ACOUSTIC STOCK MEASUREMENTS OF THE BARENTS SEA CAPELIN 1972 - 1984

A REVIEW

By

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ABSTRACT

This paper gives a review of the procedures currently used to obtain acoustic estimates of the Barents Sea capelin stock, as well as the development history of the procedures, their theoretical and technical basis, and the known sources of error. The results of the autumn surveys are given as tables and figures.

1. INTRODUCTION

Systematic acoustic surveys on the Barents Sea capelin (Mallotus villosus) started in 1971, and have continued in September-October every year since then. In principle, the same method has been used throughout this relatively long time series. The basic principle is to locate the capelin with an echo sounder, measure the total reflected echo intensity from the capelin recordings with an echo integrator, and finally to convert the integrator values to the number of fish and the biomass.

However, there have been major advances in electronics technology in this period. It is now possible to process signals derived from fish echoes fast and accurately, with equipment which is both reliable and stable.

Compared with the early 1970's more information is available today on the acoustic scattering properties and the behaviour of capelin, although more knowledge in these fields is still necessary.

For reports on the cruises 1971 - 1984 see Dragesund and Nakken, 1972; Gjøsæter et al., 1972; Dommasnes et al., 1974; Buzeta et al., 1975; Dommasnes et al., 1975; Dommasnes and Røttingen, 1976; Monstad and Røttingen, 1977; Dommasnes et al., 1979; Mamylov and Dommasnes, 1979; and Anon., 1980; 1981; 1982; 1983; 1984.

The purpose of this paper is to sum up the results from the autumn acoustic surveys 1972-1984, as well as to give a description of the evolution of the method which has taken place as the acoustic instruments and calibration procedures improved together with the increased knowledge of the acoustic properties of fish.

2. METHODS

2.1 Conversion constant

Midttun and Nakken (1971) showed that when a scientific echo sounder, with certain specified instrument settings, works in conjunction with an echo integrator, the output is proportional to the observed fish density:

$$\rho = C \cdot M \qquad (1)$$

where

ρ = fish density
C = system conversion constant
M = observed integrator value

The value of the conversion constant C can be determined through different methods, but not all of them apply to every species. However, in 1971, Midttun and Nakken published a method which could be applied to the Barents Sea capelin, consisting of finding the number of fish sampled by counting individual fish traces on the echogram. The sampling area was found by reducing the recorder gain. When the echo sounder has a calibrated gain switch, the difference between the recorder gain at normal setting and the gain giving a just visible marking on the paper for the fish in question, is used to find the sampling angle (detection angle) in the directivity diagram for the echo sounder. However, a disadvantage with this method is the requirement of single fish traces, a condition that is seldomly found for the Barents Sea capelin in autumn. But, in 1971, 8 nautical miles (abbreviated to nmi) of single fish traces were obtained, and Fig. 1 gives the results from these countings (Midttun and Nakken 1977).

The system conversion constant is the key to the absolute biomass estimations, and Nakken (1975) showed that this constant depended on fish species, size, behaviour, and on the characteristics of the sounder and the integration system. It was convenient to write C as a product:

$$C = C_I \cdot C_F \tag{2}$$

C_I is an "instrumentation constant" depending on the instrument characteristics of the particular system in question.

C_F depends on the acoustic properties of the fish. The acoustic properties are described by the terms "target strength" (TS) or "backscattering cross section" (σ_{bs}).

The theory behind these terms is described in textbooks (Urick 1975) and manuals (Burczynski 1979, Johannesson and Mitson 1983). Using definitions from Dalen and Nakken (1983) we get:

$$TS = 10 \log \sigma_{bs} \quad \text{or} \quad \sigma_{bs} = 10^{0.1\ TS} \tag{3}$$

(See also Appendix I)

The backscattering cross section of an individual fish varies with fish species, length and aspect (The angle between the longitudinal axis of the fish and the acoustic axis). It has been determined empirically for a number of species and sizes (Midttun 1982). The back scattering cross section for one fish of a given species can be expressed as a function of fish length, l:

$$\sigma_{bs} = a \cdot l^b \tag{4}$$

where a and b are determined empirically from observed values of σ_{bs} and l. The results have mostly been presented in logarithmic form using the target strength, TS, instead of the backscattering cross section.

$$TS = 10 \log \sigma_{bs} = 10\ b \log l + 10 \log a \tag{5}$$

C_F is inversely proportional to the backscattering cross section

$$C_F = \frac{1}{\sigma_{bs}} \tag{6}$$

Combination of (2), (4) and (6) gives:

$$C = C_I \cdot C_F = C_I \cdot \frac{1}{\sigma_{bs}} = C_I \cdot \frac{1}{a \cdot l^b} = C_I \cdot \frac{1}{a} \cdot l^{-b} \qquad (7)$$

and

$$\rho = C_F \,(C_I \cdot M) \qquad (8)$$

If we put $\frac{1}{a} = C_S$, then:

$$C = C_I \cdot C_S \cdot l^{-b} \qquad (9)$$

For the Barents Sea capelin this counting method has been used to establish C for certain fish lengths, and the constant $C_I \cdot C_S$ has then been determined by:

$$C_I \cdot C_S = \text{antilog } (\log C + b \log l) \qquad (10)$$

The exponent b is determined from target strength measurements on single stunned or dead fish (Equations (4) and (5)). But when the present investigations began no target strength measurements of capelin were available. However, the capelin have common structural components with clupeiform fishes (herring, sprat, etc.) which are acoustically important (physostomous swim bladders, osseous skeleton, intermuscular bones, comparatively many vertebrae, fins without spines and cycloid scales). Due to the lack of specific acoustic information on capelin, it was decided to utilize data on the relationship of target strength and length for sprat (Nakken and Olsen, 1977) using the following relationship between target strength and length for sprat at maximum dorsal aspect:

$$TS_{sprat} = 17.2 \log l - 60.8 \text{ dB} \qquad (11)$$

This equation is of the form

$$TS = 10b \log l + 10 \log a \qquad (5)$$

giving the value 1.72 for the factor b.

The values for C obtained by countings of single capelin of different length groups in 1973-1975 are given in the text table below

$$C = 1.8 \cdot 10^6 \cdot l^{-1.72} \quad (1973) \qquad (12)$$

$$C = 3.0 \cdot 10^6 \cdot l^{-1.72} \quad (1974) \qquad (13)$$

$$C = 5.0 \cdot 10^6 \cdot l^{-1.72} \quad (1975) \qquad (14)$$

The change in the conversion factor from year to year may be due to a drift in the acoustic system. The hydrophone calibration used in this period to measure the performance of the acoustic system was not a reliable procedure, and changes in performance were difficult to trace systematically. However, the change in the values of the conversion factor need not be due to instrument or technical factors alone. They may be due to differences in the behaviour (and acoustic properties) of the capelin when the counting calibration took place.

On the basis of combined target strength measurements of several clupeiform fishes, Dalen et al. (1976) suggested a value for b of 1.91.

In incorporating this new value of b, the requirement was set that the value for C should be the same for capelin of 13 cm using both 1.91 and 1.72

$$C_I \cdot C_S \cdot 13^{-1.91} = 5.0 \cdot 10^6 \cdot 13^{-1.72} \qquad (15)$$

$$C_I \cdot C_S = 8.1 \cdot 10^6 \qquad (16)$$

The C-value of $8.1 \cdot 10^6 \cdot 1^{-1.91}$ was applied in the period 1976-1982. In 1982 the Simrad EK 38 echo sounder was replaced by the EK 400 and the conversion factor had to be changed due to the different performances. By 1981, calibration on standard spheres had become an established routine, and the performances of EK 38 and EK 400 could be compared. The table below gives the measurements of energy reflected per nautical mile from the standard copper sphere of 60 mm.

Date	Energy mm/nmi	Echo sounder
Oct. 1981	539	EK 38
Oct. 1982	2170	EK 400

This, together with minor changes in performance of the EK 400 in 1982-1983 gave a conversion factor of $1.5 \cdot 10^6 \cdot 1^{-1.91}$ in January 1983 (Dalen and Nakken, 1983) and $2.2 \cdot 10^6 \cdot 1^{-1.91}$ in September 1983.

Prior to summer 1983 the conversion constant was given as equation 7. However, as standard sphere calibrations made it possible to calculate the value of C_I (see chapter on calibration), the conversion constant from summer 1983 was given as

$$\frac{1}{10a} \cdot 1^{-b} \quad \text{or} \quad \frac{1}{10} \cdot C_F \qquad \text{(equation 23).}$$

Prior to this change, the established conversion factor was only for the system onboard the "G.O. Sars". However, the autumn surveys on Barents Sea capelin are conducted by many ships whose integrator values had to be transformed through intercalibration before the "G.O. Sars" conversion could be applied. As a consequence, distribution charts etc. were given in mm integrator deflection according to "G.O. Sars" values.

With the use of the instrument constant, the "integrator values" became system independent. The dimension for $C_I \cdot M$ (see equation 8) is m^2 / nmi^2. C_F is also system independent and the dimension is m^{-2}.

2.2 Acoustic equipment and calibration

In order to monitor changes in the echo sounder system and, when needed, to restore the performance of the system, it is essential to have some method of calibration.

When the autumn surveys on Barents Sea capelin started, the calibration of the vital parameters of the echo sounder were done by measuring the performance in the transmitting mode with a hydrophone placed on the acoustic axis of the transducer, and then using the same hydrophone as a sound source to measure performance in the receiving mode. This method has been described by Forbes and Nakken (1972).

Experience has shown that this procedure is not reliable for field use due to the lack of stability over time for the calibration hydrophones. In 1975 an additional procedure was initiated, with measurement of the output voltage from the transmitting amplifier, the impedance in the transducer, and the amplification in the receiver system. These measurements were done several times during each cruise, and it was assumed that if these 3 values were kept constant, then the system performance did not change.

Since 1981 the performance and stability of the system has been checked at least once during each cruise by calibration with a standard target in the acoustic axis of the beam. In later years, a considerable amount of the field work and analysis has been done in order to find suitable standard targets, and it has been found that, for 38 kHz, a copper sphere with a diameter of 60 mm gives an accurate and reliable target strength (-33.7 dB) over the entire hydrographic range in question (Foote 1982). The calibration procedure is described in Foote et al. (1983). This calibration procedure, in contrast to earlier calibrations with hydrophones, seems to give consistently reliable results in measuring the stability of the echo sounder performance.

The introduction of the copper sphere as a standard target has made it possible to calculate the factor C_I in equation (2). The standard target has a known target strength (-33.6 dB). This value is calculated theoretically and is confirmed by field measurements.

From (3) we can calculate the value of σ_{bs} for the reference sphere:

$$\sigma_{bs} = 10^{0.1\cdot(-33.6)} = 4.3 \cdot 10^{-4} \qquad (17)$$

This may be thought of as a reflecting area, given in m^2.

The integrator output from the standard target is known, and therefore C_I can be expressed as reflecting area in m^2 per n.mile^2 by use of the formula (Dalen and Nakken 1983):

$$C_I = \frac{\sigma_{ST}}{M_{ST} \cdot D_{ST}^2 \cdot \psi} \cdot 3.43 \cdot 10^6 \qquad (18)$$

where

σ_{ST}	is the back scattering cross section of the standard target (m^2)
M_{ST}	is the integrator output from the standard target (mm/nmi)
D_{ST}	is the depth of the standard target (m)
ψ	is the equivalent solid angle of the beam of the transducer (sterad)
$3.43 \cdot 10^6$	is the number of square meters in a squared nautical mile (used in order to have the density expressed as number of fish per square nautical mile).

The value of ψ is given by the transducer manufacturer. However, there is some evidence that this value may change when the transducer is mounted on the hull of the vessel (Simmonds, 1984). This can be an important source of error, and it may be necessary to develop a method for measuring ψ after the transducer has been mounted on the hull. The text table below gives values for C_I for the EK 400 equipment on "G. O. Sars".

Date of measurement	C_I
03.10 - 82	0.078
04.01 - 83	0.064
13.12 - 83	0.054
02.08 - 83	0.0814
29.09 - 83	0.0775
13.01 - 84	0.0833
15.03 - 84	0.0831
24.05 - 84	0.073
25.07 - 84	0.087

Significant deviations in the time varied gain (TVG) have previously been important sources of error. However, equipment and procedures for detecting the magnitude of the TVG error at different depths have now been developed (Knudsen 1982). The correction factors are entered into the integrator program, and output is then adjusted correspondingly.

A potential source of error in acoustic measurements of fish density is the absorption part of the time-varied-gain functions (α). Prior to 1982 (Echo sounders EK-38) the value of α was set to 0.0105 dB/m, based on Schulkin and March (1962). More recent studies (Fisher and Simmonds 1977, Foote 1981) indicate that these values are too high and at present a value of 0.008 dB/m is utilized. This is thought to reflect the average value of α in the Barents Sea in autumn.

If the calibration procedure outlined above is followed by all vessels participating in a survey, then the integrator outputs from all vessels are directly comparable. However, if there has not been time to do a standard target calibration, or the necessary equipment or information on transducer performance (i.e. equivalent solid angle of the beam, ψ) is lacking, then systems must intercalibrate on fish recordings, (the old standard method) still seen as an efficient means for checking the standard target measurements. The procedure for this type of calibration is described by Røttingen (1978) and in a number of cruise reports. Fig. 2 shows the sailing arrangement which has given the best results.

The results from the intercalibrations have usually been in accordance with the results from the standard sphere measurements, with one important exception in the autumn 1982. During the capelin cruise that year the research vessels "G. O. Sars" and "Johan Hjort" participated from Norway. On board "G. O. Sars" a new EK 400 echo sounder had just been installed, and according to the standard sphere measurements the relation between the echo integrator output from "G. O. Sars" and "Johan Hjort" was approximately 2.5:1. However, an intercalibration on capelin recordings was also carried out during the cruise, and the relation between the integrator outputs from the two vessels was then 1:1. It was very difficult to interpret these contradicting results, and the cause of the discrepancy has still not been found. However, it could be documented that no change had taken place in the echo equipment of "Johan Hjort" since the year before, and it was therefore decided to use the conversion constant (C-value) from 1981 also in 1982. This may have caused an overestimate of the capelin stock in the autumn of 1982.

2.3 Fishing gear and sampling

The trawls used have been mostly pelagic trawls with a square opening of 14 x 14 or 16 x 16 fathoms, with small meshes ("capelin trawl"), and with an inner net with 1 cm mesh in the codend. In addition, a bottom trawl has sometimes been used (Fig. 3).

Capelin is usually found both in the codend and, if a pelagic trawl has been used, in the meshes. There is a tendency that capelin caught in the meshes are smaller than those found in the codend.

All the trawls have their own selectivity characteristics, which may be somewhat different from cruise to cruise due to small differences in the rigging of the trawls. Selectivity is a large complex with many interacting factors. Both passive (filtering) and active escape will take place and will change according to the speed of the trawl and the density of the fish concentration. Preliminary investigations of escape of capelin from different parts of the capelin trawl used by Norwegian research vessels have been carried out by attaching smallmeshed bags to different parts of the trawl (Larsen 1984). Fig. 4 summarizes the results, which indicate that when small and large capelin occur together in the catch, the small capelin will be underrepresented. For this reason it can be assumed that the one year old capelin are underrepresented in the acoustic estimates. An analysis of the calculated numbers of a yearclass for consecutive years during its lifetime leads to the same conclusion (Dommasnes 1981).

From each trawl catch a random sample is taken from the codend. Additional samples may be taken of the capelin caught in the meshes further forward in the trawl, but these are always considered nonrandom. The size of the samples has been variable - in 1973 several hundred capelin were usually taken in each sample, but since 1975 the sample size has usually been 100 fish.

From a "full sample" the following data are usually recorded for each capelin: length, weight, sex, maturity, degree of stomach filling and degree of digestion, age from otoliths, and radius of the year-rings. All data are recorded on forms, after which they are entered into a computer and run through a test program that detects "illegal" data codes or "impossible" combinations of data values. Each sample is given a number which is later used as identification. For details on sampling and ageing see Gjøsæter, (1984).

2.4 Survey design

In 1971 when the cruises started, considerable information on capelin distribution was already available, both from earlier scientific surveys in the Barents Sea, and from fishing data. The survey grid which has been applied in these investigations is mainly a parallel grid with north-south transects. It can be described as a systematic grid pattern with a nonrandomly selected starting point. It was felt that the survey grid then adopted gave the most complete coverage within a reasonable time. If the time interval used for the survey was increased, the obtained distribution would become increasingly non-synoptic.

The same grid pattern, in principle, has been used every year. In later years, with more research vessel time available, the distance between course lines has been decreased.

Aglen (1983a) has analyzed the variations between abundance indices for different degrees of survey coverage. He defined the "degree of coverage" for an area as the ratio between sailed distance and the square root of the total area covered. Integrator output was used as the index of abundance. The result (Fig. 5) indicates that a further increase of survey effort will not improve the precision significantly.

2.5 Calculations

A flowchart of the procedure for evaluating data and calculating the results is given in Appendix II.

The calculations give stock size as numbers and biomass of each year-class, based on the integrator values and sample data from the trawl catches.

In order to organize data in a manageable form, the total area investigated is divided into a relatively large number of smaller areas. For this purpose we have used the basic "squares" used in Norwegian Fisheries statistics (Fig. 6). The center of each "square" is then the geographical reference point for all data assigned to that square.

For the acoustic data, a mean integrator value is calculated for each square, usually by calculating the mean of all integrator values obtained in that square. In some instances, particularly at the edge of the area of distribution, it is often necessary to use some judgement to obtain "representative" values. The calculation of the mean integrator value for each square is done manually.

Many of the squares have no trawl stations, many have one only, and several squares have more than one. In order to get representative biological data for the recordings in each square, trawl stations selected from the square in question or from neighbouring squares are assigned to each square as the cruise proceeds. The main criterion for designating trawl stations to a square is the similarity of echo recordings. Often several types of recordings are found in one square, and must then be represented by several trawl stations. When trawl stations have been assigned to a square, a length frequency is accumulated for that square by adding up the samples from the assigned trawl stations.

The area for each square can be easily calculated when the coordinates for its corners are known.

The number of capelin of each length group in the square can be calculated as a product of density and area (A) (adapted from Nakken and Dommasnes, 1977):

$$N_i = (C_I \cdot M) \cdot \frac{p_i}{\sum_{i=1}^{n} \frac{p_i}{C_{F_i}}} \cdot A \qquad (19)$$

N_i = the number of capelin in length group i in the square

C_I = the instrument constant

M = the average integrator value calculated for the square

p_i = the proportion of the capelin in length group i to the total number of capelin in all the length groups ($\Sigma p_i = 1$)

$C_{F_i} = C_S \cdot l_i^{-b}$ where l_i is the (arithmetic) middle length in the length group i and C_S and b have been determined empirically

A = the area in square nautical miles

The calculations of all N_i for each square are presently done by computer for each half-centimeter length group. The number of capelin in each length group in a larger area or in the total area is found by adding up the number of fish in all squares included in the area. Any area larger than a square is thus defined by the squares in it.

In order to calculate age distribution and biomass it is necessary to make "keys" which give percentage age distribution in each length group. The keys are then applied to the numbers in each length group calculated for the squares, in order to give numbers and biomass in each age group for each square.

Mean length at age and mean weight in each length group can be quite different in different parts of the Barents Sea. For this reason the investigated area is divided into 3-6 subareas in such a way that mean length at age and mean weight at age are reasonably uniform for the trawl stations in that area. The length-age and length-weight keys are then compiled separately for each subarea and applied to all squares in that subarea. The subareas form the basis for compilation of other biological statistics as well.

The total number and biomass of the stock is found by adding the results from all the squares.

3. RESULTS

Figs. 7-19 give the distribution of capelin, both total and by yearclass, together with the survey grids for the period 1972-1984. Fig. 20 gives length distributions, and Tables 1-13 give the acoustic abundance estimates for the same period. Hydrography charts from these cruises for most of the years in question can be found in Loeng (1981), Loeng, Nakken and Raknes (1983) and Gjøsæter and Loeng (1984) as well as in the original cruise reports.

4. DISCUSSION

4.1 Distribution

It is seen from Figs. 7-19 that the distribution of capelin has changed from a northern and eastern distribution in the 1970's to a more southern and western distribution in the 1980's. This is a result of well documented changes in the hydrographic conditions in the Barents sea during the period (Loeng 1979,1983,1984, and Loeng and Midttun 1984). The relationship between capelin distribution and temperature has been discussed by Loeng (1981), Loeng, Nakken and Raknes (1983) and Gjøsæter and Loeng (1984).

Loeng (1981) calculated the area north of 76^0N where capelin was found and the area north of 76^0N where temperature in 100m depth was above 0^0C, using data from the autumn surveys. He found a good correlation between the two. His data also indicated that there was little capelin in areas where the temperature in 100m depth was above 2^0C, but that 3 and 4 year old capelin were generally found in somewhat colder water than the younger ones. He found no correlation between ice distribution and capelin distribution.

Loeng, Nakken and Raknes (1983) used data from the autumn surveys to investigate the distribution of capelin in relation to the mean temperature in the depth interval 0-200m. (Table 14). The 2- to 4-year old capelin were found in warmer water in the years 1980-82 than in the period 1974-79, with little difference between the yearclasses. 1-year old capelin were found in somewhat warmer water. They also found that the capelin had a higher growth during the years when they were found in warmer water (Table 15), although the picture was less clear in this case.

Gjøsæter and Loeng (1984) continued the work done by Loeng, Nakken and Raknes. They found that the change in capelin distribution during the 1970's was due in particular to a southward displacement of capelin in the area east of 35^0E, coinciding with a similar change in the temperature distribution (Fig. 24). A more sophisticated treatment of the temperature/growth data confirmed the findings in the former paper that the growth of the capelin increased during the years when the capelin were in warmer water. Gjøsæter and Loeng pointed out that effects linked to the availability of food may be as important in causing this effect as the direct influence of the temperature on growth.

4.2 Acoustic abundance estimates

Dalen et al. (1976) gave the following equation for the target strength of the maximum dorsal aspect for several clupeiform fish including capelin:

$$TS = 19.1 \log l - 64.0 \qquad (20)$$

However, during survey conditions the reflection of energy is not necessarily from the maximum dorsal aspect. The aspect angle distribution varies according to the fish behaviour, changing with time (day-night), feeding activity, vertical migration, etc. By combining results from instrument calibrations with the standard sphere, counting measurements and measurements of TS of stunned fish we can get a value for the average target strength or "effective back scattering cross section".

We have

$$\rho = C \cdot M \qquad (1)$$

and

$$C = \frac{C_I}{a} \cdot l^{-b} \qquad (7)$$

This gives:

$$\rho = \frac{C_I}{a} \cdot l^{-b} \cdot M \qquad (21)$$

and

$$\rho = \frac{1}{a} \cdot l^{-b} \, (C_I \cdot M) \qquad (22)$$

On distribution charts the factor $\frac{1}{a} \cdot l^{-b}$ is multiplied by $(C_I \cdot M \cdot 10)$, so

$$\rho = \frac{1}{10a} \cdot l^{-b} \, (C_I \cdot M \cdot 10) \qquad (23)$$

Using the values from the summer 1983:

$$\rho = 2.34 \cdot 10^{6} \cdot l^{-1.91} \, (C_I \cdot M \cdot 10) \qquad (24)$$

then

$$2.34 \cdot 10^{6} \cdot l^{-1.91} = \frac{1}{10a} \cdot l^{-b}$$

$$a = 4.27 \cdot 10^{-8}$$

and

$$10 \log a = -73.7 \qquad (25)$$

However, as described in the chapter on calibration, the C_I values have changed to a certain degree (text table on page 7). Therefore the value is raised to -74.0 to get an average representative figure of 10 log a. Using this value of 10 log a in equation (5) gives:

$$TS = 19.1 \log L - 74.0 \qquad (26)$$

This target strength value for capelin, applied in the abundance estimates, is 10 dB lower or 1/10 of the value for maximum dorsal aspect (Fig 23). For herring, Nakken and Olsen (1977) suggested a reduction of 6 dB from maximum to "field" target strength.

It should be kept in mind that this average target strength is a result of different types of measurements. One of these is the C-value obtained from counting single fish traces. But echosounder recordings of capelin can have many different forms - the most common ones are:

- very thin scattering layers where single fish can be distinguished on the recording, often extending from about 20 m to about 80 m.

- denser scattering layers where single fish can be distinguished only in the extreme upper and lower parts of the recording. Density in the middle part of the recording as well as depth and vertical extension can be variable.

- dense "carpets" close to the bottom, often together with polar cod.

- schools, usually very dense, often undertaking diurnal migration to some extent.

Quite often combinations of the above types of recordings are found, with one scattering layer relatively high up in the sea and another scattering layer deeper down, sometimes at the bottom. Under such conditions size distribution in the two layers may be different, usually with larger capelin in the deepest layer. The behaviour of the capelin is thus different in different parts of the distribution area, and the average target strength is also probably different. Recordings of single capelin, the condition in which the target strength applied in abundance estimates is obtained, occur relatively seldom. In addition the survey vessel may influence the behaviour of the capelin.

Olsen et al. (1983) report on investigations of this problem. Fig. 21 gives a summary of the results from their investigations on capelin. The figure shows that integrator values in the depth range 112-132m decreased when the research vessel passed, while the integrator values between 132 and 172m increased. This indicates that the approach and passage of the vessel causes the capelin to swim downwards. One result of this would be that the aspect angle changes during the passage of the vessel, as the capelin are more or less uniformly oriented downwards. This is verified in Fig. 21, which shows that also the sum of the integrator values for the two depth ranges is lower immediately before and during the passage of the vessel.

Aglen (1983b) analyzed the ratios between average values of integrator output obtained during the day and during the night for the years 1974-1978 (Table 16). It is interesting to note that although the ratios vary between 0.7 and 1.4, the mean is 1.0. This may indicate that, on average, the mean target strength for capelin does not change significantly from daytime to nighttime.

Target strength measurements on capelin are scarce. Angell (1983) has measured the target strength of capelin in different densities and tilt angle distributions in net cages (experimental setup described in Olsen et al. 1982 b), and has also estimated target strength by the "echo trace counting method" (Midttun and Nakken, 1971). Fig. 22 gives a short summary of his results. Curve 1 gives the average target strength when the capelin is randomly distributed and orientated within the cage. Here, the mean target strength is approximately the same with changing mean tilt angle. Curve 2 shows the same number of fish when they are systematically oriented (swimming against a current). It is generally acknowledged that fish in schools have a higher degree of orientation than fish in scattered concentrations (Radakov 1973). Thus, curve 2 may be more representative for the target strength of capelin in schools and curve 1 for capelin in a scattering layer. For a mean tilt angle of 0^0 (i.e. horizontal position) the mean target strength of the capelin in series 2 is considerable higher (5-6 dB) than in series 1. Conversely, for a mean tilt angle of 40^0 and higher, the target strength of the fish in series 1 are higher. At a mean tilt angle of 0^0 the spread (or standard deviation) in tilt angle distribution in series 1 (unoriented manner) is greater than in series 2 (orientated manner). The aspect angle which gives maximum reflection is usually in the interval -5^0 to $+5^0$ from the horizontal position. In series 2 more fish are within this interval, and as a consequence the mean target strength will be higher.

These experiments indicate that in areas where capelin are schooling, a higher target strength (or lower conversion constant) should be applied. However, schools are generally not suitable for exact abundance estimation with an echo integrator due to acoustic shadowing etc. (Røttingen 1976).

Halldorsson and Røynisson (1982) carried out in situ measurements of target strength on capelin in sheltered Icelandic waters (Fig. 23). These measurements were completed at night on scattered concentrations, which probably gave recordings comparable to those in the Barents Sea on which the "echo trace counting method" was applied. However, there was some wind (up to 20 knots) when the measurements were carried out, and although the roll or pitch of the ship was not pronounced, the values are possibly somewhat lower than they would have been in calmer seas.

The results of all the above-mentioned target strength experiments are summarized as well in Fig 9. Although some differences may be due to different calibration procedures, it seems that the target strength values applied in the abundance estimates of the Barents Sea capelin are higher than the target strength obtained from Halldorsson and Røynisson (1982) and Angell (1983), with a difference of 2-3 dB. If the values from the measurements by Halldorsson and Røynisson (1982) and Angell (1983) were applied to the stock estimates, this would result in an increase in biomass of 1.5 to 2 times.

4.3 <u>The consistency of the acoustic estimates</u>

A measure of the "goodness" or reliability of the acoustic estimates is the consistency from year to year. This can be investigated in at least two ways:

- By trying to use the estimate from one year to predict the outcome of next year's acoustic survey, taking into account fishing mortality and natural mortality. A good fit between the predicted results and those actually obtained would indicate that the acoustic estimates were reliable.

- By using the acoustic estimates from different years to calculate natural mortality, taking into account the catch. A series of reasonably close values for natural mortality for the the same age group over several years would indicate that the acoustic estimates were reliable.

The last approach was used by Dommasnes (1981), using results from the acoustic surveys in 1975 - 1980. The values of natural mortality obtained were in the range 0.35 - 1.03 for 2 - 3-year-old capelin, 0.37 - 1.80 for 3 - 4-year-old capelin, and 0.01 - 2.66 for 4 - 5-year-olds (Table 17). This did not indicate a particularly high reliability for the acoustic estimates. However, the analysis did not take into account spawning mortality, although it was mentioned as one possible cause of the large variations in natural mortality values that were obtained.

Hamre and Tjelmeland (1981) used the age composition in the catches to calculate the proportion of each age group that spawned. Assuming that all spawning capelin died after spawning, they were able to separate the natural mortality into two independent parameters - one that was due to spawning, and one that was due to "other causes". The latter would be the natural mortality for non-spawners, which they calculated for the years 1970 - 1977 (Table 18). This gave much more consistent results, although the natural mortalities obtained from the 1978- and 1979- cruises were still higher than the rest. Altogether, this indicated a fairly good reliability for the acoustic estimates.

The acoustic surveys from 1980 and later have, however, given rise to more variable results (Tjelmeland, in prep.).

5. REFERENCES

Aglen, A. 1983a. Random errors of acoustic fish abundance estimates in relation to the survey grid density applied. pp. 293-298 in: Nakken, O. and Venema, S. C. (Eds.). 1983. Symposium on Fisheries Acoustics. Selected papers of the ICES/FAO symposium on Fisheries acoustics. Bergen, Norway, 21-24 June 1982. FAO Fish. Rep., (300): 331 pp.

Aglen, A. 1983b. Echo integrator threshold and fish density distribution. pp. 35-44 in: Nakken, O. and Venema, S. C. (Eds.). 1983. Symposium on Fisheries Acoustics. Selected papers of the ICES/FAO symposium on Fisheries acoustics. Bergen, Norway, 21-24 June 1982. FAO Fish. Rep., (300): 331 pp.

Angell, J. 1983. En sammenligning av to uavhengige metoder for beregning av målstyrke og konverteringsfaktorer (C-verdier) for lodde, Mallotus villosus (Müller). Thesis, University of Tromsø, 57 pp. (In Norwegian) [mimeo.]

Anon. 1980. Report on the Norwegian/USSR acoustic survey of the Barents Sea capelin stock in September/October 1980. 8pp. [mimeo.].

Anon. 1981. Report on the Norwegian/USSR acoustic survey of the Barents Sea capelin stock in September/October 1981. 19pp. [mimeo.].

Anon. 1982. Report on the Norwegian/USSR acoustic survey of the Barents Sea capelin stock in September/October 1982. 11pp. [mimeo.].

Anon. 1983. Report on the Norwegian/USSR acoustic survey of the Barents Sea capelin stock in September 1983. 12pp. [mimeo.].

Anon. 1984. Report on the Norwegian/USSR acoustic survey of the Barents Sea capelin stock in September 1984. 12pp. [mimeo.].

Burczynski, J. 1979. Introduction to the use of sonar systems for estimating fish biomass. FAO Fish. Tech. Pap., (191):89 pp.

Buzeta, R., Dalen, J., Dommasnes, A., Hamre J., and Nakken, O. 1975. Loddeundersøkelser i Barentshavet i september - oktober 1974. Fiskets Gang, 61: 101-104. (In Norwegian)

Dalen, J. and Nakken, O. 1983. On the application of the echo integration method. Coun. Meet. int. Coun. Explor. Sea 1983 (B:19): 30 pp.[mimeo.]

Dalen, J., Raknes, A. and Røttingen, I. 1976. Target strength measurements and acoustic biomass estimation of capelin and O-group fish. Coun. Meet. int. Coun. Explor. Sea 1976 (B:37): 9pp., 2 tabs., 8 figs. [mimeo.]

Dommasnes, A. 1979. Flowchart for acoustic assessment of one or more species. Acoustic Krill Working Party-News Vol. 1 No. 7 1979. 8pp. [mimeo.].

Dommasnes, A. 1981. Stock size and mortality estimates for Barents Sea capelin based on acoustic methods. Coun. Meet. Int. Coun. Explor. Sea 1981 (H:45) 7 pp., 4 tabs., 1 fig. [mimeo.]

Dommasnes, A., Loeng, H. and Monstad, T. 1979. Loddeundersøkelser i Barentshavet høsten 1978. Fisken Hav.,1979 (1): 17-30. (In Norwegian)

Dommasnes, A., Nakken, O. and Røttingen, I. 1975. Loddeundersøkelser i Barentshavet i september-oktober 1975. Fiskets Gang, 62: 101-108. (In Norwegian)

Dommasnes, A., Nakken, O., Sætre, R. and Frøiland, Ø. 1974. Lodde-polartorskundersøkelser i Barentshavet i september-oktober 1973. Fiskets Gang, 60: 73-77. (In Norwegian)

Dommasnes, A. and Røttingen, I. 1976. Loddeundersøkelser i Barentshavet i september-oktober 1976. Fisken Hav. 1977 (2):47-59. (In Norwegian)

Dragesund, O. and Nakken, O. 1972. Lodde- og polartorskundersøkelser i Barentshavet i august-september 1971. Fiskets Gang, 58:145-148. (In Norwegian)

Fisher, F. H. and Simmonds, V. P. 1977. Sound absorption in sea water. J. Acoust. Soc. Am., 62: 558-564.

Foote, K. 1981. Absorption term in time-varied-gain functions. FiskDir. Skr. Ser. HavUnders., 17: 191-213.

Foote, K. 1982. Optimizing copper spheres for precision calibrations with optimal copper spheres. J. Acoust. Soc. Am., 73: 1054-1063.

Foote, K. G., Knutsen, H. P. and Vestnes, G. 1983. Standard calibration of echo sounders and integrators with optimal copper spheres. FiskDir. Skr. Ser. HavUnders., 17: 335-346.

Forbes, S. T. and Nakken, O. 1972. Manual of methods for Fisheries resource survey and appraisal. Part 2. The use of acoustic instruments for fish detection and abundance estimation. Food and Agriculture Organization of the United Nations. Rome. 138 pp.

Gjøsæter, H. 1984. Standard sampling procedure for Barents Sea capelin. A description of standard sampling technique and methods applied to improve the representativeness of the samples. Contribution to the joint Soviet/Norwegian symposium on Barents Sea capelin, Bergen August 1984. 12pp. + appendix. (Included in this volume)

Gjøsæter, H. and Loeng, H. 1984. Distribution and growth of capelin in the Barents Sea in relation to water temperature in the period 1974 to 1983. Coun. Meet. int. Coun. Explor. Sea 1984(Gen:16) 1-15. [mimeo.].

Gjøsæter, J., Midttun, L., Monstad, T., Nakken, O., Smedstad, O.M., Sætre, R. and Ulltang, Ø. 1972. Undersøkelser av fiskeforekomster i Barentshavet og ved Spitsbergen i august-september 1972. Fiskets Gang 58: 1010-1021. (In Norwegian)

Halldorsson, O. and Røynisson, P. 1982. Target strength measurements of herring and capelin in situ at Iceland. pp. 78-84 in : Nakken, O. and Venema, S. C. (Eds.) 1983. Symposium on Fisheries Acoustics. Selected papers of the ICES/FAO symposium on Fisheries acoustics. Bergen, Norway, 21-24 June 1982. FAO Fish. Rep., (300): 331 pp.

Hamre, J. and Tjelmeland, S. 1982. Sustainable Yield estimates of the Barents Sea capelin stock. Coun. Meet. int. Coun. Explor. Sea 1982(H:45) 1-24. [mimeo.]

Johannesson, K. A. and Mitson, R. B. 1983. Fisheries Acoustics. A practical manual for aquatic biomass estimation. FAO Fish. Tech. Pap., (240): 249 pp.

Knutsen, H. P. 1982. TAF. En spesialkonstruert enhet for kontroll av TVF-funksjonen i forskningsekkolodd. Havforskningsinstituttet, Bergen (In Norwegian) [mimeo.].

Larsen, R. B. 1984. Escapement of capelin and polar cod through different parts of a pelagic trawl measured during an acoustic survey in the Barents Sea. Report to the Fish Capture Committee, Working Group Meeting, Hirtshals, Denmark April 30-May 4 1984. 11 pp.[mimeo.]

Loeng, H. 1979. Isforholdene i Barentshavet og vest av Spitsbergen. En oversikt. Fisken Hav., 1979(2): 29-75. (In Norwegian)

Loeng, H. 1981. Nordlig utbredelse av lodde og temperaturforholdene i Barentshavet om høsten. Fisken Hav., 1981(1): 1-10. (In Norwegian)

Loeng, H. 1983. Klimavariasjoner i tre hydrografiske snitt i Barentshavet i perioden 1977-1982. Fisken Hav., 1983(3): 5-21. (In Norwegian)

Loeng, H. 1984. Klimaforholdene i Barentshavet i 1983. Fisken Hav., 1984(1): 9-15. (In Norwegian)

Loeng, H. and Midttun, L. 1984. Climatic variations in the Barents Sea during the 1970's. Coun. Meet. Int. Coun. Explor. Sea, 1976. (Gen:15) 1-10. [mimeo.].

Loeng, H., Nakken, O. and Raknes, A. 1983. Loddas utbredelse i Barentshavet i forhold til temperaturfeltet i perioden 1974-1982. Fisken Hav., 1983(1): 1-17. (In Norwegian)

Mamylov, V. and Dommasnes, A. 1979. Report. Norwegian/USSR acoustic survey of the Barents Sea capelin stock in September 1979. Acoustic estimate. 4 pp. [mimeo.].

Midttun, L. 1982. Fish and other organisms as acoustic targets. ICES Symp. Fish. Acoust. Bergen, Norway, June 1982, No. 3, 1-126. [mimeo.]

Midttun, L. and Nakken, O. 1971. On acoustic identification, sizing and abundance estimation of fish. FiskDir. Skr. Ser. HavUnders., 16(1): 36-48.

Midttun, L. and Nakken, O. 1977. Some results of abundance estimation studies with echo integrators. Rapp. P.-v. Reun. Cons. int. Explor. Mer, 170: 253-258.

Monstad,T. and Røttingen, I. 1977. Loddeundersøkelser i Barentshavet i September-oktober 1977. FiskenHav., 1977 (3): 13-28. (In Norwegian)

Nakken, O. 1975. On the problem of determining the relationship between integrated echo intensity and fish density. Coun. Meet. Int. Coun. Explor. Sea 1975 (B:26): 7 pp., 1 tab., 1 fig.

Nakken, O. and Dommasnes, A. 1977. Acoustic estimates of the Barents Sea capelin stock 1971-1976. Coun. Meet. Int. Coun. Explor. Sea 1977 (H:35):1-6, 2 tabs., 3 figs. [mimeo.]

Nakken, O. and Olsen, K. 1977. Target strength measurements of fish. Rapp. P.-v. Reun. Cons. int. Explor. Mer, 170: 52-69.

Olsen, K., Angell, J., Pettersen, F. and Løvik, A. 1983. Observed fish reactions to a surveying vessel with special reference to herring, cod, capelin and polar cod. pp. 131-138 in: Nakken, O. and Venema, S. C. (Eds.). Symposium on Fisheries Acoustics. Selected papers of the ICES/FAO symposium on Fisheries acoustics. Bergen, Norway, 21-24 June 1982. FAO Fish. Rep., (300): 331 pp.

Schulkin, M. and Marsh, H. W. 1962. Sound absorption in sea water. J. Acoust. Soc. Am., 34: 864-865.

Simmonds, E. J. 1984. The effect of mounting the equivalent beam angle of acoustic survey transducers. Coun. Meet. Int. Coun. Explor. Sea 1984 (B:32): 9 pp. [mimeo.]

Radakov, D. V. 1973. Schooling in the ecology of fish. John Wiley & Sons. New York. 173 pp.

Røttingen, I. 1976. On the relation between echo intensity and fish density. Fisk.Dir. Skr. Ser. HavUnders., 16: 301-314.

Røttingen, I. 1978. Field intercalibrations of echo integrator systems. Coun. Meet. Int. Coun. Explor. Sea 1978 (B:25): 23pp. [mimeo.]

Tjelmeland, S. (in prep.) Report to the ICES Working Group on Atlanto-Scandian herring and capelin 1985.

Urick, R. J. 1975. Principles of underwater sound. McGraw Hill, New York. 384 pp. 2nd ed.

Table 1. Acoustic abundance estimate of capelin, autumn 1972.

	Alder								
LENGDE	1	2	3	4	5+	TOT	VEKT	GJ.VOL.	KOND.
30-35						2	0.0	0.1	2.9
35-40						5	0.0	0.2	3.8
40-45						15	0.0	0.3	3.9
45-50						27	0.1	0.4	3.7
50-55						49	0.2	0.5	3.5
55-60						123	0.7	0.6	3.2
60-65	215					215	1.5	0.7	2.9
65-70	506					506	4.9	1.0	3.3
70-75	1186					1186	13.8	1.2	3.1
75-80	2655					2655	43.8	1.7	3.7
80-85	3281					3281	70.0	2.2	3.9
85-90	3165					3165	92.1	3.0	4.5
90-95	2164					2164	63.0	3.0	3.8
95-100	1210					1210	46.9	4.0	4.3
100-105	610					610	22.5	3.8	3.5
105-110	181	109				282	12.4	4.5	3.6
110-115		204				204	10.8	5.4	3.8
115-120		445	20			461	28.2	6.3	3.9
120-125		1435	39			1471	106.8	7.5	4.1
125-130		3151	465	43		3660	291.0	8.2	4.0
130-135		3880	2109	64		6053	550.6	9.4	4.0
135-140		2908	3395	172		6476	669.9	10.7	4.1
140-145		1183	4083	165		5435	618.1	11.7	4.1
145-150		464	2759	290		3511	449.5	13.2	4.1
150-155		249	1703	232	18	2210	311.7	14.5	4.1
155-160		62	1021	281	15	1396	214.7	15.9	4.1
160-165		40	622	320	43	1029	186.4	18.7	4.4
165-170			399	335	25	760	144.4	19.6	4.2
170-175			199	233	23	451	99.8	22.8	4.4
175-180			85	82	26	196	43.3	22.8	4.1
180-185			39	64	8	115	30.4	27.3	4.5
185-190				6	6	10	2.7	27.5	4.2
190-195					22	22	6.0	28.0	3.9
195-200						0	0.0	0.0	0.0
200-205						0	0.0	0.0	0.0
205-210					7	7	2.0	30.0	3.4
ANTALL:	15173.	14130.	16938.	2287.	193.	48962.			
GJ.LGD:	8.48	13.23	14.44	15.71	17.17	12.28			
VEKT :	366.2	1281.6	2074.4	373.3	40.7	4138.3			
GJ.VOL:	2.5	9.4	12.6	16.8	21.7	8.7			
KOND. :	3.9	4.0	4.1	4.2	4.3	4.0			

Alder	= age
Antall	= number x 10^{-7}
Gj.lgd.	= mean length (cm)
Volum	= biomass hectolitres x 10^{-3}
Gj.vol	= mean volume per individual (ml)
Vekt	= biomass tonnes x 10^{3}
Kond.	= condition factor (1000 x mean volume/length^3)
Lengde	= length group (mm)

Table 2. Acoustic abundance estimate of capelin, autumn 1973.

Alder

LENGDE	1	2	3	4	5+	TOT	VOLUM	GJ.VOL	KOND.
35- 40	7					7	0.	0.3	5.7
40- 45	133					133	5.	0.4	5.2
45- 50	819					819	41.	0.5	4.7
50- 55	865					865	52.	0.6	4.1
55- 60	836					836	59.	0.7	3.7
60- 65	488	69				557	45.	0.8	3.3
65- 70	613					613	61.	1.0	3.3
70- 75	952	182				1134	155.	1.2	3.1
75- 80	1142					1142	186.	1.3	2.8
80- 85	3048	131				3179	636.	2.0	3.6
85- 90	7240	219				7459	1638.	2.2	3.3
90- 95	12053	1489				13542	3791.	2.9	3.7
95-100	12960	3454				16416	5135.	3.1	3.3
100-105	8195	6267				14462	5570.	3.7	3.4
105-110	4931	5307				10241	4676.	4.5	3.6
110-115	2493	5085				7578	4149.	5.0	3.5
115-120	860	4511	52			5425	3472.	6.4	3.9
120-125	240	4194				4429	3293.	6.7	3.6
125-130	234	2456	40			2741	2380.	8.1	3.9
130-135	66	1738	132			1938	1943.	9.5	4.1
135-140	21	1271	263			1554	1781.	10.6	4.1
140-145	30	691	306	23		1053	1322.	12.5	4.3
145-150		310	579	45		938	1336.	13.8	4.3
150-155		211	648	145		1009	1616.	16.1	4.5
155-160		210	557	205		971	1829.	18.8	4.8
160-165		34	570	359		963	2011.	20.2	4.7
165-170		26	574	298	5	907	2162.	23.5	5.0
170-175		37	299	292	6	630	1613.	25.3	4.9
175-180			116	250	9	375	1143.	29.1	5.2
180-185			72	140		212	681.	31.5	5.2
185-190				30		30	110.	33.0	5.0
190-195				3		3	11.	38.0	5.3
195-200				2		2	11.	45.0	5.8
ANTALL:	58226.	37892.	4208.	1792.	20.	102163.			
GJ.LGD:	9.37	11.33	15.55	16.71	17.35	10.49			
VOLUM :	17846.	23023.	7669.	4253.	60.	52915.			
GJ.VOL:	3.0	5.6	18.6	23.3	0.0	5.0			
KOND. :	3.5	3.6	4.7	4.9	0.0	3.6			

Legend as in Table 1.

Table 3. Acoustic abundance estimate of capelin, autumn 1974.

Alder

LENGDE	1	2	3	4	5+	TOT	VOLUM	GJ.VOL	KOND.
50- 55						1	0.	0.6	4.1
55- 60	14					14	1.	0.7	3.7
60- 65	36					36	3.	0.8	3.3
65- 70	53					53	5.	1.0	3.3
70- 75	233	11				244	29.	1.2	3.1
75- 80	397	5				402	56.	1.4	3.0
80- 85	1108	100	6			1217	233.	1.9	3.4
85- 90	2493	115				2606	574.	2.2	3.3
90- 95	3727	460	29			4218	1182.	2.8	3.5
95-100	7021	1812	134			8964	2787.	3.1	3.3
100-105	7837	8245	880			16958	6424.	3.7	3.4
105-110	6180	11940	1595			19716	8319.	4.2	3.4
110-115	2599	10757	2168			15532	7732.	5.0	3.5
115-120	571	8504	2157			11233	6399.	5.8	3.6
120-125	162	6253	2107			8521	5752.	6.9	3.8
125-130	30	3650	1541	10		5232	4108.	7.9	3.8
130-135	10	1997	1616	25		3655	3341.	9.2	4.0
135-140		1041	1503	5		2551	2712.	10.4	4.0
140-145		859	1292	42		2195	2708.	12.1	4.2
145-150		402	1071	13		1485	2099.	13.9	4.3
150-155		207	646	36		889	1442.	15.6	4.4
155-160		60	541	17		615	1149.	18.1	4.6
160-165		24	311	62		398	848.	20.8	4.8
165-170		1	167	42		212	507.	23.6	5.0
170-175		6	86	51	7	145	364.	24.3	4.7
175-180			20	24		37	104.	27.0	4.8
180-185			21	15		29	95.	32.0	5.3
185-190			25			25	81.	32.0	4.9
190-195			9	9		15	58.	0.0	0.0
195-200				5		5	21.	0.0	0.0
ANTALL:	32471.	56449.	17925.	356.	7.	107203.			
GJ.LGD:	9.99	11.42	12.74	16.00	17.25	11.22			
VOLUM :	11206.	31253.	15872.	736.	18.	59135.			
GJ.VOL:	3.4	5.6	9.1	21.2	0.0	5.5			
KOND. :	3.3	3.7	3.9	4.8	0.0	3.6			

Legend as in Table 1.

Table 4. Acoustic abundance estimate of capelin, autumn 1975.

Alder

LENGDE	1	2	3	4	5+	TOT	VOLUM	GJ.VOL.	KOND.
55– 60	25					25	1.	0.0	0.0
60– 65	7					7	0.	0.5	2.0
65– 70	7					7	0.	0.7	2.3
70– 75	19					19	2.	1.0	2.6
75– 80	158					158	19.	1.5	3.2
80– 85	460	45				505	89.	2.0	3.6
85– 90	1848	21				1869	386.	3.0	4.5
90– 95	4049	285				4334	1140.	3.0	3.8
95–100	4483	806				5288	1668.	3.3	3.6
100–105	4975	1305				6278	2429.	4.1	3.8
105–110	2549	3439	33			6022	2652.	4.6	3.7
110–115	1008	5254	1041	41		7347	3854.	5.3	3.7
115–120	320	8223	3084	88	12	11727	6922.	5.7	3.5
120–125	82	6435	4085	292		10909	7730.	6.9	3.8
125–130		4455	5402	503	35	10388	8808.	8.1	3.9
130–135		2696	4397	855		7956	7889.	9.0	3.9
135–140		1655	3553	742		5943	6716.	11.1	4.3
140–145		681	2724	984		4393	5625.	12.3	4.3
145–150		241	1920	906		3063	4560.	14.3	4.5
150–155		269	1564	583		2412	3891.	16.2	4.6
155–160		150	902	1069	18	2145	4001.	18.7	4.8
160–165		108	681	841		1627	3438.	20.1	4.7
165–170			530	636		1164	2819.	22.6	4.8
170–175			224	569	32	826	2323.	24.3	4.7
175–180			148	464		610	1837.	30.0	5.4
180–185			111	157		265	917.	31.0	5.1
185–190			7	59		66	238.	0.0	0.0
ANTALL:	19990.	36068.	30406.	8789.	97.	95353.			
GJ.LGD:	9.87	12.00	13.42	15.07	14.67	12.29			
VOLUM :	6724.	24649.	33445.	15060.	131.	79955.			
GJ.VOL.:	3.7	6.8	10.4	16.0	19.0	8.1			
KOND. :	3.8	3.7	4.1	4.5	4.9	3.9			

Legend as in Table 1.

Table 5. Acoustic abundance estimate of capelin, autumn 1976.

Alder

LENGDE	1	2	3	4	5+	TOT	VOLUM	GJ.VOL	KOND.
45- 50	31					31	2.	0.0	0.0
50- 55	31					31	2.	0.0	0.0
55- 60	124					124	9.	0.0	0.0
60- 65	437					437	35.	0.0	0.0
65- 70	124					124	11.	0.0	0.0
70- 75	24					24	2.	0.0	0.0
75- 80	304					304	36.	0.0	0.0
80- 85	965					965	135.	0.0	0.0
85- 90	1542	27				1569	251.	0.0	0.0
90- 95	2191	11				2202	527.	2.0	2.5
95-100	2651		12			2663	778.	2.5	2.7
100-105	5239	74				5308	1941.	3.5	3.3
105-110	4592	287	53			4927	2091.	4.5	3.6
110-115	2966	1394	58			4412	2249.	5.3	3.7
115-120	1216	3947	497	57		5734	3496.	6.0	3.7
120-125	246	5093	1117	132		6591	4527.	7.1	3.9
125-130	36	4687	2015	325	27	7096	5609.	8.1	3.9
130-135		3183	1983	436	48	5656	5216.	9.1	3.9
135-140		2583	2349	801	6	5735	6135.	10.5	4.0
140-145		1543	2034	790	141	4505	5570.	11.9	4.1
145-150		844	2303	996	119	4250	5993.	13.5	4.2
150-155		257	1544	1022	129	2960	4796.	15.6	4.4
155-160		100	1365	851	254	2588	4689.	17.4	4.5
160-165		24	515	656	99	1296	2728.	19.6	4.6
165-170		16	412	519	56	1005	2411.	22.4	4.8
170-175			311	544	108	965	2566.	24.3	4.7
175-180			142	343	87	563	1710.	28.6	5.1
180-185			5	256	113	368	1252.	29.3	4.8
185-190			18	82	24	123	482.	40.0	6.1
190-195				30	56	86	357.	42.0	5.9
200-205				4		4	22.	0.0	0.0
ANTALL:	22719.	24070.	16733.	7844.	1267.	72646.			
GJ.LGD:	10.07	12.74	14.15	15.28	16.05	12.56			
VOLUM :	8049.	19752.	21325.	13753.	2756.	65628.			
GJ.VOL:	3.9	8.2	12.4	16.4	18.2	9.2			
KOND. :	3.3	3.9	4.2	4.4	4.5	3.9			

Legend as in Table 1.

Table 6. Acoustic abundance estimate of capelin, autumn 1977.

Alder

LENGDE	1	2	3	4	5+	TOT	VOLUM	GJ.VOL	KOND.
40- 45						297	6.	0.2	2.6
45- 50						739	15.	0.2	1.9
50- 55	483					483	14.	0.3	2.1
55- 60	916					916	37.	0.4	2.1
60- 65	1926					1926	96.	0.5	2.0
65- 70	2620					2620	157.	0.6	2.0
70- 75	4027					4027	282.	0.7	1.8
75- 80	4046					4046	485.	1.2	2.6
80- 85	5701	2				5703	1063.	1.9	3.3
85- 90	5441	55				5496	1222.	2.2	3.3
90- 95	4313	155				4468	1253.	2.8	3.5
95-100	4052	247				4299	1361.	3.2	3.4
100-105	2716	421	2			3139	1178.	3.8	3.5
105-110	1058	775	2			1834	789.	4.3	3.5
110-115	330	1945	12			2285	1156.	5.1	3.6
115-120	73	2970	42	18		3111	1842.	5.9	3.7
120-125	6	3250	202	30		3488	2466.	7.1	3.8
125-130		2508	419	40		2971	2426.	8.2	3.9
130-135		2360	800	128		3287	3207.	9.8	4.2
135-140		1295	1154	212		2669	2996.	11.2	4.3
140-145		869	1204	298	33	2410	3144.	13.0	4.5
145-150		558	1406	449	26	2442	3637.	14.9	4.6
150-155		344	1115	463	85	2012	3432.	17.1	4.8
155-160		236	1364	559	135	2292	4379.	19.1	4.9
160-165		94	870	486	98	1555	3425.	22.0	5.1
165-170		18	844	372	89	1324	3231.	24.4	5.2
170-175		13	367	489	113	983	2726.	27.7	5.4
175-180			253	347	145	746	2273.	30.5	5.4
180-185			101	173	14	286	949.	33.2	5.5
185-190			14	69	5	88	309.	35.1	5.3
190-195				20		20	84.	42.0	5.9
195-200				6		6	29.	48.0	6.2
ANTALL:	37708.	18115.	10171.	4159.	743.	71968.			
GJ.LGD:	8.38	12.49	15.00	15.90	16.46	10.82			
VOLUM :	7515.	14648.	17074.	8683.	1706.	49669.			
GJ.VOL:	2.0	8.1	16.8	20.9	23.0	6.9			
KOND. :	2.9	3.9	4.8	5.0	5.1	3.6			

Legend as in Table 1.

Table 7. Acoustic abundance estimate of capelin, autumn 1978.

Alder

LENGDE	1	2	3	4	5+	TOT	VOLUM	GJ.VOL	KOND.
35- 40						23	0.	0.2	3.8
40- 45						47	1.	0.3	3.9
45- 50						117	6.	0.5	4.7
50- 55						159	11.	0.7	4.8
55- 60						67	6.	0.9	4.7
60- 65						5	1.	1.1	4.5
65- 70		2				53	7.	1.4	4.5
70- 75	694	6				700	118.	1.7	4.4
75- 80	484	8				492	97.	2.0	4.2
80- 85	1042	42				1084	247.	2.3	4.1
85- 90	987	98				1085	267.	2.5	3.7
90- 95	2970	385				3355	857.	2.6	3.2
95-100	3270	996				4266	1342.	3.1	3.4
100-105	1079	3426				4506	1776.	3.9	3.7
105-110	308	4745				5052	2278.	4.5	3.6
110-115	169	5961	32			6162	3224.	5.2	3.7
115-120		5871	44			5915	3545.	6.0	3.7
120-125		5952	63			6015	4286.	7.1	3.9
125-130		3735	193			3928	3262.	8.3	4.0
130-135		2584	819			3402	3333.	9.8	4.2
135-140		1483	1085			2568	2810.	10.9	4.2
140-145		723	1331	41		2097	2742.	13.1	4.5
145-150		540	1420	101	12	2082	3044.	14.6	4.6
150-155		237	1669	142		2049	3442.	16.8	4.7
155-160		159	1118	315		1600	3090.	19.3	4.9
160-165		78	1014	312	28	1441	3091.	21.4	5.0
165-170		57	552	264	17	890	2085.	23.4	5.0
170-175			292	156	3	451	1215.	26.9	5.2
175-180		3	193	49	3	252	772.	30.6	5.5
180-185			108	42		150	499.	33.3	5.5
185-190			19	5	8	32	132.	41.3	6.3
190-195			6			6	22.	36.0	5.0
ANTALL:	11003.	37091.	9958.	1427.	71.	60051.			
GJ.LGD:	9.24	11.82	15.01	16.20	16.50	11.94			
VOLUM :	3103.	24875.	16469.	2948.	164.	47609.			
GJ.VOL:	2.8	6.7	16.5	20.7	23.1	7.9			
KOND. :	3.6	3.8	4.7	4.8	5.0	4.0			

Legend as in Table 1.

Table 8. Acoustic abundance estimate of capelin, autumn 1979.

Alder

LENGDE	1	2	3	4	5+	TOT	VEKT	GJ.VOL	KOND.
40- 45						6	0.0	0.2	2.6
45- 50						326	1.0	0.3	2.8
50- 55						724	2.9	0.4	2.8
55- 60						583	2.9	0.5	2.6
60- 65	77					77	0.5	0.7	2.9
65- 70	77					77	0.7	0.9	2.9
70- 75						0	0.0	0.0	0.0
75- 80						0	0.0	0.0	0.0
80- 85	13					13	0.2	1.8	3.2
85- 90	6					6	0.1	2.2	3.3
90- 95	38					38	1.1	3.0	3.8
95-100	134	79				209	7.1	3.4	3.7
100-105	325	464				789	33.9	4.3	4.0
105-110	373	1623				1682	75.7	4.5	3.6
110-115	215	2935				3145	165.4	5.3	3.7
115-120	183	6697	140			7023	427.1	6.1	3.7
120-125	31	8438	114			8583	612.0	7.1	3.9
125-130		6522	1048			7570	618.4	8.2	3.9
130-135		3944	2293			6230	589.5	9.5	4.1
135-140		1897	1683	39		3620	399.7	11.0	4.2
140-145		576	1695	12		2271	292.4	12.9	4.5
145-150		111	1441	48		1598	238.9	15.0	4.7
150-155		56	1228	89		1376	234.0	17.0	4.8
155-160		52	629	33		706	137.2	19.4	5.0
160-165		9	580	82		672	143.4	21.3	5.0
165-170			165	49	2	219	52.7	24.0	5.1
170-175			170	76		245	67.1	27.4	5.3
175-180			55	44		99	31.9	32.3	5.8
180-185			8	6		14	4.8	34.6	5.7
ANTALL:	1472.	33403.	11249.	478.	2.	47901.			
GJ.LGD:	10.26	12.31	14.24	16.00	16.75	12.51			
VEKT :	60.6	2468.3	1516.0	100.8	0.5	4140.9			
GJ.VOL:	4.1	7.4	13.5	21.1	27.0	8.6			
KOND. :	3.6	3.9	4.5	5.0	5.7	4.0			

Legend as in Table 1.

Table 9. Acoustic abundance estimate of capelin, autumn 1980.

Alder

LENGDE	1	2	3	4	5	TOT	VEKT	GJ.VOL	KOND.
6.5- 6.9	63					63	0.6	1.0	3.3
7.0- 7.4	260					260	2.6	1.0	2.6
7.5- 7.9	272					272	2.7	1.0	2.1
8.0- 8.4	534					534	9.1	1.7	3.0
8.5- 8.9	1455					1455	29.1	2.0	3.0
9.0- 9.4	2490					2490	58.7	2.4	3.0
9.5- 9.9	2633	25				2658	81.5	3.1	3.3
10.0-10.4	2968	75				3043	120.4	4.0	3.7
10.5-10.9	5275	388				5663	264.5	4.7	3.8
11.0-11.4	5874	1146	13			7033	372.0	5.3	3.7
11.5-11.9	3146	2463	4			5613	347.8	6.2	3.8
12.0-12.4	1221	3386	52			4659	344.3	7.4	4.0
12.5-12.9	593	3185	168	4		3950	343.0	8.7	4.2
13.0-13.4	256	3108	459	14		3837	390.1	10.2	4.4
13.5-13.9	59	2724	1131	14		3928	452.5	11.5	4.4
14.0-14.4		1836	2317	108		4261	561.5	13.2	4.6
14.5-14.9		756	2811	197		3764	554.8	14.7	4.6
15.0-15.4		422	2776	381		3579	604.5	16.9	4.8
15.5-15.9		92	1800	464	1	2357	447.6	19.0	4.9
16.0-16.4		43	1453	469	29	1994	437.3	21.9	5.1
16.5-16.9		7	878	410		1295	327.2	25.3	5.4
17.0-17.4		7	510	384		901	257.2	28.5	5.6
17.5-17.9			442	339		781	250.8	32.1	5.7
18.0-18.4			271	230		501	182.8	36.5	6.0
18.5-18.9			178	108		286	115.0	40.2	6.1
19.0-19.4			131	85		216	91.3	42.3	5.9
19.5-19.9			19	55		74	36.5	49.3	6.4
ANTALL:	27099	19663	15413	3262	30	65467			
GJ.LGD:	10.60	12.91	15.31	16.57	16.23	12.70			
VEKT :	1223.5	1852.5	2797.7	805.8	5.9	6685.4			
GJ.VOL:	4.5	9.4	18.2	24.7	19.8	10.2			
KOND. :	3.6	4.2	4.8	5.2	4.6	4.1			

Legend as in Table 1.

Table 10. Acoustic abundance estimate of capelin, autumn 1981.

Alder

LENGDE	1	2	3	4	5	TOT	VEKT	GJ.VOL	KOND.
3.0- 3.4	59					59	0.1	0.1	2.9
3.5- 3.9	434					434	0.4	0.1	1.9
4.0- 4.4	451					451	0.9	0.2	2.6
4.5- 4.9	690					690	2.1	0.3	2.8
5.0- 5.4	535					535	2.1	0.4	2.8
5.5- 5.9	610					610	3.0	0.5	2.6
6.0- 6.4	795					795	5.6	0.7	2.9
6.5- 6.9	1805					1805	16.2	0.9	2.9
7.0- 7.4	3180					3180	31.8	1.0	2.6
7.5- 7.9	5814					5814	75.7	1.3	2.8
8.0- 8.4	6387					6387	115.2	1.8	3.2
8.5- 8.9	5723	8				5731	120.6	2.1	3.1
9.0- 9.4	5188	34				5222	135.0	2.6	3.3
9.5- 9.9	4142	132				4274	129.3	3.0	3.3
10.0-10.4	2643	256				2399	108.2	3.7	3.5
10.5-10.9	2162	470				2632	113.6	4.3	3.5
11.0-11.4	786	896				1682	88.5	5.3	3.7
11.5-11.9	299	1743	5			2047	127.4	6.2	3.8
12.0-12.4	162	3069	19			3250	233.7	7.2	3.9
12.5-12.9	125	4195	59			4379	363.5	8.3	4.0
13.0-13.4	50	3276	229	4		3559	342.4	9.6	4.1
13.5-13.9	20	2347	466	1		2834	315.1	11.1	4.3
14.0-14.4	7	1532	641	2		2182	276.5	12.7	4.4
14.5-14.9		676	701	20		1397	201.4	14.4	4.5
15.0-15.4		355	705	140	4	1204	197.4	16.4	4.6
15.5-15.9		164	697	199		1060	189.8	17.9	4.6
16.0-16.4		94	468	197	2	761	155.4	20.4	4.8
16.5-16.9		79	344	259		682	155.6	22.8	4.9
17.0-17.4		67	157	172	4	400	106.7	26.7	5.2
17.5-17.9		52	162	182	6	402	120.0	29.8	5.3
18.0-18.4		38	66	129		233	77.7	33.3	5.5
18.5-18.9		17	51	49	10	127	46.3	36.4	5.5
19.0-19.4			15	2		17	7.8	46.0	6.4
19.5-19.9			5	19		24	11.5	48.0	6.2
20.0-20.4			1	3		4	2.3	58.5	7.0
20.5-20.9			2			2	1.3	63.0	7.1
ANTALL:	42067	19500	4793	1378	26	67764			
GJ.LGD:	8.49	12.94	15.28	16.80	17.56	10.42			
VEKT :	913.5	1823.3	814.5	321.6	7.5	3880.4			
GJ.VOL:	2.2	9.4	17.0	23.3	28.7	5.7			
KOND. :	3.1	4.1	4.6	4.8	5.2	3.5			

Legend as in Table 1.

Table 11. Acoustic abundance estimate of capelin, autumn 1982.

Lengde	Alder 1	2	3	4	5	Tot	Vekt	Gj.vol	Kond.
6.5- 6.9	4631					4631	46.1	1.0	3.2
7.0- 7.4	6164					6164	61.8	1.0	2.6
7.5- 7.9	7089					7089	78.4	1.1	2.4
8.0- 8.4	3852					3852	62.2	1.6	2.9
8.5- 8.9	4418					4418	92.0	2.1	3.1
9.0- 9.4	5449	71				5520	151.7	2.7	3.5
9.5- 9.9	5992	108				6100	191.2	3.1	3.4
10.0-10.4	5542	429				5971	224.0	3.8	3.5
10.5-10.9	3682	1826				5508	243.4	4.4	3.6
11.0-11.4	1549	3123				4672	248.0	5.3	3.7
11.5-11.9	913	4872				5785	357.1	6.2	3.8
12.0-12.4	315	5359	6			5680	417.1	7.3	4.0
12.5-12.9	30	4787	26			4843	408.8	8.4	4.1
13.0-13.4	4	3366	46			3416	339.8	9.9	4.3
13.5-13.9		2638	168			2806	319.5	11.4	4.4
14.0-14.4		1421	654			2075	273.3	13.2	4.6
14.5-14.9		1229	685	3		1917	283.2	14.8	4.6
15.0-15.4		654	1047	14		1715	292.5	17.1	4.8
15.5-15.9		336	1011	54		1401	265.2	18.9	4.8
16.0-16.4		110	731	47		888	188.9	21.3	5.0
16.5-16.9		199	631	32		862	213.7	24.8	5.3
17.0-17.4		190	558	19		767	214.0	27.9	5.4
17.5-17.9		300	307	20		627	194.7	31.0	5.6
18.0-18.4		42	259			301	103.8	34.5	5.7
18.5-18.9		26	57			83	29.8	35.9	5.4
19.0-19.4			87	14		101	40.7	40.3	5.6
19.5-19.9		14	29	14		57	24.7	43.3	5.6
20.0-20.4			14			14	7.0	50.0	6.0
Antall:	49630	31100	6316	217	0	87263			
Gj.lgd:	8.85	12.69	15.91	16.76	0.00	10.75			
Vekt :	1210.8	2789.2	1318.1	54.0	0.0	5372.2			
Gj.vol:	2.4	9.0	20.9	24.9	0.0	6.2			
Kond. :	3.1	4.1	5.0	5.1	0.0	3.6			

Legend as in Table 1.

Table 12. Acoustic abundance estimate of capelin, autumn 1983.

Alder

Lengde	1	2	3	4	5	Tot	Vekt	Gj.v
6.5- 6.9	527					527	5.3	1.0
7.0- 7.4	718					718	7.2	1.0
7.5- 7.9	1016					1016	10.9	1.1
8.0- 8.4	2756					2756	55.7	2.0
8.5- 8.9	9643					9643	208.3	2.2
9.0- 9.4	11953	146				12099	340.1	2.8
9.5- 9.9	10966	291				11257	353.2	3.1
10.0-10.4	6710	440				7150	278.1	3.9
10.5-10.9	3815	1571				5386	249.8	4.6
11.0-11.4	2161	2339				4500	249.1	5.5
11.5-11.9	849	2467				3316	212.6	6.4
12.0-12.4	216	3013	27			3256	248.3	7.6
12.5-12.9	144	2393	64			2601	231.1	8.9
13.0-13.4	14	2212	232			2458	253.0	10.3
13.5-13.9		1425	252			1677	199.2	11.9
14.0-14.4	5	1152	532			1689	231.2	13.7
14.5-14.9	9	812	466			1287	199.4	15.5
15.0-15.4		734	521	7		1262	225.6	17.9
15.5-15.9		388	438	6		832	168.8	20.3
16.0-16.4	9	278	545	14		846	192.0	22.7
16.5-16.9		165	277	9		451	117.1	26.0
17.0-17.4		107	264			371	106.1	28.6
17.5-17.9		33	133			166	54.1	32.6
18.0-18.4		11	36			47	16.1	34.3
18.5-18.9		18	22			40	16.1	40.2
19.0-19.4		1	2			3	1.3	45.0
Antall:	51511	19996	3811	36	0	75354		
Gj.lgd:	9.52	12.66	15.35	16.10	0.00	10.65		
Vekt:	1609.1	1893.3	720.4	7.0	0.0	4229.8		
Gj.vol:	3.1	9.5	18.9	19.4	0.0	5.6		
Kond.:	3.5	4.3	5.0	4.6	0.0	3.8		

Legend as in Table 1.

Table 13. Acoustic abundance estimate of capelin, autumn 1984.

	Alder							
Lengde	1	2	3	4	5	Tot	Vekt	Gj.v
8.0- 8.4	266	14				280	5.2	1.9
8.5- 8.9	998					998	20.4	2.0
9.0- 9.4	2719	34				2753	72.6	2.6
9.5- 9.9	3848	391				4239	132.9	3.1
10.0-10.4	2515	1388				3903	153.6	3.9
10.5-10.9	2076	2443	25			4544	204.8	4.5
11.0-11.4	1277	2951	80			4308	226.7	5.3
11.5-11.9	515	3009	114			3638	219.5	6.0
12.0-12.4	125	2692	194			3011	213.9	7.1
12.5-12.9	139	1742	163			2044	171.6	8.4
13.0-13.4	39	1384	284			1707	166.7	9.8
13.5-13.9	25	739	409			1173	134.2	11.4
14.0-14.4	2	513	501			1016	137.5	13.5
14.5-14.9		347	489			836	122.8	14.7
15.0-15.4		213	541	37		791	136.0	17.2
15.5-15.9		153	421	37		611	115.7	18.9
16.0-16.4		127	395	39		561	121.5	21.7
16.5-16.9		82	297	59		438	110.0	25.1
17.0-17.4		94	328	33		455	128.9	28.3
17.5-17.9		51	226	24		301	95.7	31.8
18.0-18.4		6	157	24		187	66.6	35.6
18.5-18.9		11	76	32		119	46.0	38.7
19.0-19.4		2	62	14		78	33.5	43.0
19.5-19.9			31	10		41	19.2	46.7
20.0-20.4			2	10		12	6.4	53.3
20.5-20.9				3		3	1.8	60.0
Antall:	14544	18386	4795	322	0	38047		
Gj.lgd:	10.06	12.04	15.18	17.19	0.00	11.72		
Vekt:	535.8	1367.8	872.7	87.4	0.0	2863.7		
Gj.vol:	3.7	7.4	18.2	27.1	0.0	7.5		
Kond.:	3.5	3.9	4.8	5.1	0.0	3.9		

Legend as in Table 1.

Table 14. Mean temperature ($\bar{t}$) and standard deviation (s) in the distribution area of 1, 2, 3, and 4 years old capelin in the period 1974 - 1982 (Loeng, Nakken, and Raknes, 1983).

	Age, years							
	1		2		3		4	
Year	t^0C	s	t^0C	s	t^0C	s	t^0C	s
1974	1.04	1.46	-0.15	1.00	-0.18	0.99	0.32	1.11
1975	0.61	1.01	-0.03	0.88	-0.29	0.74	-0.26	0.78
1976	1.34	1,04	0.16	0.98	0.46	1.09	0.76	1.21
1977	1.66	1.36	-0.32	0.72	-0.38	0.59	-0.37	0.59
1978	1.78	1.10	0.03	1.07	-0.11	0.77	0.13	0.69
1979	0.72	1.13	-0.05	0.86	-0.19	0.69	-0.05	0.72
1980	1.36	0.94	0.78	0.91	0.68	0.88	0.85	0.89
1981	1.51	0.78	0.63	0.88	0.53	0.95	0.53	0.90
1982	2.38	1.21	1.12	1.22	0.99	0.91	1.13	0.83

Table 15. Average weight in grams of 2 and 3 years old capelin together with mean temperatures (t) in the distribution area. The individual growth (in grams) of capelin from 2 to 3 years of age is shown in the column to the right (Loeng, Nakken and Raknes 1983).

	Age, years				Weight increase 2 to 3 years
	2		3		
Year	Weight(g)	t^0C	Weight(g)	t^0C	
1974	5.6	-0.15	9.1	-0.18	
1975	6.8	-0.03	10.4	-0.29	4.8
1976	8.2	(0.16)	12.4	(0.46)	5.6
1977	8.1	-0.32	16.8	-0.38	8.6
1978	6.7	0.03	16.5	-0.11	8.4
1979	7.4	-0.05	13.5	-0.19	6.8
1980	9.4	0.78	18.2	0.68	10.8
1981	9.4	0.63	17.0	0.53	7.6
1982	9.4	1.12	17.0	0.99	7.6

Table 16. Ratio between average integrator values obtained during day, ($\bar{M}_D$), and night, ($\bar{M}_N$), on capelin recordings in the Barents Sea in autumn onboard the "G.O. Sars" (Aglen, 1983a).

Year:	1974	1975	1976	1977	1978	Average
$\bar{M}_D$ / $\bar{M}_N$	0.9	1.4	0.7	0.9	1.2	1.0

Table 17. Instantaneous natural mortality for Barents Sea capelin by yearclass and age, as obtained by combining acoustic estimates and catch statistics (Dommasnes, 1981).

Age	Yearclass						
	1971	1972	1973	1974	1975	1976	1977
2 - 3 years			0.67	0.63	0.35	1.03	0.64
3 - 4 "		1.00	0.68	0.88	1.80	0.37	
4 - 5 "	1.16	1.20	2.14	2.66	0.01		

Table 18. Instantaneous natural mortality for immature Barents Sea capelin by yearclass and age. Adapted from Hamre and Tjelmeland, 1982.

Age	Yearclass							
	1970	1971	1972	1973	1974	1975	1976	1977
2 - 3 years		0.67	0.56	0.61	0.58	0.56	1.02	0.64
3 - 4 "	0.68	0.53	0.82	0.64	0.84	0.96	0.60	

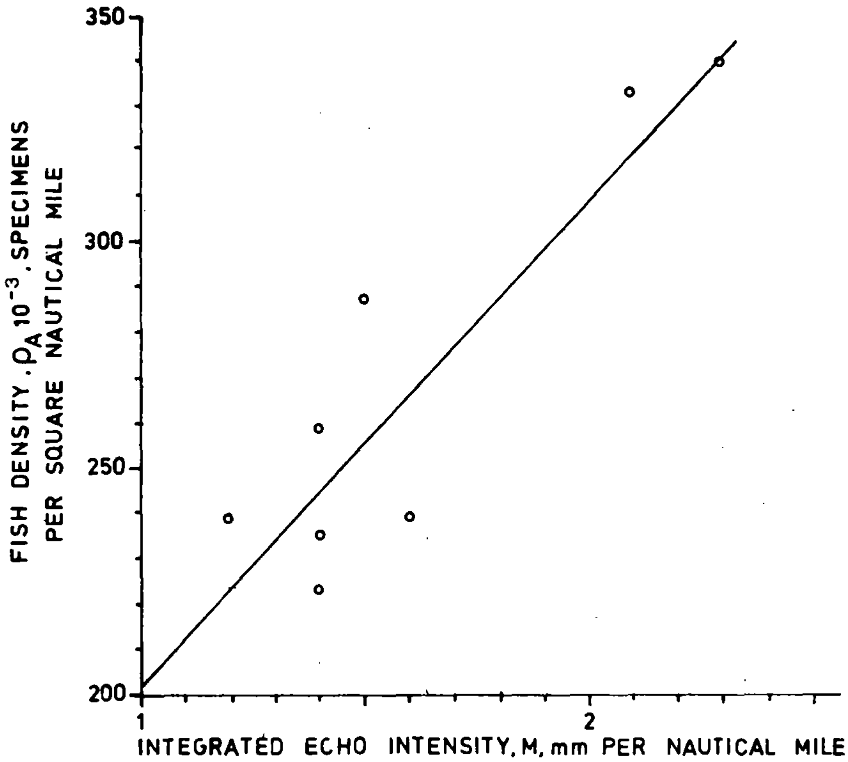


Figure 1. Corresponding values of integrated echo intensity and capelin density (calculated from counts on the recording paper) in 1971. R/V "G.O. Sars".

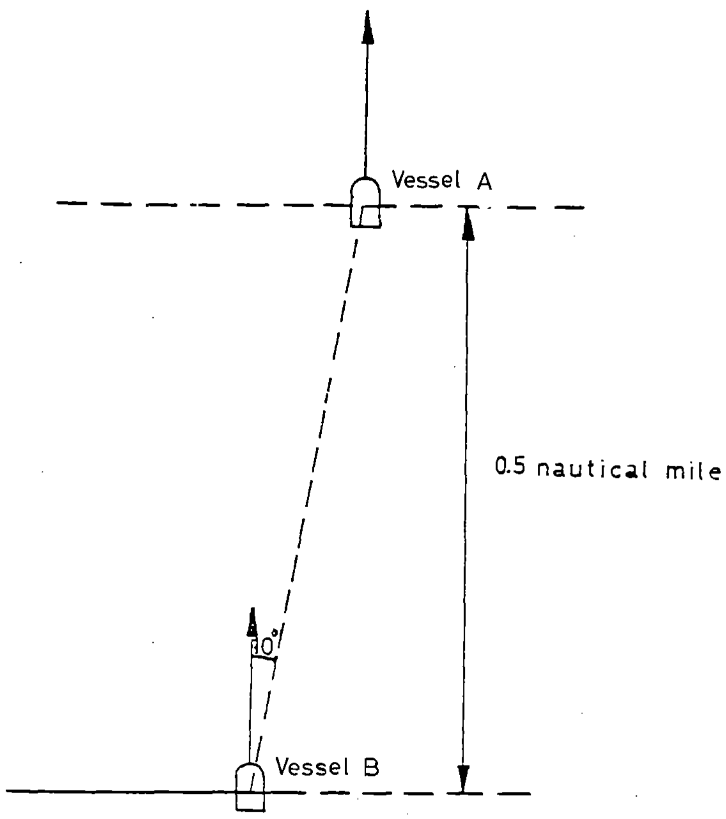


Figure 2. Sailing arrangement during intercalibrations on fish concentrations.

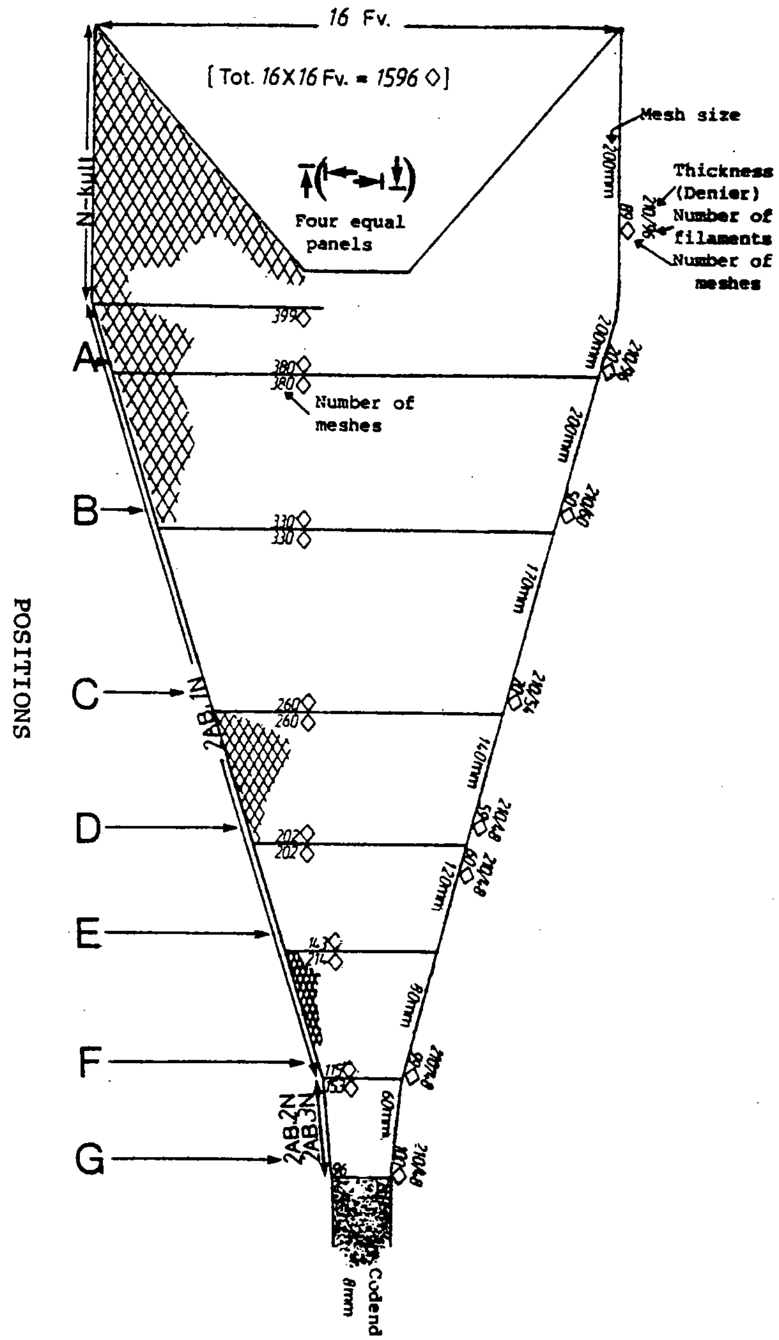


Figure 3. 16 x 16 fathom capelin trawl used for biological sampling on capelin surveys.

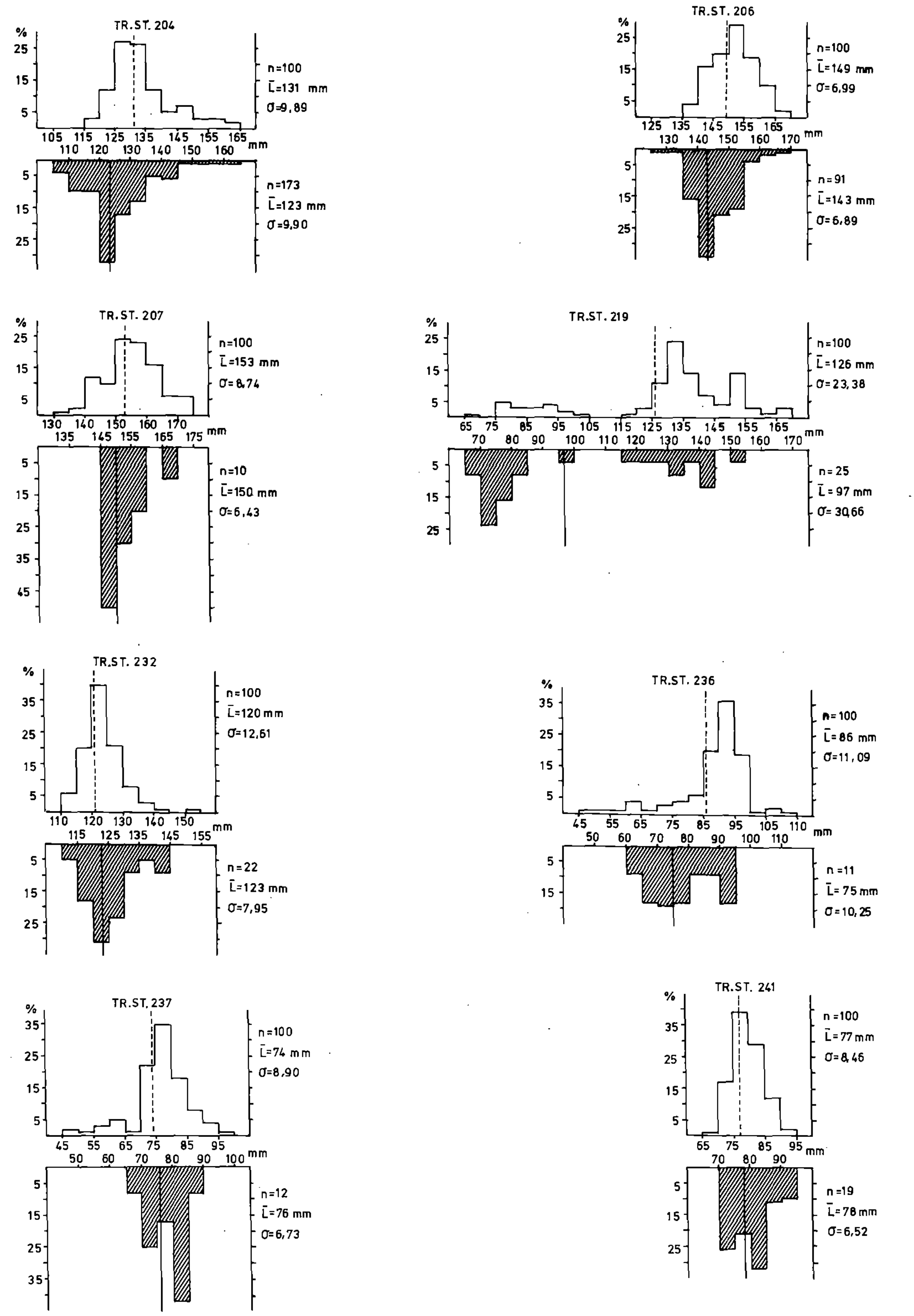


Figure 4. Length frequency distribution from codend-catch (white boxes) and of escaped capelin (hatched boxes). (From Larsen, 1984).

n = number of length measured individuals.
l = mean length
σ = standard deviation

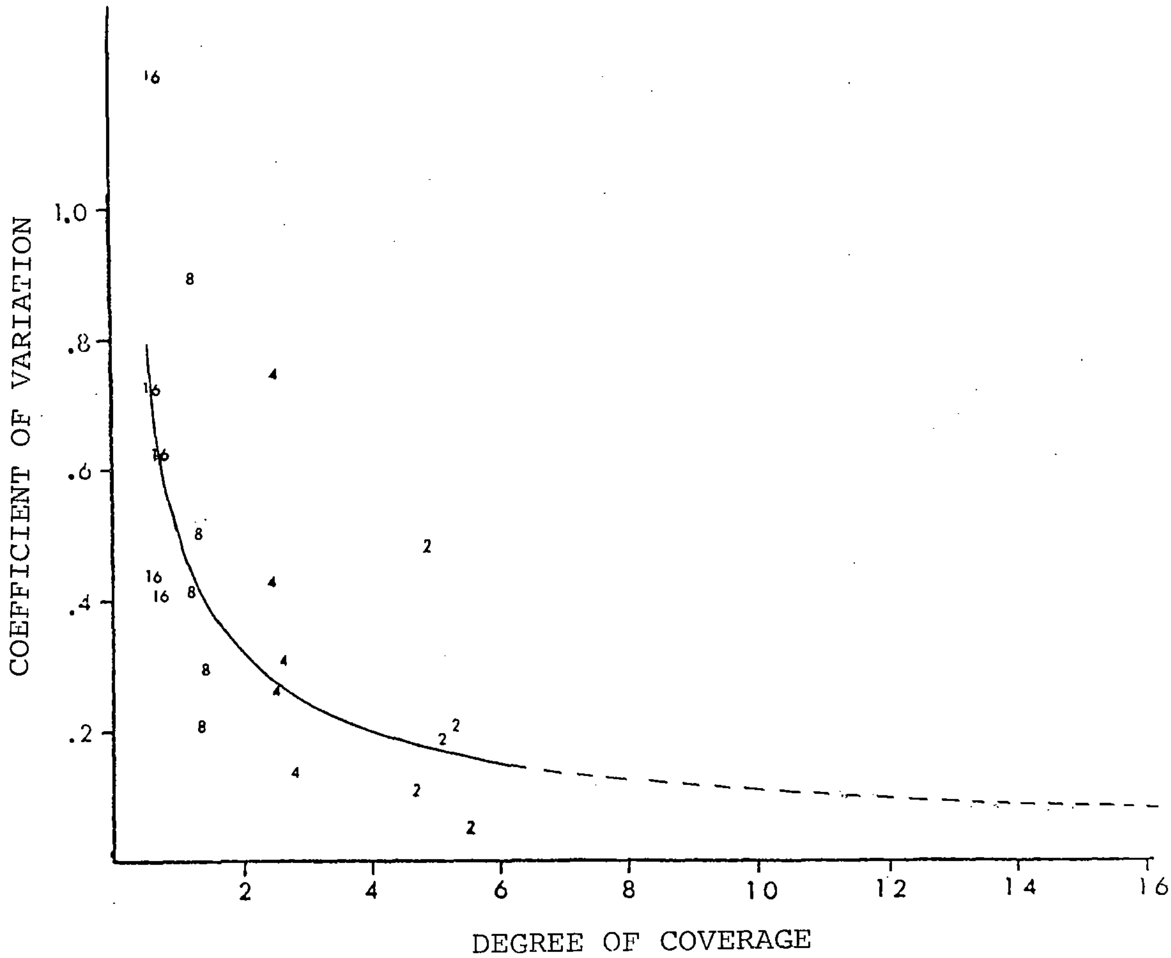


Figure 5. Corresponding values of degree of coverage and coefficient of variation for capelin surveys in the Barents Sea. Numbers denote number of observations. (Modified from Aglen 1983a).

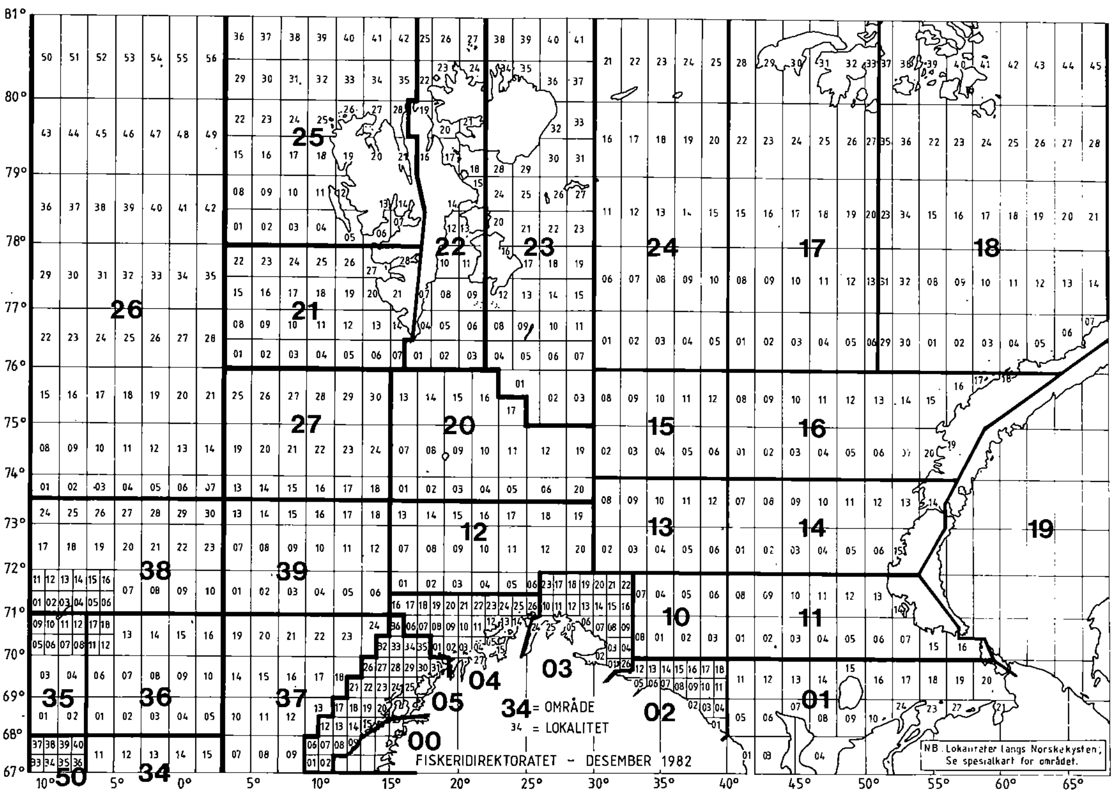


Figure 6. Areas ("squares") used in Norwegian Fisheries statistics.

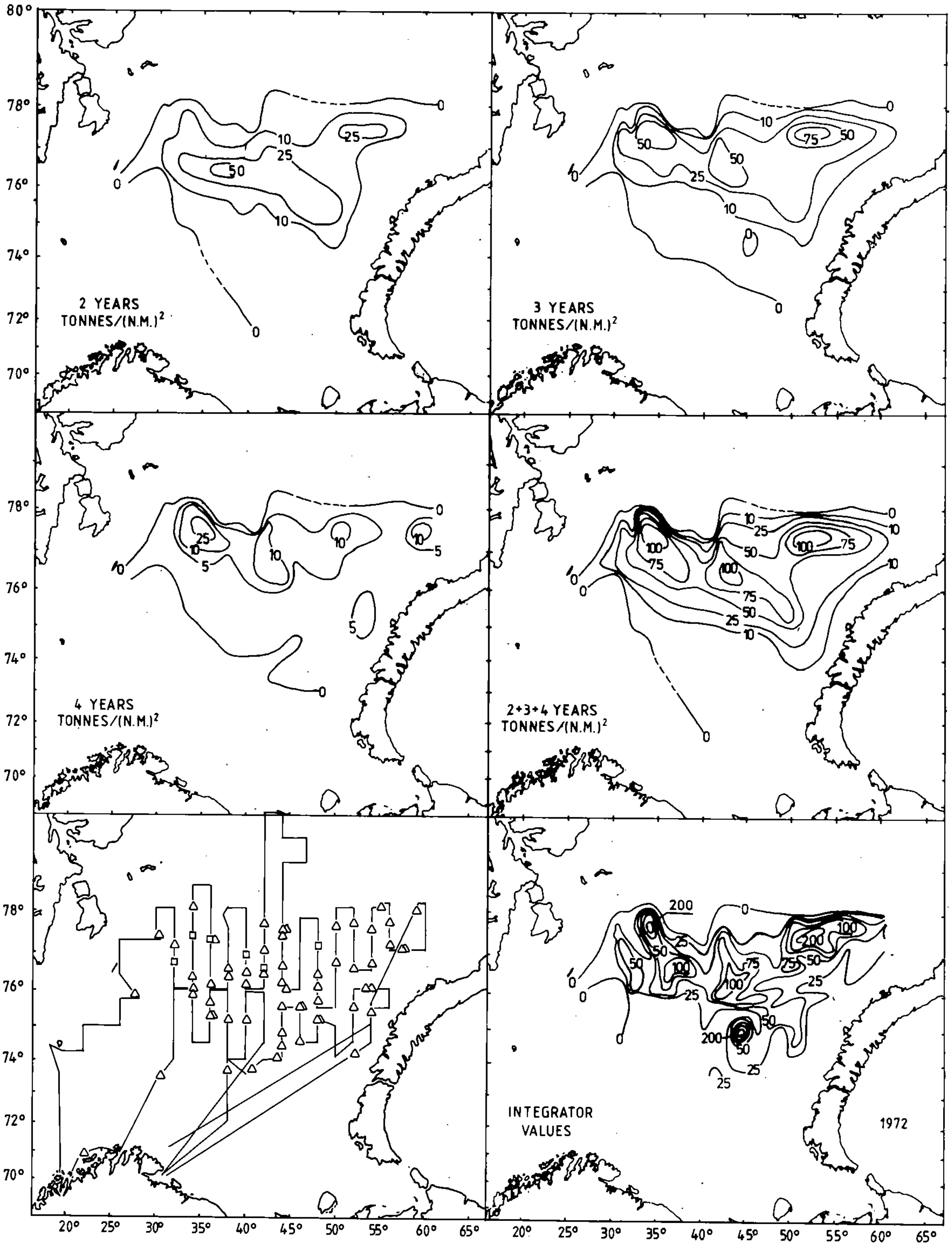


Figure 7. Calculated biomass distribution for 2-, 3- and 4-year-old capelin in 1972, total biomass distribution for 2-year-olds and older capelin, cruise track during the survey, and distribution of integrator values. Δ = pelagic trawl station, o = bottom trawl station, vvvvvv = observations of ice.

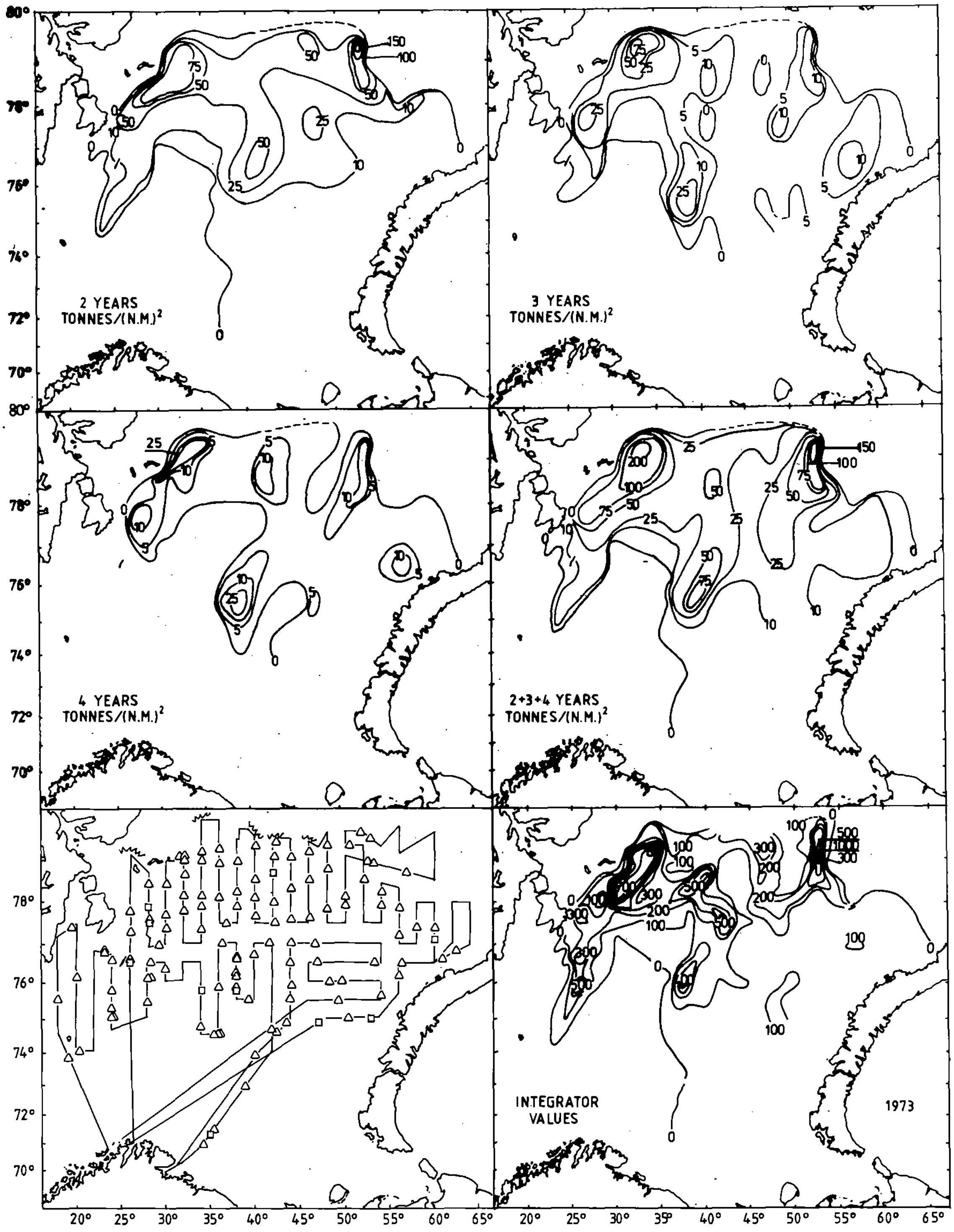


Figure 8. Calculated biomass distribution for 2-, 3- and 4-year-old capelin in 1973, total biomass distribution for 2-year-olds and older capelin, cruise track during the survey, and distribution of integrator values. Legend as in Figure 7.

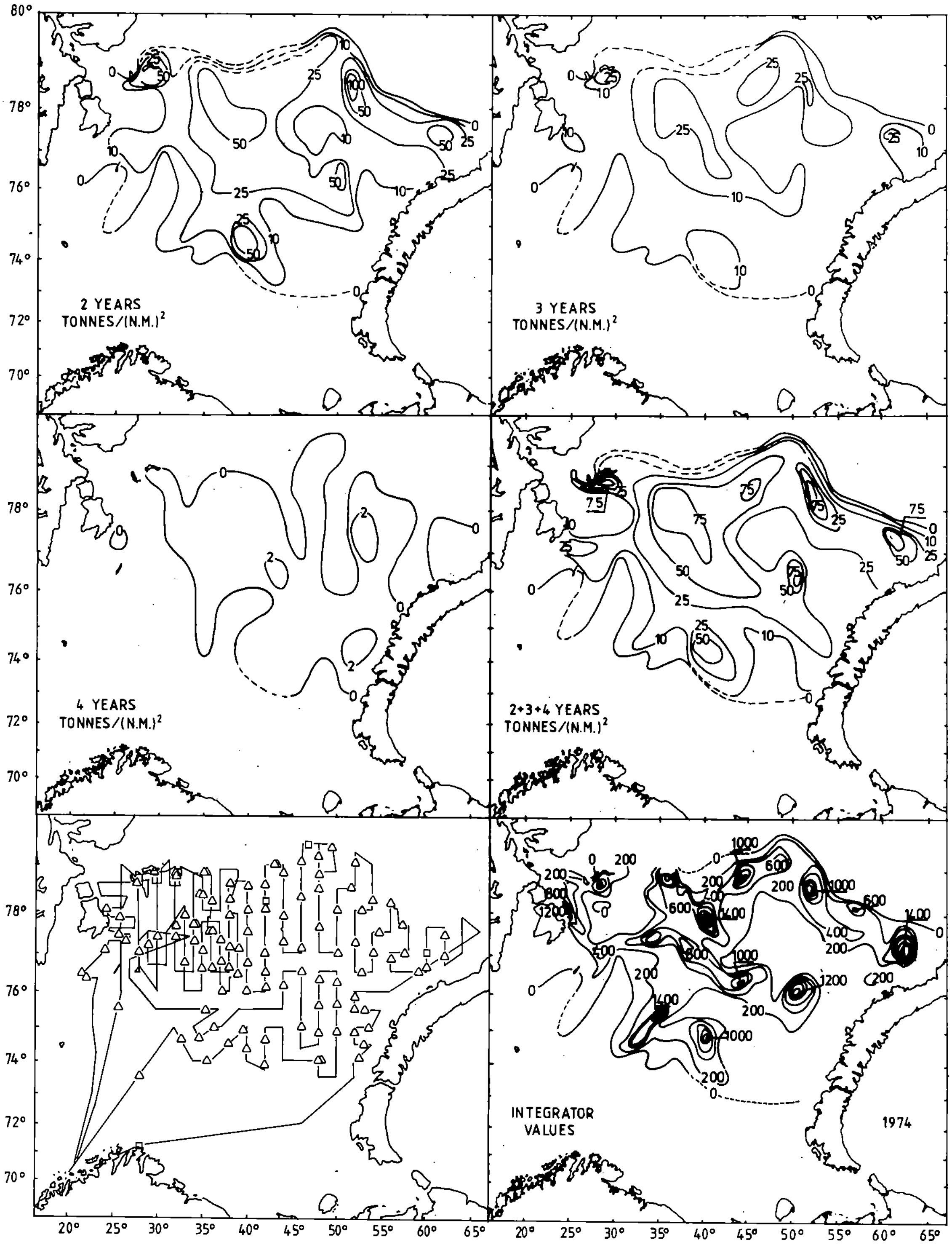


Figure 9. Calculated biomass distribution for 2-, 3- and 4-year-old capelin in 1974, total biomass distribution for 2-year-olds and older capelin, cruise track during the survey, and distribution of integrator values. Legend as in Figure 7.

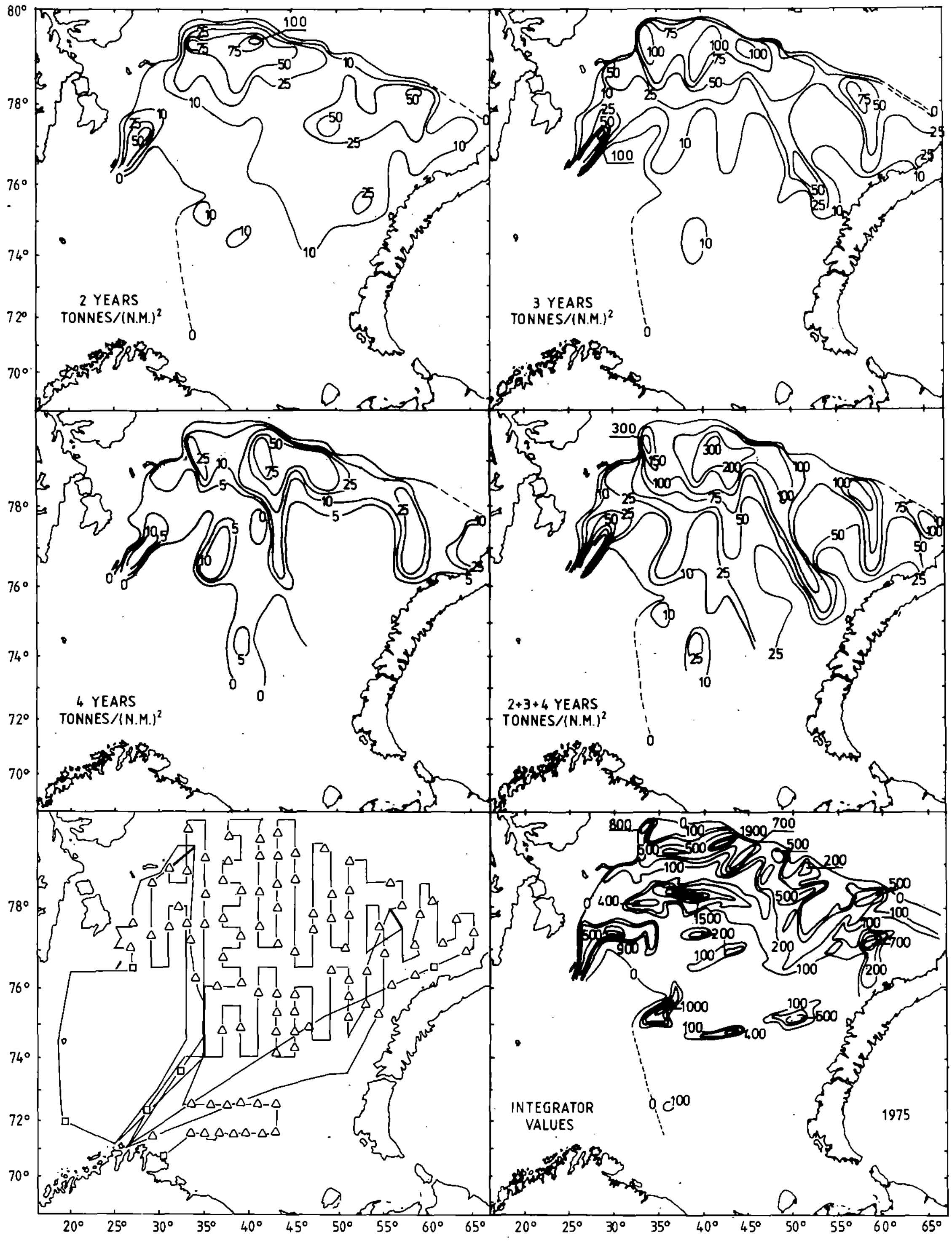


Figure 10. Calculated biomass distribution for 2-, 3- and 4-year-old capelin in 1975, total biomass distribution for 2-year-olds and older capelin, cruise track during the survey, and distribution of integrator values. Legend as in Figure 7.

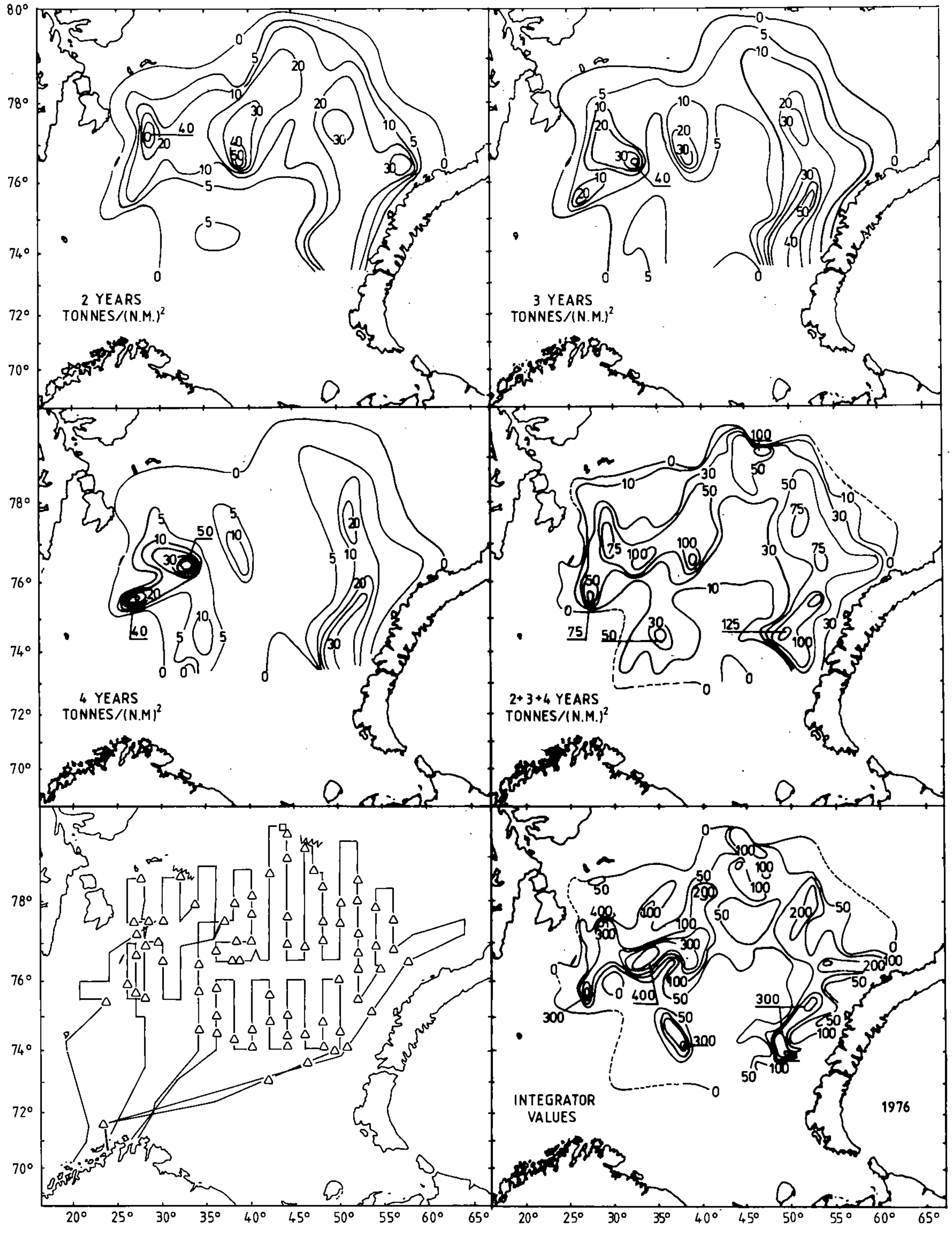


Figure 11. Calculated biomass distribution for 2-, 3- and 4-year-old capelin in 1976, total biomass distribution for 2-year-olds and older capelin, cruise track during the survey, and distribution of integrator values. Legend as in Figure 7.

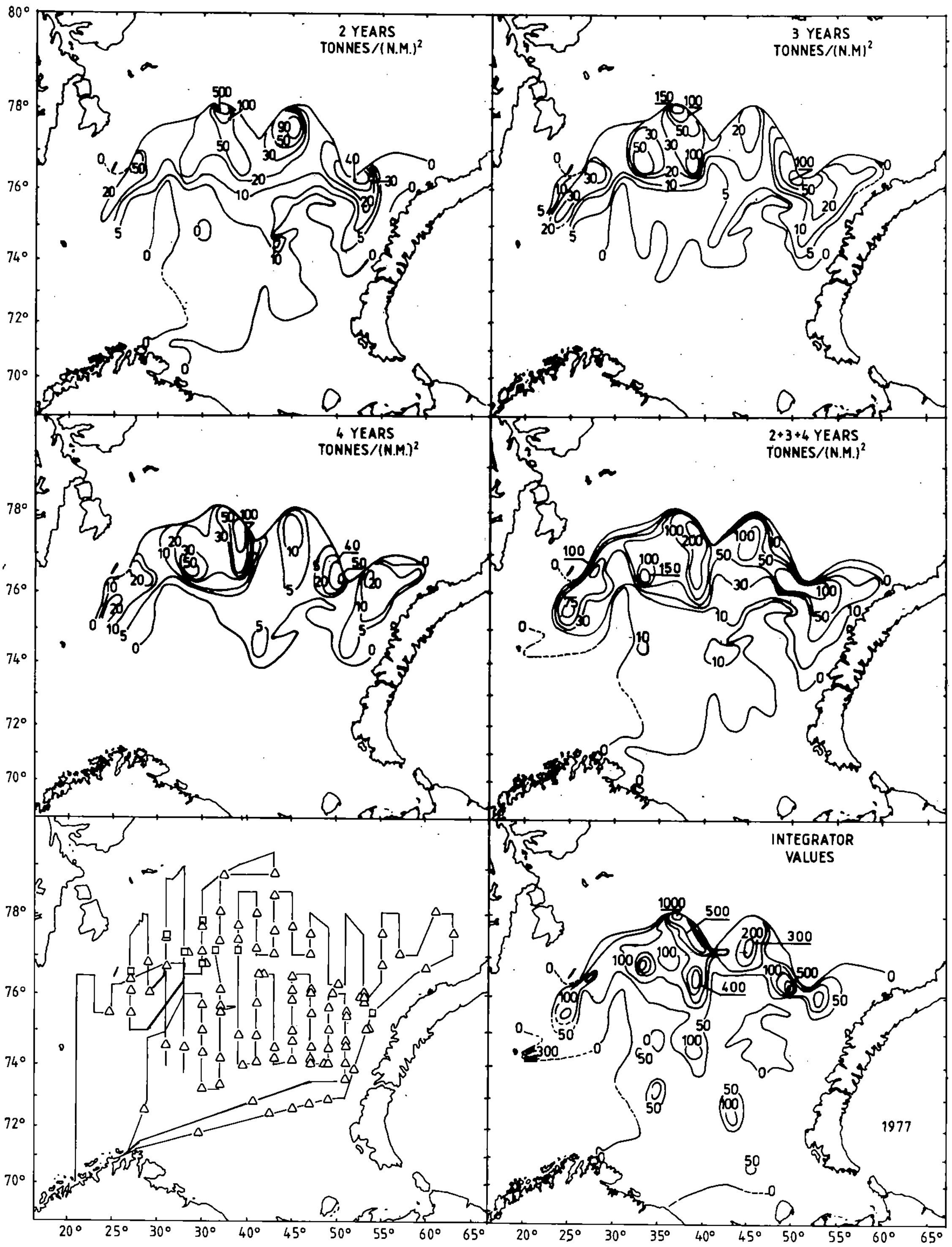


Figure 12. Calculated biomass distribution for 2-, 3- and 4-year-old capelin in 1977, total biomass distribution for 2-year-olds and older capelin, cruise track during the survey, and distribution of integrator values. Legend as in Figure 7.

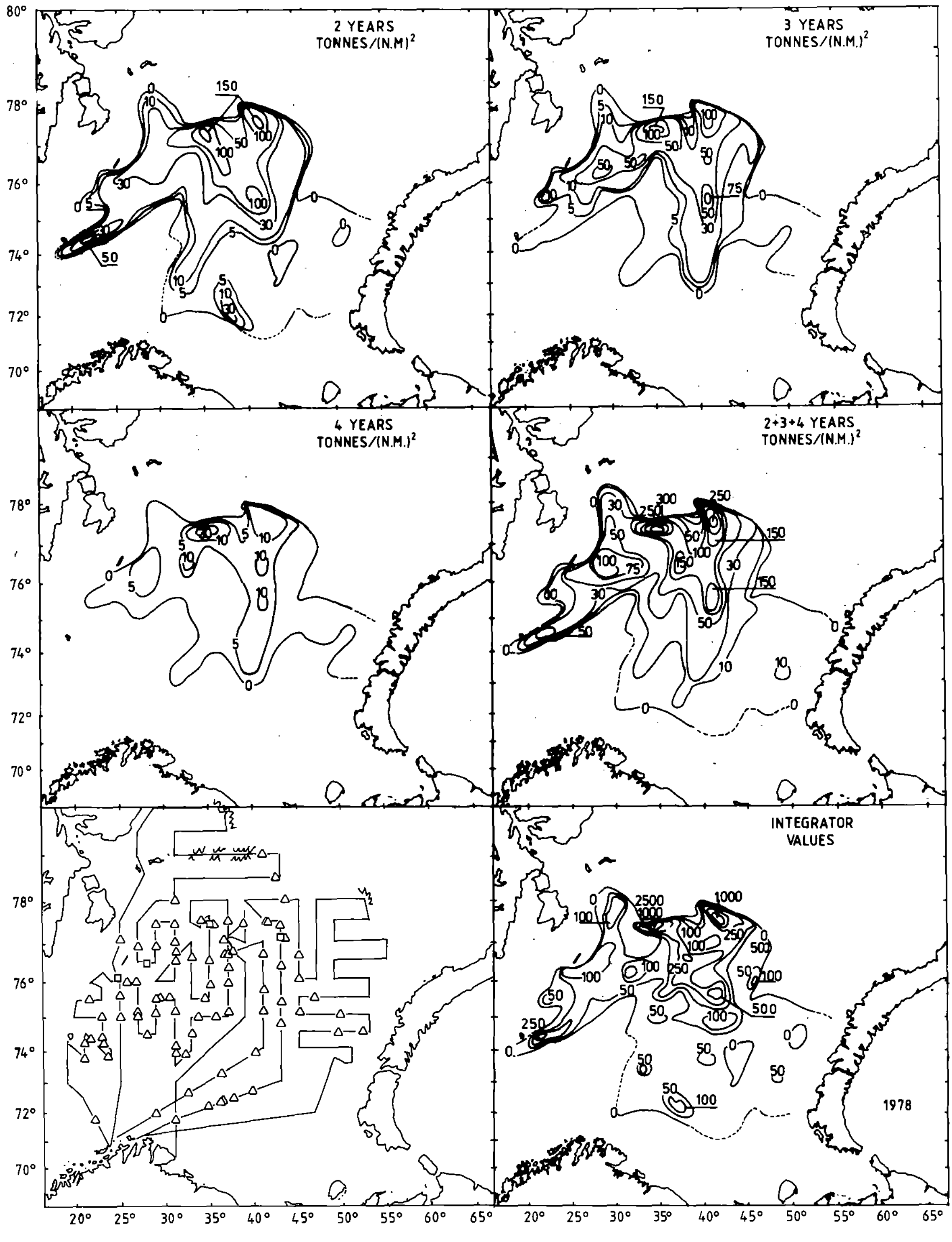


Figure 13. Calculated biomass distribution for 2-, 3- and 4-year-old capelin in 1978, total biomass distribution for 2-year-olds and older capelin, cruise track during the survey, and distribution of integrator values. Legend as in Figure 7.

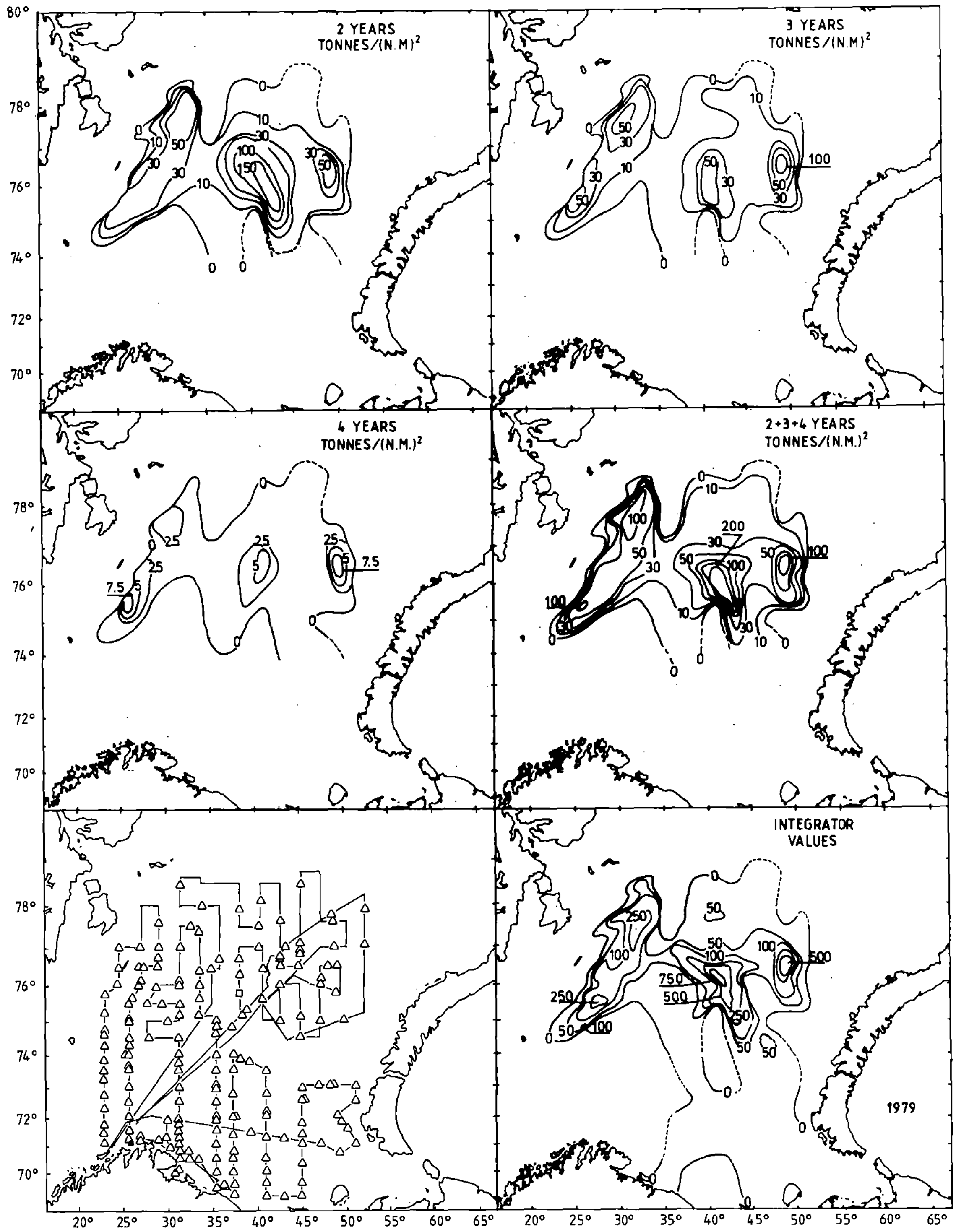


Figure 14. Calculated biomass distribution for 2-, 3- and 4-year-old capelin in 1979, total biomass distribution for 2-year-olds and older capelin, cruise track during the survey, and distribution of integrator values. Legend as in Figure 7.

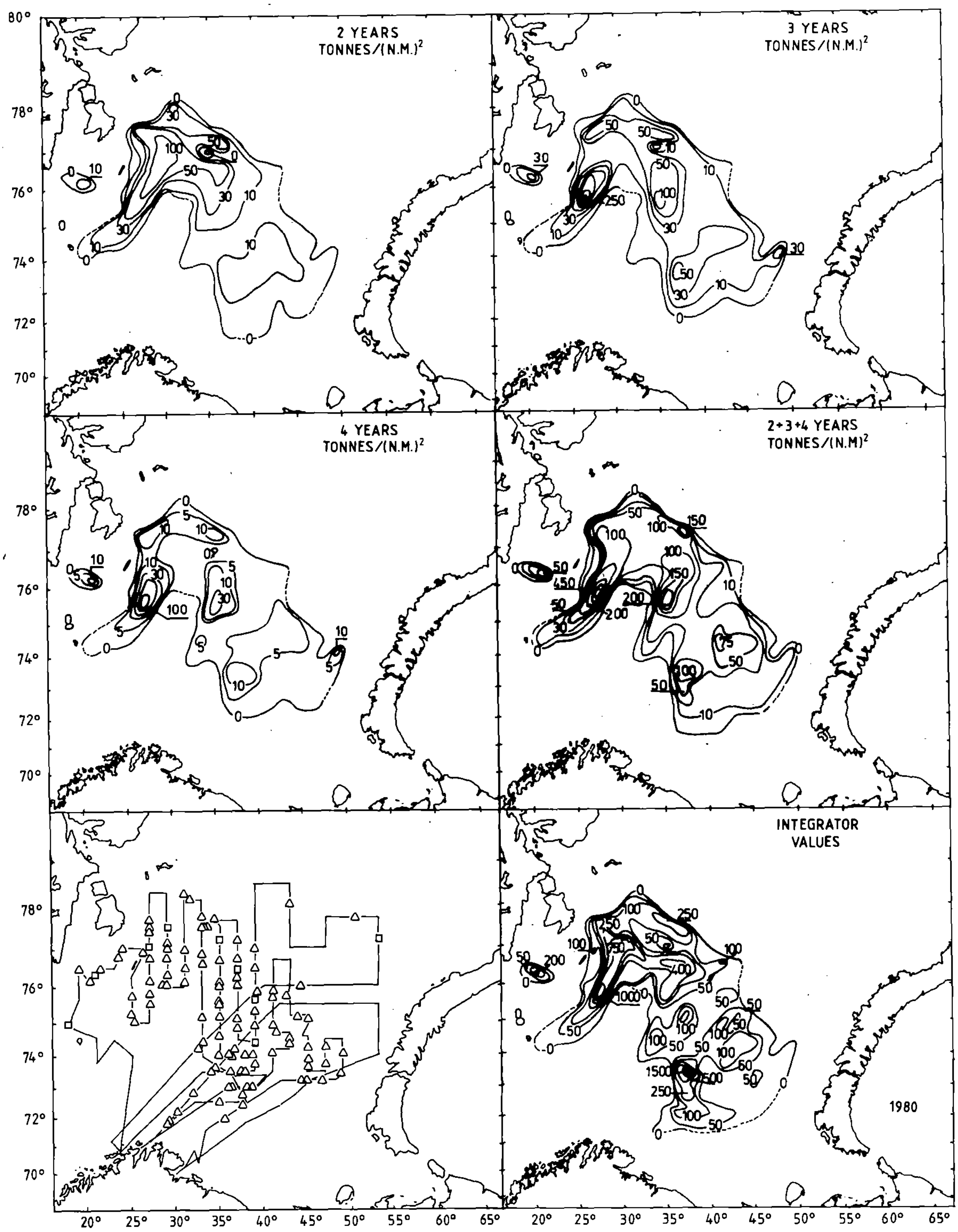


Figure 15. Calculated biomass distribution for 2-, 3- and 4-year-old capelin in 1980, total biomass distribution for 2-year-olds and older capelin, cruise track during the survey, and distribution of integrator values. Legend as in Figure 7.

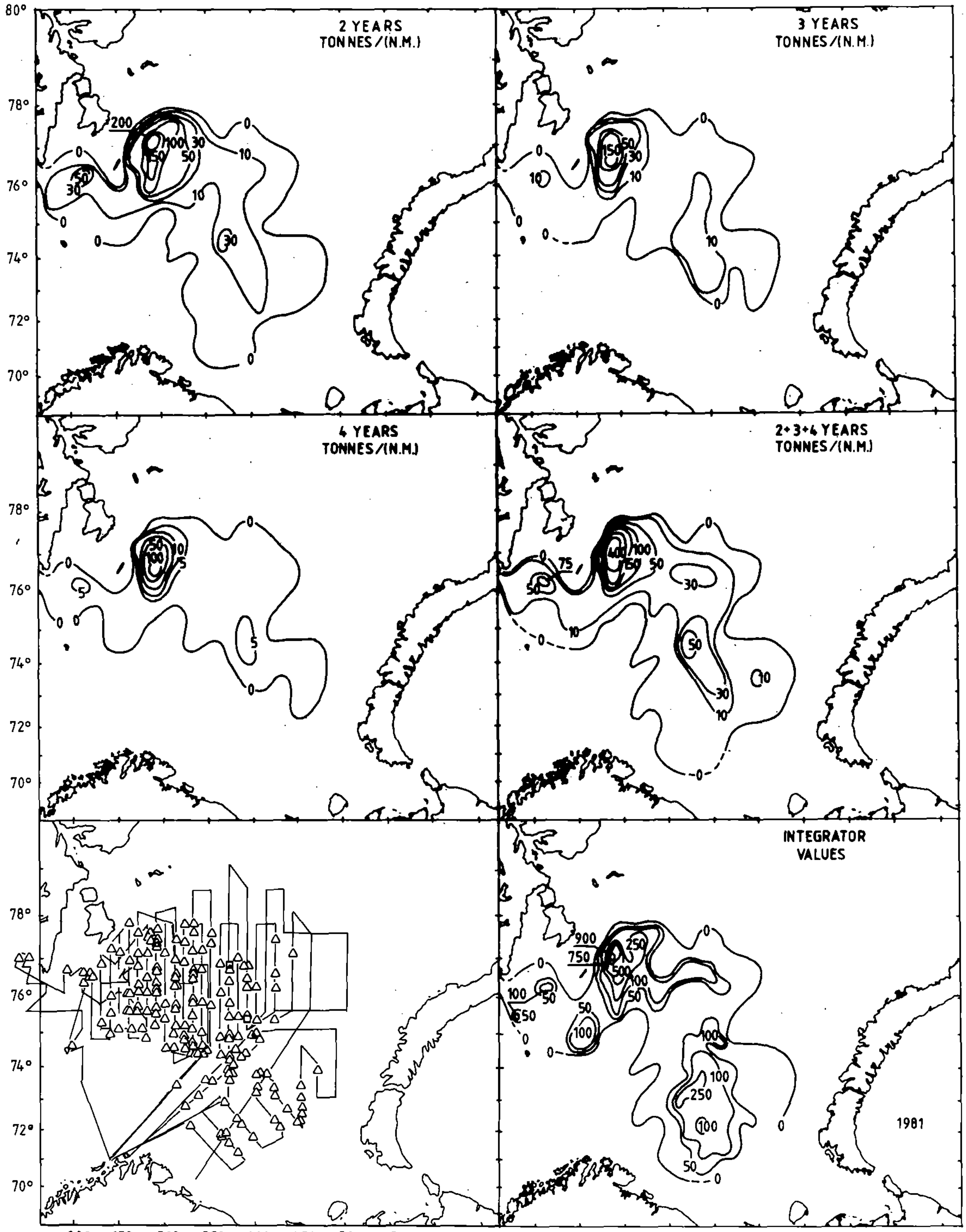


Figure 16. Calculated biomass distribution for 2-, 3- and 4-year-old capelin in 1981, total biomass distribution for 2-year-olds and older capelin, cruise track during the survey, and distribution of integrator values. Legend as in Figure 7.

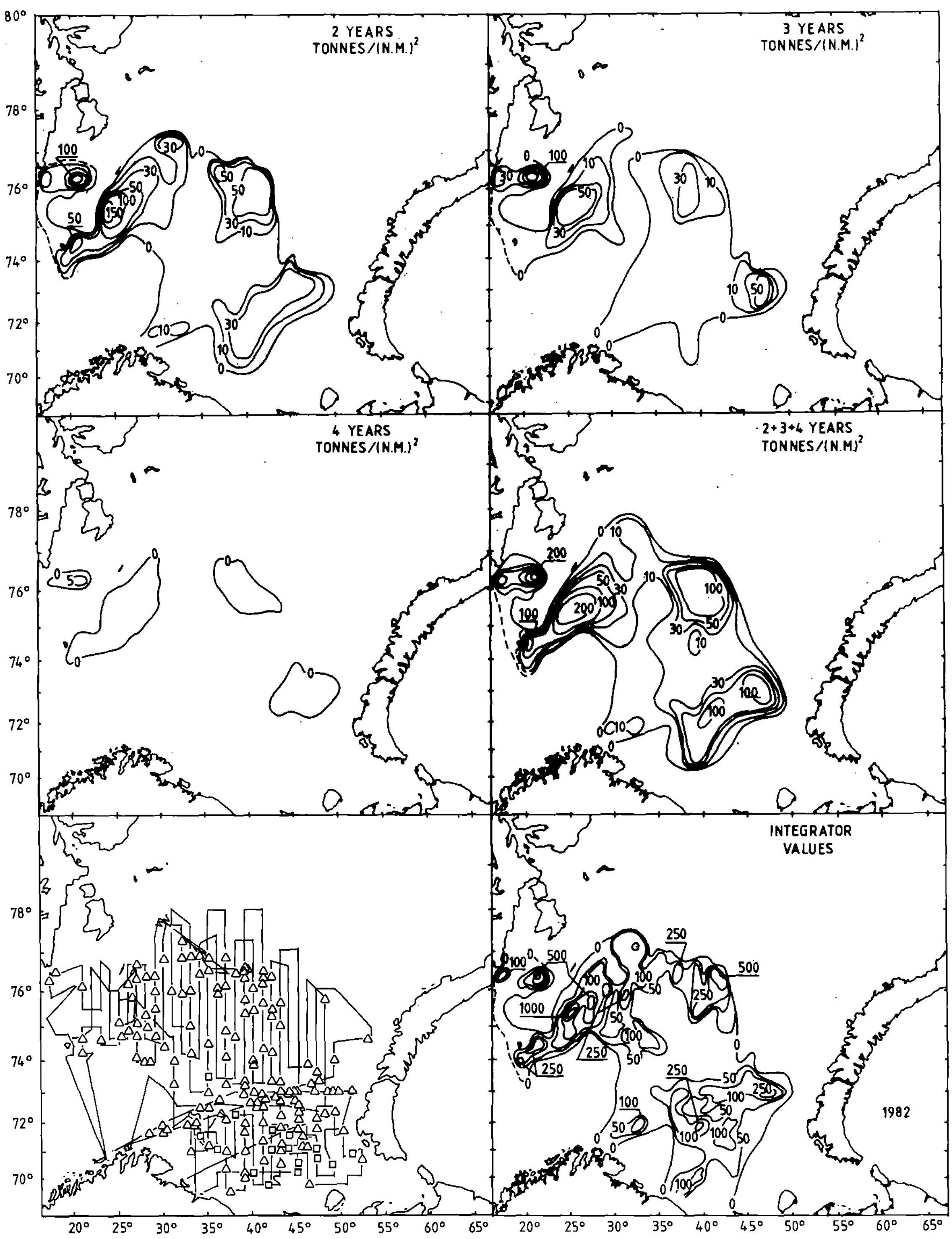


Figure 17. Calculated biomass distribution for 2-, 3- and 4-year-old capelin in 1982, total biomass distribution for 2-year-olds and older capelin, cruise track during the survey, and distribution of integrator values. Legend as in Figure 7.

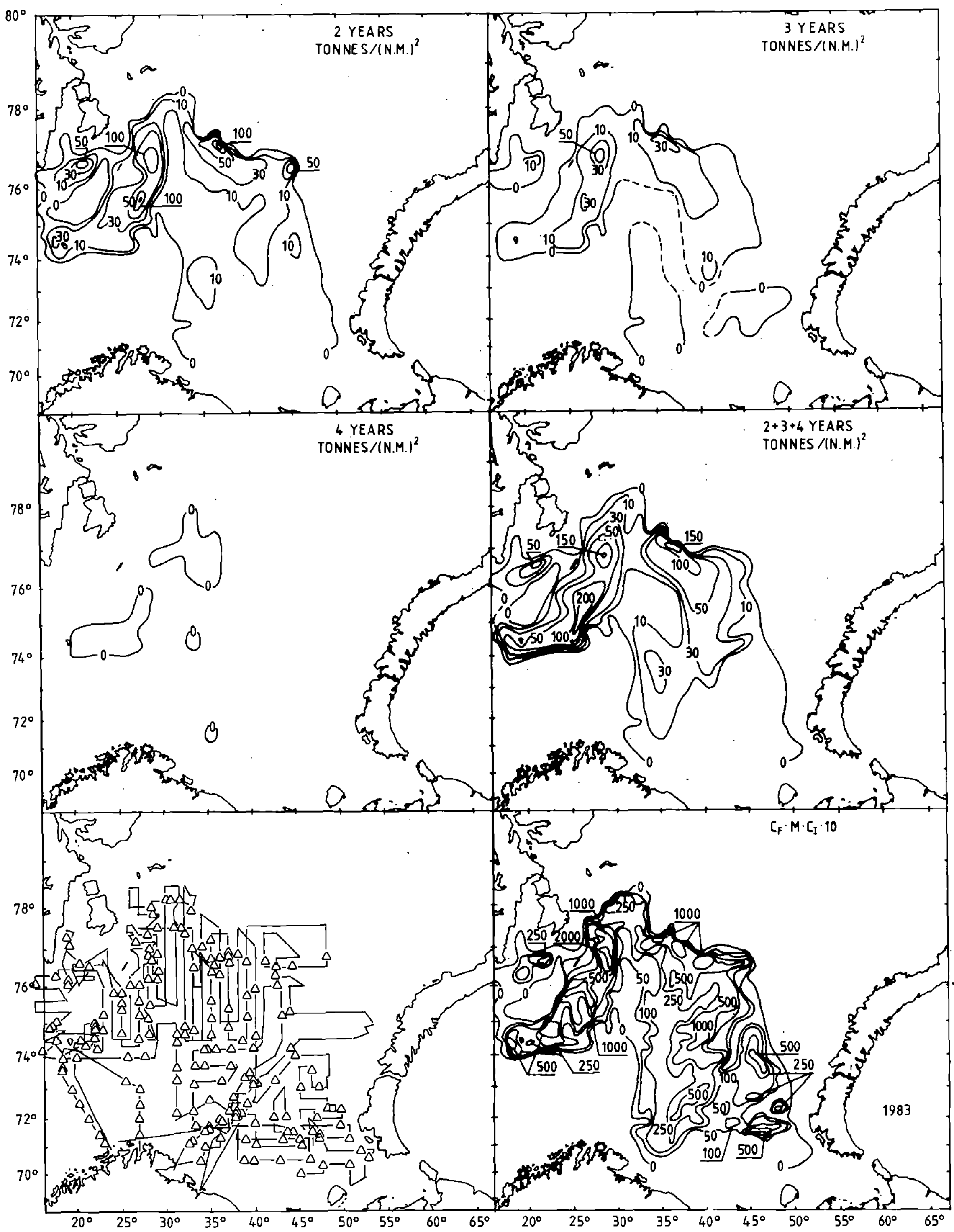


Figure 18. Calculated biomass distribution for 2-, 3- and 4-year-old capelin in 1983, total biomass distribution for 2-year-olds and older capelin, cruise track during the survey, and distribution of integrator values. Legend as in Figure 7.

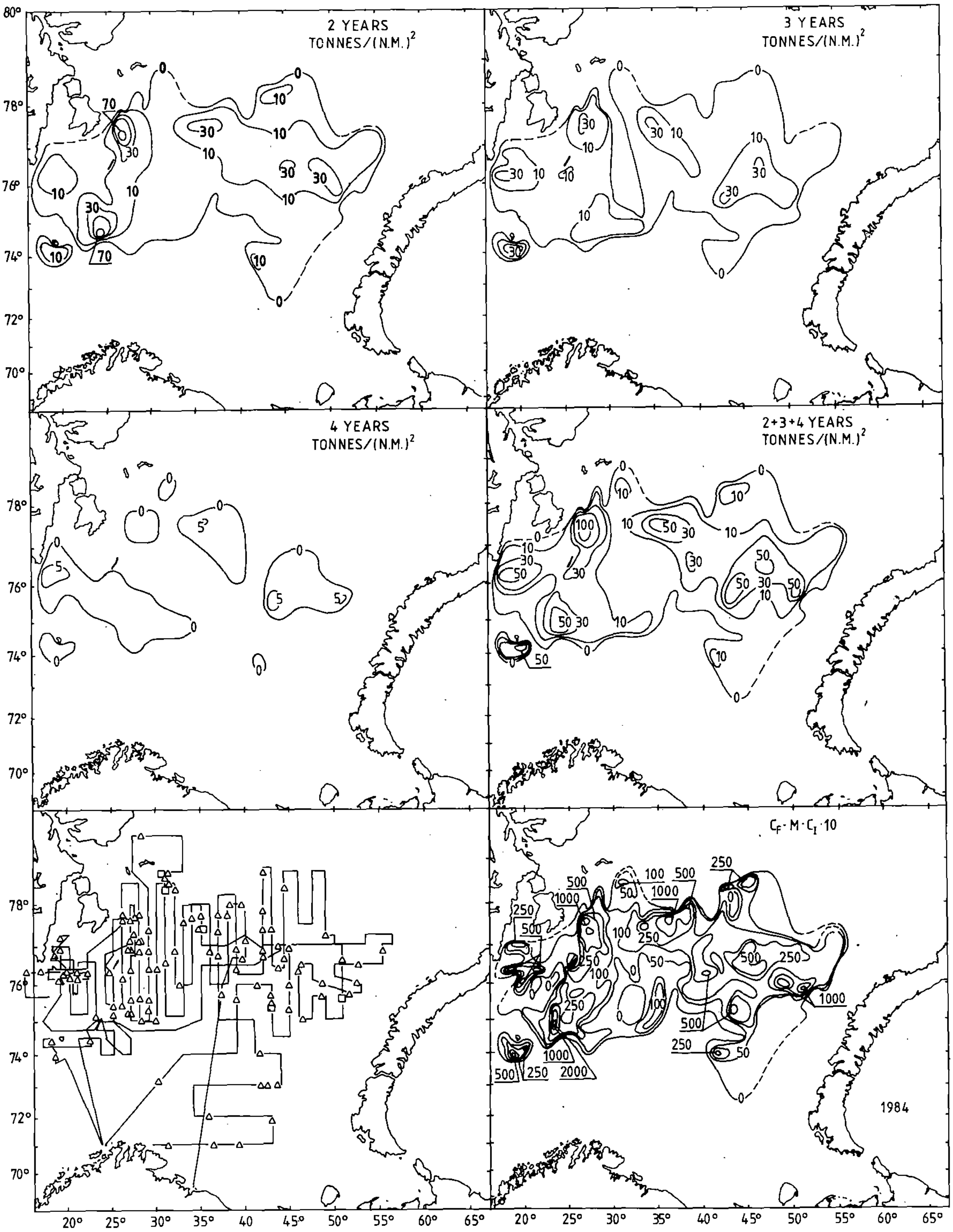


Figure 19. Calculated biomass distribution for 2-, 3- and 4-year-old capelin in 1984, total biomass distribution for 2-year-olds and older capelin, cruise track during the survey, and distribution of integrator values. Legend as in Figure 7.

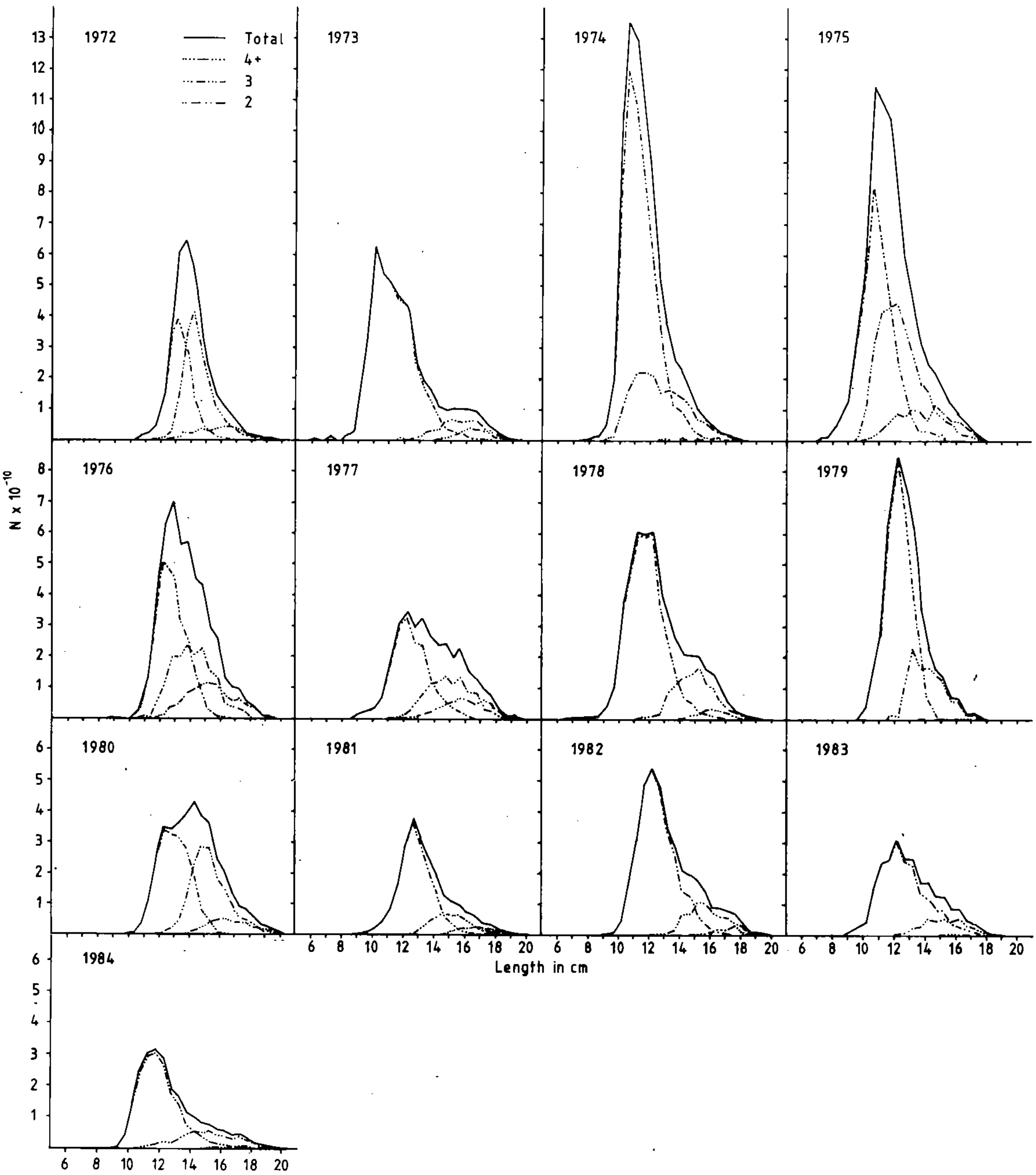


Figure 20. Length distribution of Barents Sea capelin per age-group and total, for the years 1972-1984.

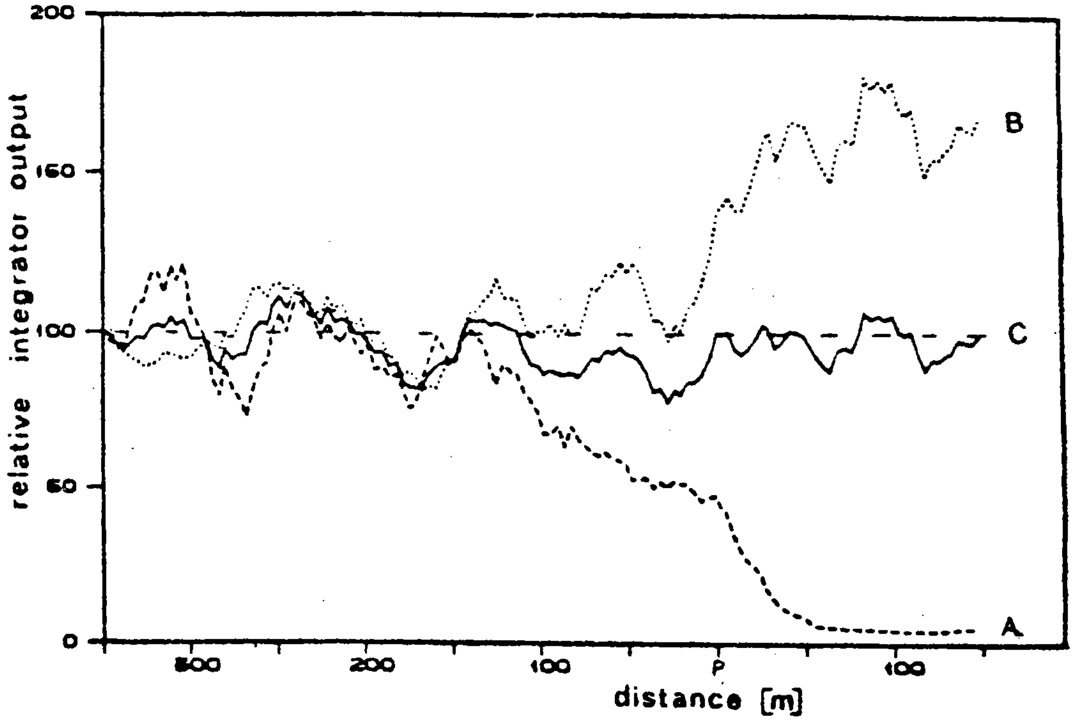


Figure 21. Relative echo integrator output (running mean per transmission), computed from echo recordings obtained using a submerged transducer (Olsen et al. 1983).

A: Capelin, $\bar{l}$=14 cm, at 112 - 132m depth at night during vessel passage (p), (R/V "G.O. Sars", 12 knots).

B: Capelin, $\bar{l}$=14 cm, at 132 - 172 m depth in the same run.

C: Sum of A and B.

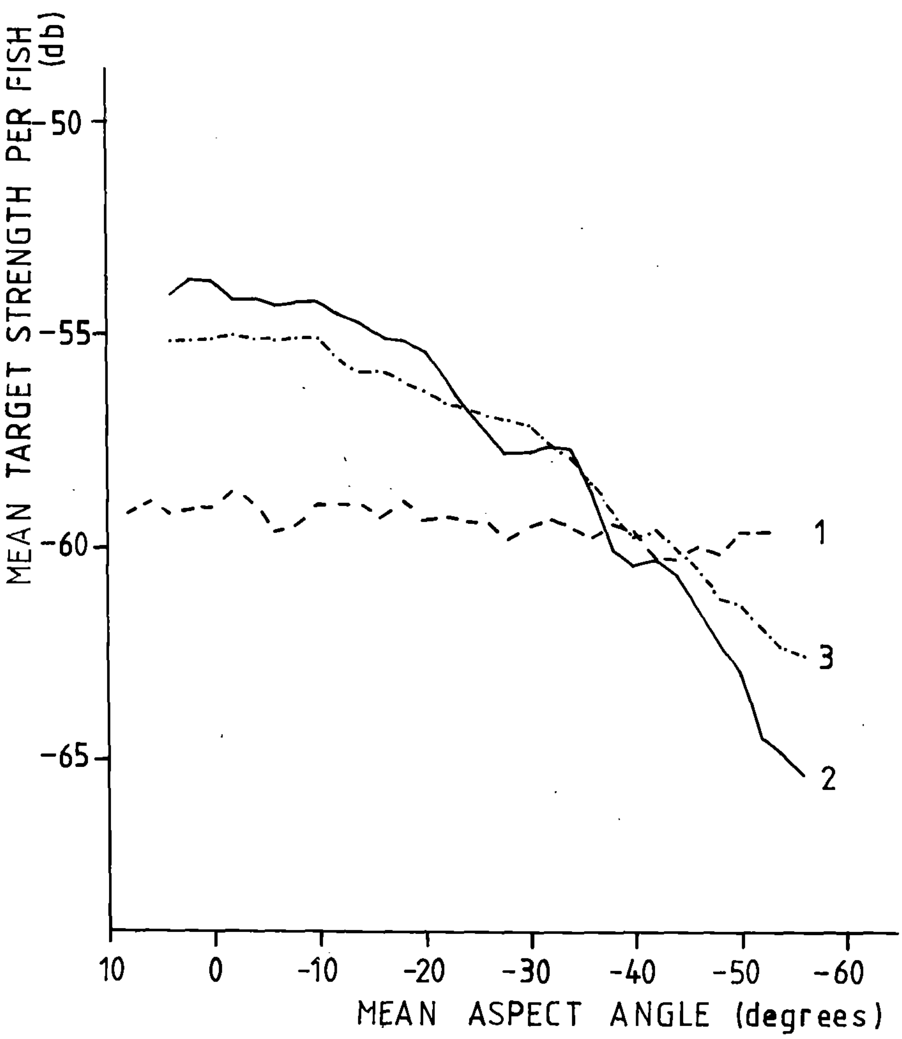


Figure 22. Target strength as a function of mean aspect angle for different fish distributions. (Angell, 1983).

Curve 1. 40 capelin unoriented. Density at 0 aspect angle: 350 specimens/m^3.

Curve 2. 40 capelin systematically oriented. Density at 0 aspect angle: 1700 specimens/m^3.

Curve 3. 73 capelin systematically oriented. Density at 0 aspect angle: 1700 specimen/m^3.

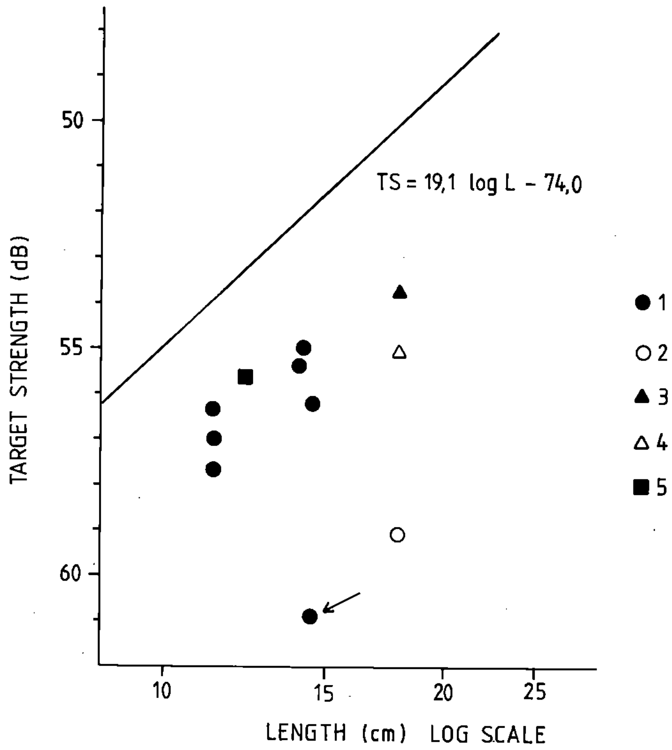


Figure 23. Results from target strength measurements on capelin.

1: In situ measurements at Iceland. Halldorson and Røynisson (1983). Arrow shows measurement when deck lights were switched on.

2: Measurement of capelin in cage. Mean aspect angle 0^o, fish not systematically oriented. (Angell 1983).

3: Measurement of capelin in cage. Mean aspect angle 0^o, 40 fish systematically oriented. (Angell 1983).

4: Measurement of capelin in cage. Mean aspect angle 0^o, 73 fish systematically oriented. (Angell 1983).

5: Target strength measured by counting echo traces September 1981. (Angell 1983).

TS = 19.1 log L - 74.0 is the target strength applied during the autumn capelin survey in the Barents Sea.

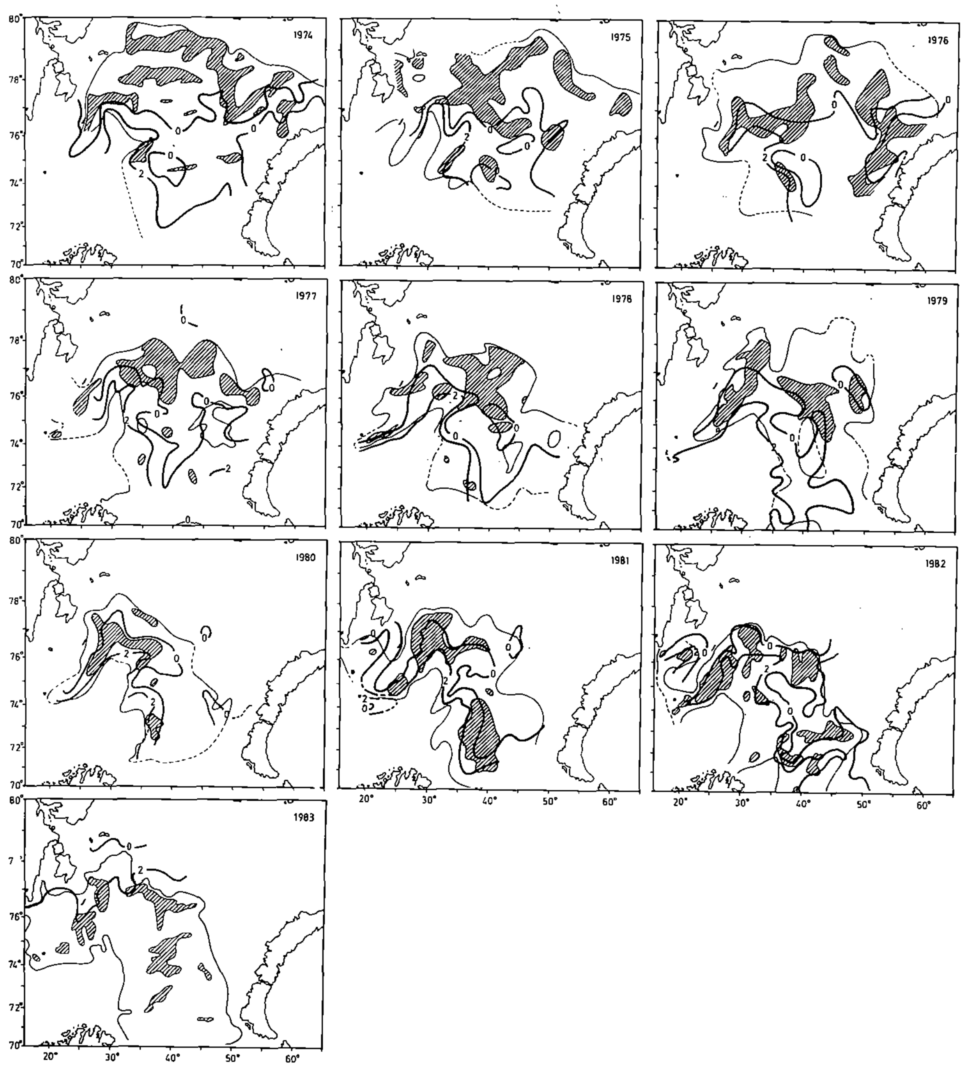


Figure 24. The distribution of the 0^0C and the 2^0C isotherms in 100 m depth and the distribution of capelin in the period 1974 - 1983. The main areas of concentration are hatched.

APPENDIX I

NEW INSTRUMENT CONSTANTS FOR ECHO INTEGRATION IN USE AT THE INSTITUTE OF MARINE RESEARCH, BERGEN FROM 15 JULY 1985.

In this paper we have used the definition of target strength given by Dalen and Nakken (1983):

$$TS = 10 \log \sigma$$

However, a more commonly used definition (see for example Johannesson and Mitson, 1983):

$$TS = 10 \log \sigma / 4\pi$$

It has been decided that the above definition of target strength shall be used in reports and publications from the Institute of Marine Research with effect from 15 July 1985.

This affects many of the formulas in this paper. In particular, it leads to changes in the levels for C_F and C_I. C_I has been incorporated into the integrator values in order to make them system independent - together with a factor of 10, to avoid decimals. The factor of 10 was dropped from 15 August 1985, so that instead of 4π we have to introduce a factor of $4\pi/10$:

$$C_{F_{new}} = C_{F_{old}} \cdot 10 / 4\pi$$

$$C_{I_{new}} = C_{I_{old}} \cdot 4\pi / 10$$

For the system conversion constant and the calculated stock this makes no difference, as we have:

$$C = C_{I_{old}} \cdot C_{F_{old}} = C_{I_{new}} \cdot C_{F_{new}}$$

However, the change does make a difference for the integrator values that are output from the integrator systems onboard the institute's research vessels, because $C_{I_{old}} \cdot 10$ was incorporated in the values before 15 July 1985 and $C_{I_{new}}$ was incorporated after that date.
Therefore, if we compare "new" and "old" integrator values, we have:

$$M_{new} = M_{old} \cdot 4\pi / 10$$

This will of course also apply to comparisons of "integrator charts" based on "old" and "new" integrator values.

For the system conversion constant the relationship will be:

$$C_{new} = C_{old} \cdot 10 / 4\pi$$

APPENDIX II

ACOUSTIC ESTIMATES, FLOW CHART FOR THE RECORDING OF DATA AND CALCULATION OF STOCK SIZE. Adapted from Dommasnes, 1979.

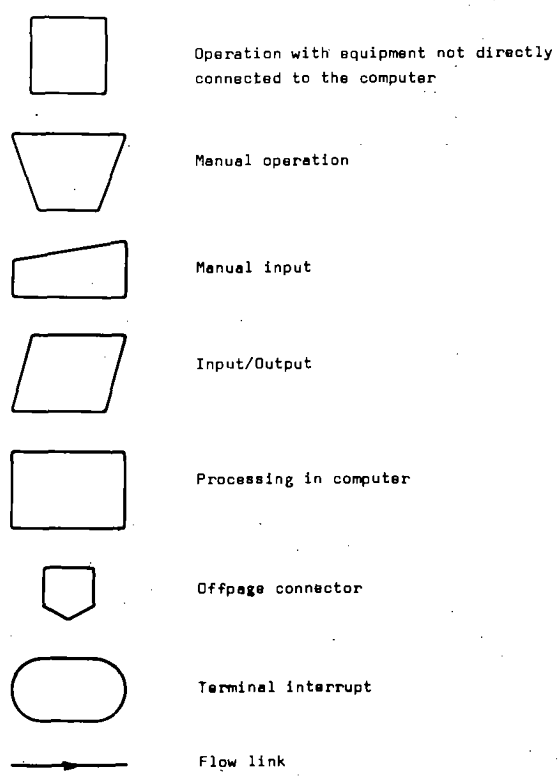
The calculations are based on a division of the total area in which the stock is to be assessed into numerous smaller areas, which here have been called "squares". The size of the squares should probably be no more than 60 x 60 nautical miles, preferably smaller, depending on the size of the total area.

The total area is also divided into 4-6 subareas in which biological characteristics like length-age and length-weight relations are assumed to be fairly uniform. The subareas are defined by the squares that are included in them.

The calculations are thus carried out and presented on three geographical levels: squares, subareas and total area.

All calculations are based on length groups.

The following symbols have been used in the flowchart:



SYNOPSIS OF THE METHOD OF BIOACOUSTIC STOCK MEASUREMENTS.

(The numbers refer to the numbers on the flow chart).

1. The echo sounder must have an output for the integrator, and the echo sounder-transducer combination must be properly calibrated.

2. Each signal is squared, and then integrated. This can be done by an analog integrator or by a digital computer.

3. Echo densities integrated over five nautical miles are printed out by the computer (or recorded manually) for several depth intervals.

4. Echoes are also recorded on echosounder paper. Recording intensity should be adjusted so that the weakest signal recorded on paper is also the weakest signal integrated.

5. Sampling is done by trawl. Ideally, the selectivity of the trawl should be known or there should be no selectivity.

6-7-8. The catch is sorted by species. For each species a random sample is taken, and length, weight, age, and other biological characteristics are recorded for each fish in the sample on special forms for punching, and entered into the computer.

9. To eliminate errors as far as possible, the sample data are run through a test program that picks out improbable or impossible data and allows those to be corrected.

10. Key data from each sample are tabulated by the computer and printed out.

11-12-13. Key data are plotted manually on charts to allow evaluation of geographical distribution of biological characteristics. On the basis of this evaluation, subareas are defined inside which the same length-age and length-weight keys can be used. The subareas are defined in the computer by listing the squares that are included.

14. The integrated echo densities are compared with the echosounder paper for each five nautical miles, and corrections are made for "false signals" (mainly bottom signals or wave noise).

15. The mean integrated echo density per nautical mile (M) in each square is calculated manually as the sum of all corrected integrated densities divided by the number of nautical miles sailed in the square.

16. Integrated echo intensities are entered into the computer as a mean value for each square.

17-18. Based on the echosounder paper and the samples, a decision is made on which sampling stations can be considered representative for the kinds of recordings found in each square. Sampling stations from neighbouring squares may also be used. The decision is entered into the computer as a list of samples for each square.

19. The length frequency (p_i) for each square is calculated from the samples assigned to that square, giving each sample entry equal weight.

20. C_I, C_S and b have been obtained empirically.

21. The area of each square is entered into the computer.

22. The number of fish in each length group is calculated for each square according to the formula;

$$N_i = (C_I \cdot M) \cdot \frac{p_i}{\sum_{i=1}^{n} = \frac{p_i}{C_{F_i}}} \cdot A$$

N_i = the number of capelin in length group i in the square.

C_I = the instrument constant.

M = the average integrator value calculated for the square.

p_i = the proportion that the capelin in length group i makes up of the total number of capelin in all the length groups ($\Sigma p_i = 1$).

$C_{F_i} = C_S \cdot l_i^{-b}$ where l_i is the (arithmetic) middle length in the length group i and C_S and b have been determined empirically.

A = the area in square nautical miles.

23. Biological characteristics other than length-age and length-weight relationships are presented in tables for each subarea, and printed out. The tables are compiled by adding relevant information from all samples in the subarea.

24-25. Length-age and length-weight tables are compiled for each square by adding the relevant information from all sampling stations assigned to that square.

26-27. Length-age and length-weight tables for each square are combined to give corresponding tables for the subareas, and printed out.

28-29-30-31. While lengths are recorded for all fish sampled, ages and weights may be recorded from some of the samples only. It is therefore possible that the length-age and length-weight keys will not cover the extremes of the length range in question. It is therefore necessary to check whether the length-age and length-weight tables cover the necessary range and, if necessary, fill in approximate values for missing parts of the tables. The additions are entered into the computer.

32. Total number of fish in each age group in each square is obtained by combining the total number at length in the square with the length-age key for the subarea. The number of fish in each age group is printed out.

33-34. Total number of fish in each age group in each subarea is obtained by adding the numbers from all squares in that subarea. The numbers are printed out.

35-36. Total number of fish in each age-group in the total area is obtained by adding the numbers from all subareas. The numbers are printed out.

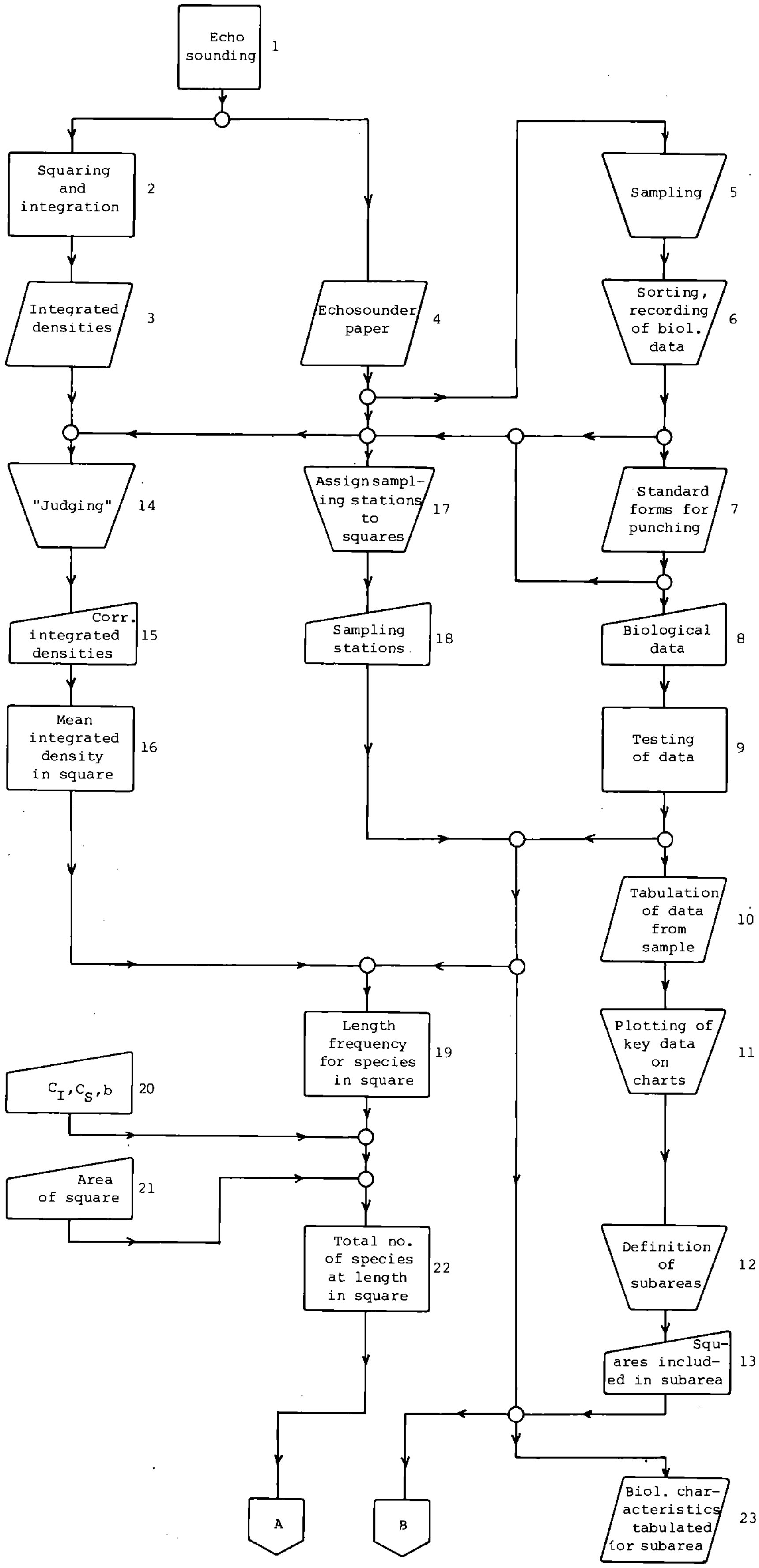
37. Total weight of fish in each age-group in each square is obtained by combining the total number at length in each square with the length-age and length-weight keys for the subarea. The weights are printed out.

38-39. Total weight of fish in each age group in each subarea is obtained by adding the numbers from all squares in that subarea. The weights are printed out.

40-41. Total weight of fish in each age group in the whole area is obtained by adding the numbers from all subareas. The weights are printed out.

42. End of the program.

FLOW CHART FOR THE RECORDING OF DATA



FLOW CHART FOR THE RECORDING OF DATA continued