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Present-Day Climatic Variations in the Barents and Labrador Seas and Their Biological Impacts

by

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ABSTRACT

Results from comprehensive investigations of general peculiarities and of relationship between large-scale variations in the atmosphere-cryosphere-hydrosphere climatic system in the NWA and Barents Sea are presented.

A close statistically significant relationship between the main parameters of climate in the World Ocean regions studied has been established, i.e. atmospheric pressure and its differences in a number of points of the area studied, air temperature, water temperature in the surface and active layers of the main streams of currents and ice coverage. In this case the long-term variations under atmospheric and oceanic conditions in the Labrador and Barents Seas are synchronously performed in a vast distance from each other (above 2.5 thou.miles), however, with a climatic trend being opposite.

One of the main sources of formation of the long-term climatic variations in the North Atlantic and of the European North seas is the North Atlantic fluctuation. Well agreement is observed between intensity of the North Atlantic fluctuation development in the west and in the east of the World Ocean region considered.

Special attention has been given to analysis for anomalous development of meteorological, hydrographic and ice conditions which has taken place both in the NWA and in the Barents Sea since early 90s. A sharp thermodynamic variation in the Barents Sea climatic system has resulted in anomalous warming comparable by scale with a well known period of "Arctic warming" in 1933-1939 and that of the NWA - in a prolonged period of anomalous cooling. Examples of essential and various impacts of hydrometeorological conditions of anomalous period in the beginning of 90s upon the reproduction and distribution of biota in the Barents and Labrador Seas are given in the paper.

INTRODUCTION

Problem of studying the long-term climatic variations, optimal consideration of these variations under ecological modelling and forecasting is the most actual in the World Ocean regions with complicated climatic conditions. Undoubtedly, the areas of the Labrador and Barents Seas also refer to these regions. Extreme year-to-year variability of meteorological, hydrographic and ice conditions which in its turn determines frequently an anomalous pattern of yearclass abundance formation, conditions for their feeding, wintering, spawning, as well as routes of their seasonal migrations, is revealed here under severe conditions of extreme northern boundaries of distribution of a number of main commercial fish species in the zone of interaction of warm Atlantic and cold polar waters. Hence, timely and objective diagnosis of long-term variations in climatic systems of the NWA and Barents Sea as the basis of their long-term forecasting should be necessary. Due to the sharp large-scale variations in hydrometeorological conditions observed over the Barents Sea area and in the NWA at present, which are frequently of anomalous or extreme character, the long-term hydrographic forecasting as the basis of adequate ecological or fisheries forecasting is especially actual.

The problem of the relationship between hydrometeorological processes in the Earth remote parts has been of interest for scientists for a long time from the point of view of methodical approach to long-term forecasting of natural processes. In a number of classical papers of 20-40s G.Walker, J.Sandstrom, V.Yu.Vize and V.V.Shuleikin have found availability of temperature "opposition" in the NWA areas, including the West Greenland, and in the NEA, including the seas of the North European basin. Early in 60s G.K.Izhevsky has broadened these scientific ideas and developed the conception on availability of a number of natural systems of planetary scale in the Northern hemisphere, in particular, the Greenland-North American (including the NWA) and Atlantic ones (including the NEA and North European basin). According to his views (Izhevsky, 1964) the natural systems function under interacting processes in atmosphere, hydrosphere and biosphere both inside each of the systems and between them. In this case a development of the mentioned processes in the Greenland-North American and Atlantic systems is antiphase and different-directed.

Sufficiently detailed analysis for general peculiarities of large-scale variations under hydrometeorological conditions in the North Atlantic areas and in the seas of the European North, including the analysis of anomalous period of 90s, is given in numerous proceedings and in ICES and NAFO scientific publications. In particular, detailed data from hydrometeorological investigations in the NWA areas have been published in numerous reports of NAFO Scientific Council meetings (papers by E.Buch, E.B.Colbourne, K.F.Drinkwater, S.A.Malnberg, B.Petrie, M.Stein, K.R.Thompson, R.W.Trites, V.A.Borovkov, I.I.Tevs and others).

Current long-term fluctuations in marine climate for the Barents And Norwegian Seas areas have been considered in detail in a number of ICES investigations (L.Midttun, R.R.Dickson, J.Blindheim, H.Loeng, V.V.Tereshchenko). Results from a number of investigations (Bochkov, Luka, 1991; Bochkov, Tereshchenko, 1992, 1994) indicate the extreme nature of development of hydrometeorological conditions in the Barents Sea in a period from the beginning of 90s and anomalous biological and commercial after-effects of this development.

Unfortunalely, no proper attention has, in our opinion, been given to the questions pertained to the relationship between current large-scale variations in climatic systems of the North Atlantic areas and the European North seas. Meanwhile, these investigations from the point of view of methodical approach will contribute to more successful settling the questions of long-term forecasting of large-scale variations in meteorological, hydrographic and ice conditions in the World Ocean regions studied, since they allow to obtain detailed and better knowledges about mechanisms of these variations formation, to control objectively temporary and spatial boundaries of transition of natural climatic systems from warming to cooling and, vice versa, to use the ralationship established empirically not only within one system but also within other neighbouring ones.

On this basis, our attention has been concentrated upon establishing the pattern and extent of the relationship between current (1951-1993) long-term variations of the atmosphere-cryosphere-hydrosphere climatic system in the Labrador and Barents Seas located in a distance above 2.5 thou.miles and included into two adjacent natural systems (according to G.K.Izhevsky) - the Atlantic and Greenland-North American ones. An attempt to classify in quantitative form and to compare the levels of thermal state of these climatic systems for 1964-1993 has been undertaken on the basis of formed homogeneous large body of climatic data. Much prominence has been given to analysis for anomalous development of hydrometeorological conditions of these seas, which has taken place since the beginning of 90s, as well as to its influence upon reproduction and distribution of biota in the Barents and Labrador Seas.

MATERIALS AND METHODS

Long-term data on the following hydrometeorological parameters have been used as the main initial information:

- mean monthly data on atmospheric pressure on the sea level and on air temperature (1951-1993) from a number of coastal and insular points in the North Atlantic and in the seas of the European North, as well on temperature of the sea surface layer in regular grid points in the area of the North Atlantic and Norwegian Sea (1974-1993) (Materials from Hydrometeorological Centre of Russia, Moscow);

- difference in values for atmospheric pressure on the sea level in Keflavik-Horta, as the index for intensity of development of the North-Atlantic fluctuation responsible for evolution of large-scale variations of meteorological and oceanographic processes in the North Atlantic and European North seas, as well as in Godthaab-Goose Bay and Jan Mayen-Stavanger - "indicators" of the North-Atlantic fluctuation development in the NWA and NEA areas. Data for 1951-1993 have been obtained from Hydrometeorological Centre of Russia, Moscow);

- data on water temperature of active layer in a number of standard hydrographic sections in the Barents (mean monthly and mean yearly for 1951-1993) and Norwegian (June-July 1954-1993) Seas, objectively reflecting variations in thermal state of water of the North-Atlantic-Norwegian-North Cape-Murman Current system and along 8-A section in autumn, the data on temperature regime of which characterise the thermal state of the Labrador Current waters (1964-1993) - PINRO hydrographic data;

- data (mean monthly and mean yearly) on ice coverage in % of the area of the Barents Sea (1951-1993), Labrador Sea and Davis Strait (1967-1993) - data of Hydrometeorological Centre in Murmansk.

In addition, a number of informative parameters for the atmosphere-cryosphere-hydrosphere system in the the North Atlantic and in the North-European basin seas obtained by PINRO from Hydrometeorological Centre of Russia has been used by the authors, as well as the data from literature.

To avoid distortions obtained when comparing and analysing the data series with a different duration the preliminary calculations have been done to adjust the data analysed to a single norm, for which the period 1951-1990 has been taken. Therefore, results from the analysis and comparison of hydrometeorological conditions of the Labrador and Barents Seas given below are, in our opinion, methodically justified, homogeneous and objective.

RESULTS FROM INVESTIGATIONS

Relationship between variations in climatic conditions of the Barents and Labrador Seas

Analysis for data on current long-term variations in climatic parameters of two natural systems of the NWA and Barents Sea indicates a close statistically reliable relationship between their meteorological, oceanographic and ice conditions.

It is clearly demonstrated in Figs. 1-3. The main peculiarities of the relationship between large-scale variations in a number of parameters of the Labrador and Barents Seas climatic systems, as an example, should be noted.

Air temperature. Close, statistically reliable, synchronous reverse relationship is pronounced between long-term fluctuations in air temperature over the Labrador (Goose Bay) and Barents (Vardo) Seas. Correlation coefficient has constituted -0.49 at n = 30 and P = 0.001 for 1964-1993. In this case, the closest relationship between long-term variations in air temperature is observed in January-March (Fig.1) when the coefficient reaches -0.75, whereas during other seasons this relationship is statistically insignificant.

Water temperature. Long-term fluctuations in temperature of Atlantic waters in the streams of the North Cape and Murman Current in the Barents Sea and subarctic waters of the Labrador Current in the NWA are synchronously related and are of "mirror" character. Thus, statistically reliable synchronous reverse relationship between long-term variations in water temperature in 0-200 m along the "Kola Meridian" section in the Barents Sea and along 8-A section in the Labrador Sea (Fig.2) makes up -0.61 (P=0.02, n=29) for 1964-1992. Similar close reverse relationship has also been registered in long-term variations of thermal state of waters in the Norwegian (5-C section along 63°N) and Labrador (8-A section) Seas (r=-0.52).

Thus, the long-term variations in thermal state of waters of the Labrador and Barents Seas are closely related and synchronously pronounced in the long-term aspect, however, with climatic pattern being opposite, i.e. intensification or attenuation of warm currents of the Barents Sea and of cold Labrador Current coincide in time. As can be seen in Fig.2, the most clearly it is pronounced in the periods of anomalous development of oceanic conditions for climatic systems of the Labrador and Barents Seas - in 1965-1969, 1972-1976, 1977-1981, 1985-1988, 1989-1993.

Ice coverage. Close reverse relationship has been established (Fig.3) between the long-term variations in ice coverage (in % of the sea area) of the Barents and Labrador Seas (r=-0.68, 1967-1993, n=27, P=0.0001) and also between the large-scale variations in ice coverage of the Barents Sea and Davis Strait (r=-0.51, 1967-1993, n=27, P=0.006) in winter. Relationship between the large-scale fluctuations in ice coverage of the Labrador Sea and Davis Strait is direct, correlation coefficient of which varies from 0.75 (mean yearly values) to 0.83 (mean values for January-March).

Thus, close reverse relationship between current large-scale variations in thermal state of atmosphere and ocean in the areas considered is pronounced with the relationship being synchronous. Thesis of "opposition" of development of environmental conditions in the Greenland-North American and Atlantic natural systems, with all the biological and commercial after-effects, confirms this by new hydrometeorological data.

Undoubtedly, one of the main factors of formation of such large-scale in time and space climatic fluctuations is the North Atlantic fluctuation which reflects a close interaction between Atlantic centres of atmosphere action - the Icelandic minimum and Azores maximum (r=-0.66, 1953-1993, n=41, P=0.000).

This conclusion agrees with classical scientific views and, in this connection, an attention should be given to a pattern of spatial manifestation of the North Atlantic fluctuation phenomenon. It can be clearly seen in Fig.4, which demonstrates a close relationship between variations in the index for the North Atlantic fluctuation in Keflavik-Horta and its local "indicators" in the Northwest and Northeast Atlantic areas. Correlation coefficients for the long-term variations in atmospheric pressure between the indices for the North Atlantic fluctuation and their analogs for the Northwest and Northeast Atlantic constitute 0.84 and 0.67, respectively (1953-1993, n=41, P=0.000).

Role of these indices for atmosphere pressure and circulation regime is also essential in formation of temperature regime of the NWA and NEA climatic systems. For example, a close statistically reliable relationship is pronounced between the index for the North Atlantic fluctuation in the NWA and corresponding variations in the air temperature, water temperature and ice coverage of the Labrador Sea area: r = 0.63, 0.54 and -0.53, respectively, and P - 0.000, 0.002, 0.005. Analogous close relationship is also typical of the Barents Sea.

As it is seen from the plot given (Fig.4), the year-to-year index for the North Atlantic fluctuation is characterized by sharp variations in its values from year to year and, therefore, a climatic effect through variations of weather conditions in the North Atlantic areas and European North seas can be extremely variable and dependent both on a level of its development intensity and on geographical position of centers of the atmospere action.

General peculiarities of present-day variations in hydrometeorological conditions of the Barents and Labrador Seas

According to the investigations (Bochkov, Luka, 1991; Bochkov, Tereshchenko, 1992), a notable intensification in variations of shorter periods has also been revealed in the Barents Sea area against a background of essential climatic variations since 60s, i.e. a progressive increase in instability of climatic system of this region. The close relationship found for present-day large-scale fluctuations in hydrometeorological processes and conformity of duration of warming and cooling periods in the Labrador and Barents Seas in 1965-1969, 1972-1976, 1977-1981, 1989-1993 indirectly indicate that intensification of its climatic system instability should also be observed in the NWA area. One of the clearest manifestation of such instability, in our opinion, is an increase in recurrence of natural anomalous phenomena which are observed in the Barents and Labrador Seas at present and a commencement of which dates from 1989 (Fig.5). In this connection it is actual to analyse in detail the general peculiarities and possible genesis of the current anomalous development of hydrometeorological conditions in the Barents and Labrador Seas to a scale of variability in the Atlantic and Greenland-North Americal natural systems and to evaluate their biological and commercial after-effects. The main positions and conclusions of the analysis given below are illustrated in Figs. 5-13.

Analysis for variations of hydrometeorological conditions in the areas of the North Atlantic and European North seas in 1989-1993 has shown the anomalous and, in separate years (1989, 1990, 1992), extreme development of the atmospheric circulation, which sharply differed from both the long-term means and conditions of the previous 30-period (Fig.4), to be the most important in a formation of these conditions. Extremity of atmospheric circulation processes is especially noticeable in winter-spring as evidenced by the following factors. In winter period 1989-1990 the lowest pressure in Iceland area (Icelandic mimimum) and the highest one on the Azores (Azores maximum) have been registered for recent decade and, according to personal communication by V.M.Bulaeva, for a whole period of observations since 1881. Absolute minima of mean monthly atmospheric pressure in winter have been recorded in Scandinavia, on the Kola Peninsula, Spitsbergen, Yan Mayen and in Greenland. No analogs of such extensive and profound depression of pressure have been found over a vast area of the North Atlantic (northward of 50°N), the Norwegian, Greenland and Barents Seas. Intensity of the Icelandic and Azores centers of atmosphere action in winter-spring has continued to remain further also during a whole period of 1989-1993, what was accompanied by an exclusive activity of the atmospheric circulation processes as evidenced by the following factors:

- in 1989-1993 a recurrence of positive anomalies of number of stormy days (Fig.6) in January-March made up 87% (in 13 of 15 months) in the Labrador Sea area and 100% (in 15 of 15) - in the Barents Sea;

- in 1989 and 1990 (January-March) 60 and 65 stormy days, respectively, at the norm 40 were observed in the Labrador Sea area, i.e. during the first quarter 20 and 25 "odd" stormy days have been registered there;

- similar pattern of anomalous development of stormy activity in that period was observed nearly in all areas of the North Atlantic, Irminger, Norwegian and Barents Seas.

Undoubtedly, activization of stormy activity in winter, observed in recent years, affects adversely the navigation and fishery in the World Ocean areas considered.

Increased recurrence of prevaling winds has completely agreed with the pattern of anomalous development of the North Atlantic fluctuation. In this case a well-defined opposition of direction of the main air mass transport in the NEA, Norwegian-Greenland basin and Barents Sea on the one hand (stable southwestern, southern air mass transport) and in the area of the NWA and Irminger Sea on the other hand (prevailing of the northwestern, northern winds).

Strong and stable winds of southwestern, southern directions contributed to a formation of abnormally high values for air temperature over the Barents Sea area, the positive anomalies of which reached 3-5°C in winter-spring (Fig.7). In 1989-1993 the recurrence of mean monthly values for air temperature, exceeding the norm, on Vardo station reached 88% in January-May, i.e. positive anomalies of air temperature were observed in 22 of 25 months of the period analyzed, and negative - only during 3 months; the absolute values for negative anomalies did not exceed 0.1-0.5°C. On the contrary, the main reason of formation of large negative anomalies of air temperature over these areas were similar strong and stable winds of the northern directions in the areas of the NWA and Irminger Sea (Fig.7). Recurrence of air temperature above the norm in January-May over the Labrador Sea area has also constituted the anomalous value - 88%. Thus, in winter period 1989-1993 stable areas of anomalous cooling and warming of air mass close by stability of their manifestation , as evidenced by the analysis, to 1972-1976, have formed over the Labrador and Barents Seas areas.

The observed above anomalous thermodynamic development of atmospheric circulation processes in 1989-1993 has induced large-scale variation in hydrographic and ice regime in the World Ocean areas studied. In this case the climatic effect of such a prolonged and heavy influence of atmospheric circulation processes upon the hydrographic and ice regime of the Barents and Labrador Seas has proved to be much considerable and was characterized by the following peculiarities.

Distribution of surface layer temperature in the North Atlantic and European North seas reflects clearly an impact of anomalies of atmosphere pressure and circulation regime considered above.Essential positive anomalies of surface layer temperature have formed over the area of the Norwegian (eastern periphery), Greenland and Barents Seas. In 1989-1993 a center of negative anomalies of water temperature was observed over the area of the NWA and Irminger Sea. Abnormality and conformity of current large-scale variations in atmospheric circulation intensity, air temperature and surface layer temperature in the Barents and Labrador Seas area are given in Fig.5, including mean monthly values for anomalies of these climatic parameters for 1989. On the whole, the situation is also typical of the period 1989-1993 considered, with details and level of development of atmospheric and oceanic conditions being different in separate years.

Main features of warming in the Barents Sea in 1989-1993

In 1989-1993 the anomalous increase in water temperature and intensification of warm current system (the North Cape-Murman-Novaya Zemlya Current) was registered in the Barents Sea.

Extreme development of the North Atlantic fluctuation observed already in winter-spring 1989 has induced the extreme variation in thermal state of water of active layer of these currents system from high negative (-0.7 - -1.5°C) anomalies, observed over a whole area of the Barents Sea already in the beginning of the year, to essential (0.7 - 1.3°C) positive ones in May-July of the same year. No such essential (Fig.8) variation from "cooling" to "warming" of water temperature in 0-200 m layer of the Murman Current along the "Kola Meridian" section has been registered during a whole period of observations since our century. Unusually sharp warming of the North Cape and Murman Current waters was continuing during 5 years, without interrupting, as it was in previous shorter periods of warming in 1959-1962, 1972-1976, i.e. separate "outbreaks" of cooling.

Warming of the Barents Sea waters in 1989-1993 does not yield to that in the second half of 30s (1932-1939), known as the period of "Arctic warming". The fact that the area of cold bottom waters with the temperature of -1.0°C and below has reduced by 5 times, compared to their area during a period of cooling in 1977-1981, also indicates the extreme level of warming of the Barents Sea waters early in 90s. If in August 1978 the Central Deep cold bottom waters with the same temperature were distributed southwards to 70°30'N and ascended the depths to 120 m, then in analogous period 1991 they were recorded only in two local sites below 200 m and far north along 74°00'N. It should be noted that exclusively low rates of water cooling were observed in winter-spring period 1989-1993. As a result of considerable thermodynamic impact of atmospheric circulation processes the seasonal minimum of water temperature in 0-200 m during a number of recent years has already been observed in February-March, by 1-2 months earlier than usually, and maximum - by 1-2 months later, i.e. the spring-summer seasons in the last period of warming in the Barents Sea were extremely prolonged. Mild ice conditions (Fig.9) close to those of the period of warming in the Arctic region in the second half of 30s have occurred to be natural consequence of the peculiarities of meteorological and hydrographic processes development over the Barents Sea area early in 90s. The recurrence of negative anomalies of ice coverage (100%) from January to April in 1990-1993 indicates a stability of phenomenon of its reduction in this period. During the last period of warming, compared to that of cooling in 1977-1981, the sea area covered with ice has decreased twice in February.

It should be noted that a rise in temperature of Atlantic waters over the Norwegian and Greenland Seas, compared to the norm and previous period 1985-1988, was not so high as in the Barents Sea, i.e. positive anomalies of temperature in 1989-1993 on the average did not exceed 0.2-0.4°C in the southern Norwegian Sea and only in the latitudes northwards 69°N they were stable - 0.5°C and above. Positive anomalies of temperature were distributed over the water column of Atlantic waters. This allows to suggest the intensification of advective transport of heat by the North Atlantic-Norwegian-North Cape Currents system to be the main factor of anomalous warming of waters in the Barents Sea in the period investigated along with the processes of heat exchange with atmosphere.

The main features of cooling in the NWA in 1989-1993

Detailed and objective, in our opinion, analysis of hydrometeorological conditions observed in recent years in the Northwest Atlantic Ocean has been presented in a number of papers at NAFO Scientific Council Meetings for 1990-1994. Therefore, we found it appropriate to present the review on hydrographic and ice conditions in the NWA area, including the Irminger Sea, as well as results from PINRO investigations, as summary of these current research.

Extreme intensification of the North Atlantic fluctuation in winter-spring period 1989-1993 accompanied by a sharp increase of stormy days (Fig.6), and recurrence of the northwestern and northern winds have provided for intensified transport of cold Arctic air mass to the NWA area throughout this period and, respectively, for a formation of a large-scale center of negative anomalies of air temperature there, covered the area of the Baffin Sea, Davis Strait and Labrador Sea (Fig.7). Such intensive manifestation of the atmoshere circulation processes has produced a sharp variation in oceanic conditions relative to the norm and previous period. Its main features are the following:

- vast area of abnormally low values for surface water temperature have formed in the area of the NWA and Irminger Sea;

- general northern air currents have contributed to essential intensification of the East Greenland-West Greenland-Baffin Land-Labrador system of cold currents; as for the Labrador Current a trend of intensification well agrees with a pattern and rate of development of the North Atlantic fluctuation;

- intensive winter cooling has given rise to a formation of large negative anomalies of water temperature (-0.3 - - 1.0°C) in active layer in the Labrador and Newfoundland areas, with maximum of heat deficiency in a bottom layer being observed not only in the Labrador and Newfoundland shelf waters but also along the continental slope in the Labrador Current Main branch area; a trend of distribution of cold waters towards deeper depth was observed;

- severe winter conditions and intensity of advection of cold in the Labrador Current have induced a considerable drop in thermal state of water on the Newfoundland Shelf; mean water temperature in a bottom layer remained to be stable by 0.3-1.0°C below the norm;

- a trend of development of hydrometeorological processes in the Labrador and Newfoundland area favoured the area extension and increase in thickness of cold intermediate water layer;

- a trend of reduction in the area occupied with transformed Atlantic waters and shifting of the boundary of cold water distribution eastwards are observed in the Baffin Land and Labrador subareas; essential drop in water temperature in the region of the Davis Strait mixed waters has been induced not only by abnormally increased rates of cooling in winter but also by attenuation of heat advection by the Irminger Current;

- severe weather conditions in 1989-1993 have caused exclusively heavy ice conditions off the NWA, especially in winter-spring: the recurrence of positive anomalies of ice coverage in the Labrador and Davis Strait has made up 100% for theperiod from January to April 1990- - 1993, i.e. this process was exclusively large -scale and stable (Fig.9); earlier than usually formation of ice and its further southern drift on the Newfoundland shelf, with the ice edge varying consistently close by its highest distribution boundaries in winter-spring, were observed in the same period.

Thus, based on the present-day data, the analysis of variations in the atmosphere-cryosphere-hydrosphere main parameters of climatic systems of the Barents and Labrador Seas in 1989-1993 confirms the concept of availability of antiphase of large-scale fluctuations of hydrometeorological conditions in the NWA and Barents Sea, and the values for these variations indicate a rise in instability of climatic systems in the World Ocean regions studied at present.

Regional biological and commercial after-effects of climatic variations in late 80s - early 90s

Current large-scale variations in meteorological conditions of the Barents and Labrador Seas are important during formation of yearclass abundance of the main commercial objects and of their distribution and behaviour during feeding, wintering and spawning migrations. In particular, heavy biological and commercial after-effects have anomalous manifestation of meteorological, hydrographic and ice conditions in these seas observed since the beginning of 90s. In accord with the data from PINRO investigations the main of them are the following.

Impact of hydrometeorological conditions on the reproduction, distribution and behaviour of marine organisms in the Barents Sea is strong and variable in anomalous period of warming in 1989-1993. Intensification of warm currents system, higher heat content of Atlantic waters and mild ice conditions have created exclusively favourable conditions for reproduction of the main commercial fish species (excluding capelin) - cod, haddock, herring and shrimp. Higher level of heat content of Atlantic waters in winter-spring at Scandinavian coast and in the southwest of the sea in the sites of the main spawning grounds for cod, haddock and herring has conditioned the earlier, by 2-3 weeks, terms of reproduction (spawning) of plankton organisms - calanus and euphausiids during these years than it was observed usually. Along with an extension of duration of vegetative period this has produced favourable feeding conditions for larvae and fingerlings of cod, haddock and herring from 1989-1993 yearclasses, and, hence, for their survival at early stages of development. Earlier spawning has also been registered for Atlanto-Scandian herring, which commences earlier than usually from two weeks to one month during a period of current warming.

Intensification of warm current system has contributed to a wide dispersal of young cod gadoid species along the Barents Sea, eliminating an impact of cannibalism, and attenuated rates of water cooling in winter and mild ice conditions provided a good survival of young cod and haddock in the periods of the first winterings. As a result of this, in abnormally warm 1989-1993 a number of high abundant and abundant yearclasses of cod, haddock and herring have appeared (Figs.10-12), as well as shrimp in the period 1989-1991, a growth of biomass of which was further delayed by intensification of gadoid species predation. On the contrary, abnormally warm current period has occurred to be unfavourable for reproduction of capelin in the Barents Sea. In this case a reverse statistically reliable relationship has first been revealed between the index for the Barents Sea capelin abundance and temperature regime in the previous 2-3 years prior to the yearclass appearance (Fig.13).

In 1989-1993 period of warming the areas of cod, haddock and shrimp have sharply extended northward and eastward what is more typical of abnormally warm years. Earlier commencement and later termination of feeding migrations of gadoid species are observed, i.e. a duration of feeding period has considerably increased (by 1-2 months) compared to normal conditions, as well as to preceding period 1977-1988.

Essential and prolonged warming of the North Cape, Murman, Novaya Zemlya and South Cape Currents waters has defined a formation of good nutritive base of zooplankton during a feeding period and it has contributed, in accord with the ichtiological investigations carried out by PINRO, to the more intensive growth of gadoid species in the Barents Sea.

This has influenced upon an increase in biomass and commercial stock of gadoid species and conditioned a successful development of fishery by russian and norwegian fishermen.

In contrast to the Barents Sea, where evolution of oceanographic conditions favoured the fisheries activity, a prolonged and considerable cooling of marine climate in the NWA was accompanied by a whole series of negative, from a point of view of fisheries activity, biological and commercial effects. The clearest of them are the following.

A prolonged (since the end of 80s) maintaining of record, by pattern and duration, of "cold" period has been followed by a sharp reduction in periods of vegetation of plankton food organisms, especially in the ice distribution area; by later commencement of peak of vegetative processes and delaying of abundant spawning of capelin by 2-4 weeks, respecively.

Area with optimum conditions for development of boreal fish ichthyoplankton has much reduced, what had effected adversely a level of their yearclasses abundance early in 90s.

Anomalous cooling of waters on the Labrador and Newfoundland shelf has notably influenced the distribution of cod inhabiting these areas. Thus, by results from the trawl-acoustic survey in 1993, on the Grand Newfoundland Bank cod aggregations have been "extruded by cold" from Div.3L, where the biomass has reduced from 189 to 6 thou.t in 1991-1993, and it increased from 151 to 200 thou.t in the southern part of the bank (3NO). Abnormally low values for bottom temperature of water in this area have conditioned a distribution of cod at deeper depths - to 700-900 m than usually.

Extreme delaying of phases in capelin yearly cycle, which has been expressed in two-month delay in spawning at the Newfoundland coast and respectively in "autumn" formation of its feeding aggregations in 1991, is much pronounced biological effect of cooling of the NWA waters. Capelin stock on the Newfoundland remains to be at a very low level, and its appearance, by the data from Spanish and Canadian scientists, in the Flemish Cap Bank and Nova Scotia areas shows an unusual shifting of the area boundaries eastwards and southwards.

Finally, if the fishery on grenadier and halibut took place at the depths, beginning from 400 m, in preceding two decades, then in a current period of cooling the main aggregations of these species occur much deeper - below 1000 m, and in separate sites - to 2000 m. Similar unusual trend has also been noted for redfish which shifted not only to further southern areas (by 1993 redfish stock in Div.3L has decreased by 10 and increased by 4 times in Div.3N, and by 10 times - in Div.3O) but also descended much deeper, i.e. from 400-600 to 900 m.

CONCLUSION

The examples given for essential and variable impact of anomalous state of environments in the Barents and Labrador Seas in a current period 1989-1993 on reproduction, distribution and behaviour of marine organisms indicate the anomalous variations in the atmoshere-cryosphere-hydrosphere climatic system in the regions of the World Ocean to be also followed by the biological and commercial effects, opposite by a pattern. Peculiarities of long-term variations in the atmosphere-cryosphere-hydrosphere climatic system in the NWA and European North seas, as well as a close statistically significant reverse relationship between large-scale climatic fluctuations in the Barents and Labrador Seas indicate that the situation observed at present, is instable and, on the expiry of definite time, it will be changed to an opposite, i.e. to the warming in the NWA and cooling in the Barents Sea.

Finally, it should be noted that the large-scale variations of hydrometeorological conditions in two adjacent natural systems, having anomalous biological and commercial after-effects, indicate a necessity for detailed and consistent ecological monitoring in the North Atlantic and European North seas within the frames of joint research projects. Rise in instability of the climatic system accentuates an objective necessity for close international cooperation in the field of development of reliable methods for long-term forecasting of natural processes.

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REFERENCES

BOCHKOV, Yu.A., LUKA, G.I. 1991. Long-term variations of oceanographic processes in the North European seas and their biological and commercial after-effects. In: "Methods for estimation and forecasting of hydrometeorological processes in fishing areas". Proceedings of Leningrad Hydrometeorological Institute. - St. Petersburg, 67-79 pp. (in Russian).

BOCHKOV, Yu.A., TERESHCHENKO, V.V. 1992. Current long-term variations of hydrometeorological conditions in the Barents Sea and their biological after-effects. In: "Ecological problems of the Barents Sea". -Proceedings of PINRO.- Murmansk, 225-243 pp. (in Russian).

BOCHKOV, Yu.A., TERESHCHENKO, V.V. 1994. Year-to-year fluctuations in water temperature, impact of environmental factors on migrational behaviour and distribution of marine organisms. - In: "Peculiarities of formation of fish resources from the Barents Sea coast and recommendations for their fisheries exploitation". - Russian Academy of Sciences, - Apatity, 16-29 pp. (in Russia).

IZHEVSKY, G.K. 1964. Systematic basis of forecasting the oceanographic conditions and reproduction of commercial fish species. -Moscow, P. 166 (in Russian).

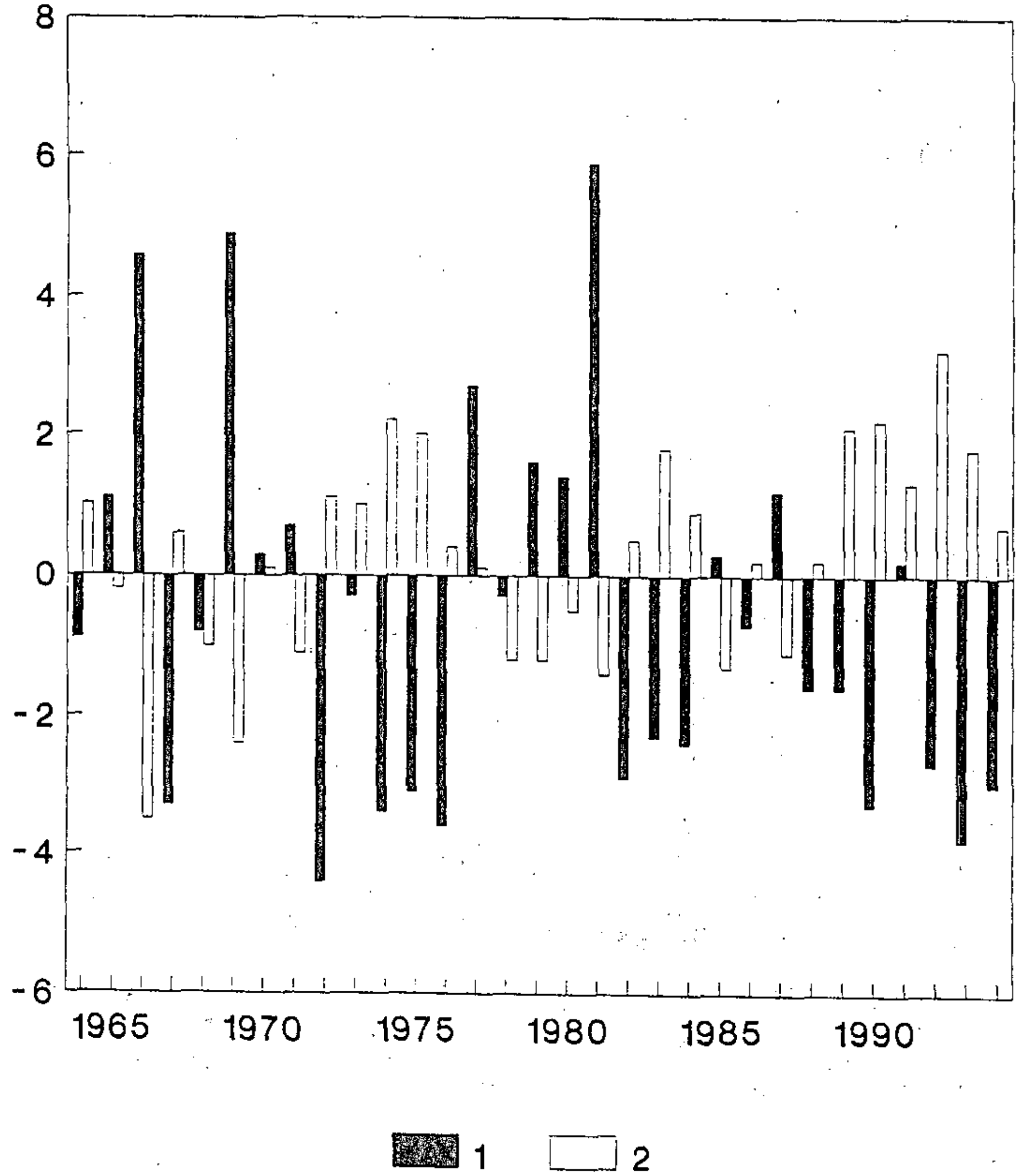


Fig.1. Anomalies of long-term fluctuations in air temperature in the Labrador (Goose Bay)-1 and Barents (Vardo)-2 areas (January-March, 1964-1993).

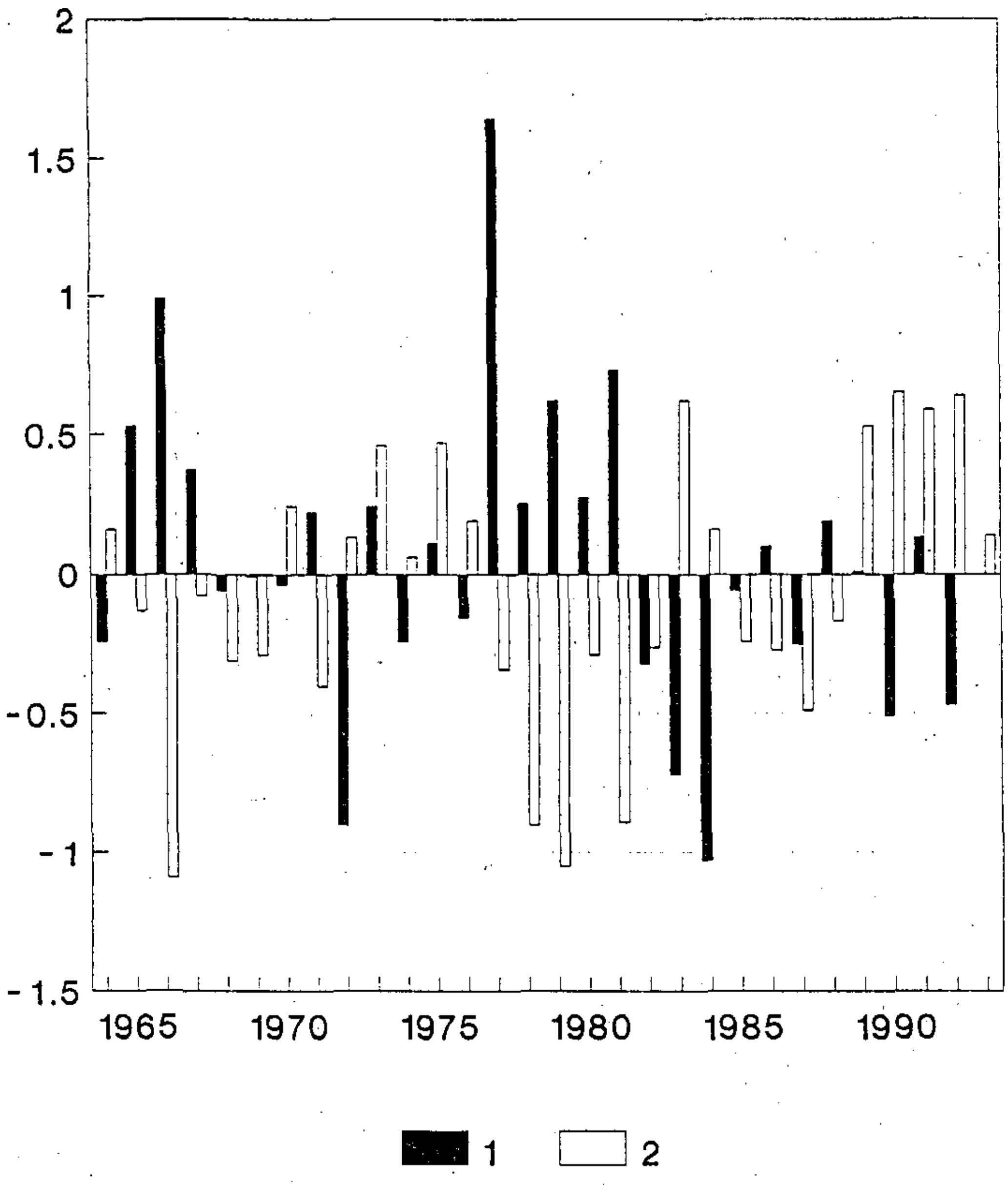


Fig.2. Anomalies of long-term fluctuations in water temperature in 0-200 m layer along 8-A (the Labrador Sea)-1 and "Kola Meridian" (the Barents Sea)-2 sections in 1964-1992.

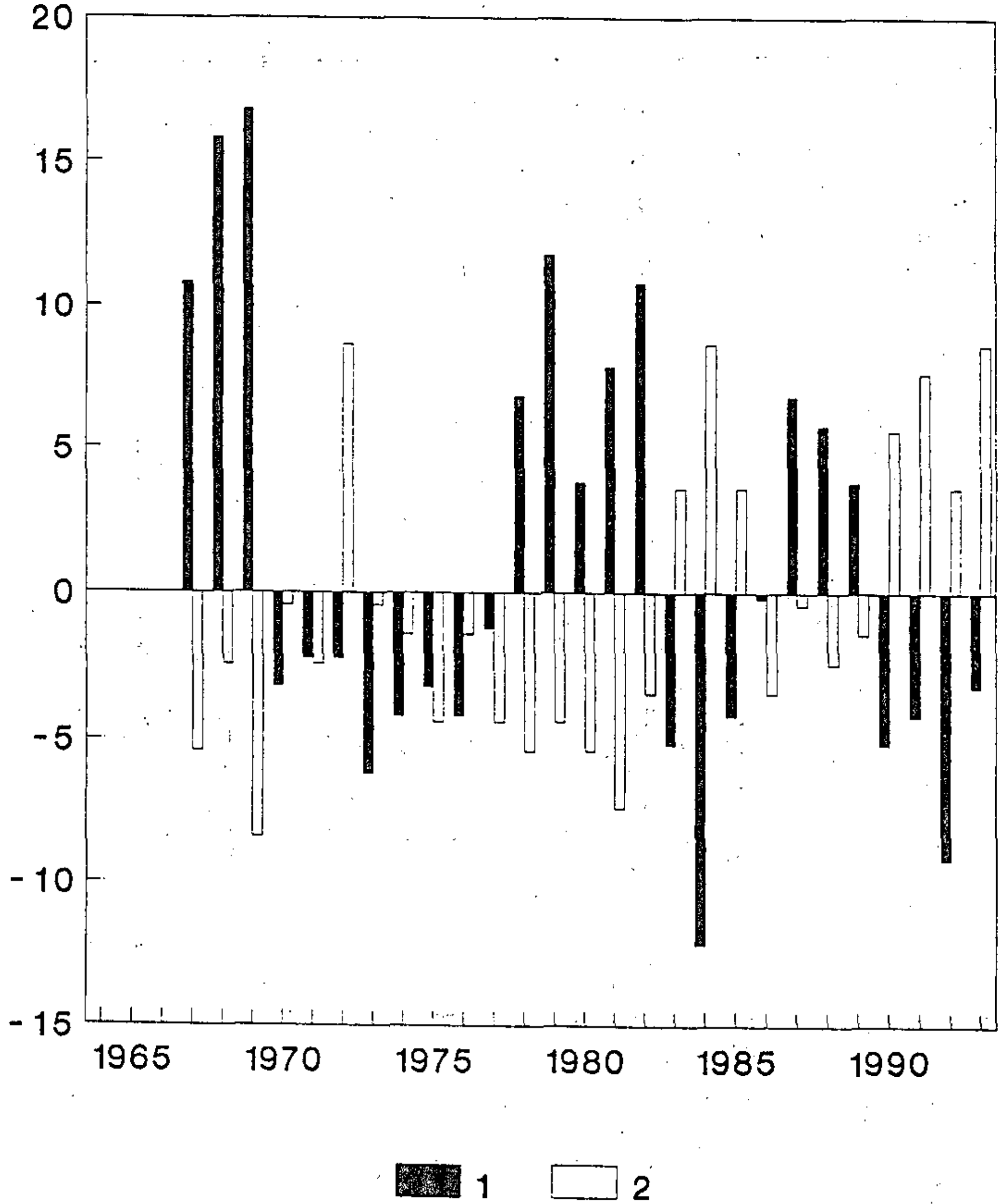


Fig.3. Anomalies of long-term fluctuations of ice coverage in the Barents -1 and Labrador -2 Seas (January-March, 1967-1993).

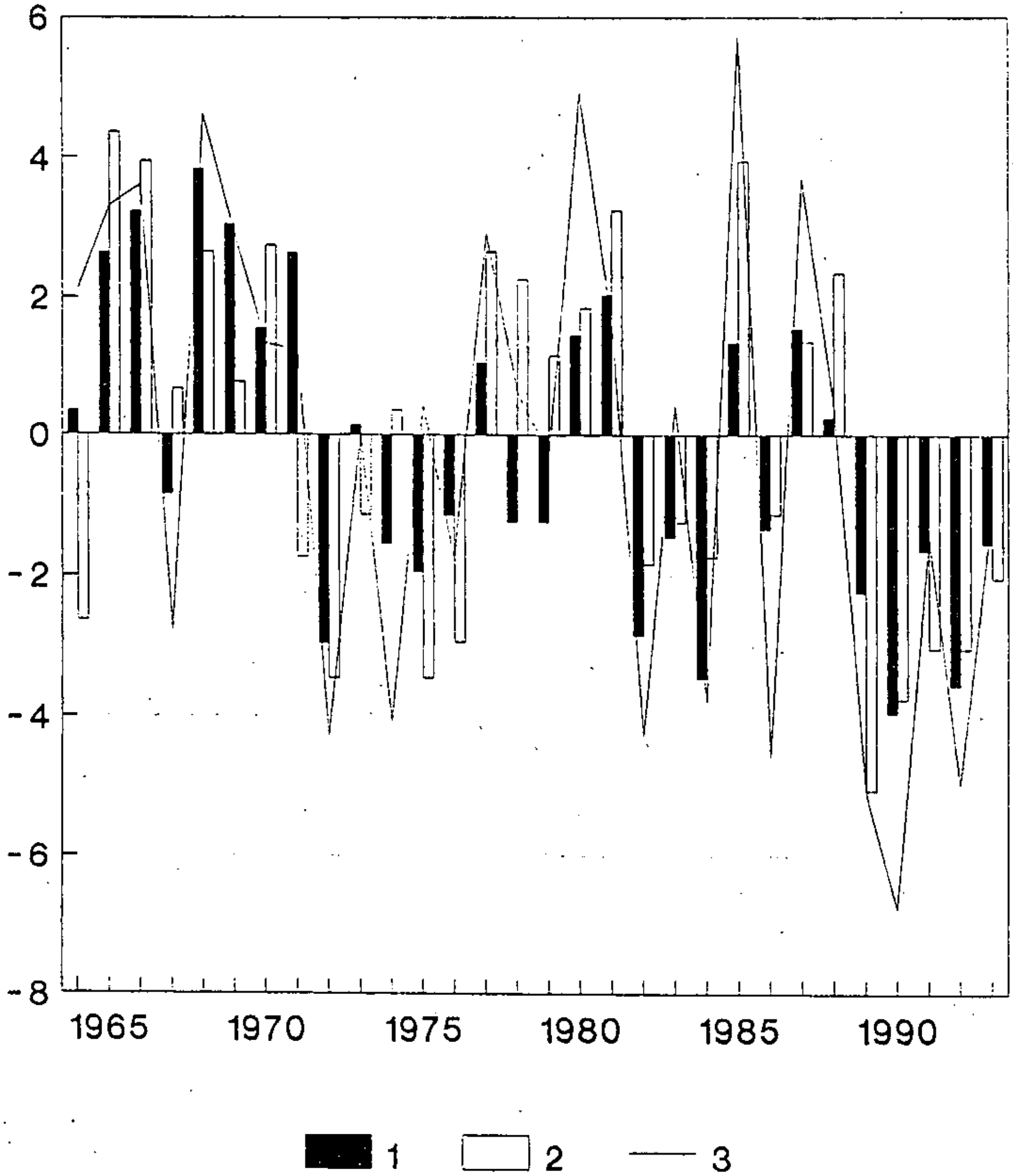


Fig.4. Anomalies of long-term variations in the index for North Atlantic fluctuation (Keflavik-Horta)and for its "indicators" in the NWA (Godthaab-Goose Bay)-1 and NEA (Jan Mayen-Stavanger) in 1964-1993.

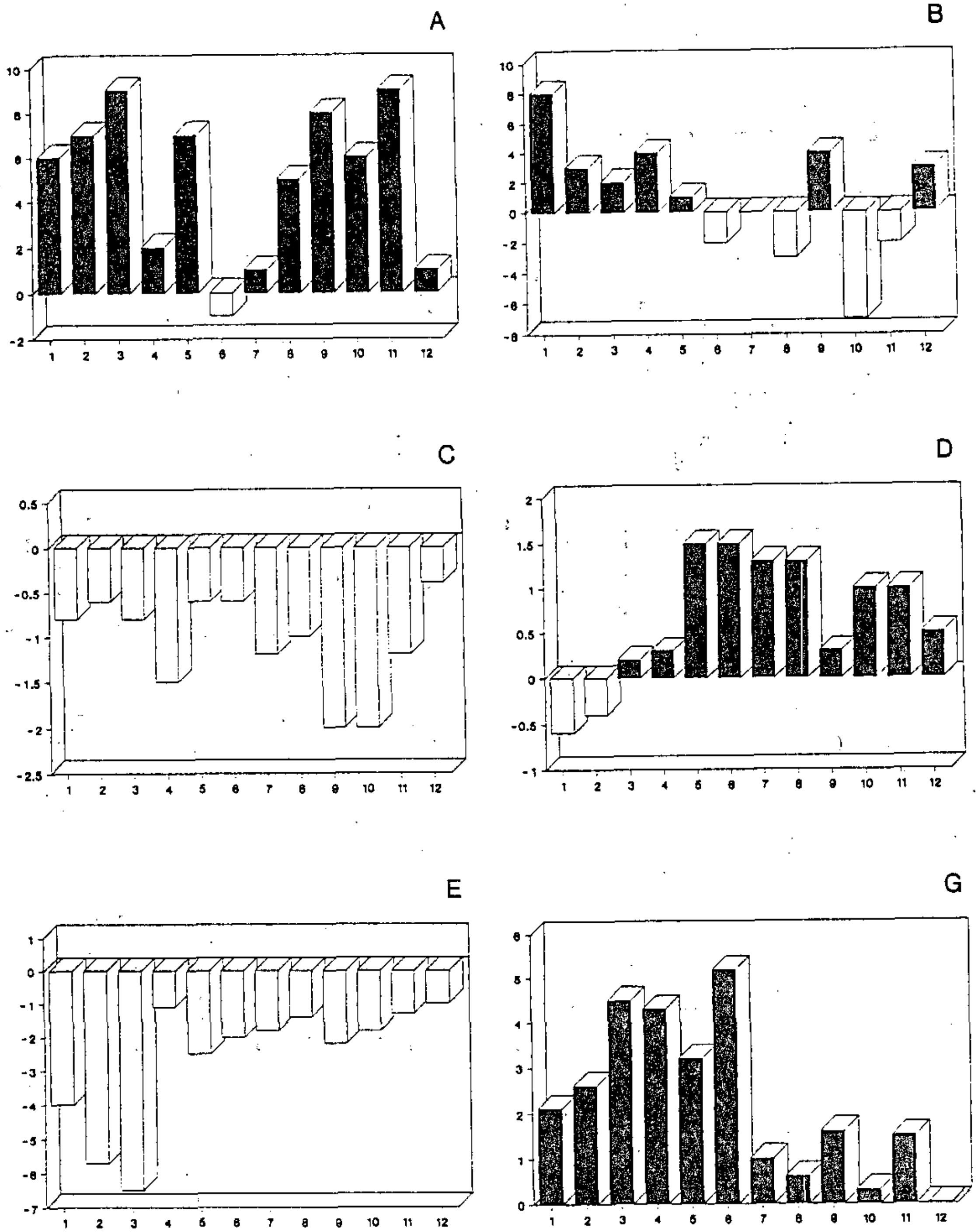


Fig.5. Mean monthly values for anomalies of stormy days (A,B), air temperature (E,G) and water surface temperature (C,D), respectively, in the Labrador and Barents Seas in 1989.

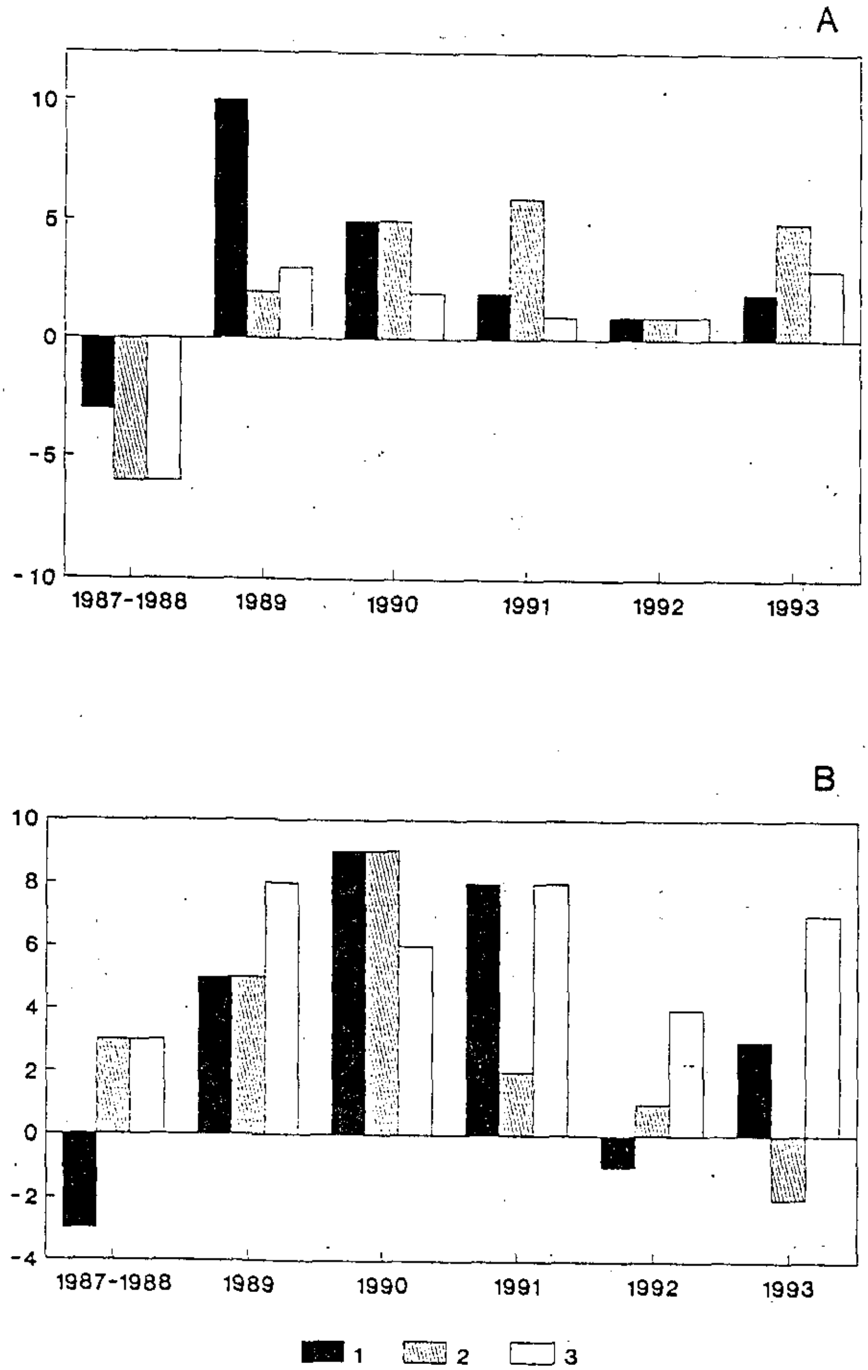


Fig. 6. Anomalies of number of stormy days for the Barents (A) and Labrador (B) Seas areas in January-March (1,2,3), 1989-1993.

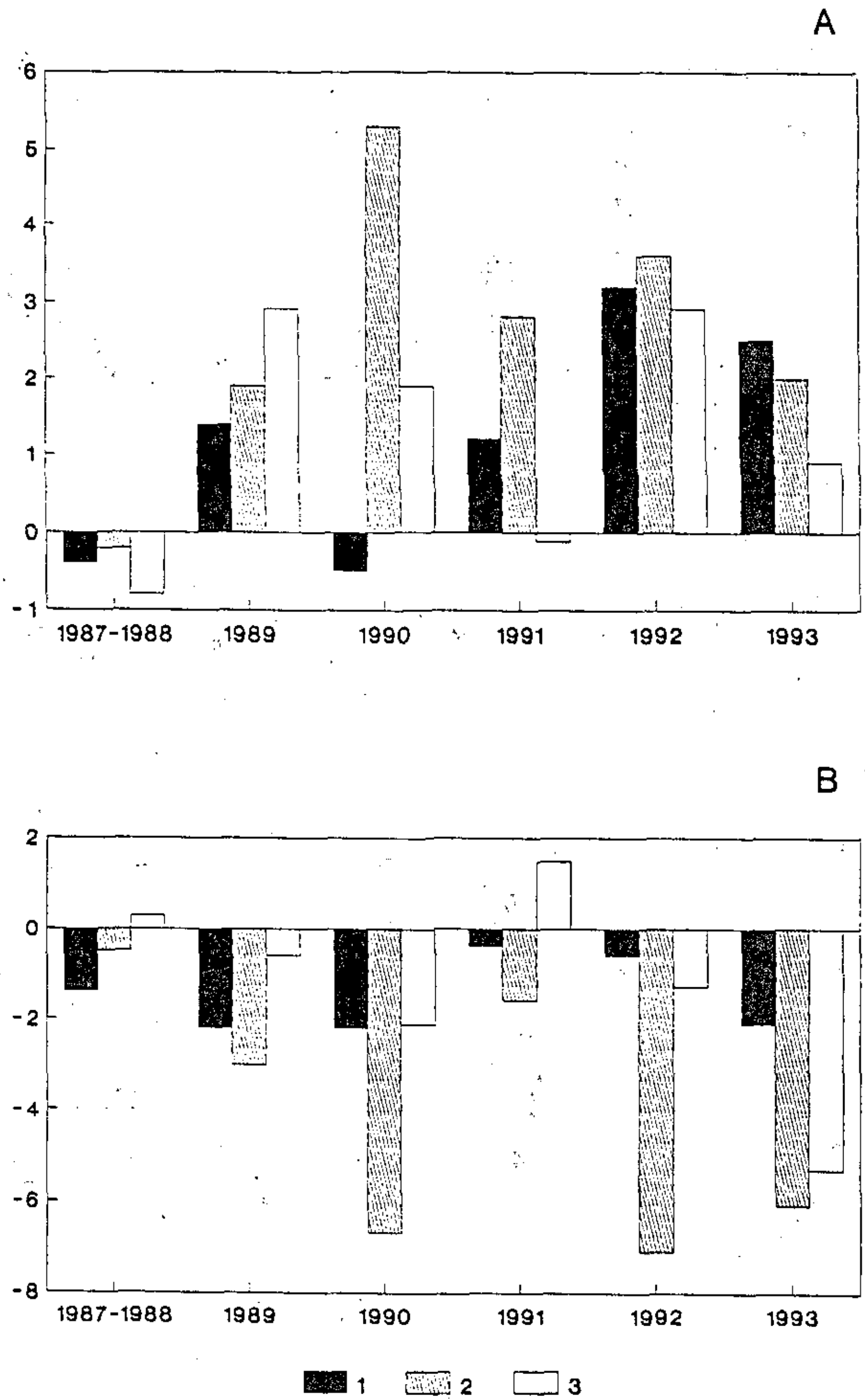


Fig. 7. Anomalies of air temperature in the Barents(Vardo)-A and Labrador (Goose Bay)Seas in January-March (1,2,3), 1989-1993.

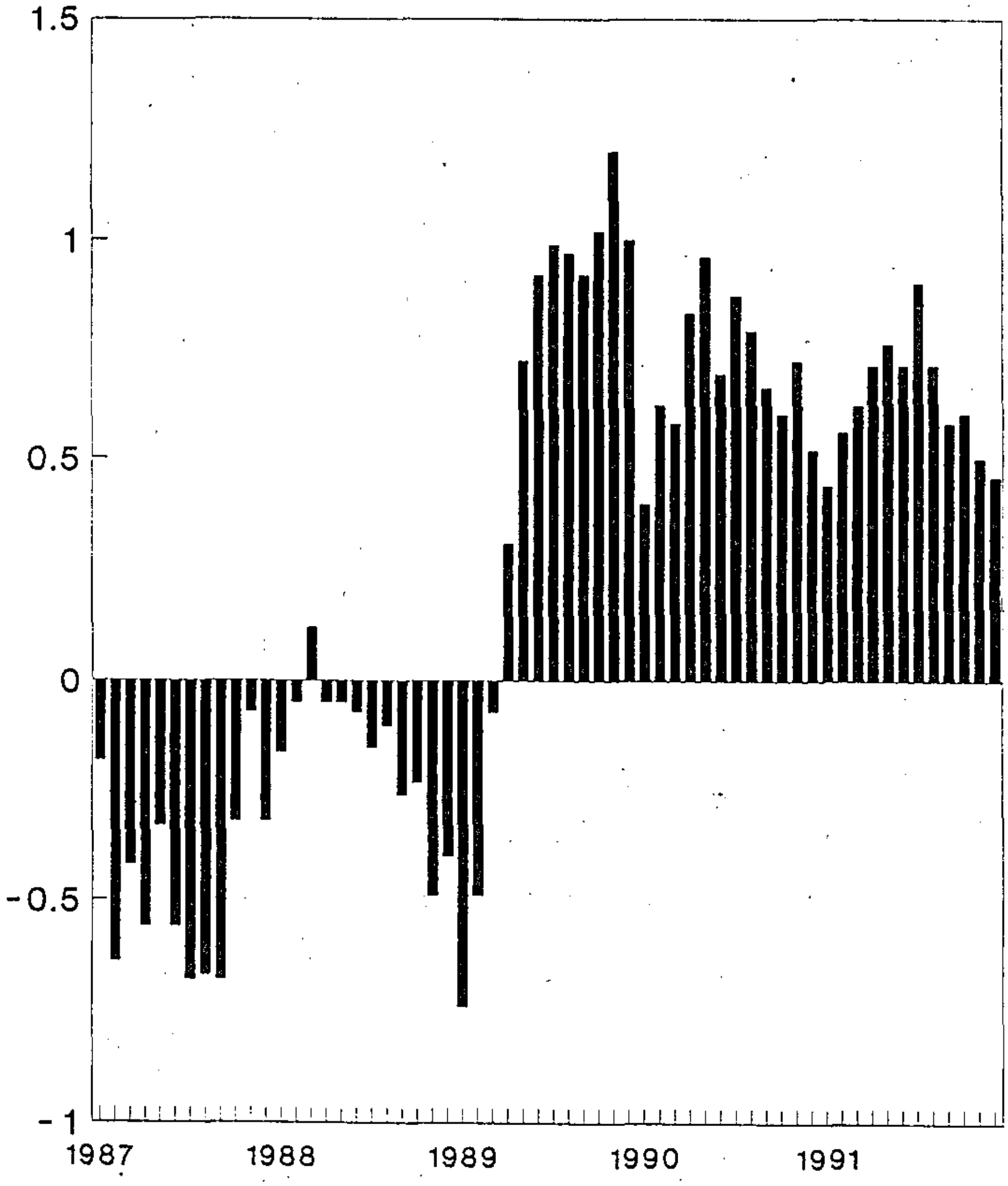
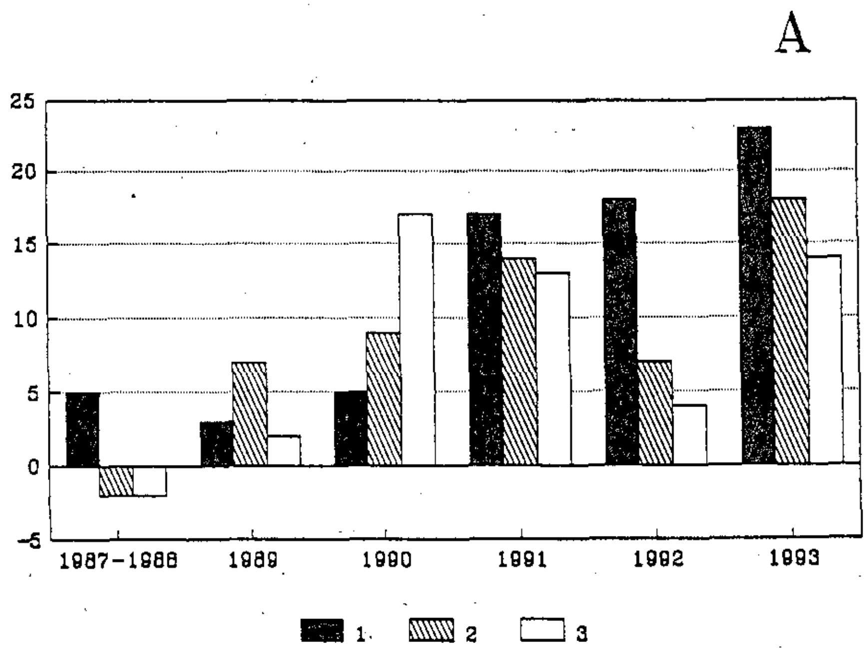


Fig.8. Monthly anomalies of water temperature in 0-200 m layer along the "Kola Meridian" section in 1987-1991.



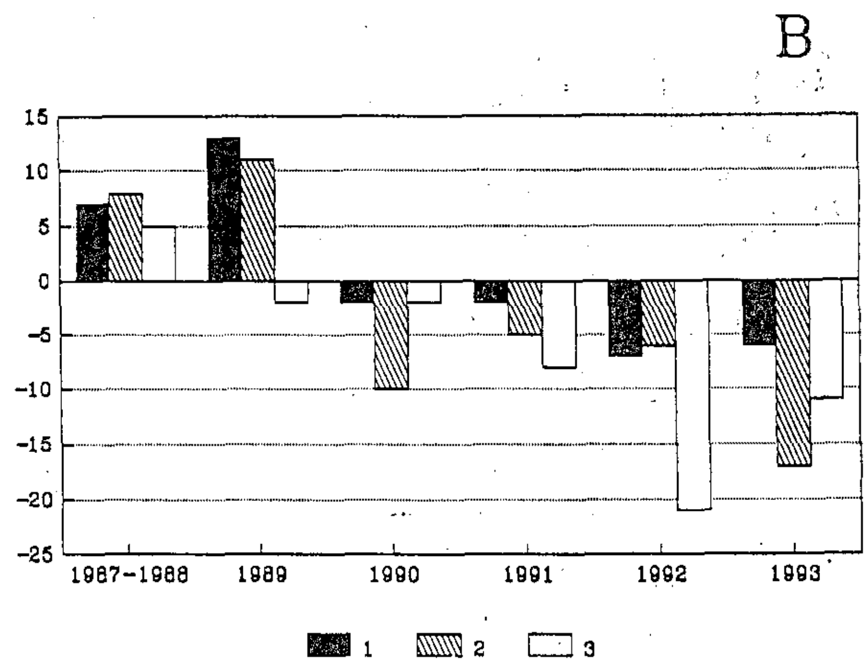


Fig.9. Anomalies of ice coverage in the Labrador (A) and Barents (B) Seas in January-March (1,2,3), 1989-1993.

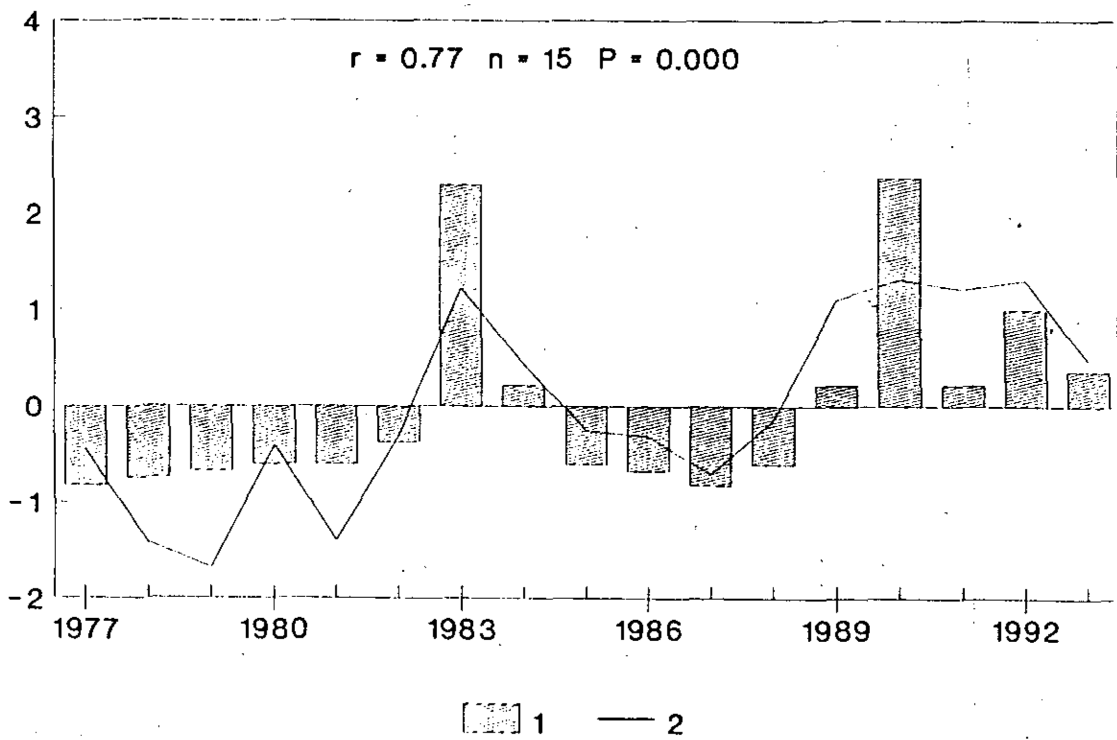


Fig.10. Normalized anomalies of mean catches of young cod at age 3 - (1) by the data from PINRO assessment surveys for ~~1977-1993 yearclasses and temperature~~ of water in 0-200 m layer along the "Kola Meridian" section - (2) in the Barents Sea.
1992 - catches
1993 - forecasting.

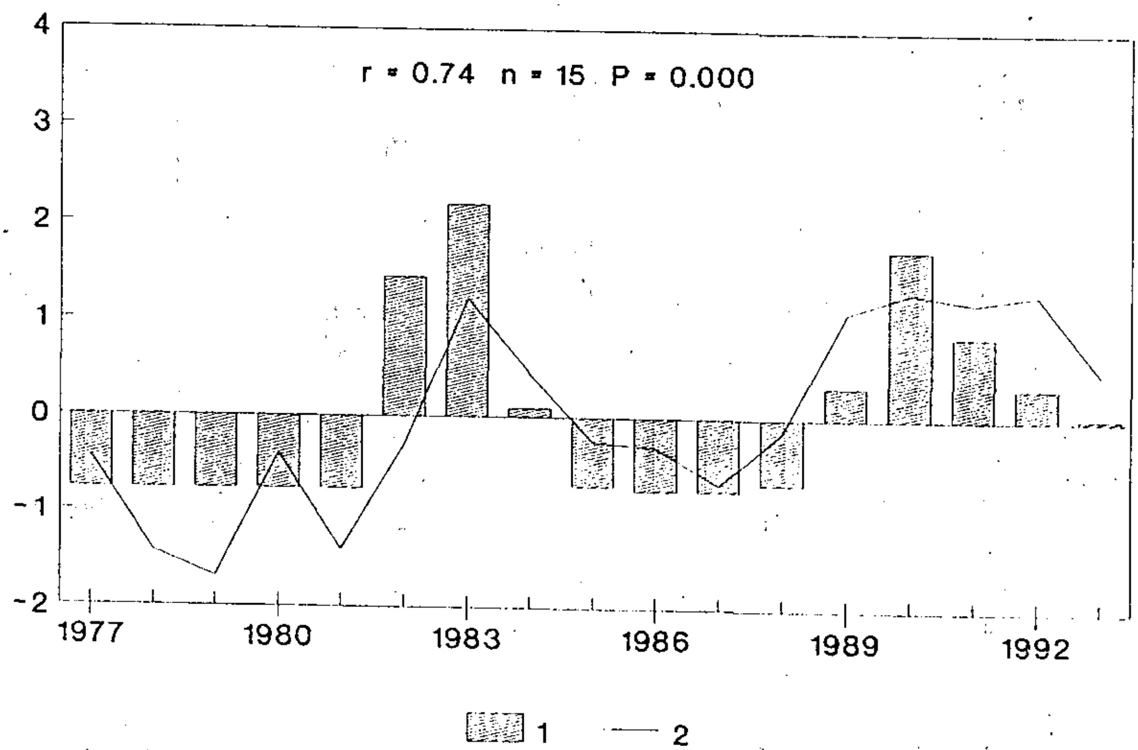


Fig.11. Normalized anomalies for mean catch of young haddock at age 3 - (1)from 1977-1993 yearclasses by the data from PINRO assessment surveys and temperature of water in 0-200 m layer along the "Kola Meridian" section - (2) in the Barents Sea.
1992 - catches
1993 - forecasting.

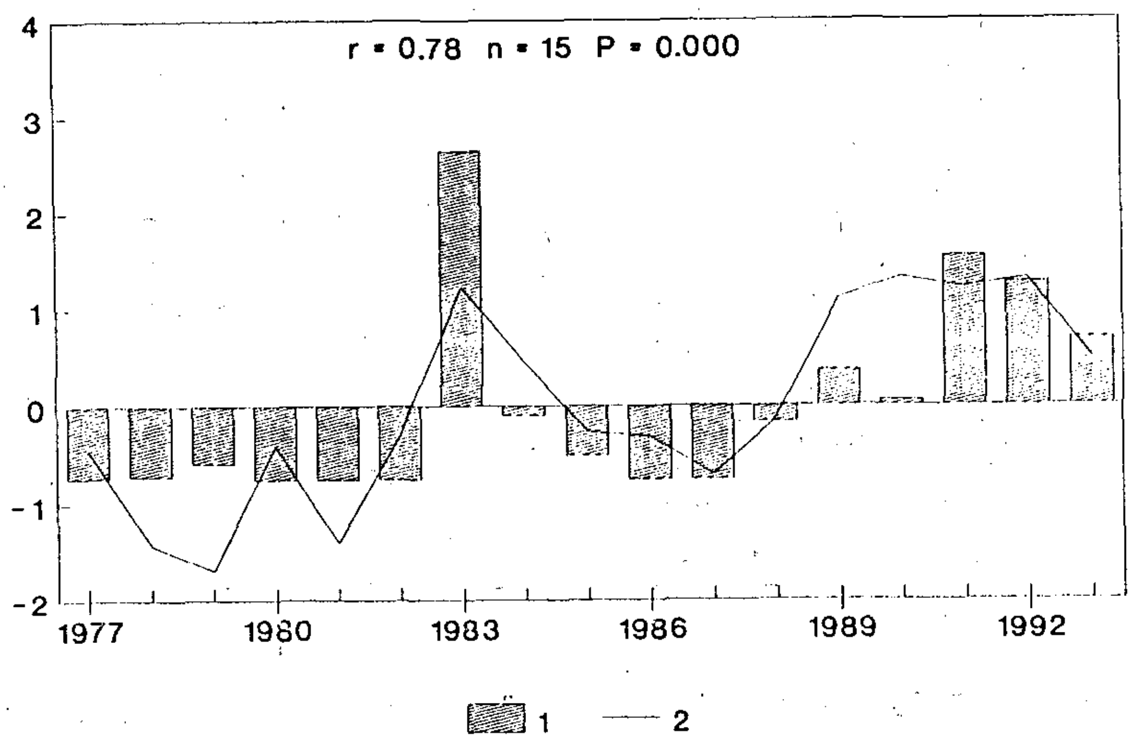


Fig.12. Normalized anomalies (log 10) of index for 0-group herring from 1977-1993 yearclasses - (1) and temperature of water in 0-200 m layer along the "Kola Meridian" section -(2) in the Barents Sea.

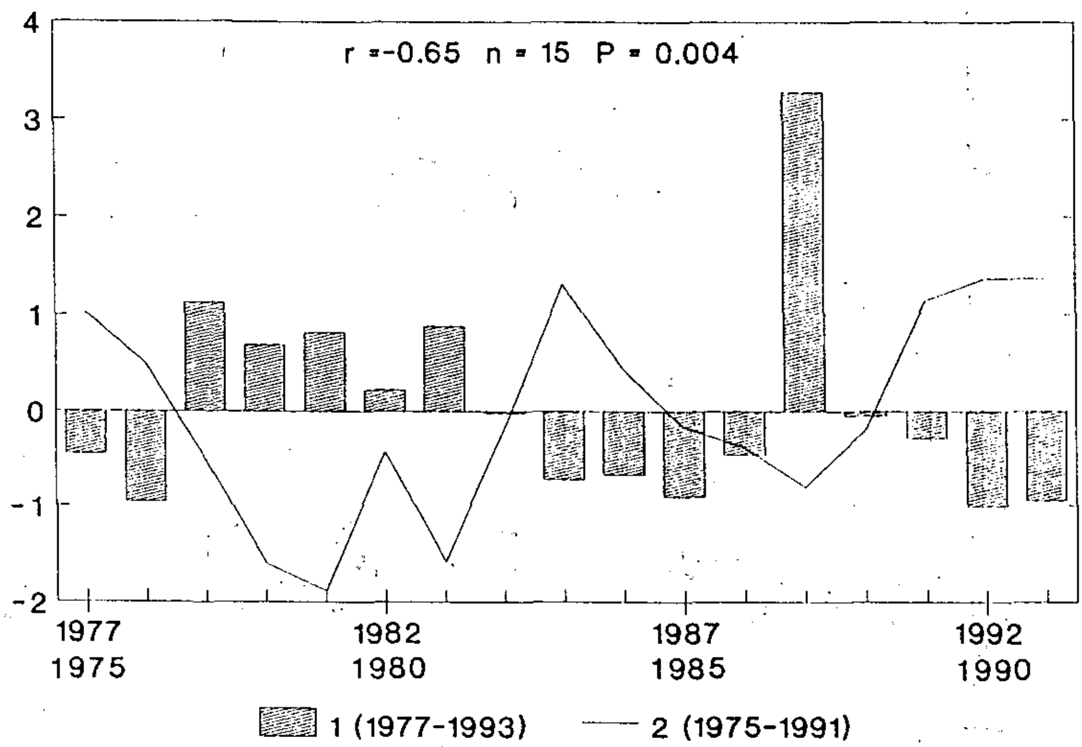


Fig.13. Normalized anomalies for index for O-group capelin abundance by results from Russian/ Norwegian surveys on O-group fish from 1977-1993 yearclasses - (1) and temperature of water in 0-200 m layer along the "Kola Meridian" section- (2) in 1975-1991, i.e. two years prior to capelin yearclass appearance.