THE HORIZONTAL DISTRIBUTION OF ARCTIC COD IN RELATION TO THE DISTRIBUTION OF BOTTOM TEMPERATURES IN THE BARENTS SEA, 1978-1984.

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ABSTRACT

The results from acoustic-trawl surveys in January-March were analyzed together with observations of bottom temperatures at the same cruises. Estimates of abundance of cod within temperature intervals of one degree were calculated for each age group, and distributions of abundance on temperature were established.

The analysis showed that the older age groups, fish aged 6 and 7 years, were consistently found in warmer water, i.e. farther west, than the younger fish. The variations in bottom temperatures of the distribution areas appeared to be larger for the younger fish, age group 1, than for the older age groups. Year to year variations of weighted mean bottom temperatures in the actual distribution areas of the various age groups were compared with corresponding variations in two fixed areas and in the Kola section. The comparison showed that the temperature variations in fixed locations only to a certain extent reflected the variations in the actual environmental conditions of the fish.

The growth of the fish increased significantly during the period of observation coinciding with an increase in mean temperature of the distribution areas of the fish during the same period.

INTRODUCTION

The stock of Arctic cod is the most important commercial fish stock in the Barents Sea. The specimens reach maturity at an age of 6-9 years and the mature portion of the stock undertakes spawning migrations southwards along the Norwegian coast in February-April. The immature cod is feeding in the Barents Sea and in the Bear Island-Svalbard area throughout the year and makes seasonal east-west and north-south migrations (Fig.1) (Maslov 1944 and 1960, Mehl et.al. 1985). In addition to the seasonal displacements of the concentrations, temperature related displacements have been reported both on small and large time and space scales (Eggvin 1938, Lee 1952, Hylen et al. 1961, Konstantinov 1967 and 1969, Mukhin 1979, Beverton and Lee 1965, Woodhead and Woodhead 1965).

In most of the investigations referred to above, the quantities of the commercial catches were used as a measure of cod concentrations and abundance, and the displacements of the main fishing areas were related to variations in temperature. Midttun et al. 1981 made a different approach. They studied the geographical distribution of each age group as observed by combined acoustic-trawling surveys and compared the displacements of the distribution areas of the various age groups with variations in sea temperature at the Kola-section for the period 1977-1981. The conclusions of the study were: "The results show a westward displacement of cod with increasing age of the fish and with decreasing water temperature in the Barents Sea. Consequently, an extreme westerly distribution of the biomass of immature cod occurs in periods when the sea temperature is low and the age of the predominant year class(es) of immature cod is relatively high, which is the situation experienced during the period 1979-1981".

In the Barents Sea the temperature decreases from west towards east. Thus, the younger age groups which are mainly located in the eastern areas inhabit waters of lower temperatures than the older ones found farther west. The present study is an attempt to analyse the temperature conditions within the actual distribution area of each age group of cod, and to investigate to what extent variations in the temperature of the environment of the fish coincide with observed variations in growth rates.

MATERIAL AND METHODS

The bulk of the material used in this study has been collected on yearly research vessel cruises lasting from late January to the beginning of March (Dalen et al. 1984). Course lines and station network have been approximately similar every year, 1978-1984 (see Hylen et al. 1985).Monthly mean values of temperature at the Kola section were placed at our disposal by the Polar Research Institute of Marine Fisheries and Oceanography, Murmansk, Soviet Union.

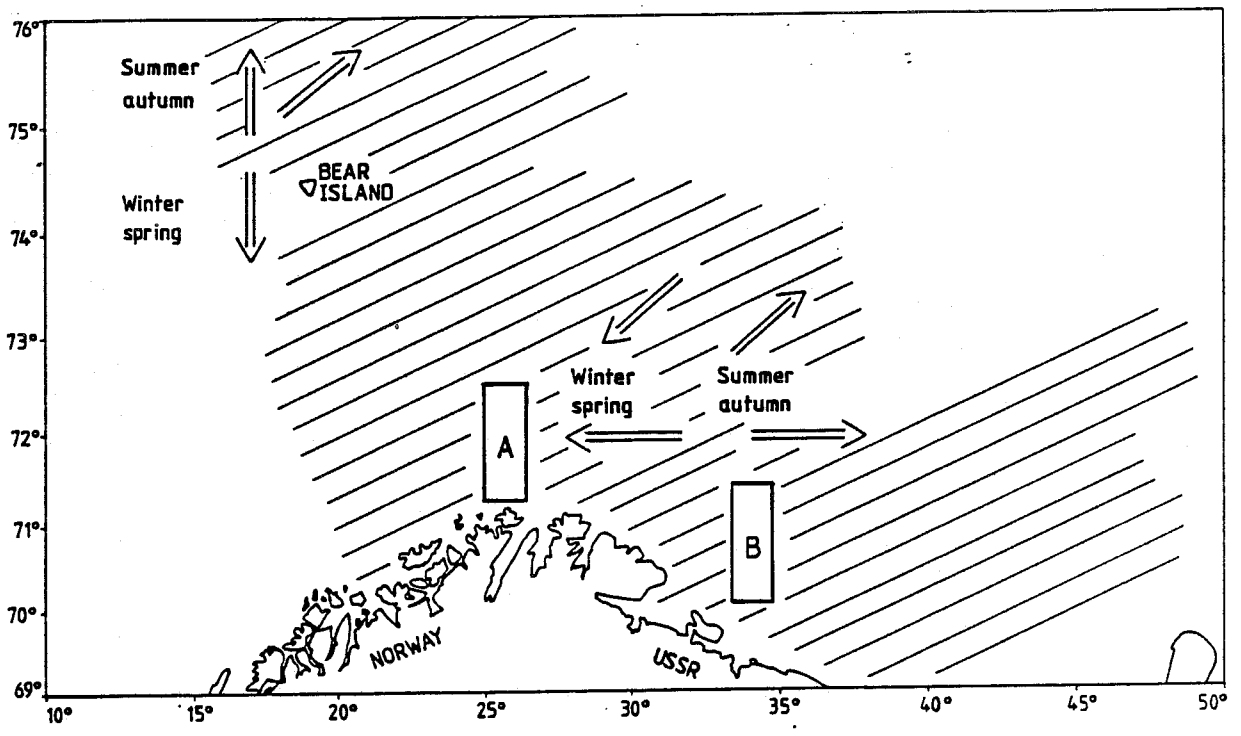

Fig. 1. Schematic representation of the distribution area of immature cod in the Barents Sea and the seasonal movements of the stock. A and B are used as reference localities for temperature.

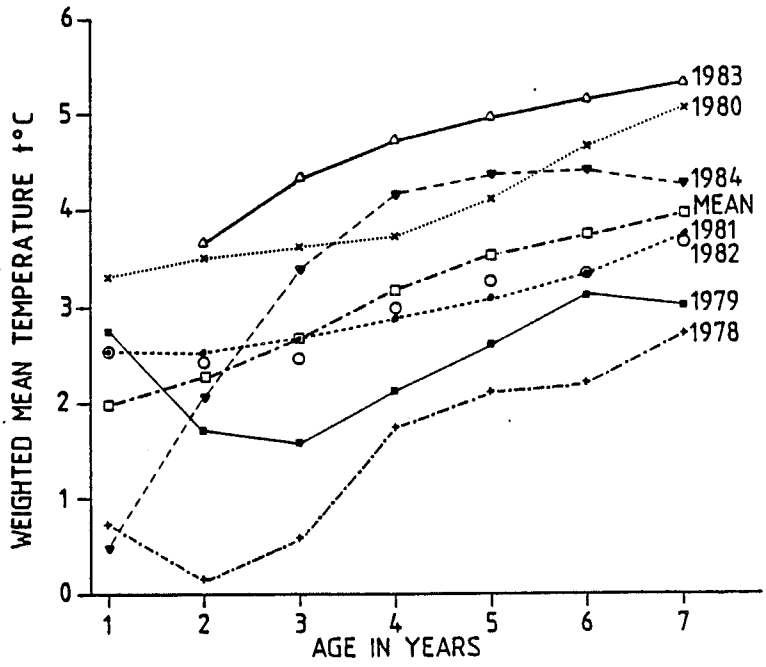

Fig. 2. Weighted mean values of bottom temperatures for the various agegroups of cod in February for the years 1978-1984. MEAN is the arithmetic mean for the whole period.

The acoustic and biological data

A comprehensive description of the sampling and processing procedures is given by Dalen and Nakken 1983. The main results of the cruises are given in reports to the annual meetings of ICES (Dalen et al. 1984, Hylen et al. 1985). In the following is given a short outline of the work: The acoustic systems measured continuously the echo abundance along the ship's track. Trawling was carried out in order to identify the species and size composition of the scatterers. A priory knowledge on fish target strength and information on species and size composition from the trawl samples were used to convert the observed echo abundance to fish densities. Density estimates (number of fish per unit area) were worked out for each 5 cm length group of cod in squares of half a degree latitude and one degree longitude. By applying age length keys to the computed length distributions, the densities of fish in each age group were calculated for the same squares. Numbers of fish were arrived at by multiplying the densities with the appropriate areas.

The temperature data

The temperature observations were made with CTD-sonde or Nansen bottles and the values observed close to the bottom - the bottom temperature - were used in the present analysis. In February, during the period of the surveys, cod was rarely observed in midwater at depths less than 100 m and the bulk of the biomass was situated in the depth layer between the bottom and 50-70 m above, as a rule in densities decreasing with distance from bottom. In most of the area the differences between the bottom temperatures and the corresponding average temperature for the 50-70 m depth slice near bottom were rather small. Furthermore, most of the biological data originated from bottom trawl samples, and therefore the bottom temperature was considered to be representative for the temperature of the environment of the fish.

The bottom temperatures were plotted into maps, isolines for each half degree centigrade were drawn manually and mean values were computed in the same squares already used for estimating of fish density and number. Thus giving a set of corresponding values of mean bottom temperature and number of fish at age.

Fish - temperature distributions

Distributions of number of fish on temperature were established for each age group by summing up the numbers in squares with equal mean bottom temperatures. Temperature intervals of one degree were used for the computations. The resulting distributions (in percent) are given in table 1. Finally, weigthed mean values and standard deviations of these distributions were computed by using the percentages (or numbers) of fish as weights in the calculations.

Table 1. The distribution of cod in relation to bottom temperatures in the Barents Sea in February. The table shows the percentages of total numbers of fish in each age group estimated for temperature intervals of one degree. Means ($\overline{t^{\circ}C}$) and standard deviations (s) of the distributions are also given.

Year	Age	-1.5	-1.0	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	$\overline{t^{\circ}C}$	s
1978	1			16	67	3	8	6				0.71	1.01
	2			53	33	12	2	0				0.13	0.77
	3			47	8	38	4	3				0.58	1.13
	4			8	3	62	16	11				1.69	0.96
	5			2	3	50	26	18	1			2.08	0.92
	6			2	2	44	31	20	1			2.18	0.92
	7			0	0	28	29	43	1			2.67	0.85
	8+			1	0	38	26	33	2			2.46	0.94
1979	1			2	3	16	34	38	7			2.74	1.09
	2			7	14	51	15	7	6			1.69	1.17
	3			16	9	38	26	10	1			1.58	1.22
	4			8	6	28	37	16	5			2.12	1.21
	5			4	4	21	34	23	14			2.60	1.24
	6			2	3	13	26	25	31			3.12	1.25
	7			3	2	14	31	24	26			2.99	1.24
	8+			2	1	11	20	14	52			3.49	1.26
1980	1						25	68	7			3.32	0.54
	2						12	80	8			3.46	0.45
	3						4	83	12	1		3.60	0.44
	4						1	82	12	5		3.71	0.54
	5						1	63	9	27		4.12	0.90
	6							40	6	54		4.64	0.96
	7							21	4	74	1	5.05	0.83
	8+						1	22	2	74	1	5.02	0.88
1981	1					9	81	9	1			2.52	0.47
	2					17	65	17	1			2.52	0.62
	3				1	16	54	27	2			2.63	0.73
	4				1	11	45	37	6			2.86	0.80
	5				1	8	35	47	9			3.05	0.81
	6					3	27	51	19			3.36	0.75
	7					1	14	45	39	1		3.75	0.74
	8+					3	18	60	18	1		3.46	0.72
1982	1					34	33	29	4			2.53	0.89
	2				1	35	35	27	2			2.44	0.86
	3			1	2	33	33	28	3			2.44	0.95
	4				1	19	26	41	12	1		2.97	1.00
	5				1	10	22	52	13	2		3.22	0.92
	6				1	7	18	57	14	2	1	3.36	0.92
	7					4	12	57	21	5	1	3.64	0.88
	8+					4	7	50	27	9	3	3.89	0.99
1983	1				-	-	-	-	-	-		-	-
	2				2	4	25	24	39	6		3.62	1.10
	3						4	22	58	15	1	4.37	0.75
	4						2	5	65	25	3	4.72	0.68
	5						1	3	52	36	7	4.95	0.72
	6						1	3	37	47	12	5.16	0.77
	7						1	2	27	54	16	5.32	0.76
	8+						1	2	25	51	21	5.39	0.79
1984	1	2	38	33	20	6	0	1				0.46	1.00
	2	1	14	17	16	20	16	16				2.03	1.67
	3			7	9	20	27	32	2	4		3.39	1.39
	4			2	2	8	23	51	7	7		4.18	1.14
	5			2	1	6	18	53	11	9		4.38	1.14
	6			3	3	8	13	48	9	16		4.41	1.39
	7			6	4	9	16	39	8	18		4.24	1.61
	8+			1	3	6	24	40	10	16		4.43	1.29

RESULTS AND DISCUSSION

Fish - temperature distributions

Table 1 shows the distributions of the various age groups of cod in relation to the bottom temperatures in the Barents Sea in February. The tendency of older fish inhabitating warmer waters than the younger age groups at that time of the year is clearly seen, although large year to year variations appear for all age groups. Fig.2. shows a plot of the weighted mean bottom temperatures against age of the fish for each year of observation, and also the arithmetic means for all seven years of observation. On an average there appears to be a systematic increase in temperature by age of approximately 0.35°C per year for fish 3 years old and older, indicating that these age groups maintain their distributions within the temperature field relative to each other more or less independent of the absolute values of temperature which vary within a range of approximately 3°C during the period of observation. For the younger age groups, fish 1 and 2 years old, there appear to be large deviations from the above mentioned trend. While the older fish seem to have adjusted themselves relative to each other in a systematic manner within the temperature field, the distributions (table 1 and Fig 2) of the younger fish appear to be more arbitrar.

The differences observed between old and young fish were to be expected when the life history of the fish prior to 1 year of age is taken into account (Fig 3). The small cod descends from the upper layers towards bottom at the end of its first year of life (October-December), and the areas where the 1-group is distributed a few months later, in February, must to a great extent coincide with the areas where the fish moves towards the bottom. Hence, the eastward extension of the 1-group in February depends mainly on the larval drift in the upper layers in the period May-October. Large year to year variations have been observed in the geographical distribution of the 0-group in August (Randa 1982) as well as in the distributions of 1 year olds in February (Nakken and Raknes 1984), variations which most probably are mainly affected by the larval drift during the proceeding summer. Hence, the location of the 1 year olds within the temperature field is determined by processes which may differ from those determining the temperature conditions in the environment of the older age groupes.

How do the weighted mean bottom temperatures for each age group compare with the temperatures in fixed areas or sections? Fig. 4 and 5 are attempts to answer this question. In Fig.4 all the weighted mean values in table 1 are plotted and for comparison the corresponding means for the two reference areas, A and B, are given. The two sets of data seem to some extent to vary in the same manner for the older age groups with exception of the 1978 values which seem too low. That year the westernmost areas (warm areas) were not covered satisfactorily, and the computed mean values for the older age groups are believed to be biased downwards, yet the younger age groups, 1-3 years old, were believed to be representatively sampled. But, even if the 1978 points for 5 years old and older fish are raised considerably, Fig. 5 will still leave the impression that

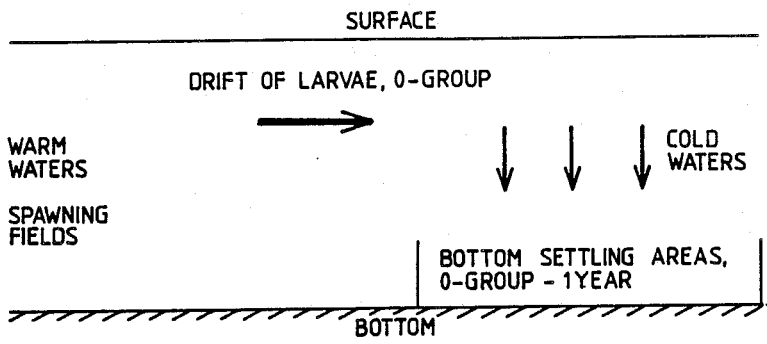

Fig. 3. Schematic representation of the transportation and distribution of Arctic Cod.

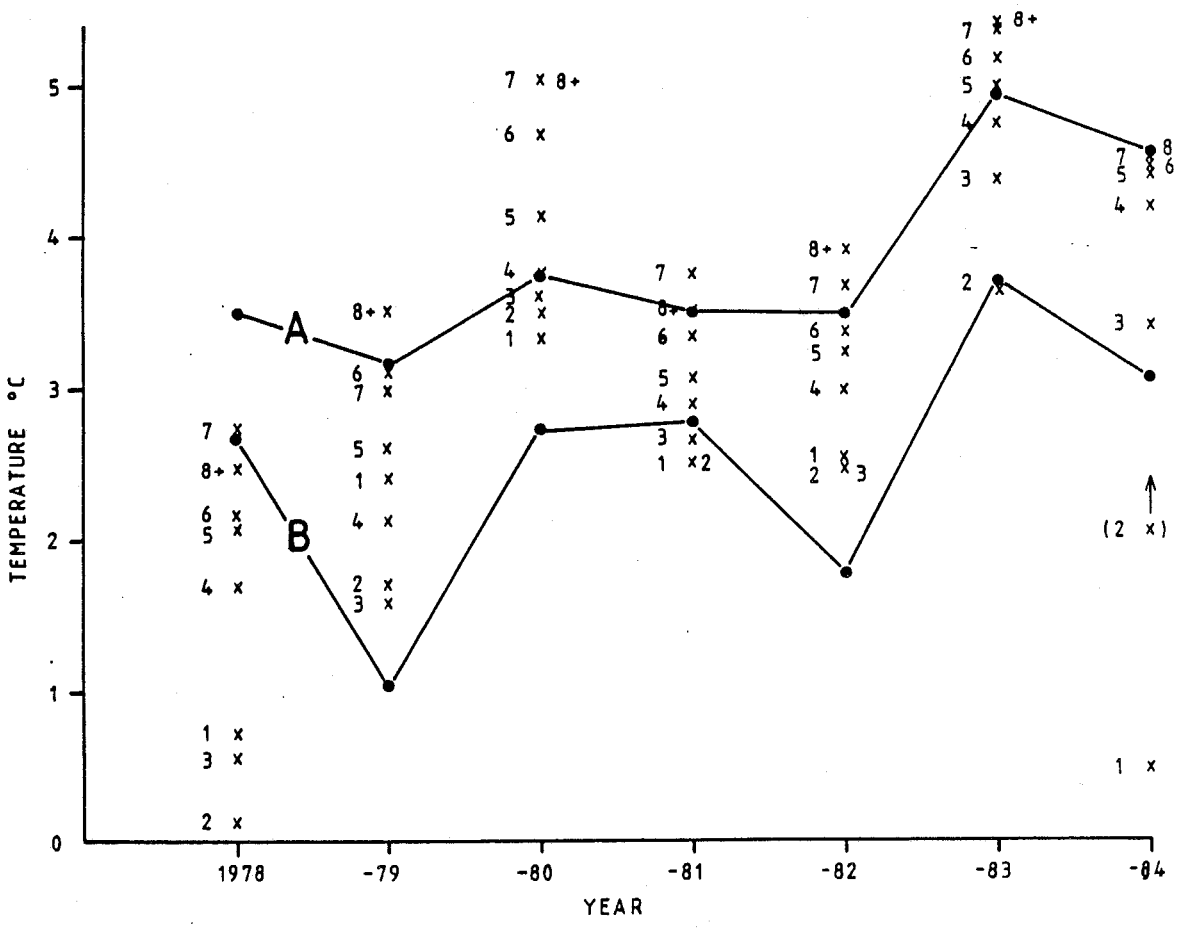

Fig. 4. Weighted mean values of bottom temperatures for the various age groups of cod (crosses) in February compared with mean values in the two reference areas A and B (dots). Figures show age in years.

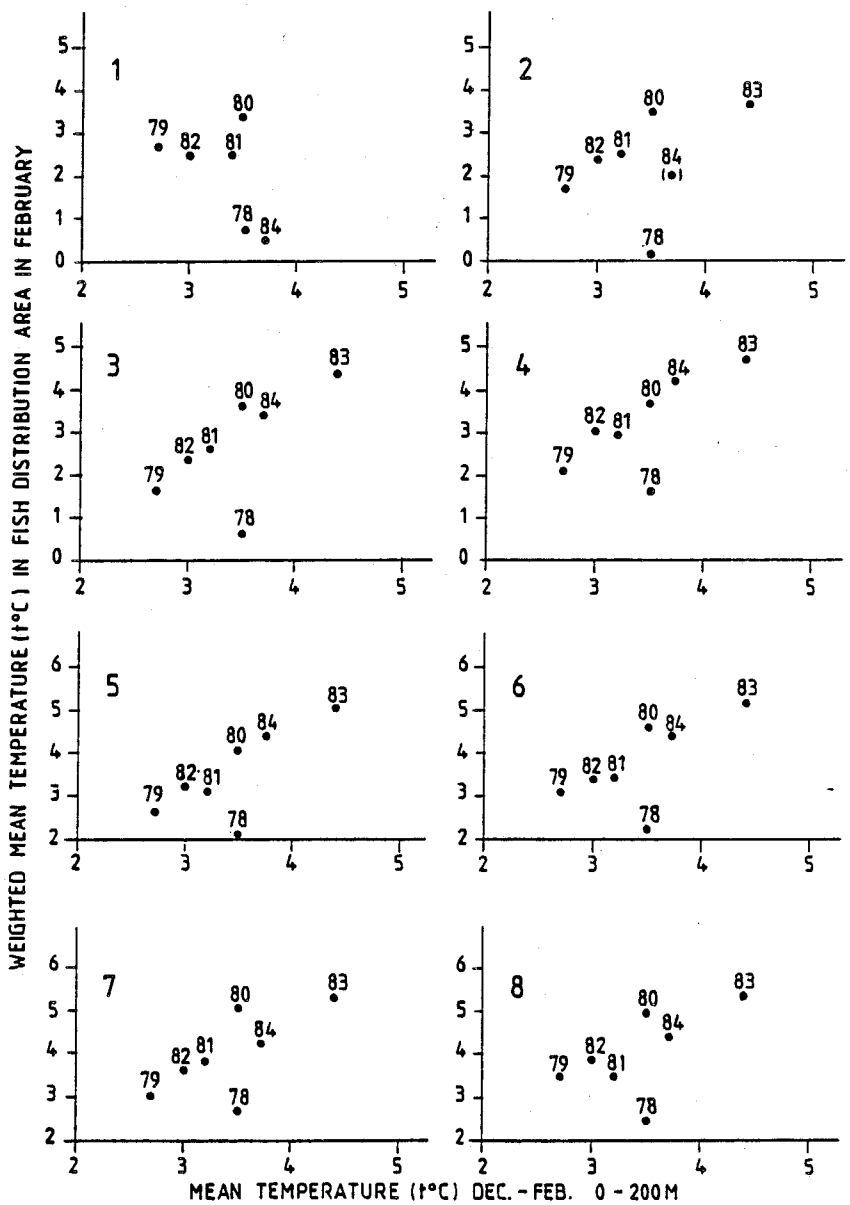

Fig. 5. Weighted mean values of bottom temperatures for the various age groups of cod plotted against mean values for December-February in the 0-200 m layer at the Kola Meridian. ($70^{\circ}30'N - 72^{\circ}30'N$, $34^{\circ}E$)

the temperature variations in the two fixed areas cannot be considered representative for the whole stock and particularly not for the youngest age groups.

Fig. 5 shows the weighted mean bottom temperatures of each age group plotted against the mean value for the months December-February in the 0-200 m layer in the Kola section. For age groups 1,2 and 7,8 there appears to be no or very poor correlation between the two sets of data, but for the 3-6 year olds the values are closely correlated if the 1978- observations are disregarded. Hence, for the period 1979-1984 the temperature variations in the Kola section reflect the variations observed in the weighted mean values for age groups 3-6 rather effectively. This indicates that the conditions in the Kola section may be considered representative for the environmental conditions for 3-6 year old cod when variations from one year to another is considered.

Why is the 1978-point falling out? Previously it was mentioned that the weighted mean-values for that year were biased downwards. However, if that point shall fit a line through the others, the weighted mean temperature that year must be raised by approximately 1.5-2.0°C, which cannot at all be accepted considering the distributions in table 1. We consider it therefore a reality that the 1978 point falls far below the other ones, and we believe that the main reason for that is the abrupt change that occurred in fish distribution in the Barents Sea during 1977-1979 (Midttun et. al 1981, Nakken and Raknes 1984). A pronounced cooling of the Barents Sea - particularly in the eastern areas - took place from 1978 to 1979, followed by a rapid westwards migration of cod during the winter 1978-1979. In periods of such severe changes in the environmental conditions the mechanisms that regulate the migration and distribution of the fish might be different from those effective during periods of less pronounced variations.

Growth and temperature

In table 2 the weighted mean values of bottom temperatures in table 1 are regrouped to show temperature at age for each year class, and arithmetic mean values for 2-4, 3-5 and 4-6 years of age are presented at the right hand side. The mean values increase consistantly throughout the period, the environment of the 1975-year class being the coldest whereas that of the 1981-year class was the warmest. Table 3 shows the mean lengths at age (total length) of the same year classes. The mean lengths show the same tendency as the temperatures in table 2, increasing consistantly from the 1975 year class to the 1980 year class, particularly concidering fish 4 years old and older.

Fig 6 shows plots of mean lengths against mean values of temperature for fish of 4,5 and 6 years of age. Clearly the mean lengths increased with increasing temperature. The plots indicate that the mean lengths increased by approximately 8-10 percent per degree increment in temperature.

It also appears that the mean lengths varied systematically with the abundance of fish; the 1975 year class being the most abundant having the smallest growth while the weak 1980 year class grew

Table 2. Weighted mean bottom temperatures (t°C) -in February- at age, for the various year classes of cod.

	Age (in years)							Mean values		
Year Class	1	2	3	4	5	6	7	2-4	3-5	4-6
1975			0.6	2.1	4.1	3.4	3.6		2.3	3.2
1976		0.1	1.6	3.7	3.1	3.4	5.2	1.8	2.8	3.4
1977	0.7	1.7	3.6	2.9	3.2	5.2	4.2	2.7	3.2	3.7
1978	2.7	3.5	2.6	3.0	5.0	4.4		3.0	3.5	4.1
1979	3.3	2.5	2.4	4.7	4.4			3.2	3.8	
1980	2.5	2.4	4.4	4.2				3.7		
1981	2.5	3.6	3.4							

Table 3. Mean lengths (in cm) at age -in February- for the various year classes of cod.

	Age (in years)						
Year class	1	2	3	4	5	6	7
1975			32	42	52	61	71
1976		24	33	43	53	63	73
1977	14	23	34	45	55	64	75
1978	13	25	36	46	56	67	
1979	18	26	38	48	58		
1980	17	26	(35)	49			
1981	15	26	36				