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Acoustic estimation of fish abundance in a large aggregation of herring

by

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ABSTRACT

A large aggregation of herring located in the southern part of Chedabucto Bay, N. S. during February 1984 was surveyed acoustically. Repeated zig-zag transects were run across the aggregation during three consecutive nights. Herring were caught by midwater trawl for identification and measurement. The size and density of the aggregation changed over time and these two factors were not inversely related. Acoustic estimates of abundance made at different times may vary by a factor of 3.0. Thus acoustic estimates of abundance based on a single observation of an aggregation may be seriously biased.

RESUME

En février 1984 on a fait le relevé par acoustique d'une importante agrégation de harengs localisée dans le sud de la baie Chedabucto (N.-E.). Pendant trois nuits consécutives, on a parcouru à plusieurs reprises des transects en zig-zag traversant l'agrégation. On a capturé des spécimens au chalut flottant pour les identifier et les mesurer. On a constaté que l'étendue et la densité de l'agrégation variaient et que ces deux facteurs n'étaient pas en relation inverse. L'abondance des poissons, estimée d'après les résultats des sondages acoustiques, peut varier par un facteur de 3,0. L'estimation de l'abondance d'après un seul sondage peut donc être fortement biaisée.

INTRODUCTION

The optimum conditions for acoustic fish abundance surveys include a thorough understanding of the distribution, in time and space, of the fish population concerned (Jakobsson 1983) and the design of surveys aimed at providing absolute estimates of abundance requires a thorough knowledge of the biology, distribution and behaviour of the fish (Johannesson and Mitson 1983). This is particularly important in highly migratory pelagic stocks such as the Icelandic capelin (Vilkjȧlmsson et al. 1983) and the Icelandic summer spawning herring (Jakobsson 1983) where successful acoustic estimates depend more on being in the right place at the right time than on statistically based sampling methods. Hence, it is reasonable to conclude that the same constraints apply to the highly mobile herring stocks in Atlantic Canada.

Additional evidence for this can be observed in the Atlantic herring fishery itself. The major catches are made by purse seine at night because the fish are usually not available to seiners, nor can they be detected by sonar during the day. When fishing, the seiners do not simply steam to the fishing grounds, hunt for a school and make a set. Often, they must wait in an area for the right conditions and they frequently return to port without making a set. In other words, although the fish are not detected by the seiners' sounders and sonars in sufficient quantity to warrant a set, the fishermen know that the fish are present and will wait for the right conditions. Usually this means that the fish are close to the bottom but might rise later so that the quantity can be appraised and, if sufficient, a set made. This strongly suggests that these fish are not accessible to acoustic estimation at all times. It also suggests that the first condition for reliable abundance estimates, that "the fish stock is known to be available for acoustic measurement in the survey area" (Johannesson and Mitson 1983), is not fulfilled in this situation.

The acoustic measurements presented in this report quantify the change in biomass in ten replicate surveys of a large concentration of herring. The greater portion of the change is attributed to variable "acoustic availability" of the fish rather than to measurement and sampling errors. The total biomass in the concentration is therefore best estimated by the maximum of the replicates rather than the mean.

MATERIALS AND METHODS

A large aggregation of herring was located in Chedabucto Bay, N. S. (45°22'N, 61°10'W) during Feburary 1984. The aggregation was surveyed using acoustic instruments and midwater trawl by the R.V. E.E. PRINCE from 3-6, February. Echograms (Fig. 1) showed the herring to form a coherent aggregation during the nights. The aggregation was about 11 km long by 4 km wide with the long axis in an approximately east-west direction. The vertical distribution at night was from the sea bed (about 50 m depth) to within about 15 m of the surface. During daylight the distribution was patchy or not visible on the echosounder (Fig. 1).

The acoustic equipment used consisted of a transducer (Ameteck Straza SPLT-5); in a towed body (Fathom Inc.) an echosounder (Simrad EK50) and a data logging system. The transducer was calibrated in the body for transmit and receive sensitivity and for beam pattern by standard reference hydrophone at the calibration facility (DREA) in Bedford Basin, N. S. The rest of the equipment and its calibration is described in Buerkle (1984).

Digitized acoustic data from the aggregation were recorded at night while steaming series of transects across the aggregation at 8 knots with the transducer at about 5 m depth. The aggregation was covered repeatedly in easterly and westerly directions. The easterly running transects were approximately NE and SE. The westerly running transects were approximately NW and SW. Changes in course from one transect to the next were made after the echo sounder showed the edge of the aggregation. On a few occassions the herring were closer inshore than the boat could safely navigate (about about 10 m depth and about 200 m from shore). In those cases a new transect was started before the edge of the fish aggregation was reached.

A log of position every 15 min was kept and this was coordinated with time marks on the echo-sounder charts.

Fish samples were collected by five tows with an Engel 400 mesh midwater trawl. The echo-sounder chart records were edited by a digitizing process to specify the time and depth windows of herring echoes in the acoustic records. By using a digitizing table the start time and time of each patch of fish on the sounder chart, as well as the time and depth of each change in bottom profile were recorded in a data file. This editing allows unwanted echoes from unidentified sources and noise to be excluded from further processing. It also allows fish signals near the sea bed to be separated from the sea bottom echoes. When fish are dense, the bottom pulse generated by echo sounders may be triggered by fish echoes rather than by the bottom echo and the portion of the fish signals below this "false" bottom pulse are lost to further processing. To prevent this, the threshold controlling the generation of the bottom pulse can be raised. This will cause the bottom echoes to be too weak to trigger the bottom pulse in some pulses and the bottom signal will be added to the fish signals. To avoid this, the editing process establishs a bottom contour in each fish patch which is used to stop integration and is particularly useful when fish occur close to rough bottom.

The digital acoustic records were processed by software that uses the edit data and the time and position data recorded during the survey. The program calculates the latitude and longitude of the start of the school and the end of the school in each transect through the aggregation. It calculates the average area scattering coefficient in each transect (Forbes and Nakken 1972; Craig 1981) and its standard deviation. It also prints a histogram of the frequency distribution of echo levels in the transect.

The average area scattering coefficient for each coverage was calculated from the average area scattering of the individual transects in the coverage weighted by transect length (Table 2) by

$$\bar{S}a = \sum W_i \bar{s}a_i \tag{2}$$

where $\bar{S}a$ is the weighted mean area scattering for the area, $\bar{s}a_i$ is the average area scattering in the ith transect, and

$$W_i = \frac{l_i}{\Sigma l_i} \tag{3}$$

where W_i is the weighting factor and l_i is the length of the ith transect. The standard error for the weighted mean (E) was calculated after Snedecor and Cockran (1967) by

$$E = \sum W_i \left(\frac{s^2_i}{n_i} \right)^{\frac{1}{2}} \tag{4}$$

where S^2_i is the variance of $\bar{s}a_i$ and n_i is the number of pulses in the ith transect.

The geographic position of transects were plotted on charts and the edge of the aggregation was delimited by eye-fitted curves joining the ends of the transects for each coverage of the aggregation. The area of the aggregation for each coverage was estimated by counting dots on plastic overlays (Bruning Areagraph).

RESULTS

Herring caught in five midwater tows were measured for length and weight. The herring ranged in length from 15 cm to 40 cm, with a mean length of 28.9 cm. The length frequency distribution (Fig. 2) was approximately normal. This length-weight relationship (Fig. 3) was calculated to be

$$Wt_{kg} = 4.834\ l_{cm}^{3.1199} \times 10^{-6} \qquad (1)$$

by the least squares method ($r^2 = .975$).

The herring aggregation was crossed by a total of 70 transects during the nights of February 3-4, February 4-5, and February 5-6, Figures 4, 5, and 6, respectively. These figures show the portions of the transects that crossed the fish aggregations and the aggregation boundaries for the three or four coverages made each night. The transects are marked with the time at the midpoint of the transect to help identify the series of transects that make up individual coverages. The 10 coverages with times from beginning to end, the number of transects and the estimated area are listed in Table 1.

The aggregation did not move appreciably during the three nights but did change in shape. The shapes assumed by the aggregation during individual nights are quite similar to each other, the changes in shape from night to night are more pronounced. A similar pattern can be seen in the estimated areas (Table 1).

A quantitative estimate of the error in the area estimates cannot be made. The boundary of the aggregation may not follow the smooth curve between transect ends which are assumed in the area estimates. The actual areas could be somewhat larger or smaller, but to be greatly in error, this would imply that major bulges and indentations in the actual aggregation boundaries occurred that were undetected by the transects. The transects in the different coverages cross different sections of the aggregation so that a major extension or indentation in the boundary between transect ends in one coverage would be expected to show up in the next coverage. Instead the transects indicate a fairly smooth change in shape and area with time that is fairly well tracked by the repeated coverages.

The acoustic estimates for each of the 70 transects through the aggregation are presented in Table 2. In addition to these, a frequency distribution of area scattering coefficients in each transect was produced. A sample of these distributions is shown in Fig. 7 where their frequency of occurrence is plotted against scattering level in class intervals of one half standard deviation from the mean. Some of these distributions are approximately normal while others deviate from normal to various degrees. A high frequency of one of the lower levels of scattering such as indicated by transect 34, indicates that the transect covered a portion of the aggregation where scattering was lower. This is verified by the corresponding of sections of lighter markings on the echograms. Obviously in an aggregation of this size patchiness of acoustic scattering should be expected. This may be due to patchiness of aggregation density, of size distribution, or even of behaviour.

The estimates of mean area scattering and variance in each transect (Table 2) are based on the assumption of reasonably normal distributions of area scattering levels. Since the distributions, at least in some transects, are not normal, the mean and the variance estimates may be in error and result in errors in the biomass estimates. In relation to other possible errors associated with this method, the errors due to non-normal distribution of area scattering are likely insignificant.

The coefficient of variation of all 71 transects (Table 2) show a strong central tendency with 63% of the values between 0.4 and 0.7. When mean scattering coefficients are estimated for transects through patchy fish distribution rather than for transects within a coherent fish aggregation as done here, the coefficients of variation are almost an order of magnitude larger (Suomala 1983). This indicates that estimates of mean scattering coefficients for transects in patchy fish distributions have large confidence intervals and that abundance estimates based on such transects are of questionable value. A more meaningful approach might be to determine mean scattering coefficients within the patches of fish and estimate the proportion of the survey area occupied by patches.

The standard errors of the mean area scattering coefficients in this aggregation are small (Table 1), the 95% confidence limits for the means are about ± 3% of the mean. It appears that mean acoustic scattering of a herring aggregation can be estimated with high precision.

The aggregation biomass is proportional to the product of average area scattering and the area of the aggregation. This product is shown as relative biomass for each of the 10 coverages as a proportion of the largest one obtained in Table 1. As with aggregation shapes and areas the range of biomass estimates during different nights is greater than that during each night. The biomass estimated during different nights varied by a factor of more than three. A single estimate of biomass in a herring aggregation, even when based on multiple transects through the aggregation, may be only one third of what it might be on another occasion.

This poses a number of questions: are these changes due to measurement errors, do they represent actual changes in biomass or are they due to other causes. Sources of measurement error are the estimates of mean scattering coefficients (in which we have high confidence) and the estimates of area of the aggregation for which there are no error estimates. If the variations in biomass estimates were due to errors in the area estimates the actual areas would have to be in error by as much as 347% and as little as 56%. This magnitude of error is highly unlikely. Therefore, the major variation in biomass estimates most probably reflects real changes in the biomass sonified or is due to other causes.

Real changes in the biomass of herring sonified of this magnitude implies a movement of large quantities of fish into and out of the survey area. This is unlikely because the edges of the aggregation were so well defined (Fig. 1) and no signs of fish were observed outside these bounds. If the herring do remain in the area, then they cannot be equally accessible for acoustic estimation at all times.

The daytime distribution of the herring in this area indicates that they go close to the bottom where they are not detected by acoustic instruments. A single 15 min tow with a bottom trawl in the area where no traces of fish showed on the echo sounder caught about 300 kg of herring

(Shotton pers. comm.). Therefore, a reasonable explanation for the variation in biomass estimates is that a variable proportion of the herring remain undetected near the bottom. Another explanation might be a change in behaviour affecting target strength. Changes in tilt angle which would produce a threefold increase or decrease in acoustic back scattering would have to be pronounced. No evidence for such changes was evident in in situ photographs of herring (Buerkle unpublished).

In total, the results suggests that the herring in this aggregation are not equally accessible for acoustic estimation at all times even during single nights. This could be a characteristic of herring in general and would mean that abundance estimates based on unreplicated acoustic survey results may have little relation to actual abundance. In replicated surveys it implies that most of the variation between replicates is not due to measurement or sampling errors but rather to changes in the sampled population. Normal statistical procedures do not apply and biomass estimates should simply be based on the largest replicate.

The largest estimate in this survey was obtained from coverage 5 (Table 1) where the average area scattering was 0.001407 sr^{-1} and the estimated area was 45.0 km^2, whose product gives a total scattering of 61726 m^2sr^{-1}.

Total scattering (m^2sr^{-1}) can be converted to biomass (kg) if the average target strength ($m^2sr^{-1}kg^{-1}$) of the surveyed fish is known. The target strength of herring was a special topic of the ICES Fisheries Acoustics Science and Technology Working Group Meeting in 1983. The report of the working group lists eight relationships of herring target strength and fish length that are in common use. It concludes that none of them could be recommended for universal application and that one should, if possible, obtain in situ data for all assessment work. Without such data, an absolute biomass estimate cannot be calculated, however, the range of possible biomass indicated by the eight relationships however can be calculated.

By using the length-weight relationship of the herring in the aggregation (Equation 1) the target strength-length relationships for individual fish (in the working group report) were converted to the target strength-length relationships per kilogram of fish. The average fish length of 28.9 cm was then used to calculated the target strength for this herring aggregation from each of the eight relationships. The results together with the estimated biomass are shown in Table 3.

The estimates vary by a factor of almost three. Of the eight relationships considered, only those of Halldorsson and Reynisson (1982) and Halldorsson (1983) are derived from in situ measurements as recommended by the working group. Both are based on the same measurements made on winter adult herring during the night. The 1983 relationship differs in that it includes the effect of depth on target strength.

Halldorsson's (1983) target strength estimate seems the most fitting to convert the Chedabucto Bay total scattering estimate to biomass. The 95% confidence interval for Halldorssons's (1983) target strength can be calculated to be about ± 1 dB. This margin of error is small and suggests that measurement errors are not the cause for the large spread in estimates from the different sources. However, these target strength measurements were made at 38 kHz while the system used for this survey used sound of 50 kHz. Target strengths in general have been shown to decrease with frequency. Love (1971) gives the frequency dependence of dorsal aspects target strength in decibels as .9 $\log\lambda$ where λ is the wavelength. According to this relationship, the target strength calculated from Halldorsson's equation is about 2.4% higher than it would be at 50 kHz. The biomass estimate of 447 000 t is therefore 2.4% too low and should be adjusted to about 458 000 t.

In addition to the herring described in this aggregation, two other areas with herring were found in Chedabucto Bay. One was located south of Green Island, the other was located in the middle of the mouth of the Bay. These areas were crossed by repeated transects similar to those in the large aggregation, but weather and herring behavior did not permit good area coverages or replicate estimates. Treating the data that were available in the same way as that for the large aggregation resulted in biomass estimates of about 75 000 t in the Green Island area and about 12 000 t in the mouth of the Bay.

Within the constraints of the uncertainty about target strength, the total biomass of herring in Chedabucto Bay in February 1984 is estimated to have been about 545 000 t.

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Table 1. Summary of measurement results in ten replicate area coverage of a large aggregation of herring.

Coverage	Time from	Time to	Number of transects	Number of pulses	Area km^2	Average scattering (sr^{-1})	Standard error	Relative biomass
1	22:21	23:48	7	1978	31.2	.987 E-3	.198 E-4	.49
2	23:40	04:14	5	3122	31.6	.585 E-3	.118 E-4	.29
3	04:10	05:11	4	3592	23.3	.773 E-3	.153 E-4	.29
4	18:57	22:46	8	7883	35.4	.961 E-3	.207 E-4	.54
5	22:38	00:20	6	3554	45.0	.141 E-2	.214 E-4	1.00
6	00:11	02:35	8	6762	44.0	.121 E-2	.201 E-4	.84
7	02:25	05.57	9	7389	46.7	.124 E-2	.258 E-4	.91
8	21:13	01:14	12	9117	43.3	.119 E-2	.196 E-4	.31
9	01:09	03:30	12	5534	39.5	.985 E-3	.223 E-4	.62
10	03:18	06:25	9	4396	34.3	.141 E-2	.251 E-4	.77

Table 2. Detailed results in 71 transects through a large aggregation of herring.

Transects #	Pulses	Miles	Average area scattering (sr^{-1})	Variance	Coefficient of variation
1	214	.616	.127 E-3	.558 E-8	.59
2	1204	3.105	.103 E-2	.415 E-6	.63
3	85	.220	.923 E-3	.248 E-6	.54
4	31	.072	.121 E-3	.121 E-7	.91
5	14	.029	.203 E-3	.156 E-7	.62
6	31	.070	.410 E-3	.182 E-7	.33
7	710	1.601	.114 E-2	.245 E-6	.43
8	399	.967	.128 E-2	.286 E-6	.42
9	538	1.459	.478 E-3	.686 E-7	.45
10	1380	3.164	.498 E-3	.942 E-7	.62
11	621	1.696	.459 E-3	.930 E-7	.66
12	181	.332	.534 E-4	.918 E-9	.57
13	750	1.885	.179 E-3	.292 E-7	.95
14	1121	2.699	.122 E-2	.526 E-6	.59
15	537	1.259	.893 E-3	.186 E-6	.48
16	390	.965	.937 E-3	.213 E-6	.49
17	673	1.937	.131 E-2	.190 E-6	.33
18	1408	3.716	.970 E-3	.306 E-6	.57
19	510	1.535	.618 E-3	.517 E-6	1.16
20	151	.363	.113 E-2	.405 E-6	.56
21	151	.347	.305 E-3	.426 E-7	.68
22	273	.759	.322 E-3	.255 E-7	.50
23	794	2.213	.123 E-2	.260 E-6	.41
24	964	2.494	.147 E-2	.294 E-6	.37
25	683	2.216	.204 E-2	.324 E-6	.28
26	56	.183	.116 E-2	.212 E-6	.40
27	482	1.055	.157 E-2	.402 E-6	.40
28	728	1.836	.205 E-2	.947 E-7	.15
29	1023	2.267	.119 E-2	.275 E-6	.44
30	572	1.524	.124 E-2	.401 E-6	.51
31	328	.910	.937 E-3	.209 E-6	.49
32	1039	2.208	.745 E-3	.201 E-6	.60
33	179	.466	.816 E-3	.287 E-6	.66
34	241	.621	.423 E-3	.187 E-6	1.02
35	986	2.406	.499 E-3	.272 E-6	1.05

Table 2. (continued)

Transects #	Pulses	Miles	Average area scattering (sr^{-1})	Variance	Coefficient of variation
36	974	2.628	.765 E-3	.346 E-6	.77
37	820	1.857	.119 E-2	.438 E-6	.56
38	720	1.871	.192 E-2	.630 E-6	.41
39	354	.737	.136 E-2	.101 E-5	.74
40	404	.953	.258 E-2	.433 E-6	.26
41	541	.956	.249 E-2	.454 E-6	.27
42	877	2.090	.148 E-2	.225 E-6	.32
43	100	.264	.102 E-2	.239 E-6	.48
44	812	2.094	.176 E-2	.234 E-6	.27
45	264	.583	.146 E-2	.388 E-6	.43
46	74	.160	.524 E-4	.109 E-8	.63
47	414	1.059	.524 E-4	.109 E-8	.59
48	67	.159	.718 E-3	.795 E-7	.39
49	1271	2.678	.156 E-2	.486 E-6	.45
50	533	1.385	.101 E-2	.251 E-6	.50
51	763	2.155	.243 E-3	.416 E-7	.84
52	191	.553	.443 E-3	.106 E-6	.73
53	49	.123	.421 E-3	.906 E-7	.71
54	336	.624	.296 E-3	.595 E-7	.82
55	500	1.652	.423 E-3	.571 E-7	.56
56	24	.049	.404 E-3	.635 E-7	.62
57	615	1.402	.129 E-2	.404 E-6	.49
58	49	.125	.283 E-2	.329 E-6	.20
59	122	.406	.149 E-2	.192 E-6	.29
60	685	1.950	.117 E-2	.132 E-6	.31
61	529	1.180	.142 E-2	.505 E-6	.50
62	144	.349	.612 E-3	.113 E-6	.55
63	563	1.541	.143 E-2	.662 E-6	.57
64	250	.623	.722 E-3	.131 E-6	.50
65	624	1.585	.111 E-2	.499 E-6	.64
66	1191	2.664	.161 E-2	.316 E-6	.35
67	611	1.300	.171 E-2	.472 E-6	.40
68	682	1.379	.174 E-2	.253 E-6	.29
69	295	.756	.129 E-2	.479 E-6	.54
70	47	.063	.311 E-3	.382 E-7	.63
71	126	.291	.368 E-3	.460 E-7	.58

Table 3. Biomass calculated from the maximum total scattering (coverage 5 of this survey) and the eight target strength-length relationships listed in the 1984 ICES Fisheries Acoustics Science and Technology Working Group report.

Relationship	Target strength dB re $m^2sr^{-1}kg^{-1}$	Biomass tonnes
North Sea Group (1983)	-34.4	170 000
Dalen et al. (1976)	-34.5	174 000
Edwards & Armstrong (1982)	-35.1	200 000
Nakken & Olsen (1973)	-35.3	209 000
Halldorsson & Reynisson (1982)	-36.2	257 000
Edwards & Armstrong (1982)	-37.8	372 000
Halldorsson (1983)	-38.6	447 000
Anon. (Norway)	-39.0	490 000

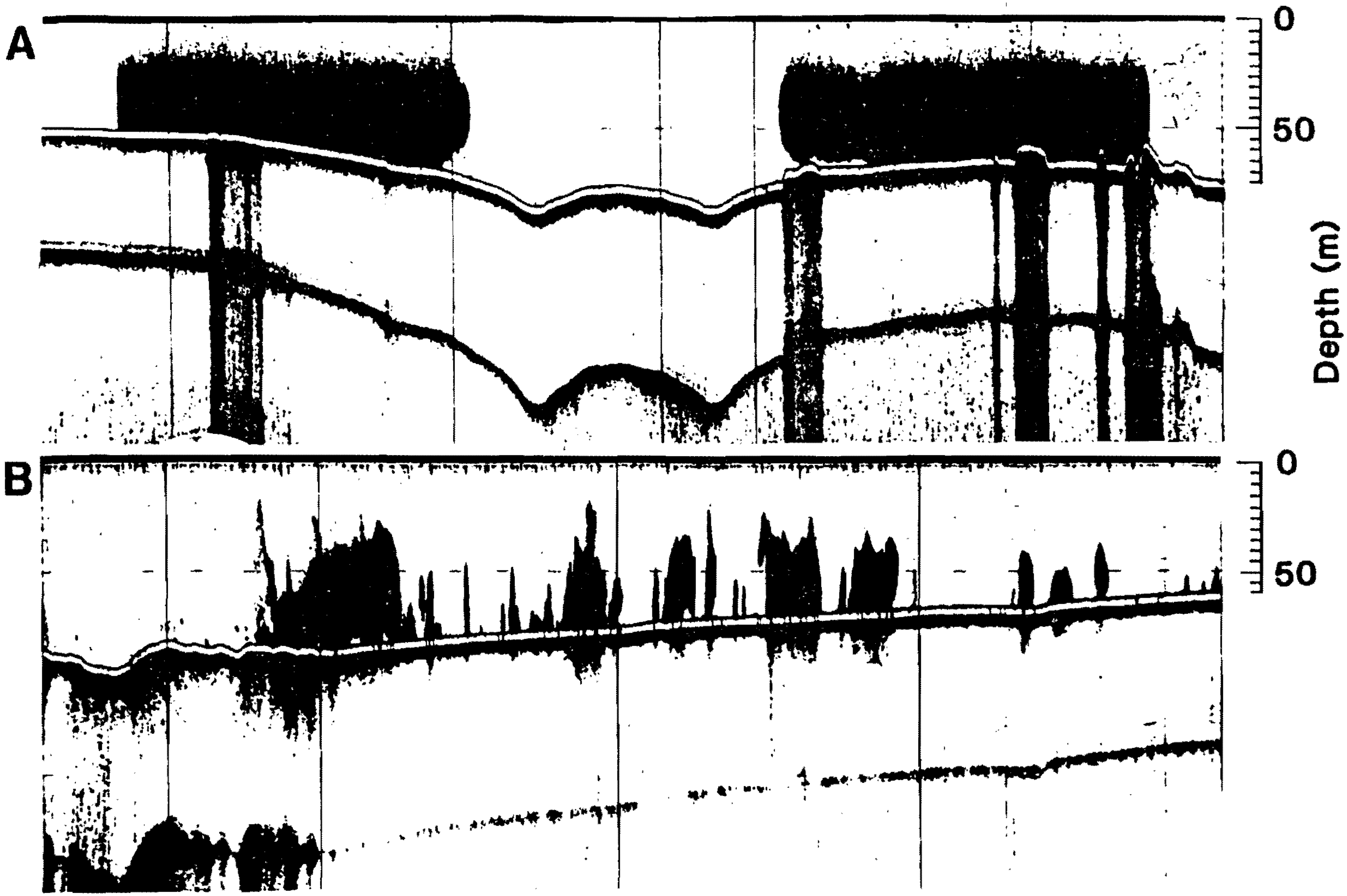

Fig. 1. Sample echogram of the vertical distribution of herring at night (A) and during the day (B).

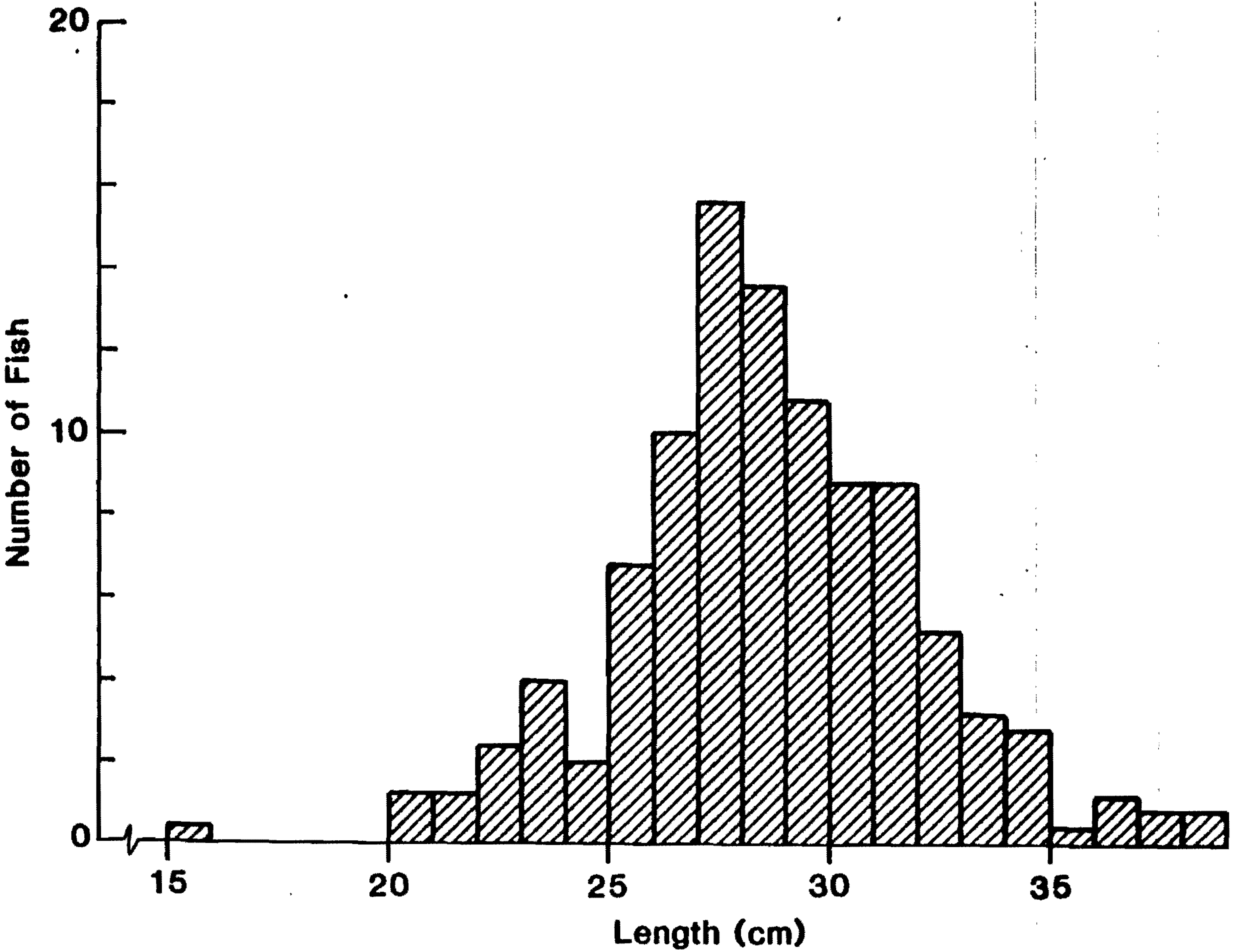

Fig. 2. Length frequency distribution of the 250 herring sampled from catches of 5 midwater tows.

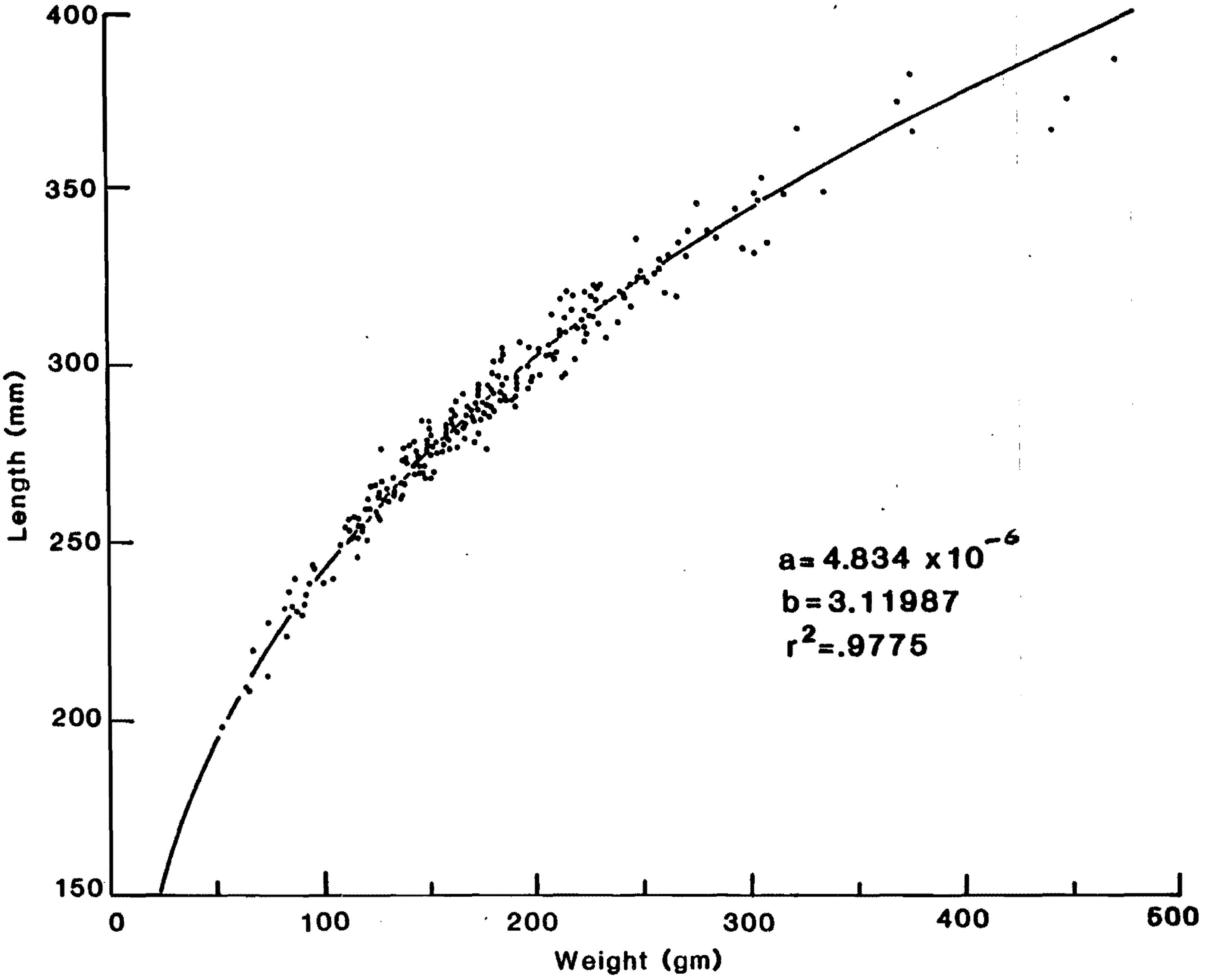

Fig. 3. Length-weight relationship of the 250 herring sampled.

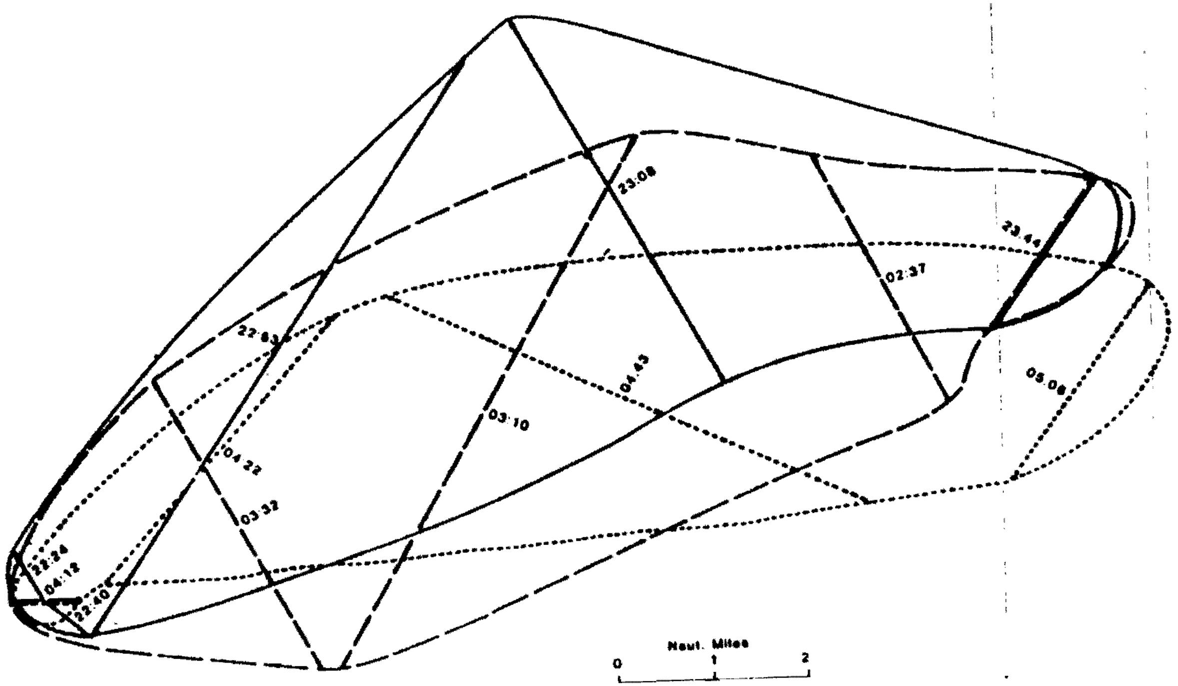

Fig. 4. Acoustic transects and aggregation boundaries for three coverages of the herring aggregation during the night of February 3-4.

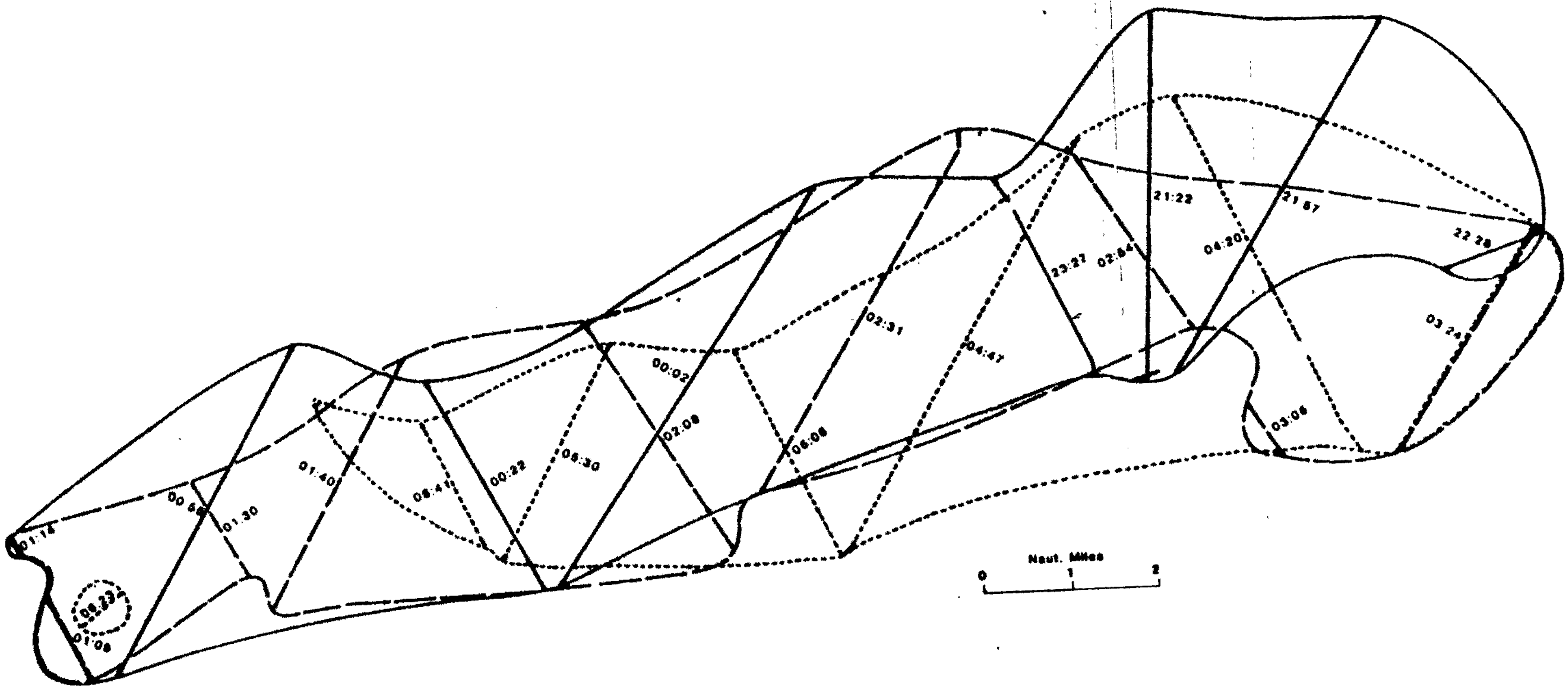

Fig. 6. Acoustic transects and aggregation boundaries for three coverages of the herring aggregation during the night of February 5-6.

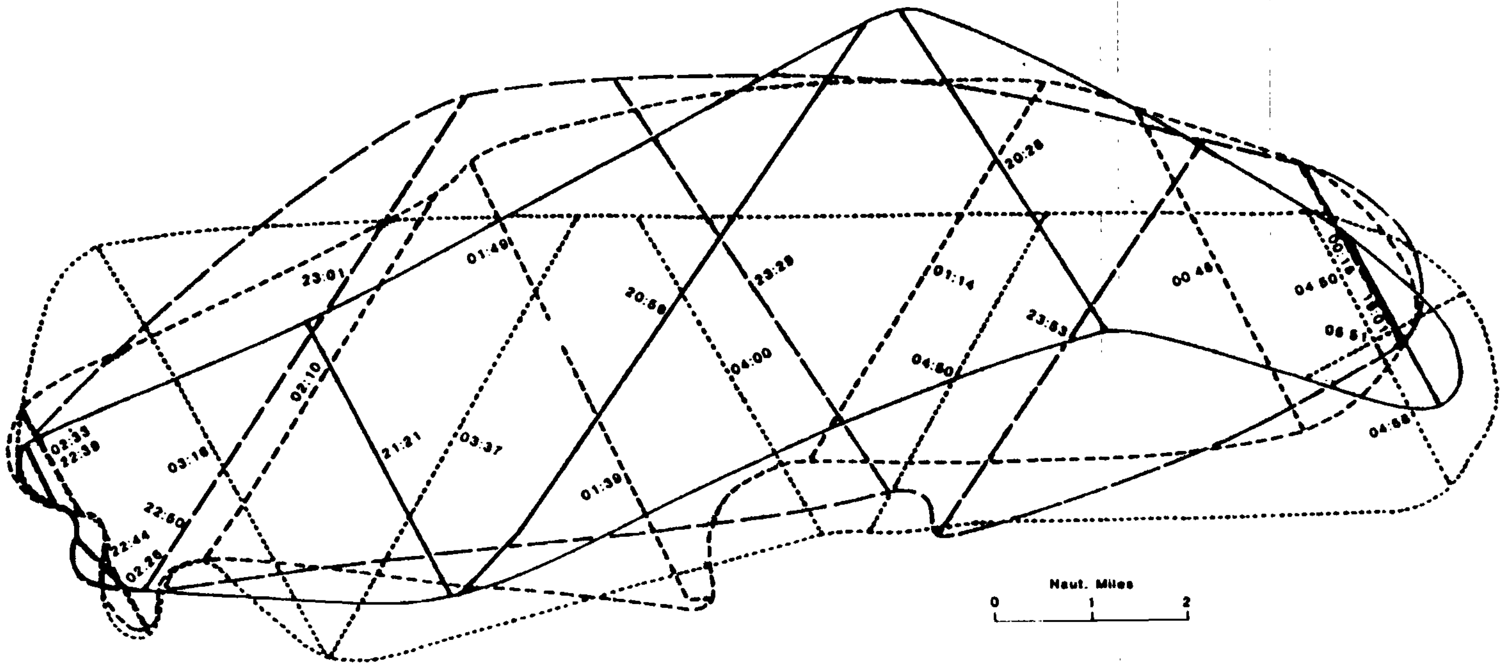

Fig. 5. Acoustic transects and aggregation boundaries for four coverages of the herring aggregation during the night of February 4-5.

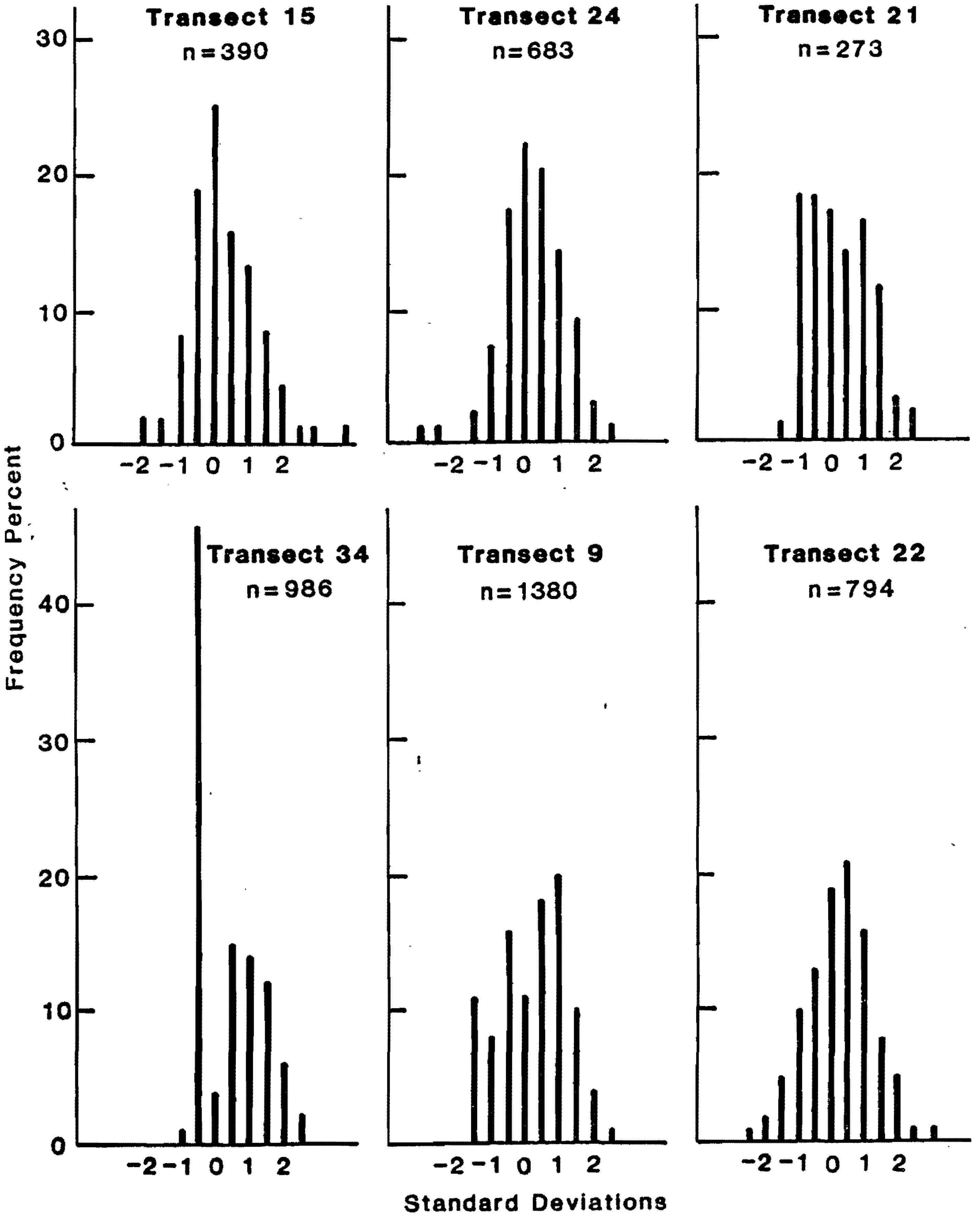

Fig. 7. Representative sample, in six transects, of the frequency distribution of acoustic scattering levels.