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W.E. RICKER Hydroacoustic Cruise to Study Rockfish Behaviour off Northern Vancouver Island, March 14-23, 1990

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W.E. RICKER HYDROACOUSTIC CRUISE TO STUDY ROCKFISH BEHAVIOUR OFF NORTHERN VANCOUVER ISLAND, MARCH 14-23, 1990

by

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ABSTRACT

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

We report preliminary results of a research cruise studying rockfish (Sebastes spp.) school structure and behaviour off Quatsino Sound, British Columbia. Diel distribution and behaviour of shelf and slope rockfishes are described, as well as the transitional pattern between nocturnal and diurnal distributions. The species studied (S. entomelas, S. proriger, S. reedi) showed restricted bathymetric ranges, whose areal extent was governed by bottom slope. Diurnal distributions were characterized by dense, bottom-oriented schools. Nocturnal distributions showed much more diffuse schools, both on-bottom and in the midwater. Transitional behaviour was completed within approximately 30 min on clear days, but was extended for up to 1 h on foggy or overcast days. The normal transition pattern was one of disaggregation of diurnal schools, followed by vertical movement. We also present brief results of observations, using a trawl surveillance sonar, of fish behaviour within the mouths of bottom and midwater trawls.

RÉSUMÉ

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

Les auteurs présentent les résultats préliminaires d'une croisière de recherche sur la structure des bancs de sébastes (_Sebastes_ sp.) et leur comportement au large du détroit de Quatsino (Colombie-Britannique). Ils décrivent la distribution et le comportement nycthémérales des sébastes sur la plate-forme et le talus continental ainsi que le régime de transition entre les répartitions nocturne et diurne. Les espèces étudiées (_S. entomelas_, _S. proriger_, _S. reedi_) présentaient des aires de répartition bathymétriques restreintes, dont l'étendue aréale était régie par la pente du fond. Les distributions diurnes étaient caractérisées par des bancs denses vers le fond. Les répartitions nocturnes, quant à elles, présentaient des bancs plus diffus, sur le fond et dans la zone méso-pélagique. Le comportement de transition a été atteint en moins de 30 minutes environ les jours de temps clair, mais il se prolongeait jusqu'à 1 heure les jours brumeux ou nuageux. Le régime de transition normal était un régime de désagrégation des bancs diurnes suivi d'un déplacement vertical. Les auteurs présentent également des résultats sommaires des observations, effectuées au moyen d'un sonar de surveillance des chaluts, du comportement des poissons à l'intérieur des ouvertures des chaluts de fond et des chaluts semi-pélagiques.

INTRODUCTION

The Offshore Rockfish and Hydroacoustic programs at the Pacific Biological Station are using hydroacoustic technology to examine the problems of biomass estimation from traditional bottom trawl surveys for rockfish. The impetus for this project came from previous work which suggests that normal swept-area, bottom trawl surveys for rockfishes may be substantially biased (Leaman and Nagtegaal 1982, 1986; Leaman and Stanley (in prep.)). We believe this is because rockfishes are aggregating species, they are attracted to a limited number of specific bathymetric features, and they have highly dynamic behaviour, both on a diel basis and in response to the survey gear. Our long-term objectives are to describe this behaviour, the physical characteristics of the aggregations at each stage, and to assess whether there is sufficient stability in them to permit or improve estimation of biomass from trawl or acoustic surveys.

This report presents background calibration procedures, methods, and initial results of a cruise on the R/V W.E. RICKER to the northwest coast of Vancouver Island in March, 1990. The objectives of the cruise were to conduct detailed mapping of several representative slope rockfish aggregations, collect echo integration data on the three-dimensional biomass structure of the aggregations, and describe their diel behavioural patterns. We also employed a trawl surveillance sonar to examine the behaviour of rockfish around the mouths of bottom and midwater trawls.

METHODS

HYDROACOUSTIC EQUIPMENT

The R/V W.E. RICKER is equipped with 38 and 50 kHz Simrad echo sounders and a 30 kHz Atlas-Krupp sounder, which doubles as a net sounder. Each of these sounders has a hull mounted transducer with a relatively narrow beam width of ≈10° full width half maximum (FWHM). The Atlas-Krupp uses a 'third wire' when connected to the net transducer. The latter has a wider beam angle (≈25°), necessary for observations around the net. The output displays for these sounders are located on the bridge and are typically used for exploratory work and fishing operations.

Additional acoustic equipment was installed in the vessel's hydroacoustic laboratory. It was used primarily for detailed observations and measurements of fish biomass, distribution and behaviour. This equipment included two independent sets of BioSonics echo sounders/integrators, several IBM-PC compatibles and auxiliary equipment. The acoustic instruments were installed in standard electronic racks. All instruments are powered by a 120 VAC, 60 Hz, uninterruptible supply. The lab also has a remote display from the navigational computer on the bridge. LORAN coordinates, speed, radar image and course are all simultaneously visible.

A Simrad FS 3300 trawl surveillance sonar was leased from Simrad Mesotech Systems Ltd., to evaluate its potential for monitoring the fishing gear and fish behaviour. Two Simrad staff members accompanied the cruise for three days, to set up the trawl sonar and teach scientific staff how to operate it.

BIOSONICS ECHO SOUNDING SYSTEM

Two complete sets of scientific acoustic gear were used for simultaneous measurements, and as insurance against breakdown. The instrumentation consisted of two BioSonics Model 101 echo sounders, two BioSonics Model 111 chart recorders, a BioSonics Model 121 echo integrator, a custom modified BioSonics Model 120 echo integrator/data logger, two AST-286 IBM-PC compatible computers, a PCM/VCR digital audio recording system, a Tektronix oscilloscope and an echo sounder interface unit. Gear for the 'wet end' included a towed body containing a roll and pitch sensor, and either or both of two Simrad 38 kHz ceramic transducers with elliptical beam patterns of 8°x12° FWHM.

One of the Simrad 38 kHz ceramic transducers and the roll and pitch sensor were installed in the towed body. Hydroacoustic equipment in the lab was connected to the towed body via a lab cable, a deck cable and an armoured tow cable. All electrical cable connections were made using waterproof plugs. Either a 60 m or a newer 300 m, 1.27 cm diameter armoured tow cable was used. Each cable contains three shielded, twisted pairs to connect to one or two transducers and the roll and pitch sensor. The armoured cable is torque-balanced and constructed from steel strands laid in two layers over a core of electrical cables. Its three shielded, twisted pairs are especially constructed to block water and increase crushing resistance.

The rockfish of interest are found between 100 and 300 m depth but, with the 60 m cable, the transducer normally flies ≈20 m below the surface. At that depth, the rockfish of interest would be at a range larger than 100 m. With increasing range, the quality of the acoustic signal deteriorates. In particular, there is a diminished signal to noise ratio, as well as poorer horizontal and vertical resolution. A low signal to noise ratio primarily affects primarily the detection of smaller fishes, and is prohibitive if target strengths of single fish are to be estimated. Lack of horizontal resolution will lead to apparent broadening of single fish and schools on the echogram. Narrow schools, in particular, may appear much wider than they really are. Limited vertical resolution results in poor detection of near bottom fish, especially on rough ground. Therefore, to remove as many artifacts from the acoustic data as possible, the transducer and towed body should be lowered to within at least 100 m of the target.

Five methods to fly the towed body at greater depths were considered: increased cable length; attached depressor; slower towing speed; cable fairing; and, a self-depressing towed body. The first three methods were investigated but the last two were rejected for cost reasons. However, a self-depressing towed body would probably be the only satisfactory permanent solution and, ideally, it should be steerable. Such a vehicle could be flown at a range of depths independent of vessel speed. It could also be veered to the side of the vessel to study fish/vessel interactions, or carry an upward-looking transducer to explore the neglected near-surface layers.

In preparation for the cruise, the new 300 m armoured tow cable was rigged and calibrated. Pre-cruise sea trials of this cable with depressors could not be scheduled. Instead, a polypropylene rope of the same length was used to test wing and parallel-vane depressors from the R/V KETA, on February 16, 1990. The wing depressor, ≈0.9x0.3 m, was a trawl door from an Isaacs-Kidde midwater trawl. It was flown in a standard configuration with bridles attached to its leading edge. The parallel-vane depressor consisted of a grid of five horizontal steel strips in a steel frame, ≈0.9x0.9 m. Bridles from its four corners led to a common point, from which it was towed. Both depressors had movable weights and adjustable bridles.

Visual observations on pre-cruise trials were made when the depressor was just below the surface. At greater depths the vessel's scanning sonar was directed towards the depressor and depth was calculated from bearing and range. The performance of the depressor was also judged from the tension and angle of the tow cable.

On the R/V W.E. RICKER, the towed body was deployed by a deck-mounted HIAB crane while cruising at 2-3 kts. A small powered drum on the HIAB was used for the 60 m tow cable. As a temporary measure, the 300 m cable was deployed from the port sweep winch. Once the towed body was in the water and the armoured cable had been paid out, a tow point on the armoured cable was attached via a rubber shock cord to the stern of the vessel. The relationship between towed body depth, stability, and vessel speed was determined without the depressors and under normal operating conditions.

SIMRAD FS 3300 TRAWL SONAR

The Simrad FS 3300 trawl sonar consists of a sonar head, a power supply/amplifier, a signal processor and a colour monitor. Its ceramic 330 kHz transducer has an elliptical beam pattern with ≈1°x20° FWHM. The entire system is powered by 120 VAC, 60 Hz. A time lapse VCR was used to record the sonar display image for later analysis, and a second monitor allowed simultaneous viewing by the scientific staff and the fishing master.

For this cruise, the Atlas-Krupp net sounder transducer was removed from the third wire and the Simrad sonar head was spliced in its place. The Simrad electronics and display were installed in the aft end of the wheelhouse, close to the fishing station. The Simrad and Atlas-Krupp transducer units are of approximately the same size and their headrope attachment is similar. The Simrad sonar head samples in a vertical plane parallel to the net opening, by rotating its transducer about an axis parallel to the longitudinal axis of the trawl. The display shows a vertical slice through the water near the mouth of the net. The entire trawl opening is visible, including headrope and groundrope gear, as well as any heavy lines near the opening, such as the bridles. If the surface or bottom are within range, they are also visible. Individual fish or schools of fish appear in different colours depending on their size and density. The range, scan sector aim, sector size and scan rate are adjustable to optimize the sonar display. There are eight range settings from 10 to 250 m. The displayed sector can be aimed in any direction by 30° steps. Sector sizes of 30, 60, 120, 180 or 360° can be selected. Four scan rates are available with slower rates resulting in higher display resolution.

Additional information is available on the sonar display. Two moveable cursers can be used to measure the distance between objects, or from the transducer to an object. Numeric displays give the depth of the transducer and the water temperature, while two bar graphs indicate their rate of change.

ACOUSTIC SAMPLING METHODS

Transect patterns and survey design

An initial search pattern was executed off northern Vancouver Island to find concentrations of rockfish sufficiently dense to yield useful observations. The search covered ≈20 M along the shelf break, in 1-2 M legs, between the 100 m and 300 m isobaths (Figs. 1-2).

Once adequate concentrations were found, two smaller areas were selected and parallel transects, perpendicular to the depth contours, were laid out to obtain a detailed view (Figs. 3-4). Rockfish generally congregate along specific depth contours, thus a composite picture of the concentrations can be built up from repeated slices. This picture was supplemented by isobathyic transects (Fig. 5), that ran parallel to the major direction of the contour. The variation in school continuity and density that was observed along these transects provided important clues for the correct interpretation of the perpendicular transect data. Echo sounding of the grids was carried out several times over each 24-h period to observe the diel variation in school structure. Particular emphasis was given to crepuscular (dawn and dusk) periods, during which fish distributions change dramatically. Table 1 gives a summary of the transect data.

Data acquisition

Data acquisition and analysis methods used on this cruise were those of Kieser (1983) and Kieser et al. (1987). They employ standard procedures (Burczynski 1982, Clay and Medwin 1977, Forbes and Nakken 1972) and are summarized only briefly here.

The BioSonics echo sounder was initialized to transmit a 0.6 ms, 38 kHz, 1 kW pulse every second. Its time varied gain (TVG) was set to $20 \cdot \log(R) + 2 \cdot \alpha \cdot R$ to compensate for spreading and absorption losses, where R is range and α is the absorption coefficient. Its adjustable gain was set to a level where echoes from exceptionally dense fish schools would saturate the receiver. Thus, most schools and larger single fish, to a range of approximately 200 m, were accurately detected. Range here refers to the distance from the transducer to the object of interest; its depth is given by transducer depth plus range.

An oscilloscope and thermal chart recorder were used to monitor and display the echo. A typical echogram (Fig. 6) shows a substantial concentration of fish at a range of 90 to 220 m and the edge of the continental shelf as prominent features. The lower threshold for the echogram was not set for optimal viewing but to show all signals that were accepted by the echo integrator. Therefore, random noise appears relatively heavy below 200 m but contributes little to the signal, compared with actual schools. A BioSonics echo integrator recorded the echo intensity, hence relative fish density. Echo intensity measurements were obtained for a series of 5, 10 and 20 m range strata, covering most of the range from the transducer to the bottom. An echo integration sequence was completed every 60 pings (1 min), resulting in a fish density estimate for each of the boxes shown in Fig. 6. A digital audio recording system (PCM/VCR) was employed to store the echo and position information for later analysis.

A bottom window and bottom isolation were used to track the bottom (Kieser 1985) and to limit echo integration to ≥5 m above the bottom. This provided reliable bottom tracking and bottom discrimination under most conditions. The measured echo intensities were sent in RS232 format from the integrator to an IBM-PC compatible computer. For some measurements, both BioSonics echo sounders were operated simultaneously, one connected to the ship's hull-mounted 38 kHz transducer and the other to the transducer in the towed body. The sounders were triggered at the same time and their outputs were recorded by two chart recorders. Charts were synchronized by manual event marks. No interference between the two systems was apparent on the echograms. The 300 m armoured cable was used to obtain acceptable separation between the transducers.

Data analysis methods

Prior to the cruise, both echo sounding systems, cables, and transducers were calibrated at the University of Washington, Seattle. The echo integration equation, important instrument settings and calibration constants are given in Appendix Tables A1-A2. In addition to the echograms, echo integration data files, and magnetic tapes, precise paper and electronic records of all important events (instrument settings, start of transects or series, etc) were kept. The electronic record is referred to as the 'event' file.

The hydroacoustic data are collected to provide estimates of bottom depth, average fish depth, fish volume density, surface density, biomass, and distribution. However, extensive calculations with custom software are required to transform these data into a useful format, and to the desired estimates. The results from these calculations can be printed, plotted, or written to ASCII files for subsequent analysis. Standard printed output includes local and global fish volume, surface density, average fish depth, and biomass estimates. Transect patterns and biomass distribution plots are also available. Plots normally produced include volume density versus depth and surface density, and biomass centroid versus distance off bottom.

During the analysis, the echo integrator output is scaled by a system calibration constant and an assumed fish target strength (TS) of -32.0 dB/kg, to yield an estimate of the fish density (kg/m^3) for the insonified volume. This estimate is converted to surface density (kg/m^2) by summing over all range strata of interest. Surface density is then multiplied by the appropriate surface area to obtain a biomass estimate (kg).

TRAWL AND BIOLOGICAL SAMPLING METHODS

Trawl sampling

Trawl hauls were conducted to verify the species composition of the hydroacoustic targets and for testing the Simrad FS 3300. Catch rates were not used for calibrating biomass estimates. The Nor'Eastern bottom trawl (Fig. 7) was deployed from the two forward sweep winches. The Diamond 5 midwater trawl (Fig. 8) was deployed from the midships net drum.

As all catches were less than 1000 kg, catch composition was estimated directly, by sorting and weighing the catch of each species. Selected rockfish species were sampled for length and sex (Tables 2-5), after Nagtegaal et al. (1986).

Oceanographic sampling

Five sampling stations were occupied for the Cooperative Plankton Research Program of the Biological Sciences Branch. These followed the methods and included the stations F1-F2 and E1-E3 of Shaw (1988). Each site included a CTD cast and an oblique plankton tow with 1.0 m bongo net.

RESULTS

TRANSDUCER DEPTH STUDIES

Depressors

Both the parallel vane and the midwater wing depressors were stable and performed well. However, the parallel vane depressor exerted a much larger downward force, which will be important when it is used to pull the towed body to depth. Depth of the parallel vane depressor increased non-linearly with tow line length due to the catenary assumed by the line, in response to weight and water pressure (Fig. 9). Vessel speeds ranged between 2.5 and 6 kts but had little effect on depth. At 2.5 kts the drag force was $\approx$100 kg, and increased rapidly with speed. It is possible that the catenary assumed by the polypropylene line will be somewhat exaggerated, compared with the armoured cable under similar circumstances, due to the former's greater diameter.

Based on these tests, it appears that the parallel vane depressor will fly at approximately 100 m depth, with the 300 m armoured cable, at normal sounding speeds (9 kts). Further trials are needed to develop an appropriate rigging for the parallel vane/towed body system, to ensure that the towed body will remain stable under the influence of the depressor wash.

Reduced Vessel Speed

On March 17th a series of tests was conducted with the towed body and the two armoured cables, to determine what depth could be obtained at reduced vessel speeds. The depressor was not used for these tests.

With the 60 m cable and normal sounding speed (9 kts), the towed body flew at a depth of ≈20 m. With the 300 m cable, a depth of ≈30 m was obtained at the same speed. At lower vessel speeds, and using the longer cable, the towed body flew at much greater depths. A maximum depth of 120 m was obtained, at 2.5 kts. However, the echogram and the roll and pitch sensor in the towed body showed decreasing stability of the body with decreasing speed (Figure 10). Thus, reduction to <3 kts cannot be used to lower the transducer unless a mechanism to stabilize the transducer is found. The minimum speed at which acceptable stability was maintained was ≈3.5 kts, corresponding to a towed body depth of ≈80 m.

Loss of stability at low speeds may arise from two sources. First, reduced flow of water over control surfaces on the towed body may allow more pitch and roll in its movement. Second, as the vessel slows the tow cable angle becomes steeper and the catenary decreases, which may result in a greater transfer of the ship's motion to the towed body. Deployment of the towed body to a depth of 100 m or more, while moving at speed adequate to maintain stability, may require the use of a depressor.

CONCURRENT SAMPLING WITH TWO ACOUSTIC SYSTEMS

It is generally assumed that the survey vessel does not significantly disturb the fish. Acoustic observations have shown that this is not always the case, in particular when the survey vessel is trawling or when deck lights are used at night (Olsen et al. 1983). Information on the potential vessel/fish interaction can be obtained by simultaneously sampling with a hull mounted and a towed transducer.

The technical feasibility of this sampling mode was explored on March 19, between 0500-0808 (events 213-244), while running the southern grid series. The first echo sounder was configured in its usual way, with the 60 m cable and towed body, and the second sounder was connected to the hull-mounted

38 kHz transducer. Very similar echograms were obtained and no interference between the two echo sounders was observed. This lack of interference will allow us to use this method to study fish vessel interactions on future cruises.

FISH DISTRIBUTION AND BEHAVIOUR

Two aggregations of rockfishes suitable for the study were found off the Kains Is.-Quatsino Sound area during the initial, broad trackline search. They extended from approximately 180-240 m depth and tended to be oriented isobathyically. More detailed 0.2 M rectangular grids, as well as isobathyic tracklines at ≈50 m intervals, were mapped around these aggregations. These latter tracklines allow higher bathymetric resolution across transects. Both the northern and southern aggregations extended ≈1.4 M along the shelf break but the southern aggregation occupied a much broader horizontal distance across the continental shelf (≈1.1 M vs. 2.2 M).

Identification of the species responsible for the acoustic sign was difficult because bottom trawling could not be conducted directly on the hard bottom of the grid sites. However, midwater trawling on elements of the aggregations extending into the midwater off the shelf obtained species composition samples similar to those of commercial vessels fishing coincidentally in the area, with bottom trawls. The species composition was approximately 60% S. entomelas, 30% S. proriger, 10% S. reedi (Appendix Table A3). Given the depth range involved (<240 m) and acoustic observations of the sign extending isobathyically off the edge into the midwater, where it was sampled with the midwater trawl, we believe that our samples are representative of the fish observed acoustically in the grid transects.

There were notable differences in the distribution of fish at the two sites. The bathymetry was steeper and relief higher on the northern grid, resulting in ≈50% shorter trackline lengths than those for the southern grid (Figs. 3-4). Since rockfish species have characteristic bathymetric ranges (Nagtegaal 1983, Leaman and Nagtegaal 1982), fish density at this northern grid was much higher (Figs. 11-12). Fish at the latter site occurred in more isolated and smaller schools. The acoustic data from these tracklines will be analyzed in a future report, with major emphasis on the determination of total biomass associated with the nocturnal and diurnal school structures. However, we present here a preliminary description of diel distribution and behaviour.

Diurnal distribution

Fish in the northern grid were distributed diurnally in a relatively continuous series of schools, extending 0-30 m off bottom at ≈190-210 m depths, and extending isobathyically off the shelf break, in a 25-40 m layer of similar clumps (Fig. 11). However, most of the sign assumed to be rockfishes occurred within 30 m of the bottom during daylight hours. There also were herring-like columnar schools extending 75-125 m off bottom, typically at the shallow edge of the shelf break. Very little sign of fish in deeper water (>250 m) was found.

On the southern grid, fish schools were much more isolated diurnally than on the northern grid (Fig. 12). The broader horizontal area of the characteristic depth ranges for these species was associated with inter-school distances 5-10 times greater than those to the north. However, vertical distribution of schools at the two grids was similar.

Nocturnal distribution

The two grids displayed greater differences in nocturnal patterns than were observed diurnally. In both areas, but particularly in the northern grid, the horizontal distribution across the shelf and the bathymetric distribution increased twofold nocturnally (Fig. 13-14). This increase was associated with a disaggregation of the diurnal schools, rather than an increase of inter-school distance and similar school sizes. At the northern grid, the nocturnal distribution was characterized by a broad, continuous layer 0-30 m off bottom, and much denser isolated schools 20-60 m off bottom (Fig. 13). In addition, there was a more diffuse continuous layer in 250-280 m extending over deeper water to the seaward edge of the shelf.

The southern grid showed a layer of isolated schools, 100-130 m off bottom, overlaying a continuous but less dense underlayer, over 190-210 m bottom depth (Fig. 14). In addition, we observed a relatively uniform layer, 20-30 m thick and 0-20 m off bottom, in 210-240 m depth. This layer also extended isobathyically off the edge, up to 1.5 M out, although more commonly it was ≤0.25 M off the edge. A much less dense layer at 250-280 m was also seen and interpreted as plankton, based on the lack of discrete targets. The herring-like columnar schools, high in the water column, were less commonly observed at this site.

Transitional behaviour

The general transition from diurnal to nocturnal patterns was one of disaggregation and rising in the water column. However there were specific features at each of the grids. At the northern grid, the typical diurnal bottom layer disaggregated and exposed more distinct schools, which initiated the vertical movements. These dense schools rose into the midwater very quickly (2-3 m/min) and remained relatively distinct throughout the night. These fish eventually established themselves at approximately 100 m depth, over 200-250 m. A second, much more diffuse, group initiated vertical movement within 1-5 min of the first group. Fish in this second group could be resolved individually and formed a broad layer 20-30 m deep, at a depth ≈20 m under the first group. What appeared to be the bulk of the biomass seen diurnally simply disaggregated and formed a broad band 2-10 m off bottom and expanded to cover a bathymetric range of approximately 60 m (Fig. 13).

At the southern grid, there was a two-stage disaggregation process. The first stage was similar to that at the northern grid, i.e. a disaggregation exposing distinct schools, followed by vertical movement of these schools. However, at this site the distinct schools which rose in the water column also disaggregated, to form a broad layer of individual fish targets 80-100 m off bottom, over a denser but more diffuse bottom layer (Fig. 15).

The nocturnal to diurnal transition happened in approximately reverse order at both sites. It occurred over a 30 min period, from the first indication of downward movement, to complete aggregation on the bottom. The faint middle layer, at least, went through some aggregation prior to major descent. The overall process began at what was perceived, by the human eye, to be first light. While it was completed within the 30 min period on clear days, heavily overcast and foggy days doubled the time for the transition. It appears that illuminance plays a key role in triggering these activities.

Echo integrator

The echogram provides good qualitative information on fish distributions, their depth in relation to the bottom, school shapes and other characteristics. A weak, but persistent surface echo appeared between 15 and 25 m (Fig. 6), this was easily excluded as the rockfish were at 90 to 240 m range. The echogram results are complemented by the results from the echo integrator. Figure 16 gives a plot of surface density, biomass centroid and range to the bottom for the sample echogram in Fig. 6. The range clearly shows the edge of the continental shelf. Several strong fish schools appear as spikes in the surface density trace, and can be compared to the echogram. The biomass centroid gives the mean range for the fish in the water column. Plots of this kind allow us to study, for example, differences in diurnal and nocturnal distributions, where schools are equally dark on the echogram but densities actually change between day and night.

'Porcupine' plots provide another way to visualize the acoustic data. Figure 17 displays fish surface density along transects 20-27, during the first diurnal exposure of the northern grid. The uprights give surface density values from 0.001 to 0.1 kg/m^2, on a logarithmic scale. The corresponding nocturnal survey yielded quite a different picture (Fig. 18). Surface densities were considerably higher, many of them exceeding 0.1 kg/m^2, especially on transect 27. In part, these results reflect the scale of measurement relative to aggregation size, and the fact that the diurnal distribution is highly aggregated. For example, the resolution of our echo integration data is one min of sounding distance (≈280 m) by 10 or 20 m depth intervals. Therefore, school density can be measured accurately only for large, uniform aggregations. The plots become more meaningful when the contours are included and when data for an entire 24-hour period or longer are compared.

Observations with the Mesotech/Simrad FS 3300 trawl surveillance sonar

We used the sonar on both the midwater and bottom trawls and recorded the output on VHS videotape. On the midwater trawl, the sonar permits determination of whether fish are going above, below, or to the sides of the net, and adjustment of fishing depth and direction accordingly. When fishing for rockfishes, there did not appear to be any bias in the distribution of the fish as they entered the net. While not distributed uniformly on any encounter, there was no bias in where the individual clumps entered the net on different encounters. When fish were chased to the bottom they could be seen escaping to the sides of the net as the bottom approached.

With the bottom trawl, fish entered in the bottom half of the net. Time limitations prevented trawling on several different size schools, to ascertain whether fish escaped to the sides of the trawl. None were noted, but bottom interference may have precluded seeing small numbers. We saw no fish escaping over the top of the net, when fish were seen entering the net. These observations conform with inferences drawn from previous behavioural observations. We did not encounter a very large school of fish (several times the vertical mouth opening of 7-8 m). A school that size would permit examination of the theory that demersal slope rockfishes move hard to bottom as the trawl approaches.

BIOLOGICAL SAMPLING

Seven tows were completed during the cruise (Appendix Table A3). The first tow was conducted in Quatsino Sound to test the functioning of the Simrad FS 3300. Three midwater tows on the northern sounding grid and one bottom tow on the southern grid were conducted (Fig. 1). Two bottom tows were also conducted on aggregations of *Sebastes alutus* in Queen Charlotte Sound. Tows 1, 3-4, and 5-6 included use of the FS 3300. Catch rates for both midwater and bottom trawl tows were generally <1500 kg/h.

Samples of S. entomelas, S. proriger, and S. reedi, were taken from haul 2 (midwater trawl) (Tables 2-5). A sample of S. alutus was collected from haul 6, (bottom trawl) (Fig. 19). Length frequencies (Table 2) approximated those observed in other research cruises and in commercial catches (Shaw and Archibald 1981). The S. alutus sample was 95% male, reflecting the spatial segregation of the sexes during the early spring period of parturition. Females do not generally return to the inside of Queen Charlotte Sound, from their migration to deep water spawning grounds, until late May or early June (Leaman 1985). The S. entomelas catch of tow 4 appeared to be based on a spawning aggregation (Table 3). The catch was ≈80% female, most of which were ready to release larvae. Conversely, the smaller sample of S. entomelas in haul 2 had equal proportions of males and females. S. proriger sampled off Quatsino Sd. (Table 4) exhibited the strong sexual dimorphism in size, common to this species (Leaman 1988).

ACKNOWLEDGEMENTS

We are grateful to Capt. Al Ranger and the crew of the R/V W.E. RICKER for their cooperation and assistance during the cruise. We also thank Bob Hungar (Pacific Biological Station), who instructed us in the use of the parallel vane depressor and skippered the R/V KETA during the depressor trials.

Jim Galloway and Jim Parks (Institute of Ocean Sciences, Victoria) designed and constructed an improved interface for the PCM/VCR digital audio recording system that extended its usefulness to multichannel and RS232 digital data recording, and we thank them for those efforts. We also acknowledge the assistance of Graham Gillespie in the processing of the trawl and biological sampling data.

Finally, we thank Don Chase and Steve Chelton of Simrad Mesotech Systems Ltd. for their patient instruction and assistance in the use if the FS 3300 trawl surveillance sonar.

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Table 1. Details of initial search transects and those for the northern and southern grids. Event numbers, identifying significant features, times and changes, are unique across transects.

Transect	Date	Time	Events		Comment
Initial search pattern:					
1 10	16	12:15	7	47	Initial search, northern area
ISO	16	19:31	47	52	Isobath
DEPTH	17	14:25	65.5		Towed body depth vs speed, 300 m cable
Northern grid:					
20 27	17	16:10	72	92	Small area, day distribution
27 20	17	18:20	93	107.5	Small area, day/night
20 27	17	20:12	108	127	Small area, night
20 27	18	4:58	129	144	"
27 20	18	7:42	146	161	" , night/day
30 32	18	9:35	165	173	Isobath
20 27	18	20:12	178	194	Small area, night
27 20	18	22:01	195	210	"
20 27	19	05:00	213	229	"
27 20	19	06:37	230	246	" , day
30 32	19	08:32	246	257	Isobath
- -	19	09:53	258	265	Noise test
- 35	19	16:44	268	287	Transect N to S, night
Southern grid:					
40 47	20	05:12	289	304	Small area, day
47 40	20	08:16	305	319.5	"
40 47	20	11:17	321	336	"
40 47	20	17:49	338	357	" , night
47 40	20	21:03	358	372	"

Table 2. Summary of length frequency, by sex, for *Sebastes alutus* collected aboard the R/V W.E. RICKER, March 14-23, 1990.

Area	Cape Scott	
Date (DDMMYY)	210390	
Depth (m)	242	
Set	6	
Length (cm)	M	F
18	-	-
19	-	1
20	1	0
21	0	0
22	0	0
23	1	0
24	0	0
25	0	1
26	2	1
27	1	2
28	0	3
29	0	0
30	0	0
31	0	0
32	1	0
33	0	0
34	2	0
35	3	0
36	8	0
37	2	0
38	29	0
39	29	1
40	23	-
41	38	-
42	11	-
43	4	-
44	-	-
Total	155	9

Table 3. Summary of length frequency, by sex, for _Sebastes entomelas_ collected aboard the R/V W.E. RICKER, March 14-23, 1990.

Area	Quatsino		Quatsino		Total	
Date (DDMMYY)	180390		190390			
Depth (m)	200		200			
Set	2		4			
Length (cm)	M	F	M	F	M	F
36	-	-	-	-	-	-
37	1	1	1	1	2	2
38	1	0	0	0	1	0
39	1	3	0	1	1	4
40	2	1	0	2	2	3
41	2	1	0	2	2	3
42	7	1	0	1	7	2
43	4	1	1	5	5	6
44	2	2	0	7	2	9
45	2	4	1	4	3	8
46	2	1	-	5	2	6
47	5	2	-	12	5	14
48	1	0	-	12	1	12
49	0	3	-	14	0	17
50	1	5	-	13	1	18
51	-	3	-	6	-	9
52	-	0	-	2	-	2
53	-	1	-	2	-	3
54	-	0	-	1	-	1
55	-	0	-	-	-	0
56	-	1	-	-	-	1
57	-	-	-	-	-	-
Total	31	30	3	90	34	120

Table 4. Summary of length frequency, by sex, for Sebastes proriger collected aboard the R/V W.E. RICKER, March 14-23, 1990.

Area	Quatsino	
Date (DDMMYY)	180390	
Depth (m)	200	
Set	2	
Length (cm)	M	F
27	-	-
28	1	1
29	3	0
30	7	0
31	11	0
32	4	1
33	12	2
34	2	4
35	-	6
36	-	7
37	-	21
38	-	23
39	-	21
40	-	10
41	-	6
42	-	2
43	-	-
Total	40	104

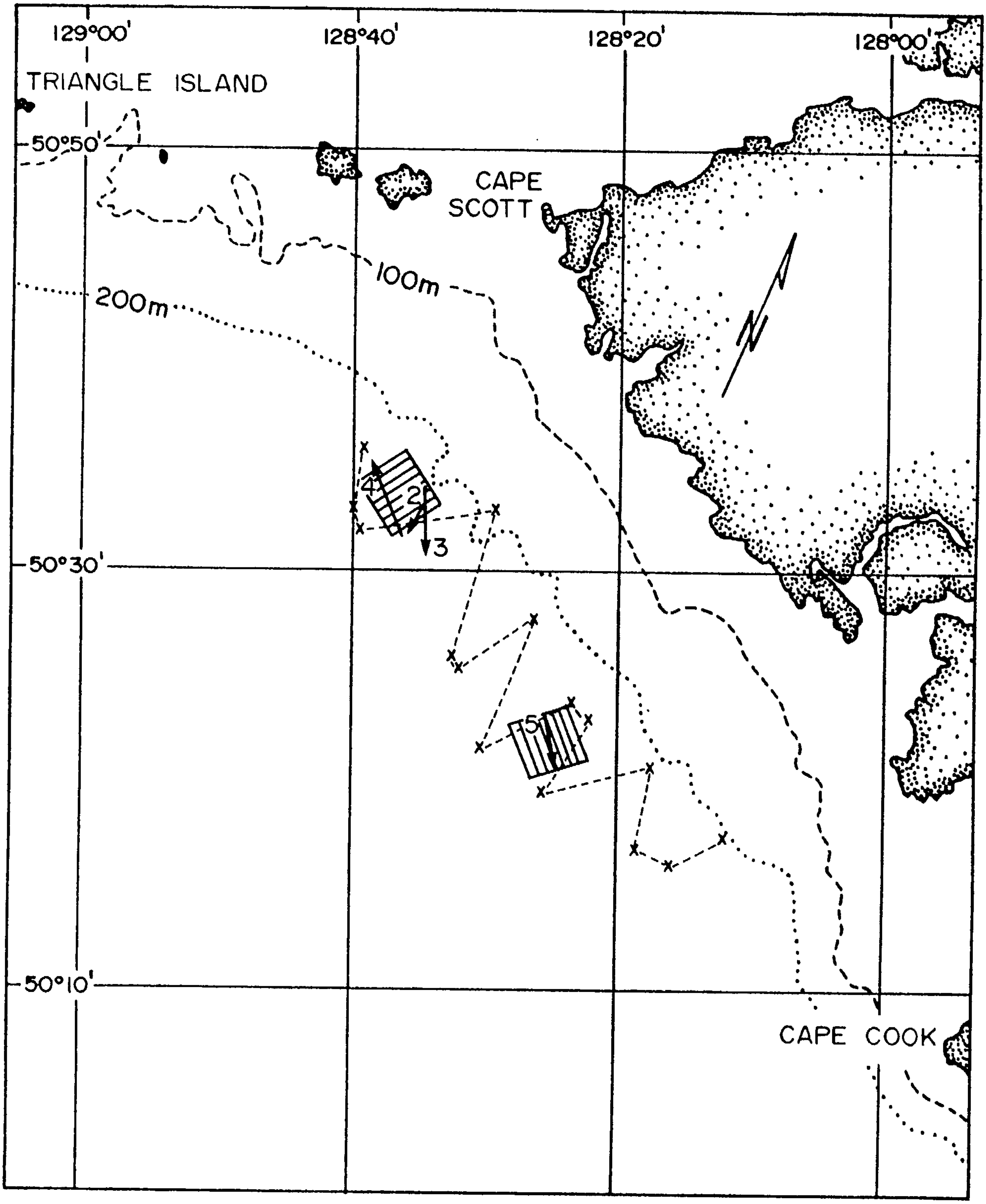


Fig. 1. Northwest coast of Vancouver Island showing initial search track (dashed line), the northern and southern grids of detailed investigation, and tow locations for hauls 2-5. R/V W.E. RICKER hydracoustic cruise, March 14-24, 1990.

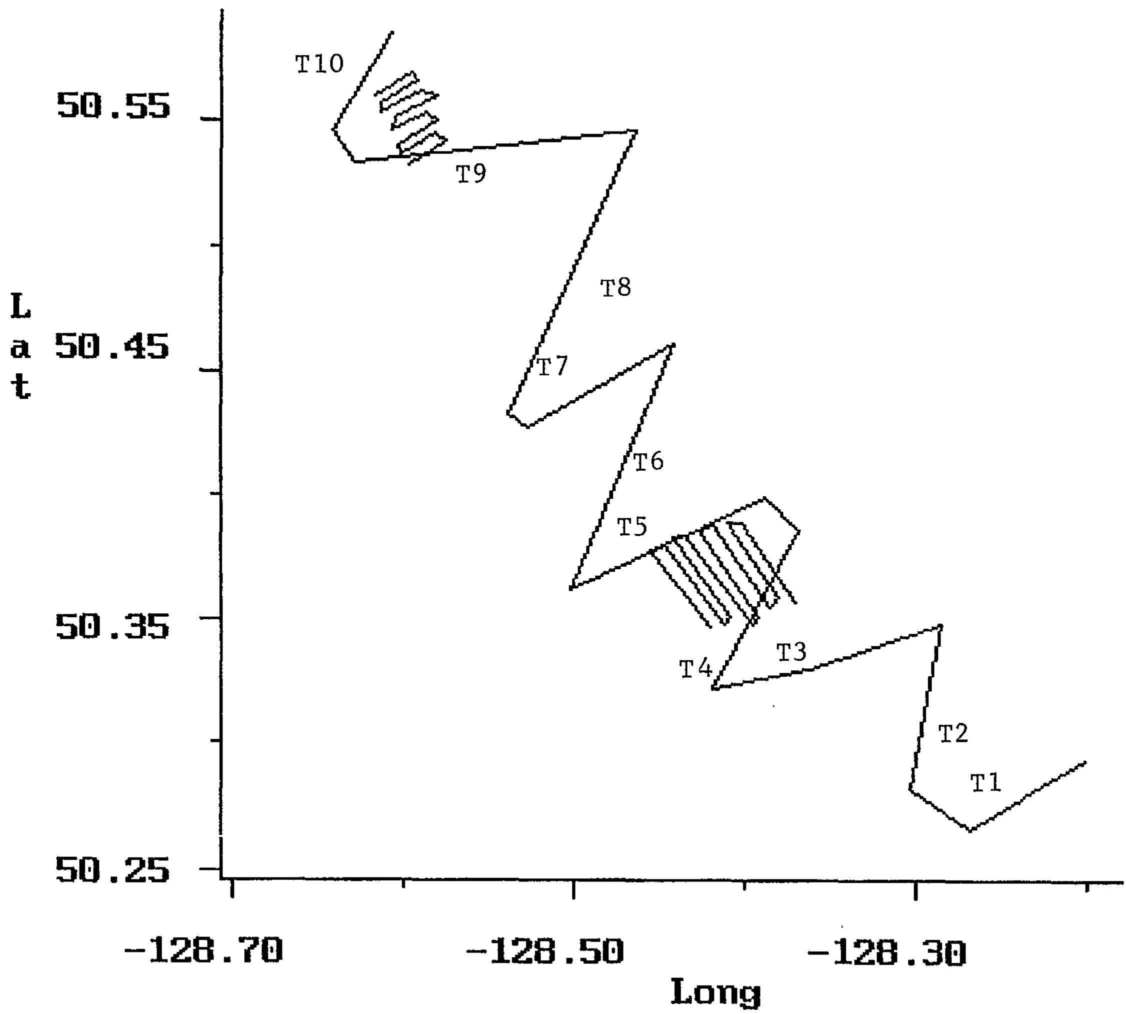


Fig. 2. Transects 1-10 for the initial search pattern and typical parallel transects for the southern and northern grids off Quatsino Sound.

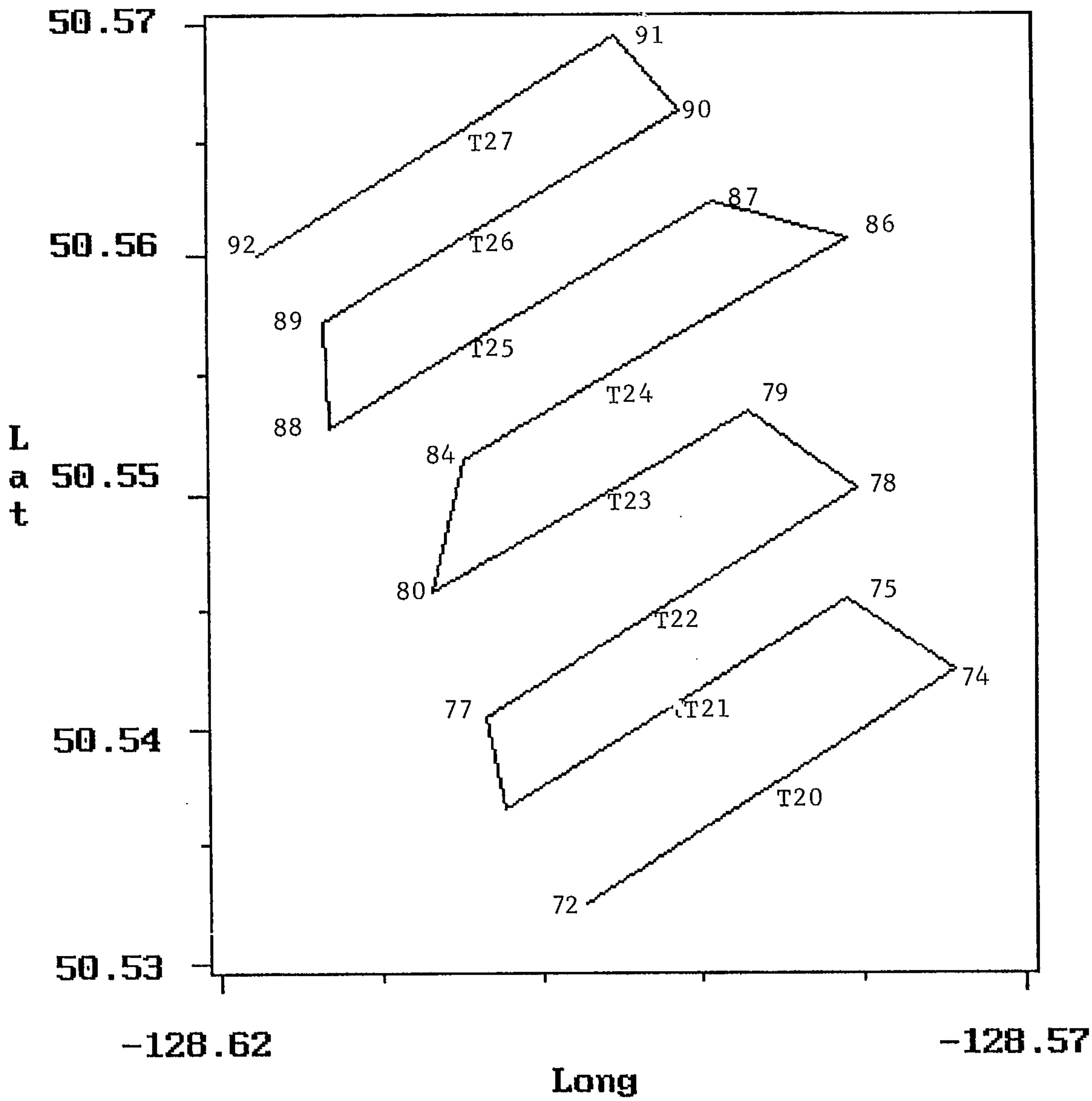


Figure 3.

Fig. 3. Parallel transects, 20-27, for the northern grid. Transect length ≈ 1 M, width ≈ 0.2 M. Event numbers mark transect end points.

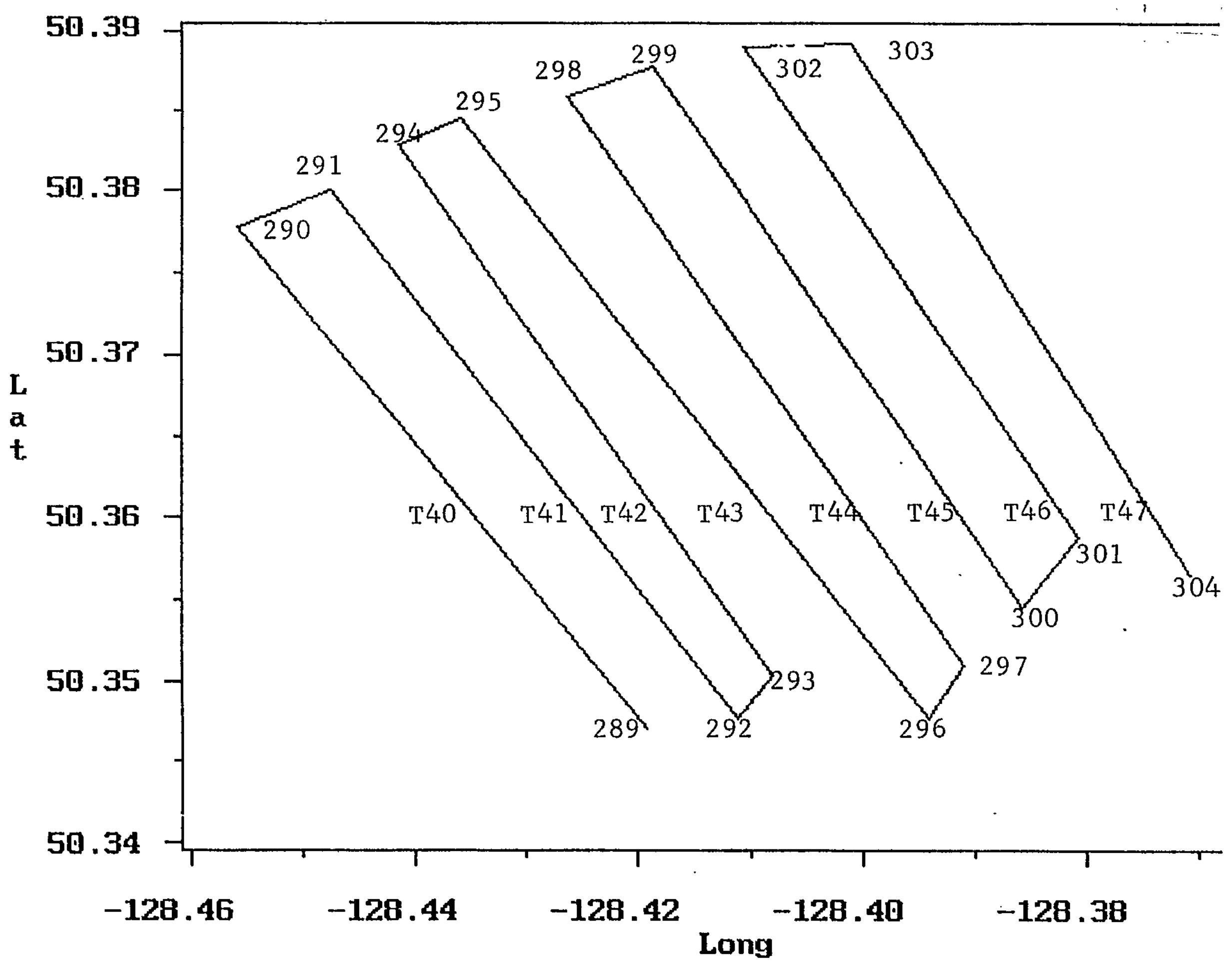


Fig. 4. Parallel transects, 40-47, for the southern grid. Transect length ≈2M, width ≈0.2M.

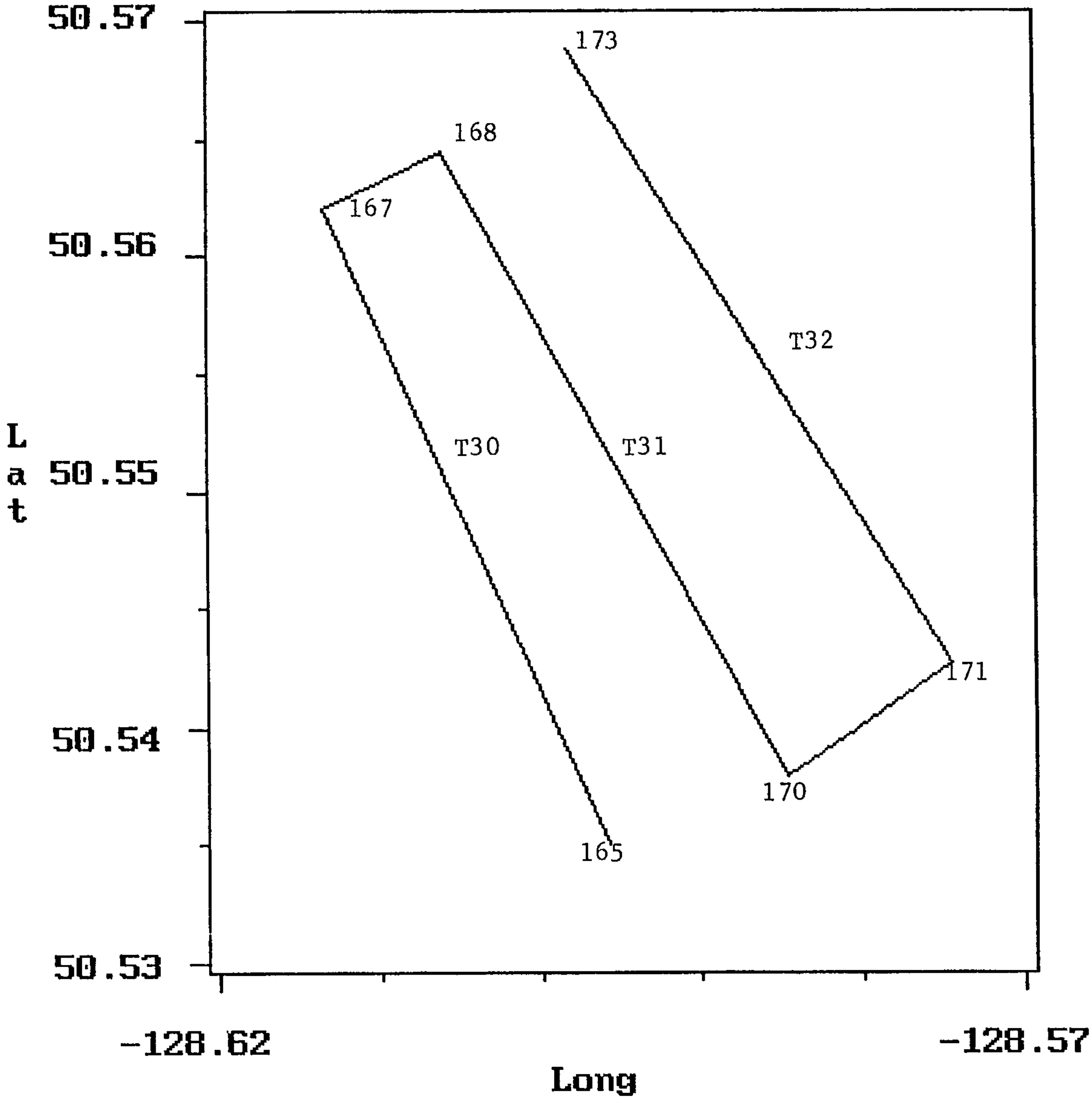


Fig. 5. Parallel transects, 30-32, along isobathyic contours, for the northern grid.

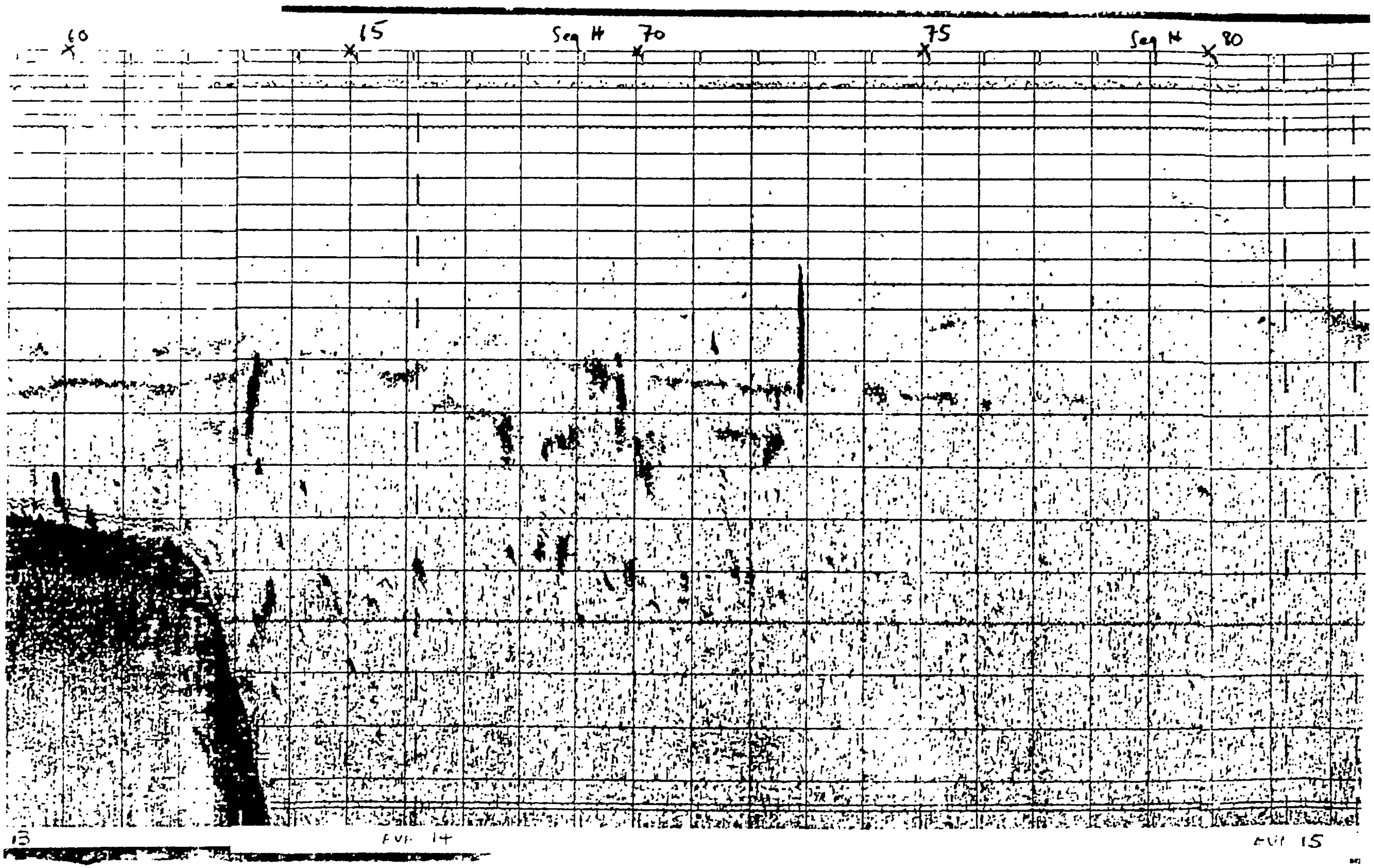


Fig. 6. Typical echogram recorded March 16, 1990, events 13-17, range 0-300 m. Range mark intervals are 5, 10 or 20 m. Note edge of the continental shelf at left, dense fish schools and second bottom echo at right.

Fig. 7. Details and dimensions of Nor'Eastern 105 bottom trawl used for sampling and verifying acoustic sign.

NET DIMENSIONS AND CHARACTERISTICS FOR BOTTOM TRAWL

VESSEL W. E. Ricker NET Nor'Eastern

OBSERVATION PERIOD March 14-23, 1990

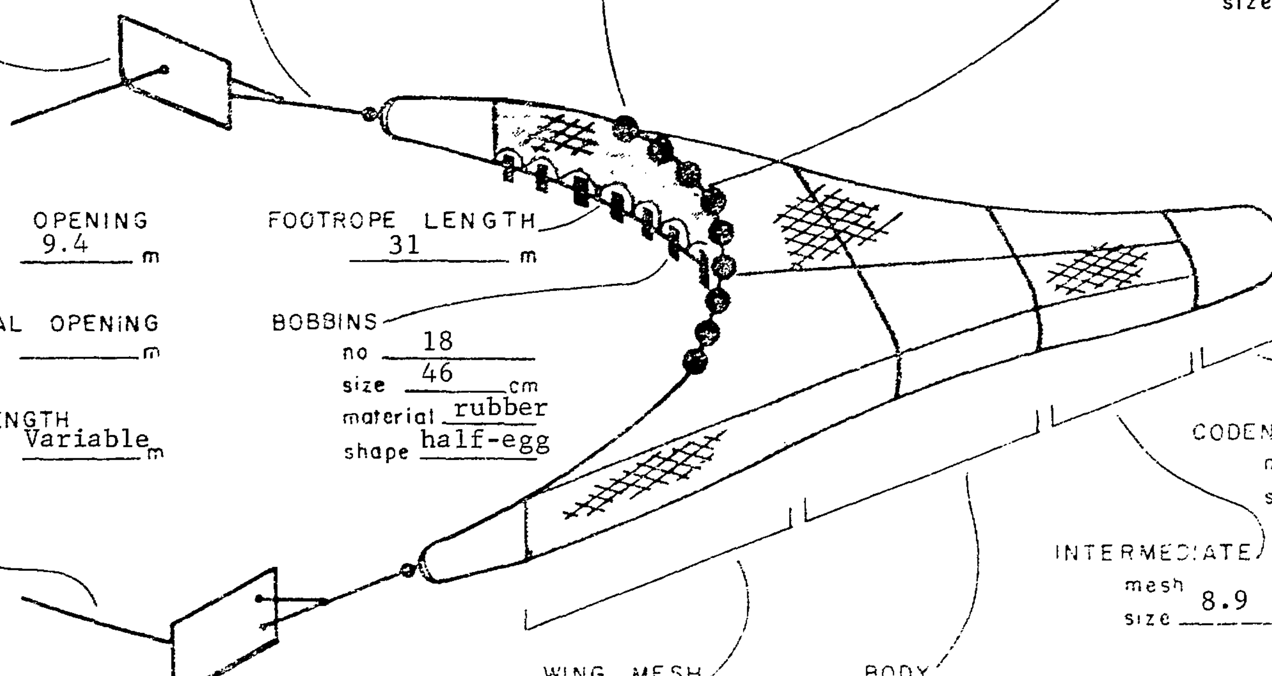
TRAWL DOORS
shape Oval
type Polyvalent
dimensions
____ m.x ____ m
weight 1000 kg

BRIDLE/SWEEPLINE
length 40 m

FLOATS
number ____
size 30 cm
material plastic
shape sphere

HEADROPE LENGTH
27 m

CODEND LINER
mesh size ____ cm



VERTICAL OPENING
9.4 m

HORIZONTAL OPENING
____ m

WARP LENGTH
Variable m

FOOTROPE LENGTH
31 m

BOBBINS
no 18
size 46 cm
material rubber
shape half-egg

CODEND
mesh size 8.9 cm

INTERMEDIATE
mesh size 8.9 cm

WING MESH
mesh size 8.9 cm

BODY
mesh size 8.9 cm

Fig. 8. Details and dimensions of Diamond V midwater trawl used for sampling and verifying acoustic sign.

NET DIMENSIONS AND CHARACTERISTICS FOR MIDWATER TRAWL

VESSEL NAME W. E. RICKER   VESSEL TYPE Stern trawler   OBSERVATION PERIOD March 18-23, 1990

TRAWL DOORS

Shape Square
Type Süberkrub
Dimensions
4 m x 4 m.
Weight ____ kg.

SWEEPLINE / DANDYLINE

Length 55 m.

FLOATS

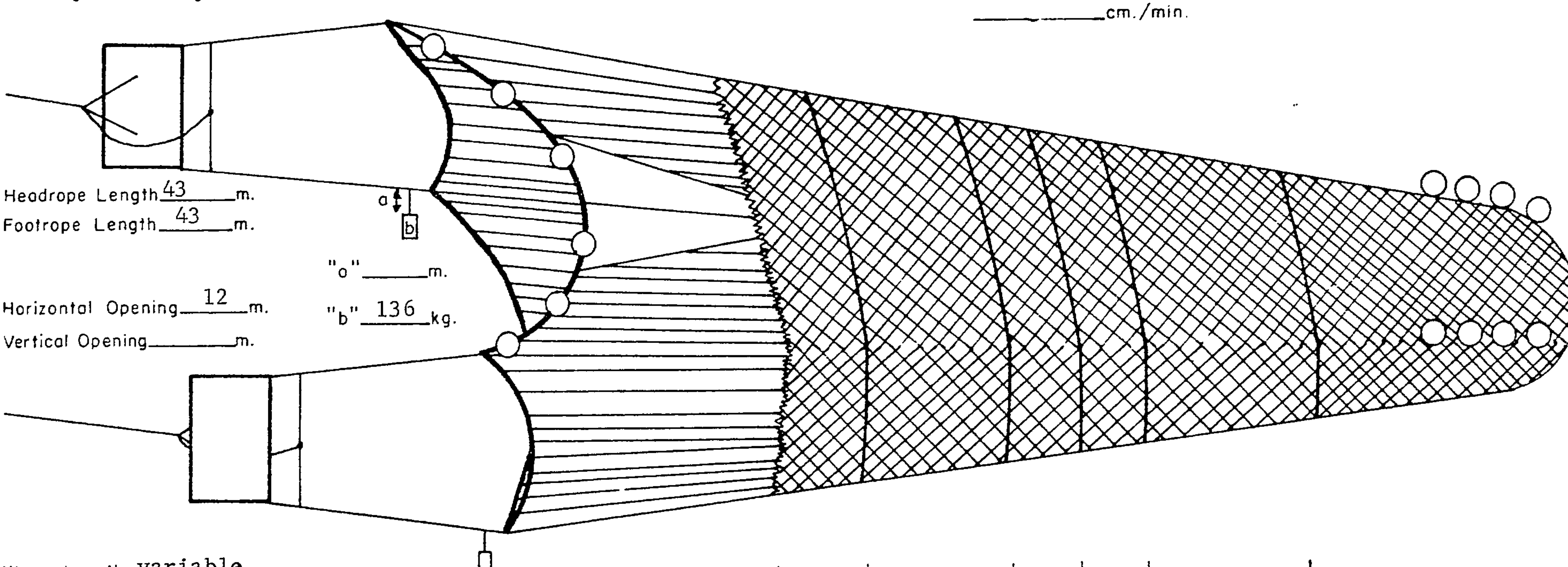
Number 8
Size 20 cm.
Shape sphere
Material plastic

FISH FINDER

Name See text
Model No. ____
Frequency ____ kc.
Paper Type (wet or dry)
Speed of Advance
____ cm./min.

NET RECORDER

Name ____
Model No. ____
Frequency ____ kc.



Headrope Length 43 m.
Footrope Length 43 m.

"a" ____ m.
"b" 136 kg.

Horizontal Opening 12 m.
Vertical Opening ____ m.

35

Warp Length variable

Length ____ m. | ____ m. | ____ m. | ____ m. | ____ m. | ____ m. | ____ m.

MESH SIZE 56 cm. 56 cm. 41 cm. 20 cm. 12 cm. 4 cm. 4 cm.

WINGS

(mesh or line) Mesh
Mesh Size 56 cm.
Line Spacing ____ cm.
Line Thickness ____ cm.
Material nylon
Height of Wings 40 m.

Mesh Material
nylon

CODEND

(floats or weights)
Number none
Size ____ cm.
Weight ____ kg.
Material ____
Shape ____

Canadian Diamond 5

Fig. 9. Relationship between the depth of the parallel vane depressor and towline length. Observed depth is independent of vessel speed.

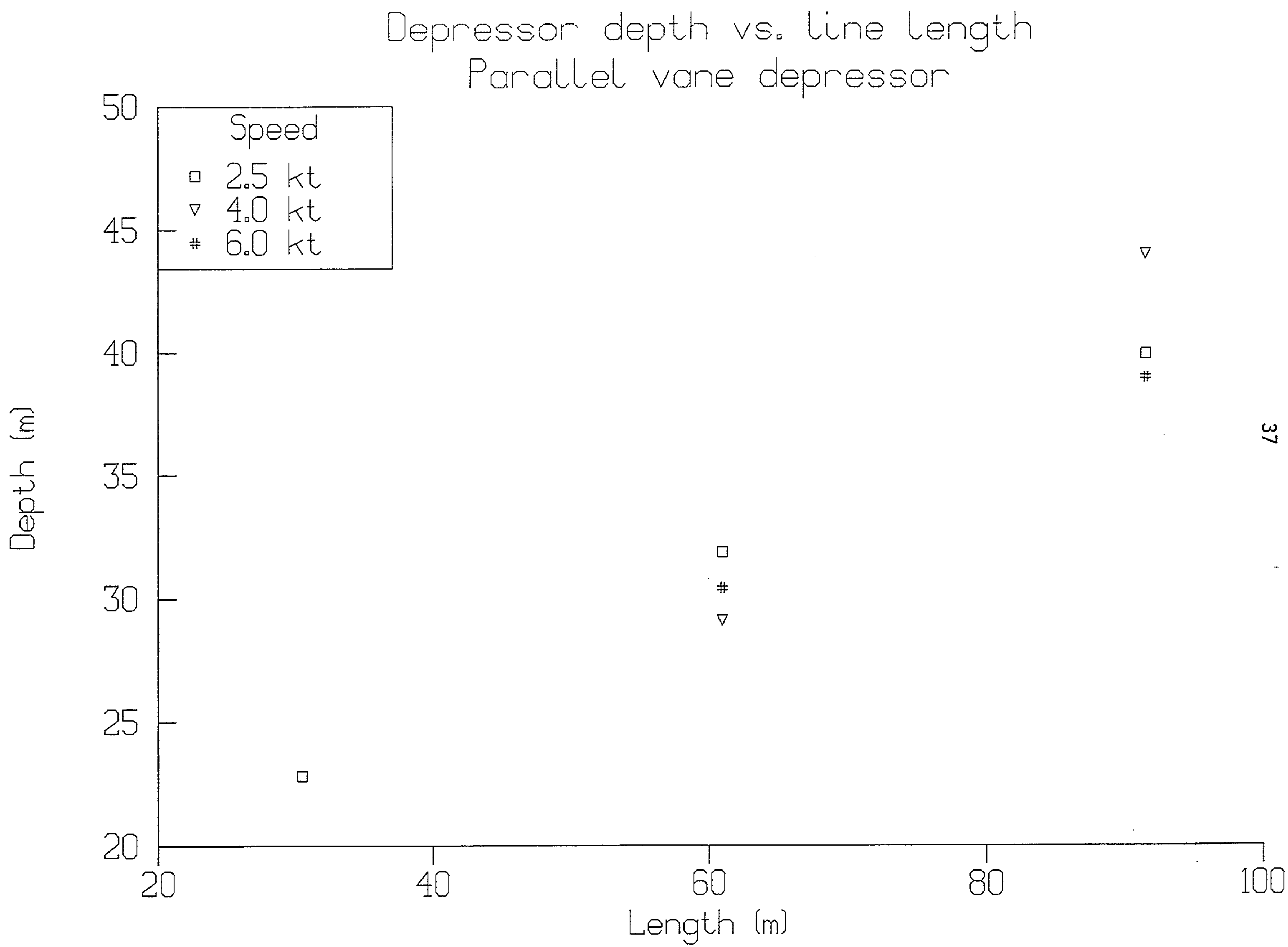
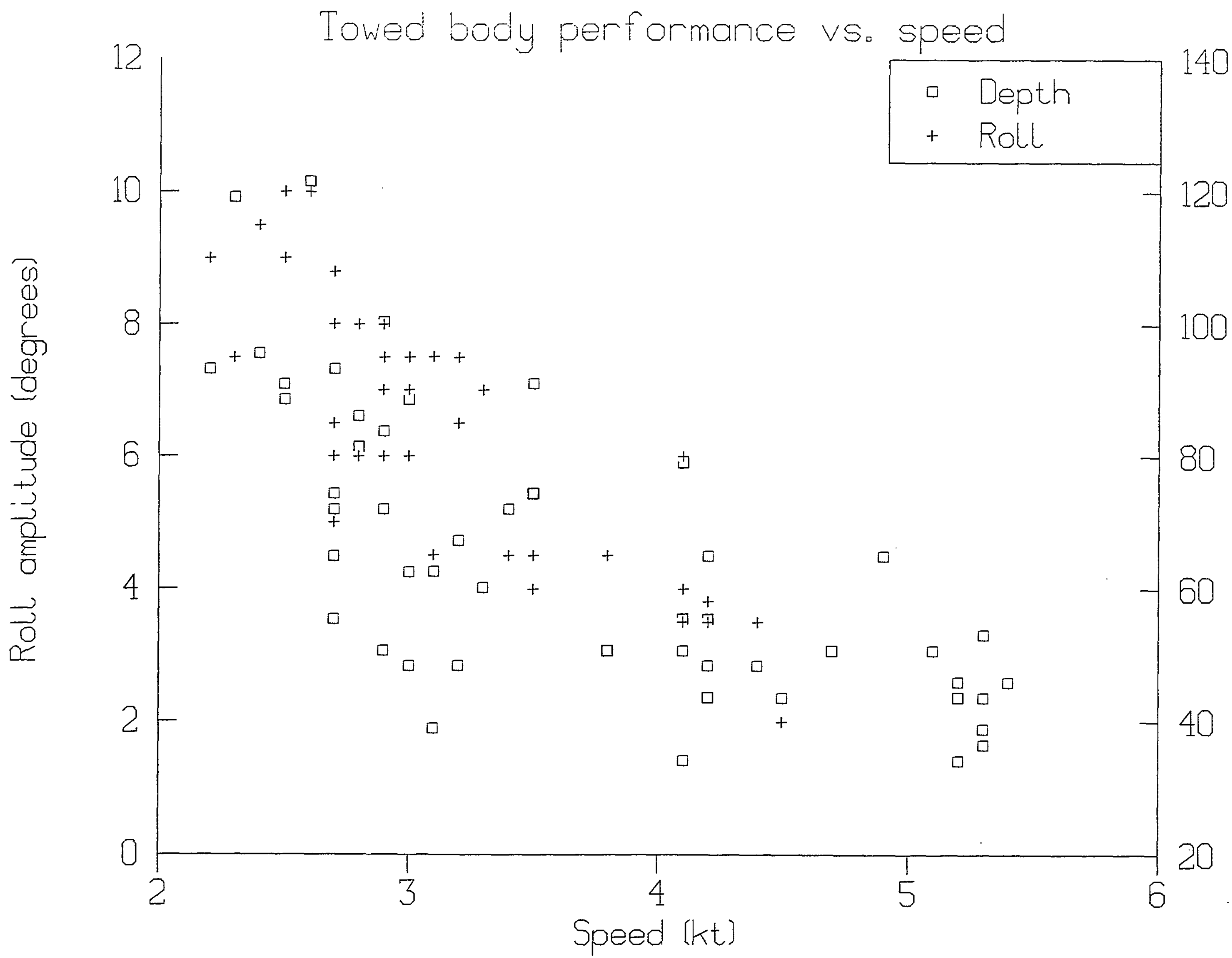

Depressor depth vs. line length
Parallel vane depressor
Speed
2.5 kt
4.0 kt
6.0 kt
Depth (m)
Length (m)
50
45
40
35
30
25
20
20
40
60
80
100

Fig. 10. Towed body depth and roll amplitude versus vessel speed, using the 300 m armoured cable. The echogram deteriorates significantly when the roll amplitude exceeds ≈5°, which is half of the transducer beam width.



Towed body performance vs. speed
Depth
Roll
Roll amplitude (degrees)
Depth (m)
Speed (kt)
0
2
4
6
8
10
12
20
40
60
80
100
120
140
2
3
4
5
6

Fig. 11. Typical diurnal fish distribution at the northern grid, showing dense on-bottom schools and high relief of the bottom (18/3/90, 08:00).

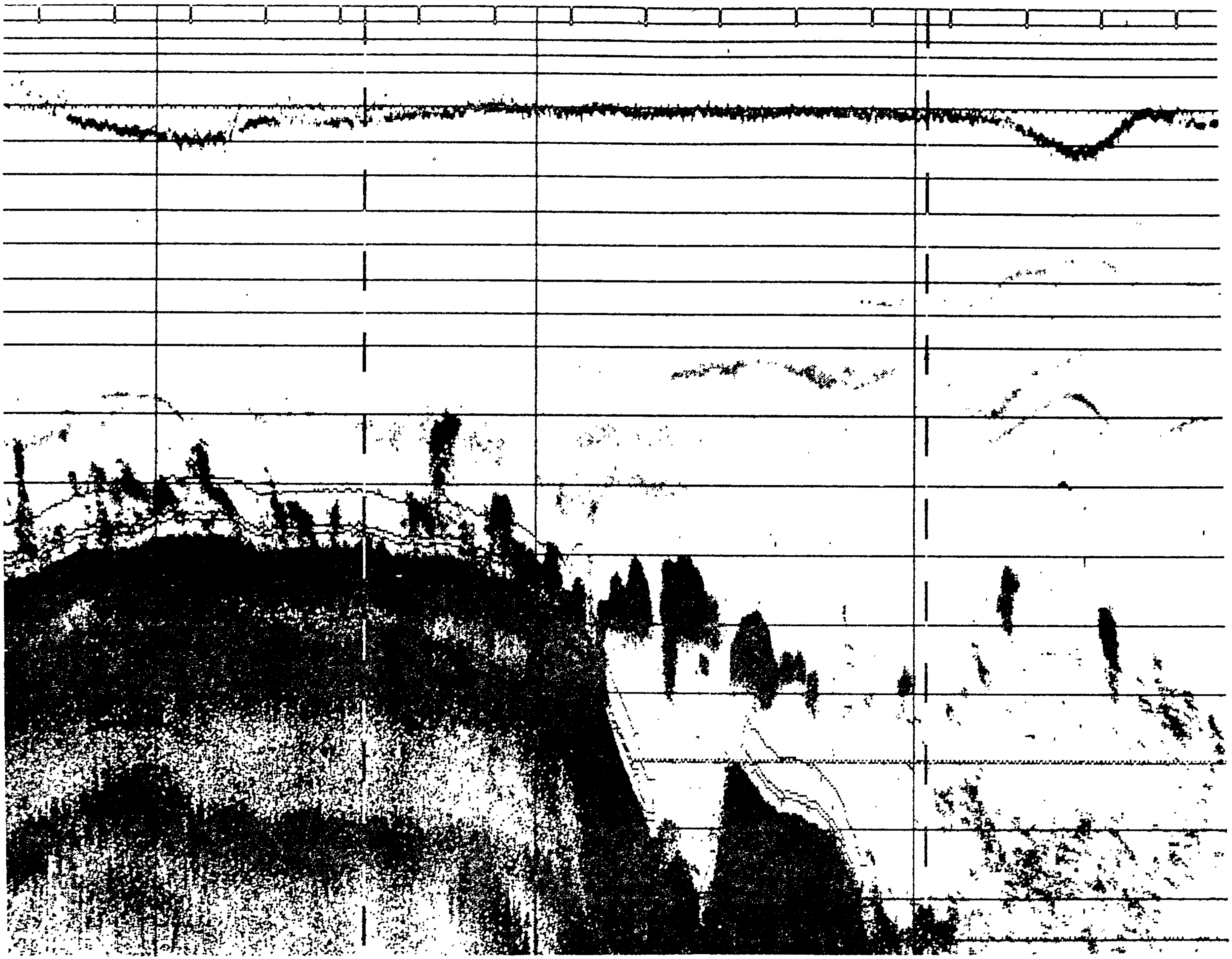


Fig. 12. Typical diurnal distribution of fish at the southern grid, showing wider inter-school school distance and lower bottom relief than at northern grid (20/3/90, 13:00).

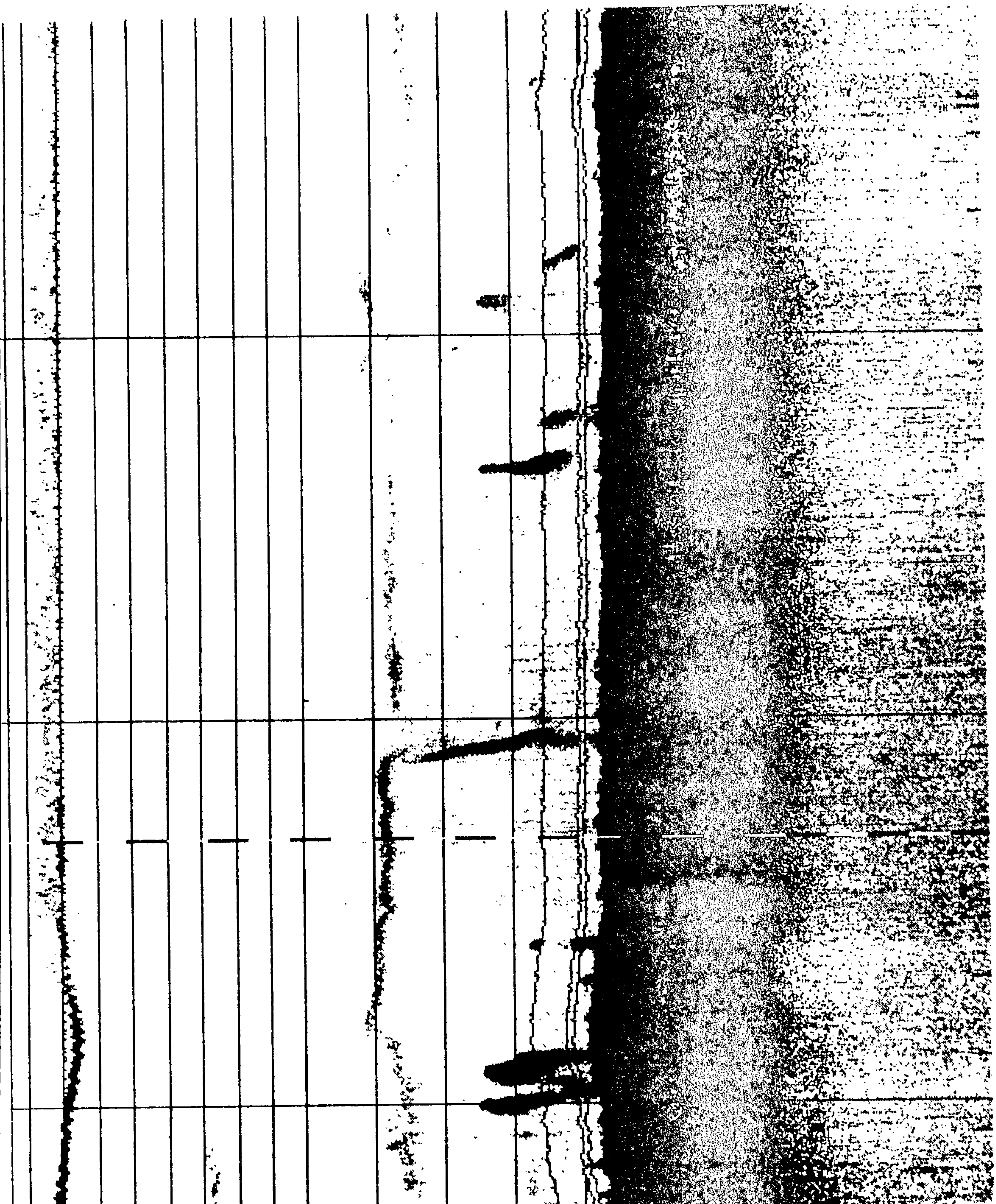


Fig. 13. Typical nocturnal fish distribution at northern grid (18/3/90, 22:00).

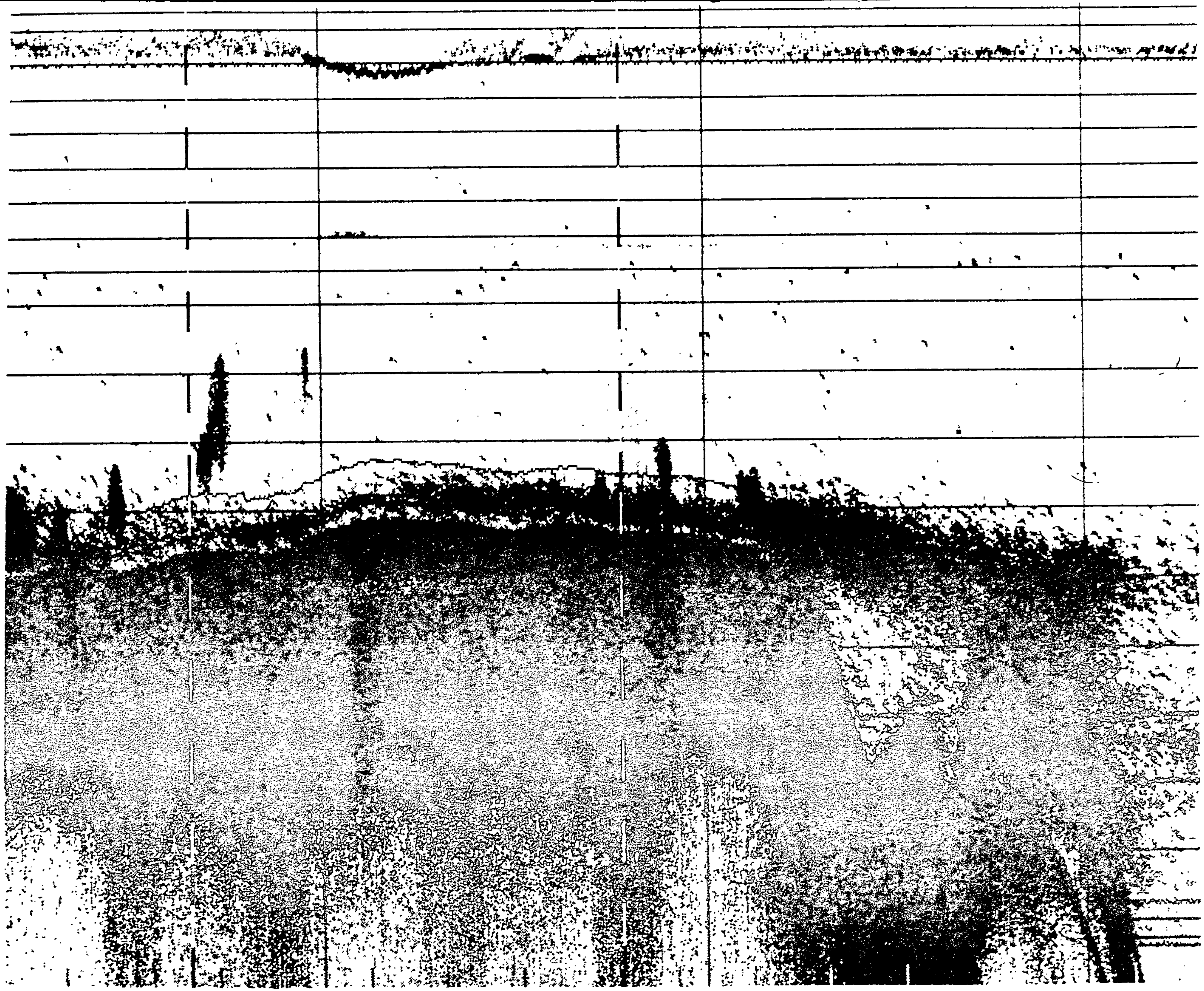


Fig. 14. Typical nocturnal fish distribution at southern grid (20/3/90, 22:00).

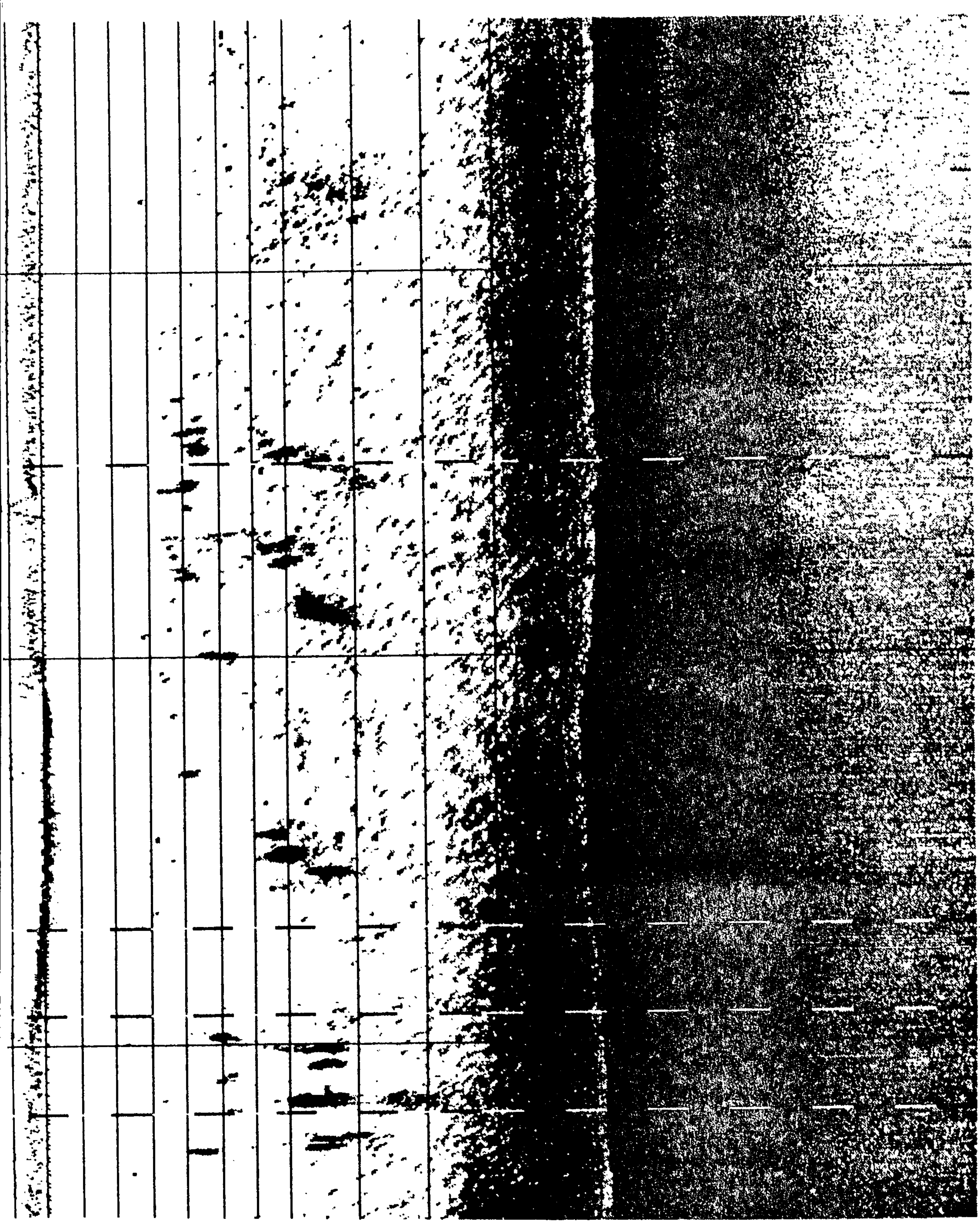


Fig. 15. Upper water column, nocturnal fish distribution at southern grid, showing broad layer of isolated fish sign over more diffuse bottom layer.

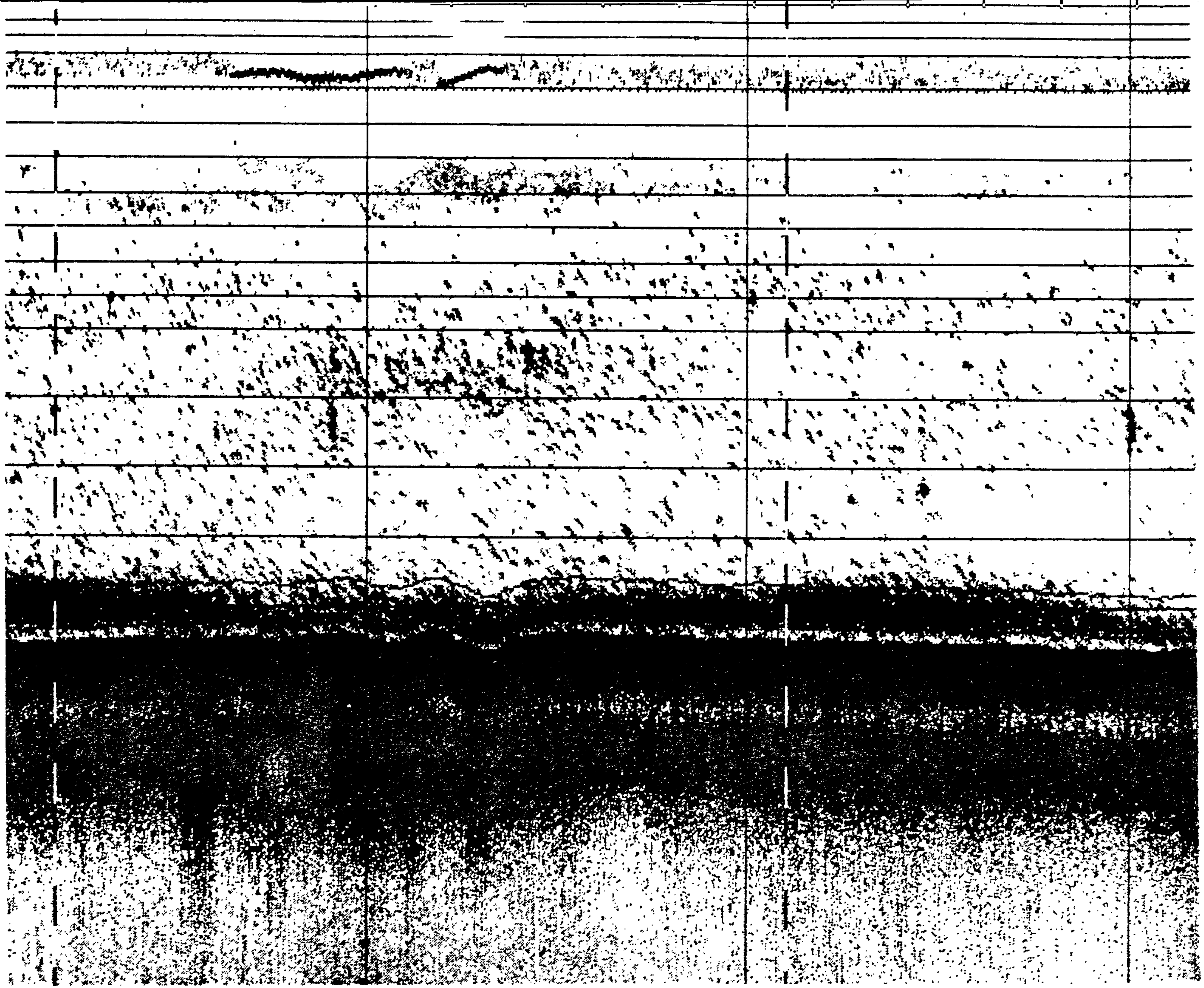
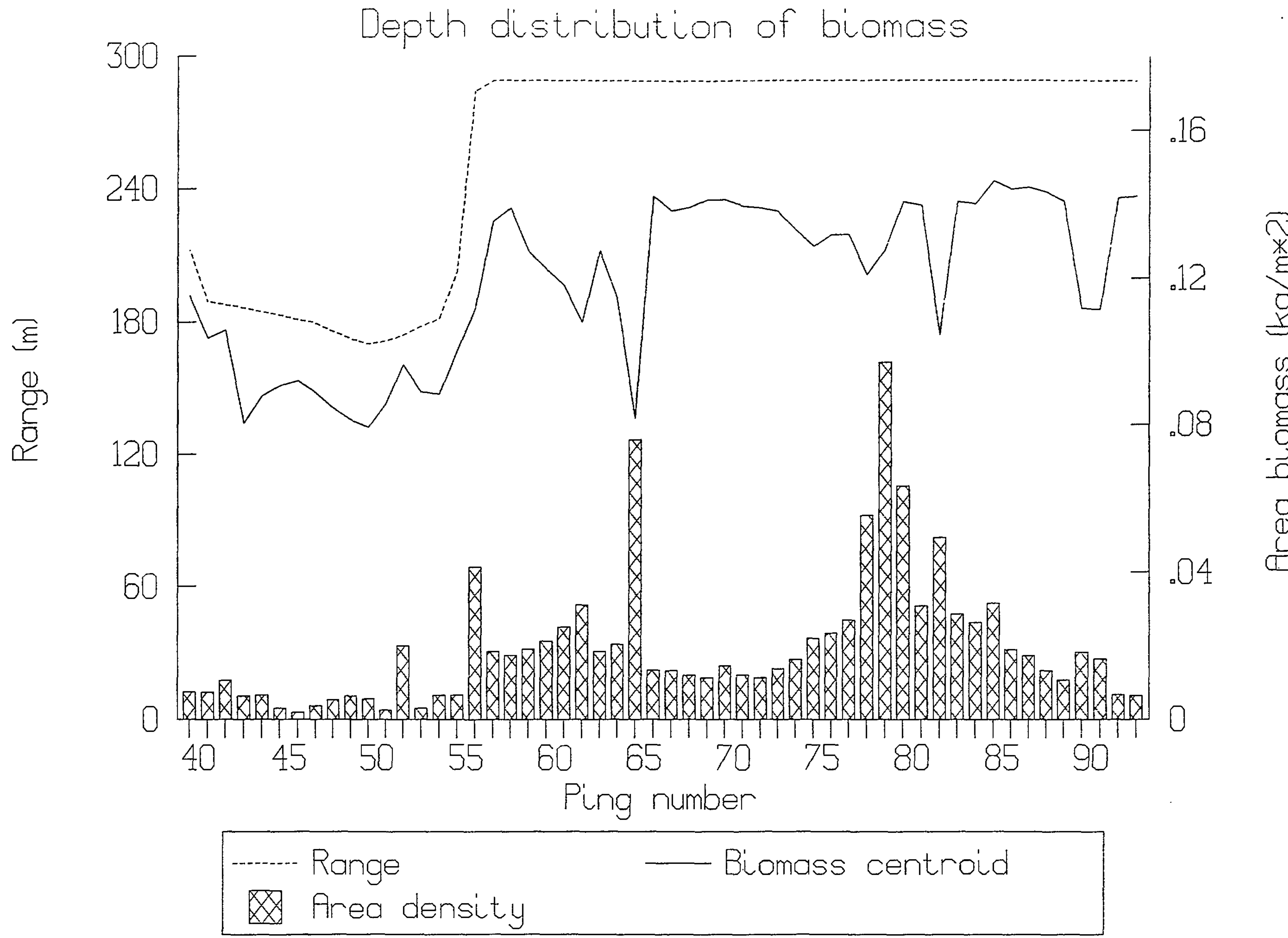


Fig. 16. A plot of surface density, biomass centroid and range to the bottom versus distance (ping number). These measurements can be compared with the visual information presented in the echogram (Figure 6). A range of 50-300 m or less was integrated. Event 13 was recorded March 17th, 13:52 hours.


Depth distribution of biomass
300
240
180
120
60
0
Range (m)
.16
.12
.08
.04
0
Area biomass (kg/m*2)
40
45
50
55
60
65
70
75
80
85
90
Ping number
Range
Biomass centroid
Area density

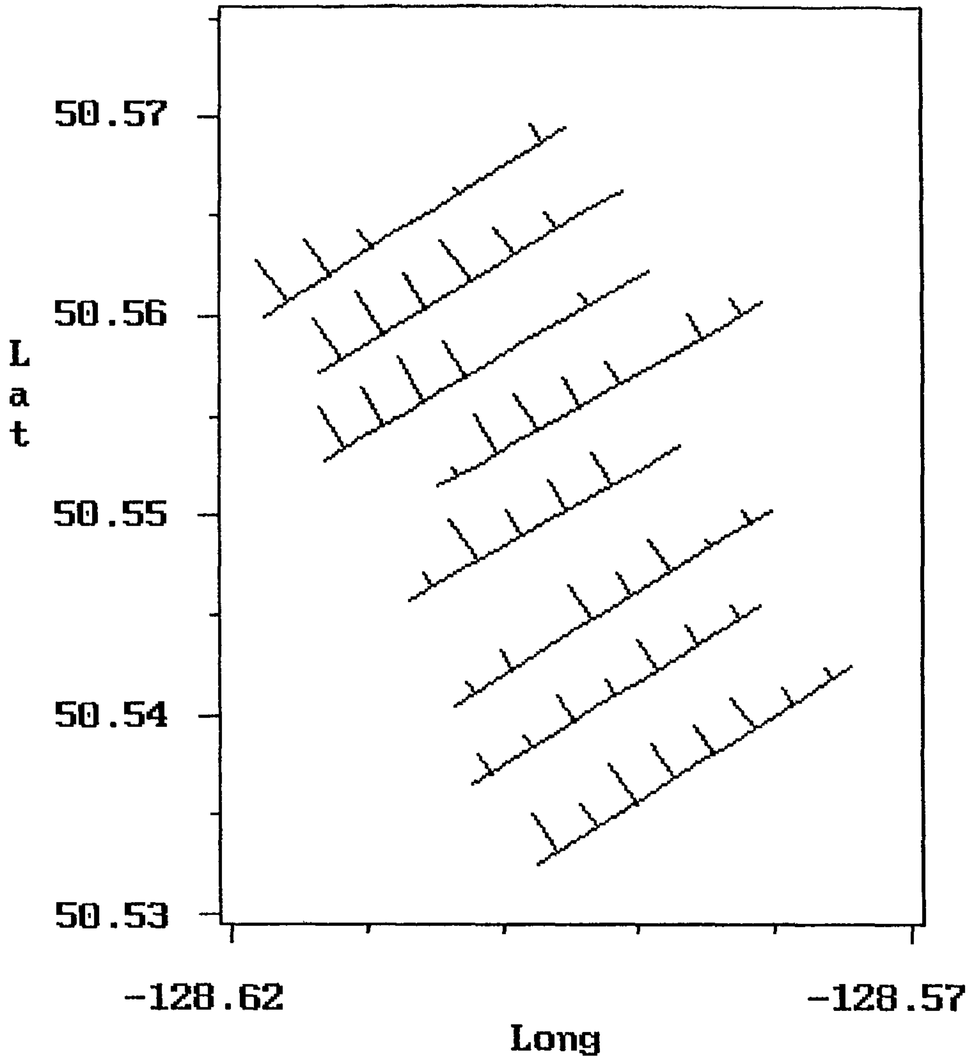


Fig. 17. 'Porcupine' or surface density plot shows an areal view of the diurnal fish distribution. Data collected March 17th, transects 20-27, events 72-92. The uprights give surface density values from 0.001 to 0.1 kg/m² on a logarithmic scale.

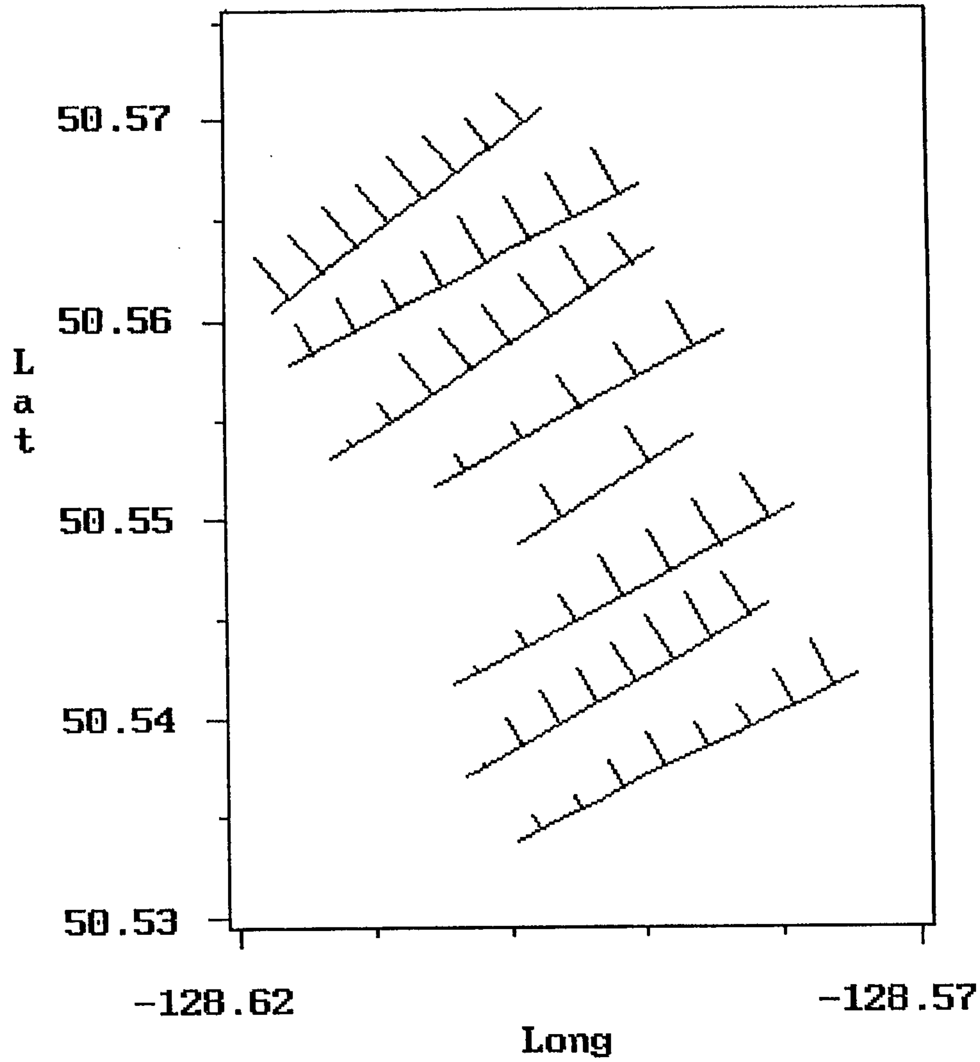


Fig. 18. 'Porcupine' plot, March 18th, transects 20-27, event 178-194, nocturnal distribution. The uprights give surface density values from 0.001 to 0.1 kg/m² on a logarithmic scale.

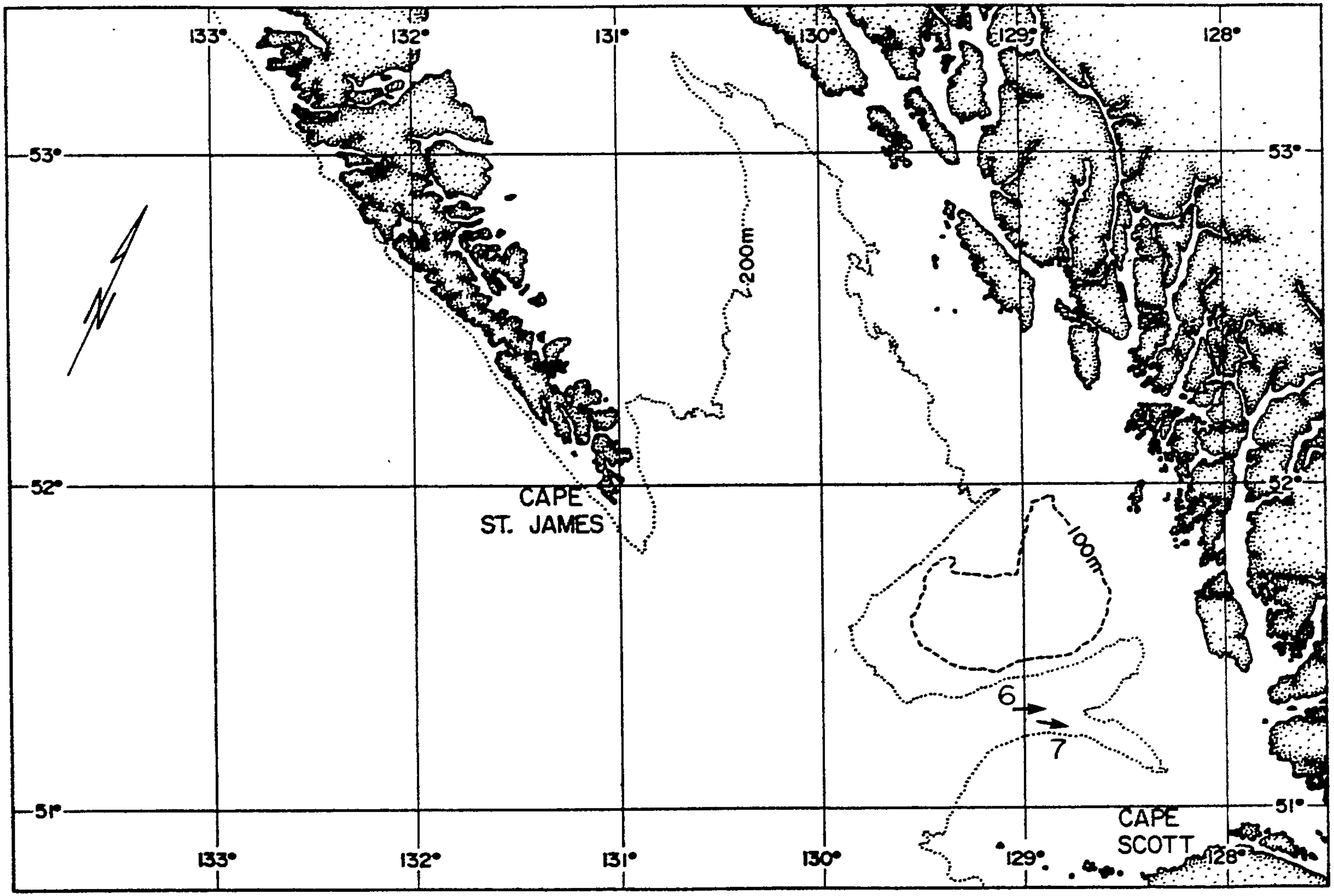


Fig. 19. Locations for hauls 6-7 in Queen Charlotte Sound, R/V W.E. RICKER hydracoustic cruise, March 22-23, 1990.

Appendix Table A1. Echo integration equation and systems calibration constants.

Echo integration can be described by an equation that accounts for the physical aspects of the hydroacoustic measurement. The equation is valid if a good signal to noise ratio is present and an average fish target strength can be defined. For convenience, the parameters are given in logarithmic form. For each range stratum and integration sequence, the integrator outputs an intensity, I, that is given by:

$$I = TL + RS + SH + SA + \Omega + CT + BW + RG + TS + \rho$$

The following definitions are used:

I	Intensity, V^2
TL	Transmit level, dB re $1\mu Pa$ at 1 m
RS	Receive sensitivity, dB re $1V/\mu Pa$ at 1 m
SH	Two way gain through shell of the towed body, dB
SA	Spreading and absorption gain, $-(20 \cdot \log \cdot R_0 + 2 \cdot \alpha \cdot R_0)$
R_0	Reference range, m
α	Absorption, dB re 1/m
Ω	Beam factor
	$= 10 \cdot \log[\int\int b^2(\theta,\Phi) \cdot \sin(\theta)\ d\theta d\Phi]$
$b(\theta,\Phi)$	One way transducer directivity function, Power
CT	Range increment $= 10 \cdot \log(c \cdot \tau/2)$
c	Velocity of sound in water, m/s
τ	Transmit pulse width, s
BW	Bandwidth factor $= 10 \cdot \log(I_1/I_0)$
I_1	I generated by a bandwidth limited input pulse
I_0	I generated by a square input pulse of the same hight
RG	Receiver gain setting, dB
TS	Average fish target strength, dB re 1/kg
ρ	Fish volume density, kg/m^3

These parameters have been carefully determined and are given in Appendix Table A2. The first three values were measured at the hydroacoustic calibration barge of the Applied Physics Laboratory, University of Washington, Seattle. The calibration is performed periodically and provides a check on the overall system performance and stability.

Appendix Table A2. Values used in the echo integration equation. TL, RS, SH, and Ω are derived from a hydrophone-based calibration that is repeated regularly. The receiver sensitivity, RS, refers to a reference range of 1.0 m, however, it is measured with TVG at 30 m.

Quantity		Source/Comment
TL	220.3 dB	U of W, 6 March 1990
RS	-133.76 dB	U of W, 6 March 1990
SH	-0.6 dB	U of W, 24 March 1982, plot 3717, 3718
SA	0.0198 dB	
R_0	1.0 m	
α	0.0099 dB/m	
Ω	-17.55 dB	
CT	-3.50 dB	
c	1490 m/s	
τ	0.6 ms	
BW	0.8 dB	Kieser et al. 1987
RG	-12.0 dB	
TS	-32.0 dB	
ρ		Parameter to be estimated

Appendix Table A3. Bridge log information, W.E. RICKER, March 14-23, 1990.

Haul No.	1	2	3	4
Date	MAR 15	MAR 18	MAR 19	MAR 19
Area (Major, Minor)	3D,27	3D,27	3D,27	3D,27
Start Time (PST)	18:24	17:51	12:55	15:02
Duration (Min)	12	41	95	55
Start N. Lat. (Deg)	50	50	50	50
(Min)	30.2	33.1	34.2	31.6
W. Long (Deg)	127	128	128	128
(Min)	43.6	34.8	34.6	36.0
Start LORAN-C X	13978.0	13715.9	13712.9	13715.5
Y	29901.3	29909.6	29915.4	29901.6
Finish N. Lat. (Deg)	50	50	50	50
(Min)	30.1	31.8	30.8	34.9
W. Long (Deg)	127	128	128	128
(Min)	44.5	35.6	34.5	38.1
Finish LORAN-C X	13973.8	13716.7	13725.5	13693.6
Y	29900.6	29902.7	29897.6	29918.4
Haul Distance (Km)	1.1	2.6	5.9	6.9
(N Mi)	0.6	1.4	3.2	3.7
Direction (Deg.True)	275	229	180	334
Bottom Depth (m)	120- 122	192- 258	187- 197	410- 202
(Fm)	66- 67	105- 141	102- 108	224- 110
Modal Depth (m)	121	200	200	200
Net/Gear Depth (m)	..- ..	170- 240	140- 185	120- 95
(Fm)	..- ..	93- 131	77- 101	66- 52
Modal Net Depth (m)	..	200	140	107
Footrope-Bottom (m)	0- 0	12- 10	30- 5	298- 99
Distance (Fm)	0- 0	7- 5	16- 3	163- 54
Modal Distance (m)	0	12	20	199
Water Temp. (Deg C)	0.0- 0.0	9.2- 7.0	0.0- 0.0	8.7- 7.2
Temp. Depth (m)	0- ..	0- 190	0- ..	0- 200
Gear Type	113	202	202	202
Tide	EBB	EBB	FLOOD	FLOOD
Total Catch (Kg)	0	490	0	352
Remarks	USABLE	USABLE	USABLE	USABLE

Appendix Table A3. (continued)

Haul No.	1	2	3	4
Date	MAR 15	MAR 18	MAR 19	MAR 19
Area (Major, Minor)	3D,27	3D,27	3D,27	3D,27
Arrowtooth flounder	..	..	..	..
Rex sole	..	..	..	..
Other flatfish	..	..	..	..
Sebastes alutus	..	..	..	..
S. babcocki	..	..	..	..
S. brevispinis	..	2	..	..
S. entomelas	..	304	..	345
S. flavidus	..	5	..	..
S. paucispinis	..	..	..	7
S. proriger	..	139	..	..
S. reedi	..	40	..	..
Sebastolobus alascanus	..	..	..	..
Other rockfish	..	..	..	..
Pacific cod	..	..	..	..
Pacific hake	..	..	..	..
Sablefish	..	..	..	..
Walleye pollock	..	..	..	..
Other roundfish	..	..	..	..
Spiny dogfish	..	..	..	..
Other selachii	..	..	..	..
Total Catch (Kg)	0	490	0	352

Appendix Table A3. (continued)

		5	6	7
Haul No.		5	6	7
Date		MAR 20	MAR 21	MAR 22
Area (Major, Minor)		3D,27	5A,11	5A,11
Start Time	(PST)	15:36	12:31	8:20
Duration	(Min)	86	34	30
Start N. Lat.	(Deg)	50	51	51
	(Min)	23.6	17.8	15.6
W. Long	(Deg)	128	129	128
	(Min)	25.5	0.7	57.6
Start LORAN-C	X	13793.2	13405.9	13431.4
	Y	29860.2	30118.1	30109.7
Finish N. Lat.	(Deg)	50	51	51
	(Min)	20.2	18.2	15.4
W. Long	(Deg)	128	128	128
	(Min)	24.6	57.8	55.2
Finish LORAN-C	X	13808.6	13418.4	13444.2
	Y	29841.9	30121.3	30109.9
Haul Distance	(Km)	6.5	3.5	5.7
	(N Mi)	3.5	1.9	3.1
Direction (Deg.True)		145	73	90
Bottom Depth	(m)	212- 455	242- 241	211- 211
	(Fm)	116- 249	132- 132	115- 115
Modal Depth	(m)	220	242	211
Net/Gear Depth	(m)	100- 95	..- ..	..- ..
	(Fm)	55- 52	..- ..	..- ..
Modal Net Depth	(m)	100	..	..
Footrope-Bottom	(m)	100- 350	0- 0	0- 0
Distance	(Fm)	55- 191	0- 0	0- 0
Modal Distance	(m)	100	0	0
Water Temp.	(Deg C)	8.7- 7.4	0.0- 0.0	8.6- 6.4
Temp. Depth	(m)	0- 100	0- ..	0- 200
Gear Type		202	113	113
Tide		FLOOD	EBB	EBB
Total Catch	(Kg)	0	700	136
Remarks		USABLE	USABLE	USABLE

Appendix Table A3. (continued)

Haul No.	5	6	7
Date	MAR 20	MAR 21	MAR 22
Area (Major, Minor)	3D,27	5A,11	5A,11
Arrowtooth Flounder	..	56	68
Rex Sole	..	2	..
Other flatfish	..	..	..
Sebastes alutus	..	555	68
S. babcocki	..	20	..
S. brevispinis	..	36	..
S. entomelas	..	..	..
S. flavidus	..	..	..
S. paucispinis	..	..	..
S. proriger	..	..	..
S. reedi	..	..	..
Sebastolobus alascanus	..	7	..
Other rockfish	..	..	..
Pacific Cod	..	5	..
Pacific Hake	..	5	..
Sablefish	..	4	..
Walleye pollock	..	5	..
Other roundfish	..	..	..
Spiny dogfish	..	5	..
Other selachii	..	..	..
Total Catch (Kg)	0	700	136