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DISTRIBUTION AND GROWTH OF CAPELIN IN THE BARENTS SEA IN RELATION TO WATER TEMPERATURE IN THE PERIOD 1974 TO 1983.

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ABSTRACT

The variation in the distribution of the different age-groups of capelin in the Barents Sea were studied in relation to temperature variation in the period 1974 to 1983. In addition, growth of the capelin were compared to the temperature data for the years 1977 to 1983. The data were collected on yearly cruises in September-October.

During the period 1976 to 1980 a pronounced south- and westward displacement of all capelin age-groups was observed. The displacement coincided with decreasing water temperature in the region. It was found that the older age-groups, 2, 3 and 4 year old fish, inhabited significantly warmer water masses in the years 1980 to 1983 than previously. Growth, especially for the two year olds, changed correspondingly, as it was higher in 1980 to 1983 than previously in the studied period.

1. INTRODUCTION

The Barents Sea capelin spawns at an age of 3-6 years (Dragesund, Gjøsæter and Monstad 1973, Hamre and Tjelmeland 1982) and 4 year old fish is usually dominating in the spawning stock. The majority of the capelin probably spawn only once. The spawning grounds stretches from the White Sea area in the east to the Lofoten area in the west. The spawning usually takes place in March to April and The last years most of the spawning has taken place at the coast of Troms and Finnmark.

Distribution maps (Dragesund et al. 1973, Hamre and Tjelmeland 1982) show that in the feeding period, in summer and autumn, the stock is dispersed over most of the Barents Sea. The youngest age-groups, the 0- and 1-group, are confined to the southern and western parts of the distribution area, while the older fish has a more northern and eastern distribution. In late autumn, when the sea becomes covered with ice, the capelin migrates southwards. The immature part of the stock stops off the coast and migrates north again in the spring. The maturing part, however, continues on a spawning migration to the coast. Since 1971 the autumn distribution of this capelin stock has been studied at the Institute of Marine Research, Bergen. The results show a south-westward displacement of the distribution during the period. Loeng(1981) showed that this displacement coincided with a displacement of the isotherms. In 1971 to 1976, when the water masses of the Barents Sea was relatively warm, the capelin resided far to the north and east. In the years 1977 to 1980, when the northeastern part of the Barents Sea became colder, the capelin distribution was found more to the south and west. This displacement is shown in Fig. 3. To be able to study these events more in detail and their possible influence on growth and maturity, each age-group and yearclass have to be analysed sperately.

This paper aims at a description of

- the geographical displacement of the temperature field.
- the geographical variation in the capelin distribution.
- the capelin distribution relative to the temperature field.
- the growth variation in capelin.

2. MATERIALS AND METHODS

All the material for this study comes from the joint Soviet/Norwegian cruises to assess the distribution and abundance of the Barents Sea capelin stock in September- October each year.

2.1 Acoustical and biological data

Abundance and distribution of capelin were assessed by means of an echo integrating system in combination with trawling for identification of the registrations (Nakken and Dommasnes 1975). From the catches samples were taken, from which the distributions of age, length, weight and maturity were recorded (Gjøsæter 1984a). This gave information on the number of capelin and their biological characteristics distributed on yearclass in the stastistical squares and subareas in which the Barents Sea was devided (Fig. 1). Growth in length during the last season was estimated using the method of backcalculation based on otolith growth zones (Gjøsæter 1984b). These growth estimates, calculated for each subarea separately, were weighed by abundance to get representative distributions (Gjøsæter 1984a). The growth estimates were reached by substracting the backcalculated length at the deposition of the outermost winterring from the length at sampling. This implies the assumption that the growth has stopped at the time of sampling in September.

2.2 Hydrografical data

Hydrografical stations were taken along the survey routes, after 1978 with a frequency of every 30 nautical mile. In previous years the station grid was more variable. Observations were done by Nansen casts, Bisset-Berman STD-sonde or Neil-Brown CTD-sonde. For every station the mean temperature in the depth interval 10 to 200m was

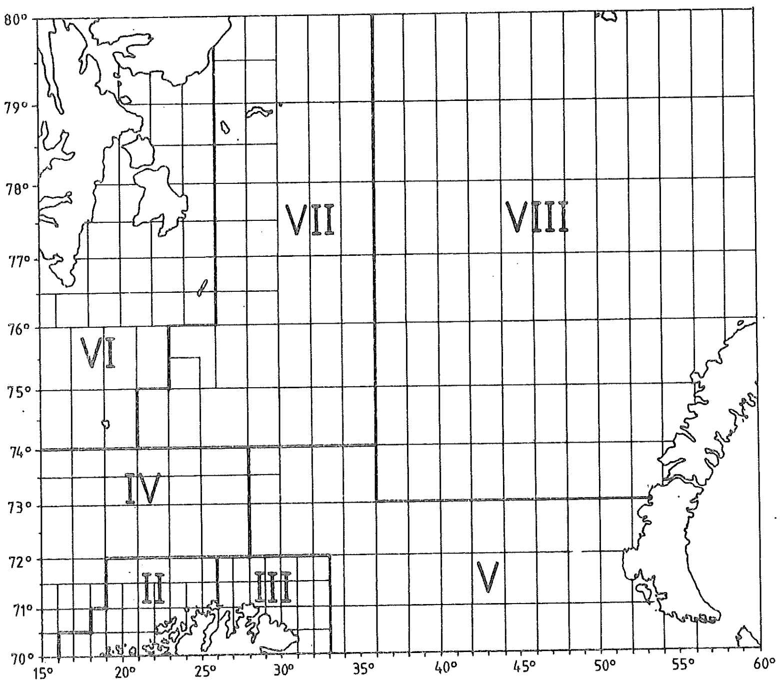

Figure 1. Map covering the Barents Sea, showing the statistical squares and subareas (roman numerals) mentioned in the text.

calculated. This depth interval was chosen based on a general knowledge of the vertical distribution of capelin at this time of the year.

In every statistical square the mean temperature for this depth interval was calculated, following one of the two methods outlined below.

1. Each hydrografical station was given a weight (m_i) based on its representative area in the square. The temperature t_i is multiplied by this weight. This is done for all stations (N) in the square and by division by the sum of the weights, (M), the mean temperature ($\bar{t}_m$) is reached.

$$\bar{t}_m = \frac{1}{M} \sum_{i=1}^{N} t_i m_i \qquad (1)$$

2. Isolines were drawn for the mean temperature in 10 to 200 m for every 0.5^{o}C in the whole distribution area. The area (a_j) between the isoterms t_j and t_{j+1} was multiplied by the mean temperature in the area. This was done for the areas between all the isoterms (K) in the square and the mean temperature $\bar{t}_a$ was reached by deviding by the total area in the square, A.

$$\bar{t}_a = \frac{1}{A} \sum_{j=1}^{K-1} \frac{t_j + t_{j+1}}{2} a_j \qquad (2)$$

The first method yield good results when there are 2-3 stations in each square, and small horizontal temperature gradients are found. The second method is better in areas with few observations and strong horizontal gradients.

In 1981 both methods were applied for the whole Barents Sea. The results from the two methods for the different squares are plotted against each other in Fig. 2. In 80 % of the squares the difference is

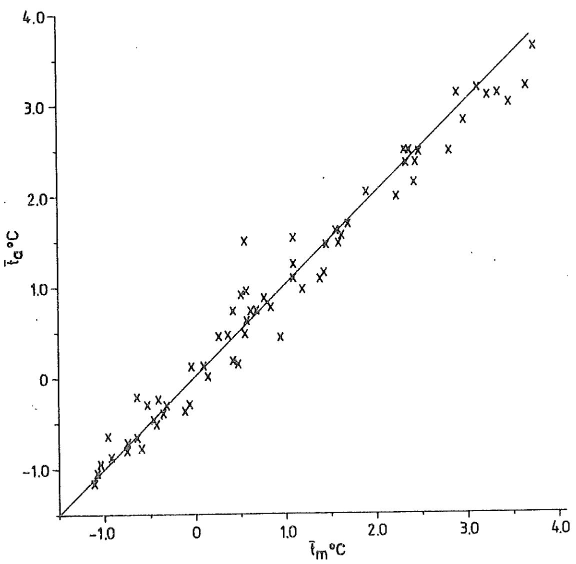

Figure 2. Calculated mean temperature in 10-200 m for all statistical areas in 1981, using the different methods mentioned in the text.

smaller than 0.25°C. A linear regression analysis yielded a straight line (Fig. 2) with a regression coefficient of 1.0 running through the origo. The correlation coefficient was 0.99. This shows that in practical work it is irrelevant which method is used and they may be applied concurrently. Consequently the first method was applied were the hydrografic covering was good, and the second was applied were there were few observations or great temperature differences.

3. RESULTS

3.1 Temperature and capelin distribution

3.1.1 Horizontal distribution

The distribution of capelin (all age groups) each year in the period 1974 to 1983 is shown in Fig. 3. A marked soutwestward displacement is seen to have taken place from 1976 to 1977. The following years only small changes in the distribution west of 35°E has taken place. In the eastern area the distribution has gradually been found further to the south and west. The most southern distribution was found in 1982.

The areas of most dence consentrations (shaded on Fig. 3) are disperced throughout the distribution area. However, also these areas has moved to the south and west during the period 1976 to 1980, when the distribution area was most contracted. The three last years a small eastward movement can be seen.

West of 35 E only small changes in the locations of the isoterms for 0°C and 2°C in 100 m depth (Fig. 3) has taken place. The 0°-isoterm has not moved and the 2°-isoterm has moved only 60 nautical miles to the south. However, in the eastern part of the Barents Sea the changes have been grater. Especially between the years 1976 and 1977 a great displacement has been observed. In the following years both isoterms mooved to the south and west, the 0°-isoterm most pronounced. The last three years a small northward movement of both isoterms can be seen.

While a considerable part of the capelin distribution was found to the north and east of the 0°-isoterm in the years 1976 to 1979, only a small part of the stock was found in these cold water areas in the later years (Fig. 3). In the years 1980 to 1982 most of the stock was situated between the 0°-isoterm and the 2°-isoterm, while in 1983 the majority of the capelin was found south of the 2°-isotherm.

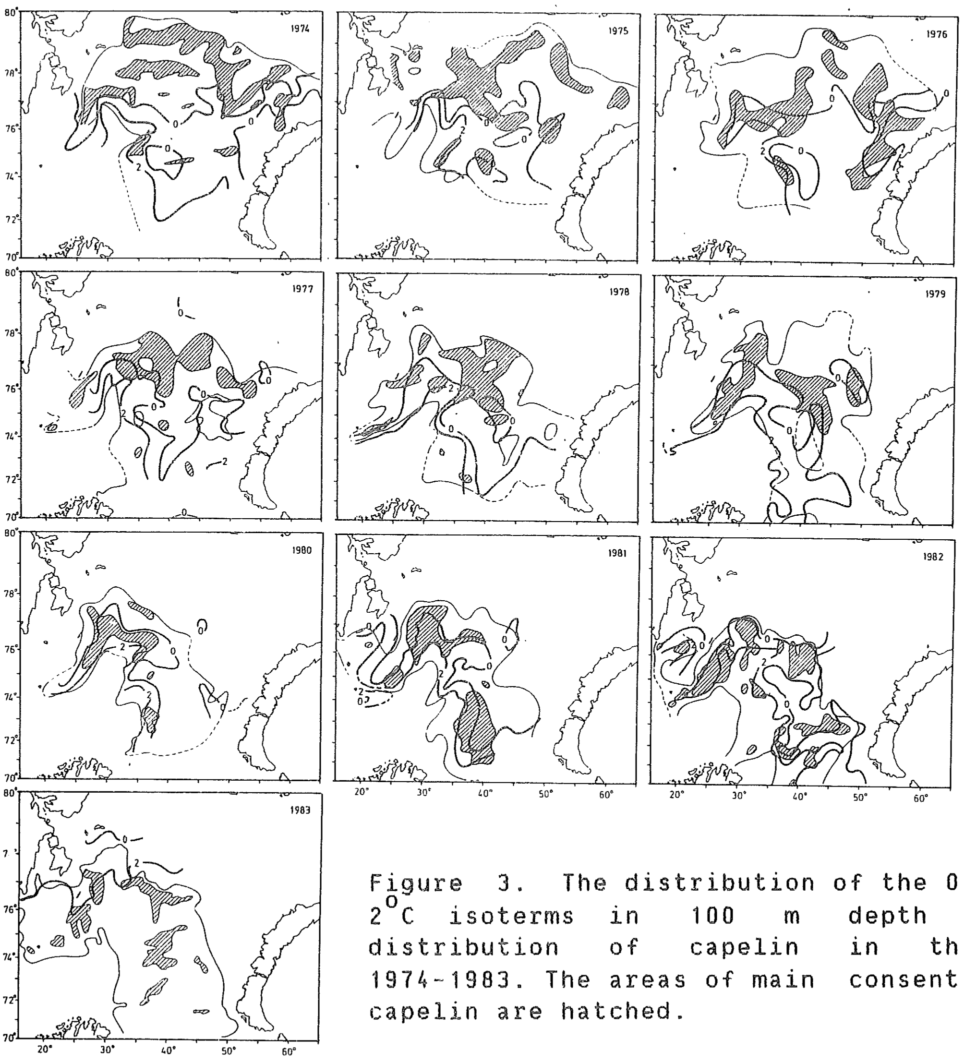

Figure 3. The distribution of the $0^{o}C$ and the $2^{o}C$ isoterms in 100 m depth and the distribution of capelin in the period 1974-1983. The areas of main consentration of capelin are hatched.

Distribution areas for the different age-groups of capelin in 1981 are shown in Fig. 4. The statistical squares containing more than 2 % of the different age-groups are shaded. Total distribution areas for the 1 and 2 year olds were almost identical. However, the greatest consentrations of the 1-group was found in the warmer water in the southern part of the area, while most of the 2 year olds were situated further north. The 3- and 4-group had almost identical distribution areas, and the greatest consentrations was found in the same area as for the 2 year olds.

This distribution pattern was typical for all studied years; the greatest consentrations of the two to four year old fish was found further to the north than the consentrations of the 1-group.

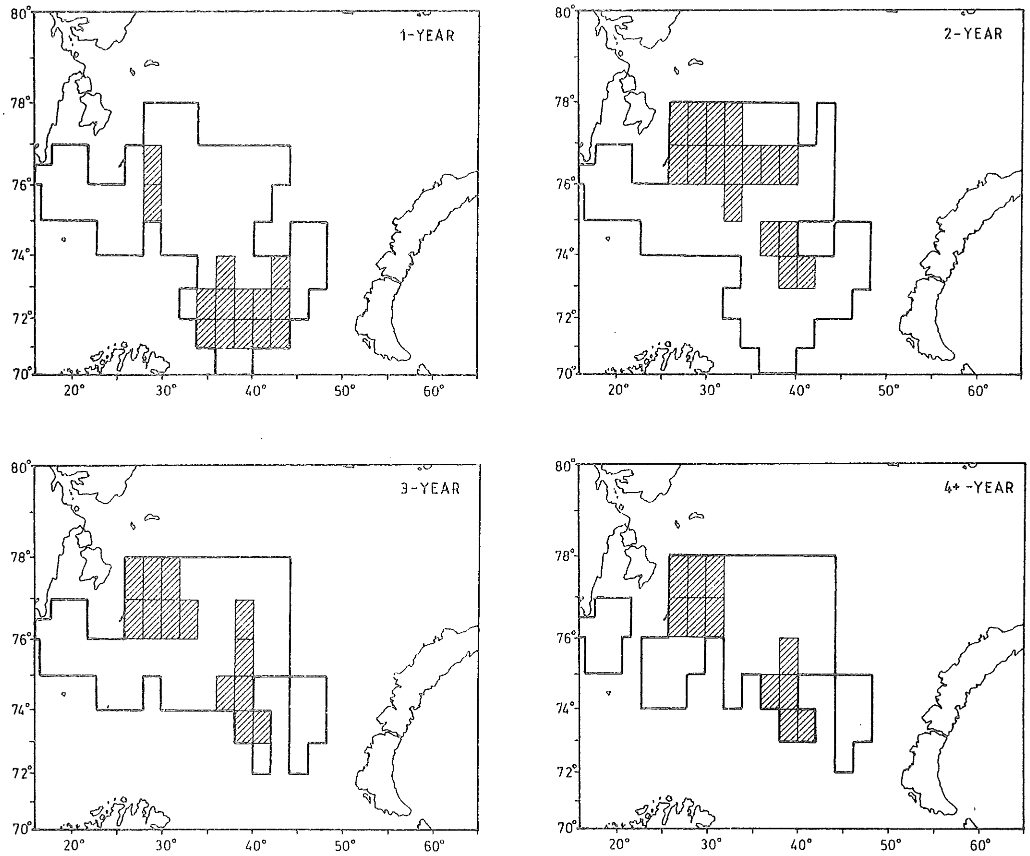

Figure 4. The distribution area of the different age-groups of capelin in 1981. Statistical areas containing more than 2% (in number) of each age-group are hatched.

3.1.2 Vertical distribution

A typical temperature distribution along a north-south transect in the Barents Sea in autumn is shown in Fig. 5. In the south most of the water column is dominated by Atlantic water with temperature exeeding 2 °C. In the north, Arctic water with temperature between -1.8 and 0 °C is dominating. Between these two areas a transition area is found, in which the water masses are distributed in accordance with the circulation pattern on and around the Central Bank.

In the autumn, one year old capelin has been found at depths between 10 and 100 m, while older capelin most often resides in the water column between 10 and 200 m. The oldest age-groups may sometimes be found even deeper, at 250-300 m depth, but the number of capelin found at these depths are probably wery small compared with the total abundance. Inside its depth interval, the capelin undertake diurnal migrations. At daytime it is found in small schools at variable depths, while at nighttime it is most often disperced in a layer at shallow depths.

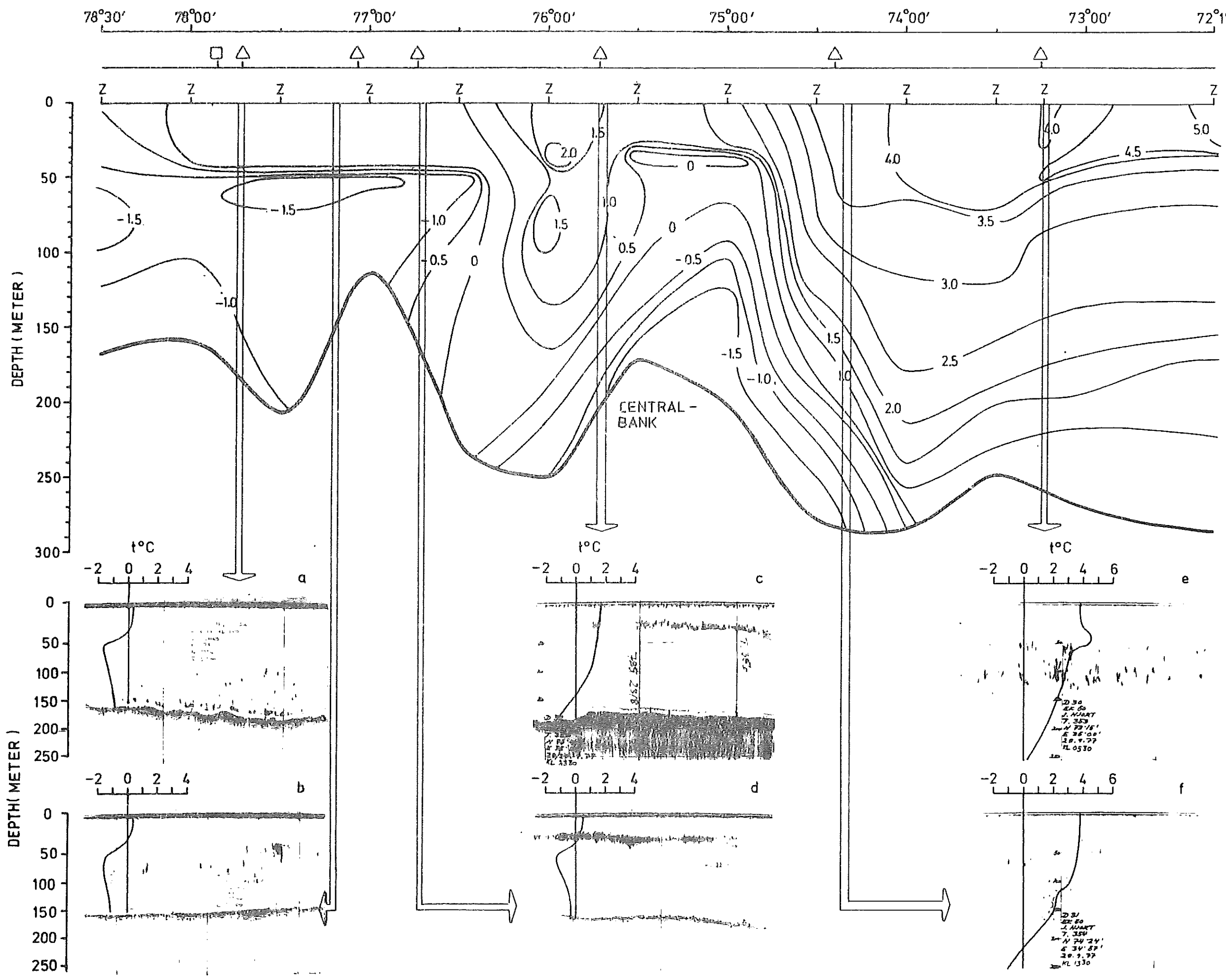

Figure 5. Temperature distribution along a section at 35gE in 1977. z: hydrographical station, △: pelagic trawl, □: bottom trawl. The echogramms (a-f) below show the vertical distribution of capelin and the vertical temperature profile at the trawl stations.

This distribution pattern is illustrated by the echogramms depicted in Fig. 5, showing registrations of capelin at some trawlstations taken along the hydrographical section in 1977. At daytime, the capelin was found in small schools at various depth (echogramms a and f). At nighttime the registrations were gathered in a layer, generally found between 10 and 100 m depth (echogramms c and d). The echogramms b and e shows typical transition situations found at dusk and dawn.

By comparing the temperature distribution in the section (Fig. 5), the temperature profiles on the trawlstations, the echogramms and the age distribution in the trawl catches, it is seen that in the north, the adult capelin was residing in water masses with temperature above 0° C only at nighttime. At daytime these consentrations were found in considerable colder water, and during the vertical migration at morning and night they passed through the temperature minimum, which many places in the north lies between -1.5° and -1.8°C. These observations makes 10-200 m a reasonable depth stratum to represent the vertical distribution of capelin 2 year old and older.

3.2 Climatic variations

The movement of the 0^{o} - and 2^{o}-isoterms in 100 m depth (Fig. 3) especially between the years 1976 and 1977, indicate significant climatic changes in the Barents Sea during the investigation period. The temperature variations in the Atlantic water in the influx area between the Bear Island and the Norwegian coast was studied by Blindheim and Loeng (1981). In this area the temperature decreased $0.9^{o}C$ between September 1976 and September 1977, and the low temperatures persisted in 1978 and 1979. From 1980 onwards an increase in temperature was observed in the influx area, and in the autumn 1982 and 1983 the temperatures were at the same level as before the period of strong cooling (Loeng and Midttun 1984).

In the eastern part of the Barents Sea the temperature development was a bit different. The cooling started at the same time as in the western part, but the temperature remained low during the whole period 1977 to 1982 with minimum temperature in 1978 to 1979 (Loeng and Midttun 1984). In 1983 the temperature started to rise rapidly, and within one year the temperature reached the same level as before the cooling started in 1977.

3.3 Covariation of the temperature field and the capelin distribution

Changes has thus been observed both in the temperature conditions and in the capelin distribution in the Barents Sea in the period 1974 to 1983. The capelin distribution compared with the position of the isoterms in 100 m (Fig. 3) indicate that the capelin has inhabited warmer water masses in 1980 to 1982 than before. To study this more thoroughly, frequency distributions for the different age-groups were plotted against mean temperature in 10 to 200 m in the statistical squares they were found in September each year (Fig.6). It seems that the capelin responded to the cooling down of the water masses in 1976 to 1977 by a westward movement, which kept its position relative to the temperature field. The more protracted freqency distributions observed in 1977 to 1978 (Fig. 6) may be associated with this event.

However, during the period of warming up of the water masses since 1980, no corresponding movement of the capelin distribution area seems to have taken place. This eventually led to a situation were greater parts of the capelin stock came to live in water masses with higher temperature than previously. The mean temperature in the distribution areas of the different age-groups (Table 1) shows a considerable increase from 1979 to 1983, and especially the last year.

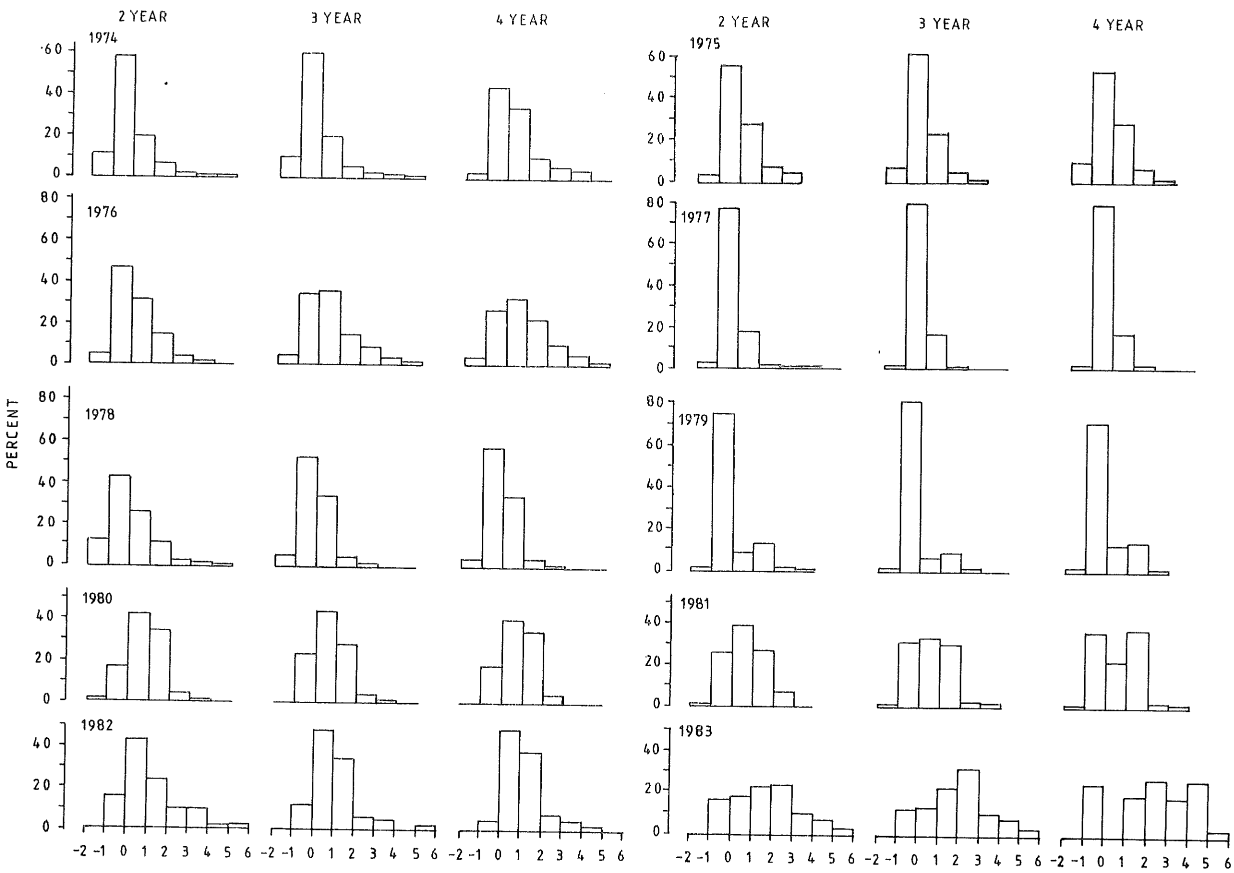

Figure 6. Frequency distribution (per cent of numbers) of the different age-groups of capelin related to mean temperature for the depth interval 10-200 m.

Table 1. Mean temperature ($\bar{t}$) and standard deviation (s) in the distribution area of 2, 3 and 4 year old capelin in the period 1974 to 1983.

YEAR	AGE 2		AGE 3		AGE 4	
	$\bar{t}^{o}C$	s	$\bar{t}^{o}C$	s	$\bar{t}^{o}C$	s
1974	-1.15	1.00	-0.18	0.99	0.32	1.11
1975	-0.03	0.88	-0.29	0.74	-0.26	0.78
1976	0.16	0.98	0.46	1.09	0.76	1.21
1977	-0.32	0.72	-0.38	0.59	-0.37	0.59
1978	0.03	1.07	-0.11	0.77	0.13	0.69
1979	-0.05	0.86	-0.19	0.69	-0.05	0.72
1980	0.78	0.91	0.68	0.88	0.85	0.89
1981	0.63	0.88	0.53	0.95	0.53	0.90
1982	1.12	1.22	0.99	0.91	1.13	0.83
1983	1.82	1.51	1.95	1.41	2.11	1.66

3.4 Growth of the capelin

The growth of the capelin, represented by the mean length increment, is plotted versus the mean temperature in the distribution area of capelin in Fig. 7. The mean growth, weighted by abundance, shows a similar variation as the temperature up to 1981. In 1982 and 1983 the growth has levelled off somewhere between the 1980 and 1981 level. Fig. 7 clearly demonstrate that the youngest capelin has the fastest growth.

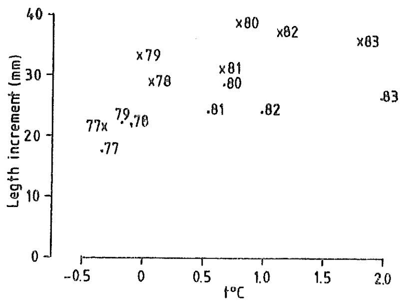

Figure 7. Length increments versus temperature plotted for the total stock of two year olds (x) and three year olds (•) for the period 1977 to 1983.

To obtain more corresponding values of temperature and growth, values from the different subareas have been plotted versus each other in Fig. 8. The results indicate increasing growth with increasing temperature, especially for the 2 year old capelin. Linear correlation analysis gave positive correlations between the variates but no strong relationships were found (Table 2).

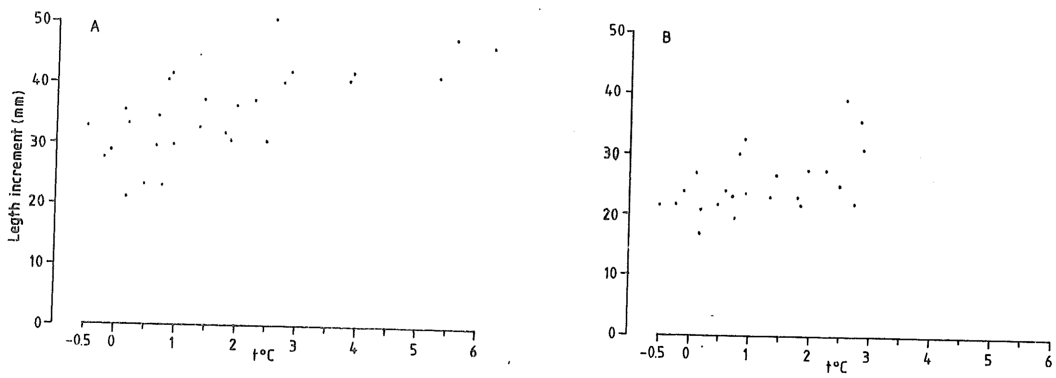

Figure 8. Length increment plotted versus temperature for the two year old capelin (A) and the three year olds (B) in each subarea in the period 1977 to 1983.

Table 2. Correlation coefficients (r) and number of pairs of variates (n) for a linear correlation analysis carried out on four strata.

Stratum	r	n
Two year olds, separated on subareas	0.70	28
Three year olds, separated on subareas	0.55	24
Two year olds, whole distribution area	0.71	7
Three year olds, whole distr. area	0.69	7

4. DISCUSSION

The movement of the capelin stock towards south and west was seemingly following the changes in the temperature field before 1979 (Fig. 3). This is also seen from Fig. 6 and Table 1. which show that the main consentrations of both two, three and four years old capelin in this period were found in a constant position relative to the temperature field from year to year, at about 0^{o}C, and inside a very narrow temperature range. In the years 1980 to 1982 there was a change in the capelin's position relative to the temperature field. The mean temperature in the capelin distribution field increased by about 0.8 to 1.2^{o}C, and at the same time the temperature range in the distribution field became broader. In 1983 the capelin was found in still warmer water, (table 1) which may be assosiated with the observed temperature increase in the eastern part of the sea.

The investigation shows that the capelin, during its diurnal migration passes through water masses with temperature below -1.5^{o}C. The time spent in these areas is however, short, and Fig. 6 shows that greater consentrations of capelin has never been found in water masses with a mean temperature below -1^{o}C. This may explain the concurrent geografical movement of the temperature field and the capelin distribution area during the period of cooling down of the sea. It is seen (Fig. 6) that during the whole investigation period there has been some capelin consentrations residing at higher temperatures, also in the "cold water period". However, only a small fraction of the adult stock has been found in water masses with mean temperatures above 2^{o}C. The majority of capelin two years and older seems to stay in water masses with mean temperature between -1^{o}C and 2^{o}C.

The substantial increase in the temperature in the water masses were most of the capelin stock have been found seems to be acompanied by an increase in growth (Fig.7, 8). The computation of linear correlation coefficients (Table 2)was done mostly for illustrative purposes, and does not imply the assumption that a possible covariation between temperature and growth would be of a linear type. In fact, a nonlinear type of regression would probably give a better fit to these data. However, a discussion of which type of function would best describe a possible temperature/growth-relationship has not been the intention here. Neither would it have been possible without more data covering a larger range of observations for both variates.

Any growth differences which can be observed in the field and ascribed to temperature variation will probably be a combined effect of direct and indirect causes. These effects may well for some temperatures work in opposite directions, partly masking each other (Gjøsæter and Loeng 1984).

The direct influence of temperature on growth, linked to the physiology of the fish, will probably be small as long as the stock is able to reside in watermasses with temperature in the range to which the stock is adapted.

Temperature effects linked to the availability of food may be of equal importance. These effects will be very complicated and difficult to trace through the food web. A shift in temperature could alter the general hydrograpic conditions, and thus the availability of nutrients for the primary producers, it could effect the growth of the organisms on different levels in the food web, it could influence the abundance of food competitors for the capelin and so on.

The methodological error which may affect this type of investigation is primarily the possibility of temperature not being representative for the measured growth. This could result from either horizontal movement during the growing season, or the depth interval 10-200 m not being representative for the depth distribution of the capelin. Investigations carried out in 1981 (Gjøsæter et.al. 1983) showed that the migration towards the feeding areas was primarily taking place in July, and probably much of the growth is taking place afterwards. Consequently the measured temperatures should be representative for the areas where most of the growth have been taking place.

Another problem is how differences in the available energy is affecting growth in length. The apportioning of available energy to growth in length, growth in weight, including fat storage and growth of gonads, and to maintenence cost, including migration, is as yet poorly understood.

The observed covariation between growth in length and temperature indicates that there is a general rise in linear growth with increasing temperature over the temperature interval observed.

5. CONCLUSIONS

In the period 1974 to 1983 considerable changes in the temperature regeime in the Barents Sea has been taking place. These changes have been different for the eastern and western part of the capelin distribution area.

In the western area there was a significant decrease in the temperature from 1976 to 1977, and the sea was coldest in 1977 to 1978. In 1979 to 1983 the temperature increased again.

In the eastern area the sea was much colder in the whole period 1978 to 1982 than in the period 1974 to 1977, and the temperature the last years has been lower than the mean temperature in the period 1920 to 1979.

In the period 1976 to 1980 there was a movement towards south and west of the capelin distribution area and the areas of highest consentrations. The distribution area did not change much in the period 1980 to 1983.

Up to 1979 the changes in capelin distributin area resembled the changes in the temperature field. The mean temperature in the capelin distribution space was a litle below 0 ^{o}C. In the years 1980 to 1982 the mean temperature increased to 0.6 - 1.1 ^{o}C.

The majority of capelin 2 years old and older was found in water masses with temperature between -1 and 2 ^{o}C.

The growth of the 2- and 3-group capelin has increased in the period from 1977 to 1981, concurrently with the rise in temperature and change in distribution area.

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