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International Council for
The Exploration of the Sea

C.M. 1986/H:64
Pelagic fish committee
Ref. Hydrography committee
Theme session Q

GROWTH OF THE BARENTS SEA CAPELIN (*MALLOTUS VILLOSUS*)
IN RELATION TO CLIMATE¹)

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ABSTRACT

The history of capelin assessment in the Barents Sea has shown that the growth of individual capelin has varied between years and different parts of the capelin distribution area. As the number of individuals in this stock is very high, even small changes in individual growth will affect the surplus production and the catches which may be taken from it. If this growth could be estimated in advance, the assessment could be made more precise.

Temperature variation has been suggested as a factor which could be partly responsible for the variation in growth. To study this possibility, we compared corresponding values of temperature and length increment of the capelin in different parts of the Barents Sea from 1976 to 1985. The mean temperature in subareas was calculated by averaging the temperatures for the depth interval 10-200 m at all of the hydrographical stations taken each September in each statistical square which the sea is divided, and then combining the squares to form subareas. The estimates of growth were calculated by subtracting the backcalculated length corresponding to the outermost winter ring in the otolith from the length at sampling.

A positive covariance between water temperature and growth was indicated when all the material was considered, but no clear correspondance was found between temperature and growth within subareas.

¹) This is an extended version of a paper, first presented at the USSR-Norwegian symposium "The Barents Sea capelin" in 1984.

INTRODUCTION

Capelin has for years been the dominating pelagic fish species in the Barents Sea. The stock has supported a fishery with annual catches of the order of one to three million tonnes. The capelin mature at an age of two to four years, at a length of 15 - 19 cm. The spawning takes place close to the coasts of Norway and USSR, and most of the capelin die after spawning. During summer and autumn the adult capelin feeds in the northern part of the sea. The feeding area shifts in the east-west direction in response to climatic variations (LOENG, NAKKEN and RAKNES 1983).

The hydrography of the Barents Sea is generally determined by three water masses closely connected to the following current system: The Norwegian Coastal Current and the Norwegian Atlantic Current, which enter the Barents Sea from the west and cover the southern Barents Sea, and the cold Arctic current system in the north (LOENG 1986, MIDTTUN and LOENG 1986).

MATERIAL AND METHODS

The present investigation is based on observations made during the annual joint USSR-Norwegian capelin survey in the Barents Sea carried out since 1976. The investigations have been performed within the period from 6 September to 11 October, with the aim of describing the geographical distribution of the stock, its structure and its size.

Echo intensities were integrated continuously along the tracks, and mean values were recorded for each 5 nautical mile interval. The integrated echo intensity was allocated to species according to the trace pattern on the echogram and the trawl catches. Trawl stations were used for identification purposes and to obtain observations on length, weight, maturity stage, and age of the capelin. By means of these data, numbers of individuals and biomass in length- and age-groups were computed and distributed on different statistical squares and subareas (Fig.1). A detailed description of the bioacoustic method for abundance estimation is given by NAKKEN and DOMMASNES (1975); DOMMASNES and RØTTINGEN (1985)

The estimate of growth was calculated by subtracting the backcalculated length corresponding to the outermost winter ring in the otolith from the length at sampling. A description of the method is given by GJØSÆTER (1985). This growth estimate covers the growing season in the current year until the time of sampling. To be able to compare growth estimates and correlate them with temperature observations, it was assumed that the growing season had ended by the time of sampling.

Temperature observations were made along the survey routes with a distance of 30 nautical miles applying a Neil Brown CTD-system. Nansen casts were taken at some stations in a few years.

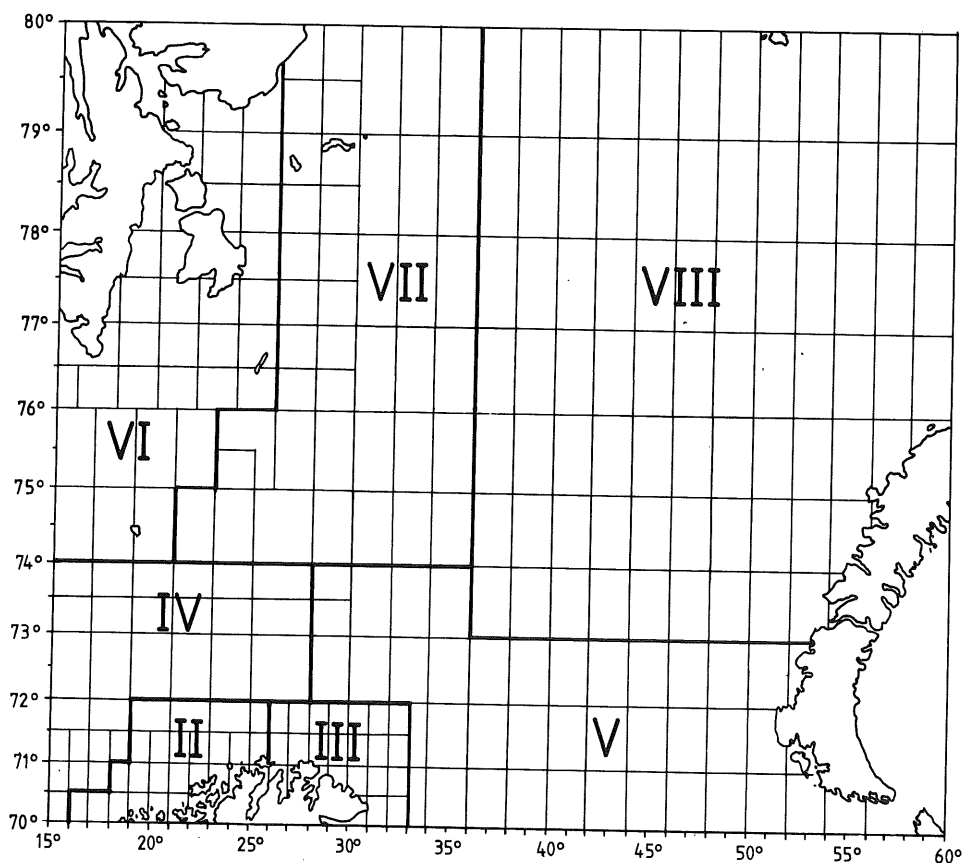


Figure 1. Map covering the Barents Sea showing the statistical squares and the subareas (Roman numerals) mentioned in the text.

In each statistical square, mean temperature has been calculated for the depth interval 10-200 m using the method described by LOENG *et al.* (1983). When calculating the mean temperature for the subareas (Fig.1), only squares containing capelin have been used. In this calculation, all squares have been given the same weight, independently of the density distribution of capelin. The calculation of the mean temperature for each year class in the whole Barents Sea is, however, based on the frequency distribution of capelin in relation to the temperature, i.e., the number of capelin within a temperature interval is taken into consideration.

RESULTS

Table 1 shows the mean temperature in the distribution area of two- and three-year-old capelin in the period 1976-1985. Within each year, the different age groups is seen to be distributed in water masses of the same temperature. However, from one year to another there are marked changes in the environmental temperature. In the period 1977-1979 the changes were small, but thereafter an evident increase took place in the environmental temperature with maximum temperature observed in 1983.

Table 1. Mean temperature (\bar{t}) and standard deviation (s) in the distribution area of 2 and 3 year old capelin in the period from 1976 to 1985.

YEAR	AGE			
	two years		three years	
	$\bar{t}^{\circ}\text{C}$	s	$\bar{t}^{\circ}\text{C}$	s
1976	0.16	0.98	0.46	1.09
1977	-0.32	0.72	-0.38	0.59
1978	0.03	1.07	-0.11	0.77
1979	-0.05	0.86	-0.19	0.69
1980	0.78	0.91	0.68	0.88
1981	0.63	0.88	0.53	0.95
1982	1.12	1.22	0.99	0.91
1983	1.82	1.51	1.95	1.41
1984	0.56	0.75	0.99	1.27
1985	0.29	0.54	0.55	0.74

The estimated growth of the capelin, represented by the mean length increment, is plotted versus the mean temperature in the distribution area of capelin in Fig. 2. The mean growth, weighted by abundance, shows a similar variation as the temperature up to 1981. In 1982 and 1983 the growth was at the 1980 to 1981 level. In 1984 and 1985 the mean growth rate decreased sharply. Fig. 2 also demonstrate that the youngest capelin has the fastest growth.

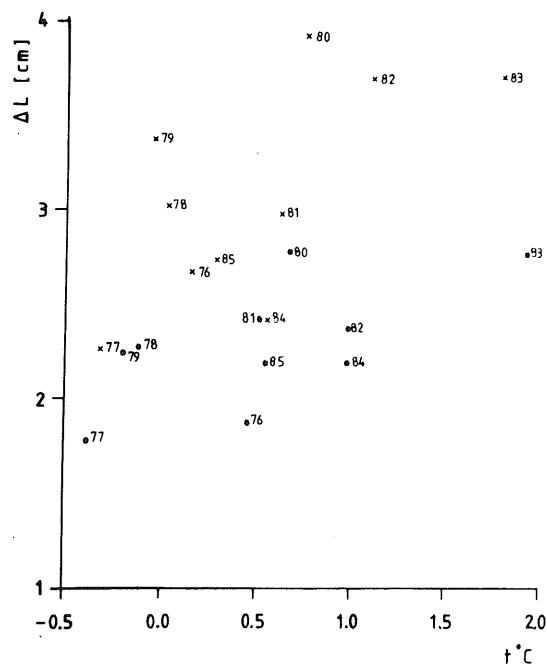


Figure 2. Length increments versus temperature plotted for the total stock of two-year-olds (x) and three-year-olds (·) for the period 1976 to 1985.

We have also plotted corresponding values of temperature and growth from the different subareas (Fig. 3). The results indicate increasing growth with increasing temperature. Linear correlation analyses gave positive correlations between the variates, but no strong relationships were found (Table 2). The variation in growth for a given temperature is seen to be substantial. The relation between the temperature and growth for the two-year-olds in the various subareas within the same year is shown for the years 1977, 1982, and 1983 in Fig. 4. These years were selected because the capelin was distributed over a wide area and thus over a large temperature interval. The linear correlation coefficients for these three distributions are 0.92, 0.82, and 0.85 for 1977, 1982, and 1983 respectively (Table 2).

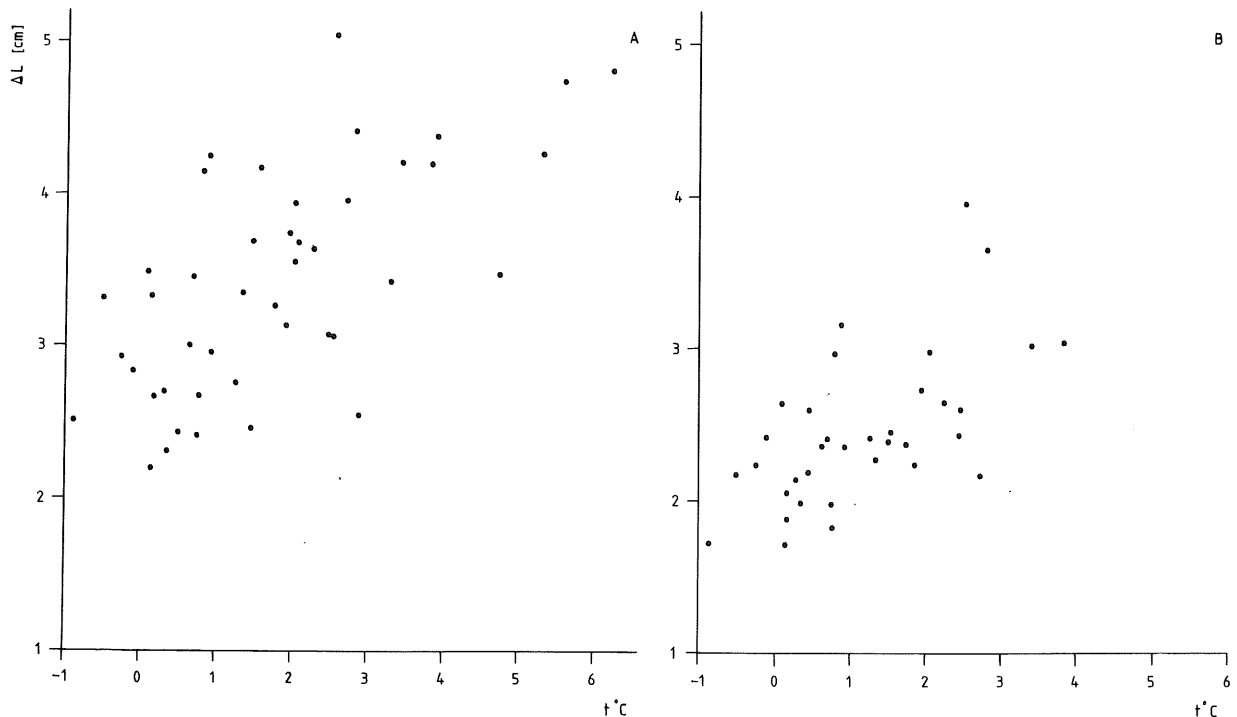


Figure 3. Length increment plotted versus temperature for the two-year-old capelin (A) and the three-year-olds (B) in each subarea in the period 1976 to 1985.

Table 2. Correlation coefficients (r) and number of pairs of variates (n) for a linear correlation analysis carried out on the various groups of data.

Group	r	n
Two-year-olds, separated on subareas	0.65	44
Three-year-olds, separated on subareas	0.49	36
Two-year-olds, whole distribution area	0.66	10
Three-year-olds, whole distribution area	0.60	10
Two-year-olds, separated on subarea, 1977	0.92	5
Two-year-olds, separated on subarea, 1982	0.82	6
Two-year-olds, separated on subarea, 1983	0.85	6

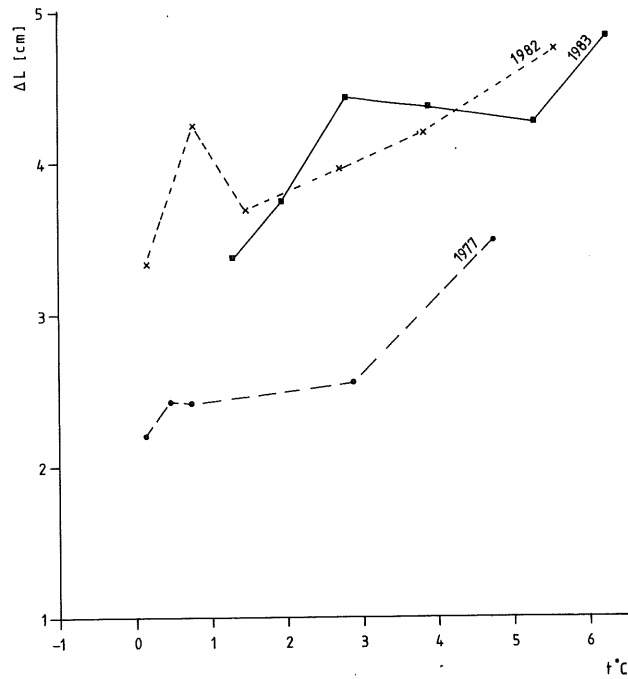


Figure 4. Length increment plotted versus temperature for the two-year-old capelin in all the subareas in the years 1977, 1982, and 1983.

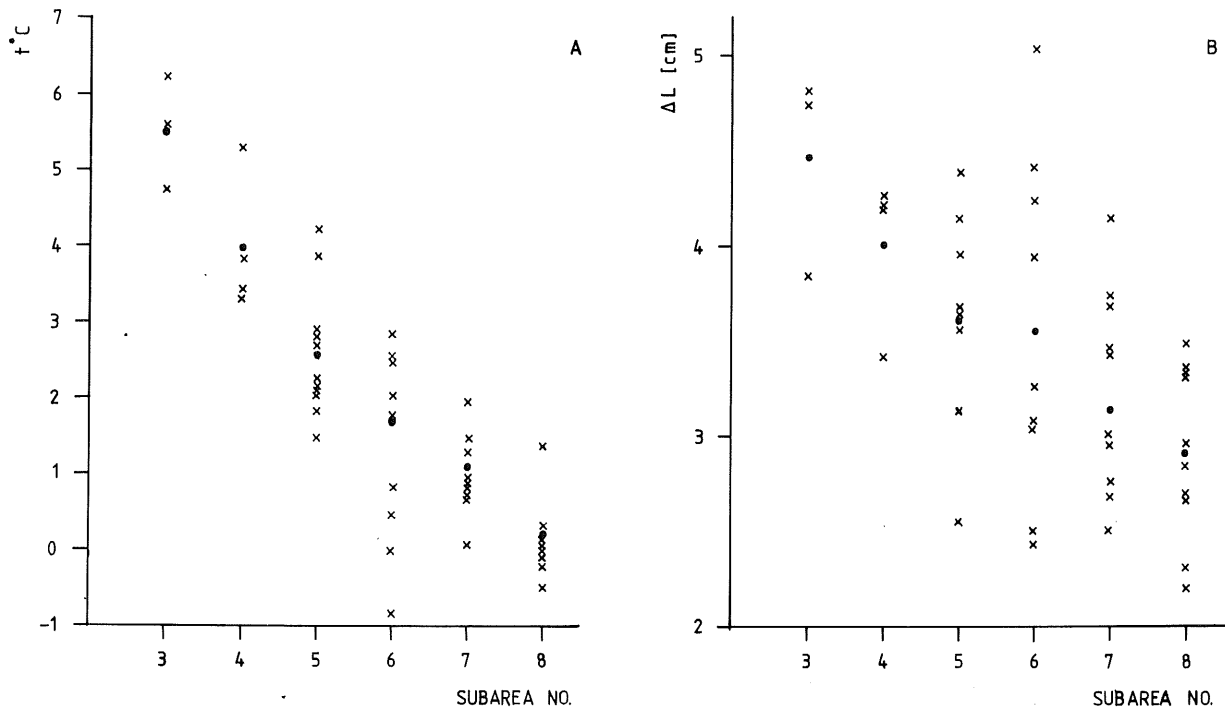


Figure 5. Temperature (A) and length increments of two-year-olds (B) plotted versus subarea number. Each observation (x) represents one year. The average temperature and length increments for each subarea (●) are indicated on the figure.

Mean water temperatures and growth rates for the ten-year period are plotted for the different subareas in Fig. 5a and 5b, respectively. Both these variates are decreasing with increasing subarea number, (that is from south-west to north-east), although a large year-to-year variation within subareas is evident. Subarea 6 is the most variable, both with respect to the temperature and the growth.

Time series of growth and temperature for four subareas are shown in Fig. 6. Fast growth has taken place both in periods of low temperatures, (subarea 5, 7, and 8 in the years 1979-81) and high temperatures (all subareas in 1983). However, the plots indicate that the higher the temperature, the better is the correspondence between growth and temperature. From 1981 to 1984 there is quite good agreement between the variates.

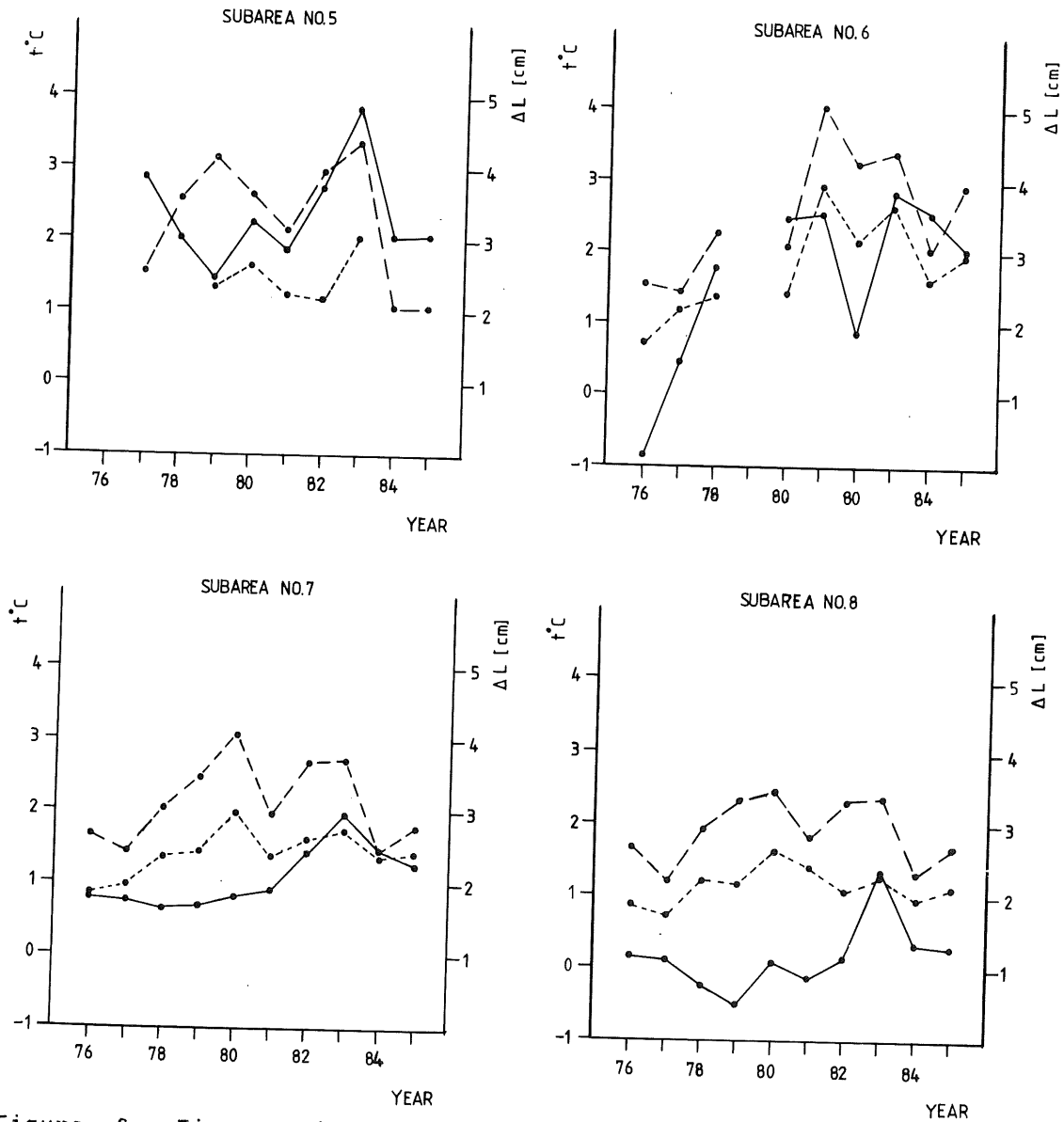


Figure 6. Time series of temperature and growth of two- and three-year-old old capelin shown for the four subareas with most complete observation series. Growth 2-year-olds (— — —), growth 3-year-olds (---), temperature (————).

DISCUSSION

When considering the results presented in Figs. 2 - 4 and Table 2, a rise in temperature is associated with increased growth. The results do not, however, demonstrate a strong relationship between the variates. This may, in fact, reflect the strength of the relationship in nature between temperature and growth under the Barents Sea conditions. Alternatively the absence of a stronger relationship in our results may come from inadequate methods, introducing "noise" to the relationship.

The computation of linear correlation coefficients (Table 2) was done mostly for illustrative purposes, and does not imply that the covariation between temperature and growth is linear. In fact, a nonlinear regression would probably give a better fit to some of the groups of 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 this be possible without more data covering a larger range of observations for both variates.

When both temperature and growth are plotted versus a third variate, namely the distribution area (Fig.5), quite strong relationships are evidenced, especially when the average values over the ten-year period are considered. A possible interpretation is that each subarea has a typical range of temperatures and a typical range of growth rates, and when the variation is removed by taking the average over the years, both variates are seen to be strongly related to geographical area and hence, to each other.

Different sources of error may have obscured the hypothesized positive relation between temperature and growth. Firstly, we have the possibility that the temperature is not representative for the estimated growth. This could result from either horizontal movement during the growing season, or the depth interval 10-200 m not being representative of the depth distribution of the capelin.

Investigations carried out from 1979 to 1982 (GJØSÅTER *et al.* 1983) showed that the migration towards the feeding areas took place primarily in July and August, and the growth seemed to be low during this period. Also OZHIGIN and LUKA (1985) showed that the main feeding migration takes place during the period from July to September. Consequently, the measured temperatures should be representative of the areas where most of the growth has taken place.

The depth distribution of capelin has been observed to vary with the time of day. Most of the fish in age groups two and older have been found between 10 and 200 m, undertaking vertical migration with a diurnal rhythm. The mean temperature for the interval 10 to 200 m should cover the mean temperature experienced by capelin, although exceptions may occur if a part of the water column has temperatures which are avoided by the capelin.

Secondly, the estimation of growth may have introduced an error. The assumption that the growing season is ended by the time of sampling in September is not entirely true. By comparing the width of the zone from the outer winter ring to the otolith margin in September with the width of the past year's growth zone the next spring, it has been shown that about 90% of the otolith growth has taken place by the time of sampling in September. If this affects the fish in all of the subareas equally, it will only affect the absolute values of the

growth and have no effect on the shape of the temperature/growth distribution. However, it is impossible to test whether this is the case, because the material from the spring cannot be distributed on subareas. In any case, this effect is probably quite small.

Methodical errors in the growth estimation are also probably quite insignificant, as only the outer part of the otolith is used for growth estimation, which therefore is quite insensitive to any error in the estimation of the intercept of the L-axis in the otolith radius/fish length plot. It is difficult to assess the amount of methodical error in the investigation. It may be argued that a much stronger covariation between temperature and growth than indicated in our results possibly exists in nature, but is masked by variation introduced to the data by different sources of errors.

On the other side, the results may give a correct picture of the temperature/length-growth relation. The growth will to a large extent be influenced by environmental factors, among which the amount of suitable food and temperature is probably the most important. The partition of the food energy into metabolism, growth of the gonads, and storage of fat will additionally affect the growth in length.

The temperature can affect the growth either directly, influencing the physiology of the fish, or indirectly, through the effect of temperature on the availability of food organisms. The better correspondence between temperature and growth when the temperature is above 1.0-1.5° C (Figs. 3 and 6) could indicate that the relation between temperature and growth is dependent on which temperature interval is considered, thus weakening the relation when the whole temperature interval experienced by the capelin stock in the Barents Sea is included.

The direct effect on growth will probably change in nature and magnitude according to the position relative to this optimal temperature. Each fish stock will probably be adapted to a range of temperatures including an optimal temperature. If the fish experiences temperatures near the boundaries of its tolerable range, the effects will probably be negative and strong. Approaching the optimal temperature, the direct effects on growth will probably be less serious. However, the probability of finding adult capelin living outside its tolerable temperature range in the Barents Sea is probably very low, as the fish could in most cases be able to move actively away from such areas. This is not to say that the capelin will always be able to find and reside in areas with optimal temperatures.

The introduction of large stocks of herring and cod to the southern part of the Barents Sea may have forced the capelin to move away from the areas with the optimal growth conditions. Table 2 shows that the capelin stayed in relatively warm water in the years 1982-1983, when there was relatively small stocks of other species. When strong year classes of herring and cod started to occupy the southern Barents Sea from late 1983, the capelin was found in colder water masses, further to the north and east. This could be a mechanism to avoid food competitors and predators. However, at the same time, the size of the capelin stock decreased sharply, and the apparent movement from warmer to colder water masses may also be explained by a depletion of the part of the stock which inhabited the southern and western areas.

Temperature effects linked to the availability of food may be of equal importance. These effects may be divided into two categories. A shift

in temperature could alter the general hydrographic conditions, and thus the availability of nutrients for the primary producers. It could affect 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 change in climate is mainly an effect of variations in the inflow of Atlantic water (LOENG 1986, LOENG and MIDTTUN 1986). The temperature and volume of inflowing Atlantic water will determine the water temperature in the southern Barents Sea, the position of the polar front (the area between Atlantic and Arctic water masses), and, somewhat, the ice conditions. This could in turn affect the local production of food organisms. In addition, the transport of zooplankton by currents is known to vary with the rate of Atlantic inflow (OZHIGIN and USHAKOV 1985). Consequently, climatic changes will influence capelin growth through variations in available food. But in this case, the water temperature is not the primary cause of the changes of food availability, but is only an indicator of changes in the water masses.

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

An important question is how much of the growth variation observed may be ascribed to environmental differences and, in particular, temperature. This depends on which other causes of growth variation exist. The natural growth variation, which is found in all populations, will have no influence on the mean values, unless subpopulations with a growth deviating from the mean is non-randomly distributed. PROKHOROV (1965), analysing otolith growth zones, concluded that there was no reason for dividing the capelin stock into two or more different ecological units, as proposed by RASS (1933). These results were confirmed using genetic methods (DUSHCHENKO 1985).

The fact that the length growth of the fish is just a part of the total metabolism may partly explain the relatively weak relation that is observed. The apportioning of available energy to growth in length, growth in weight, including fat storage and growth of gonads, and to maintenance cost, including migration, is as yet poorly understood.

CONCLUSIONS

The observed covariation between growth in length and temperature indicates that there is a general rise in length growth with increasing temperature over the observed temperature interval. This covariation is stronger when only the temperatures above 1.0- 1.5°C are considered.

As the mechanisms of this overall effect is not known, the observed relation should be used very carefully for predictive purposes. The results show the need for further investigations of environmental effects on growth. Such studies may or may not give support to the tentative conclusion that a rise in temperature will probably be associated with a rise in growth.

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