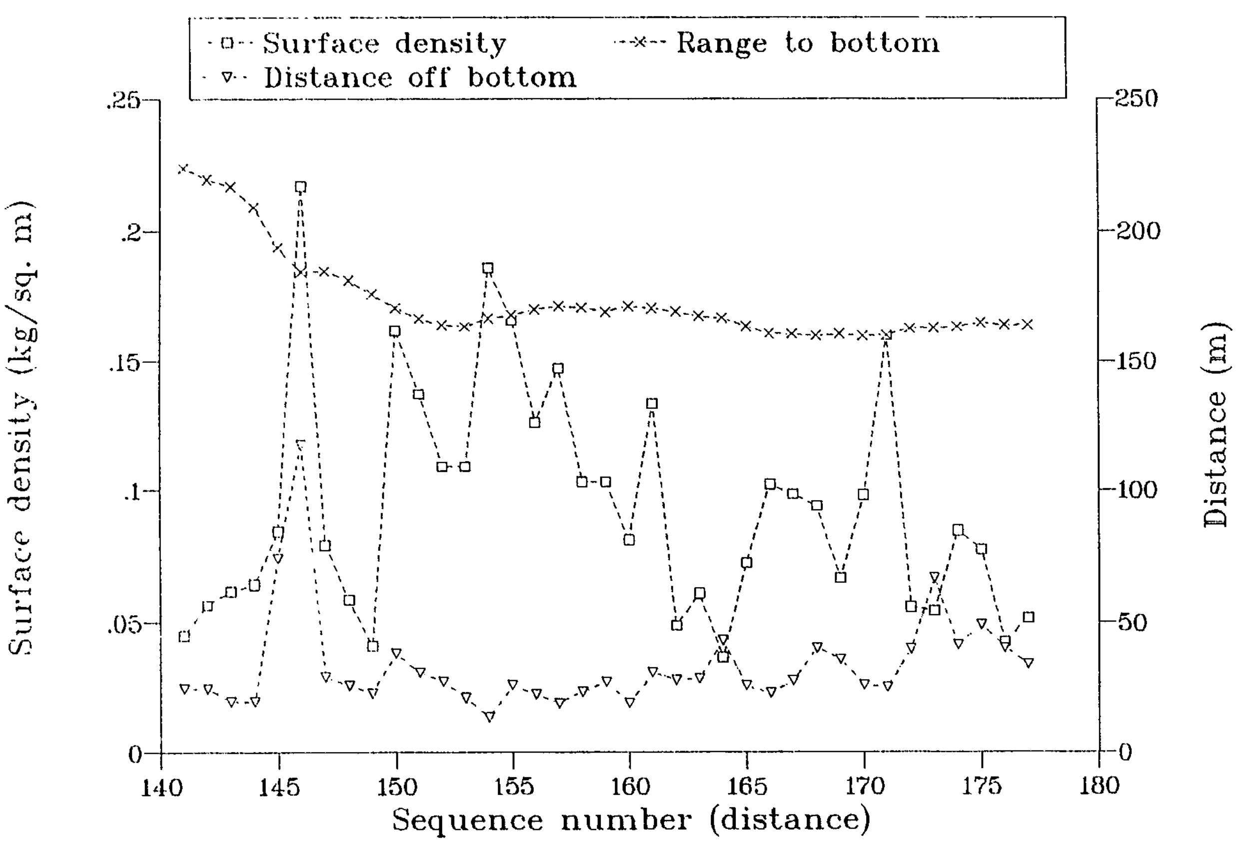


Fig. 13. Transect of RICKER trailing EASTWARD HO. RICKER D02A-D02B, EVE 182-198, 24/10/90, 13:04. EASTWARD HO set 8, EVE 150-165.

Fig. 14. Range to bottom, mean distance of fish off bottom, and surface density based on echo integration versus distance (sequence number). a) Leading transect (LD01). b) Trailing transect (TR01).


Surface density
Range to bottom
Distance off bottom
Surface density (kg/sq. m)
Distance (m)
Sequence number (distance)

a.


Surface density
Range to bottom
Distance off bottom
Surface density (kg/sq. m)
Distance (m)
Sequence number (distance)

b.

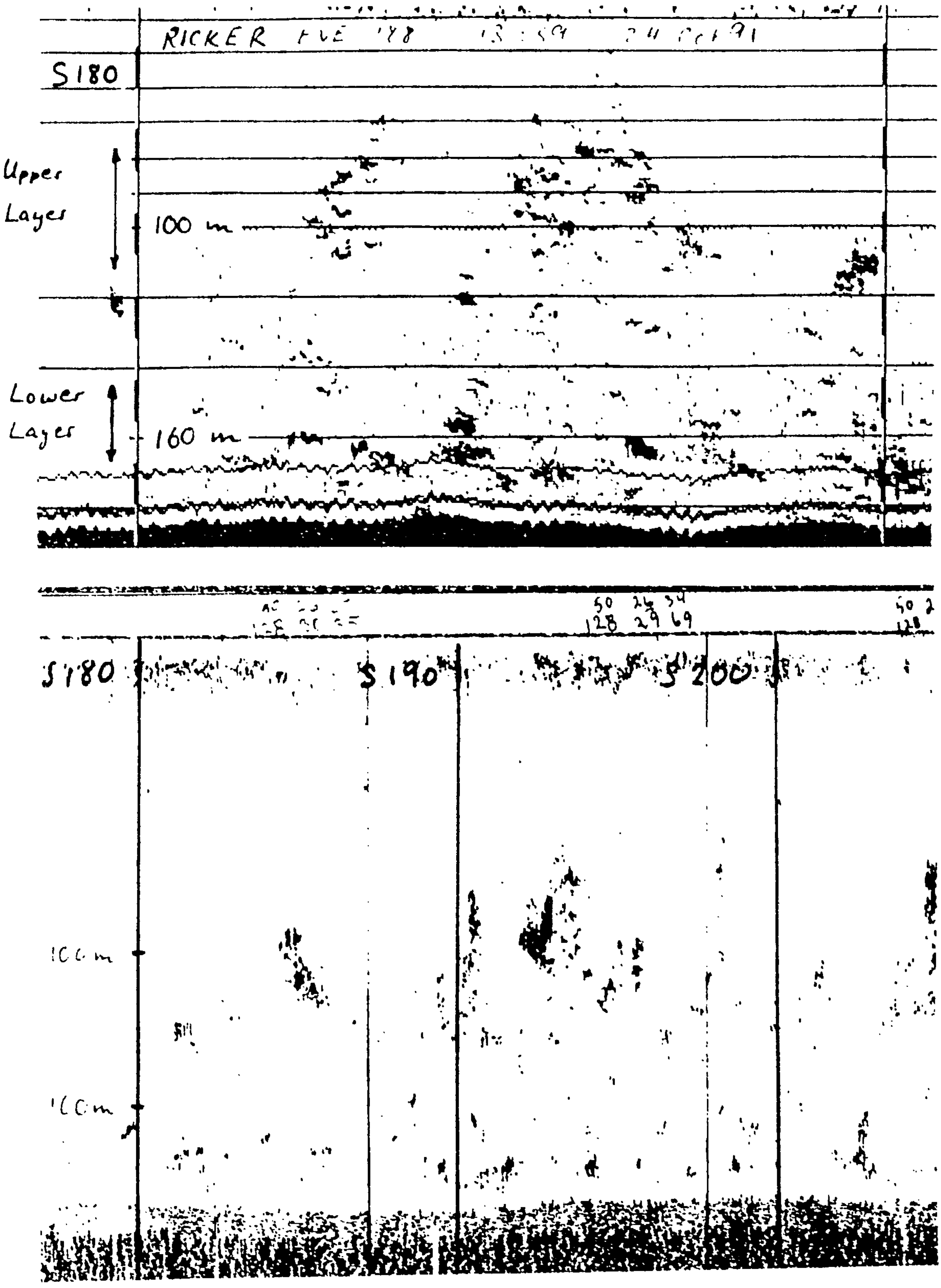
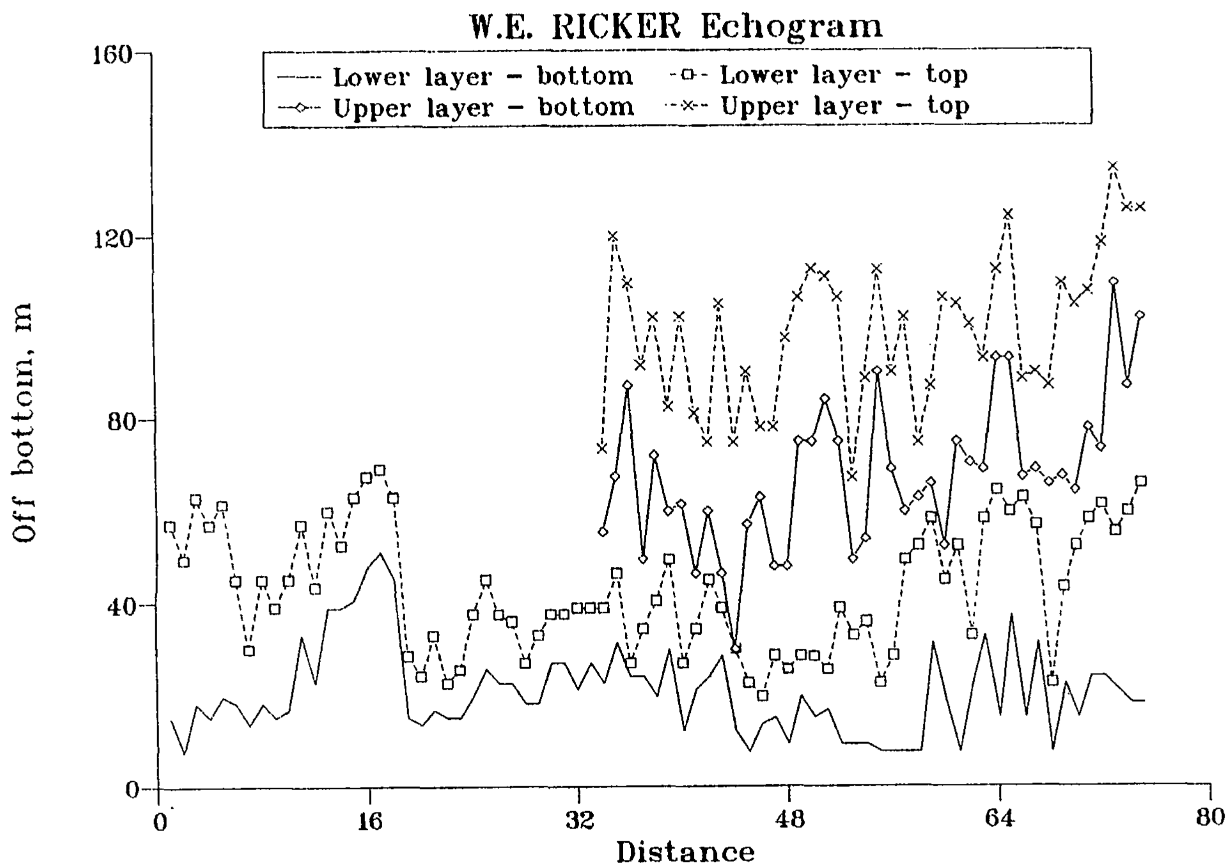
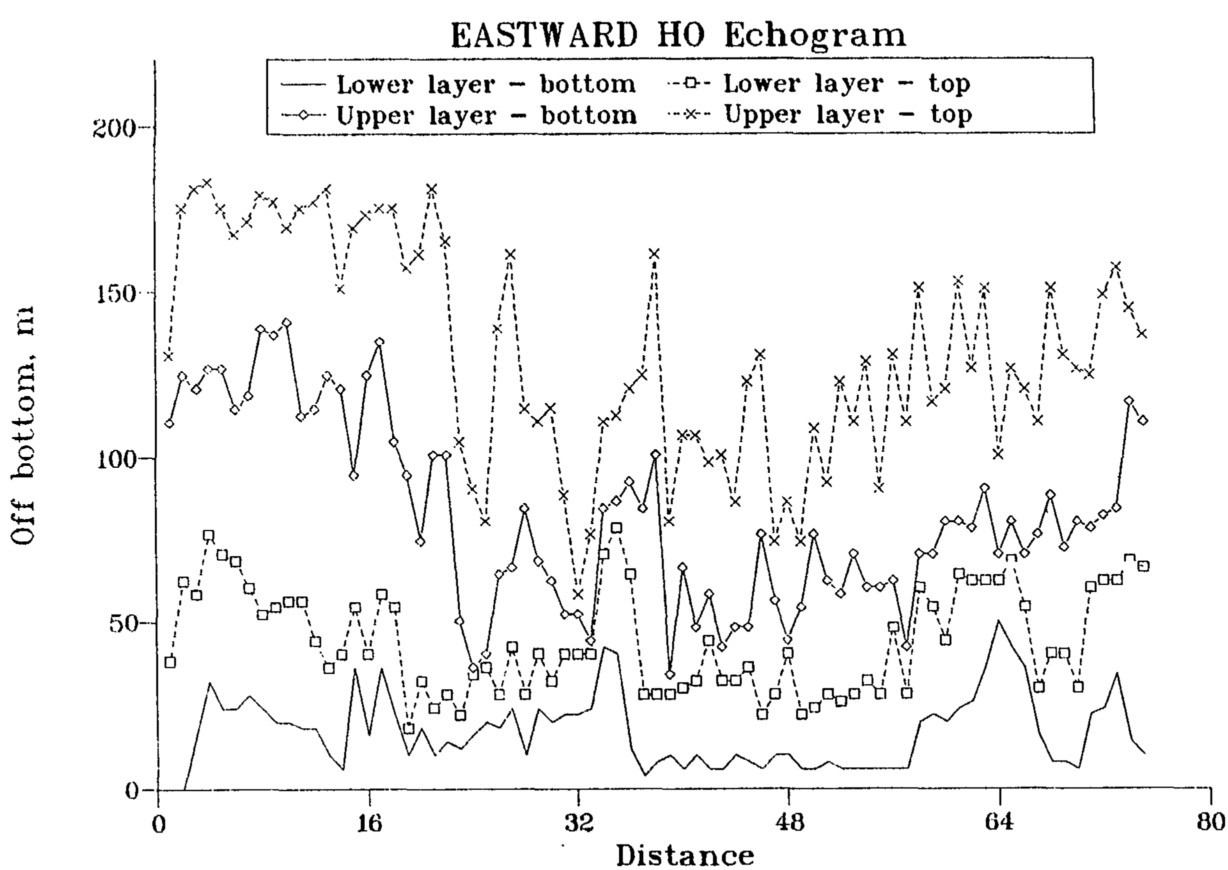


Fig. 15. Echograms from RICKER (DB02) and EASTWARD HO (DB01) illustrating upper and lower fish layers. Corresponding sequence numbers have been marked on the echograms.

Figure 16. Off bottom distance for upper and lower boundaries of the near bottom and midwater fish layers versus distance along transects D01 (Distance scale 1 to 34) and D02B. a) RICKER echogram data, note lack of upper layer along D01. b) EASTWARD HO echogram data.

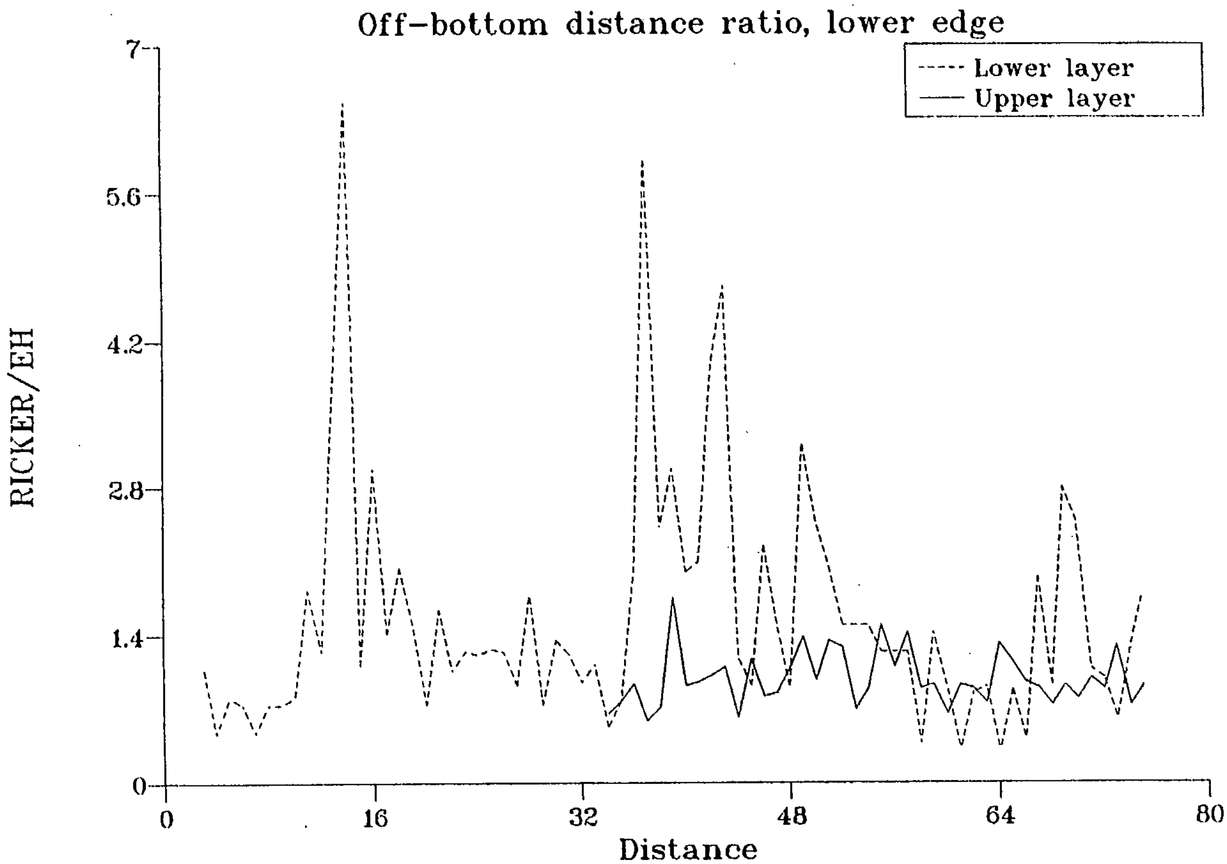

W.E. RICKER Echogram
Lower layer - bottom
Lower layer - top
Upper layer - bottom
Upper layer - top
Off bottom, m
Distance
0
40
80
120
160
16
32
48
64
80

a.

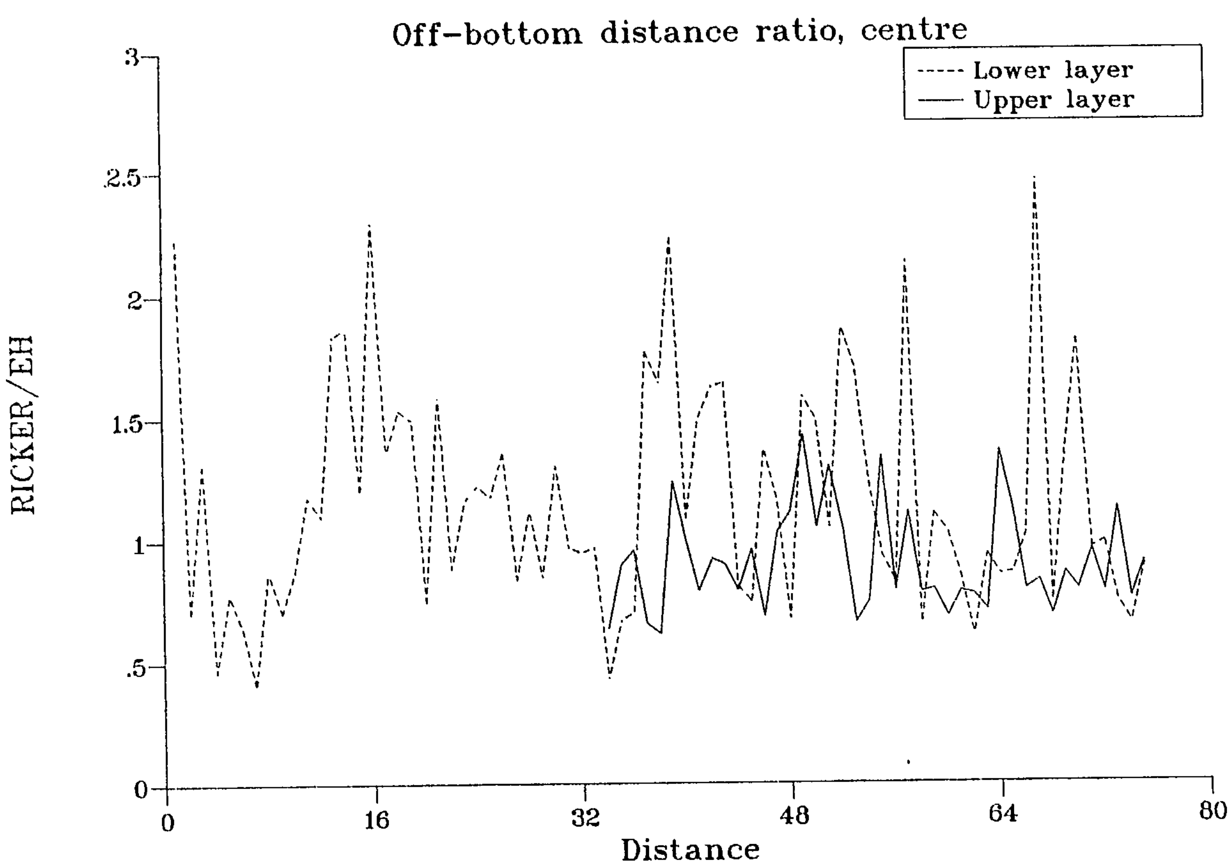

EASTWARD HO Echogram
Lower layer - bottom
Lower layer - top
Upper layer - bottom
Upper layer - top
Off bottom, m
Distance
0
50
100
150
200
16
32
48
64
80

b.

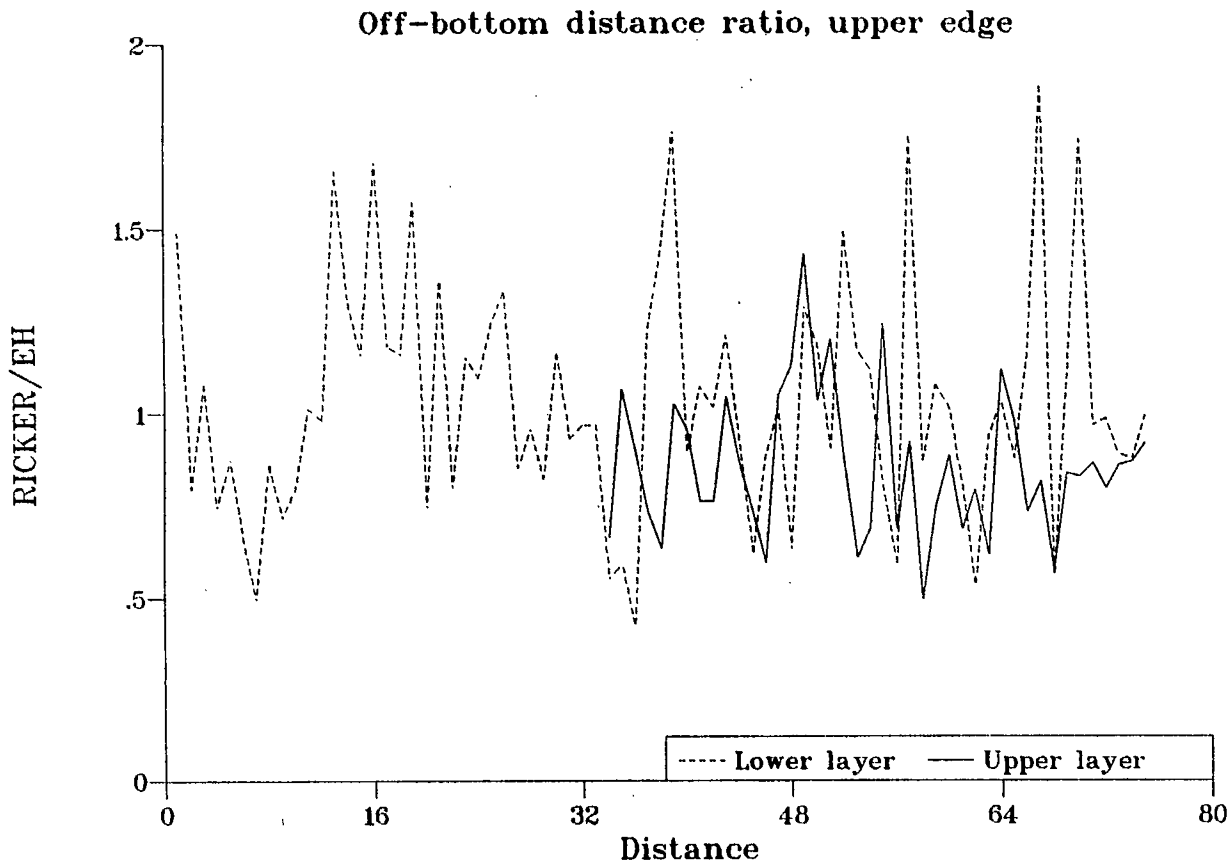
Fig. 17. Ratio of off-bottom distance for the lower and upper fish layers. a) Lower Boundary. b) Centre of layers. c) Upper boundary. d) Average of lower, centre and upper boundaries.


Off-bottom distance ratio, lower edge
Lower layer
Upper layer
RICKER/EH
7
5.6
4.2
2.8
1.4
0
0
16
32
48
64
80
Distance

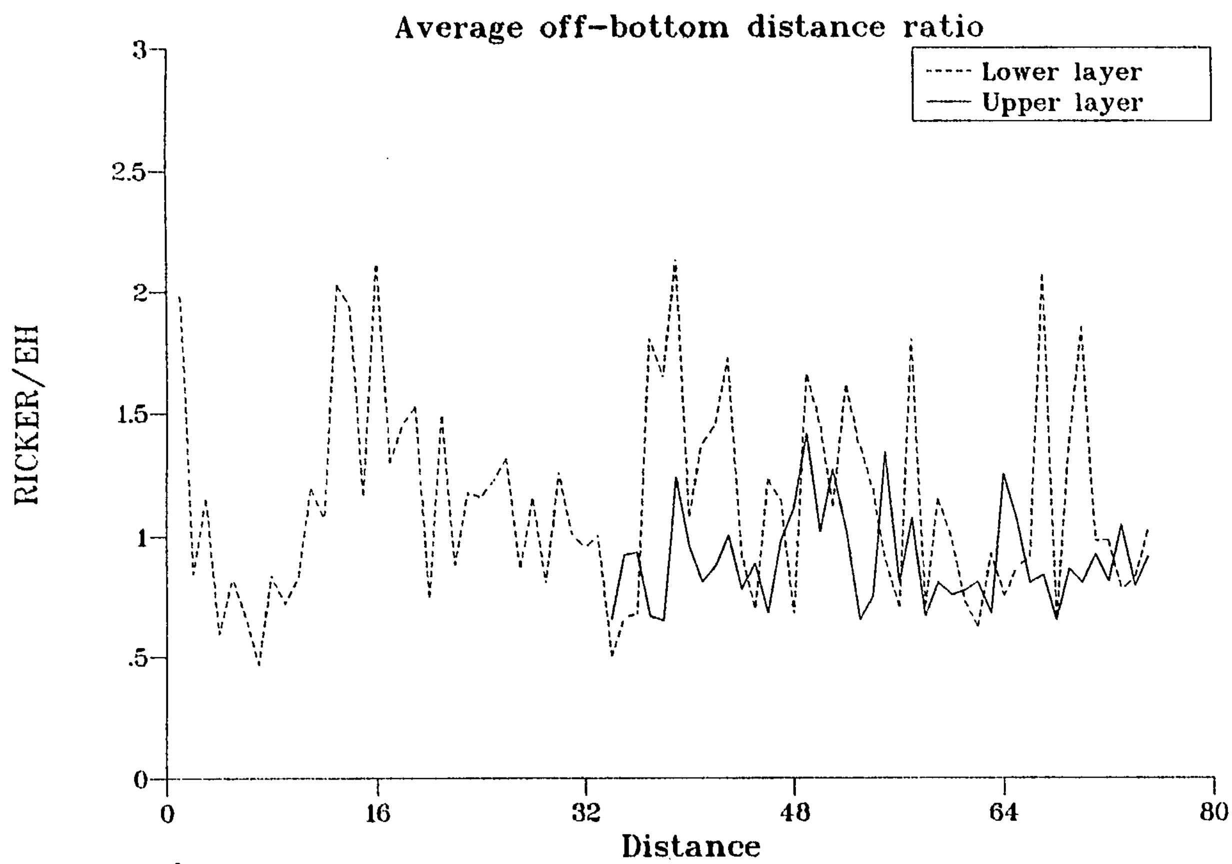
a.


Off-bottom distance ratio, centre
Lower layer
Upper layer
RICKER/EH
3
2.5
2
1.5
1
.5
0
0
16
32
48
64
80
Distance

b.


Off–bottom distance ratio, upper edge
RICKER/EH
2
1.5
1
.5
0
0
16
32
48
64
80
Distance
----- Lower layer
—— Upper layer

c.


Average off–bottom distance ratio
RICKER/EH
3
2.5
2
1.5
1
.5
0
0
16
32
48
64
80
Distance
----- Lower layer
—— Upper layer

d.

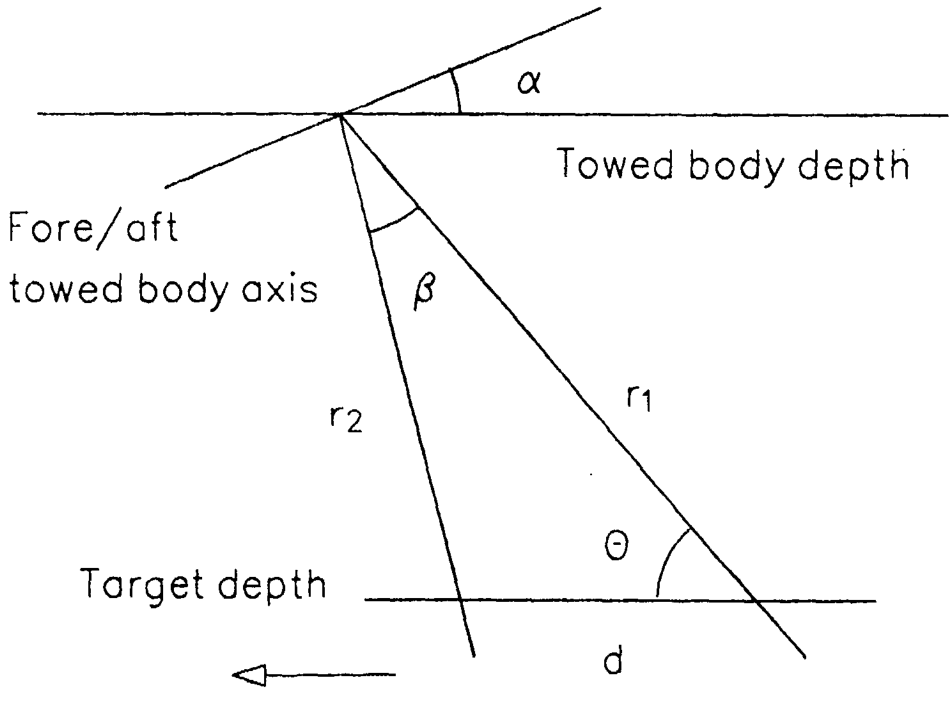


Fig. 18. Transducer/target geometry. The arrow gives the direction of travel of the target, in the reference frame of the towed body.

Appendix Table A1. Bridge log of the W.E. RICKER, October 15-27, 1990.

		1	2	3	4
Haul number		1	2	3	4
Date		Oct 18	Oct 25	Oct 25	Oct 26
Area (Major, Minor)		5A,11	5A,11	5A,11	3D,25
Start time	(PDT)	15:37	9:25	12:00	9:21
Duration	(Min)	90	57	80	62
Start N. Lat.	(Deg)	51	51	51	49
	(Min)	13.1	13.4	13.3	35.2
W. Long	(Deg)	128	129	129	127
	(Min)	43.3	1.1	..	15.4
Finish N. Lat.	(Deg)	51	51	51	49
	(Min)	11.3	12.1	11.7	38.5
W. Long	(Deg)	128	129	129	127
	(Min)	36.4	5.3	6.4	18.0
Haul distance	(km)	8.7	5.4	7.6	6.9
	(N Mi)	4.7	2.9	4.1	3.7
Direction	(Deg.True)	113	250	155	290
Bottom depth	(m)	181- 181	186- 176	174- 178	147- 142
	(fm)	99- 99	102- 96	95- 97	80- 78
Modal depth	(m)	181	183	176	145
Gear type		113	113	113	113
Tide		EBB	..	..	..
Total catch	(kg)	1134	733	0	0
Remarks		TORN-USE	USABLE	USABLE	USABLE

Appendix Table A1. (Continued)

Haul number	1	2	3	4
Date	Oct 18	Oct 25	Oct 25	Oct 26
Area (Major, Minor)	5A,11	5A,11	5A,11	3D,25
Arrowtooth flounder	127	299	..	..
Dover sole	..	2	..	..
English sole	15	..	..	..
Petrale sole	..	2	..	..
Other flatfish	T	..	..	..
S. alutus	265	2	..	..
S. babcocki	41	..	..	..
S. brevispinis	78	79	..	..
S. flavidus	45	43	..	..
S. paucispinis	123	133	..	..
S. pinniger	T	19	..	..
S. proriger	22	20	..	..
S. reedi	T	11	..	..
Other rockfish	T	..	..	..
American shad	4	..	..	..
Lingcod	90	9	..	..
Pacific cod	..	11	..	..
Pacific hake	26	T	..	..
Sablefish	T	17	..	..
Walleye pollock	216	2	..	..
Other roundfish	..	..	..	..
Ratfish	..	3	..	..
Spiny dogfish	82	81	..	..
Other Selachii	..	..	..	..
Total Catch (kg)	1134	733	0	0

Appendix Table A2. Bridge log of the F/V EASTWARD HO, October 15-27, 1990.

		1	2	3	4
Haul number		1	2	3	4
Date		Oct 20	Oct 21	Oct 21	Oct 21
Area (Major, Minor)		3D,27	3D,27	3D,27	3D,27
Start time	(PDT)	6:48	12:36	18:27	23:11
Duration	(Min)	168	171	203	112
Start N. Lat.	(Deg)	50	50	50	50
	(Min)	21.9	22.2	22.9	22.8
W. Long	(Deg)	128	128	128	128
	(Min)	22.8	24.5	25.9	25.1
Finish N. Lat.	(Deg)	50	50	50	50
	(Min)	27.6	29.6	29.3	27.1
W. Long	(Deg)	128	128	128	128
	(Min)	31.8	33.1	32.7	30.6
Haul distance	(km)	15.0	17.0	14.3	10.0
	(N Mi)	8.1	9.2	7.7	5.4
Direction	(Deg.True)	235	346	311	321
Bottom depth	(m)	265- 225	221- 207	219- 212	219- 218
	(fm)	145- 123	121- 113	120- 116	120- 119
Modal depth	(m)	229	214	223	218
Gear type		100	100	100	100
Tide		FLOOD	..	SLACK	FLOOD
Total catch	(kg)	9072	9072	6804	2268
Remarks		USABLE	USABLE	USABLE	SNAG-USE

Appendix Table A2. (Continued)

Haul number	1	2	3	4
Date	Oct 20	Oct 21	Oct 21	Oct 21
Area (Major, Minor)	3D,27	3D,27	3D,27	3D,27
Arrowtooth flounder	480	121	1102	834
Dover sole	53	T	120	16
Pacific halibut	T	..	..	33
Petrale sole	..	..	T	8
Rex sole	T	30	T	T
Other flatfish	..	..	..	..
S. alutus	3817	5704	1294	627
S. babcocki	..	T	..	..
S. brevispinis	T	121	95	58
S. crameri	53	..	..	..
S. diploproa	2748	T	..	..
S. elongatus	27	T	24	16
S. entomelas	..	30	192	..
S. flavidus	..	..	95	8
S. paucispinis	T	1092	335	..
S. pinniger	..	30	..	..
S. proriger	..	152	24	8
S. reedi	347	637	791	198
S. zacentrus	T	546	144	33
Seb. alascanus	27	T	24	T
Other rockfish	..	T	T	T
Lingcod	T	273	240	25
Pacific cod	T	62	72	16
Pacific hake	827	152	1509	322
Sablefish	560	62	719	25
Other roundfish	..	T	T	..
Ratfish	53	30	24	33
Spiny dogfish	80	30	T	8
Other Selachii	T	..	..	..
Invertebrates	T	T	T	T
Total catch (kg)	9072	9072	6804	2268

Appendix Table A2. (Continued)

Haul number		5	6	7	8
Date		Oct 22	Oct 22	Oct 24	Oct 24
Area (Major, Minor)		3D,27	3D,27	3D,27	3D,27
Start time	(PDT)	7:36	11:57	9:27	12:55
Duration	(Min)	172	219	133	155
Start N. Lat.	(Deg)	50	50	50	50
	(Min)	22.0	28.6	21.9	28.3
W. Long	(Deg)	128	128	128	128
	(Min)	24.5	32.5	25.2	33.7
Finish N. Lat.	(Deg)	50	50	50	50
	(Min)	29.2	22.2	27.6	23.0
W. Long	(Deg)	128	128	128	128
	(Min)	32.5	21.3	31.4	26.5
Haul distance	(km)	16.1	17.6	12.8	13.9
	(N Mi)	8.7	9.5	6.9	7.5
Direction	(Deg.True)	315	133	322	113
Bottom depth	(m)	225- 212	221- 212	240- 216	223- 227
	(fm)	123- 116	121- 116	131- 118	122- 124
Modal depth	(m)	219	218	229	225
Gear type		100	100	100	100
Tide		FLOOD	EBB	FLOOD	SLACK
Total catch	(kg)	9072	11340	5443	4536
Remarks		USABLE	USABLE	USABLE	USABLE

Appendix Table A2. (Continued)

Haul number	5	6	7	8
Date	Oct 22	Oct 22	Oct 24	Oct 24
Area (Major, Minor)	3D,27	3D,27	3D,27	3D,27
Arrowtooth flounder	129	113	70	18
Dover sole	T	38	T	..
Pacific halibut	T	T	47	53
Petrale sole	64	..	..	..
Rex sole	T	..	T	..
Other flatfish	..	..	..	..
S. alutus	5888	8778	4023	1825
S. babcocki	32	75	..	..
S. brevispinis	..	264	279	461
S. crameri	..	..	..	..
S. diploproa	T	264	23	T
S. elongatus	32	T	..	T
S. entomelas	..	38	..	..
S. flavidus	T	..	..	..
S. paucispinis	901	941	582	673
S. pinniger	..	..	..	..
S. proriger	32	..	..	..
S. reedi	161	226	186	514
S. zacentrus	64	113	23	177
Seb. alascanus	T	T	..	..
Other rockfish	T	..	..	T
Lingcod	T	377	..	762
Pacific cod	..	T	..	..
Pacific hake	1415	75	47	53
Sablefish	290	..	140	..
Other roundfish	..	T	..	..
Ratfish	32	..	T	T
Spiny dogfish	32	38	23	T
Other Selachii	T	..	..	..
Invertebrates	..	..	T	T
Total catch (kg)	9072	11340	5443	4536

Appendix Table A3. Common and scientific names for species encountered by the R/V W.E. RICKER and the F/V EASTWARD HO, October 15-27, 1990.

Rockfish	
Pacific ocean perch	S. alutus
Redbanded rockfish	S. babcocki
Silvergray rockfish	S. brevispinis
Darkblotched rockfish	S. crameri
Splitnose rockfish	S. diploproa
Greenstriped rockfish	S. elongatus
Widow rockfish	S. entomelas
Yellowtail rockfish	S. flavidus
Rosethorn rockfish	S. helvomaculatus
Bocaccio	S. paucispinis
Canary rockfish	S. pinniger
Redstripe rockfish	S. proriger
Yellowmouth rockfish	S. reedi
Yelloweye rockfish	S. ruberrimus
Sharpchin rockfish	S. zacentrus
Shortspine thornyhead	Sebastolobus alascanus
Flatfish	
Arrowtooth flounder	Atheresthes stomias
Petrale sole	Eopsetta jordani
Rex sole	Glyptocephalus zachirus
Pacific halibut	Hippoglossus stenolepis
Dover sole	Microstomus pacificus
English sole	Parophrys vetulus
Roundfish	
Sablefish	Anoplopoma fimbria
Pacific cod	Gadus macrocephalus
Pacific hake	Merluccius productus
Lingcod	Ophiodon elongatus
Walleye pollock	Theragra chalcogramma

Appendix Table A3. (continued).

Selachii	
Ratfish	Hydrolagus colliei
Longnose skate	Raja rhina
Starry skate	R. stellata
Spiny dogfish	Squalus acanthias
Other Fish	
Blackbelly eelpout	Lycodes pacificus
Darkfin (Bartail) sculpin	Malacocottus zonurus
American shad	Alosa sapidissima
Invertebrates	
Squid	Ommastrephes bartrami
Octopus	Octopus sp.
Prawn	Pandalus platyceros