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DEPENDENCE OF THE BARENTS SEA COD GROWTH UPON CONDITIONS OF THEIR FEEDING ON CAPELIN AND WATER TEMPERATURE

by
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ABSTRACT

The aim of the present paper is to find factors effecting variability of Arcto-Norwegian cod length and to create regression models of cod growth. Using a long-period series of observations (1949-1993) an asynchronous, statistically meaningful linear correlation between the Southern Barents Sea cod length at age 3-9 years and temperature of water at 0-200 m depths on the Kola section during the latest 2-4 years was revealed. A linear dependence of cod length upon abundance of the Barents Sea capelin was also estimated. Linear regression models permitting to calculate with good advance an expected length of cod from all age-groups under study have been developed.

INTRODUCTION

A rational fishery is impossible without taking into account fish growth rate and studying causes of its variation. Different factors of both biotic and abiotic media such as water temperature, feeding conditions, density of cod population etc., were recognized as causes of changes in cod growth (Rollefsen, 1938, 1954; Saetersdal & Cadima, 1960; Dementyeva & Mankevich, 1965; Ponomarenko, 1968; Borisov, 1978). Significance of individual factors and their contribution into the general dispersion of growth indices varies by years and by periods.

Nowadays, study of cod growth variations obtains increasing scientific and practical importance. Data on mean weight of cod are used not only for single-species modelling of abundance dynamics and TAC cod TAC calculation but also for multispecies modelling of the Barents Sea fishable community, in particular, when it is necessary to estimate an amount of capelin eaten out by cod and calculate TAC for capelin. That is why we returned back to the problem of quantinative regularities of cod growth. Linear growth of cod was studied in relation to temperatures of water and cod population densities.

MATERIALS AND METHODS

Cod age samples collected during 1949 - 1993 on a round-the-year basis in the Southern Barents Sea (ICES Area I) were used as the principal material for this work. That is why mean length of cod of the same year-classes calculated by these data may be considered as mean yearly length (Table 1). The age of cod was read from otoliths.

The data given in Table 1 reflect well-pronounced trends (especially for younger age-groups of cod) which may be to some extent conditioned by periodic changes of trawl types with different mesh size (Ponomarenko V., Ponomarenko I., Yaragina, 1985). Before 1961 trawls with 90 mm mesh size were used, in 1961-62 - 110 mm, in 1963-66 - 120 mm, in 1967-80 - 130 mm for manila or 120 mm for kapron, and since 1981 until now - 125 mm for kapron.

To evaluate non-uniformity of time series caused by changes in trawl types the study period was sub-divided into three sub-periods (1949-1966; 1967-1980; 1981-1993). Trawl mesh-size within each sub-period was conventionally assumed to be constant. Mean length of cod of studied age-groups for these sub-periods is given in Table 2. From the Table it is evident that it increased from 1949-1966 to 1981-1993 by 2.1-4.1 cm for 3-4 year-old cod and by 5.4-7.3 cm for 8-9 year-olds.

Table 2. Mean length of cod (cm) calculated for periods with relatively constant mesh-size of trawls

Period, years	Number of years	Age, years 3	4	5	6	7	8	9
1949-1966	18	37.9	44.5	51.3	60.1	68.8	77.8	85.1
1967-1980	14	38.8	45.8	54.0	62.0	70.2	77.8	85.0
1981-1993	13	40.0	48.6	57.0	65.1	74.5	83.2	92.4

To eliminate this non-unoformity hindering obtaining reliable statistical estimates the time series were "reduced" to the latest period (1981-1993). For this purpose the difference between mean lengths of cod from each age-group of this period was added to those for 1949-1966 period and similarly to those of the 1967-1980 period. This resulted in the same mean lengths of cod of the same age for all the three sub-periods. "Reduced" data are presented in Fig. 1a. This procedure allowed us to eliminate trends conditioned by trawl mesh size enlargening. But slight increase of mean length of cod from the beginning of the study period to 1970-ies still remained in fish of younger age-groups. Mean yearly water temperature in the 0-200 m layer on the Kola Section in the Southern Barents Sea was used as an index of water heat content. Its yearly variations are presented in Fig.1b. Indices characterizing food supply variations were presented only by two main prey components, capelin and euphausiids. Two indices of capelin abundance (3- and 4-year-old capelin abundance) the portion of which in cod diet is especially large (Ushakov et al.,1992) are used in this work. These indices relate to both total cod biomass and that part of cod biomass which fed on capelin throughout the year (Table 3). Abundance of each age-group of capelin was calculated as mean arithmetical of year-classes abundance indices estimated by the results of two regular acoustic surveys with due considerations of spring and autumn harvesting (Anon, 1989). Feeding of cod on capelin was judged by thefrequency of capelin occurrence in cod stomachs. Data on cod biomass were taken from ICES Arctic Fisheries Working Group materials (Anon, 1993). Euphausiids abundance indices were taken from a paper by Drobysheva (1988).

Both correlation and regression analyses were used as principal methods of investigation. To separate a quasi-cyclic component in the time series under study a period-gramm-analysis was used. Closeness of correlations found and quality of regression dependence was evaluated according to recommendations given by Foerster & Roentz (1983).

RESULTS AND DISCUSSION

Variability of growth indices is typical for Arcto-norwegian cod. Variations between maximum and minimum values of mean length fluctuate from 8.9 cm for cod at age 4 to 15.3 cm for 9 year-old cod (Table 4). The older are the fish the smaller is dispersion, standard deviation and standard error (They are minimal in 5-6 year-old fish), but those increase to the maximum in 9 year-old cod. Distribution of mean lengths of cod from all groups under study is close to the normal which is confirmed by coefficients of asymmetry and excess.

Table 4. Statistical characteristics of "reduced" data on mean length of cod of different age in the Southern Barents Sea in 1949-1993.

	Age, years						
	3	4	5	6	7	8	9
Data series	45	45	45	45	45	45	45
Series mean	41.4	50.2	58.0	65.8	75.0	83.6	92.8
Median	41.7	58.2	58.2	65.7	75.2	83.4	92.1
Mode	41.3	51.2	57.9	65.6	75.9	84.7	91.2
Dispersion	5.78	4.97	4.72	4.86	5.66	6.79	9.61
Standard deviation	2.40	2.23	2.17	2.21	2.38	2.61	3.10
Standard error	0.36	0.33	0.32	0.33	0.35	0.39	0.46
Minimum	35.1	44.7	52.7	60.0	67.9	76.9	84.7
Maximum	45.5	53.6	62.2	70.9	89.9	90.1	100.0
Span	10.4	8.9	9.5	10.9	12.0	13.2	15.3
Asymmetry	- 0.56	-0.39	-0.50	-0.41	-0.58	0.00	0.25
Excess	0.07	-0.43	0.26	0.69	0.88	0.60	0.65

An analysis of the data shows a considerable conjugacy of yearly changes in length of cod of all age-groups. Besides, there is a 1-2 year retardation of extremes (maxima and minima) compared with younger age-groups which is well-pronounced during the latest 20 years (Fig.1). Correlation coefficients between cod lengths turned out to be high enough (0.77-0.86) especially in adjacent age-groups. This testifies that there is a complex of reasons causing changes in mean length of cod from all age groups under study. This regularity has already been mentioned by T.F.Dementyeva (1976). Yearly changes of cod length also expose quasicyclic components. A harmonic analysis indicated that fluctuations with 6-8 year periods contributing from 35 to 51% of general dispersion are typical for cod from all age-groups. Besides, cod from younger and older age-groups have fluctuations with a period of 11 years. These quasicyclic variations are noticeable also in yearly changes of water temperature though they are less pronounced. This allows us to consider water temperature as one of factors effecting cod growth. This fact was

mentioned by many authors as a positive relationship (Dementyeva & Mankevich, 1965; Dementyeva, 1976, Hermann, Hansen; Jonsson, 1965; Ponomarenko et al., 1985). Warmer water results in faster growth of cod and vice versa.
Kohler (1964) considers that water temperature effects growth of cod indirectly, through food.
D.V.May, A.T.Pinhorn, R.Wells and A.M.Fleming (May et al., 1965) in their studies of cod growth off Newfoundland found that cod living in cold waters of high latitude have more rapid growth rate but smaller maximal theoretical length compared with fish living in warm southern water. The authors mention that their results contradict other scientific sources. Hence, we may state that no clear notion about the effect of water temperature upon cod growth still exists.
As we were analysing length of cod at certain age it seemed expedient to try to find a relation with temperatures averaged for several years or for a certain period of life of a year-class like it was done by Dementyeva & Mankevich (1965) who consider that temperature in any way gradually influence the fish growth. But this approach results in considerable smoothing of temperature data, i.e., riddling of short-time temperature fluctuations and worsening of relationship between variables, if any.
To find this out the sums of mean yearly temperatures for periods from 1 to 9 years preceding the year of fish capture were correlated with the length of cod. The results obtained testify that summing or averaging for a period of 5 years or more brought no significant relationship. For cod at age 3-5 years the best correlation was obtained at summing (averaging) temperatures for two years. Lengths of 5-7 year-old cod are correlated in the best way with temperatures averaged for 3 years, fish at age 8-9 have the best correlation at averaged temperatures during 4 years before their capture.
Besides, being shifted retrospectively by 5-7 years and by the same periods of averaging of temperatures a meaning but reverse correlation is observed (minus 0.35 - minus 0.53). This may be explained by presence of cod lengths and temperatures from the above mentioned quasi-cyclic fluctuations with periods about 6-8 years.
Thus we may conclude that there exists a direct statistically meaning relationship between variations in cod length and temperature of water,- the higher is the temperature of water during the latest two years before fish entering a certain age-group the larger are the fish. This temperature index is therefore of prognostic value.
It is well-known that larger fish of younger age-groups is also larger when adult. We have checked this on Arcto-Norwegian cod and revealed that there exists a direct statistically meaning relationship between length of cod of the same year-classes at age n and n-1 years. Correlation coefficients vary from 0.57 to 0.70; hence, length of the preceding age-groups may serve as a potential predictor.
The basic food object for cod is capelin. Its abundance effects both feeding conditions and growth of cod. Using the cross-correlation analysis we found out that a direct statistically meaning relationship exists between length of cod and index of capelin abundance which also considers capelin consumed by cod. Correlation coefficients in various age-groups of cod vary from

0.47 to 0.70. The best relationship was observed for 3 year-old fish at 0-shift, i.e. during the year of cod capture. For cod aged 4-5 the best correlation with capelin abundance index is at minus 1-year shift relative to the year of fishery. For 6-8 year-olds this shift equals to minus 2 years, for 9-year-olds - minus 3 years. This means that length of 4-9 year-old cod depends mainly upon their feeding on capelin during 1-3 preceding years. The capelin abundance index which includes their consumption by cod may also be considered as a possible predictor (except for cod at age 3).

Another important factor effecting cod growth is their own abundance or biomass. At a stable feeding supply the higher is cod abundance or biomass the stronger is food competition and, therefore, the slower is cod growth. We have analysed the effect of cod biomass upon their growth but failed to find statistically meaning relations during the study period.

It is known that capelin is not a sole food object for cod having a wide spectrum of organisms in their diet which includes cod and redfish juveniles, shrimp, polar cod, herring, euphausiids etc. Because of lack of long-period data on cod feeding on these object we made an attempt to find a relationship between cod growth at age 3-9 and euphausiids abundance. Unfortunately, no statistically meaning correlation was found.

Hence, those parameters which may turn to be potential predictors for designing a multiple regression model for cod are: averaged for a 2-4-year period water temperature in the 0-200 m layer on the Kola Section, capelin abundance indices and length of cod of the studied year-class minus one year. Despite the absence of meaning correlations with the length of cod its biomass and abundance of euphausiids averaged by 3-year periods were included into independent variables and used in the multiple regression analysis as factors capable to contribute to the explanation of general dispersion of cod lengths.

To obtain multiple regression models of cod growth depending upon the above parameters we used a step regression method. Independent variabled were included into the model if F-criterion value exceeded 4.

Because of small series of data on capelin abundance all relevant calculations and regression models were based upon materials collected during 1973-1990. Data for 1991-93 were used for evaluation of quality of models on independent material.

Finally we have obtained equations for cod at age 3-9 years of the following type:

$$L_n = A_n + \sum_{j} A_{n,j} \cdot x_j$$

where L_n - cod length at age n years (n=3......9);

$A_{n,j}$ - regression coefficients;

x_j - independent variables: water temperature (mean yearly and averaged for 2-4 years), capelin abundance indices, cod length at age n-1 years, biomass of cod and abundance of euphausiids (j = 1....7);

x_j= 0 if jth variable does not take part in the equation;

A_n - free members in the equation.

Determination coefficients for this equation are changing from 0.66 to 0.92 (See Table 5). It means that variables included into these equations explain from 66% to 92% of general dispersion of cod length at insignificant contribution of water temperature. Mean square errors (S) of regression vary from 0.9 cm to 2.8 cm. To evaluate quality of the equation a S/δ criterion (ratio of mean square error of the regression to mean square deviation of a dependent variable. Mean square deviation (δ) was assumed as $\delta_{allowable}$. For practical usage equations in which S/δ ratio was less than 0.70 were taken. All equations obtained satisfied this requirement (Table 5).

Table 5. Determination coefficients (R^2, mean square errors (S) and S/ ratio for regression models of cod growth (age 3-9) obtained for the period 1973-1990.

Parameters	Age, years						
	3	4	5	6	7	8	9
R^2	0.92	0.88	0.84	0.89	0.92	0.83	0.66
S, cm	0.95	1.10	1.26	1.02	0.95	1.95	2.83
S/δ	0.35	0.41	0.53	0.43	0.36	0.56	0.70

The quality of models was evaluated using independent material of 1991-1993. Only in 3 cases out of 21 the prognostic error exceeded assumed allowable error ( ).Hence, the correctness was 86%. The quality of regression models may be illusatrated by Fig.2.

After it was stated that this approach brings satisfactory results we made additional calculations in which data from the most recent years (1991-1993) were used. We were trying to obtain dependences corresponding to the above criteria but having a larger advance. Such models have been built for cod at age 3-8. They have lower determination coefficients and higher mean square errors and S/δ ratio compared with equations obtained on 1973-1990 data. But what is important - they satisfy our requirements, and allow to have a 3-4-year advance. Unfortunately we failed to receive a reliable dependence for cod at age 9.
Finally, using these models we calculated expected mean lengths for 3-8 year-old cod for 1994-97. The results of this prognosis are presented in Table 6.

Table 6. Predicted mean length of cod (cm) at age 3-8 years for 1994-1997

Year	Age, years					
	3	4	5	6	7	8
1994	40.3	47.3	57.4	67.6	75.5	87.6
1995	37.3	44.3	55.5	61.6	72.4	83.3
1996	36.7	43.7	54.9	59.7	70.5	79.5
1997	38.9	45.6	55.5	63.1	70.9	77.9
mean long-time length	40.0	48.6	57.0	65.1	74.5	83.2
Minimum	35.1	44.7	52.7	60.0	67.9	76.9

CONCLUSIONS

According to our calculations a considerable decrease in mean length of cod of all age-groups is expected till 1996 down to values close to the minumum during the whole study period. In 1997 the trend may change for the opposite especially in fish of younger age-groups.

Variations in water temperature to a great extent determine lengths of 3-9 year-old cod, but this takes place during 2-4 years preceding entering the fish into a proper age-group. There exists a direct relationship between the length of cod and temperature conditions, i.e. the higher is the temperature during the last 2-4 years of this 3-9 year-old fish the longer is their mean length.

There also exists a statistically meaning relationship between cod length and capelin abundance index which accounts consumption of capelin by cod though this parameter is less essential for general dispersion of lengths of cod from all age-groups under study than the temperature.

Multiple regression models satisfactorily describing yearly changes in length of 3-9 year-old cod with a 1-year advance. have been obtained.

Their determination coefficients reach 0.66-0.92. Reliability of predictions based on independent data for 1991-1993 was 86%.

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Table 1. Mean length of cod by age-groups in the Southern Barents Sea, cm

Year	Age, years: 3	4	5	6	7	8	9
1949	36.3	41.0	48.8	55.8	65.9	75.8	81.7
1950	37.8	43.1	48.7	56.1	64.4	75.6	82.7
1951	35.2	42.0	50.1	58.7	65.8	75.7	83.0
1952	37.8	44.1	50.3	59.9	57.1	76.0	81.6
1953	34.2	41.5	50.4	60.6	68.9	77.8	85.2
1954	38.8	45.1	53.0	62.5	72.1	80.2	85.7
1955	33.7	43.5	50.5	59.5	69.7	78.9	86.0
1956	37.8	45.5	51.8	59.8	69.3	79.5	86.8
1957	37.0	44.7	52.5	61.7	68.7	73.0	85.9
1958	40.5	45.5	51.7	61.1	69.5	76.9	82.3
1959	38.5	46.3	51.9	60.1	67.6	76.2	83.6
1960	38.4	46.2	53.6	61.7	69.8	77.0	85.2
1961	38.2	44.3	53.6	62.1	71.5	77.6	83.8
1962	39.9	45.5	51.2	61.4	70.7	79.7	84.3
1963	40.3	45.5	51.8	60.0	69.7	78.9	89.2
1964	38.6	44.2	49.6	59.9	71.0	81.5	88.6
1965	37.0	45.0	51.2	59.9	69.6	79.5	90.5
1966	41.1	46.6	53.4	60.6	67.7	76.2	84.2
1967	39.1	43.7	57.3	65.0	71.8	77.7	83.7
1968	39.4	45.3	54.2	62.4	68.6	77.0	83.8
1969	41.2	45.7	52.9	61.0	69.9	77.6	84.1
1970	39.8	46.1	55.3	60.3	68.6	76.8	83.2
1971	41.3	48.2	56.1	62.7	71.1	77.9	84.8
1972	42.3	48.8	56.0	64.5	70.4	80.1	86.5
1973	38.1	44.7	55.9	63.0	72.0	78.9	90.6
1974	36.5	43.4	51.6	60.9	71.5	76.7	84.5
1975	39.5	44.8	53.2	60.8	68.3	77.4	84.0
1976	38.7	45.2	53.0	61.1	69.5	77.3	83.4
1977	38.4	45.9	53.9	61.4	70.2	79.1	85.8
1978	38.0	44.9	55.1	62.3	69.9	77.1	83.8
1979	34.9	42.6	52.0	61.1	70.2	77.2	83.4
1980	36.3	43.8	52.2	60.9	69.2	78.3	86.8
1981	40.4	47.0	52.7	60.6	71.2	80.5	87.2
1982	41.2	46.6	55.3	62.7	70.8	78.4	84.7
1983	42.9	51.8	59.9	67.3	74.0	80.1	92.6
1984	43.3	51.5	60.4	69.4	77.9	83.4	92.1
1985	44.6	52.4	58.7	68.2	78.2	86.1	90.2
1986	41.9	50.7	58.5	65.1	77.1	87.8	95.7
1987	35.1	48.6	57.5	67.2	76.1	90.1	100.0
1988	37.2	44.7	53.6	63.9	75.3	87.5	99.5
1989	36.8	46.2	52.7	60.0	67.9	75.9	89.4
1990	41.3	53.6	59.6	63.7	72.0	79.1	91.3
1991*	45.2	53.5	60.1	67.5	75.5	81.4	94.0
1992	45.5	53.4	61.7	70.9	79.9	88.3	97.4
1993	42.5	53.1	62.2	68.8	79.2	86.5	92.8

*

Table 3. Indices of abundance of capelin and euphausiids, portion of cod fed on capelin and biomass of Arcto-Norwegian cod

Year	Capelin abundance index: relative to total cod biomass, 10^9 spec/thou. tons	Capelin abundance index: relative to biomass of cod fed on capelin, 10^9 spec./thou. tons	Cod biomass, x000 tons	Euphaus. abundance	Portion of cod fed on capelin
1962	–	–	2900	521	–
1963	–	–	2513	–	–
1964	–	–	1966	128	–
1965	–	–	2130	87	–
1966	–	–	3026	179	–
1967	–	–	3855	108	–
1968	–	–	3978	111	–
1969	–	–	3417	322	–
1970	–	–	2423	334	–
1971	–	–	1965	243	–
1972	–	–	2048	870	–
1973	0.110	0.291	2965	241	0.272
1974	0.128	0.212	3066	152	0.424
1975	0.293	0.504	2734	2269	0.442
1976	0.266	0.514	2511	232	0.418
1977	0.236	0.444	2145	412	0.416
1978	0.230	0.611	1794	135	0.295
1979	0.398	0.919	1327	431	0.307
1980	0.446	0.927	1227	718	0.369
1981	0.362	0.700	1085	555	0.375
1982	0.342	1.072	938	674	0.247
1983	0.456	1.327	750	190	0.252
1984	0.249	1.547	908	315	0.142
1985	0.159	3.228	1008	147	0.044
1986	0.033	0.194	1295	1275	0.205
1987	0.003	0.053	1129	553	0.063
1988	0.001	0.012	833	658	0.098
1989	0.017	0.125	934	270	0.121
1990	0.023	0.122	1084	195	0.151
1991	0.107	0.495	1657	48	0.155
1992	0.123	0.595	1252	50	0.323
1993	0.080	0.252	2344	102	0.320

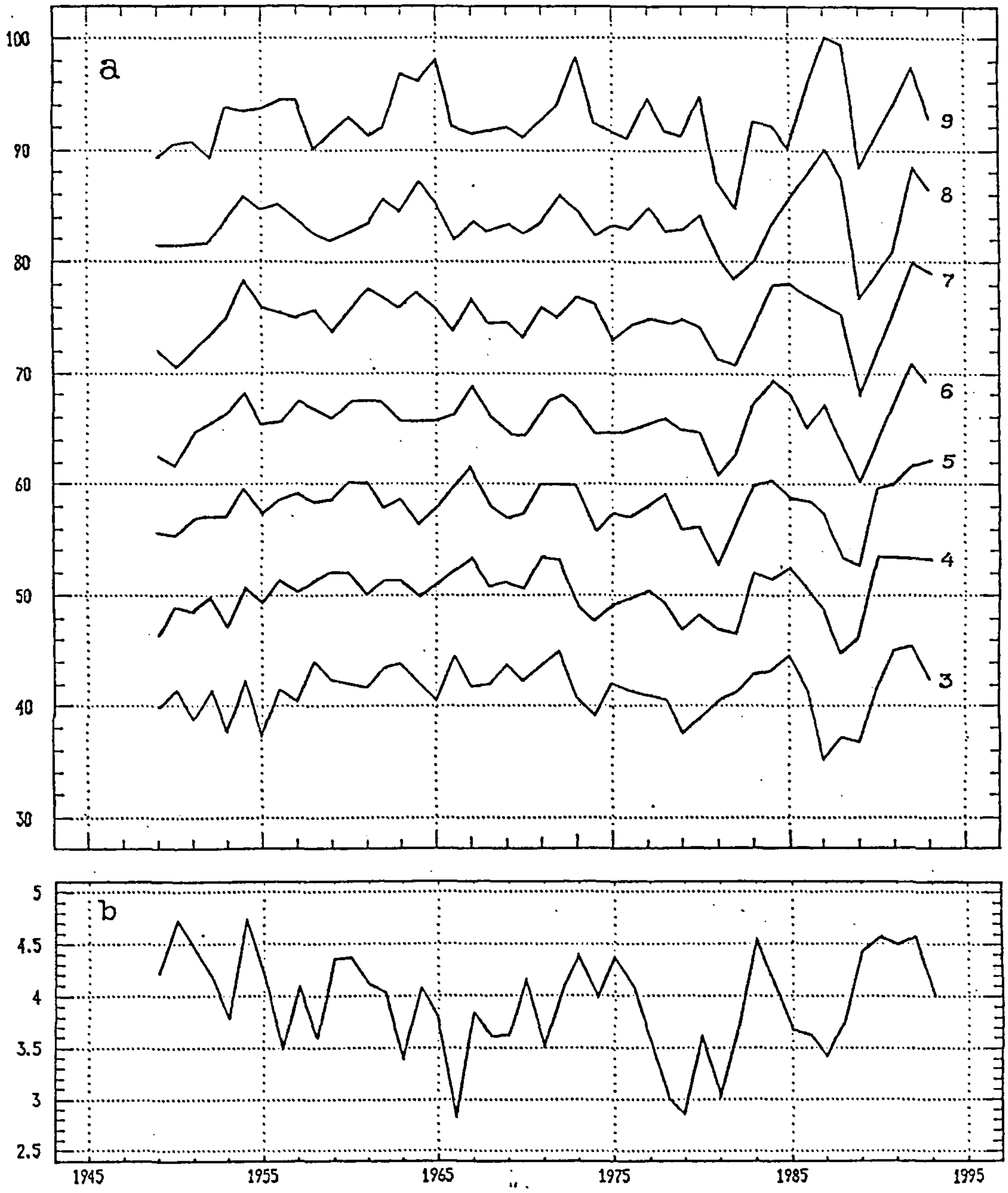

Fig.1 Yearly changes in cod mean length "reduced" to the 1981-1993 period at cod age 3-9 (a) and water temperature at depth 0-200 m on the Kola Section (b)

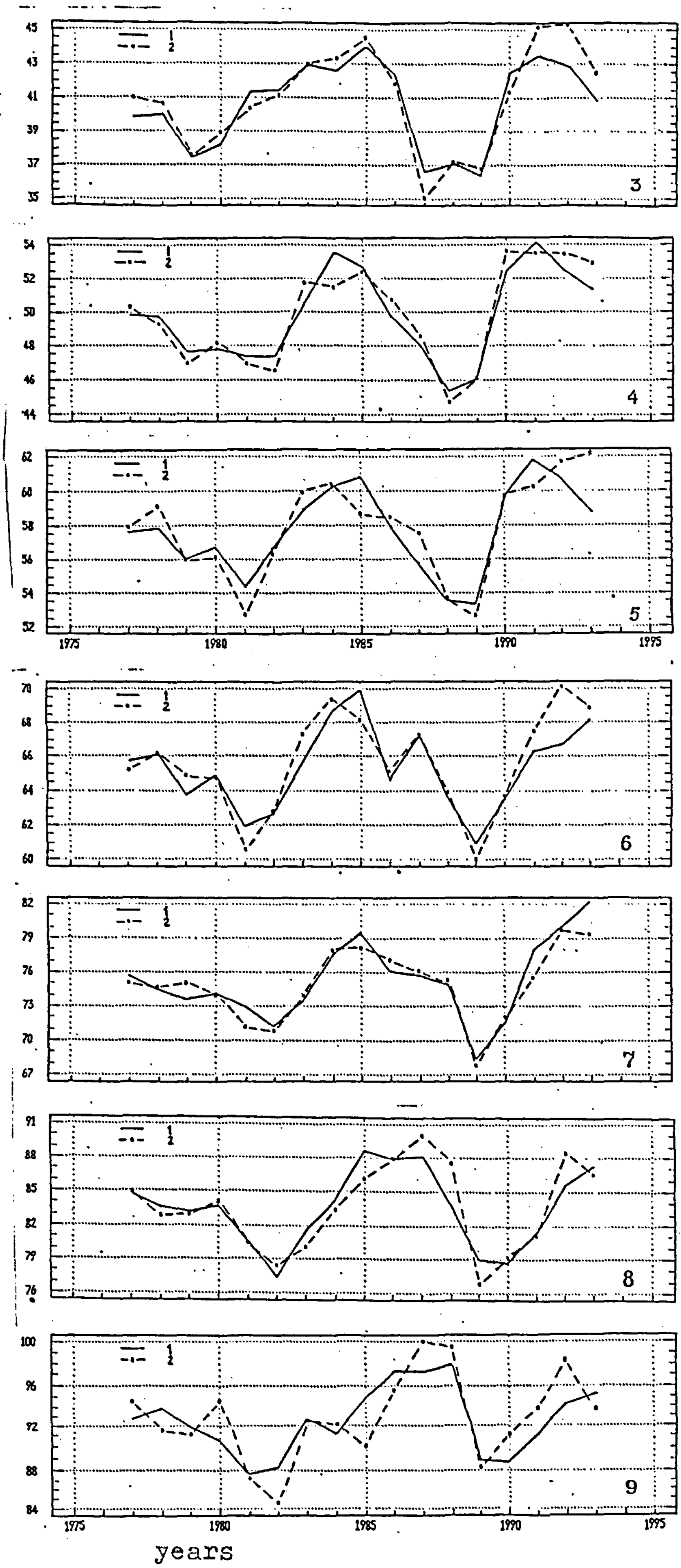

Fig. 2 Calculated by the model (1) and actual cod length at age 3-9