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On the geographical distribution of Arctic Cod in relation to the distribution of bottom temperatures in the Barents Sea, 1977-1984.

by

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ABSTRACT

The results from acoustic-trawl surveys in January-March were analysed together with observations of bottom temperatures at the same cruises. Distributions of fish abundance for each age group of cod on temperature were established. The analysis showed that the older age groups, fish aged 6 and 7 years, were consistently found in warmer waters, i.e. further to the west, than the younger fish, aged 1-3 years. The variations from year to year in bottom temperatures of the distribution areas appeared to be largest for the youngest fish, the 1 year olds, and considerably larger than the corresponding temperature variations in two fixed reference areas. The mean lengths at age 4, 5 and 6 years were observed to increase significantly for the year-classes 1975-1980 and this increased growth coincided with an increase in mean temperature of the distribution areas of the fish.

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 yearly spawning migrations southward 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). In addition to the seasonal displacements of the concentrations also temperature related displacements have been reported both on a small and large time and space scale (Eggvin 1938, Lee 1952, Hylen et al. 1961, Konstantinov 1967, 1969 and Mukhin 1979). The main conclusion arrived at from the studies referred to is: When temperatures are low in the Barents Sea the concentrations of young cod are found further west and south than in periods with high sea temperatures.

In most of the investigations referred to above, the volumes 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 related the displacements of the distribution areas of the fish to variations in sea temperature for the period 1977-1981. The main results of their investigations appear from Fig. 2. The Barents Sea was divided into three sectors - West of 30°E, between 30° and 34°E and east of 34°E - and Fig. 2 shows how the various age groups were distributed with respect to these sectors. Two pronounced features are clearly identified in the figure: A systematic westward displacement of fish as it grows older and a displacement of all age groups which follows the variation of the annual mean temperature in the Kola section. Midttun et al. (1981) also attempted to quantify the apparent relation between cod distribution and sea temperatures and showed that a drop in annual mean temperature in the Kola section from 4°C to 3°C coincided with a transfer of fish from the middle and eastern sectors to the western one of about 30% of the 3–5 year olds. The authors conclusion of the study was: "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 young cod occurs when both the sea temperatures are low and the age of the predominant yearclass(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 situated in the eastern parts inhabit waters of lower temperatures than the older ones. In order to be able to throw some more light on the possible cod-temperature relationship one should therefore know the temperature conditions within the actual distribution area of the various age groups. In the present paper we have computed the average temperatures in the distribution areas of each age group in February and compared these with similar values in two fixed reference localities for the period 1977–1984. We have also studied the development of the mean lengths of the fish throughout the same period.

MATERIAL AND METHODS

The material has been collected on yearly research vessel cruises lasting from late January to the beginning of March (Dalen _et al_. 1983). Courselines and station network (Fig. 3) have been approximately the same every year, 1977–1984. Each year since 1981 two commercial trawlers have been hired to cooperate with the research vessel in order to increase the number of fish samples (Fig. 3).

The acoustic and biological data

A comprehensive description of the sampling and processing procedures is given by Dalen and Nakken 1983. The results of the cruises are given in reports to the annual meetings of

ICES (Dalen *et al.* 1983). In the following is given a short outline of the work.

The acoustic systems measure continuously the echo abundance along the ships track. Trawling is 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 are used to convert the observed echo abundances to fish densities. Density estimates (number of fish per unit area) are 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 are calculated for the same squares. Numbers of fish are arrived at by multiplying the densities with the appropriate areas.

The temperature data

The temperature observations were made with STD-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 time of the survey, cod were rarely observed in midwater at depths less than 150 m and the bulk of the fish were situated in the depth layer between the bottom and 50–70 m above, as a rule in decreasing densities with distance from bottom. Furthermore, nearly all the biological data originated from bottom trawl samples and therefore the bottom temperature was selected. In most of the area the differences between the bottom temperatures and an average temperature for the 50–70 m bottom near depth slice will be rather small.

The bottom temperatures were plotted into maps, isolines for each half degree centigrade were drawn manually and average values were computed in each square for which estimates of fish density and number had been worked out. Thus giving a set of corresponding data on temperature and number of fish.

The calculation of the mean temperature for each age group were made in the following way. For squares falling within the same one degree interval of temperature the number of fish were added together to give a total number of fish of a given age. This was done for all the temperature intervals, resulting in a distribution of fish numbers on temperature for each age group. Finally, the mean values and standard deviations of these distributions were calculated using the number of fish as weights in the calculation.

RESULTS AND DISCUSSION

The geographical distribution of temperature and fish

The series of distribution maps of bottom temperatures in Fig. 4 demonstrate the large temperature variations which occurred in the area throughout the period of investigation. An extreme westward displacement of the isotherms took place from 1977 to 1979, and the bottom temperatures in the entire area to the east of 34°–35°E dropped to below 0.5°C in 1979. From 1979 to 1980 the isotherms were displaced slightly eastward again and this distribution was more or less maintained throughout the period 1980–1982, but in 1983 a pronounced eastward displacement had taken place, the observed distribution being similar to that in 1977. In 1984 the bottom temperatures were considerably lower than in 1983 but higher than those experienced throughout the period 1979–1982.

The geographical distributions of young cod as recorded by the acoustic integration systems are shown in Fig. 5. From 1978 to 1979 the distribution area of the fish decreased considerably. In 1977 and 1978 quite large amounts of fish were recorded to the east of 35°E and to the north of 72°N while in 1979, and particularly in 1980, the distributions were limited to a rather narrow area off the Norwegian coast. In the entire period 1979-1983 fish was scarce in the eastern parts of the sea and more offshore north of Norway but in 1984 the distribution was more similar to the distributions experienced in 1977 and 1978. When comparing the two sets of maps (Figs 4 and 5) it seems that the displacements of the two distributions, bottom temperature and fish coincided, but with a time lag. The coldest years were 1979 and 1982 while the most westerly fish distributions were observed in 1980 and 1983. Mukhin (1975) examined how the catch rates in various areas of the Barents Sea varied with the mean temperatures in the Kola section. He observed a rather high correlation between temperatures in the second half of the year and the catch rates in the eastern areas during the following spring. Midttun et al. (1981) using the same data on fish as we have used, indicated a similar time lag (Fig. 2). Since complete maps of fish distribution are available only for the winter season (February) it is impossible to describe the apparent time lag more accurately.

It should be noted that the distribution maps in Fig. 5 include all age groups of young cod - and haddock as well. In order to study the distribution of the various age groups in relation to bottom temperatures the procedure described in the preceeding chapter was adopted. The results of the computations are shown in Table 1.

Table 1. shows how the fish in each age group was distributed in percent in relation to the bottom temperatures. The mean values and standard deviations of the distributions are also presented as well as the acoustic estimates. [The estimates for 1980 are too low due to a calibration error of the integration system, but this error will not affect the relative distributions of fish in relation to temperature].

By examination of table 1. it is seen that the older fishes inhabited warmer waters than the young ones (Midttun et al. 1981). It also appears that the bottom temperatures in the waters inhabited by each of the age groups varied considerably throughout the investigation period, the variations being larger for the younger fish than for the older. In Fig.6 these variations can be compared with the bottom temperature variations in two fixed reference areas. The two sets of data seem to vary in the same way for the older fish, age group 4 and older ones, with exception of the 1978 observations which seem to low. In 1978 the western areas of the fish distribution were not covered satisfactorily (Fig.4) and consequently the calculated mean values for the older age groups, 4 - 8+, should be expected to be too low. The temperatures representing the areas inhabited by the younger fish, age groups 1 - 3, in 1978, are believed to be representative, as these age groups were distributed in the eastern parts of the sea.

From Fig.6 it appears that the two years showing the eastern-most distribution of the younger age groups, were 1978 and 1984. In 1978 all the three young fish age groups, 1-3 were inhabiting waters of low bottom temperatures in the eastern Barents Sea whereas in 1984 only the one year olds showed an extreme eastern and low temperature distribution. In the period in between, 1979-1983, the youngest fish, age group 1, were observed in areas further West with temperatures closer to those experienced for the older fish. In this connection it should be remembered that the winter distribution of the 1 year old fish probably to a large extent depends on the drift patterns of the larvae and 0-group stages when the fish is distributed in the upper 75 m of the water column The 0-group fish migrates to the bottom layer in late autumn and hence the distribution of the 1-group in February might reflect the areas of bottom settling of the 0-group.

Growth and temperature

In Fig. 7 the mean lengths of the various agegroups are given. A significant and steady increase of mean lengths seem to have taken place during the observation period for all yearclasses after the 1975 yearclass.This is clearly seen in Fig. 8 where the mean lengths are plotted against the mean winter temperatures. The 1976 yearclass which during its second, third and fourth year of life inhabited rather cold waters had a mean length as 4 year olds of about 42 cm while the 1980 yearclass inhabiting warmer watermasses were 49 cm as 4 year olds. The tendency of increased mean lengths with increasing water temperature seems quite clear also for the 5 and 6 year old fish. However, it also appears from Fig. 8 that the lengths varied with the strengths of the yearclasses, the growth increasing with decreasing abundance, the 1975-yearclass being the most abundant also showing the smallest growth, while the weak 1980 yearclass grew faster.

The increased growth of the cod might have lead to maturation of the fish at a younger age. Hylen and Nakken (1982, 1983 and 1984) have shown that the percentage of 5-8 year old fish in the spawning stock in later years, have increased significantly as compared to previous periods (Ponomarenko et al. 1980). Fig. 6 shows that the yearclasses for which this earlier maturation has occured, 1975-1976-1977-1978, have inhabited gradually warmer waters and have shown a consistently increasing growth and a decreasing abundance. The coupling between the large environmental changes and the various population parameters (distribution area, abundance, growth and maturity) for the Arctic Cod is probably far more complex than the simple length-temperature relationship indicated in Fig. 8, which was experienced during the investigation period. The development of the abundant 1983-yearclass will in this context be an important subject of observation during the coming years.

References

Dalen, J., Hylen, A., Nakken, O., Randa, K. and Smedstad, O.M. 1983. Preliminary report of the Norwegian investigations on young cod and haddock in the Barents Sea during the winter 1983. Coun. Meet. Int. Coun. Explor. Sea. 1983 (G:15): 1-22 (Mimeo.)

Dalen, J. and Nakken, O. 1983. On the application of the echo integration method. Coun. Meet. Int. Coun. Explor. Sea. 1983 (B:19): 1-30 (Mimeo.)

Eggvin, J. 1938. Trekk fra Nord-Norges oceanografi sett i sammenheng med torskefisket. Fisk. Dir. Skr. Ser. HavUnders., 5(7): 33-46.

Hylen, A., Midttun, L. og Sætersdal, G. 1961. Torskeundersøkelsene i Lofoten og i Barentshavet 1960. Fiskets Gang 47(5): 101-114. 16 fig.

Hylen, A. and Nakken, O. 1982. Stock size of North-East Arctic cod. Estimated from Acoustic survey data 1982. Coun Meet. Int. Coun. Explor. Sea, 1982 /G 61: 1-12. (Mimeo.)

Hylen, A. and Nakken, O. 1983. Stock size of North-East Arctic cod, estimates from survey data 1982/1983. Coun. Meet. Int. Coun. Explor. Sea, 1983/G 57: 1-14. (Mimeo.)

Hylen, A. and Nakken, O. 1983. Stock size of North-East Arctic cod, estimates from survey data 1983/1984. Coun. Meet. Int. Coun. Explor. Sea, 1984/G 45:1-13. (Mimeo.)

Konstantinov, K.G. 1967. Forecasting of the distribution of fish concentrations in the Barents Sea according to the temperature factor. Fish. Res. Bd. Can., Translation Series No. 1132: 1-28.

Konstantinov, K.G. 1969. Effect of natural factors and fishing on the abundance of groundfish in Northern Seas. Fish. Res. Bd. Can., Translation Series No. 1559: 1-12.

Lee, A.J. 1952. The influence of hydrography on the Bear Island cod fishery. Rapp. P.-v. Réun. Cons. Explor. Mer. 131: 74-102.

Midttun, L., Nakken, O. og Raknes, A. 1981. Variasjoner i utbredelsen av torsk i Barentshavet i perioden 1977-1981. [Variations in the geographical distribution of cod in the Barents Sea in the period 1977-1981]. Fisken Hav., 1981 (4): 1-16.

Mukhin, A.I. 1979. Distribution of the demersal fishes in the Southern Barents Sea depending on the heat content of water masses. Coun. Meet. Int. Coun. Explor. Sea, 1979 (G 18): 1-8, 2 figs.

Ponomarenko, V.P., Ponomarenko, I.Ya. and Yaraguia, N.A. 1980. Growth and maturation of the Lofoten-Barents Sea cod. Coun. Meet. Int. Coun. Explor. Sea, 1980/G 25: 1-28. (Mimeo.)

Table 1. The abundance of cod in relation to temperature. The table shows the frequency distribution (percent of numbers) of fish on bottom temperatures for each age group. Mean values ($t^{o}C$), standard deviations (s) and acoustic estimates are given.

Year	Age	Temperature ^{o}C -1.5	-1.0	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	$t^{o}C$	s	Number (million)
1978	1		16	67	3	8	6					0.71	1.01	28
	2		53	33	12	2	0					0.13	0.77	235
	3		47	8	38	4	3					0.58	1.13	797
	4		8	3	62	16	11					1.69	0.96	153
	5		2	3	50	26	18	1				2.08	0.92	172
	6		2	2	44	31	20	1				2.18	0.92	25
	7		0	0	28	29	43	1				2.67	0.85	14
	8+		1	0	38	26	33	2				2.46	0.94	19
1979	1		2	2	16	34	4	8				2.41	1.09	15
	2		7	14	51	15	7	6				1.69	1.17	13
	3		16	9	38	26	10	1				1.58	1.22	109
	4		8	6	28	37	16	5				2.12	1.21	498
	5		4	4	21	34	23	14				2.60	1.24	77
	6		2	3	13	26	25	31				3.12	1.25	44
	7		3	2	14	31	24	26				2.99	1.24	14
	8+		2	1	11	20	14	52				3.49	1.26	7
1980	1					25	68	7				3.32	0.54	1
	2					12	80	8				3.46	0.45	10
	3					4	83	12	1			3.60	0.44	20
	4					1	82	12	5			3.71	0.54	80
	5					1	63	9	27			4.12	0.90	182
	6						40	6	54			4.64	0.96	21
	7						21	4	74	1		5.05	0.83	9
	8+					1	22	2	74	1		5.02	0.88	3
1981	1				9	81	9	1				2.52	0.47	3
	2				17	65	17	1				2.52	0.62	73
	3			1	16	54	27	2				2.63	0.73	59
	4			1	11	45	37	6				2.86	0.80	123
	5			1	8	35	47	9				3.05	0.81	245
	6				3	27	51	19				3.36	0.75	271
	7				1	14	45	39	1			3.75	0.74	39
	8+				3	18	60	18	1			3.46	0.72	14
1982	1				34	33	29	4				2.53	0.89	1
	2			1	35	35	27	2				2.44	0.86	4
	3		1	2	33	33	28	3				2.44	0.95	71
	4			1	19	26	41	12	1			2.97	1.00	86
	5			1	10	22	52	13	2			3.22	0.92	93
	6			1	7	18	57	14	2	1		3.36	0.92	73
	7				4	12	57	21	5	1		3.64	0.88	74
	8+				4	7	50	27	9	3		3.89	0.99	6
1983	1			-	-	-	-	-	-			-	-	
	2			2	4	25	24	39	6			3.62	1.10	17
	3					4	22	58	15	1		4.37	0.75	17
	4					2	5	65	25	3		4.72	0.68	50
	5					1	3	52	36	7		4.95	0.72	65
	6					1	3	37	47	12		5.16	0.77	35
	7					1	2	27	54	16		5.32	0.76	16
	8+					1	2	25	51	21		5.39	0.79	11
1984	1	2	38	33	20	6	0	1				0.46	1.00	2382
	2	1	14	17	16	20	16	16				2.03	1.67	506
	3			7	9	20	27	32	2	4		3.39	1.39	175
	4			2	2	8	23	51	7	7		4.18	1.14	80
	5			2	1	6	18	53	11	9		4.38	1.14	63
	6			3	3	8	13	48	9	16		4.41	1.39	46
	7			6	4	9	16	39	8	18		4.24	1.61	16
	8+			1	3	6	24	40	10	16		4.43	1.29	2

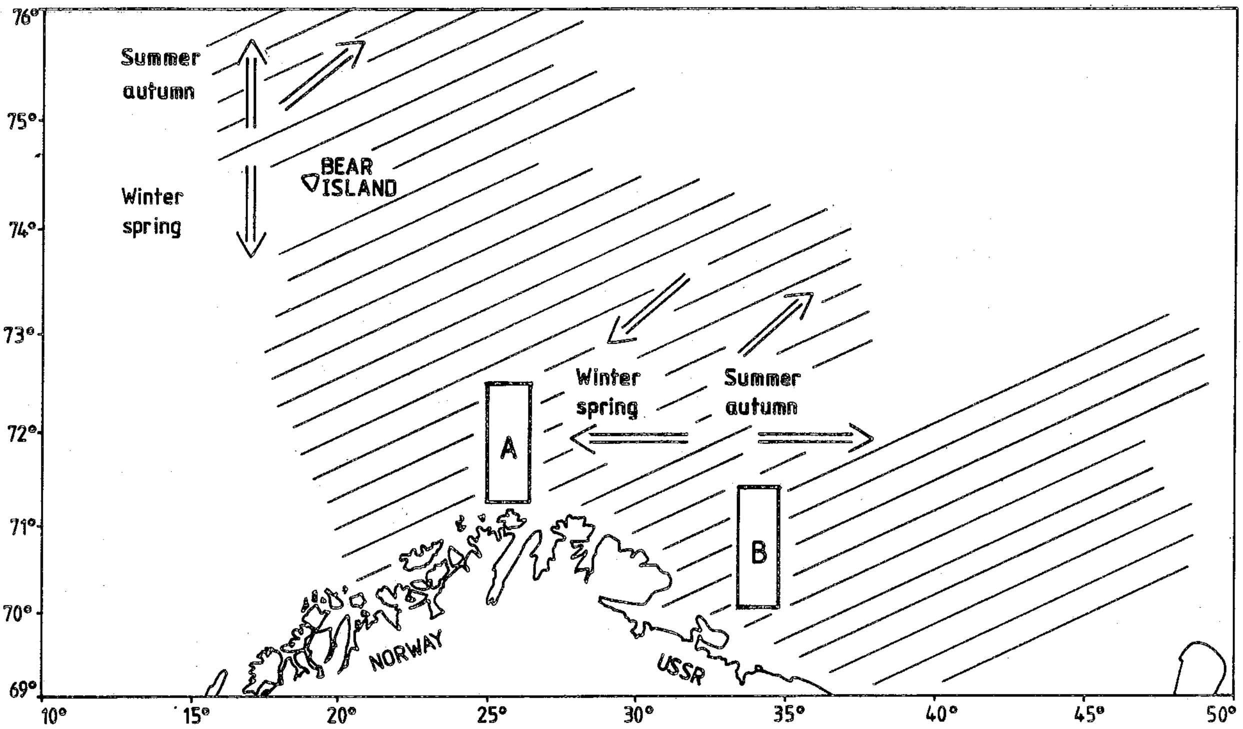

Fig. 1. Schematic representation of the distribution area of immature cod in the Barents Sea and the seasonal movements of the stock. A and B are used as reference localities for temperature.

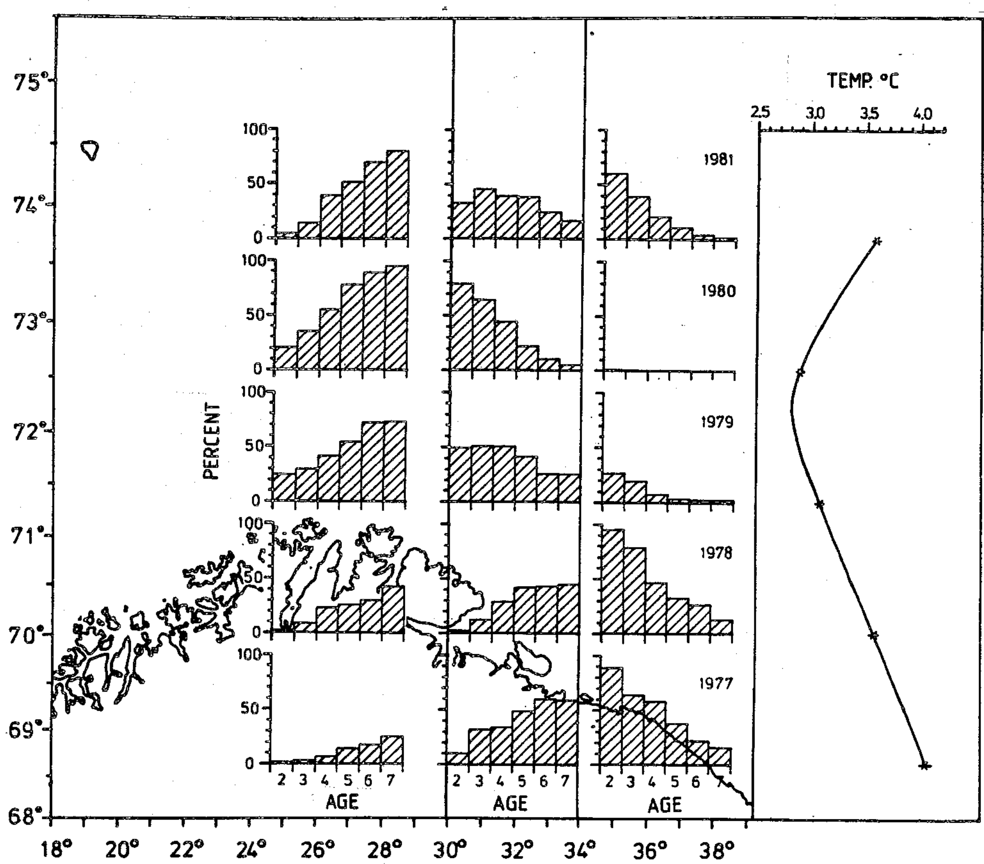

Fig. 2. The distribution (per cent of numbers) of various age groups of cod in the Barents Sea in February - March 1977 - 1981. Right: annual means of temperature in 0 - 200 m depth in the Kola section, for the calendar year prior to the biological observations.

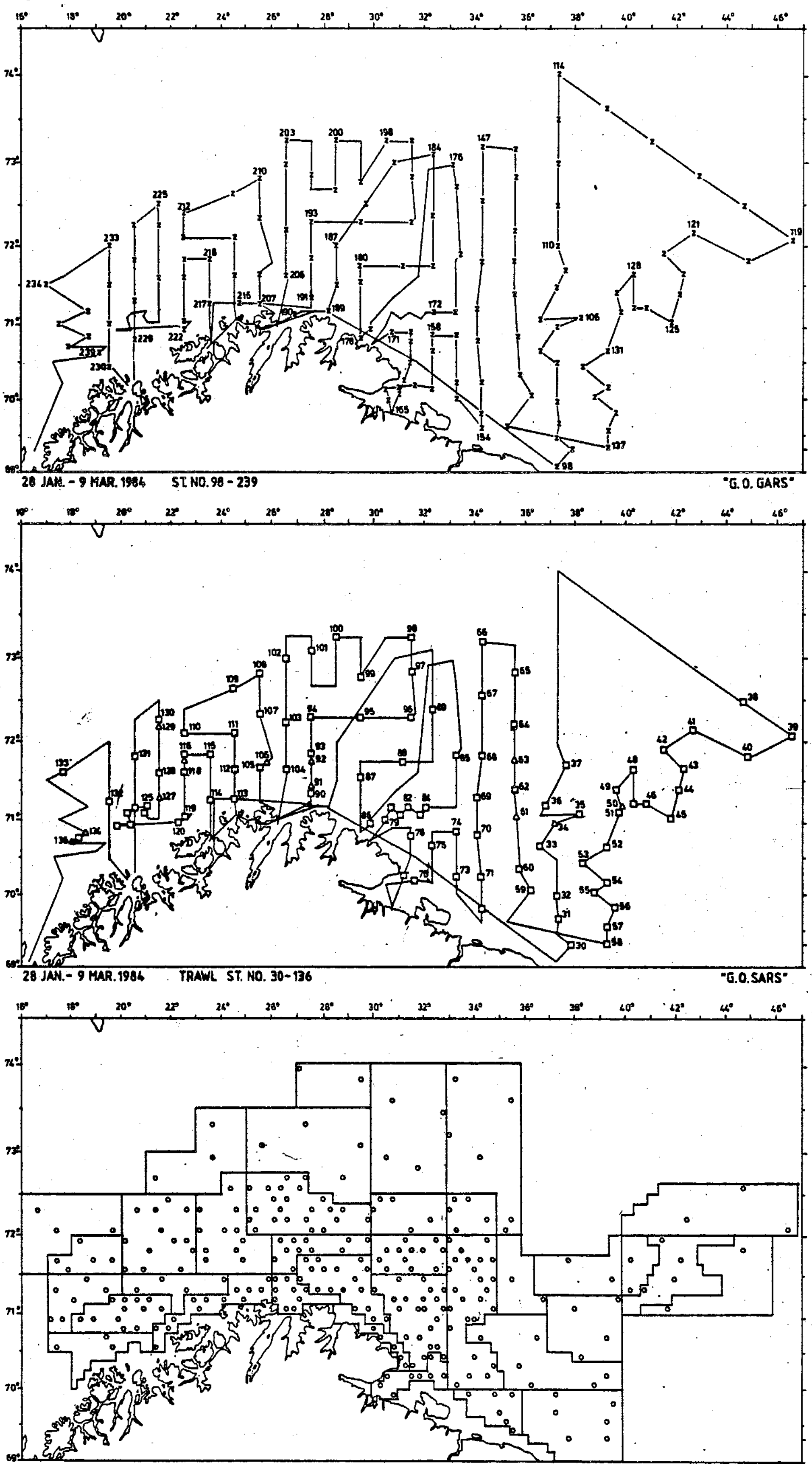

Fig. 3. Course lines and stations in the Barents Sea in February - March 1984. Upper: STD-sonde stations, Middle: Trawlstations worked by the research vessel, □ - bottom trawl, Δ - pelagic trawl, Lower: Bottom trawl stations worked by two trawlers.

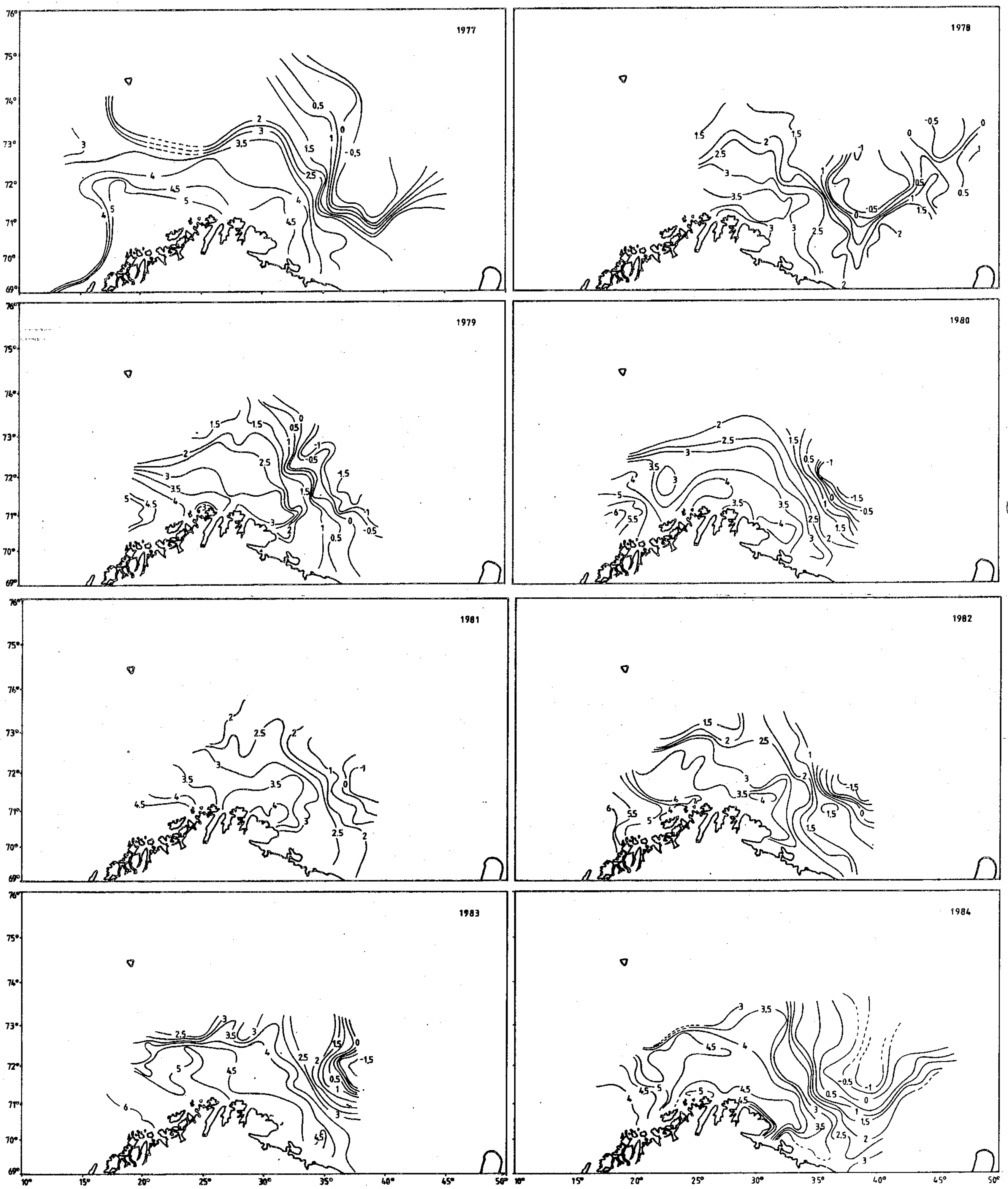

Fig. 4. The temperature ($t^{0}C$) distributions at the bottom in the Barents Sea in February - March, 1977 - 1984.

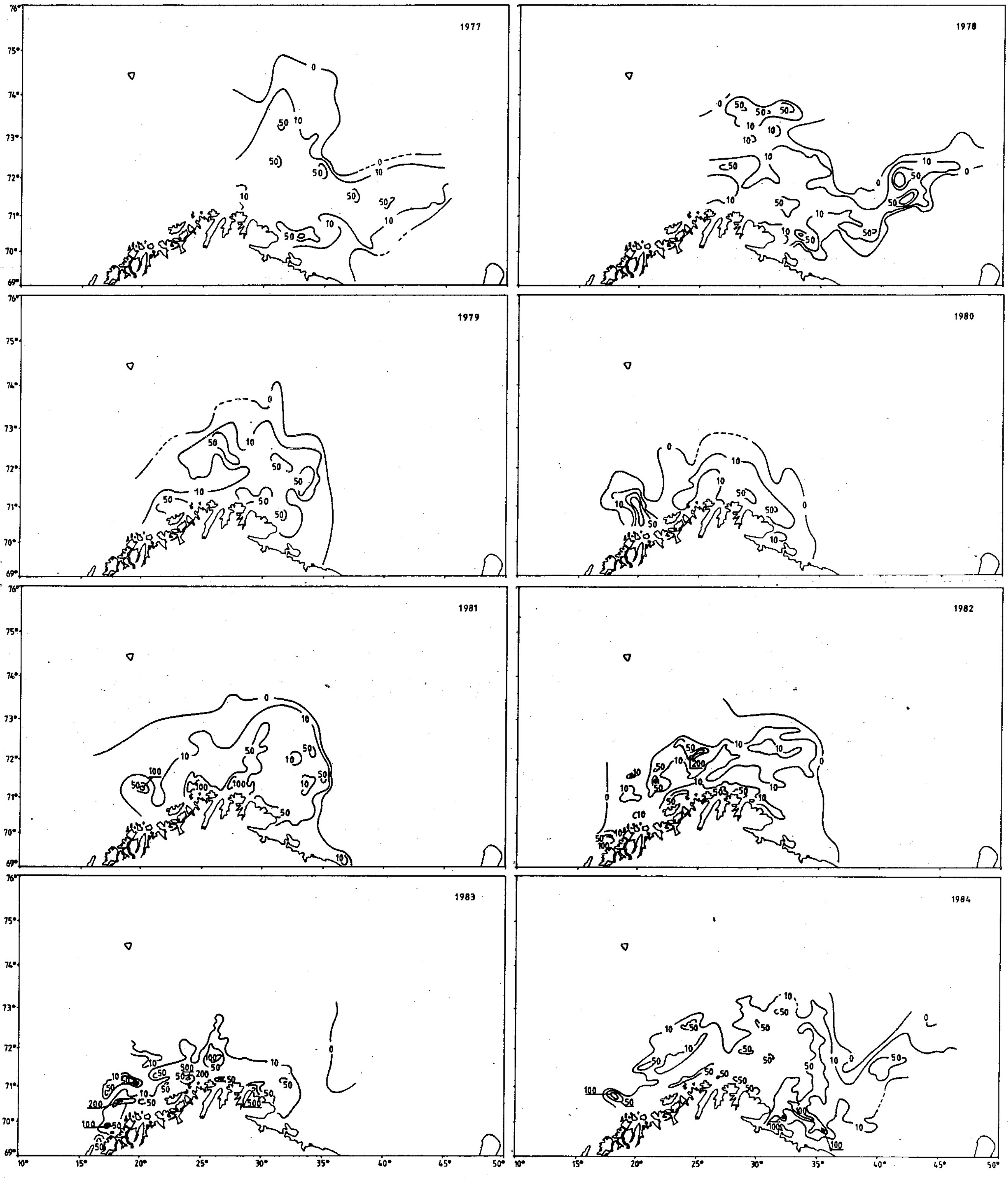

Fig. 5. The distributions of echo abundance (relative units) of cod and haddock in the Barents Sea in February - March, 1977 - 1984.

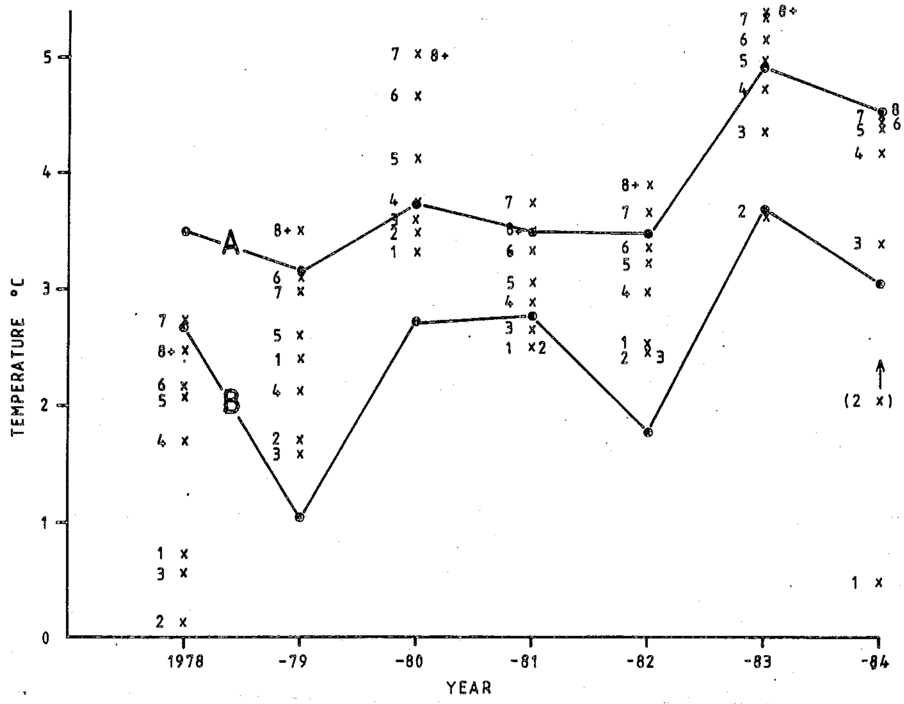

Fig. 6. Mean bottom temperatures in February in the distribution areas of the various age groups of cod compared with the bottom temperatures in the two reference areas A and B. Figures show age in years.

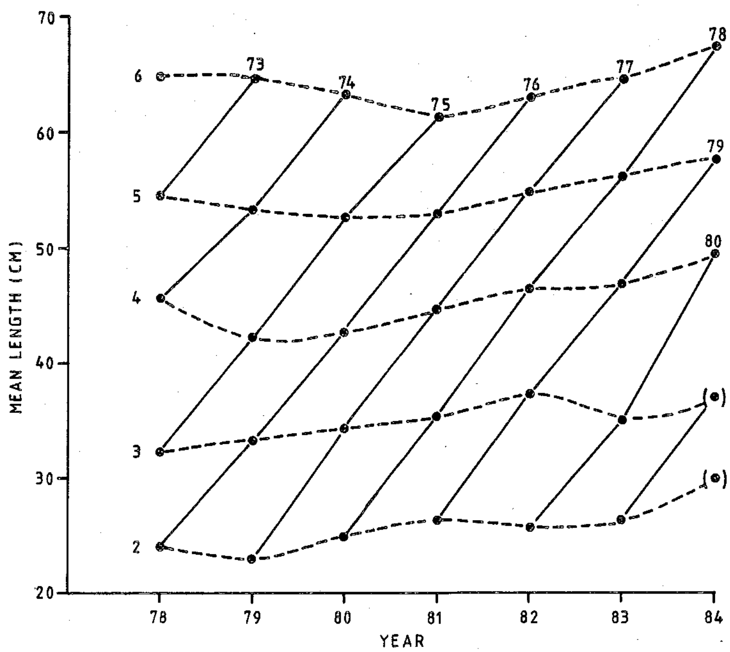

Fig. 7. Mean lengths (total length) of cod in the Barents Sea in February. Full lines indicate yearclasses, dashed lines indicate agegroups.

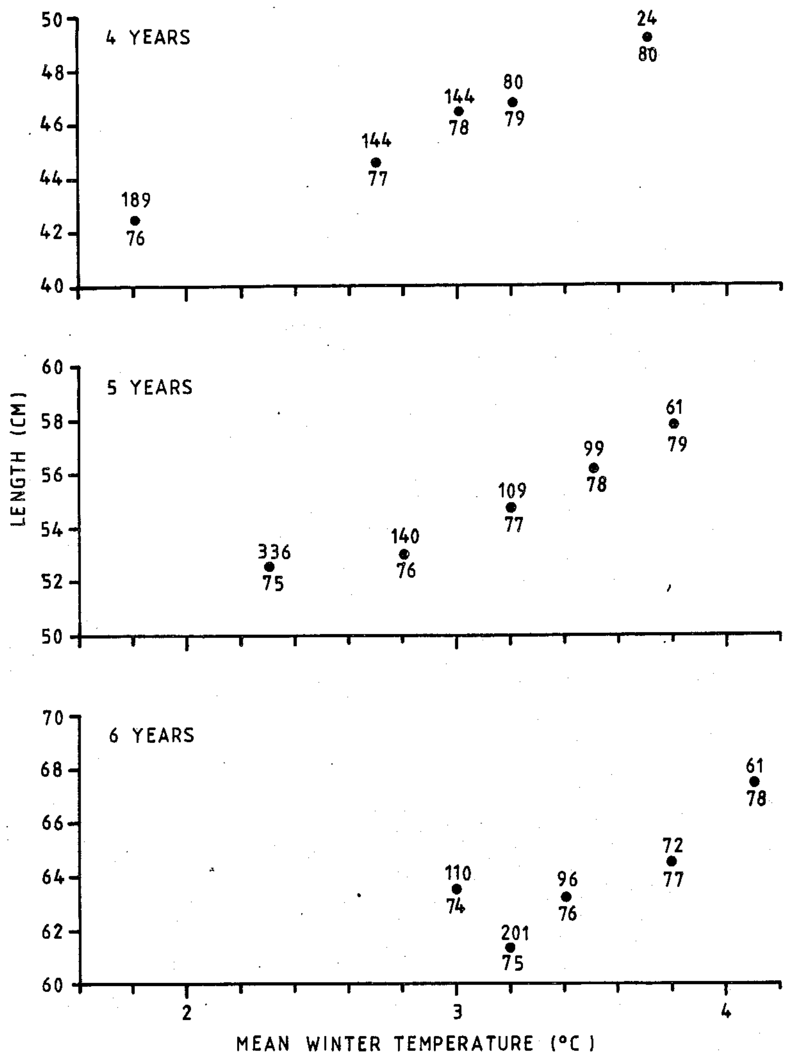

Fig. 8. Mean lengths at 4, 5 and 6 years of age plotted against the mean bottom temperatures in winter for the intervals 2-4, 3-5 and 4-6 years of age respectively. The figures below the points show yearclasses while those above the points show total number of fish in the yearclasses.