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The Use of Hydroacoustic Surveys to Estimate Capelin Biomass in NAFO Divisions 2J + 3KLNO

by

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Introduction

Capelin (Mallotus villosus) have been exploited in small scale inshore fisheries in Newfoundland for decades. In the early 1970's, a large offshore international fishery developed. Catches increased rapidly from 72,000 t in 1970 to 370,000 t in 1976 and have declined since then. Quota regulation of the fishery has been in place since 1976.

Because of the short life span and the high variability in year-class strengths of this species, it has been necessary to assess the status of the stocks on an annual basis to provide advice on quota levels. Standard analytical models such as virtual population analysis (Gulland 1965) and cohort analysis (Pope 1972) are not suitable for capelin stock assessment because of the extremely high spawning mortality occurring during the reproductive phase of the life history.

Sequential capelin abundance models, similar to virtual population analysis but accounting for the high spawning mortality, have been developed (Carscadden and Miller 1979) to provide an historical perspective of capelin population dynamics but have been limited in their usefulness because of the lack of reliable catch per unit effort data in recent years combined with extremely low fishing mortality rates.

In recent years, hydroacoustic stock assessment techniques have been used to assess a variety of schooling pelagic fish stocks in the eastern Pacific and the Barents Sea (Midtunn 1981, Trumble et al. 1982, Thorne 1972, Dommasnes and Rottingen 1976). Northwest Atlantic capelin stocks are particularly well suited for hydroacoustic stock assessment for several reasons. Capelin school size and distribution can be highly variable depending on factors such as seasonality of the survey and age composition of the surveyed population. Hydroacoustic surveys permit large spatial coverage in a relatively short time period allowing complete coverage of the expected range of the capelin stock. The acoustic survey allows estimation of the pre-recruit part of the stock which is not available from commercial fishery models. Acoustic surveys are independent of school size, shape, and depth distribution allowing for complete coverage except in the very near bottom and near surface zones. Hydroacoustic stock assessments are independent of commercial fishery data and are unaffected by the potential bias inherent in using sequential abundance models that are tuned by commercial catch per unit effort indices. Capelin aggregations usually tend to be clean with little mixing with other species which permits a biomass estimate free of other species contamination.

Acoustic surveys are carried out in three different capelin stocks (NAFO Division 2J3K, 3L, and 3NO) on a yearly basis. These stocks have been delineated on the basis of spawning areas and morphometric and meristic studies (Carscadden and Misra 1979, Campbell and Winters 1973). The surveys cover large geographic areas with variable depth ranges and detect capelin of varying age, maturity, and feeding activity at different times of the year. Results of two surveys carried out during 1985 on the 3L and 3NO stocks are presented as an example of the technique. Sources of variation and potential bias are discussed.

Materials and Methods

Acoustic data were collected using a Simrad EK400 echo sounder operating at 49.0 kHz with a pulse length of 0.6 milliseconds. A time-varied-gain of 20 log R + 2αR was used. Returned

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echo signals were demodulated and fed to a custom designed microprocessor controlled data acquisition system (Stevens et al. 1985). This system sampled the signal at a 15 kHz sampling rate corresponding to one sample every 5 cm of water depth. Any samples exceeding a predefined threshold voltage were digitized and written to 9-track computer tape for subsequent echo integration analysis on another computer system.

The transducer used was an Ametek-Straza SP187LT with a half power beam angle of 6°. The transducer was housed in a remote towed body that was kept at a depth of 10-20 m below the surface at a distance of 100-150 m behind the ship to minimize any effects of vessel noise. Vessel speed was maintained at 10 knots except during bad weather when it was reduced accordingly.

The geographic area to be covered for each survey was subdivided into discrete blocks based on the expected distribution of capelin determined from earlier surveys (Fig. 1 and 2). Within each block, a systematic zigzag survey design was used. The choice of a zigzag pattern was made for the following reasons.

Acoustic surveys of fish populations carried out by other investigators have employed both zigzag and parallel designs (Thorne et al. 1971, Johannesson and Vilchez 1979, Midtunn 1979) although some more complicated and less appealing designs have been attempted. The choice of survey design has usually been subject to the discretion and imagination of the researcher rather than being considered for ease of statistical analysis and data intepretation. A recent study by Kimura and Lemberg (1982) has provided a theoretical framework for the selection of the most appropriate survey design. Assuming fish schools were elliptical, computer simulations of surveys were conducted at varying fish densities and varying intensity of area coverage. They concluded that a zigzag pattern resulted in smaller confidence limits than a parallel pattern when less than 5% of the area was surveyed. If the coverage was more extensive, then the parallel design produced an estimate with less bias. In capelin acoustic surveys, a very large area must be covered to take into account the potential extent of capelin distribution for each stock, less than 5% (and typically less than 1%) of the area is sampled in any one survey. Also due to time constraints, a zigzag design was found to be the most efficient means of utilizing expensive ship time.

Timing of the surveys was chosen to correspond with seasonal distribution patterns of the different stocks. A prespawning survey was carried out in NAFO Division 3L in May as prespawning concentrations from the 3L and 3NO stocks congregate at this time of year. Prerecruits of both stocks are also available to be surveyed. A subsequent survey was carried out in the late June and early July in Division 3L and 3NO and covers prerecruits of both stocks and the mature spawning component of the 3NO stock which has congregated to spawn in southern 3NO. A survey during September-October is also carried out on feeding concentrations of capelin in Divisions 2J and 3K.

Midwater trawl fishing sets were conducted throughout the survey to provide length and age distributions of capelin and to determine the extent of mixing with other species.

A weight/target strength regression; T.S. (dB) = 11.56 log W (gms) - 65.95, was calculated using data from in situ target strength measurements using live capelin specimens (Buerkle, personal communication). This regression shows that target strength per kilogram is -34dB +- 0.5dB over the expected range of capelin sizes encountered during surveys. This is well within the range of variation of the individual specimen target strength per kilogram and this mean value of -34dB/kilogram is used for analysis of all capelin acoustic surveys.

Subsequent analysis of the digitized acoustic data was carried out by squaring the sample voltage (rms) levels and averaging over one meter depth intervals. Data were corrected to an ideal TVG function of 20 log $R+2\alpha R$, the attenuation coefficient was set at 0.0175dB/meter (Miller and Stevens 1984). Data were accumulated over 10-minute intervals corresponding to a survey track distance of 3.1 km and averaged. The density (in kg/m^3) for depth R is then calculated from:

$$\lambda = \bar{V}_{R^2} \times \frac{1}{R^2{}_x \, P^2{}_0 \, \bar{b}^2 \, \frac{\bar{\sigma}}{4\pi} \, \pi c t \, G^2{}_0} \qquad (1)$$

where $\bar{V}_{R^2}$ is the average rms voltage squared at depth R
R^2x is the receiving sensitivity of the transducer
P^2o is the rms transmitted pressure level
$\bar{b}^2$ is the average beam pattern factor
$\frac{\sigma}{4\pi}$ is the target strength per kilogram
c is the speed of sound and seawater
t is the pulse length of the transmitter pressure level
and G^2o is the fixed gain of the echo sounder

The total density (kg/m^2) per square meter of surface area is then calculated by summing the individual densities per m^3 over the depth range. If sampling within the survey block indicated the presence of other species in the acoustic sample, the density estimate was adjusted proportionally to the percentage by weight of capelin in the midwater trawl samples. An average density estimate was then calculated from these individual estimates for the entire survey block. Total biomass for the block is calculated by applying the mean block density to the total surface area of the block. Coefficients of variation due to sampling variation only are calculated using a cluster sampling model (Nakashima 1981). Age and length composition is then determined for each survey block using the samples taken in that survey block. The overall age and length composition is then determined by combining the block results weighted by their respective biomass estimates.

Results

The two acoustic surveys, Gadus 109 in Division 3L (May 10-29, 1985) and Gadus 111 in Divisions 3LNO (June 21-July 8, 1985) followed cruise tracks as shown in Figures 1 and 2. Locations of fishing sets made during the surveys are also indicated in the figures. Ice coverage to the north of the survey blocks A, B, C and D restricted survey coverage in this area during cruise 109.

Sampling data from capelin caught in midwater trawl sets were used to provide age and length compositions for each survey block (Fig. 3 and 4). Total age and length distributions were calculated from the combined samples for each survey block weighted by the biomass estimate for that block. Both surveys indicated the presence of a strong 1983 year-class as immature 2-year-olds.

The vertical distribution of capelin related to whether surveying occurred in the day or night is illustrated in Figures 5a-g and Figures 6a-e. The presence of a '+' mark indicates that 1% or greater of the total accumulated capelin density in the first 100 m sampled below the transducer occurred at the indicated 5 m depth zone. Day and night survey periods are indicated on each figure. Figure 5g shows the results for repetitive day/night surveys over the same transect. There is a clearly evident trend of movement to the surface at night and down in the water column during the day. Figures 7a-d show typical echograms of both immature capelin and mature spawning capelin during both day and night periods. Daytime concentrations are typically tightly packed into distinct schools. Night-time concentrations are generally very dispersed and extend to the surface.

A summary of the results of both acoustic surveys is presented in Table 1. Biomass per m^2 for each survey block is the mean of all ten minute interval densities for that block. The δ parameter indicates the relative importance of either inter- or intra-transect variance to the sample variance (Nakashima 1981). If δ approaches the lower limit of δ, intra-transect variance is the major component; if δ approaches 1.0, inter-transect variance is the major component. The coefficients of variation are applicable only as sampling variation and do not represent variation due to target strength or calibration measurements. Total biomass estimates for each survey block represent an aereal expansion of the biomass per m^2 to the total area of the survey block. Biomass was estimated from Gadus 109 for Division 3L to be 4,175,000 t. Biomass was estimated at 1,285,000 t for Division 3L and 226,000 t for Divisions 3NO from Gadus 111.

A summary of transect data is presented in Table 2, showing the number of transects per block, transect length, the range of mean densities, and the range of intervals per transect. Differences in the number of intervals per transect are attributable to variation in vessel speed and navigational errors.

Table 3 shows acoustic densities for repeats of the same transect conducted during day and night periods.

Discussion

Both surveys were able to cover the expected range of distribution of capelin except the northern area during Gadus 109. Capelin concentrations were observed at the ice boundary and presumably continued farther to the north. When the survey area is restricted, the biomass estimate is biased downward by an unknown amount. A total biomass estimate in such a case should only be considered as a minimum estimate of stock strength.

Age and length compositions for each survey block were provided by the number of samples as indicated in Figures 3 and 4. Although research sampling gives a more unbiased sampling of the age and length structure of the total population, the number of samples available to provide the age and length composition is small and is limited by the amount of time the acoustic survey vessel can spend fishing for samples. Estimates of the population structure would be improved if another vessel were able to conduct fishing sets in conjunction with the acoustic survey vessel.

During an acoustic capelin survey, the transducer is towed behind the ship in a towed body approximately 20 m below the surface in order to remove interference caused by ship noise. Sampling of the returned acoustic signal does not begin until 5 m below the transducer. This results in a 25 m zone at the surface that is not sampled acoustically. Movement of capelin towards this upper zone at night is indicated by the data shown in Figures 5, 6, and 7. This would suggest that on day/night repeats of the same transect, densities should be higher during the day than at night. However the data from Table 3 show the opposite with three out of four replicates having higher night densities than in the day. This would suggest that some change in capelin distribution during the day is biasing the acoustic density estimate downward. A variety of factors may be responsible. Target strength is greatly reduced by any change in the fish tilt angle from horizontal (Nakken and Olsen 1973). Behavioral differences such as feeding activity during the day may result in a more non-horizontal distribution which would result in a lower target strength. During the day a proportion of the fish may be distributed in the near bottom zone which is unavailable for acoustic sampling. If fish concentrations are very dense, masking of the returned acoustic signal from the bottom part of the school may occur. Any or all of these factors may help to explain the difference in day and night density estimates. Differences between day/night estimates have not yet been quantified but are a probable source of major variation in acoustic survey biomass estimates.

Capelin biomass for Division 3L was indicated at 4,175,000 t from Gadus 109 and at only 1,285,000 t from Gadus 111. This drop may be partly attributable to the movement inshore and to the south of spawning components of the stock, but the largest part of the Gadus 109 estimate was 2-year-old 1983 year-class capelin which would not spawn in 1985. Some immature capelin move into the inshore area but it is unlikely that the large difference between the Gadus 109 and 111 surveys is attributable to this. Other factors such as a northerly feeding migration may be responsible but the degree of this is unknown at present.

The estimate of target strength (the amount of acoustic energy reflected per unit of target species) that is used in equation 1 to estimate the fish density directly affects the overall biomass estimate from the survey. Researchers in the field of fisheries acoustics have recognized the importance of this parameter and much effort has been devoted to accurately determining it for certain species such as cod and herring (Nakken and Olsen 1973, Goddard and Welsby 1973, Haslett 1973, Olsen et al. 1973, Ehernberg 1982, Robinson 1982). For estimates of capelin target strength, we have relied on one set of experimental in situ target strength measurements carried out on pre-spawning male and female capelin (Buerkle, personal correspondence). No other estimates of Northwest Atlantic capelin are available. New advances in acoustics using dual beam and split beam transducers promise improved methods and ease of measuring target strength during the acoustic survey itself. However, the lack of more precise quantitative data on target strength at this time is a limitation of the reliability of capelin acoustic survey results as a measures of absolute capelin abundance.

Summary

1. Acoustics provides a method to quickly survey a large area for pelagic species distributed throughout the water column.
2. Acoustic data cannot be analyzed in the near bottom zone and cannot be collected from 5 m below the transducer to the surface.
3. Sampling by fishing should be carried out as often as possible during the survey to provide samples to determine age and length composition of the biomass estimate and to estimate the proportion of other species present.
4. Differences in distribution between day and night may account for a major part of the total variance in acoustic survey estimates. Knowledge of seasonal distribution is essential to determine the best time and area in which to conduct the survey. However, fluctuations in distribution from year to year may still change the proportion of the stock available to the survey.
5. Accurate measurement of target strength is essential to improved reliability of survey biomass estimates. Technological development in acoustics may provide the capability to get real-time target strength estimates as the survey is being conducted.

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Table 1. Survey results from Gadus cruise #109 (3L, May 1985) and cruise 111 (3LNO

Div.	Block	Area (km^2)	Biomass/gm^2 (gms)	Delta (δ)	Lower limit for delta (δ)	Coefficient of variation	Biomass ('000 t)
Gadus cruise 109							
3L	A	5162	78.0	.90	-.09	0.19	403
	B	4562	194.1	.94	-.05	0.27	885
	C	5464	248.7	.97	-.03	0.30	1359
	D	6817	63.8	.97	-.03	0.21	435
	E	23345	34.0	.98	-.02	0.25	794
	F	10770	27.8	.96	-.04	0.36	299
TOTAL		56120	74.4				4175
Gadus cruise 111							
3L	A	10433	33.7	.91	-.09	0.16	352
	B	18542	31.6	.97	-.03	0.34	586
	C	19468	12.5	.97	-.03	0.23	243
	D	24788	4.2	.96	-.03	0.23	104
TOTAL		73231	17.5				1285
3NO	E	25368	8.9	.98	-.02	0.29	226

Table 2. Summary of target data for Gadus cruises 109 and 111.

Cruise	Block	No. of transects	Target strength (km)	Range of mean transect densities	Range of no. of intervals per transect
Gadus 109	A	15	37.0	14.4-218.7	11-12
	B	5	74.6	45.6-394.3	23-24
	C	4	111.9	95.2-443.3	33-37
	D	4	139.5	31.6-97.5	32-39
	E	12	139.5	8.3-102.0	42-46
	F	8	93.9	2.9-85.2	26-29
Gadus 111	A	30	37.0	3.0-115.7	10-12
	B	7	113.7	9.0-100.9	35-37
	C	7	113.7	5.2-29.6	34-38
	D	9	114.1	.8-10.8	34-37
	E	7	172.4	2.6-24.5	53-57

Table 3. Day/night repetitive transect results.

Cruise	Pair	No. of transects	Daytime density	Nightime density
Gadus 109	1	34-35	87.2	95.2
	2	32-35	87.0	54.8
	3	36	84.2	145.2
Gadus 111	1	36	27.6	29.6

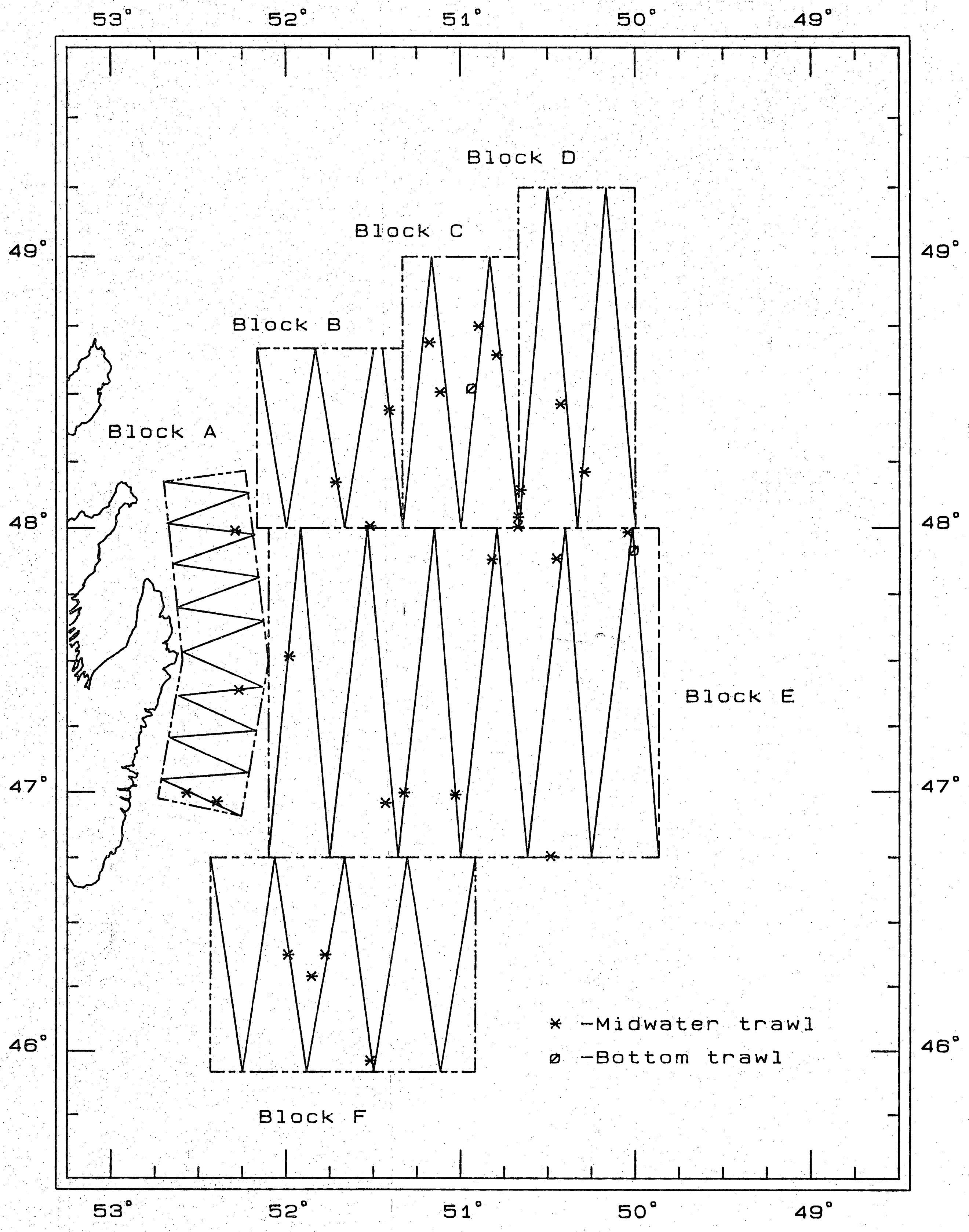


Figure 1. Gadus 109 cruise track, May 1985

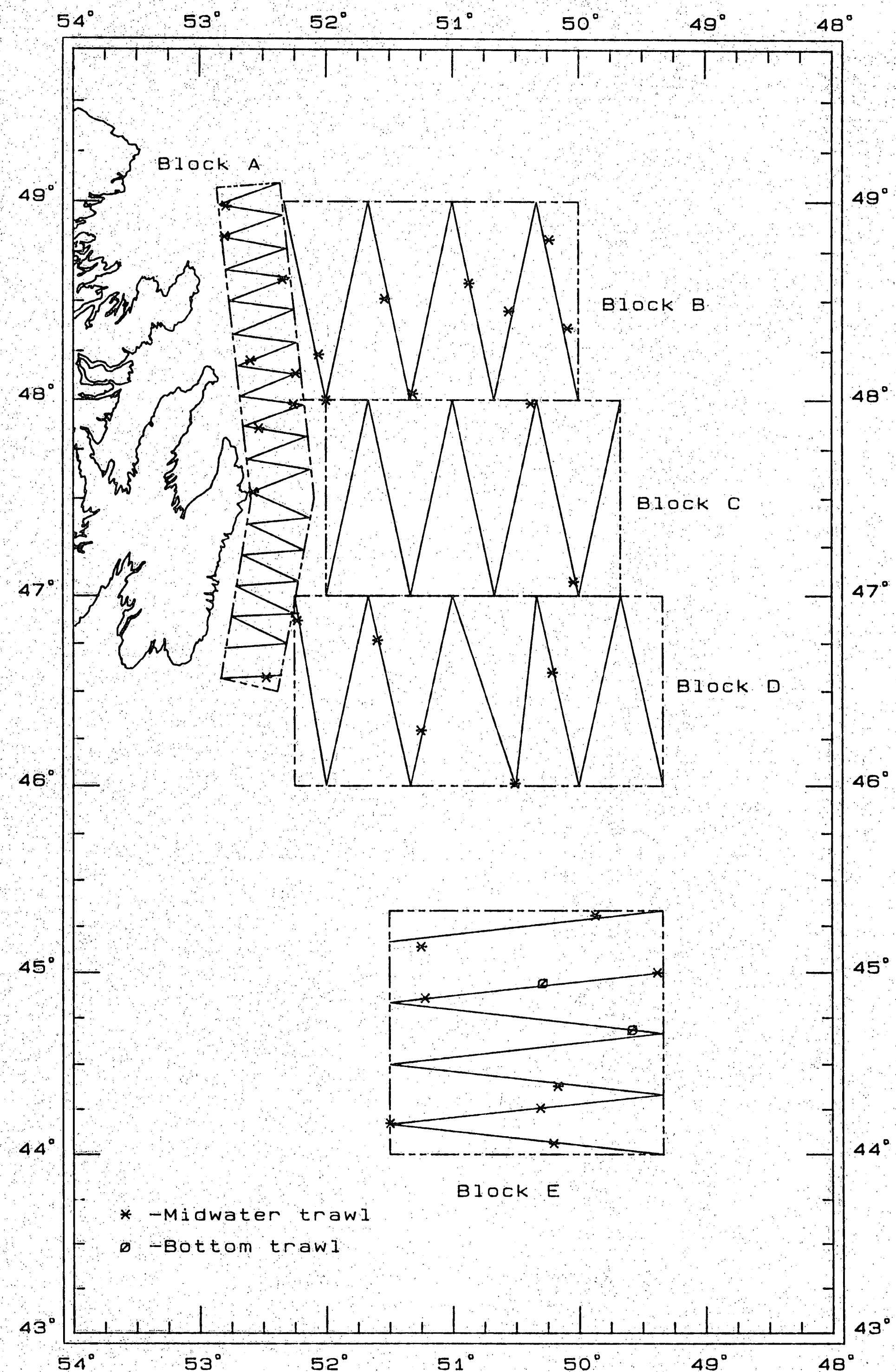


Figure 2. Gadus 111 cruise track June–July 1985

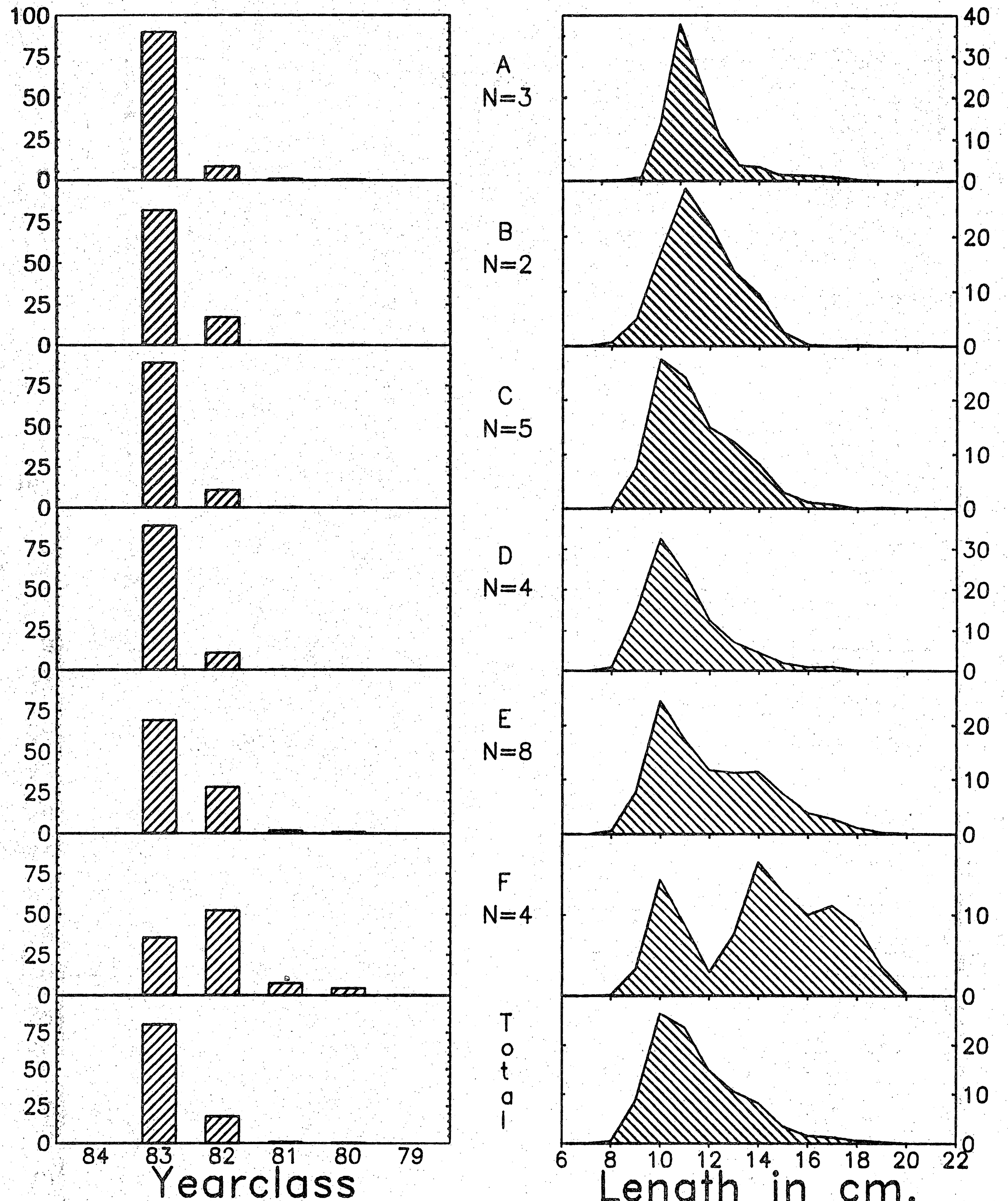


Figure 3. Age and length compositions from Gadus Atlantica Cruise 109

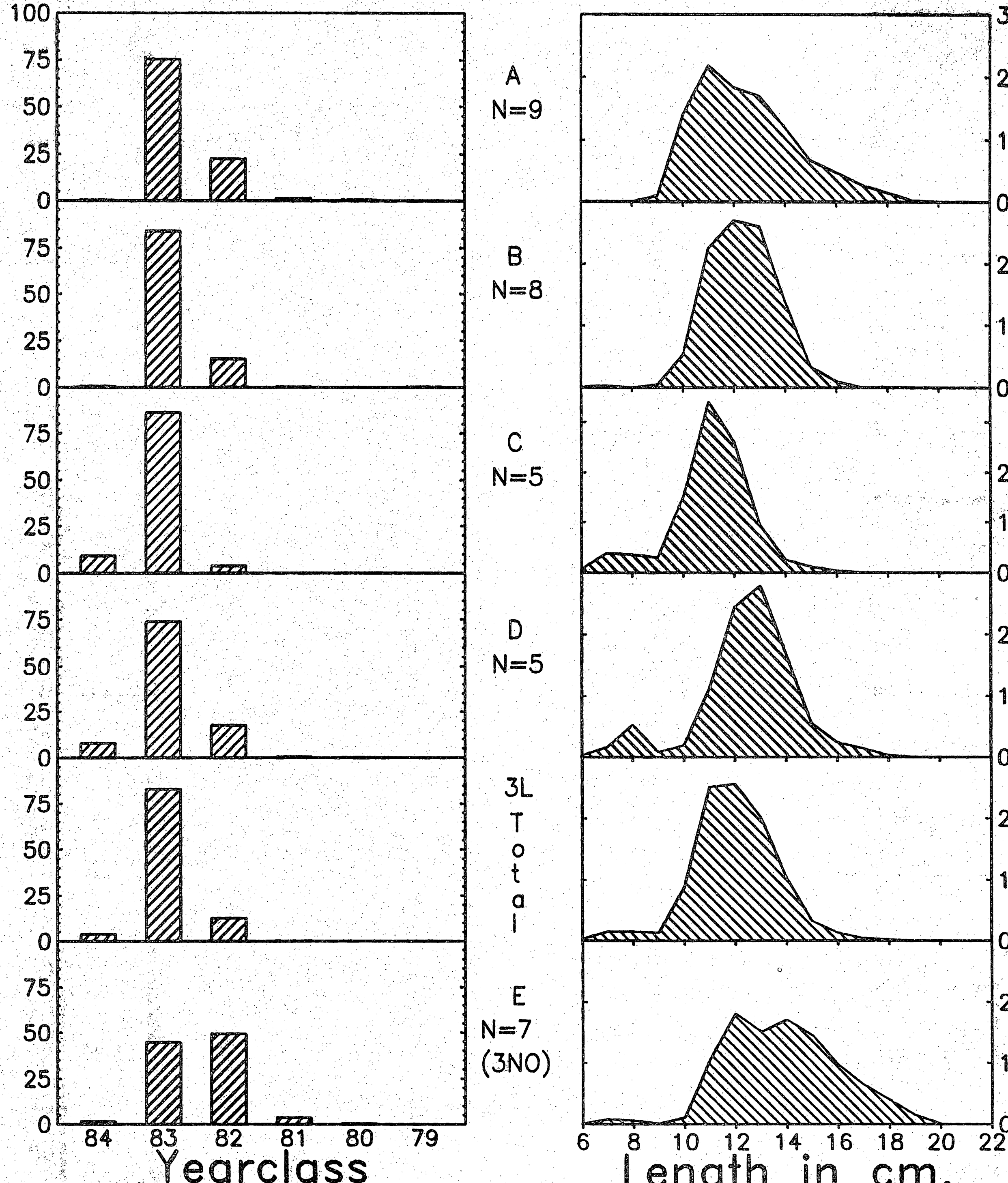


Figure 4. Age and length compositions from Gadus Atlantica Cruise 111

Figure 5a. Gadus 109 Block A diurnal distribution

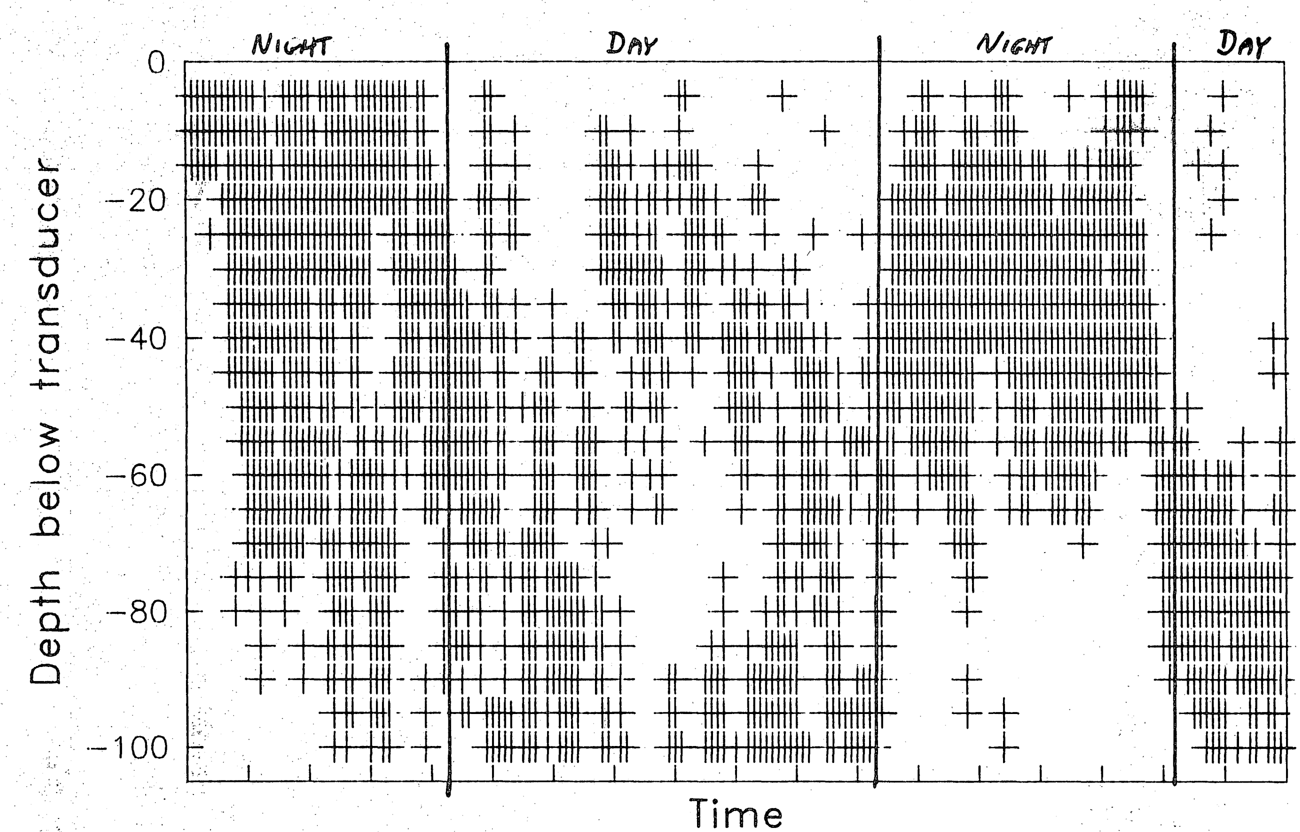


Figure 5b. Gadus 109 Block B diurnal distribution

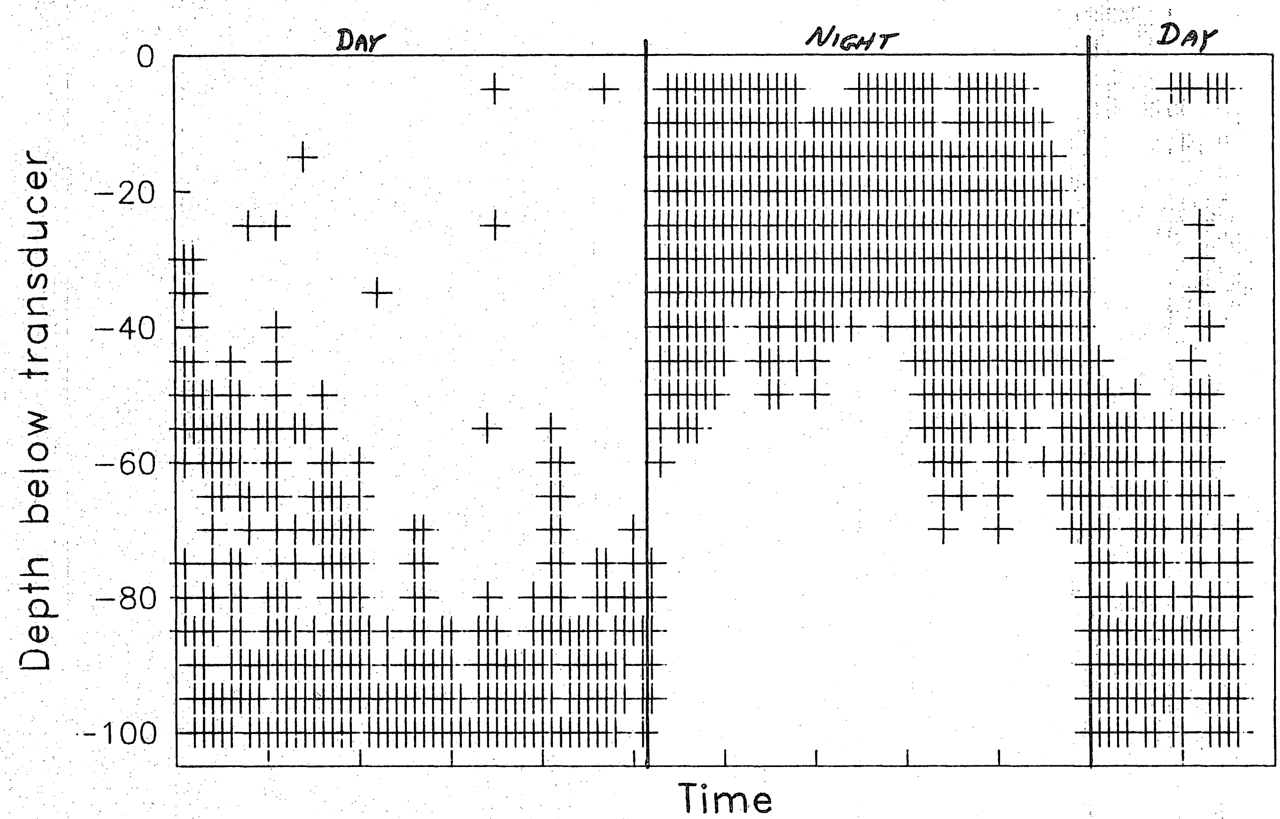


Figure 5c. Gadus 109 Block C diurnal distribution

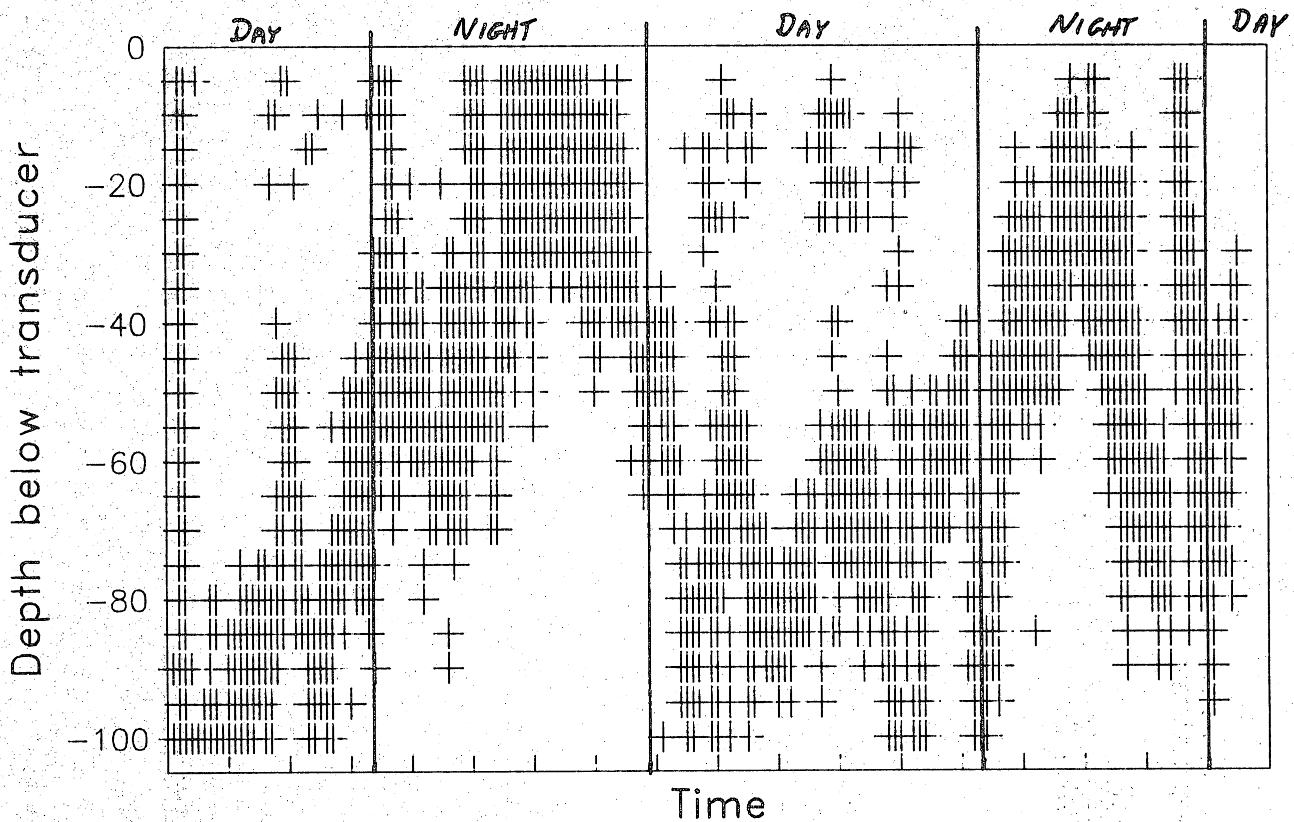


Figure 5d. Gadus 109 Block D diurnal distribution

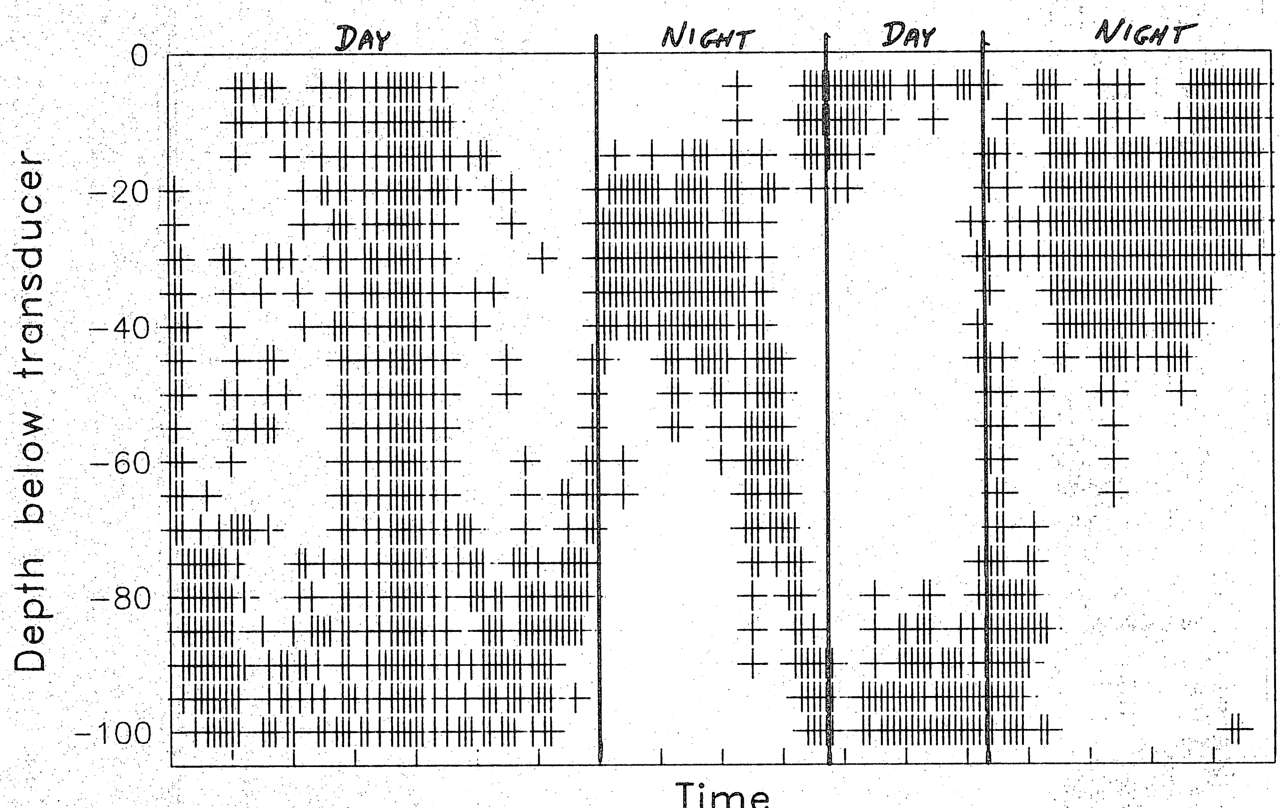


Figure 5e. Gadus 109 Block E diurnal distribution

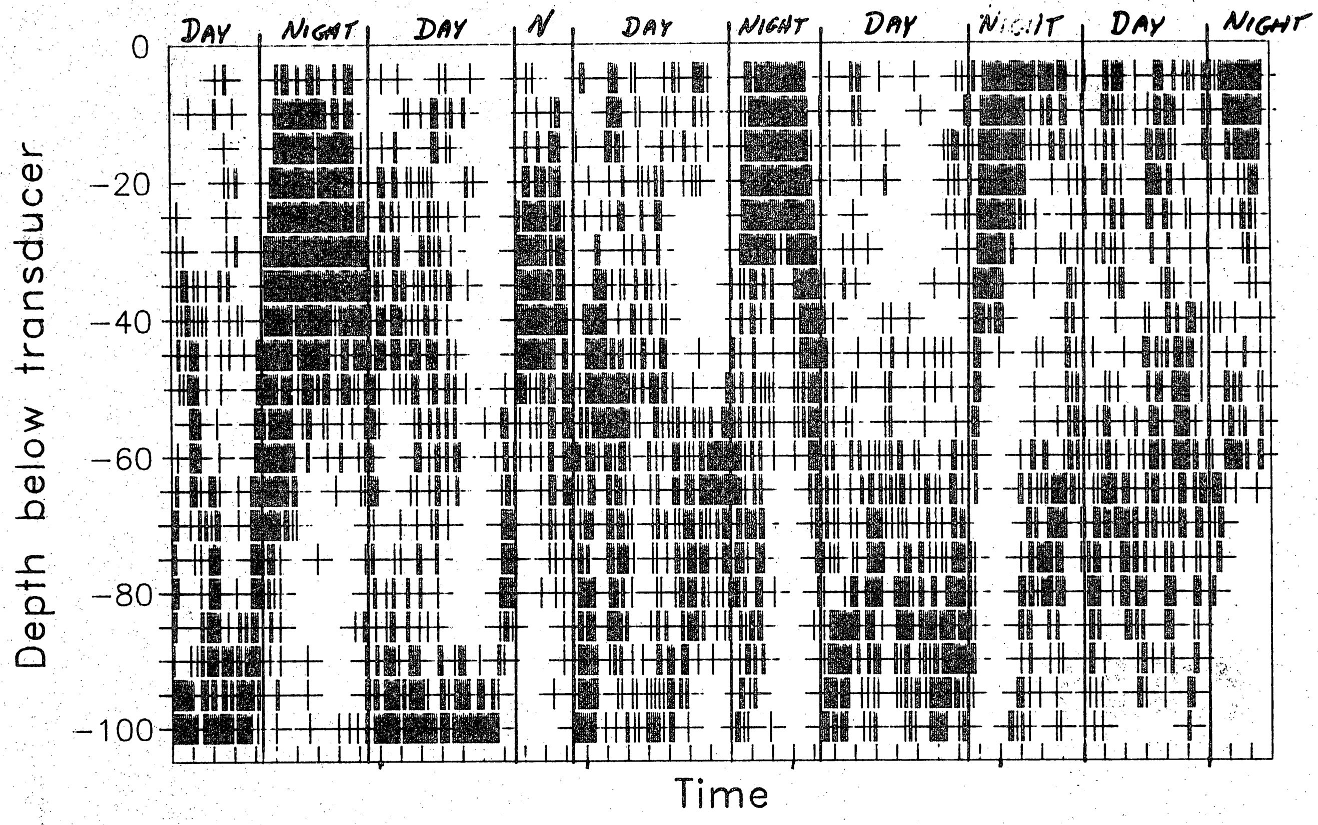


Figure 5f. Gadus 109 Block F diurnal distribution

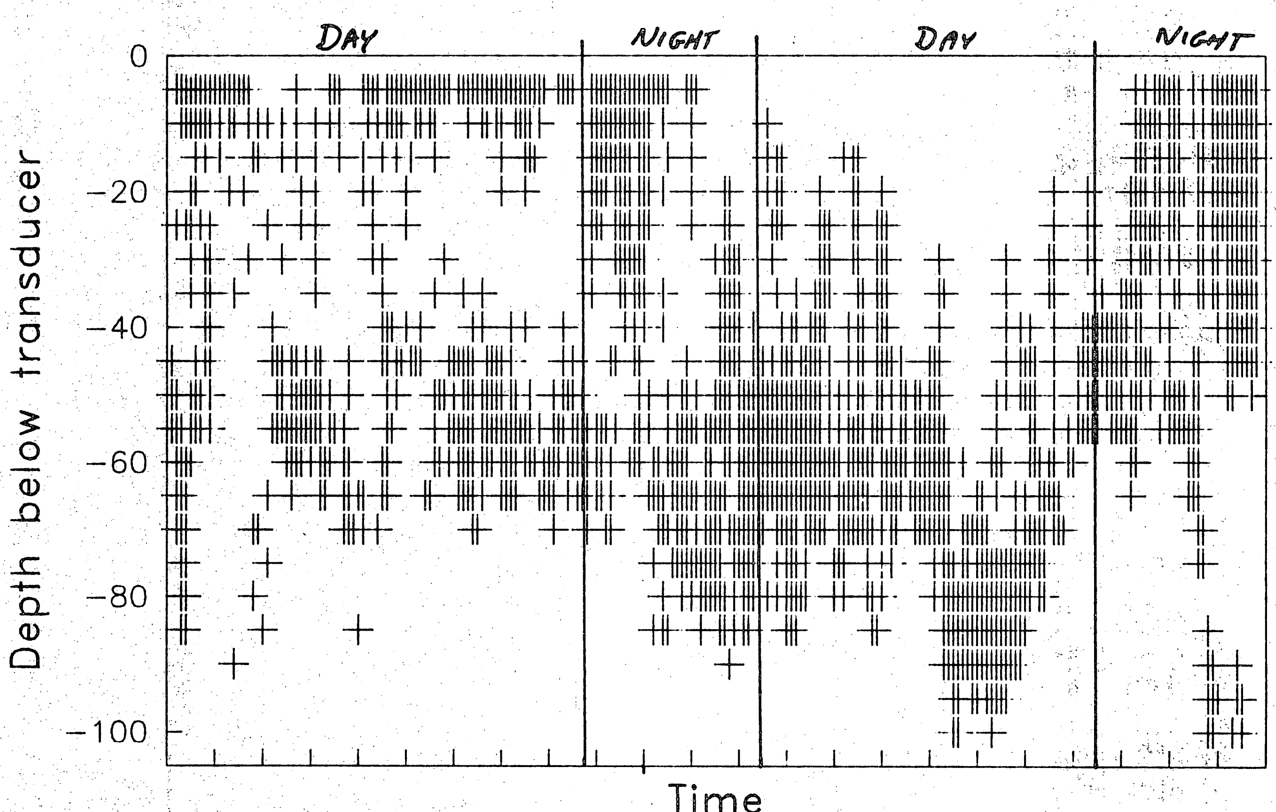


Figure 5g. Gadus 109 Repetitive transect diurnal distribution

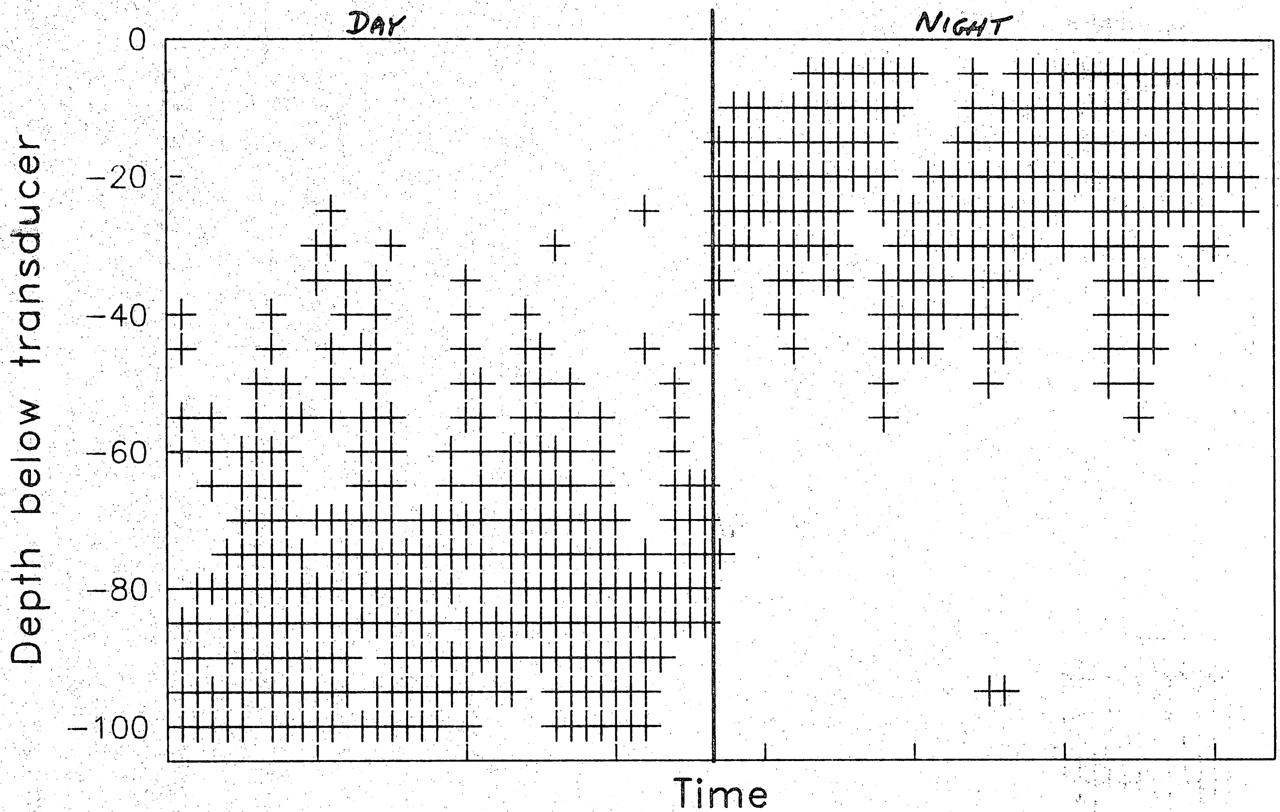


Figure 6a. Gadus 111 Block A diurnal distribution

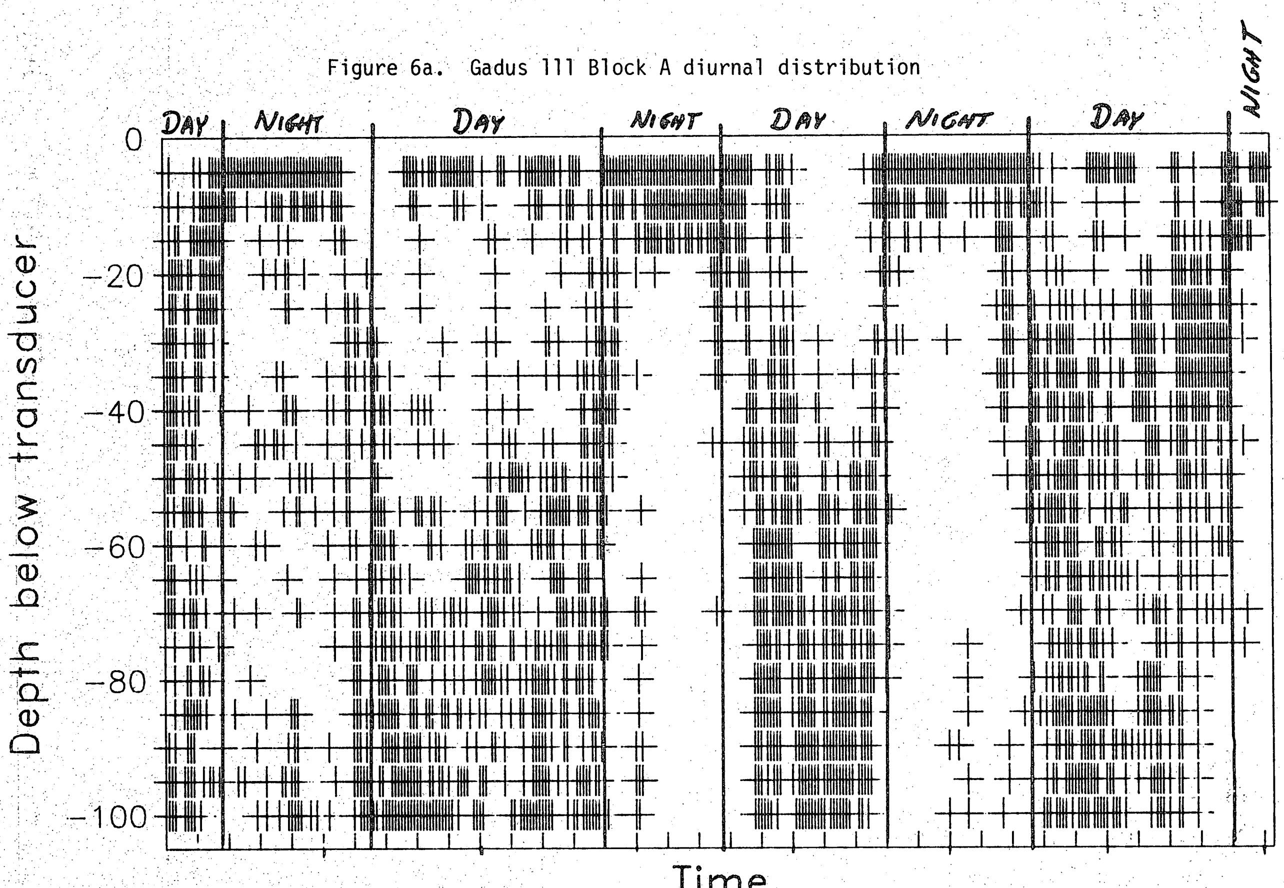


Figure 6b. Gadus 111 Block B diurnal distribution

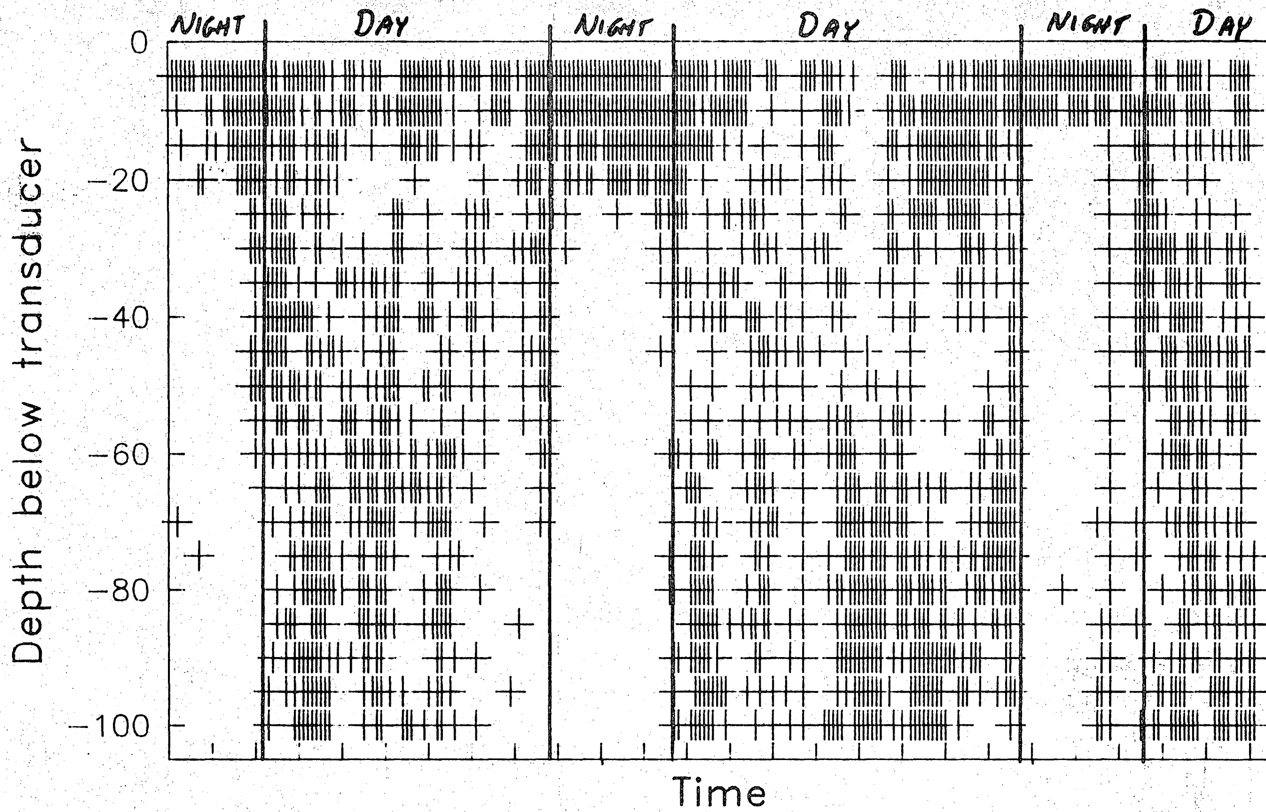


Figure 6c. Gadus 111 Block C diurnal distribution

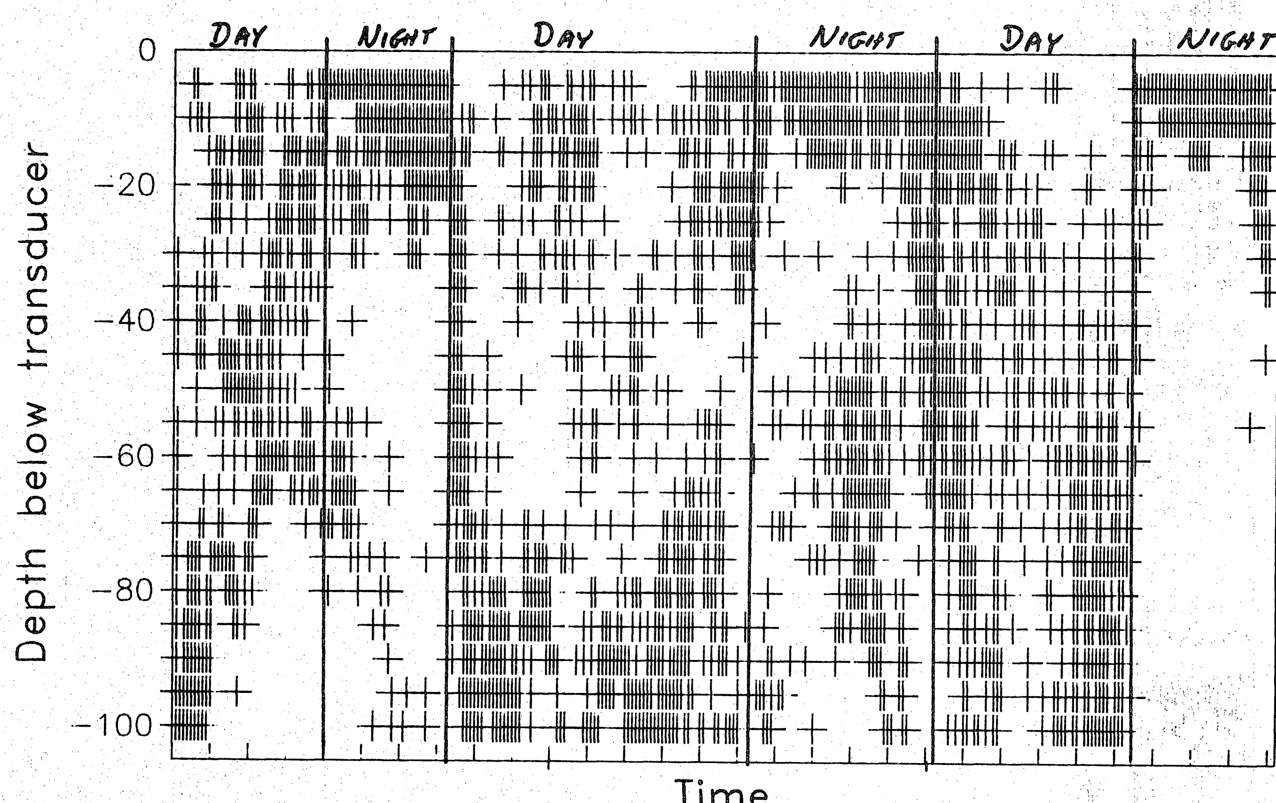


Figure 6d. Gadus 111 Block D diurnal distribution

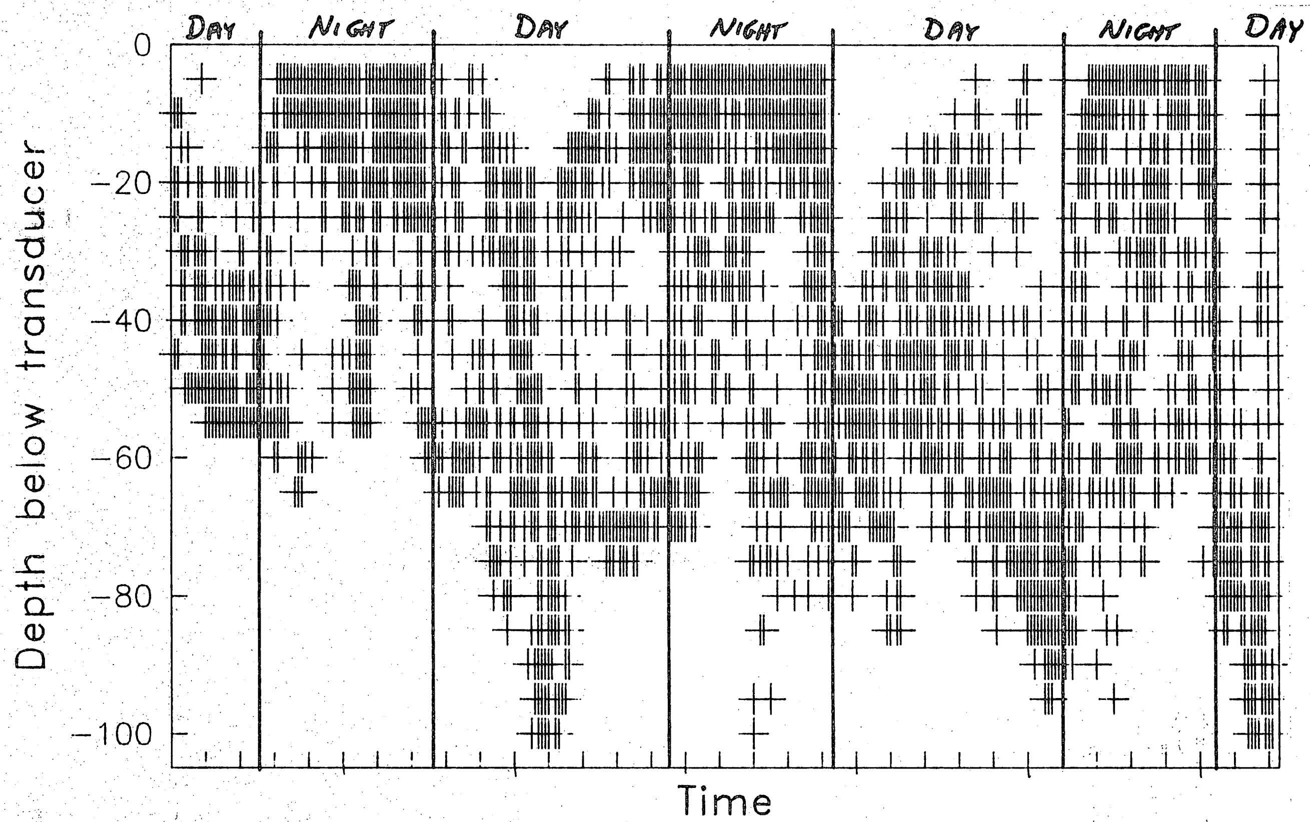
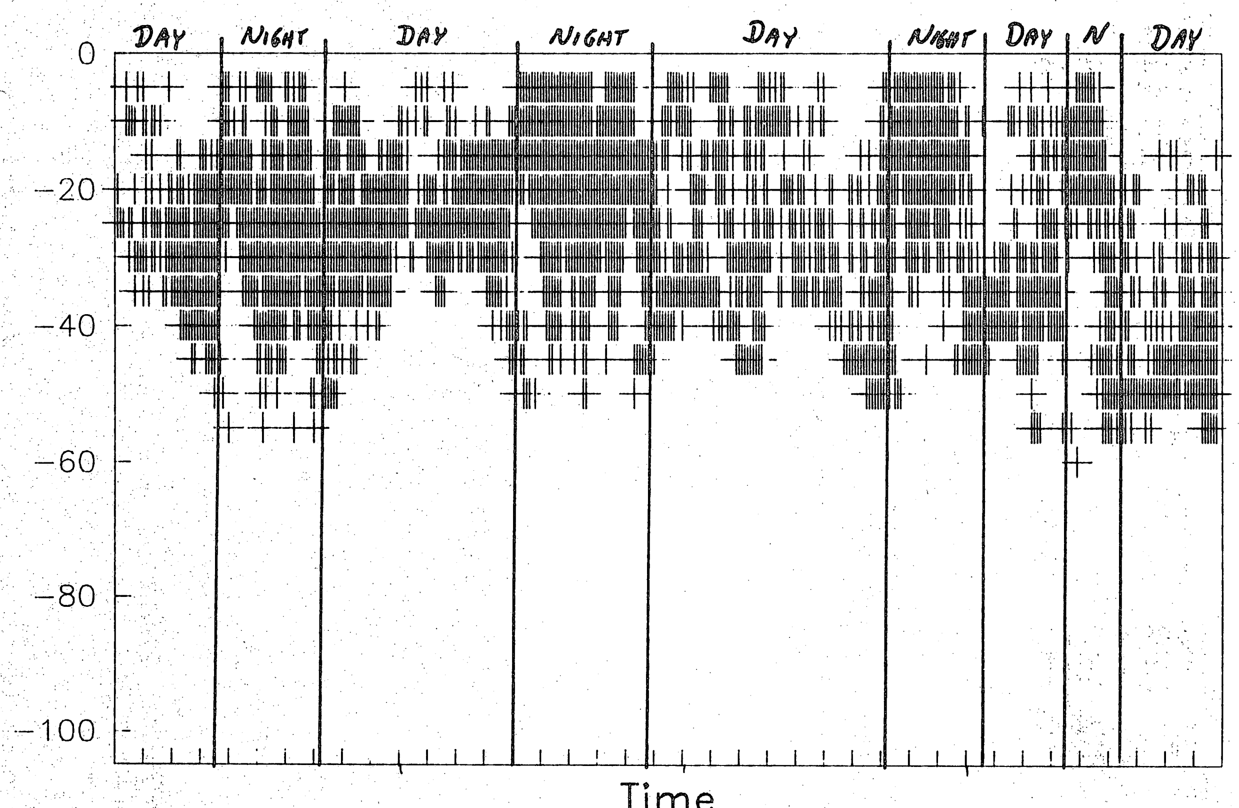


Figure 6e. Gadus 111 Block E diurnal distribution



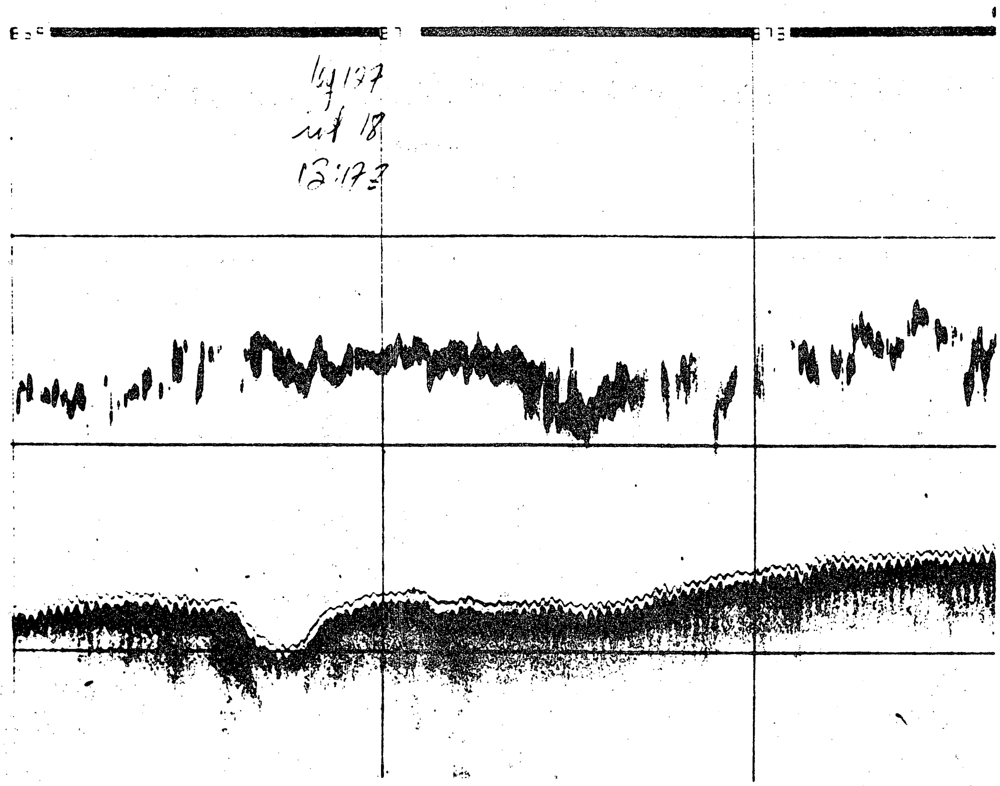


Figure 7a. Typical day echogram of immature capelin

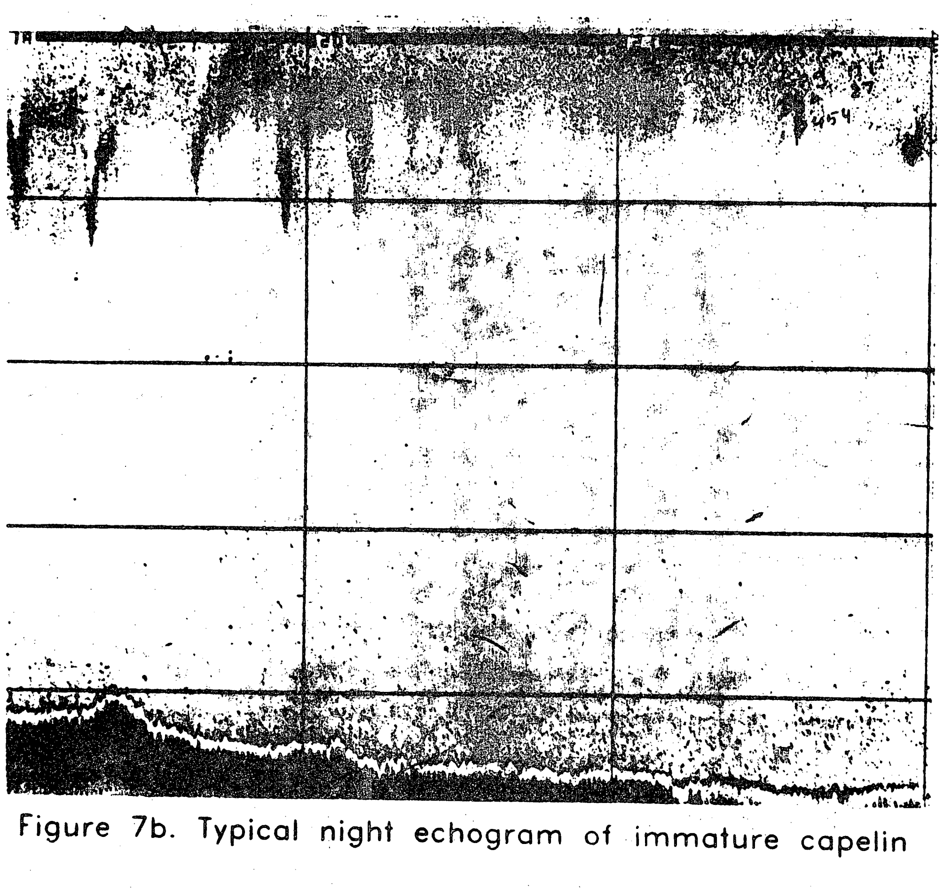


Figure 7b. Typical night echogram of immature capelin

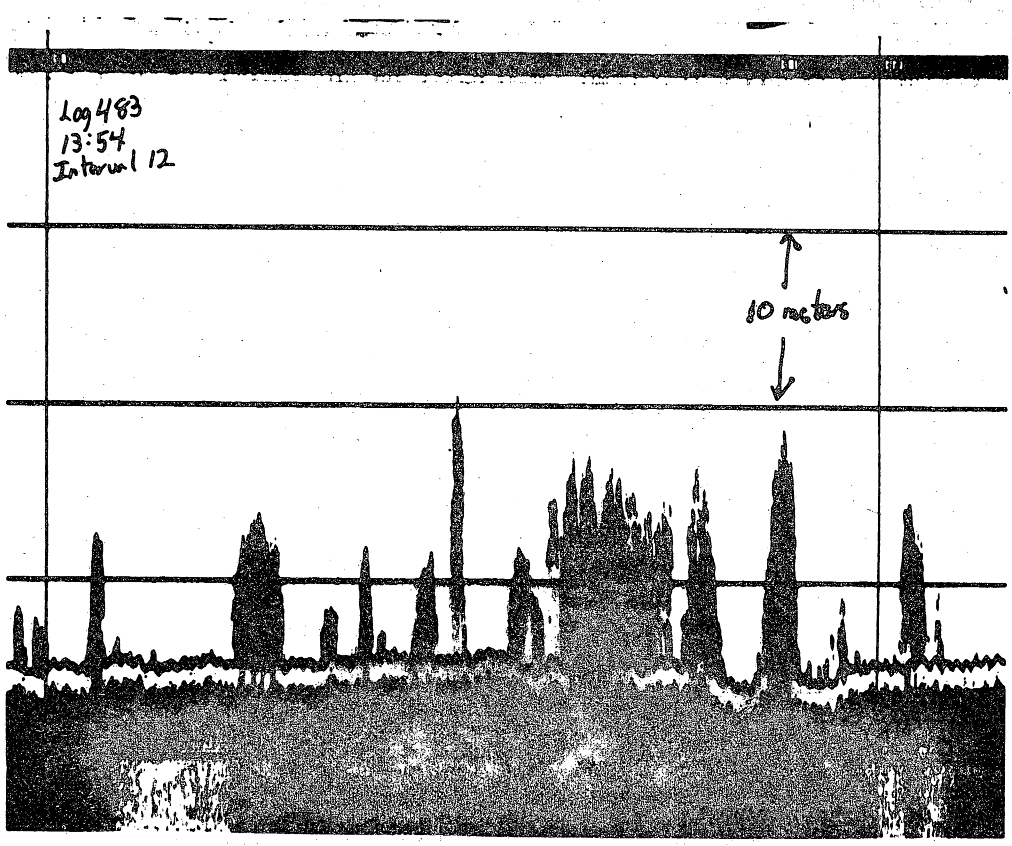


Figure 7c. Typical day echogram of mature capelin

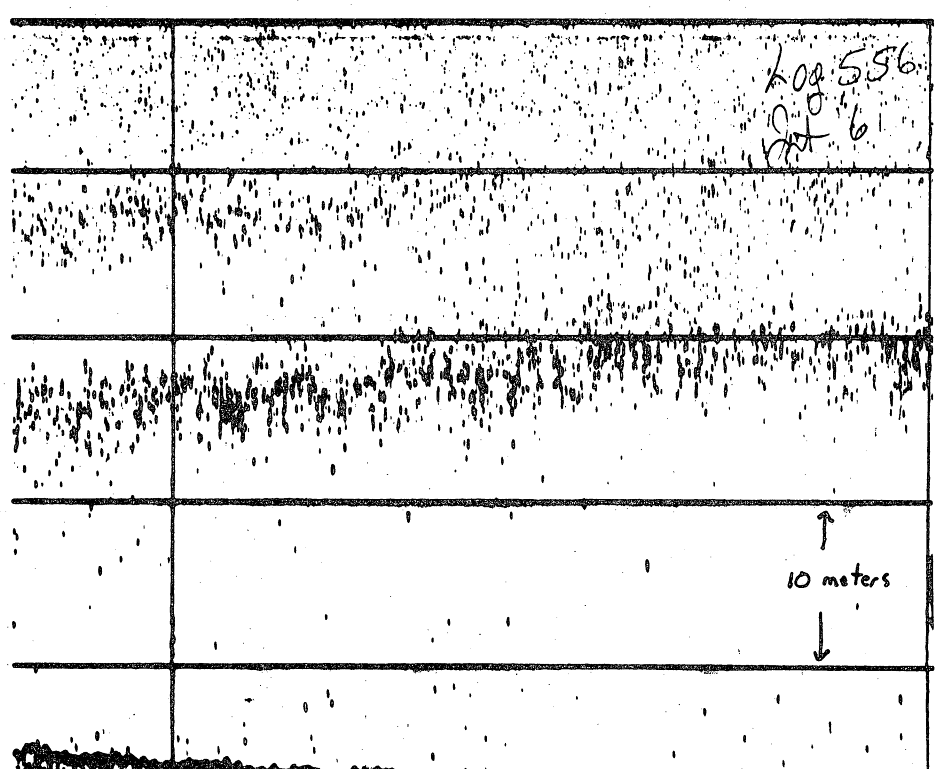


Figure 7d. Typical night echogram of mature capelin