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On the Influence of Long-term Changes of Environmental Factors on the State of Some Fish Population Stocks in the Northwest Atlantic

by

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ABSTRACT

The changes of the northern stock of the spawning cod biomass in the Canadian waters and the West Greenland cod biomass are compared with the changes of SST's in the Irminger Sea. The correlation between variations of SST's and cod biomass in the above-stated areas is indicative of possible influence of climatic changes on the fish stock state.

INTRODUCTION

Over the recent thirty years, considerable changes of stocks of some commercial fish species, in particular, the biomass of the Newfoundland cod northern spawning stock, West Greenland cod biomass and the Scotian silver hake were observed in the Northwest Atlantic.

In the end of the seventies - early in eighties, the stocks of the above-mentioned fish reduced to the minimum followed by a marked increase by the mid-weighties. The viewpoints concerning the causes of these changes differ. One of the causes is thought to be the introduction of 200-mile fishing zones an fishery regulation measures. The study of the factors governing the fish abundance dynamics is of great importance for the fisheries development.

The present report is aimed at considering the relationship of one of the most important and accessible environmental parameters - water temperature and the state of the above-mentioned fish stocks.

SPECIAL SESSION ON CHANGES IN FISH POPULATIONS

MATERIALS AND METHODS

Mean monthly SST's taken by the USSR Hydrometeocenter in the centers of 5°-squares on the Scotian Shelf (40-45°N, 60-65°W) and in the Irminger Sea (55-60°N, 30-35°W) were used as a predictor of changes of environmental factors. Publications on the Scotian silver hake biomass estimates (Fanning, Waldron and Bourbonnais, 1987; Noskov, 1987), the biomass of the Newfoundland cod northern spawning stock (FO'C'SLE, 1988), the West Greenland cod biomass (Schumacker, 1988) and other papers were used for the analysis of changes of the fish stock state.

The technique of plotting integral curves of the water temperature anomalies at the sea surface widely adopted in the oceanological studies of global variations of oceanological and hydrometeorological factors in the North Atlantic (Zverev, 1972; Girs, 1971) was used.

To a certain degree, the integral curves are of abstract nature, however, they are good for identification of a tendency to intensification (at positive values of anomalies), weakening (at negative values of anomalies) or stabilizing (at small variability of these values) the studied process.

Below, the term "the tendency to change of the sum of anomalies of the sea surface temperatures ", will be replaced by "the change of water temperatures" for short.

It should be noted first of all that the sea surface water temperatures are considered as an index reflecting the interaction of oceanological systems: the warm Gulf Stream waters and cold waters of the Labrador Current in the Nova Scotian Shelf area, warm waters of the North-Atlantic Current merging with the Irminger Current and cold polar and Labrador waters in the Irminger Sea and West Greenland areas.

The increase of the sum of water temperature anomalies on the Scotian Shelf is considered to be the result of intensification of the Gulf Stream influence (approach to the Shelf) while the decrease is assigned to increased influence of the cold Labrador Current. The rise of the water temperatures in the Irminger Sea can be attributed to increased effect of the warm Irminger Current and movement of the subpolar front to the north and to the west while the drop of temperatures could be caused by weakening of the Irminger Current, strengthening of the East-Greenland Current and retreat of the sub-polar front to the south and to the east.

The STT observation series used were for the Irminger Sea and Nova Scotian Shelf for the 1977 to 1988 period, i.e. starting from the introduction of the special fisheries regime by Canada and a longer observation series for the Irminger Sea for the 1956 to 1988 period. For construction of shorter observation series by month for the 1977 to 1985 period, the mean SST values were determined, and the obtained anomalies were then summed and summarized on a 3-month and yearly bases (table 1). For construction of a longer observation series the mean SST values for the fourth quarter (October-December) of each year were used. The anomalies and their sum (table 2) were determined for the 1962 to 1988 period.

Thus obtained integral curves of water temperature anomalies were compared to estimates of the above-mentioned fish species.

In addition, the integral curve showing the tendency to movement of the boundary of the waters with the surface temperature of 10°C in the north-south direction along 35°W (table 3) was constructed. To construct this curve, intersection points of 10°N and 35°W were read from monthly SST charts of the USSR Hydrometeocenter; the distance between such a point and 53°N was calculated to within 10 miles and then the gained monthly distances were summed and summarized by quarter and averaged for a year. The integral curve shows the intrayear and year-to-year tendency to movement of the boundary of the waters with the temperature of 10°C relative to 53°N (Gibbs' break). As the first approximation, the drift of this water boundary can be interpreted as the shift of the sub-polar front in the north-south direction.

The choice of the 10°-isoterm at the sea surface was stipulated by the fact that it coincides with the sub-polar front and is simultaneously the southern boundary of distribution of tropical zooplanktonic forms. The mixed fauna zone extends southwards of this isotherm and occupies a vast space. As a wide band, it stretches from the south-west to the north-east in the direction of the North-Atlantic Current water spreading.

To determine the depth of lieing the waters with the temperature of 3.5-4.5°, classified as the north-western interstitial water mass by Muromtsev (1977), the massive of deepwater temperature observations by 5° Marsden trapezia for twelve months averaged for the 1951 to 1980 period and compiled for this purpose in the Oceanographic Data Center by the Lamanov's group was used. (Hydrophysical parameters in energy active North Atlantic areas, 1985).

RESULTS AND DISCUSSION

The analysis of the published data on the change of the fish biomass shows considerable fluctuations of abundance and biomass of some commercial fish species over the recent 10-30 years. Among these are: the Scotian silver hake, the biomass of the Newfoundland cod northern spawning stock and the cod biomass in the West Greenland area belonging to different ecological groups. The silver hake inhabit moderate waters while the cod prefer colder waters.

Nevertheless the change of these fish biomass followed a similar trend: a drastic drop in the end of the seventies - early in eighties, and the impetuous increase by the end of the eighties. An assumption that there exists a common reason responsible for this kind of abundance dynamics and fish biomass pattern, possibly related to global climatic changes of environmental factors, suggests itself. The opinion of Stein and Messtorff (1988) that the influence of climatic changes on the variation of the cod abundance and biomass in separate divisions and in the West Greenland area on the whole is influenced by climatic changes is of indubitable interest.

The comparison of changes of the sum of water temperature anomalies in the Irminger Sea and of the cod biomass in the West Greenland area showed that a slight increase was observed over 1977 to 1981 period, and a marked temperature drop at the Irminger Sea surface over 1982-1988 period (fig. 1). In the second case, it can be attributed to slackening of the Irminger Current and strengthening of the water of the polar origin. To substantiate this assumption the character of movement (drift) of water boundaries with the surface water temperature of 10°C along the 35 meridian relative to 53°N (fig. 2), which can be interpreted as the shift of the subpolar front in the north-south direction, is considered. From 1976 to 1981, year-to-year fluctuations of the boundary of the waters with the temperature of 10°C are not well pronounced, however, beginning in 1982, considerable movement of this boundary, particularly intensified in the second half of the year, has been observed. Maximum recorded amplitudes of these movements were in 1982, 1984 and 1985. During that period, the vast area of the Irminger Sea experienced the influence of colder waters.

During the same period, but with a three year delay, an opposite trend of the cod biomass variation in the West Greenland area was observed. It markedly reduced from 252 thous. tons in 1982 to 44 thous. tons in 1985 followed by a sharp rise to 613 thous. tons by 1987, i.e. the 14-fold increase over two years (table 4). Consequently from the anomalies of the water temperature in the Irminger Sea the trend to the cod biomass change in the West Greenland area can be forecasted three years head at first approximation using the equation of back linear regression written as:

$$B = -41.9 \text{ SST's} + 249,$$

where B is the biomass, and SST's is the sum of SST anomalies.

As the trend to further decrease of the sum of SST anomalies was observed during 1985 to 1988, the increase of the cod biomass in the West Greenland should be expected in the forthcoming years.

The analyses of the sea surface water temperature changes in the Irminger Sea during the 1956 to 1988 fall-winter period, and the Newfoundland northern spawning cod biomass from 1962 to 1988 showed that a trend to the increase of the sum of the SST anomalies in the Irminger Sea continued from 1956 to 1977 having changed from 2.45°C to 8.11°C. Then a backward trend set in which resulted in the reduced sum of anomalies reaching 3.11°C in 1988. The cod spawning biomass changed in antiphase with the temperature changes. So, from 1962 to 1977, it decreased from 1.3 to 0.4 mill. tons (fig. 3). The coefficients of the back linear correlation for the considered parameters for the 1962 to 1988 period are as follows:

comparison of current years	$r = -0.78 \pm 0.05$
a year ahead	$r = -0.86 \pm 0.04$
two years ahead	$r = -0.88 \pm 0.03$

When plotting the spawning biomass values against the sum of the water temperature anomalies for one and the same years over the 1964 to 1972 period (decrease of biomass), the points fit an actually straight line, the equation of which can be written as:

$$B = -159\ SST's + 1764$$

During the biomass growth period from 1977 to 1987 (except for years 1981 and 1982), the points also fit the straight line though at the other level. The equation is as follows:

$$B = -150 + SST's + 1261.$$

Over a number of years (1962, 1963, 1973 to 1976, 1981, 1982 and 1988), the points fit a kind of an intermediate line:

$$B = -160\ SST's + 1560 \text{ (see fig. 4).}$$

Therefore during the investigation period diversely oriented cyclic changes of the sum of water temperature anomalies in the Irminger Sea and the Newfoundland cod northern stock biomass took place. As the temperature changes usually preceded those of the biomass, the trend of variations of the Newfoundland cod spawning biomass can be forecasted at first approximation from the temperature data 1-2 years ahead.

Thus on the grounds of the above-stated evidence it can be assumed that considerable changes of the spawning cod biomass in the Newfoundland area are related to global climatic variations of oceanographic conditions in the North Atlantic that occurred during the investigation period.

The detailed analysis of variations of the sum of the anomalies of the water shelf temperatures and different indices of the silver hake biomass and catch per effort for the Nova Scotian area was published in 1988 (Baidalinov and Rikhter, 1988). It can be only added that a direct relationship of the water temperature and silver hake biomass changes existed in that area. The data contained in the table show considerable changes of the studied parameters over 1977-1981 and 1983-1986 periods.

Thus from the above-stated data it can be suggested that considerable long-term changes of the state of the stock considered above are stipulated by climatic variations of oceanographic conditions which by strengthening and weakening the systems of warm and cold currents, create favourable or unfavourable conditions in the habitat, to which the fish populations respond by the increase or decrease of the abundance and biomass evidently through provision with the food resources.

The identification of the mechanism of influence of long-term changes of environmental factors on the dynamics of the commercial fish abundance and biomass is of great importance.

The West Greenland area is known (Stein and Messtorff, 1988) to be influenced by the northern subpolar gyral. According to these authors, general features of the temperature regime on the West Greenland Banks is as follows: the water temperature changes from 1 to 4.5°C, down to 500 m, the influence of the warm constituent of the Irminger Sea waters is obvious, and deeper, these layers mix with the Labrador waters. So the climatic changes of the oceanological regime of the waters in the Irminger Sea can be assumed to influence the regime of the West Greenland area.

We believe that two types of the intermediate water masses (as per classification by Muromtsev, 1977) are of great importance for the subpolar gyral system. These are the North-Western type (temperature 3.5 - 4.5°C, salinity 34.87 - 34.98°/oo, oxygen content 5.1-6.2 ml/l) and the North-Atlantic type (temperature 5-14°C, salinity 35.0 - 35.9°/oo, oxygen content 4.0 5.5 ml/l). The subpolar front passing along the left Gulf Stream boundary and the North-Atlantic Current divides these water massives. In the subpolar front zone, the rising streams are strong. Their rate somewhat exceeds that of sinking streams, therefore, the frontal zone serves rather as the area of rising of deep waters to the surface than the area of intensive water sinking. With depth, the subpolar front divides these water massives not horizontally, but vertically, having changed from the hydrological front to the interface between steadily stratified water massives (Gruzinov, 1975). The subpolar front zone is characterized by simultaneous development of different biological seasons which, combined with individual planktonic complexes in diverse water massives, provides a stable food base for the fish throughout the year (Gruzinov, 1985). In the open part of the North Atlantic, a number of vast and steady in time regions of maximum concentrations of the zooplankton biomass related to peculiarities of water circulation in the subpolar gyral exist. One of them, the largest in the North Atlantic in terms of area, is located to the north of the Newfoundland as north as 59°N and 41°W, and occupies the entire south-eastern part of the Labrador basin (Bulatov, 1971).

The data in fig. 5 show that the depth of the North-West interstitial water mass markedly descreases westwardly with the drop of the surface temperature in the Irminger Sea. It is likely that the long-term decrease of the SST's in the Irminger Sea results in the water backing with the North-West interstitial water massive in the West Greenland area. It can be assumed that due to intensified contrasts (gradients) between the warm underlying and upper layer cold waters the conditions set which favoured the growth of the Arctic and boreal zooplanktonic forms and the other organisms forming the food base for the West Greenland cod having resulted in a significant cod biomass increase.

In other words, global changes of the oceanological water regime seem to cause variations in the animal world communities at the ecosystem level including the stock state of commercially important fish species. It should be noted that the pattern of these global changes in the atmosphere-ocean system occurring simultaneously over a vast area differ. In some areas they are synchronous, in the others they are in the antiphase, and still in the other areas they occupy the intermediate position. Therefore the monitoring of the environmental factors and the state of commercial fish stocks can be used as a non-traditional method for gaining expert values of separate fish population abundance dynamics.

Thus global climatic changes of the environmental factors exert an immense influence on the state of the fish stocks. Intensified or lowered contrasts (gradients) between warm and cold water massives cause favourable or unfavourable conditions in living organisms habitats throughout the trophic chain thus stipulating long-term increase or decrease of the commercial fish biomass.

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Table 1

Change of sum of SST's anomaly in the Irminger Sea in 1977-1988

Month	I977	I978	I979	I980	I98I	I982	I983	I984	I985	I986	I987	I988
I	-0,7	-0,1	-I,5	0,4	5,4	6,6	I,8	-4,9	-II,3	-I2,7	-20,8	-2I,6
2	-I,0	-0,I	-0,4	0,2	5,5	6,8	I,I	-5,5	-II,I	-I2,5	-22,0	-23
3	-I,5	0,0	-0,3	I,I	5,3	6,7	0,6	-6,6	-II,4	-I3,I	-22,7	-236
4	-I,4	-0,I	0,7	I,3	5,0	6,I	0,2	-7,3	-II,8	-I3,8	-22,2	-24,4
5	-I,5	0,I	I,3	I,7	4,7	5,I	-0,7	-8,0	-I2,3	-I5,4	-22,5	-24,5
6	-I,7	-0,7	I,7	2,8	4,5	4,7	-I,2	-8,8	-I2,5	-I6,I	-2I,4	-23,9
7	-I,7	-I,2	I,2	2,8	5,0	4,9	-2,3	-9,7	-I3,2	-I7,5	-20,9	-25,5
8	-I,2	-I,I	0,8	3,8	4,4	4,2	-3,9	-9,9	-I3,8	-I8,2	-I9,4	-26,6
9	-I,I	-0,6	0,6	4,3	4,8	3,6	-4,0	-I0,4	-I3,7	-I8,3	-I9,2	-26,3
I0	-I,I	-0,3	0,5	4,3	5,2	2,8	-4,5	-II,0	-I3,5	-I8,8	-20,5	-26,I
II	-0,7	-0,3	0,3	4,6	5,4	2,4	-4,8	-II,2	-I3,I	-I9,7	-2I,3	-26,I
I2	-0,2	-0,8	0,I	5,I	5,9	I,5	-4,4	-II,3	-I2,7	-20,2	-2I,3	-25,3
I-3	-I,I	-0,I	-0,7	0,6	5,4	6,7	I,2	-5,7	-II,3	-I2,8	-2I,8	-22,7
4-6	-I,5	-0,3	I,2	I,9	4,7	5,3	-0,6	-8,0	-I2,2	-I6,I	-22,0	-24,3
7-9	-I,3	-I,0	0,9	3,6	4,7	4,6	-3,4	-I0,0	-I3,6	-I8,0	-I9,8	-26,I
I0-I2	-0,7	-0,5	0,3	4,7	5,5	22	-4,6	-II,2	-I3,I	-I9,6	-2I,0	-25,8
I-I2	-I,2	-0,5	0,4	2,7	5,I	4,7	-I,8	-8,7	-I2,6	-I6,4	-2I,I	-24,7

Table 2

Change of sum of SST's anomaly in the Irminger Sea and of northern spawning cod stock biomass in the West Greenland area in 1962-1988

Year	Sum of SST's anomaly, C°	Biomass, thousand tons			Year	Sum of SST's anomaly, C°	Biomass, thousand tons		
		literary	calculated	deviation, %			literary	calculated	deviation, %
I962	2,45	I230	II7[illegible]	-5	I976	8,II	I70	260	53
I963	2,75	II20	II20	0	I977	8,II	90	40	-55
I964	3,55	I200	I200	0	I978	7,74	I00	I00	0
I965	4,42	I030	I060	3	I979	7,27	I30	I70	3I
I966	5,82	860	840	2	I980	6,94	270	220	-I8
I967	5,82	800	840	5	I98I	7,0I	390	440	I3
I968	6,32	780	760	-2	I982	6,0I	480	360	-25
I969	6,62	730	7I0	-3	I983	5,58	420	420	0
I970	6,85	570	670	I7	I984	4,98	390	5I0	3I
I97I	7,52	570	570	0	I985	5,0I	5I0	5I0	0
I972	7,25	580	6I0	5	I986	4,08	600	650	8
I973	6,58	480	5I0	6	I987	3,08	800	800	0
I974	7,35	4I0	380	-7	I988	3,II	I000	I060	6
I975	7,86	300	0						

Table 3

…um of distances (miles) of intersection points of 10°-isotherm at 35 meridian off 53°N

for 1976 through 1988 period

Month	I976	I977	I978	I979	I980	I981	I982	I983	I984	I985	I986	I987	I988
I	-I50	-840	-420	-630	-I0I0	-650	-800	-I780	-I990	-2450	-3395	-4235	-4455
2	-330	-960	-540	-750	-II90	-970	-980	-I930	-2I60	-2645	-3605	-4455	[illegible]
3	-540	-II40	-660	-930	-I4I0	-II30	-II90	-2050	-2330	-2855	-3645	-4635	[illegible]
4	-660	-I220	-780	-I050	-I540	-I250	-I380	-2I70	-2420	-3095	-4055	-4785	[illegible]
5	-720	-I300	-900	-III0	-I300	-I340	-I590	-2290	-25I0	-32I5	-4I90	-4885	-5045
6	-8I0	-I240	-990	-III0	-II20	-I430	-I7I0	-24I0	-26I0	-3275	-4280	-4935	-5045
	-870	-I000	-8I0	-990	-940	-II90	-I530	-2I70	-2420	-32I5	-4I90	-4675	-4865
8	-630	-460	-540	-750	-400	-950	-I260	-I970	-2I20	-2945	-4060	-4285	-4685
9	-390	-220	-240	-540	-I60	-740	-II50	-I770	-I940	-2045	-3805	-4025	-4445
I0	-420	-I60	-I80	-540	-220	-560	-I2I0	-I7I0	-I940	-3005	-3805	-4005	-4445
II	-540	-220	-270	-660	-430	-620	-I330	-I690	-2060	-3095	-3925	-4II5	-45I5
I2	-720	-300	-5I0	-780	-640	-680	-I660	-I780	-2240	-32I5	-4I25	-4235	-4635
I-3	-340	-980	-540	-770	-I203	-983	-990	-I920	-2I60	-2650	-36I5	-4445	-4645
4-6	-730	-I253	-890	-I090	-I320	-I340	-I560	-2290	-25I0	-3I95	-4I75	-4866	-5005
7-9	-630	-560	-530	-760	-500	-960	-I3I3	-I970	-2I60	-3035	-40I6	-4328	-4665
I0-I2	-560	-267	-320	-660	-430	-620	-I380	-I927	-2080	-3088	-3952	-4II6	[illegible]
I-I2	-565	-765	-570	-820	-863	-976	-I3II	-I977	-2227	-2992	-3940	-4440	[illegible]

Table 4

Change of sum of SST's anomaly in the Irminger Sea and cod biomass in the West Greenland area (Schumacher, 1988) in 1979-1988

Year	Sum of SST's anomaly	Biomass, thous. tons			
		Year	According to Schumacher 1988	Calculated	Deviation,%
I979	0,4	I982	252,4	232,2	-8
I980	2,7	I983	I38,7	I35,9	-2
I98I	5,I	I984	34,7	35,3	2
I982	4,6	I985	43,8	56,3	28
I983	-I,8	I986	I04,0	324,4	-
I984	-8,7	I987	6I3,2	6I3,5	0
I985	-I2,6	I988	-	(776,9)	-
I986	-I6,4	I989	-	(936,2)	-
I987	-2I,I	I990	-	(II33,I)	-
I988	-24,7	I99I	-	(I283,9)	-

Brackets contain cod biomass values for the West Greenland area preliminarily estimated from the SST's.

Table 5

Change of Scotian Shelf silver hake biomass (thous. tons) and catch per effort in 1977-1981 and 1983-1986

Indices	I977-I982	I983-I986
Biomass 1+	I43-I87	262-8I7
Biomass 2+	II2-I50	209-299
Biomass in the begining of the year	I58-I93	255-888
Biomass	332-376	329-676
Catch per fishing day	20,9-29,5	30,5-44,3
Catch per trawling hour	I,2I-I,90	I,75-4,23

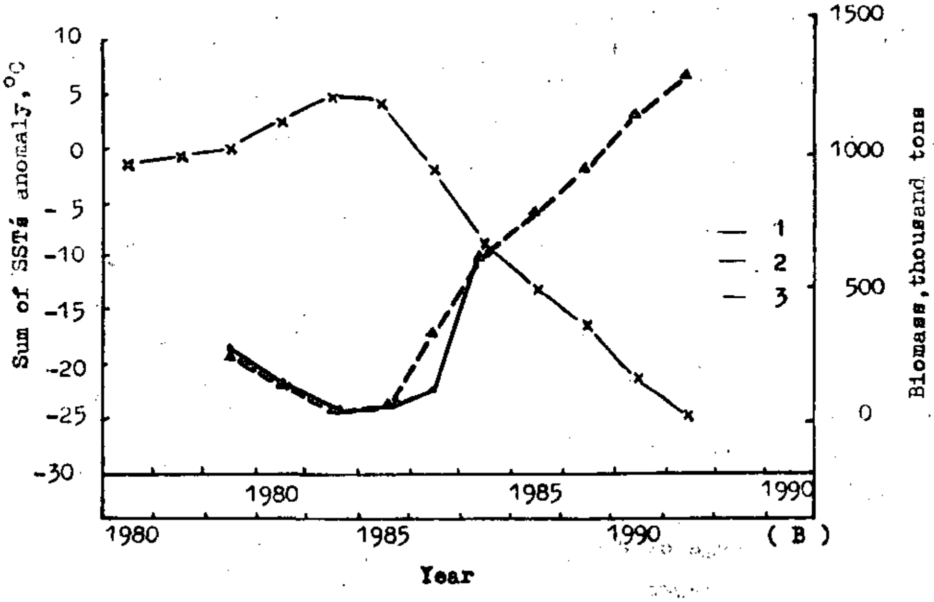

Fig. 1. Change of the sum of SST's anomalies in the Irminger Sea and cod biomass in West Greenland area in 1979-1987.

1 - sum of SST's anomalies in the center of 55-60°N, 30-35°W square;

2 - cod biomass according to Schumacher, 1988;

3 - calculated values of cod biomass.

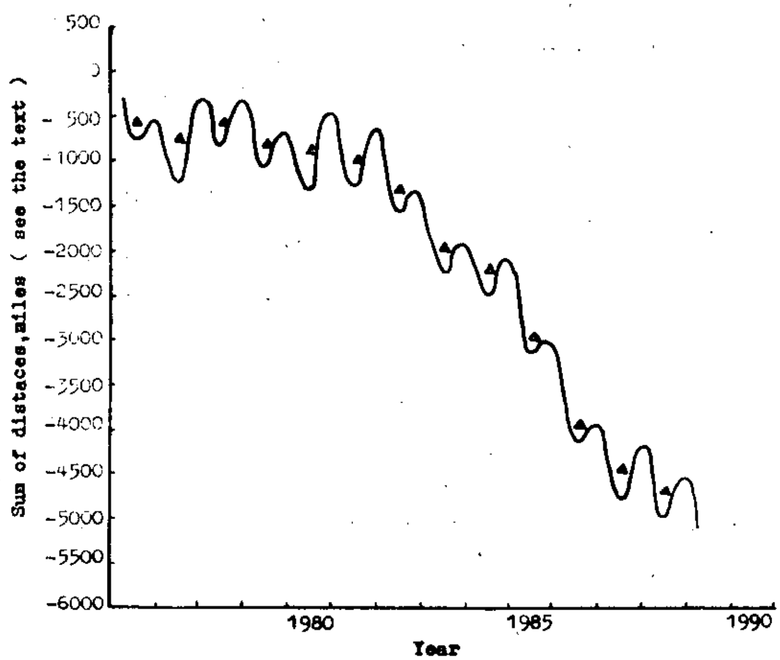

Fig. 2. Integral curve showing movement of boundary of waters with the temperature of 10°C along 35 meridian relative to 35°N over the 1976 through 1988 period.

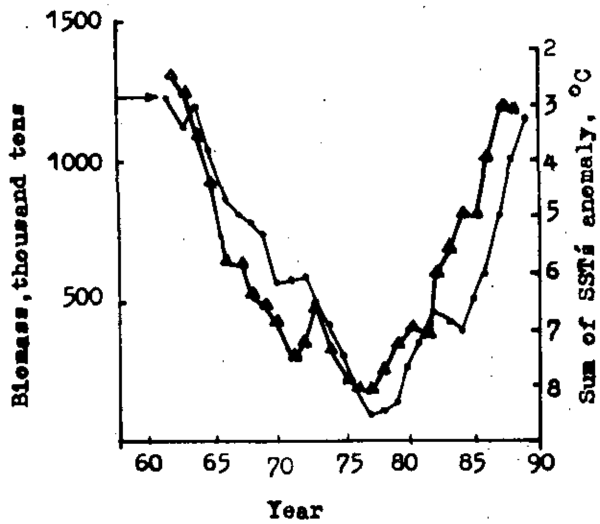

Fig. 3. Change of sum of SST's anomalies in the Irminger Sea and the biomass of Newfoundland spawning cod northern stock (Stein and Messtorff, 1988) in 1962-1988.

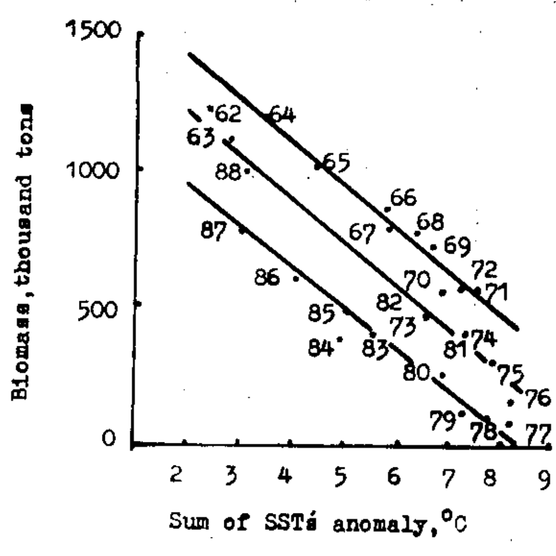

Fig. 4. Newfoundland spawning cod biomass against the sum of SST's anomalies in the Irminger Sea for 1962 to 1988 period.

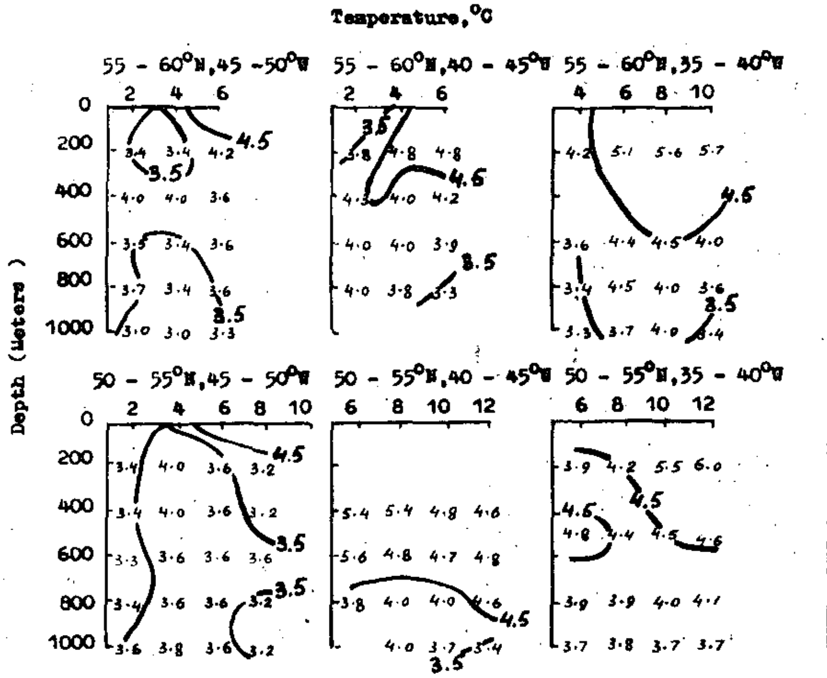

Fig. 5. Vertical water temperature distribution by 6-5° square in the North Atlantic. Data averaged for 1951-80 period.