2A 95-27

Acoustic Estimate of Herring Biomass in the Green Island Area of Prince William Sound, Alaska, 1993

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Regional Information Report[1] No. 2A95-27

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Commercial Fisheries Management and Development Division, Central Region
333 Raspberry Road
Anchorage, Alaska 99518

June 1995

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ACKNOWLEDGEMENTS

We would like to thank Dave Scheel and Dave Marino for comments on this manuscript. We also thank Herb Jensen and Virgil Carroll with their vessels and respective crews during the acoustic survey. We also thank the local commercial fishers for input into survey design.

PROJECT SPONSORSHIP

This research was funded by the Cordova District Fishermen United.

ABSTRACT

An acoustic and net sampling survey was conducted in October 1993 to estimate the biomass of the Prince William Sound Pacific herring stock. The survey was conducted in the Green Island Trench area of the Sound after the commercial fishery harvested about 1,000 tons a week earlier. Commercial search-light sonars were used to search the area to locate herring school groups. Once school groups were located, they were mapped and fish density was estimated in real-time using a dual beam scientific sonar. Commercial purse seines were used to collect species, size and other pertinent biological information. The total herring biomass in the region was estimated to be about 20,000 tons. Over 75% of the fish, 16,712 tons, were found in an area of approximately $30.1 * 10^6 m^{-2}$ near Applegate Reef .

INTRODUCTION

Acoustic techniques are widely used to assess abundance of pelagic fish stocks, including herring (Urick 1967; Thorne 1983b; Ehrenberg and Lytle 1972). Acoustic echointegration and dual beam processing of target strength are based on sonar theory (Urick 1967; Ehrenberg and Lytle 1972). Scientific echosounders are used to measure the amount of energy reflected from fish concentrations, which can be converted to fish density with information on the energy reflected from a single fish (its target strength) and knowledge of the sample volume (transducer directivity). Net sampling is routinely conducted to subsample the acoustic targets to verify species, size, and obtain other biological information on the ensonified fish (Thomas 1992).

Historical information on the abundance of Pacific herring *Clupea pallisi* in Prince William Sound (PWS) consists of commercial catch records, aerial estimates of the length of milt patches along beaches, and herring spawn deposition surveys (Funk 1994; Donaldson et al. 1993). Single beam acoustic surveys without net sampling support had been used for estimating the biomass of PWS herring in the fall between 1980 and 1985 (ADF&G, PWS Area Annual Finfish Management Report Series 1980-1986, Box 669 Cordova, AK). Between 1988 and 1992, the Alaska Department of Fish and Game (ADF&G) used spring spawn deposition surveys to estimate the biomass of spawning herring. In the spring of 1993, a record run of adult PWS herring (134,000 tons) was forecast and the spawn deposition survey was not conducted.

The spring 1993 aerial survey of the length of milt patches along the beaches suggested that the returning biomass was less than half of expected. This small return was followed by a commercial harvest substantially lower than expected. In addition, the herring spawning stock was found to be infected with a potentially lethal virus, viral hemorrhagic septicemia (VHS; Meyers et al. 1994). The low numbers of returning fish and the disease prompted serious concerns about continued oversummer mortality and the long-term viability of the stock. Thus, the Cordova District Fishermen United (CDFU) funded the Prince William Sound Science Center (PWSSC) to conduct an acoustic and purse seine survey to estimate the stock size and health of adult herring in PWS during the fall of 1993. This project developed into a team effort between CDFU, ADF&G, and PWSSC.

Study Site

PWS is a complex fjord/estuary (Schmidt 1977) located at the northern margin of the Gulf of Alaska (Figure 1). PWS covers an area of about 8800 km^2 with approximately 3200 km of shoreline (Grant and Higgins 1910). The current acoustic survey was conducted in the southwestern portion of PWS near Green Island in Montague Strait (60°15'N, 147°25'W; Figure 2).

MATERIALS AND METHODS

The acoustic survey was conducted between 20 October and 26 October, 1993 using two commercial purse seiners. One seiner was assigned the responsibility to conduct acoustic mapping of biomass and the other to purse seine the fish targets. The acoustics vessel was outfitted with a BioSonics model 101 echo sounder, operating at 120 Khz frequency. A 120 Khz dual beam, pre-amplified transducer was mounted on a 1.2 m BioSonics Biofin in a down-looking configuration. The Biofin was towed at a depth of about 2 m at approximately 5 m off the starboard side of the seiner. The catching vessel provided direct measure and species composition of acoustic targets and supplementary biological information on herring. The catching vessel was equipped with a 55 m deep (3.18 cm stretched mesh) by 414 m long seine typical of the gear-type used in the commercial bait herring fishery.

Survey Design

The acoustic survey was a multistage sampling design (Cochran 1967). The first stage used historical commercial fishing areas, local fishers knowledge of herring location and behavior, and data from the recent commercial herring harvest to reduce the search area for herring concentrations (school groups) in PWS. The area to be searched intensively was the Montague Straits region near Green Island. A small amount of search effort was allocated to verify the absence of fish at Knowles Head, another historical overwintering site. Anecdotal information from fishers familiar with PWS herring suggested that adult herring migrate from the Gulf of Alaska into PWS in the fall and that this migration is complete by the end of September. The survey was conducted between 7 and 10 October, 1993, during an interval of small tidal exchange to minimize the probability of inclimate conditions.

Stage two was to search and locate herring school groups within Montague Strait (Figure 1). Historical information and fishers knowledge played another role in this stage by identifying specific isobaths herring schools are found within. Hence, herring schools were located by cruising within specific depth contours using commercial quality search (sweeping) light sonar and down-looking echosounders. The search-light sonar and down-looking sonar were used by the fishermen to assess if there were commercial quantities of herring present. Where such quantities of herring were found, they were mapped and biomass was measured.
The third stage of sampling was to map a school group and measure its density using a dual beam echosounder. The acoustic survey transects were run in a zigzag fashion over the school group (Figure 3). These dual beam acoustic surveys were replicated in both day and night for large school groups.

Acoustic Parameters

Target strength information for herring was derived from average length to target strength (in decibels) per kg fish after Thorne (1983a). Thorne's (1983a) empirical relationship assumes the following logistical equation:

$$\gamma = \frac{\sigma}{\overline{W}} = a\bar{l}^{-b} \qquad (1)$$

where σ is the mean acoustic backscattering coefficient, W is the mean weight (in kg), l is the mean length (in cm), and a and b are constants. Values for the constants (a and b) are obtained from data for a variety of fisheries presented by Thorne using a linear regression of $\log_{10} l$ versus 10 log (σ/w), where 10 log (σ/w) is referred to in Thorne (1983a) as "target strength per kg."

The average herring length and weight data were compiled from samples obtained by the Alaska Department of Fish and Game (ADF&G, unpublished data) during the commercial herring food and bait fishery between 7 to 10 October, 1993. These measured data were applied to Thorne's (1983a) empirical relationship to obtain the ratio $\gamma = \sigma/w$ and the mean backscatter coefficient (σ).

As a crosscheck, we generated in situ measurements of target strength from a small subset of dual beam acoustic data. We compared our in situ mean backscatter coefficient with Thorne's (1983a) empirical formula. In addition to the in situ target strength measure comparison, captured fish from the catching vessel provided a further check for consistency of observed length and weight from the commercial catch.

Biomass Estimation

Herring biomass was calculated for each survey between 20 October and 26 October 1993. The general calculation of the population density using echointegration for a single cell *jk* (Figure 4) on a transect is given as:

$$\beta_{jk} = \rho_{jk} \cdot \overline{w}_{jk} = \frac{C(ei)_{jk} \cdot P_{jk}}{\frac{\overline{\sigma}_{jk}}{\overline{w}_{jk}}} \qquad (3)$$

where β_{jk} is the population density (mass per unit volume), ρ_{jk} is the density of scatterers, w_{jk} is mean weight of scatterers, C is acoustic constant (calibration settings ie., gain etc.) ei_{jk} is the mean of the voltage squared, P_{jk} is percentage of cell *jk* within the water column, and σ_{jk} is mean backscattering coefficient for targets within cell *jk*.

The biomass for a region of surface area A is determined by using a set of line transects along which a total of nrs point estimates of biomass per unit area is obtained. Specifically,

$$B = \frac{\sum_{j=1}^{nrs} \sum_{k=1}^{nst} \beta_{jk}}{nrs} \cdot A \tag{4}$$

where nrs is number of reports (along the line transects), nst is number of depth strata, and A is survey area.

For the herring biomass estimate in PWS we followed Thorne (1983a). Specifically, we assume that σ_{jk}/w_{jk} is independent of cell *jk*, hence, for all *jk* σ_{jk}/w_{jk} is a constant γ, and γ is given by equation 1. With this assumption, equation 5 simplifies to:

$$\beta_{jk} = \frac{C}{\gamma} \cdot (ei)_{jk} P_{jk} \tag{5}$$

and the herring biomass B in an area is given as

$$B = \frac{C}{\gamma} \frac{\sum_j \sum_k \cdot (ei)_{jk} P_{jk}}{nrs} \cdot A \tag{6}$$

RESULTS

Historical Data

The Green Island area of PWS was chosen as the area to search for herring schools. During 1993, the herring commercial food and bait fleet harvested 986.1 tons (Donaldson et al. 1993) from the Green Island area.

Searching

The distribution of herring schools was patchy throughout the Green Island area and the largest concentration was located near Applegate Reef (Figure 2). Searching for herring schools included areas north of Seal Island, south to Montague Strait (Danger Island, Cape Clear), and the west side of Montague Island through Montague Point (Figure 1). The Knowles Head and Johnstone Point areas were also searched with the commercial search-light sonar and echosounders, and no significant school groups were located for mapping and density estimation. However, occasional small schools (probably less than 500 tons) were observed in these areas, which are unaccounted for in our herring biomass estimate.

Herring schools were observed during both day and night searches and generally exhibited a diel migration. During daylight they were located near the bottom in tightly grouped schools and at the onset of darkness they moved upward, spreading out in a more contiguous discrete layer near the surface (Figure 5a, 5b, 6a, 6b)[1]. This observation and visuals are consistent with other herring researchers (cf. Thorne 1983b; Ehrenberg and Lytle 1972).

In addition to herring exhibiting a diel migration, we noted herring schools were concentrated around a 90 m deep isobath located around Green Island and Applegate Reef. Fish targets were consistently observed at that depth during daylight hours especially northwest of Applegate Reef. Likewise, during the 23 October sonar searches we observed several feeding humpback whales, *Megaptera novaeangliae*, in the Green Island area near large schools of herring. Humpback whales could be used as search indicators because they are known to eat herring (Craig Matkin, personal communication).

Acoustic Surveys (Stage 3)

Target Strength - The mean length, weight, and σ for commercial and acoustic survey data are reported in Table 1. The mean length of herring caught during the commercial food and bait fishery were 214 mm (J. Wilcock, ADF&G personal communication). The average σ multiplied by average weight of fish totalled $8.9 * 10^{-5}$. The average length of herring captured by test fishing during the survey was 208 mm. The average σ determined acoustically, in situ, was $1.1 * 10^{-4}$ and differed by approximately 20% of Thorne's (1983a) estimate (Table 1). Figure 7 shows individual target strengths of fish in the water column along an acoustic transect as dervied from dual beam analysis.

Biomass Estimation

The biomass estimates during the acoustic survey are given in Table 2. An area of approximately $30.1 * 10^6$ m^2 northwest of Applegate Reef contained the highest biomass during the acoustic survey. Four acoustic surveys were completed northwest of Applegate Reef on 23 October 1993, and the herring biomass ranged from ~13,000 tons to 22,500 tons with a mean of 16,712 tons (Table 2; Figure 2).

The second most abundant concentration of fish was located between Green and Montague Islands near Channel Island, on 22 October 1993, and had an estimated mean biomass of

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[1]Day (Figure 4) and night (Figure 5) herring diel migration behavior. These figures contain no units and are not intended to show any quantities. The x-axis from left to right is time and distance from beginning to end of acoustic survey. The y-axis is depth in meters below light blue line with day or night inscription; the transducer surface.

~1,000 tons (Table 2; Figure 2). The total biomass of herring from all surveyed areas around Green Island totalled ~20,000 metric tons.

The first day of the acoustic survey a small population was detected around Applegate Reef. This population was estimated to be approximately 600 tons. This initial survey may not adequately describe the herring biomass that evening because the fish may have avoided the survey vessel because the deck lights were accidentally left on during the survey.

DISCUSSION

Large aggregations of herring have consistently been observed during late fall and early winter in the northern Montague Strait area in recent years (Donaldson et al. 1993). It is assumed that these herring represent between 50 and 75% of the herring biomass based on (Gaudett 1984; Jim Kallander, Herb Jensen, and Robert Honkola, Cordova District Fisherman United, personal communications). This survey estimated that 20,000 tons of herring were located near Green Island between 20 October and 26 October, 1993. Assuming the anecdotal information on distribution is correct, the estimate of total biomass present in PWS in the fall of 1993 was 30,000-40,000 tons.

The multistage sampling design provided a practical approach for estimating the biomass of Pacific herring in the Green Island area of PWS. The nesting of quantitative acoustic procedures within semi-quantitative reconnaissance surveys was robust in terms of the fishers acceptance of the measurements. Albeit commercial fishing sonars and echosounders are not calibrated measurement tools, when coupled with experienced fishers knowledge they can provide the tools with which to meaningfully judge the relative density of fish in an area. Furthermore, when this reconnaissance is coordinated with quantitative sonars to estimate fish density the design approaches proportional allocation of sampling, which is most efficient (Cochran 1967). The fact that fishers make a living from such real-time abundance estimates makes the reconnaissance step robust and believable. The efficiency of this reconnaissance stage is significant. For example, the catching vessel searched the southern portions of Montague Strait and indicated low abundances near LaTouche Island. This information allowed the acoustic vessel to proceed with replicated acoustic surveys concentrated in the Green Island area. An advantage of the multistage sampling design is that expensive boat time can be condensed in time and space and make estimation of biomass economically possible.

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TABLE 1. Average length, weight, and backscattering coefficient (σ) for commercial and acoustic fishery in PWS October 1993.

Fishery	Mean Length (mm)	Mean Weight (g)	Backscattering Coefficient σ (m^2)
Commercial	214	140.6	$8.9 * 10^{-5}$
Acoustic	208	129.9	$1.1 * 10^{-4}$

calculated from mean lengths as in Thorne (1983a)
††calculated from measurements of net sampling
‡calculated from acoustic *in situ* measurements

TABLE 2. Location, total herring biomass (tons), mean, and standard deviation of herring acoustic survey 20 October to 26 October, 1993. NNE = north north west, SSW = south south west, SE = south east, NE = north east, W = west. † = no replication.

Date	Location	Area ($10^6 m^2$)	Survey (n)	Biomass m^{-2} (tonnes)	Mean Biomass (Standard Deviation) (tonnes)
10/20	NNW Applegate Reef	14.0	1	$2.99 * 10^{-5}$	418†
	SSW Applegate Reef	9.7	1	$2.23 * 10^{-5}$	216†
10/21	SE Little Green Is	9.6	1	$6.24 * 10^{-5}$	599†
10/22	SE Little Green Is	13.0	1	$0.56 * 10^{-5}$	73†
*	SE Little Green Is to NE Green Is		1	$5.62 * 10^{-5}$	*
	SE Channel Island	24.1 18.7	1 2	$4.42 * 10^{-5}$ $5.33 * 10^{-5}$	1,030 (47)
10/23	NW Applegate Reef	30.1 30.1 30.1 30.1	1 2 3 4	$74.82 * 10^{-5}$ $49.87 * 10^{-5}$ $42.77 * 10^{-5}$ $54.62 * 10^{-5}$	16,712 (4141)
10/24	SE Applegate Reef	7.2	1	$13.79 * 10^{-5}$	993†
	NE Green Island	9.3	1	$2.30 * 10^{-5}$	217†
	W Stockdale Harbor	4.0	1	$2.41 * 10^{-5}$	97†
	Total Biomass				19,049

* Single transect from SE Little Green Island to NE of Green Island not included in total biomass.

Figure 1: Prince William Sound, Alaska. Blue and red line indicate acoustic survey transect at the northern entrance of Montague Strait. Searching boundary of both commercial seine vessels from approximately Sheep Bay to the southern entrance of Montague Strait located near southern tip of Montague Island.

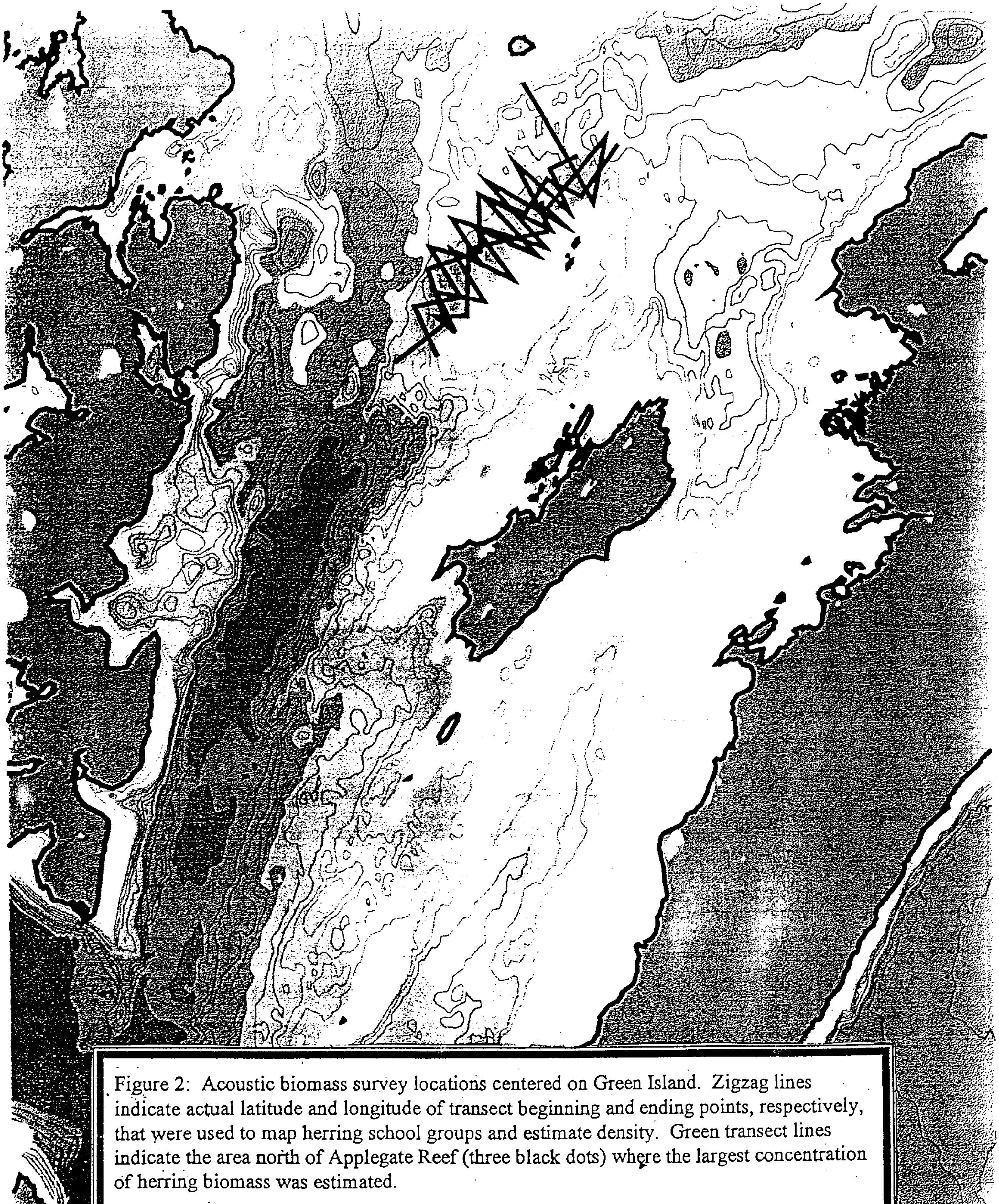

Figure 2: Acoustic biomass survey locations centered on Green Island. Zigzag lines indicate actual latitude and longitude of transect beginning and ending points, respectively, that were used to map herring school groups and estimate density. Green transect lines indicate the area north of Applegate Reef (three black dots) where the largest concentration of herring biomass was estimated.

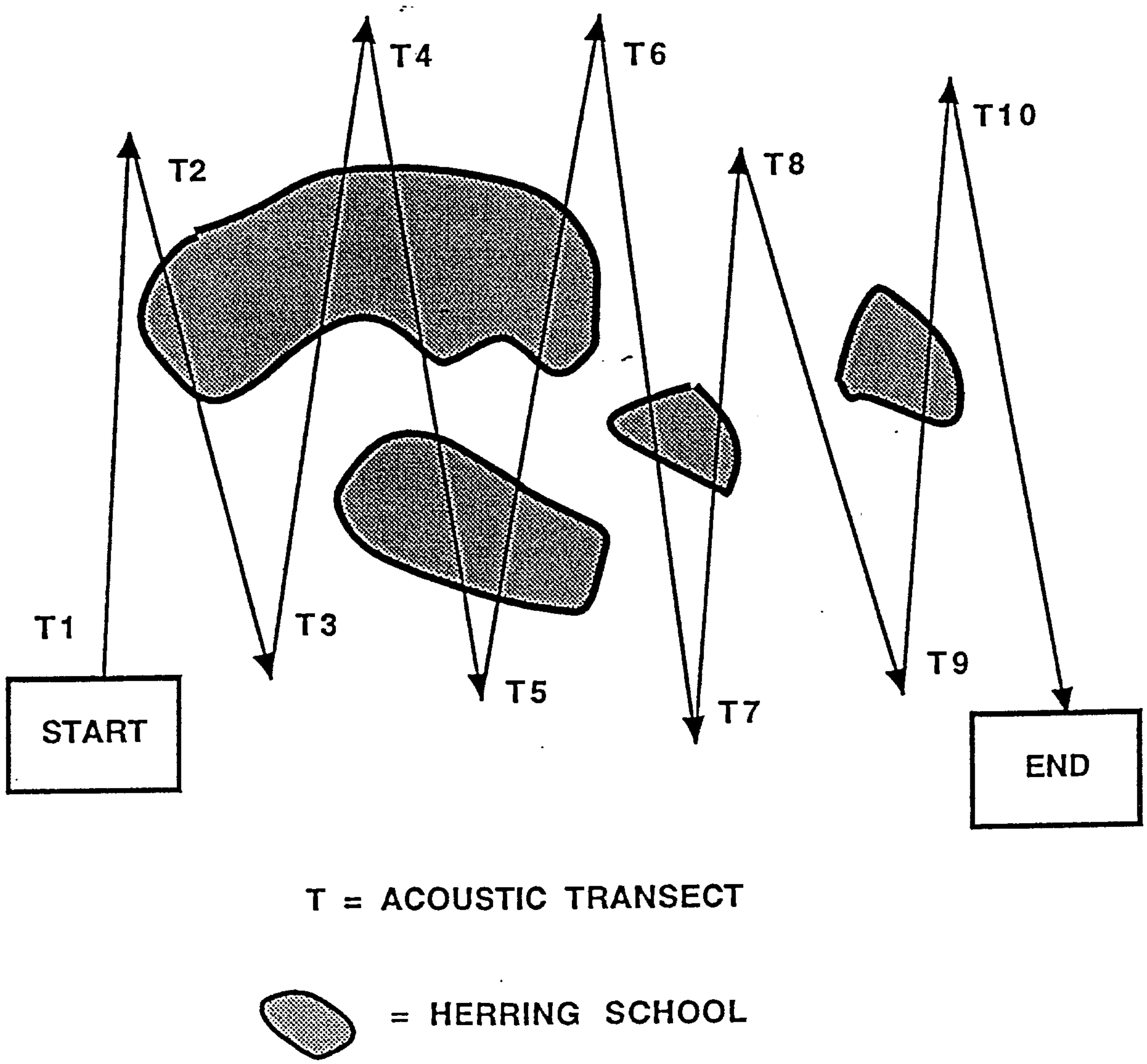

Figure 3: A hypothetical schematic of the zigzag transect design used to map and estimate biomass of herring schools.

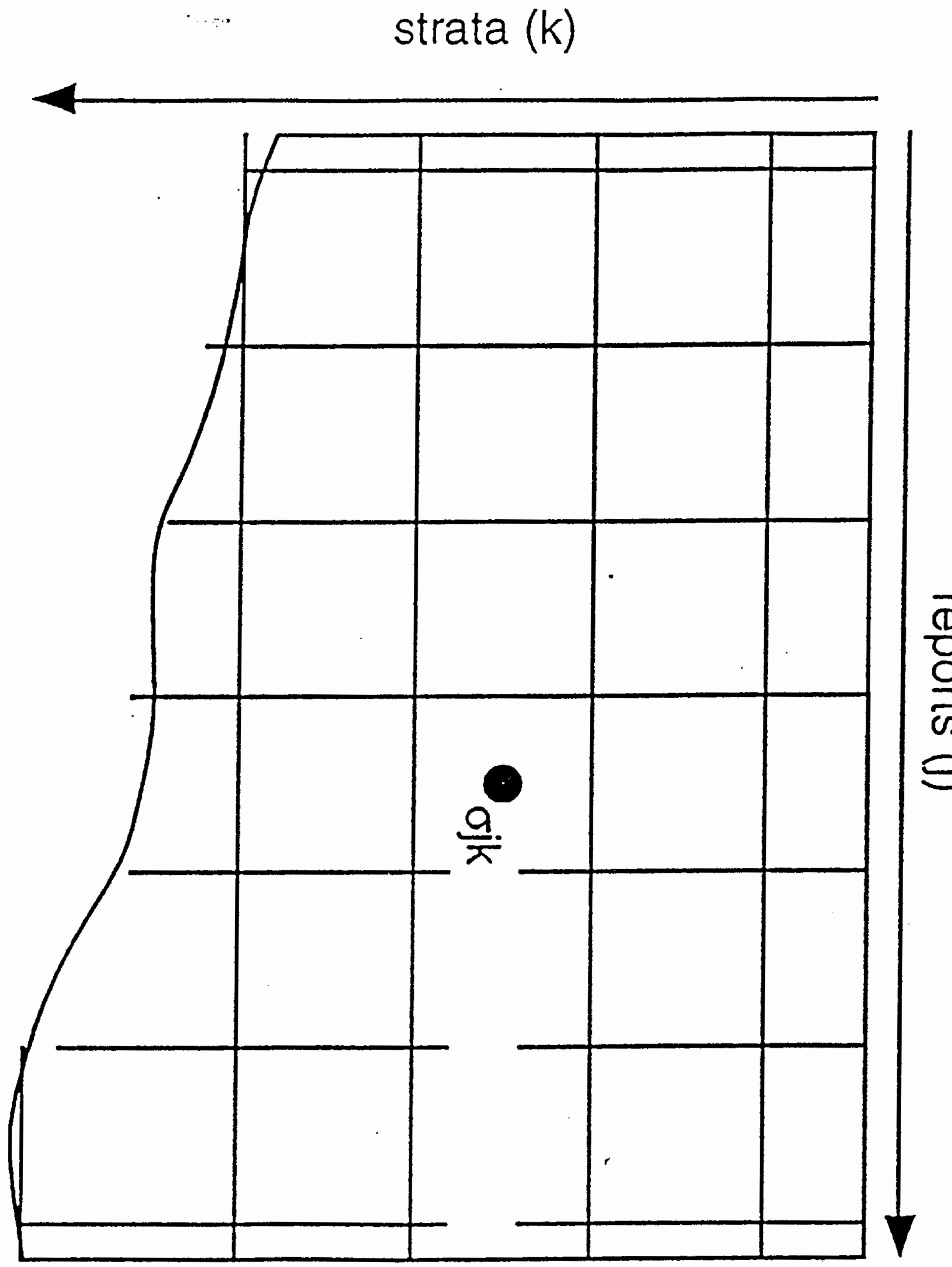

Figure 4: The breakdown of an acoustic transect by depth and distance into cells for estimating biomass. Each cell *jk* has an estimate of mean backscatter σ (*j* is distance interval of the cell as determined by time or number of pings of the transect and *k* is the depth interval of the cell which is usually as determined by time within a transmit pulse or meters)

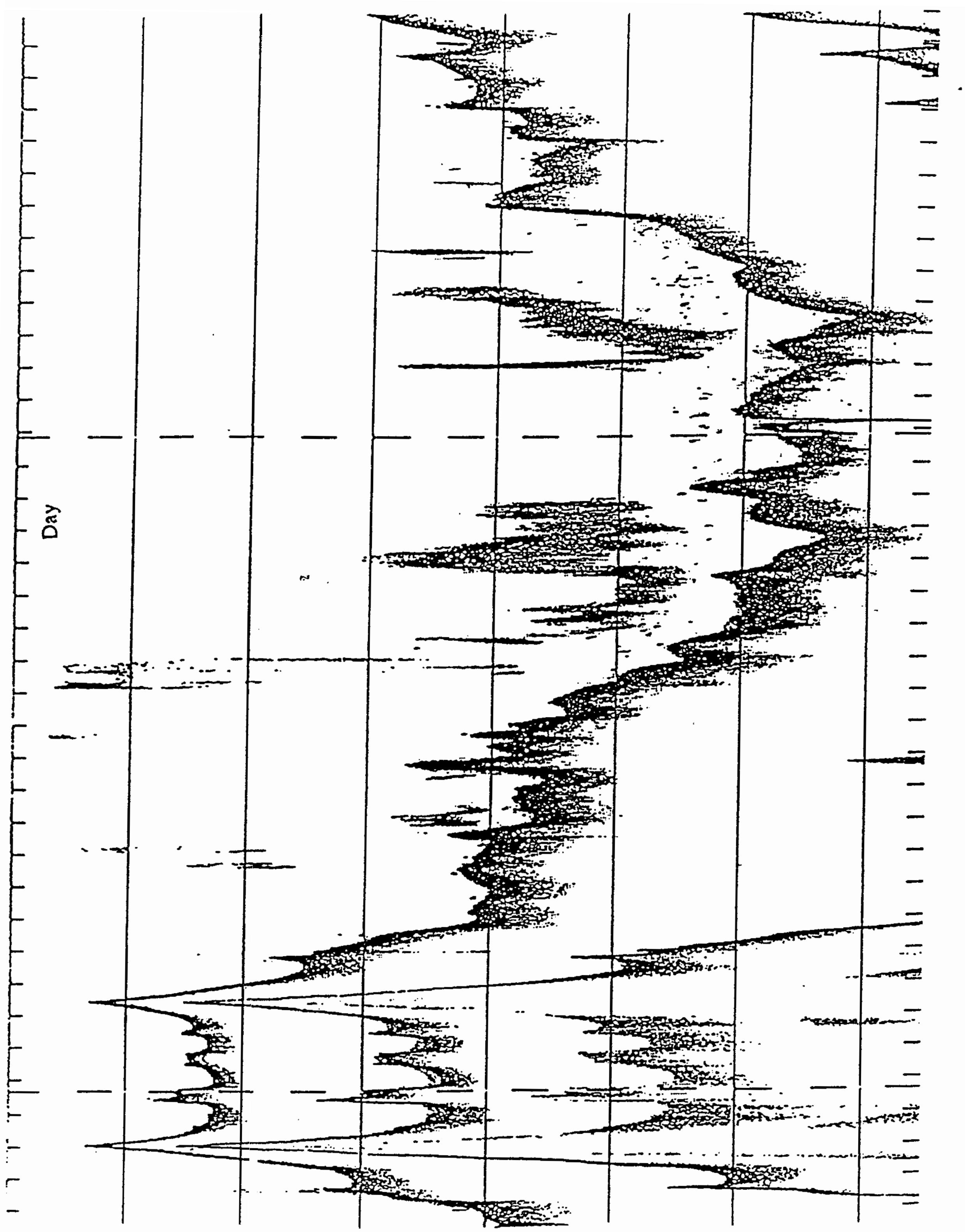

Figure 5a: Echogram of the daytime vertical distribution of herring biomass along a transect near Applegate Reef on 23 April 1993. The top of the x axis is the surface of the water column and the y axis is depth in 20 meter intervals. The bottom is the continuous irregular line through the figure which indicates roughness of the bottom near Applegate Reef. The herring schools are primarily between 60 and 110 meters depth.

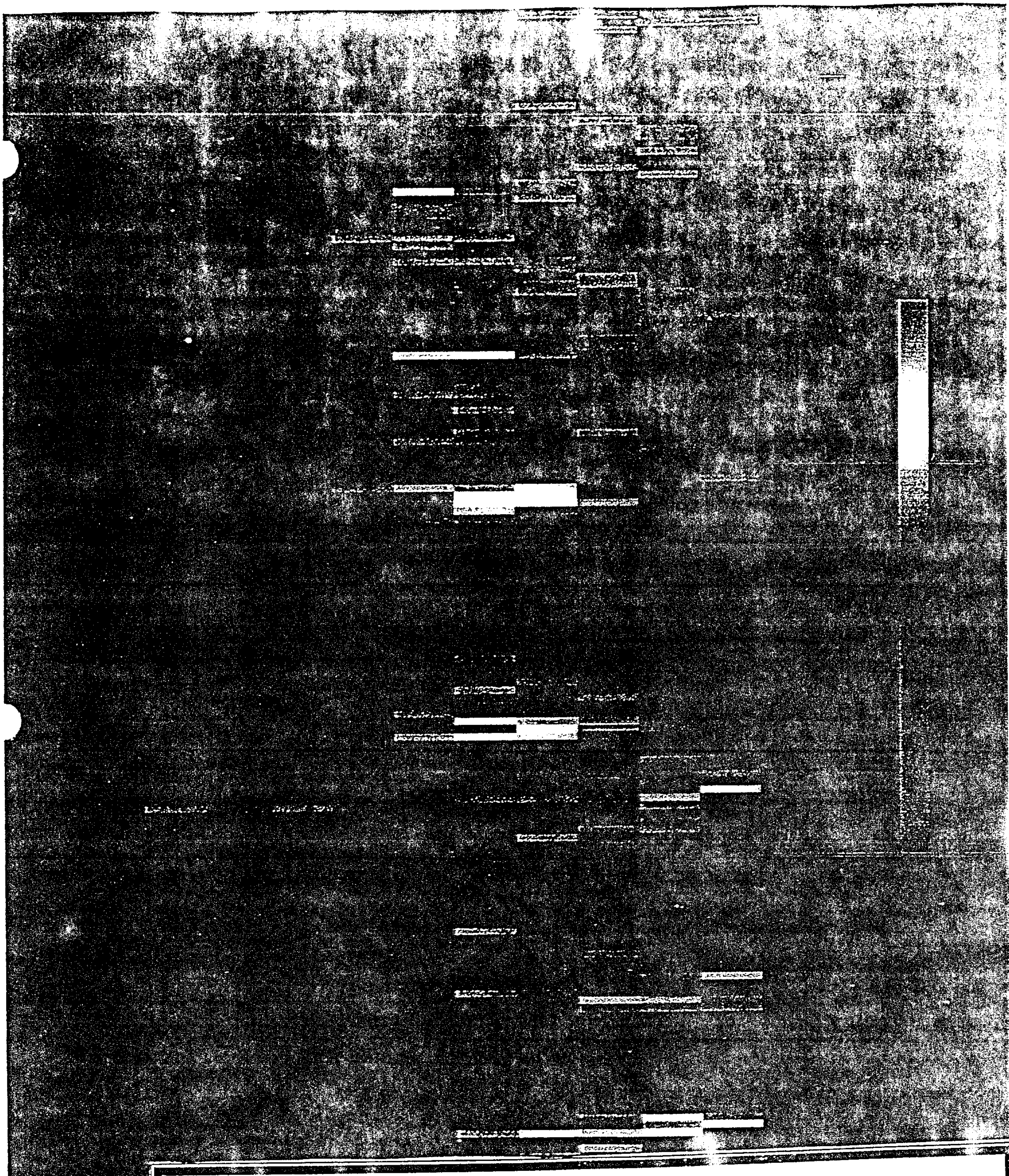

Figure 5b: Schematic of the processed cells along the same daytime transect shown in 5a. The x axis is time and distance, the y axis is depth, the color scale is from low to high biomass.

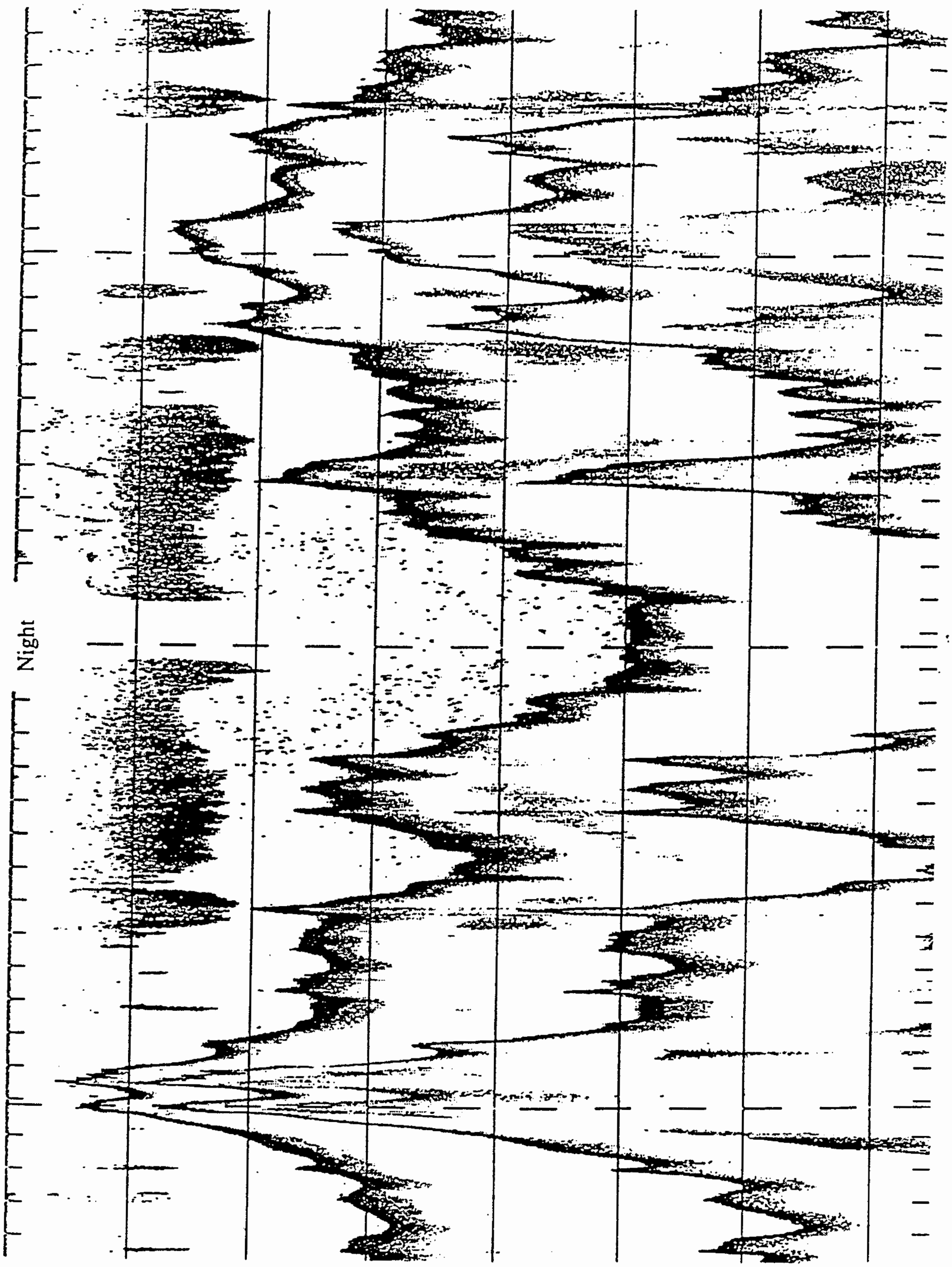

Figure 6a: Echogram of the night time vertical distribution of herring biomass along a transect near Applegate Reef on 23 April 1993. The top of the x axis is the surface of the water column and the y axis is depth in 20 meter intervals. The bottom is the continuous irregular line through the figure which indicates the roughness of the bottom near Applegate Reef. The herring schools are primarily between 10 and 40 meters depth.

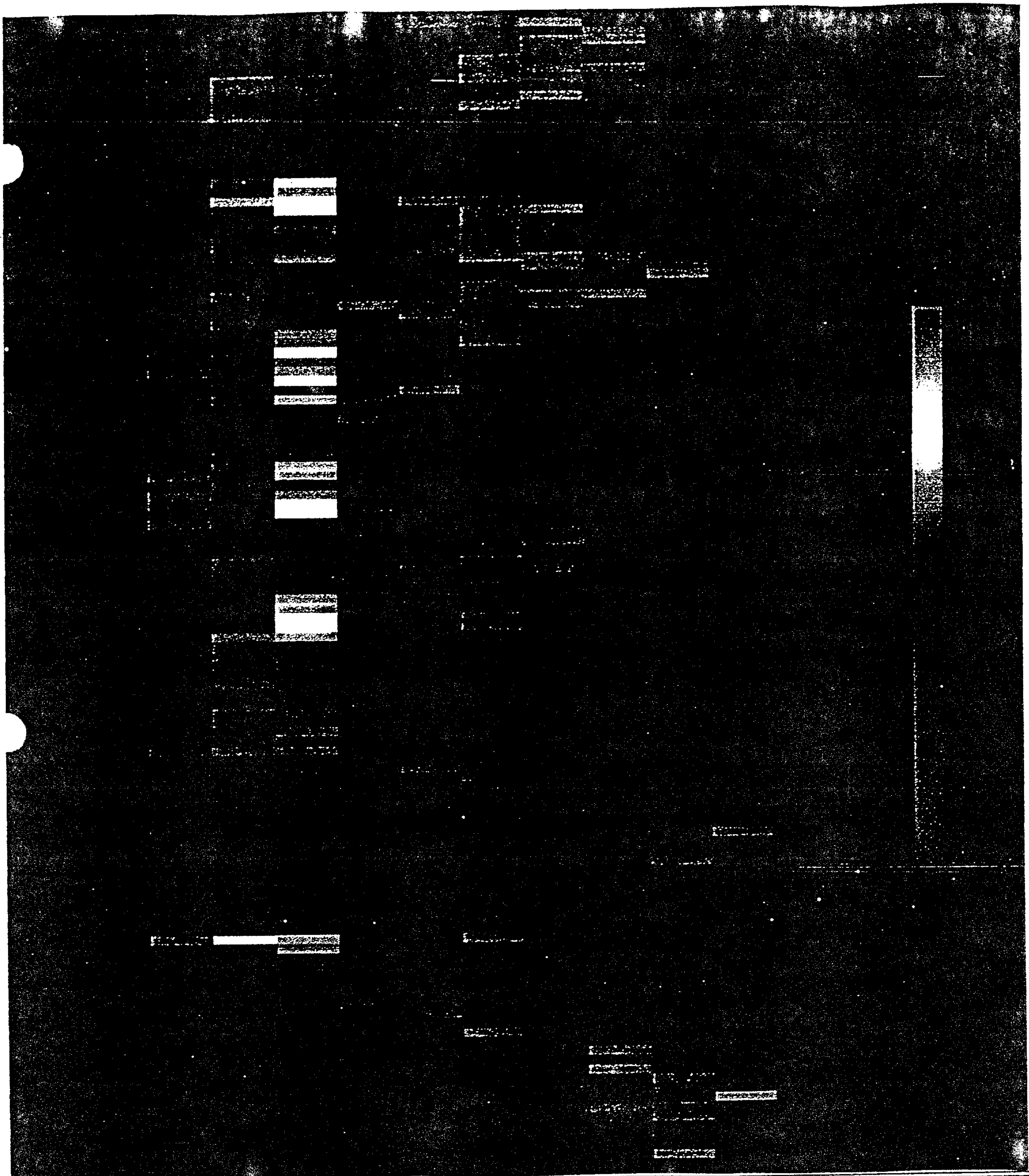

Figure 6b: Schematic of the processed cells along the same night time transect showm in 6a. The x axis is time and distance, the y axis is depth, the color scale is from low to high biomass.

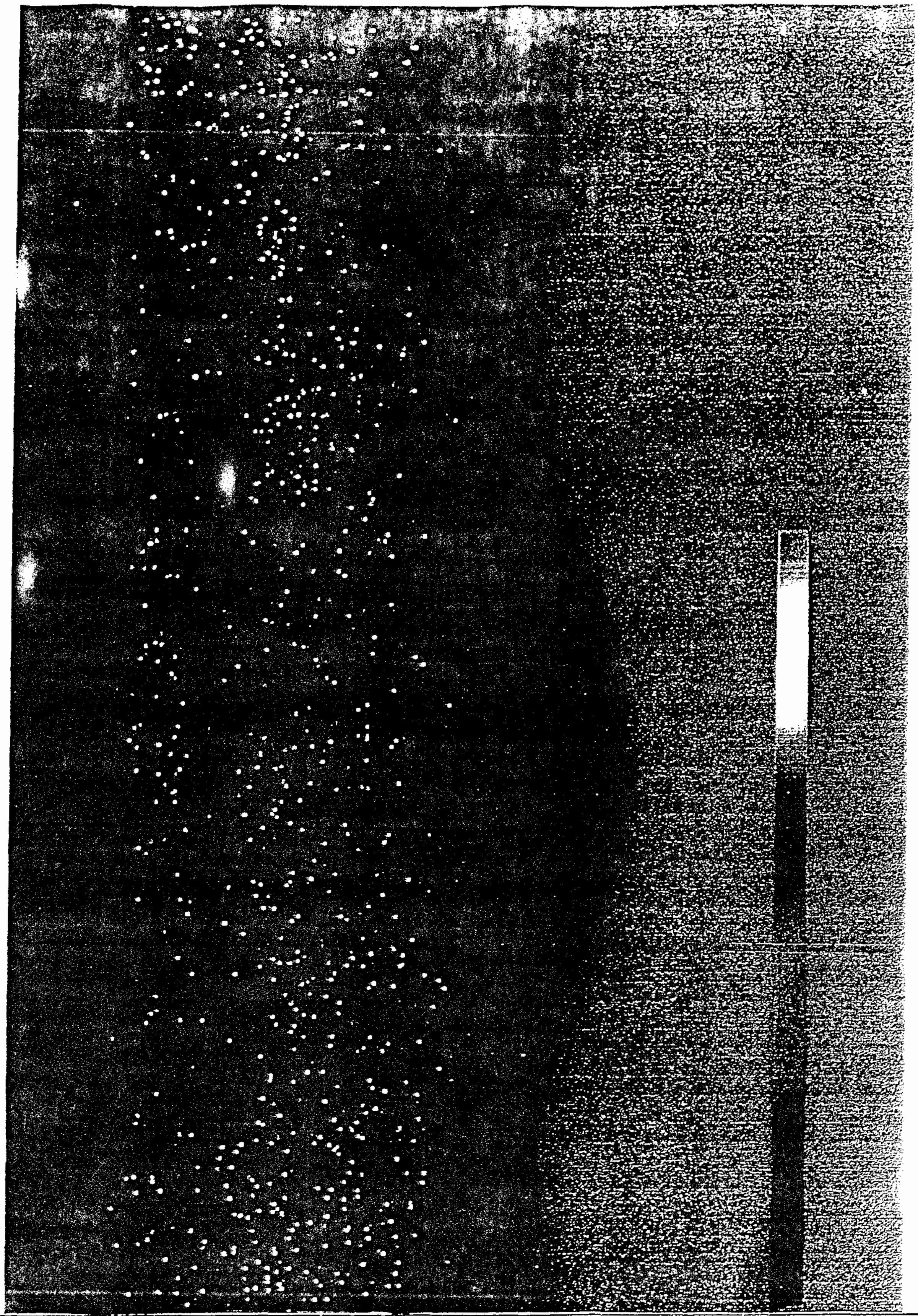

Figure 7: Target strength of individual fish along one transect near Green Island. Color scale bar goes from purple (small) to red (large) fish. The x axis is time and distance. The y axis is depth (in m). Note larger (red) targets near bottom structure and trend with smaller fish nea. urface.