# Scientific Cooperation in the Russian Arctic: Research from the Barents Sea up to the Laptev Sea

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**Edited by Eike Rachor**

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## Contents

# Foreword

This volume of „Berichte zur Polarforschung" contains several papers originating from Russian-German cooperation in the Russian Arctic seas (mainly the Barents Sea region), especially from members of the Murmansk Marine Biological Institute (MMBI), Kola Scientific Centre of the Russian Academy of Sciences, and their partners at the Alfred-Wegener-Institute for Polar and Marine Research in Bremerhaven, Germany (AWI).
A review paper of S. F. Timofeev (MMBI) about the hitherto existing knowledge of zooplankton in the Laptev Sea is included, as well as a review paper of the former director of the Dalnie Zelentsy Station of MMBI, Yu. I. Galkin, about his studies on the long-term variability of benthic molluscs in the Barents Sea.

Unfortunately, the editing of this specific volume of „Berichte zur Polarforschung" was delayed. Accordingly, very new results (e.g. since 1996) were not included in the majority of the papers. Therefore, I want to mention that overviews about the continuation of the Russian-German cooperation in the Arctic are available in several other volumes of „Ber. Polarforsch.", including reports of expeditions (e.g. nos. 211, 226, 234, 237, 255).

Taking in account the delay mentioned, nevertheless, the general introduction written by G. G. Matishov in 1996, is still valid and presented below.
I want to thank all the Russian partners and several German reviewers for their patience and help in the amending and editing work.

Eike Rachor (AWI),
editor of this specific volume

## Introduction

The histora of the scientific and technical coorperation in Arctic investigations between the Alfred-Wegener-Institute for Polar and Marine Research Bremerhaven (AWI) and the Murmansk Marine Biological Institute RAS (MMBI) began with the signing of the first inter-institute agreement in February 1991. This date coincided with the beginning of a new phase in the Arctic Ocean investigations to reveal its role in the global budget of energy and matter fluxes. A main effort of international scientific activities since 1991 was directed to the European and Asian shelves.

The AWI was one of the initiators and a main executor of these investigations. The unique sientific and ice-breaking RV „Polarstern" was the means of archieving these aims. It was the research vessel's appearance in the Eurasian Actic that opened quite new stages and horizons in the understanding of the mechanisms which form the interconnection between the inanimated and animated nature of the deep-water Actic basins and the shelf-slope boundaries.

The Murmansk Marine Biological Institute is closely connected with the seas of the western (Eurasian) Arctic for more than 50 years. Since the mid 30th, when the first investigations of biological communities of the Murman coast began, the

institute has carried out research work on board of its ships over the large area from the North to the Kara Seas for more than 40 years.
Uniting the MMBI efforts with those of the AWI enabled the Russian scientists to expand the zone of their research work up to near-Pole areas.

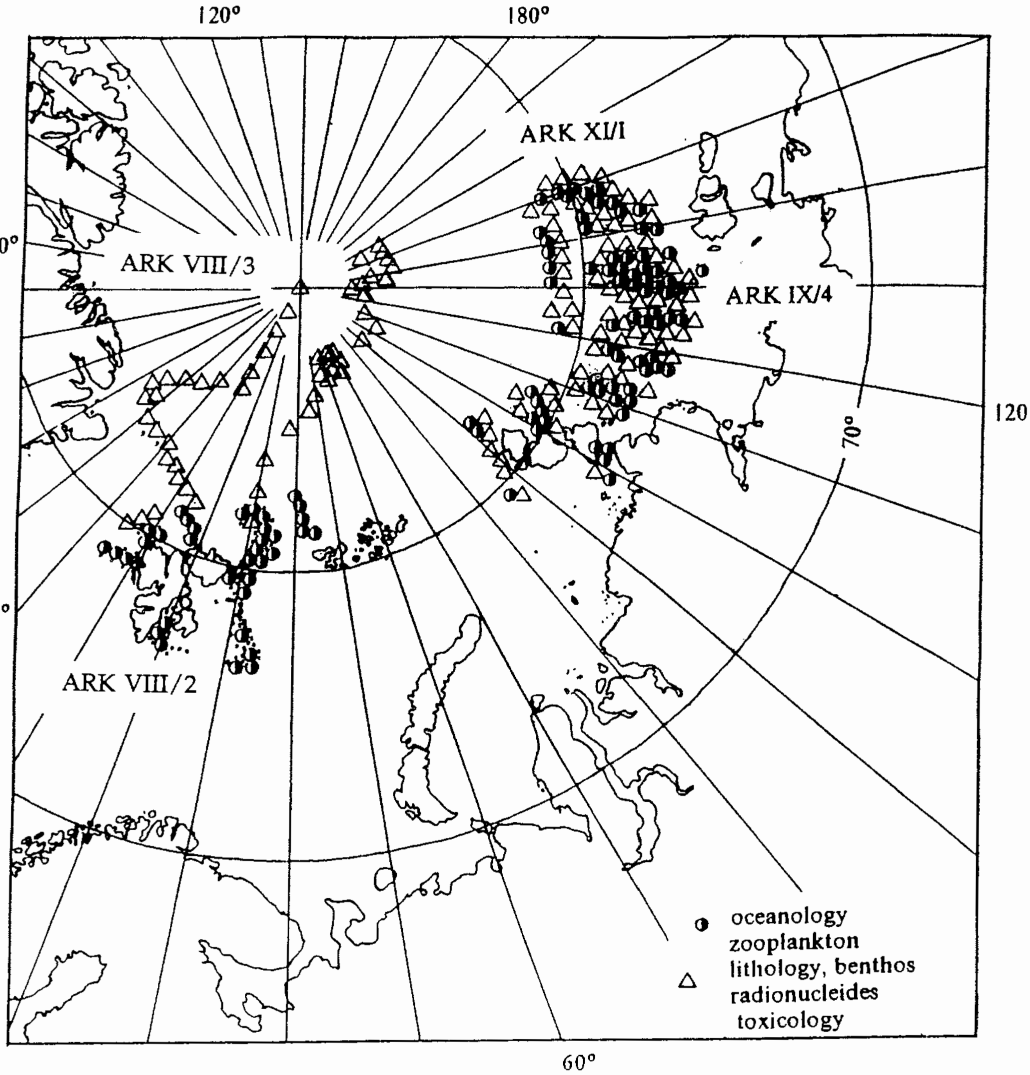
During 1991-1995, specialists of the MMBI took part in four Arctic expeditions on board RV „Polarstern", and thereafter, also in 1996 (ACSYS), 1997 (Yermak Plateau) and 1998 (Alpha Ridge). The geographical areas covered during the cruises of 1991 till 1995 as well as the scientific branches involved in the data collection are indicated in Fig. 1. As seen from this figure, the main areas of the investigations were chronologically shifted from the west to the east. The project „The Laptev Sea System" together with the research in the adjacent deep sea basins became a very important focus in the interdisciplinary investigations, in the realisation of which many scientific organisations in Germany and Russia have taken part.

The following collection of articles is mainly devoted to several results of the joint efforts of the AWI and the MMBI in the high Arctic in 1991-1995. The most distinguished and unique feature of most of these contributions is that the majority of the natural data were received on board the ice-breaking RV „Polarstern". The thematic range range of this collection is very wide - from hydrology to contamination (and, thus, toxicology). Parts of the materials are still of fragmentary character, reflecting the first experience of joint work under new circumstances and, sometimes, very severe sampling conditions. Several data mark the beginning of deeper partnerships of scientists from both institutes. Such partnerships have been expanded within scientific projects under the aegis of national and international (INTAS, ESF) scientific funds (for instance, the projects „Processes of sedimentation in the Kara Sea", „Zoobenthos and climate variability in the Barents Sea").

The principal branches of all joint investigations of scientists of the AWI and the MMBI are as follows: Research related with the geological history of the Arctic, with paleo-oceanography, sedimentology and geochemistry (including contaminants, even from fallouts), with the biogeography of zooplankton and benthos and the dynamics of benthos communities.

We hope that this collection will be continued by new issues of articles. A good basis for the subsequent scientific cooperation of both institutes has been the memorandum on future cooperation (1995-1999), signed by the directors of AWI and MMBI during the visit of EU-administrators and representatives of the European Science Foundation at the MMBi in July 1995.

Professor Dr. Gennady Matishov,
Academician, Director MMBI




Introduction. Figure 1

**Map of the Arctic expeditions of the German RV „Polarstern" with MMBI participation** (ARK VIII = 1991; ARK IX = 1993, ARK XI = 1995)

# Oxygen indication of the descending convection of sea water near the Svalbard archipelago („Polarstern" expedition, June-July, 1991)

Adrov, N.M. & Matishov, D.G.

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In June-July, 1991, during a complex oceanological survey of RV „Polarstern", data to confirm the hypothesis of the formation of deep (near-bottom) Arctic waters at the shelves of the Greenland Sea and the Barents Sea were collected (Fig. 1).

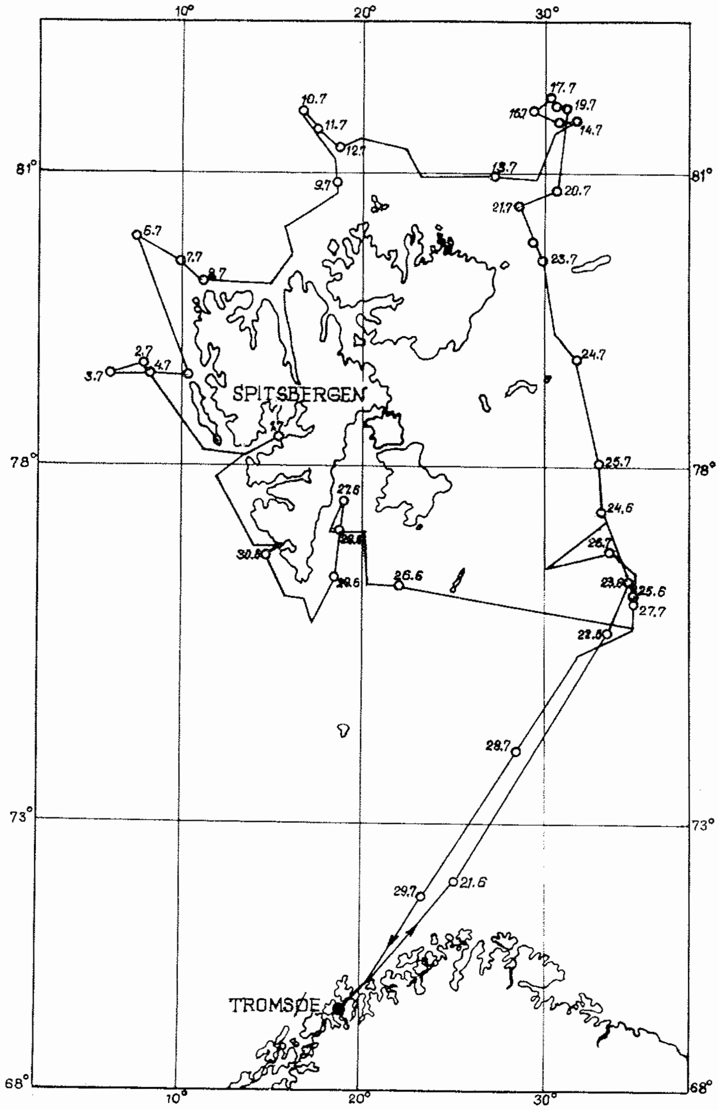



Fig. 1.

RV „Polarstern" expedition route

20. 6. - 20. 7. 1991
(„Arctic EPOS")

According to Zubov (1944), the main cooling of the superficial water takes place at low depths in these seas during the winter seasons. As a result, cold water may descend into the bottom layer of the deep Arctic basin (and into the abyssal zone of the Greenland Sea, particularly). In order to adopt or to reject this hypothesis, a method should be used which permits to trace the fate of cold water during its downward movement.

This problem may be solved by investigating the process of water transfer with the aid of direct (tracer) and indirect (indicator) parameters. The properties of a tracer will not be influenced by ocean processes; accordingly, floats, buoyes etc. may be used to trace the horizontal transfer. The vertical one may be investigated by means of several man-made radioisotopes or other conservative substances. If an index is to be used, the properties of which are connected with ocean system variability, an index-indicator may be chosen.

Some indicators apparently react only to physical conditions in the system. Water temperature and salinity, floating ice boundaries and other indices depending on energy and moisture exchange between ocean and atmosphere may be good examples. Indicators of a second kind are mainly related to biological processes.
These indicators are biogenous elements, like chlorophyll-a concentration, fluorescence etc. Indicators of the third kind possess the properties of both abovementioned kinds, and one of them, dissolved oxygen, was used in this investigation. This choice may appear unexpected, as the main reason of its variability is traditionally considered the activity of marine organisms, i.e. biological processes. But, there is another important reason of the oxygen content variability, which is connected with physical processes in ocean.

Essentially, the problem is as follows: Cooling of the superficial water layer results in change of its density and, consequently, in descending of some amount of water. Due to the rate of this process, the cooled water may not get its 100% oxygen saturation and descends with its deficiency. But, how can we distinguish physical and biological contributions ?
To answer this question, changes of the dissolved oxygen concentration should be considered, and causes influencing it must be clarified.

The problem of the origin of oxygen deficiency was studied by M. Adrov (1959), who discussed mechanisms of the formation of low oxygen contents in the water column. A vertical decrease of dissolved oxygen concentration is interpreted by the following hypothesis: Under normal - well mixed - conditions everywhere in the water column the ratio between temperature, amount of dissolved salts and amount of dissolved gas is constant. Owing to this regularity, correlation indices between distribution of the oceanographic parameters are close to the extremal ones, as long as the existing equilibrum is not disturbed. After increasing or decreasing of any of the interconnected parameters by any external factor (heat absorption and radiation, precipitation or water evaporation, ice melting and formation, activity of organisms), the absolute values of the correlation indices decrease, and fluctuations of the investigated parameter appear in the disturbed sites.

If organisms did not participate in oxygen exchange between ocean and atmosphere, oxygen contents in ocean and atmosphere would depend only on physical conditions. In the circulation systems of open oceans these physical conditions are determined by advective and convective transportation of water particles. Advective transportation is accompained by contact between water and air parcels, whereas the convective one can be accompanied by isolation of them. Thus, the cooled water will exchange oxygen with atmosphere under advective transportation, whereas we may record little or no exchange under convective descending.

Physical and biological conditions providing oxygen exchange between ocean, atmosphere and biosphere are a priori considered by us as normal, as far as under any deviation from saturation, equilibrating mechanisms are persisting.

The air pressure in the lower atmosphere layers may be considered as constant with about 1000 millibars. Oxygen absorption and desorption by ocean water with the atmosphere depends on several factors; the keys of them (temperature and salinity) determine water density and values of both, gas absorption and emission. To study the saturation of small water parcels with oxygen in such big objects as water masses, we can disregard fluctuations of both, atmospheric pressure and salinity. Water saturation with oxygen under small changes of salinity is determined by dissolved oxygen concentration and water temperature. Similar to thermohalinous transformation, the thermooxygenous one depends on the duration of interaction between water and atmosphere. Saturation hysteresis phenomena are recorded in autumn-winter, when cooling waters do not manage to absorb sufficient atmospheric oxygen and, during convective descending, obtain a dissolved oxygen deficiency of physical origin.

The normal saturation with oxygen is 100% not only because this value is the saturation maximum for water under existing physical conditions without biology, but, also, as it describes the average thermooxygenous state of the superficial water layer. The latter circumstance is not less important for the study of the ocean oxygenous structure than the existence of an oxygen minimum.

Under constant parcel temperatures, increasing oxygen concentrations may result from photosynthesis of marine algae, whereas oxygen decrease is mainly connected with its consumption during respiration of hydrobionts.

The choice of a parcel's way along the isoxygene is of special interest, as in this case the distance covered by its way up and down with constant $O_2$ will be proportional to the intensity of cooling or heating.
Simultaneous decreasing of both, dissolved oxygen concentration and temperature, shows a disturbance of the inversely proportional function of oxygen and temperature change which is typical for the aired ocean water. Such a disturbance may be caused by some peculiarities of water circulation under pronounced cooling of the ocean surface in middle latitudes. In low latitudes such oxygen deficiency attains maximum values, whereas in high latitudes (for example, in the Norwegian-Greenland basin and in the Barents Sea, if no transitional water bodies are recorded) waters even with low concentrations of dissolved oxygen possess high oxygen yields (80 to 85%).
The superficial water saturation, which averages 97 to 99%, permits to use the equation of thermooxygenous transformation of superficial water bodies in order to calculate deviations of the dissolved oxygen concentration from the standard,

i.e. to use this equation for estimation of the average thermooxygenous state of water.

Norm equations of thermooxygenous transformation (similar to transformation equations for transitional and deep waters) express the inversely proportional dependence of dissolved oxygen concentration on temperature. On the contrary, in central water bodies a directly proportional dependence of oxygen on temperature is recorded. Under such circumstances, the correlation between oxygen and temperature has lower values than in superficial, transitional and deep waters.

If we consider changes of oxygen ($\delta O_2 = O_2^m - O_2^1$) and temperature ($\delta T = T_m - T_1$) budgets; with $O_2^1$ and $T_1$-values of oxygen and temperature at the initial stage of thermooxygenous transformation of a water body, and $O_2^m$ and $T_m$ - those at the final stage, then the advection condition will be as follows ($\zeta$ = oxygen saturation level):

$$\delta T < O\ ;\ \delta O_2 > O\ ;\ \zeta = \text{const.}$$

Advection is a direct transportation of water particles mainly due to work of the thermal machine of ocean-atmosphere. It is accompanied by matter exchange between water and air bodies, in this case - by oxygen exchange under transportation of water particles and their cooling.

Convection is a transportation of water particles requiring negative buoyancy due to cooling (or evaporation). After beginning, it is not accompanied by further exchange between ocean and atmosphere. The convection condition for water thermooxygenous transformation in the circulation system of open ocean is as follows:

$$\delta T < O;\ \delta O_2 = O;\ \delta\zeta < O$$

The negative oxygen budget related to biological processes is not connected with temperature changes. Accordingly, the conditions of biological oxygen consumption are considered to be described by

$$\delta T = O;\ \delta O_2 < O;\ \delta\zeta < 0\ .$$

Fig. 2 demonstrates vectors of convective and advective components of thermooxygenous water transformation and biological oxygen consumption in the time interval $t_1$ to $t_m$.

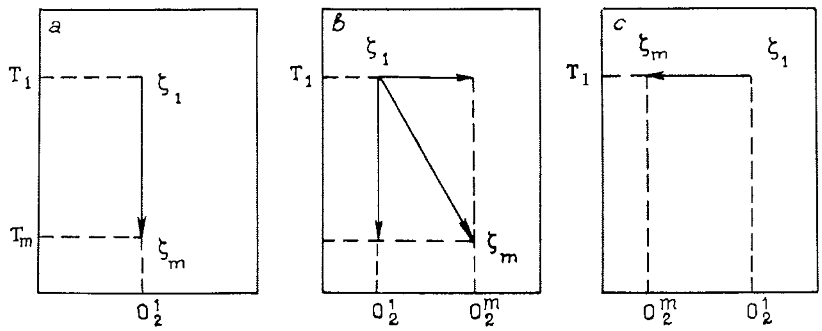



Fig. 2. Temporal changes of temperature T, dissolved oxygen concentration $O_2$ and level of oxygen saturation z under:

a) convection, b) advection and c) biological oxygen consumption

In our region, the nearest place for analyses of such water transformations is the Barents Sea (s. also contribution of Ilyin et al., this volume). The range of oxygen change in the Barents Sea (exclusive of waters oversaturated with oxygen up to 120% due to extraordinarly high photosynthesis of phytoplankton, and stratified fjord waters with saturation of less than 80%) makes up, approximately

$$O_2=7.5\pm1.0 \text{ ml/l}; \ \zeta=100\pm20\%.$$

The oversaturation of water with oxygen results from predomination of two processes: 1) the physical one - advective transportation of water parcels, which absorb atmospheric oxygen and become saturated up to 100%; and 2) the biological process - by which water becomes oversaturated.
It is more difficult to explain the origin of under-saturation in total, esp. the extremum at 80%, as we know almost nothing about a possible contribution of physical processes to the oxygen under-saturation of water. These processes should be evaluated.

A generalized scheme based on statistical data (from several expeditions) was used to estimate contributions of physical and biological processes to the formation of waters with oxygen deficiency in the Barents Sea. According to this scheme, changes of oxygen and temperature from 0 to 50 m beneath the surface are characterized by inversely proportional functions and are approximated by a line almost coinciding with that of the 100% saturation of superficial waters with oxygen. At 75 to 300 m beneath the surface, the dependence between oxygen and temperature is direct. The line approximating this function connects oxygen values close to the normal ones with minimal values of $O_2$= 6.6 ml/l; $\zeta$= 80% at T= -1 °C

The linear dependence between oxygen and temperature, and the representation of the temperature and oxygen changes in vector space T, $O_2$ have permitted to create a model of thermooxygenous transformation of the Barents Sea water body (Fig. 3). A calculation of physical and biological components of the dissolved oxygen deficiency can be carried out via this model (Adrov, 1993). Data on temperature, dissolved oxygen concentration and values of water saturation with oxygen in points A, B, B', C and D are given in the Table 1.

Let's imagine that a water parcel at the time $t_1$ is in the point A and moves, by convective immersion, to point C at the time $t_m$; then: $\delta T$= -5.5°C; $\delta\zeta$= -12%; $\delta O_2$=O ml/l. If the parcel undergoes advective transportation, it arrives at D, with $\delta T$= -5.5°C, $\delta O_2$= 0.9 ml/l, $\delta\zeta$= 0%. If oxygen is only spent by biological processes, the parcel moves to point B with $\delta O_2$= -0.4 ml/l, $\delta\zeta$= -5%, $\delta T$=O °C.

Table 1: Values of temperature and oxygen in points A, B, B', C and D (Fig. 3)

| Point | T °C | $O_2$, ml/l | $\zeta$, % |
|---|---|---|---|
| A | 4.5 | 7.0 | 97 |
| B | -1.0 | 6.6 | 80 |
| B' | 4.5 | 6.6 | 92 |
| C | -1.0 | 7.0 | 85 |
| D | -1.0 | 7.9 | 97 |

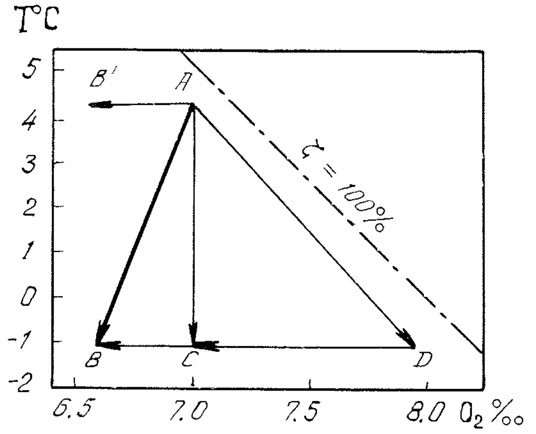



Fig. 3. Model of thermooxygenous transformation of the Barents Sea water mass.
AB - principal vector of transformation. Constituting vectors:
AD - advection, AC - convection, CB - biological oxygen consumption

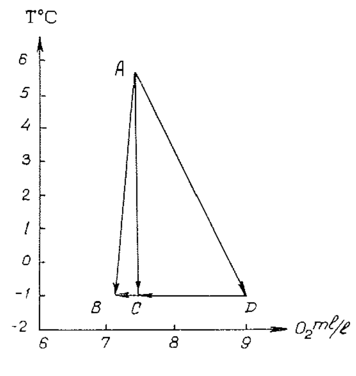
The calculation of physical and biological components of the dissolved oxygen deficiency can be reduced to a determination of modules of vectors DC and CB, totally constituting an absolute value of the oxygen deficiency DB vector module (Table 2 A.).

Table 2: Components of the dissolved oxygen deficiency
A. in the Barents Sea (archive data)
B. in the region studied by RV "Polarstern" in summer 1991

| | Oxygen deficiency (DB) | | Biolog. consumption (CB) | | Saturation hysteresis (DC) | |
|---|---|---|---|---|---|---|
| | (ml/l | %) | (ml/l | %) | (ml/l | %) |
| A. | 1.3 | 17 | 0.4 | 5 | 0.9 | 12 |
| B. | 2.0 | 22 | 0.4 | 4 | 1.6 | 18 |

Table 2 A. shows that the saturation hysteresis in the Barents Sea after strong cooling may be more than twice as much as biological oxygen consumption and, then, is the main factor of formation of waters with dissolved oxygen deficiencies. According to the "Polarstern" expedition data (e.g. Luchetta et. al., 1992), components of the dissolved oxygen deficiency (Table 2 B.) are calculated, and a model of thermooxygenous transformation is created (Fig. 4).

Fig. 4. Model of thermooxygenous transformation of water according to data of the „Polarstern" expedition 1991



In the North European basin seas, open to the influence of the Atlantic water masses, cooling and subsequent descending of the superficial water takes place. The conditions causing this process develop due to a certain combination of external factors acting within limited späce and during short terms. As a result, limited volumes of cold water arise in the water column and near the bottom; their distribution is of great spatial and temporal irregularity.

The occurrence of layers with abnormal properties is a result of the activity of the thermal machine ocean-atmosphere changing the thermohalinous properties of water parcels. The questions about waters forming these layers, patterns of their circulation and exchange with adjacent water bodies may be answered by means of temperature and salinity characteristics demonstrating energy and mass exchange between ocean and atmosphere.

It is generally known that in all circulation systems water temperature decreases from the ocean surface to bottom, whereas salinity can decrease, increase or be constant. Conditions of constant salinity hamper the revelation of differences between advective and convective changes of thermohalinous properties of the parcels. Thus, salinity changes during water transportation from surface into the depths are superimposed by salinity changes through horizontal transportation.

To analyse the ambiguity of the vertical salinity changes, let us use a condition of steadiness of vertical water stability and consider sea water properties like density. In the geometrical space T, S, ρ three cases of changes of thermohalinous properties may be distinguished under two constant conditions of water temperature decreasing and its density increasing (Fig. 5).

The first case is an example of convective transportation: a water parcel directly gives a part of its heat to the ocean; no water vapour is formed. This type of the transportation takes place without mass exchange between ocean and atmosphere, and water salinity is constant. The convection conditions may be represented as $T_{t\,1} > T_{t\,2,}$ ; $S_{t\,1} = S_{t\,2}$ .

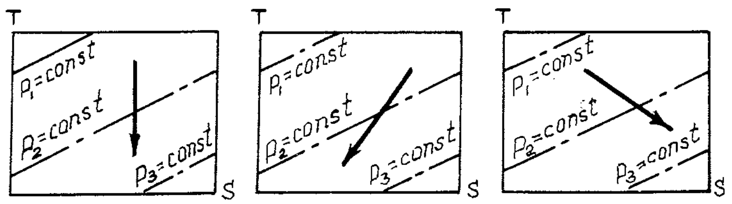



Fig. 5. Three kinds of changes of thermohalinous properties of water parcels in ocean water masses

In the second and third cases, heat and mass of water parcels participate in the work of the thermal machine ocean-atmosphere. Then, heat output of each parcel is proportional to the amount of water abandonning in form of vapour (the more water is vapoured, the greater are the heat expenses). Such changes of water temperature in the ocean are in accordance with changes of the parcel salinity.

If its vertical steadiness is disturbed, the parcel will move down. Simultaneously (in the 2nd case), the parcel realizes advective shift. Precipitation fallen during this water transportation and representing condensed vapour rehabilitate a part of the water body of the parcel. This, on a larger scale, results in a decrease of water salinity of the circulation systems of open oceans. In terms of geography, heat store is a relative value, as the parcel having spent a part of its heat and mass is considered to be cold in temperate regions and to be warm in the polar ones. The condition of advection of this sort is as follows: $T_{t1}>T_{t2}$ ; $S_{t1}>S_{t2}$.
The parcel moves along isopycnals, and the advection is called isopycnal.

In polar regions (or in regions with pronounced evaporation), there is one more type of advection - the diapycnal one: a water parcel moves in the T, S, r surface and crosses isopycnals (the 3rd case). This phenomenon takes place in polar waters isolated with ice cover, when only an insignificant amount of water vapour moves into the atmosphere. During the period of the ice cover existence, the matter exchange between ocean and atmosphere is disturbed. Therefore, under cooling, a part of its water body is "evaporated" and transforms into ice. The rest, having got no precipitation from atmosphere which could compensate for the expense of its water body, increases in density and descends. In this case, the contribution of the convective component increases. The condition of the diapycnal movement may be represented as $T_{t1}>T_{t2}$ ; $S_{t1}<S_{t2}$.

These theoretic considerations result in the development of a scheme of T,S-transformation of the Barents Sea waters (Fig. 6).

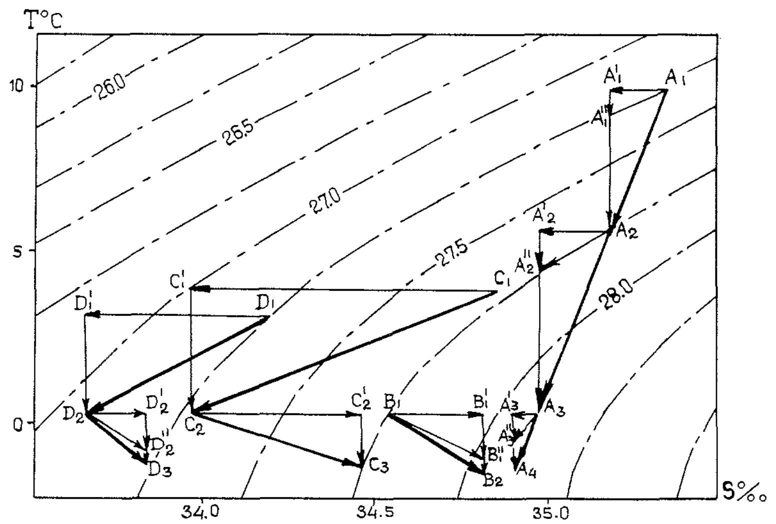



Fig. 6. Vector T, S-scheme of water mass transformation in the Barents Sea. Thick arrow-heads point to principal vectors of Subarctic ($A_1A_4$) and Arctic ($B_1B_2$) waters of the Gulf Stream system, front waters $C_1C_2$ and $C_2C_3$, and Arctic Ocean waters $D_1D_2$ and $D_2D_3$; thin arrow-heads point to the constituting vectors of temperature and salinity budgets of the water masses

Vector $A_1A_2$ of the scheme characterizes sub-polar waters of the Gulf Stream system. The inclination of isopycnals changes according to the T range. Therefore, the relation between the convective and advective components of transformation (represented by ratios of modules of vectors $A_1A_2''$ : $A_1''A_2$ etc.) differs at different transformation stages of these water masses: The convection role is very important at the transformation stages within the positive T area, $A_1A_2$ and $A_2A_3$ ; whereas it decreases in the range of negative temperature, at the $A_3A_4$ stage. These subpolar waters never form ice as far as they have high T and S values preventing any ice formation under winter conditions typical for the Barents Sea.

Formation of abyssal waters possessing extremely low temperatures from superficial waters of the Gulf Stream system is of low probability. The great advection of Atlantic warm waters supports the constancy of all thermohalinous characteristics of this water mass. Except for these subpolar waters of the Gulf Stream system, the whole water of the Barents Sea is open to ice formation, which is confirmed by diapycnal transformation components $B_1B_1''$, $C_2C_3$ and $D_2D_2''$. Limited volumes with abnormal distributions of hydrologic features are obviously developed from these waters.
The waters $D_2D_2''$ (conventional density less than 27, 25) have no connections with the Gulf Stream system. As a result their salinity is low and their heat stock is small as compared to waters of Atlantic origin. During winter cooling these waters are rapidly cooled and stratified (usually they occur in shallow coastal regions) and promote rapid ice formation.

## Conclusions

The analysis of T, S and T, $O_2$ -schemes permits several conclusions. There is a dependence between hydrodynamic processes and the content of the oxygen dissolved in the water; its physical properties permit to choose oxygen as an indicator for descending movements of water parcels in the ocean.

The thermooxygenous structures of the Arctic basin waters differ greatly from those in the North Atlantic region. A transitional layer is absent from the Arctic basin. Accordingly, the minimal relative saturation of waters with oxygen in the Arctic basins is recorded not in waters with temperatures of 8 to 12 °C at 300 to 800 m beneath the surface (as in the North Atlantic region), but in the waters with an extraordinarily low temperature (-2°C to +1°C) in the abyssal zone.

The oxygen minima existing in the region surveyed by the RV "Polarstern" expedition (profiles of the Yermak Plateau, and north of Seven Islands archipelago, s. Luchetta et al., 1992) have presumably resulted from local cooling of the Atlantic water current moving to north and northeast. The mechanism of their formation may be the following: Superficial ocean water with a salinity of 35 ‰, temperature of 5°C, and under full oxygen saturation with 7.0 ml/l, after cooling to 1°C, becomes saturated with oxygen only for 85%. Under this saturation the descended water forms limited volumes with oxygen minima at the depth corresponding to its new density.

The mechanisms of the formation of oxygen deficiencies during transportation of water parcels from the surface to the depths are the same in the subpolar Barents Sea and polar Greenland Sea. Our calculation of physical and biological components of the oxygen deficiency shows that the physical always predominates. But, the degree of the predomination is different in deep and shallow seas. For example, in the Barents Sea saturation hysteresis is twice the biological consumption, whereas in the Greenland Sea the predomination factor makes up 4. These data demonstrate, how much the role of descending water movements increases at polar latitudes, especially in deep-water regions.

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The European Science Foundation, Strasbourg, supported the participation of D.G. Matishov in the "Polarstern" expedition 1991.

## Summary

### Oxygen indication of the descending convection of sea water near the Svalbard archipelago („Polarstern" expedition, June-July, 1991)

Adrov, N.M. & Matishov, D.G.

The mechanism of the formation of limited volumes of cold (and $O_2$-undersaturated) waters in the water column and near the bottom is expounded. They differ by their characteristics from the main bulk of water masses. Dissolved oxygen, salinity etc. have been chosen as tracers. The idea of the method is that the evolution of any separate parameter of the oceanic system (chosen as a tracer) is determined by other parameters it interacts with. The information on such parameters unevidently contains the "history" of a separate component. Data kept in archives and material taken from the RV "Polarstern" expedition ARK VIII/2 (June-July 1991) have been used for the analysis.

# Notes on the Bryozoan fauna in the area north of the Spitsbergen archipelago

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In the seventies of the 19th century, Norwegian scientists initiated investigations of the benthos fauna in the shallow-water areas north of Spitsbergen. At the end of the 1890s, the Russian expedition on board the ice-cutter „Yermak" also collected benthos material. But, these were only sporadical observations which did not give a detailed picture of the bottom fauna richness, including bryozoans, in this area (Koltun, 1964). More detailed information, both on the fauna in general and on the bryozoans in particular, were received during the expedition of the ice-breaker „F. Litke" in 1955, when six benthos stations were carried out in the North of the Spitsbergen islands (Koltun, 1964, Gostilovskaya, 1964) (s. Fig. 1).

This presentation is based on the material collected during the expedition of the German RV „Polarstern" to the North of the Spitsbergen archipelago in 1991 and on comparison with previous data. Only a part of the material collected by ichthyologists from St. Petersburg was transported to MMBI and analyzed, while the rest is kept at the Zoological Institute RAS (St. Petersburg) and were identified by V.I. Gontar (1996).
These qualitative samples of bryozoans were collected with Otter and Agassiz trawls at 10 stations (s. cruise report, Rachor, 1992). Three of them are located in the western part of the area, two in the middle, the other 6 - in the eastern part (Fig. 1). The depths range was over 700 meters. The shallowest site was located in the eastern part of the area at a depth of 130 meters. The animals were preserved in 4% of neutralized formalin; after sorting, they were transferred to the 70% ethanol.

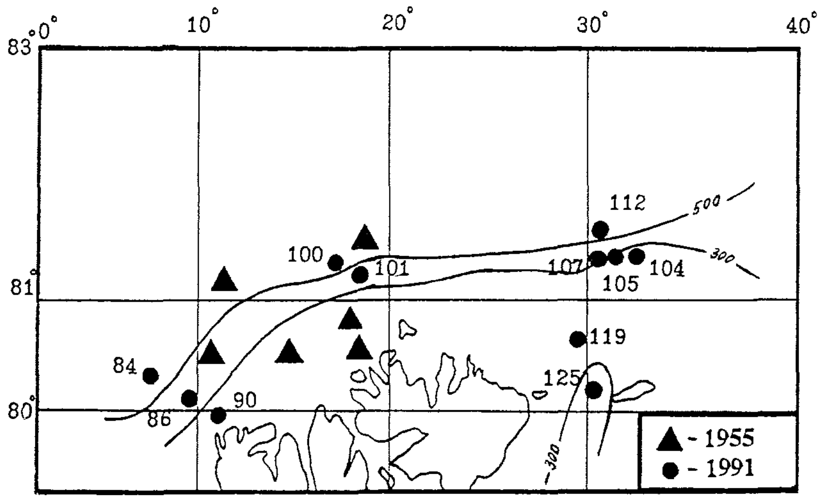


Fig. 1: Locations of stations north of Svalbard, sampled in 1955 and 1991

Table: Species composition of bryozoans in the North off Spitzbergen

| | Species names | Biogeography | 1955 | 1991 | areas |
|---|---|---|---|---|---|
| | Cyclostomata: | | | | |
| 1 | *Tubulipora ventricosa* Kluge | BA, at, cp | # | | |
| 2 | *Idmonea atlantica* Forbes | BA, at, cp | # | | |
| 3 | *I. atlantica* var. *gracillima* Busk | BA, at, ameu | # | x+ | e,s |
| 4 | *Diplosolen intricarius* (Smitt) | A, cp | | x+ | e,s |
| 5 | *D. obelia* var. *arctica* (Waters) | BA, ws | | + | s |
| 6 | *Defrancia lucernaria* (M. Sars) | BA, at, cp | # | + | s |
| 7 | *Crisia eburneo-denticulata* Smitt | A, cp | # | | |
| 8 | *Stegohornera lichenoides* (L.) | BA, at, cp | # | x+ | w,e |
| 9 | *Hornera pseudolichenoides* Gontar | A | | + | s |
| 10 | *Lichenopora verrucaria* (Fabricius) | BA, ws | | x+ | w,m |
| 11 | *Lichenopora hispida* Fleming | BA,ws | # | x | e |
| | Ctenostomata: | | | | |
| 12 | *Alcyonidium disciforme* Smitt | A, cp | # | | |
| 13 | *A. gelatinosum* var. *anderssoni* Abricossov | A, euas | | + | s |
| 14 | *A. mamillatum* var. *erectum* Andersson | A, cp | # | | |
| 15 | *A. radicellatum* Kluge | A, euas | | + | w,s |
| | Cheilostomata: | | | | |
| 16 | *Eucratea loricata* var. *arctica* (L.) | BA, ws | # | | |
| 17 | *Callopora lineata* (L.) | BA, ws | # | | |
| 18 | *Sarsiflustra abyssicola* (G.O. Sars) | BA, at, cp | # | + | w,m,s |
| 19 | *Carbasea carbasea* (El. et Sol.) | BA, ws | | x | w,e |
| 20 | *Dendrobeania pseudomurrayana* Kluge | BA, ws | | x | w,e |
| 21 | *Dendrob. pseudomurrayana* var. *fessa* Kluge | BA, ws | | x | w,e |
| 22 | *Kinetoskias smitti* Danielssen | BA, at, cp | # | + | e |
| 23 | *Scrupocellaria scabra* var. *paenulata* Norman | BA, ws | # | | |
| 24 | *Cribrilina watersi* Andersson | BA, at, ameu | # | x+ | e |
| 25 | *Phylactella labiata* (Boek) | BA, at, ameu | | x+ | e |
| 26 | *Smittina majuscula* (Smitt) | BA, ws | # | x | e |
| 27 | *Smittina peristomata* (Nordgaard) | BA, at, euas | # | | |
| 28 | *Smittina glaciata* (Waters) | A, euas | | + | e |
| 29 | *Parasmittina jeffreesi* Norman | BA, ws | | + | e |
| 30 | *Pseudoflustra soloda* (Stimpson) | A, cp | # | x | e |
| 31 | *P. hincksi* Kluge | A, cp | # | | |
| 32 | *P. anderssoni* Kluge | A, cp | # | | |
| 33 | *P. sinuosa* (Andersson) | A, cp | # | x | e |
| 34 | *Porella compressa* (Sowerby) | BA, ws | | x | e |
| 35 | *P. plana* (Hincks) | A, cp | # | | |
| 36 | *P. minuta* (Norman) | BA | | + | s |
| 37 | *Porelloides struma* (Norman) | BA, at, ameu | # | x | e |
| 38 | *Cystisella saccata* (Busk) | BA, ws | # | | |
| 39 | *Palmisellaria skenei* var. *tridens* (Busk) | A, cp | # | | |
| 40 | *P. skenei* var. *bicornis* (Busk) | BA, at, euam | | + | e |
| 41 | *Schizoporella smitti* Kluge | HB, euas | | x | e |
| 42 | *Hippodiplosoa borealis* (Waters) | A, euas | # | | |
| 43 | *Myriapora coarctata* (M. Sars) | BA, ws | # | x | e |
| 44 | *M. subgracilis* (D'Orbigny) | BA, amas | | + | e |
| 45 | *Tessarodoma boreale* (G. Sars) | SBA, at | # | | |
| 46 | *Sertella septentrionalis* Harmer | SBA, cp, at | | x | w,e |
| 47 | *S. beaniana* (King) | AmB | | + | e |
| 48 | *S. beaniana* var. *watersi* (Nordgaard) | A, cp | | x | e |

ctd.

| Species names | Biogeography | 1955 | 1991 | areas |
|---|---|---|---|---|
| 49 *Rhamphostomella scabra* (Fabricius) | BA, ws | # | | |
| 50 *Rh. bilaminata* (Hincks) | A, cp | | x | e |
| 51 *Escharopsis lobata* (Smitt) | BA, ws | # | | |
| 52 *Cellepora nodulosa* Lorenz | A, cp | # | x+ | e,s |
| 53 *C. canaliculata* Busk | A, at, eu | # | | |
| 54 *Escharoides bidencapi* (Kluge) | A, euas | | x | e |

Explanations: Biogeography
A - Arctic; BA - Boreal-Arctic; HB - High Boreal; SBA - Subtropic-Boreal- Arctic; B - Boreal; ws - wide spread; cp - circumpolar; eu - European; euas - Eurasian; ameu - American-European; euam - Euroamerican; at - Atlantic
\# - identification by Gostlovskaya; + - by Gontar (1996); x - by the author
Areas: w - western (stations 84, 86, 90); m - mid (100, 101); e - eastern (104, 105, 107, 112); s - southeastern (119, 125; only Gontar)

Altogether, 35 bryozoan species and subspecies were identified in the samples of 1991 (see Table). 18 species and 4 lower taxa were registered the first time in the investigation area, namely:
*Diplosolen intricarius, D. obelia* var. *arctica, Hornera pseudolichenoides, Alcyonidium. gelatinosum* var. *anderssoni, A. radicellatum, Lichenopora verrucaria, Carbasea carbasea, Dendrobeania pseudomurrayana, D. pseudomurrayana* var. *fessa, Phylactella labiata, Parasmittina jeffreesi, Smittina glaciata, Pseudoflustra birula, Porella minuta, P. compressa, Myriapora subgracilis, Schizoporella smitty, Sertella septentrionalis, S. beaniana, S. beaniana* var. *watersi, Rhamphostomella bilaminata, Escharoides bidencapi.*
Only 8, 2, and 10 taxa were found at the western, mid and south-eastern stations, respectively; but, in the north-eastern part, where the samples were obtained from a small bottom area, 27 taxa were present.

According to Gostilovskaya (1964), the bryozoan fauna in the north of Spitsbergen numbered 33 species at that time. The total number of bryozoans, now known for study area, comprises 52 species and 2 additional subspecies (see Table).

The differences in species composition and their numbers revealed between the 1950s and 1990s are explained by the differences in the sampling locations. The stations carried out by „F. Litke" covered the area more equally, and their locations did not coincide with the locations of the stations carried out in 1991 (Fig. 1).

An analysis of the bryozoan distribution in the Arctic Ocean in connection with environmental conditions can be carried out only on the basis of the actual collections, because previous authors did not mention either depths or the character of the bottom sediments at each individual station. According to our study, the bryozoan fauna is the most diverse at depths of 200-250 meters, where the number of species at every station increased by 3-5 times in comparison to both the shallower and deeper stations, where only 1-4 different species were observed in the samples (Fig. 2). Based of the bottom sediment descriptions on the sample labels, it is concluded that the richness of this fauna is determined by the presence of suitable substrates and bottom sediments for the development of bryozoans, and, these in turn are conditioned by the hydrodynamics in the area and the bottom relief.

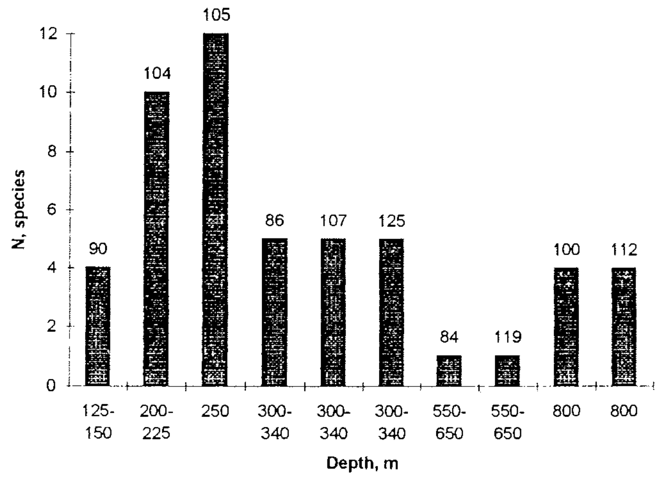


Fig. 2: Distribution of bryozoan species numbers as a function of depth (station numbers are shown above columns)

Maximal numbers (12) of bryozoan species are registered in the place of the depths fall, where the current velocity is the highest, and where the amount of the coarse rock material in the bottom sediments (consisting of gravel and pebbles) prevails over other fractions. In the research area, these places correspond to the depths 200-250 meters - the continenal slope edge. However, inside the northern seas, in the offshore shelf zone, maximal richness of the bryozoan fauna has been registered at depths of 100-150 meters (Gontar & Denisenko, 1989; Denisenko, 1990).

A biogeographical analysis of the bryozoan fauna of the stations investigated shows that the basis of this group consists of the Boreal-Arctic wide spread and circumpolar species. The Arctic and Boreal-Arctic forms prevail over the species of Boreal origin (small Table). The comparison of our data with those collected in the 1950s reveals that Boreal-Arctic forms generally prevail over other groups and that (other) Boreal species are very rare. Nevertheless, in spite of the insufficient study of the bryozoan fauna, the available data testify some influence of the warm Atlantic waters on the biogeographical structure of the group. Notwithstanding the high latitudes here, like over the large area of the Barents Sea and in the area of Franz-Josef-Land, some Boreal forms are present. They penetrate into the Arctic under the influence of the warm Atlantic waters.

| | 1955 | 1991 |
|---|---|---|
| Arctic | 12 | 11 |
| Boreal-Arctic, at | 10 | 12 |
| ws | 9 | 9 |
| Subtropic-Boreal-Arctic | 1 | 1 |
| Boreal (AmB, HB) | 0 | 2 |

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# Comparative description of the oxygen regimes in the waters of the continental slopes in the Barents Sea and the Laptev Sea

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The marginal Arctic seas represent an extensive continental bar; in the north, it turns into the continental slope and abyssal region of the Arctic Ocean. In spite of similarities of many physico-geographical factors, these seas have some hydrological and hydrochemical peculiarities resulting from certain natural factors including differences in the inflow of Atlantic waters and river runoff.

The current work studies peculiarities of the dissolved oxygen distribution in waters at the continental slope of the northern deep water parts of both, the Barents and the Laptev Seas. Oxygen is one of the principal elements of aquatic ecosystems and is widely used by hydrobiologists and chemists as an indicator of biological activities and water quality. The oxygen concentration is determined by the ratio between reduction and oxidation processes in water, exchange processes with atmosphere and within the water masses. Having some tracer features, the dissolved oxygen content is also used for identification of water masses (see contribution of Adrov & Matishov, this volume).

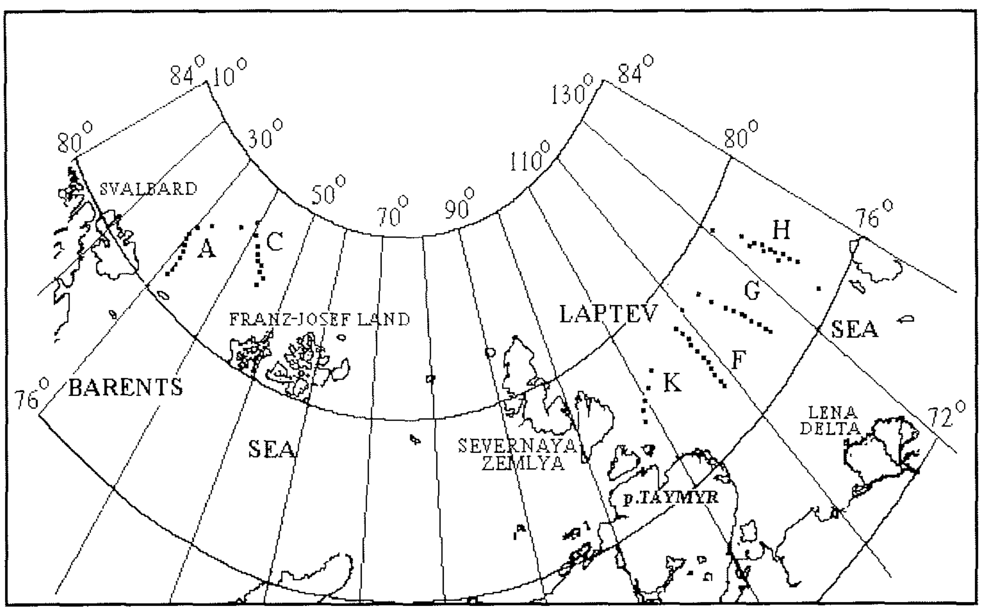



Fig. 1. Stations studied during the expedition ARK-IX/4 of RV "Polarstern", 1993.
A - K: sections in the continental slope areas (s. cruise report, Fütterer, 1994)

## Material and methods

The samples were collected on board RV "Polarstern" at the continental slopes in the northern parts of the Barents and the Laptev Seas in August-September 1993 (Fig. 1).
The area in the Barents Sea part of the continental slope (sections A and C) is situated beyond the conventional border between the Barents Sea and the Arctic basin (Dobrovolskii & Zalogin, 1982). Therefore, we term this „the Barents Sea region".

At 74 deep-water stations 1300 water samples were taken (from water surface till bottom) and analysed for the dissolved oxygen concentration. Water was sampled with a „Rosette" bottle arrey, combined with a CTD. The single bottle volume was 10 litres. The dissolved oxygen concentration was determined in accordance with the routine Winkler volumetric method (Strickland & Parsons, 1972). After keeping of the fixed water in a dark place and dissolving of the precipitate, a 50 ml aliquot was titrated with 0.01 N sodium thiosulphate; for this, an automatic calibrated dropper and automatic titration equipment with visual titration finish were used. During the whole expedition, titration was conducted by the same operator. Controls were carried out by titration of repeated aliquots.

As the studies were conducted during Arctic summer, minimal ice coverage was envisaged. More details about sampling and environmental conditions are given in the „Polarstern" cruise report (Fütterer, 1994).

## Results

Dissolved oxygen concentration is significantly determined by hydrological processes. In this connection it may be beneficial to give at first a brief description of hydrological conditions recorded in the studied regions in the course of the observations:
Three structural zones - superficial, intermediate and deep - are apparently distinguished in the water vertical structure in both regions. Water temperature in the superficial zone was the same in both regions and varied from -1.5°C to -1.8°C. At 80 to 120 m beneath the surface the temperature increased up to 0°C. Salinity of the superficial waters in the Barents Sea region ranged betweeen 32.5 and 33.9 in dependence on the melting influence. In the north part of the Laptev Sea the superficial water salinity varied within a wider range, from 27 to 33.5. Water salinity increased in the deeper layers in both regions. Fig. 2 shows thermal and salinity structures of the waters (s. U. Schauer et al., 1995).
In the intermediate structural layer water temperature and salinity increased greatly (Fig. 2). Their values differred insignificantly in the studied regions.
The deep (near-bottom) waters in the Barents Sea region and in the Laptev Sea have similar thermal and salinity properties, too. Water temperature in this layer varies from -0.5 to -0.8°C, and salinity ranges between 34.85 and 34.97.

A typical feature of water masses in the studied regions is their high concentration of dissolved oxygen in all structural zones from the surface down to the bottom. Even in the lowest water layers (at more than 3000 m beneath the surface), the absolute oxygen content is not less than 6.75 ml/l in both the Barents Sea

Fig. 2. Vertical salinity and temperature distributions in the water masses along the section C in the northeastern Barents Sea region (s. Fütterer, 1994)

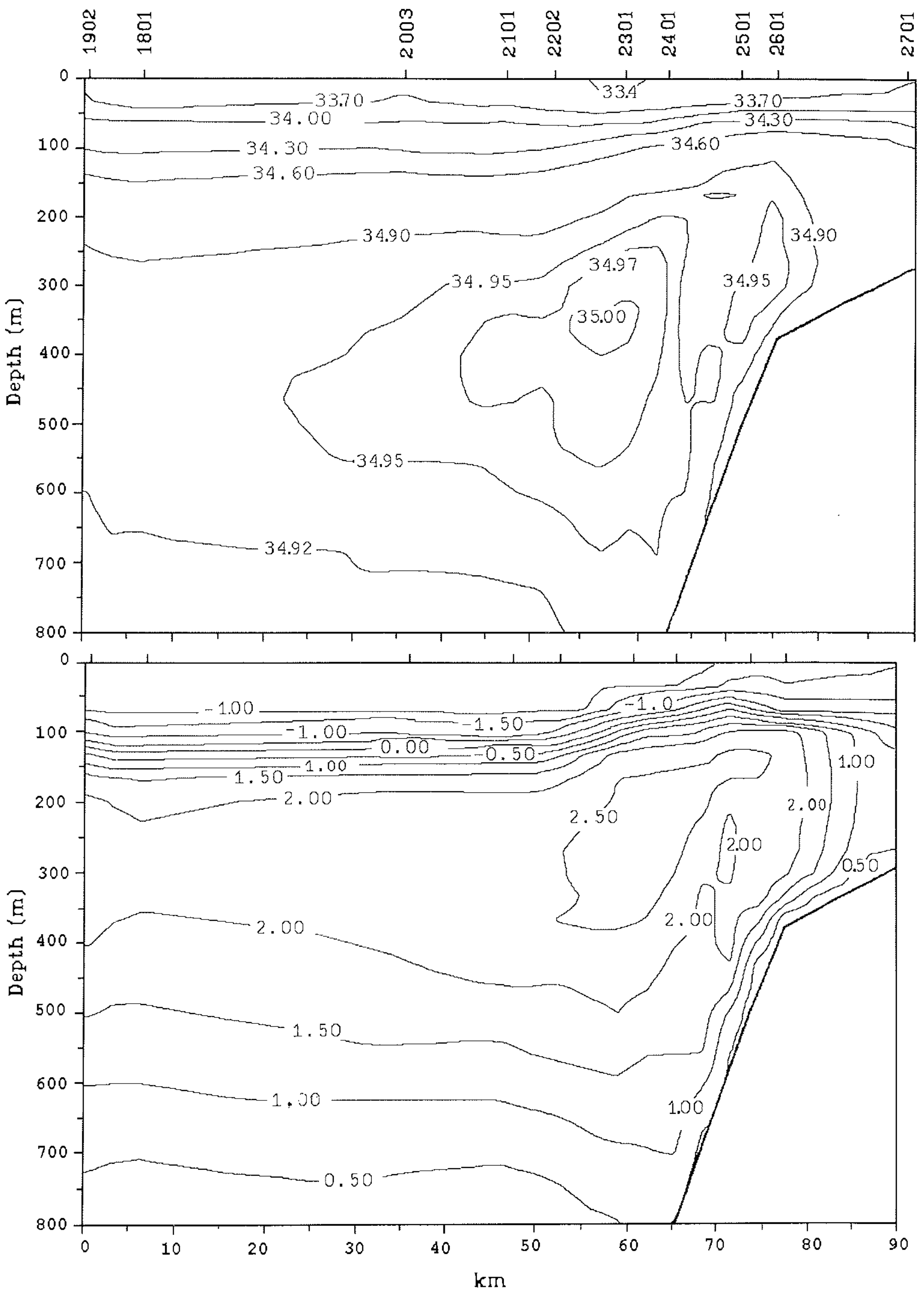


Fig. 3. Section C: Vertical distribution of dissolved oxygen (ml/l) over the Barents Sea region waters

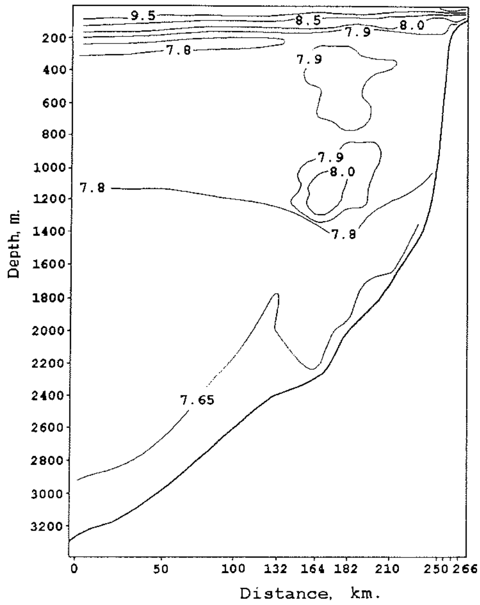
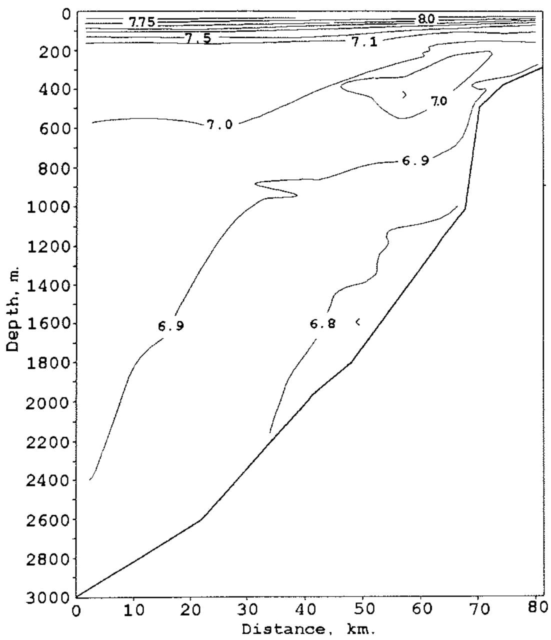



Fig. 4. Section G: Vertical distribution of dissolved oxygen (ml/l) over the Laptev Sea waters.



region and the Laptev Sea, which points indirectly to pronounced ventilation of and, may-be, low biological consumption in the deep-waters (Figs. 3, 4). In the superficial structural zone the maximal oxygen contents and oxygen concentration gradients are recorded. They range between 8 and 9.5 ml/l, sometimes exceeding these values (Figs. 3, 4). The highest concentrations are usually recorded in the zone of drastic depth increase and transition of the shelf into the continental slope. Water saturation with oxygen is close to 100%.

In the Barents Sea region a narrow zone adjacent to the Spitsbergen archipelago is characteristic by its higher oxygen content (9 to 9.5 ml/l $O_2$). These waters are oversaturated with oxygen by up to 12%. In spite of rather high dissolved oxygen concentrations (7.5 to 8.0 ml/l), the adjacent waters have oxygen deficiencies (5 to 8%).

In the Laptev Sea, superficial waters enriched with oxygen, form an extensive area in the central part of the region. Oxygen concentrations get 8.5 to 9.4 ml/l here, and saturation makes up 100 to 110% (Figs. 4, 5). Another (smaller) area of high oxygen concentrations is formed in the zone of mixing of the Arctic and continental waters which is situated in the shallow part of the region (the southern stations of the section G). In general, in the northern part of the Laptev Sea the superficial water saturation ranges between 97 and 110%, whereas in the Barents Sea region - between 92 to 106% (Fig. 5).

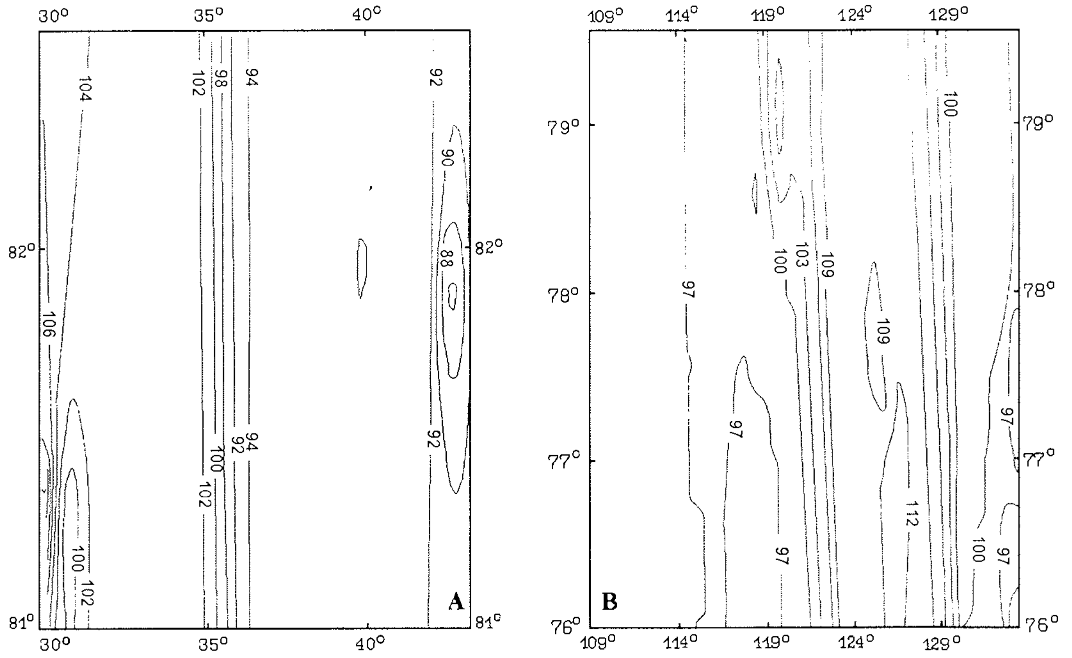
Unlike in the more southern regions, the oxygen maximum is confined to the thin upper layer of 10 to 20 m beneath the surface.

In 200-250 m to 1200 m depths a transitional oxygen maximum is recorded in both seas. In the Barents Sea region, the oxygen concentration in this transitional maximum layer is 7 to 7.1 ml $O_2$ /l, and in the Laptev Sea it varies from 7 ml/l in peripheral zones (sections K, H) to 8 ml/l in the central part of the region (sections G, F). But, in the layer of the transitional maximum no increase of water saturation with oxygen is recorded; it makes up 85 to 92%. The vertical structure of the oxygen distribution is given in Figs. 3 and 4.

In the deep water layers the oxygen distribution shows a monotonous pattern. Its concentration decreases insignificantly with depth, and at 3000 m it is on average 0.1 ml/l less than at 2000 m. In the central part of the Laptev Sea the oxygen concentration is maintained at 7.8 to 7.7 ml/l, and in the peripheral regions it makes up 7.0 to 6.9 ml/l. In the Barents Sea region the oxygen content of the deep waters is the same as in the peripheral regions of the Laptev Sea.

In the structural layer near by the bottom a small decrease of the oxygen concentration to 6.8 to 7.6 ml/l is noted. The oxygen deficiency increases up to 15 - 18% in the Barents Sea region, and up to 8 to 16% and in the Laptev Sea.

Fig. 5. Relative content of dissolved oxygen (%) in the superficial waters in the Barents Sea region (A) and in the Laptev Sea (B).



## Discussion

The dissolved oxygen distribution in every term is conditioned by the balance of physico-biological factors acting in the regions. Oxygen is distributed heterogeneously in the superficial water layer in form of spots and focuses.
The focus area of high concentration in the Barents Sea region near Spitsbergen is of probably biogenous origin. The temperature difference between waters in this region and adjacent ones is insignificant and not more than 0.2 °C. But, salinities of the waters enriched with oxygen range from 32.5 to 32.9, while they vary in the adjacent waters between 33 and 34.9. Accordingly, enrichment of the superficial layer with oxygen may result from phytoplankton blooms in water lenses freshened due to ice-field melting.

The focus area of the increased oxygen content in the central part of the Laptev Sea originates from the advection of mixed Arctic waters of the Eurasian sub-basin (according to the classification by Nikiforov & Shpeiher, 1980). Water salinity varies here between 33 and 33.5, temperature averages about -1.8 °C. Salinities of the adjacent waters (typically Arctic ones) are less than 33, and the water has practically the same temperatures. In Arctic seas, water saturation with oxygen decreases greatly (from 110% to 96-98%). It should be mentioned here that unlike the Barents Sea region, the water mass in the Laptev Sea shows an oxygen deficiency of 2 to 4%.

Continental river runoff is of great importance for the formation of hydrological and hydrochemical regimes. It influences mostly the southern regions of the Barents and the Laptev Seas. River runoff in the Barents Sea, however, is insignificant and does not extend far to the north. Absence of islands and elevations from the Laptev Sea allows penetration of river runoff, mainly from the Lena, far to the north. In the zone of interaction between Arctic waters and river runoff, there is another (the less extensive) focus area of increased oxygen concentration. It makes up 9.5 to 9.9 ml/l $O_2$, and saturation gets up to 116 % (Figs. 4, 5). Water salinity there is 31 to 32.

According to literature data, in the more southern regions of the Barents Sea, over-saturation goes up to 30% in summer (Norina, 1965; Ilyin et al., 1985), whereas in the Laptev Sea (Rusanov et al., 1979) it very seldom exceeds 5%. But, in the course of ice melting (which is confirmed by water freshening in the superficial layer) a range of conditions favourable for phytoplankton blooms arise according to the opinion of many authors (Vize, 1943; Belysheva, 1970). This phenomenon results in a superficial water over-saturation with up to 110 to 116% oxygen from time to time.

Continental river runoff influences much more the more southern regions. Salinity decreases to 27 and less. Specific features of oxygen rates - with deficiencies of 6% and more - develop here. Such deficiencies are caused by oxydation of organic and inorganic matters brought by river runoff (including freshwater plankton that died in salt water; Rusanov, 1986).

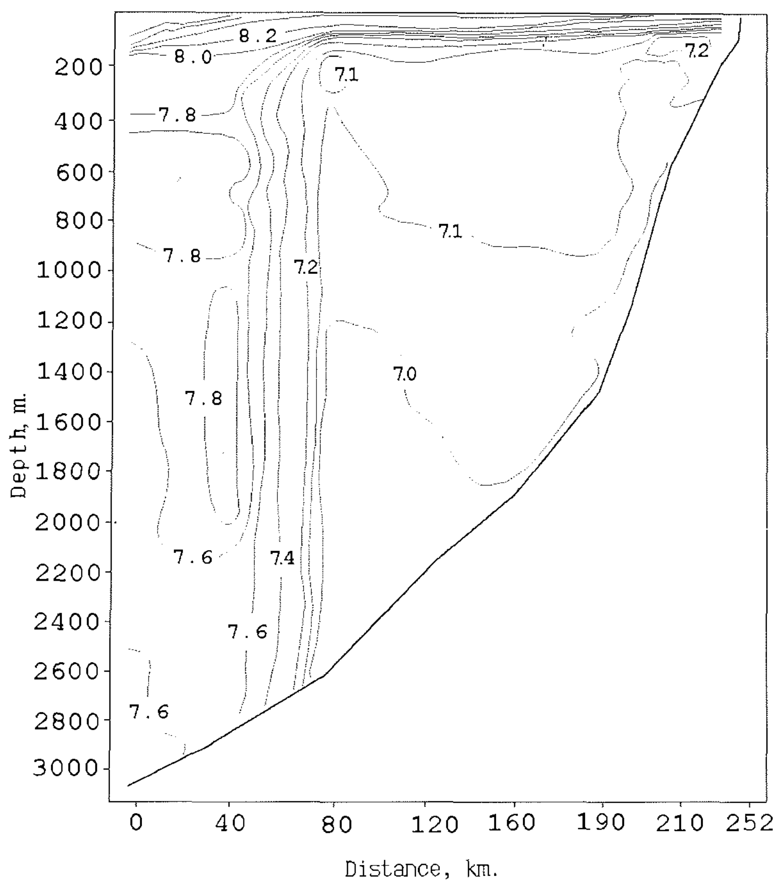
The maximal oxygen concentration is situated in a thin superficial layer (till 10 to 20 m beneath the surface) over the deep northern parts of the seas. In the more southern regions, for example, in the Barents Sea at the latitude of the Nadezda Island (Hopen), the oxygen maximum is found from 30 to 50 m, just above the density threshold (Ilyin et al., 1985).

The existence of the transitional oxygen maximum in the Barents Sea region and in the Laptev Sea is connected with the distribution of Atlantic waters of high salinity and positive temperature in the layer from 200 to 1200 m beneath the surface (Fig. 2).

Atlantic waters enter the Arctic basin through the Spitsbergen branch of the Norwegian Current through the Fram Strait, and from the Barents Sea along the St. Anna Trench east of Franz Josef Land archipelago (Nikiforov & Shpeiher, 1980; Rudels et al., 1994). In the Arctic basin, the Atlantic waters are transformed and lose a part of dissolved oxygen (10% at an average) in the course of their movement from the Fram Strait through the Arctic basin (Rusanov, 1986).

Figures 3, 4 and 6 show that Atlantic waters of the Barents Sea region and the Laptev Sea differ greatly with regard to their dissolved oxygen concentrations. Based on these differences, we can conclude that we observe the both mentioned currents. One of the Atlantic water currents presses itself against the Laptev Sea continental slope and forms here a focus of increased concentration of dissolved oxygen. In the adjacent Atlantic waters the oxygen concentration is much less. The two Atlantic water masses differ by their properties and are separated by a hydrological front. This front is recorded by the high saturation of the bottom water in the oxygen field in the middle part of section F in the Laptev Sea (Fig. 6).

Fig. 6. Front in the dissolved oxygen field in the Laptev Sea waters (section F).



It may be supposed that this core of oxygen-saturated waters (7.8 - 8.0 ml/l) is formed by the waters which enter the central part of the Laptev Sea (sections G and F) from the Barents Sea, as it is stated by Rudels et al. (1994). In the Barents Sea, between Franz Josef Land and the Novaya Zemlya archipelago, in the Atlantic waters, similar oxygen concentrations (7.6 to 8.5 ml/l) have been recorded (Ilyin, unpubl. data). But, these data are not confirmed by other investigations (Nikiforov & Shpeiher, 1980; Loeng et al., 1993).

Atlantic waters with lower contents of oxygen enter the Laptev Sea, probably, after having crossed the Fram Strait. Oxygen contents of the Atlantic waters of the Fram Strait (the layer is 500 m) are 7 ml/l on average (Rusanov, 1986). Similar concentrations have been observed in the investigated areas.

In the both regions waters near the bottom are highly saturated with oxygen (82 to 92%). The high saturation of the bottom structural zone with oxygen is characteristic of not only continental slope waters, but also of the whole Arctic basin, which distinguishes polar regions from other ocean areas (Ivanenkov et al., 1979).

The analyses of the bottom layer saturation with oxygen permits to distinguish two regions in the Laptev Sea: the central one (section G and northern stations of section F) and the peripheral one (sections K, H and southern stations of section F). In the central part the oxygen deficiency makes up 8 to 10%, whereas in the peripheral zone it gets 14 to 16%. Probably, by mixing with superficial and bottom waters, the Atlantic waters enriched with oxygen and advected from the Barents Sea influence greatly the formation of areas of high oxygen contents in all structural layers of the deep-water region of the Laptev Sea.

## Conclusion

Based on the investigation of the data obtained during the expedition ARK IX/4 we can conclude that the two studied Arctic regions with similar climatic conditions and bottom geomorphology demonstrate the same general regularities determining the formation of their water oxygen regimes. In the summer season, both regions possess two (superficial and transitional) oxygen maxima. In the deep-water structural layer the oxygen distribution is even. In both regions, areas of increased oxygen concentrations exist in the layer of mixing of superficial Arctic waters with waters resulting from ice melting.

Nevertheless, these regions demonstrate some essential differences. The formation of the most extensive focus of the maximal oxygen concentration in the north of the Laptev Sea results from the mixing of the superficial Arctic waters with the transitional waters of the Atlantic origin. One of the most principal differences is the existence of two water masses of Atlantic origin in the Laptev Sea: advected from the Fram Strait a branch with relatively low oxygen content, and from the Barents Sea another branch. The latter branch is characterizied by higher concentrations of dissolved oxygen and influences all structural layers in the northern deep part of the Laptev Sea. The participation of continental runoff in the oxygen field formation is another peculiarity of the northern Laptev Sea.

Thus, as compared with the investigated Barents Sea region, the Laptev Sea water has a more complicated hydrological structure, conditioning the more complicated mosaic pattern of oxygen distribution.

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## Summary

### Comparative description of the oxygen regimes in the waters of the continental slopes in the Barents Sea and the Laptev Sea

Ilyin, G.V., Luchetta, A. & Ponitz, P.

The distribution of soluble oxygen in the continental slope waters of two Arctic regions (conventionally named as Barents Sea region and Laptev Sea region) is analysed using samples and data of the RV "Polarstern" ARK-IX/4 international expedition 1993. Common features as well as differences in the character of oxygen distribution are found. Two maxima (surface and intermediate) and a mosaic structure of the oxygen fields in the surface structural layers are characteristic for the oxygen distribution.

Oxygen conditions of the Laptev Sea region, unlike the Barents Sea region, are determined by two water masses of Atlantic origin. The influence of these waters is the cause of the formation of centres of high oxygen concentrations in all structural layers of the Laptev Sea.

# Oil hydrocarbons in the Laptev Sea bottom sediments

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Among the most significant sources of ecosystem contamination with oil hydrocarbons in some Arctic regions are waters of warm currents originated from the Gulf Stream (Simonov et al., 1974, Ilyin & Petrov, 1994). Oil pollutants entering the sea from vessels and sewage from the Scandinavian and Kola coasts are brought into the Arctic basin and adjacent seas by these waters. A second source is the atmospheric transport of hydrocarbons, which brings mainly pyrolysis products into the sea medium (Romankevich et al., 1982). A considerable other share to the contamination is produced by the Pechora and by the Siberian rivers; but, this question is poorly tackled in the literature.

The interest in the oil pollution of the Arctic regions results not only from the global distribution of this pollutant, but also from the increasing development towards the exploitation of hydrocarbon deposits on the Arctic shelves. From this point of view, our study of hydrocarbon composition in the Laptev Sea bottom sediments continues a series of investigations of the Arctic ecosystem contamination, in general, and, specifically, those in the Russian Arctic. The Murmansk Marine Biological Institute has carried out such studies during many years (Kalitovich, 1990; Ilyin & Petrov, 1994; Schekaturina et al., 1995).

This work purposes to obtain some data on the accumulation of oil hydrocarbons and their composition in the Laptev Sea bottom sediments, to analyse the distribution of aliphatic and aromatic hydrocarbons in these samples, and to attempt to reveal sources of the hydrocarbons. Results of the study will promote further research of hydrocarbon composition in bottom grounds of the region. They are necessary as background values for the further monitoring of oil pollution in the Arctic and searching for its sources.

## Material and methods

Samples of bottom sediments were collected in the northern deep-water regions of the Laptev Sea in August-September 1993 during the expedition of RV "Polarstern" ARK-IX/4 (Fig. 1). The samples were taken by a multiple box sampler (Mehrfach-Kastengreifer). The upper layer to 3 cm beneath deposit surface was studied. Before chemical analysis all samples were kept in a freezer at -20.5° C.

The extraction of oil hydrocarbons from the sediments was carried out by two techniques:
(1) a sub-sample of dry material was thoroughly mixed with 20 ml of a water-acetone (1:1) solution; then 40 ml of hexane were added. After 16 hours the sample was shaken for 2 hours, and the hexane layer was then removed. The water-acetone layer was additionally extracted by 40 ml of hexane (by shaking for 30 min). The extracts were united, dried by water-free sodium sulfate and rectified in a column with aluminium oxide.

(2) Hydrocarbons were extracted by a mixture of hexane-methylene chloride in a Soxlet apparatus during 18 hours. The further preparation of the extract was carried out according to the first method.
Comparisons of the results of parallel samples have revealed differences ranging between 7 and 10%.

The identification of aliphatic hydrocarbons was conducted by gas chromatography with flame-ionisating detector and the data treatment system CR-3 Chromatopac. For the component identification we used a documentation of parameters of standard alkanes C7-C34; d8-naphthalene, d10-anthracene, methylstearit and d7-isopropylatic ester 2,4-D were used as internal standards.
Aromatic compounds were analysed by mass-spectrometry, with use of the data treatment system SUPERINCOS.
Quantitative determinations of individual polyaromatic hydrocarbons were carried out by the method of external standards using deuteroderivatives of naphthalene and anthracene. As external standards corresponding mixtures containing 18 polyaromatic hydrocarbons were used.
The hydrocarbon concentration is expresses in mg/kg dry weight of the sediment. Preparations and chemical analyses of the bottom sediment samples were carried out by the firm "Sovelan Aroma" (Moscow, VNIRO).

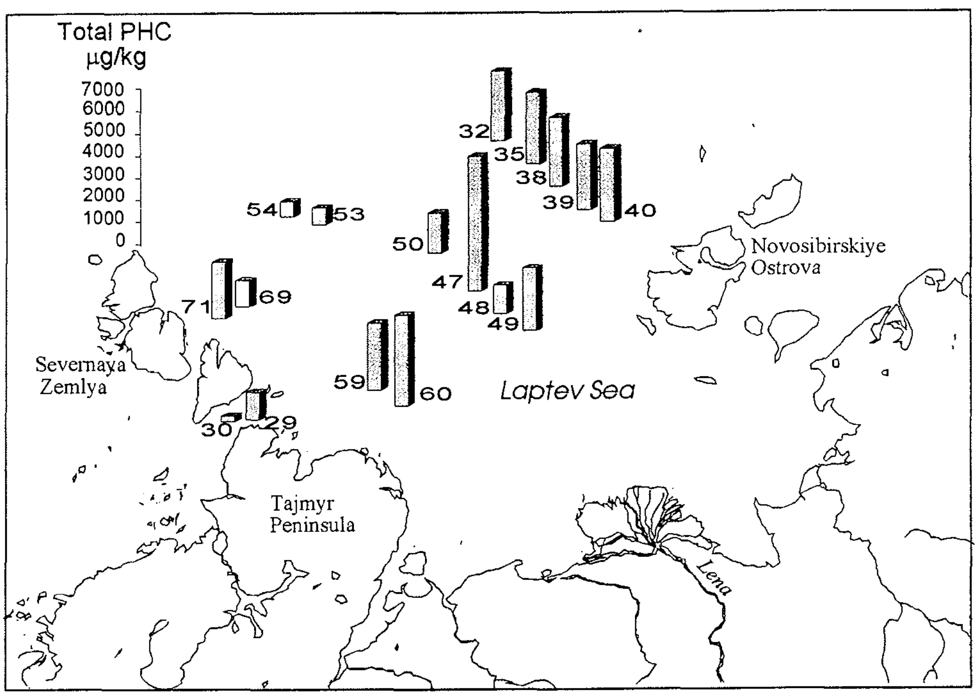


Fig. 1. Total concentration of oil hydrocarbons in the Laptev Sea bottom sediments (µg/kg dry ground)

## Results

In the hydrocarbon composition we distingnished normal alkanes in the range C12-C34, isoprenoides and 18 aromatic mono-, bi-, tri- and polynuclear compounds. The total content of oil hydrocarbons in sediment samples is given in Fig. 1. Among these compounds, the alkanes predominate by mass (96 to 99.9% of the total concentration of oil hydrocarbons).

The highest alkane concentration in the northern Laptev Sea is recorded in the peripheral stations and at the edge of the continental slope: 35, 39, 40, 47, 49, 59, 60 and 71. The total content of normal alkanes together with isoprenoids (phytane and pristane) in these stations makes up 2852 to 4062 µg/kg. In other locations, both paraffin and total hydrocarbon concentrations are much less and range from 718 to 1782 µg/kg.

In spite of some differences in both, qualitative and quantitative hydrocarbon composition at different stations, the Laptev Sea bottom sediments show a similarity of the quantitative composition of individual n-alkanes. In particular, almost all samples contain little amounts of the paraffins nC12-nC19 and greater amounts of the paraffins nC20-nC31. Fig. 2 demonstrates the structures of hydrocarbon aliphatic series in the bottom sediments from some typical sites.

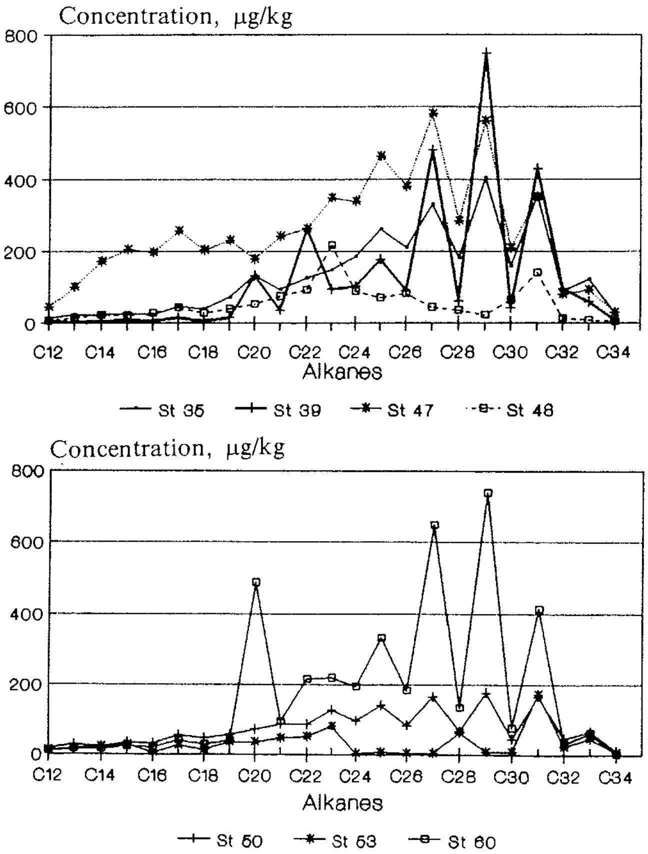


Fig. 2. Content of aliphatic hydrocarbons in bottom sediments at selected Laptev Sea stations

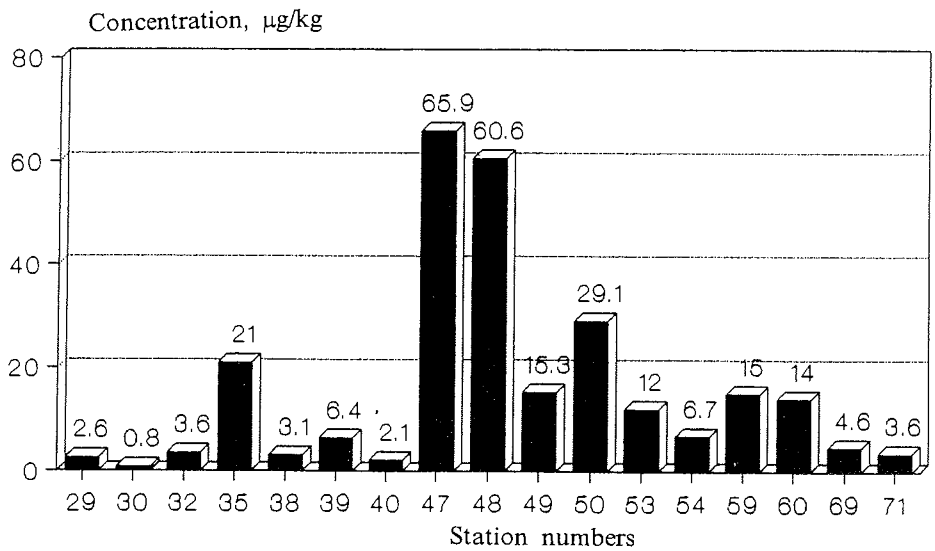


Fig. 3. Total concentration of aromatic hydrocarbons in the Laptev Sea bottom sediments

The content of aromatic hydrocarbons in the Laptev Sea bottom sediments is rather low and exceeds 1% only in some sites. Rather high arene concentrations were recorded at the stations 47 and 48 (Fig. 3) with more than 60 μg/kg, respectively. In other sites concentrations of aromatics range between 0.8 and 29 μg/kg.

It should be noted that the relative content of polyaromatic hydrocarbons (PAH) in the total sum of hydrocarbons makes up 0.1 to 2.5%. But, we can distinguish several stations, where PAH predominate among aromatic hydrocarbons of bottom sediments, and the prevalent arenes are polynuclear compounds (Table 1).

Among the arenes of potencially oil origin we identified 6 compounds: naphthalene, methyl-naphthalene, dimethyl-naphthalene, fluorene, methylphenantrene, chrysene. Their concentrations are insignificant and make up totally 2.1 to 31.4 μg/kg.
Concentrations of benzo(a)pyrene (one of the most dangerous ecotoxicological pollutants) in the Laptev Sea bottom sediments ranges from trace levels to 0.4 μg/kg, and increases only at stations 47 and 48 (0.7 and 2,1 μg/kg, respectively).

Table 1: Content of aromatic hydrocarbon groups in the Laptev Sea bottom sediments (µg/kg, dry weight)

| Stations | Sum di-nuclear arenes | Sum tri-nuclear arenes | Sum poly-nuclear arenes | Predominant arenes |
|---|---|---|---|---|
| 29 | 0.5 | 0.5 | 1.6 | anthracene, naphthalene |
| 30 | 0.3 | 0.4 | 0.1 | naphthalene, anthracene |
| 32 | 1.0 | 1.3 | 1.3 | anthracene |
| 35 | 5.3 | 3.3 | 12.4 | benz(b+j+k) fluorantene |
| 38 | 0.4 | 0.5 | 2.2 | benz(e)pyrene |
| 39 | 1.2 | 1.0 | 2.4 | benz(b+j+k) fluorantene |
| 40 | 1.0 | 1.1 | 1.0 | anthracene |
| 47 | 31.5 | 1.7 | 32.7 | benz(a)antracene |
| 48 | 26.3 | 13.2 | 21.1 | anthracene |
| 49 | 4.0 | 3.4 | 7.9 | anthracene |
| 50 | 7.4 | 6.5 | 15.0 | anthracene |
| 53 | 5.2 | 3.0 | 3.8 | anthracene |
| 54 | 2.7 | 2.1 | 1.9 | anthracene |
| 59 | 5.1 | 2.5 | 7.4 | perylene |
| 60 | 3.9 | 3.1 | 6.9 | benz(†)anthracene |
| 69 | 1.1 | 1.8 | 1.6 | methylphenathrene |
| 71 | 1.4 | 0.8 | 1.4 | anthracene |

## Discussion

Accumulation of oil hydrocarbons in bottom sediments and their structural composition are determined by several factors including those resulting from activities of hydrobiological communities, diagenesis, and burying of allochthonous pollutants transported by water currents and atmospheric circulation (Romankevich et al., 1982; Kiryukhina & Milovidova, 1985). The role of these factors is different, and we can estimate it by analyses of group and individual hydrocarbon composition in the studied region.

The investigations demonstrate that deep-water bottom sediments in the Laptev Sea accumulate rather small alkane amounts. Their total concentration is only comparable to the lowest concentrations in other Arctic regions which are reported in the literature, for example, in marine grounds of Alaska - 600 to 17500 µg/kg dry weight, in those of the Beaufort Sea - 2600 to 23600 µg/kg (Thomas et al., 1982, 1988). In the North Sea, near a polluted drilling site, some hundreds mg of oil were found per kg dry sediment (due to oil-based drill cuttings, Daan et al., 1992).

Analyses of the distribution of individual paraffins reveal that in the studied samples the increase of mass of aliphatic hydrocarbons is caused by normal alkanes C20, C23-C25, C27, C29, C31 (Fig. 2). The origin of long-chained hydrocarbons C23, C25, C27, C29 is connected with biosynthesis; these compounds are typical of waxes of terrestrial and high aquatic plant remains (Romankevich et al., 1982). Consequently, the presence of maxima in the spectrum of C23, C25, C27 and C29 points to the great role of terrigenous sources of these hydrocarbons and is typical of unpolluted bottom sediments.

The further analysis of aliphatic hydrocarbons (in particular, determination of typical ratios - CPI, isoprenoides pristane/phytane) shows that in most of the bottom sediment samples hydrocarbons of biogenous origin predominate rather than those of oil genesis. The CPI index in most sites makes up 1.3 to 2.2, which is closer to biogenous. The exception to the rule are deposits at the stations 39, 40, 47, 49, where CPI is 0.8 to 1.1, which points to the oil source of the hydrocarbons (Bordovskii et al., 1977; Muir et al., 1987, 1992).

Values of the isoprenoide ratio may be also used for determination of hydrocarbon genesis. Predomination of pristane over phytane points to biogenous origin of alkanes. Pristane results from its biosynthesis in plankton organisms and other hydrobionts including fishes (Plant & Mackie, 1979; Ganzalez Cesar et al., 1992). In most of samples the ratio pristane/phytane is more than 1.5 and points to biogenous origin of the hydrocarbons. The lesser values of this ratio (0.6 to 1.2) indicating the presence of oil hydrocarbons of anthropogenous origin are recorded again at the stations 39, 40, 49, 54 and 69.

It is easy to note that typical oil alkanes are recorded in such places where maximal hydrocarbon concentrations are found. All these stations are situated at small depths in the zone of the shelf transition into the continental slope. According to hydrological data obtained during the expedition, at the same depth the continental slope is bordered with Atlantic warm waters with a salinity of about 34.9. Within these areas, in superficial water layers a heavy freshening (up to 31 to 33 ‰) due to ice melting or river runoff (stations 47-49) takes place (Ilyin et al., 1996). Accordingly, in this slope area there exist some conditions for physico-chemical transformations of sea water under mixing, and for intensive formation of organic-mineral suspensions and their sedimentation. Emulgated and dissolved oil products brought in the Laptev Sea from different sources and via the atmosphere are absorbed by the suspension particles and enter bottom sediments.

With regard to the arenes accumulation level, the bottom sediments of the deep-water part of the Laptev Sea can be compared to those of the Pechora Sea. Bottom sediments there differ from those in other parts of the Barents Sea by much lower (by 5-6 and more) concentrations of the aromatic hydrocarbons and a very small share of arenes in the total contents of oil hydrocarbons (Ilyin & Petrov, 1994; Schekaturina et al., 1995). High contents of arenes in the bottom sediments do not always coincide with maximum contents of alkanes (Fig. 2, 3).

By group analysis of arenes (di-, tri-, polynuclear arenes) it may be pointed out that total concentration of arenes of potentially oil origin (di-, tri-nuclear) in the Laptev Sea sediments (2.1-31.4 μg/kg) is similar to the values in the bottom sediments of the Pechora Sea (0-38 μg /kg dry sediment, Kankaanpaa et al., 1995). The mentioned stations (39, 40, 49, 54, 69) are characterised by a predomination of the PAH group within the aromatic hydrocarbons (Table 1).

Polycyclic hydrocarbons are typical of fuel combustion products and are widely distributed with air masses (Shaw et al., 1979; Bjorseth & Olutsen, 1983). In the studied region of the Laptev Sea their prevalent accumulation in sediments occurs in the mentioned area of the interaction of Atlantic, Arctic and riverine waters, which underlines the role of sedimentogenesis in this region.

The main indicator of the pollution level of bottom sediments with oil hydrocarbons is usually a high share of the most dangerous cancerogenic and mutagenous compound - benzo(a)pyrene. Its concentrations in the Laptev Sea bottom sediments (mostly < 1 µg/kg) are lower than in the Barents Sea (0.3 to 13.3 µg/kg), in the North Sea (7 to 172 µg/kg) (SFT, 1993; Schekaturina et al., 1995), and in the southern part of the Beaufort Sea (0.6 to 33.0 µg/kg) (Stich & Dunn, 1980). This concentration is less than the "maximum allowable concentration" (20 µg/kg) and is not regarded dangerous for the bottom biota (Tirelygin et al., 1980; Khesina et al., 1987).
Compared to the mainly insignificant benzo(a)-pyrene concentrations, its increased content at stations 47 and 48 (0.7 and 2.1 µg/kg, respectively) requires elucidation (Fig. 4). These stations are strongly influenced by river runoff with superficial water salinities from 31 to 32. It is suggested that the main source of benzo(a)pyrene entering the Laptev Sea bottom sediments is river runoff transporting industrial and every-day sewage from Siberian industri-al regions. According to the authors' observations (unpublished), in the Pechora Sea (similar to the considered Laptev Sea region in respect to accumulation of all groups of oil hydrocarbons) the principal source of benzo(a)-pyrene seems to be there Atlantic waters.

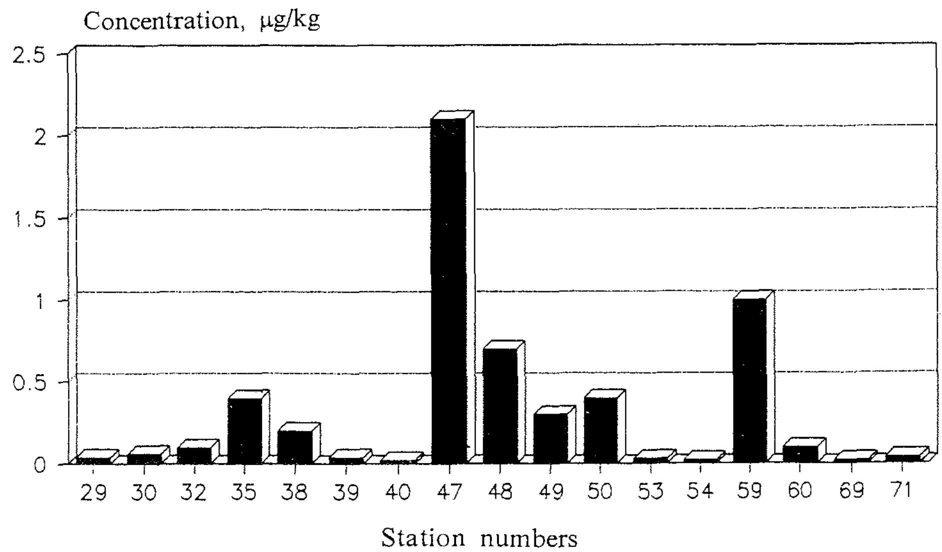


Fig. 4. The contents of benzo(a)pyrene in the bottom sediments of the Laptev Sea

## Conclusions

The presented data permit to conclude that the total contents of oil hydrocarbons and of individual hydrocarbon groups in the continental slope bottom sediments of the Laptev Sea are essentially less than in other Arctic and sub-Arctic seas. The quantitative hydrocarbon contamination is similar only to the Pechora Sea bottom sediments.

The analysis of the hydrocarbon distribution in the sediments in the studied region seems to underline the importance of the peculiar geomorphological situation there (a transitional zone between shelf and continental slope). Due to the interactions of different water masses, this area may be regarded as a zone that is very active in hydrodynamic and geochemical respects. In the bottom sediments of this zone a heavier accumulation of hydrocarbons of all groups takes place, including those of biogenous, oil, pyrolysis origin and of benzo-(a)pyrene.

We suggest that hydrocarbons from mineral oil sources are mainly advected with Atlantic waters. The sources of pyrogenous hydrocarbons in the Laptev Sea bottom sediments seem to be both Atlantic waters (transporting them from North Europe), and precipitation, fallen in the considered area or transported with ice drift. Despite the similarity of the Pechora Sea and this region, the main benzo(a)-pyrene source in the Laptev Sea seems to be river runoff.

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## Summary

### Oil hydrocarbons in the Laptev Sea bottom sediments


Ilyin, G.V., Schekaturina, T.L. & Petrov, V.S.

The qualitative and quantitative distribution of hydrocarbons on bottom sediments in the northern part of the Laptev Sea is studied on the basis of samples obtained during the expedition ARK IX/4 of the German RV „Polarstern" in August-September 1993. The considered area is characterised by an extraordinarily low contamination of oil hydrocarbons (725-3317 µg/kg dry sediment) and may be regarded one of the least polluted regions of the Arctic seas. The geomorphological features of the sea floor, where the shelf turns into the continental slope, may be decisive for high activities of hydrodynamical and geochemical processes. These permit heavier accumulation of hydrocarbons of biogenous, pyrolysis and mineral oil origins and of benzopyrene. The contaminants are presumably transported to the region with Atlantic waters, Siberian rivers and air masses.

# Some results on Cs-137 distribution in the Laptev Sea bottom sediments

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In the last few years the interest in studies of the distribution, accumulation and transportation of anthropogenic radionuclides as chemical components in the marine environment has distinctly increased. Due to the presence of sources of radioactive contamination at the coast, current radioecological processes are of special importance for seas of the Arctic Ocean. At present, anthropogenic radionuclides have been studied to a great extent in the region of the Barents - Kara Seas (Matishov et al., 1994 a,b; Rissanen et al., 1995). There is poor information on radionuclides in the Laptev Sea environment, however. Nevertheless, it is a very peculiar Arctic reservoir though there are no apparent local radionuclide sources in this sea or along its coasts. But, several Siberian rivers are transporting material into the Laptev Sea.

The Laptev Sea is a typical Arctic basin where Holocene and modern bottom sediments have been formed under shallow-water conditions and the great influence of continental waters. Numerous rivers including Olenek, Khatanga, Anabara, Yana, Omoloi and Goosikha enter this sea, and also the biggest Siberian river, Lena, the annual runoff of which averages about 520 $km^3$ (Ivanov, 1976). Terrigenous sediments typical for the sea are constituted of different ratios of aleurites and pelites (Yashin & Kosheleva, 1994). In geomorphological respect, the high-latitude Laptev Sea is a shallow-water shelf bordered by a gentle continental slope and some deep sea areas in the north. In the zone of the continental slope natural phenomena are apparently influenced by warm Atlantic waters originated from the "Gulf Stream" system.

The present work is devoted to the study of Cs-137 (caesium-137) distribution and accumulation in the bottom sediments in the marginal shelf zone, continental slope and abyssal plains in the Laptev Sea.

## Material:

Sediment samples were obtained with a "multibox corer" at 20 stations during the expedition of RV "Polarstern" ARK IX/4 in August-September 1993 (Fütterer, 1994) by G.V. Iljin (MMBI). They were collected along several down-slope sections, which permitted to describe Cs-137 concentrations in bottom sediments at water depths from 120 to 3200 m. All the samples were taken with a china

spoon from the 2-3 cm upper, modern sediment layer. They were kept in plastic bags and, later, transported to the Regional Laboratory in Northern Finland of the the Finnish Centre for Radiation and Nuclear Safety (STUK). There, they were dried at 105° C and homogenized before packing into cylindrical containers of 35 ml. Then, the samples were measured more than 1000 minutes with high purity Ge-detectors. Standard deviations of the measurements varied from 5 to 16%.
Cs-137 was the only anthropogenic radionuclide detected in the gammaspectrometric measurements. Natural radionuclides were not analysed, but, potassium-40 (K-40) concentrations were also obtained from the spectra.

## Results:

In all investigated regions of the underwater continental margin and abyssal plains, the marine superficial sediments contain Cs-137 either originating from the global fallout in the 1950's and 60's or from various other human activities. To north-west of the Kotelnii Island (New Siberian Islands), Cs-137 concentration in rough aleurites of the continental slope (200 to 300 m depth) makes up 7 to 10 Bq/kg dry sediment (Fig. 1).

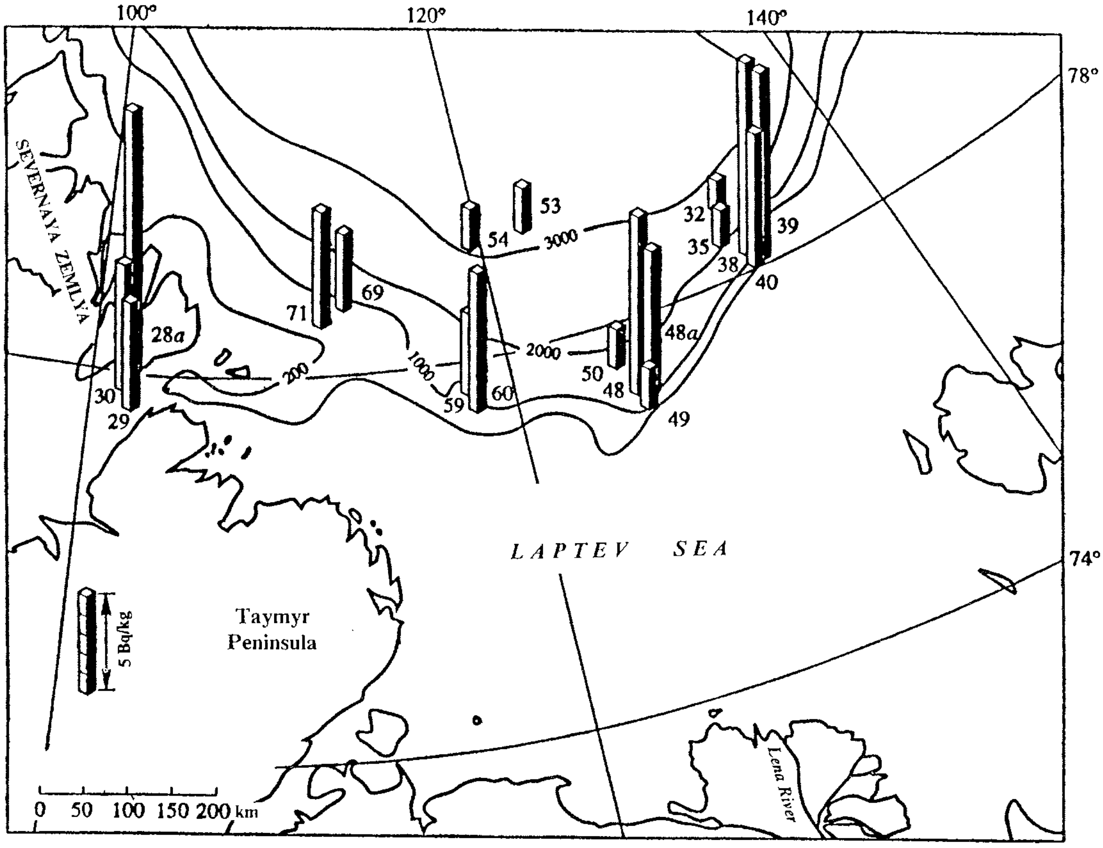


Fig. 1. Bottom sediment sampling sites in the Laptev Sea and Cs-137 concentration (Bq/kg dry surface sediments).

North of the River Lena delta, at the section from the shelf border to the continental foot, the Cs-137 concentration in aleurite sedi-ments varies between 1.9 and 8.8 Bq/kg, and north-east of the Taimyr Peninsula concentrations in fine sands and aleurites range from 3.8 to 6.8 Bq/kg (Fig. 1). In the Vilkitskii Strait, at depths from 120 to 160 m, surface sediments contain Cs-137 from 5.7 to 13 Bq/kg. Lower Cs-137 concentrations (1.6 to 2.2 Bq/kg) are recorded in clayey muds in the abyssal plains at depths of more than 3000 to 3200 m. It is reasonable that in the upper part of the Laptev Sea continental slope loose sediments are characterized by slightly increased Cs-137 concentrations (6.8 to 9.8 Bq/kg). Potassium-40 concentrations in the bottom sediments range between 630 and 880 Bq/kg.

## Discussion:

In the 20 sampling stations in the Laptev Sea, the Cs-137 concentrations of the surface sediments varied from 1.6 to 13 Bq/kg dry weight. These results are at the same low level as in earlier studies of surface sediments in the other parts of open Russian Arctic Sea areas (Rissanen et al., 1995; Matishov et al., 1994b). The main source of these radiocaesium concentrations is obviously the global fallout in the 1950's and 60's. Because no samples were collected directly outside the outlets of the Siberian rivers, nothing can be said about possible transport by the rivers.
The small variations noticed may be caused by many natural factors, e.g. the morphology of the bottom, in the entire sea area and especially in the vicinity of the sampling sites, type of sediment (hard or soft), sedimentation rate, currents near the bottom, effects of ice and river transport. Therefore, more information is needed of the local variability of these factors, if the reasons for such low concentration differences ought to be discussed.

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## Summary

### Some results on Cs-137 distribution in the Laptev Sea bottom sediments

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Cs-137 concentration and distribution over bottom sediments in the Laptev Sea marginal shelf zone, continental slope zone and abyssal plains are given in the present work. The material was collected during the expedition ARK-IX/4 of the German RV "Polarstern" in August-September 1993. Cs-137 concentrations range from 1.6 to 13.0 Bq/kg dry sediment weight. These low concentrations are obviously mainly originating from the global fallout in the 1950's and 60's.

# History of studies of the bottom relief and sediments in the Russian Arctic seas

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As early as in the 18th century, Pomors (Russian people inhabiting the Kola Peninsula coast) made use of information about bottom sediments in anchorage places. However, the first scientific expeditions were realized later, in the 19th century. Expeditions were headed by prominent navigators such as F. Litke in 1821-24 (Litke, 1928), A. Nordenskjöld in 1878-80 (Nordenskjöld, 1921), and F. Nansen in 1893-96 (Nansen, 1904). Descriptions of bottom relief and qualitative composition of the sea bottom were carried out along individual routes, becoming the basis for the Barents Sea geology. Simultaneously, some meteorological, hydrological, zoological and other observations were carried out. The first general sea floor map based on a square network of bottom sampling was created in the very beginning of our century owing to the results obtained by the expedition headed by N.P. Knipovich in 1898-1906 (Knipovich, 1906). It was the beginning of a comprehensive bottom sampling carried out by oceanological, hydrographical and fishery expeditions. Among the first studies providing rather detailed geological descriptions of bottom sediments, that of Ya.V. Samoilov and A.G. Titov (1917) should be mentioned.

Internationally, the time from 1870 to 1910 has been named „Oceanographic Golden Age" because of many fundamental scientific discoveries made by the British "Challenger" expedition in 1872-76, followed by Norwegian, Belgian and Austrian expeditions. The following decade is famous for intellectual revolutions conditioned by the "continental drift" conception proposed by the German scientist A. Wegener in 1912 rather than for results of empirical sciences. In 1920-30, several publications of Nansen (1904, 1922) and Holtedahl (1920, 1924, 1929) were devoted to the Barents Sea and the Norwegian Sea. However, most of the oceanographic expeditions of that time studied open ocean regions. This was fostered by the development of the deep-water echo sounding technology since 1920. Since 1921, after creation of the Floating Marine Institute (PLAVMORIN), Russia has become a leader in the investigation of Arctic seas, including the development of methods such as bottom probing with sampling tubes.

Scientific institutions founded in the 1930s, e.g. State Oceanographic Institute, U.S.S.R., Scientific Institute of Marine Fishery and Oceanography (VNIRO), and Polar Scientific Institute of Marine Fishery and Oceanography (PINRO), became the heirs of PLAVMORIN and its marine expeditions on board of the vessel "Persei". Ya.V. Samoilov, T.I. Gorshkova, M.V. Klenova, V.P. Zenkevich, M.M. Ermolaev, P.S. Vinogradova, I.K. Avilov, V.M. Litvin, V.D. Rvachev and other prominent scientists fruitfully studied bottom reliefs and sediments in the Barents, Kara and White Seas over a long period.

M.V. Klenova's books "Sea Geology" (Klenova, 1948) and "The Barents Sea Geology" (Klenova, 1960), dealing with the qualitative composition of bottom deposits and with sedimentary processes, give the most complete review of the results obtained by marine geologists of the post-revolutionary „first wave". It should be mentioned that, though some M.V. Klenova's conclusions have been revised, principal results are still valid owing to the thoroughness of field observations and high quality of laboratory analyses.

Bottom sediment sampling was carried out with drags, bottom samplers and ground tubes of different types. In the 1960s, the tube lengths trended to the increase. At the same time, M. Ewing and J. Ewing started a first attempt of seismic profiling and sea bottom sounding in the Barents Sea on board of the famous American RV „Vema" (Ewing & Ewing, 1970). The geological interpretation of these geophysical data has shown a sediment thickness of several kilometres and indicated the likely presence of gas and oil deposits within it. But, studies of the upper sediment sequences, which should be measured to a high accuracy, needed the development of the high-frequence seismic methods called „geosounding" according to modifications by I.A. Gimpelson's experiments in 1971-74, or „geoacoustics" according to V.E. Melnitskii's experiments in the 1970s (Gurevich & Gimpelson, 1974).

After decreased geological activities during and immediately after the Second World War, a „second wave" of geological investigations was initiated by several institutions like PINRO (by P.S. Vinogradova, V.M . Litvin, V.D. Rvachev, B.N. Kotenev, G.G. Matishov, A.I. Dmitrienko et al.), Murmansk Marine Biological Institute (MMBI; by V.I. Gurevich, G.A. Tarasov, L.G. Pavlova, T.V. Yakovleva et al.; see Mar. Biol. Res., 1974, 1982), at the Scientific Institute of Arctic Geology (by V.D. Dibner, V.E. Melnitskii, E.N. Shkatov et al.), VSEGEI (by M.A. Spiridonov, A.E. Rybalko et al.), and the Institute of Oceanology of the Academy of Sciences of the USSR (by A.I. Bazhchishin and others).

In the 1960-70s, marine geological research changed from the mere description of general lithological sequences as demonstrated by M.V. Klenova's description of sediment core samples to the thorough chrono-stratigraphic identification of the bottom sediments on the basis of palaeomagnetic (first experiments in the Barents Sea were conducted by T.I. Linkova in 1978; Blazh-chishin et al., 1979), radioisotope and micropalaeontological investigations. Studies carried out by Malyasova (1981a,b), Khitrova and Kulikov (1974), Lebedeva and Ivanova (1982), Rudenko et al. (1989), and Sharapova (1993) laid an important basis for modern palynostratigraphy based on the Blitt-Sernander International Scale. Investigations on foraminifers, the results of which were used in the North European seas by the Danish scientist Feiling-Hanssen and in the Barents Sea by Shtshedrina (1958) and Digas (1969), were carried out on samples from the Barents Sea Quaternary sediments at different times by micropaleontologists such as I.I. Burmistrova, S.V. Tamanova, V.Ya. Slobodin, T.S. Troitskaya, G.N. Nedesheva, L.V. Polyak, O.F. Baranovskii, L.V. Ivanova, L.Ya. Kagan., O.G. Okuneva, L.A. Tverskaya, T.A. Khoosid, I.A. Sakharova (Pogodina), N.V. Belyaeva, N.I. Xhruzhinina, and S.A. Korsun. Foraminifers are well known indicators for marine palaeoecology and, together with some geochemical tracers, such as boron content - the so called „palaeothermometer of water reservoirs", different ecological zones (e.g. of warm and cold waters, with normal salinity or freshened) can be identified and reconstructed from marine deposits.

In the 1970s, traditional equipment (drags, bottom samplers, ground tubes) were mainly used for bottom sampling. An increasing demand towards longer sediment cores led to the introduction of percussion tubes of the percussive-plunger construction type. Last, but not least, micropalaeontological, palaeomagnetic and radioisotope methods became more and more popular for lithostratigraphic studies. As a result, the traditional division of deposits into two classes, ancient glacial clays and post-glacial sandy-muddy sediments, was replaced by a more detailed stratification for not less than four temporal ecozones. They are (from bottom to top, e.g. in up to 2 m long cores):
(1) - Late (upper) Pleistocene to late Dryas,
(2) - Early Pre-Boreal and Boreal,
(3) - Middle Atlanticum,
(4) - late Holocene to Sub-Boreal and Sub-Atlanticum.

Other bottom samples, e.g. sediment cores up to 5 m long, show all 10 zones in accordance with the Blitt-Sernander International Scale (Dryas, Bölling etc.).
In 1979, the first palaeo-magnetic analyses casting doubts on the late Pleistocene age of ancient clays was based on the NIS "Kurchatov" expedition data (Blazhchishin et al., 1979).

In the 1970-80s, a number of expeditions were carried out in the World Ocean, which allowed to interpret glacial shelf geology with regard to global oceanology. As a result, new ideas and new interpretations have appeared. G.G. Matishov proposed a principally new conception of the Arctic Ocean periglacial (Matishov, 1982). Furthermore, new generalizing interpretations such as physiographic, geomorphological and other maps as well as publications on morphostructure and morphotectonics of glacial shelves of the Norwegian, Greenland and Barents Seas were published (Matishov, 1977a,b, 1980, 1982, 1984).
Dibner (1979) paid special attention to the origin of ancient clays, as he considered them to represent a direct evidence of the Pleistocene cover glaciation. The point is that in those years the character and expansion of Quaternary glaciations was a matter of contention between two hypotheses which classified all Quaternary geologists into "glacialists" and "marinists".

The American scientists G. Denton and T. Hyghes (1981) may be considered to be the uttermost "glacialists"; based on their Antarctic investigations they have developed a scheme of the ancient Panarctic glaciations including the whole Arctic Basin with adjacent territories. The uttermost "marinists" deny any possibility of the existence of a large-scale glacial cover in the Arctic seas at any time and attribute the most of the Quaternary sediments to be of marine or glacial-marine origin. O.V. Suzdalskii (1976), V.Ya. Slobodin, I.D. Danilov (1978, 1979), R.B. Krapivner and I.I. Gritsenko (1986, 1989) are among the marinists having influenced strongly the ideas on the Quaternary geology of the Barents Sea region. In Russia, M.G. Grossvald (1983) was the adherent of the pan-glaciation ideas and co-author of Denton and Hyghes. Other "glacialists" kept more moderate positions. They constitute the main group of investigators who, according to the certain peculiarities, distinguish both glacial and marine sediments in the Quaternary formations. This point of view permits to identify local glaciation focusses, for example Scandinavia, Novaya Zemlya and others, which manifested themselves in Pleistocene glacial periods and then disappeared during interglacials (Velichko, 1973, 1979; Matishov, 1976, 1982). In this case, a temptation appears to create hypothetical palaeo-dynamic "sea-mainland-glacier" models, to which G.G. Matishov, V.S. Zakharidze, Yu.A. Pavlidis, Yu.G. Samoilovich adhered at different times.

In the later 1970s, the Barents Sea shelf has become an area of oil and gas search. At first, this search was conducted by a single industrial institution (MAGE) of the USSR Ministry of Geology. Later, organizations belonging to the Ministries of Geology and of Gas Industry of Russia joined the project. As a result, large and rich marine oil and gas fields were discovered. Additional information on the Quaternary marine geology and sediments became necessary as a prerequisite for installation of offshore drilling equipment, pipelines, etc. Since the beginning of 1980s, due to extensive drilling and core recovery, namely engineering geology has provoked the most essential data on the Barents Sea latest sediments especially in the lowest stratigraphic layers. Only now, questions connected with the Neogene and earlier Pleistocene may be answered by the analysis of these data.

Some attention was also paid to the study of stony matter of the sea floor used for geological mapping of the pre-Quaternary deposits. V.I. Gurevich and V.B. Khasankaev (MMBI) revealed some regularities of coarse material drift and transport after its separation from the source substrate (Gurevich, Khasankaev, 1974; Khasankaev, 1978). Dibner (1979) summarized all information in a generalized geological map of the Barents Sea „bottom stony matter" (BMS). The map showed bottom exposures of the Palaeozoic and Mesozoic rocks, but did not meet the requirements for the State Geological Map of the USSR. Nevertheless, this map has demonstrated that geological survey of the shelf (SGS) is possible by means of simple technical equipment.

In 1980, MAGE started ist shelf survey (SGS) at first at the Kola Shelf and later off the south and east coasts of the Barents Sea. As the bottom sounding was accompained by complex geophysical studies, a variety of maps for different purposes were produced. It should be noted that in addition to the main geological map showing remote Quaternary cover, a map of Quaternary deposits was obtained. At a scale of 1 : 1,000,000, it shows spatial interactions between deposits of different ages and facies. It is of interest that the scientific controversy between "glacialists" and "marinists" greatly influenced data and interpretation of the SGS. - The first unpublished map, drafted by Samoilovich in 1983, showed marginal glacial structures, whereas a later version by A.V. Skorobogat'ko (1984) did show neither any moraines nor marine-glacial structures.

Bottom sediments in the West Arctic seas have been extensively studied by industrial institutions from Murmansk (MAGE, AMIGE, KTE NPO „Arktikmorneftegasrazvedka") and other places since the 1980s. The recognised leaders in the regional marine geology (R.B. Krapivner, I.I. Gritsenko, V.E. Melnitskii, V.V. Nazimov, Yu.G. Samoilovich) were joined by N.A. Polyakova, V.N. Bondarev, A.V. Skorobogat'ko, and D.A. Kostin. The Research Institute of Ocean Geology developed the SGS methods, and data on the Barents and Kara Sea geology were currently generalized (B.G. Lopatin, V.I. Gurevich, V.S. Zarkhidze, D.S. Yashin, L.V. Polyak, E.E. Musatov). Results of the engineering geology were subjected to scientific treatment and generalized in the Research Institute of Marine Geology under the leadership of A.B. Valpeter and O.G. Epshtein. In 1985-89, in some regions of the Barents Sea, studies headed by M.A. Spiridonov and A.E. Rybalko (VSEGEI, Leningrad) and exceeding the previous ones in respect of complexity and use of new methods were carried out. A variety of geophysical methods (seismoacoustics, echo sounding, geothermal measurements) were used. Magnetic and other properties as well as the qualitative composition of the core samples were studied and completed by detailed micro-palaeontological analyses on board of research vessels.

In the same period, the new-built research vessels „Dalnie Zelentsy" and „Pomor" of the Murmansk Marine Biological Institute enabled new investigations by bottom sampling headed by G.G. Matishov and G.A. Tarasov as well as improvements in scientific interpretations. Micro- and macro-faunistic methods became widely used: V.V. Alekseev and E.K. Zamilatskaya investigated the mollusc fauna, I.A. Pogodina and S.A. Korsun concentrated on the foraminiferan, L.V. Razumovskii on diatom distributions, and A.Yu. Sharapova conducted spore-palynologic analyses. Scientists from other institutes like the Institute of Geology of the Kola Scientific Centre (Apatity), the Institute of Geology of the Russian Acad. Sci. (Moscow), the Moscow State University, the Rostov State University (Rostov-on-Don) etc. participated in these expeditions and activities.

These scientific co-operations fostered the theoretical interpretation of the obtained data very much. Thus, a detailed lithogenetic classification of the bottom sediments was developed (Lavrushin, 1970; Lavrushin et al., 1990). Previously, the classification distinguished 3 groups, glacial, glacio-marine and ice-marine. Within these groups a diversity of types and subtypes were recorded. For example, glacio-marine sediments comprise two types of different origin. The first is connected with moraine material separated from the (floating) glacier foot due to its melting. The second one represents graded glacio-turbidite deposits formed by bottom mud flows with their subsequent sedimentation. Thus, a pure glacial origin of ancient clays is called into question. They may represent under-water moraine material. The results of scientific co-operation between MMBI and other institutes are reflected in a number of publications (Anonymus, 1988; Evzerov, 1987; Matishov, 1989a, 1989b; Matishov & Tarasov, 1992).

Some new ideas about the origin of shelf structures of bottom relief and of soft sediment thickness have arisen. Gataullin & Polyak (1990) deny an under-water moraine existence in the Central depression in the Barents Sea. They consider that relief-forming units similar to glacier structures are nothing else than supraglacial flow till, under-water embankments formed by sedimentation of mud-stony matter during melting of the shelf glaciers. The interpretations of Tarasov (1992, 1993, 1995) were close to these ideas; he connected the formation of thick soft deposits of „glacial genesis" with under-glacier flows of thaw water and subsequent sedimentation of moraine material. Such embankments show a very peculiar pattern on seismograms; as a consequence they got the name „transparent thicknesses". Their origin is the object of much concentrated attention in Russian and foreign literature. Since the geological survey of the south-western part of the Barents Sea in 1976, Norwegian geologists find everywhere moraine fields. According to Anderson (1981) and Vorren (1989,

1992) numerous stops of the glacier are traced in the course of its retreat 18,000 to 9,000 years ago. The British scientist J. Boulton (1979), however, who proposed the alternative („marine") hypothesis about the absence of glaciation from the Barents Sea, even in the midst of the 1990s does not deny it and considers the marine origin of transparent thicknesses to be proved.

Nevertheless, in 1990s, the controversy between glacialists and marinists lost its meaning, as the accumulation of facts and their comprehensive analyses by the latest methods permitted no extremal points of view. M.G. Grossvald, in his new computer model, has moved the centre of the Eurasian last glaciation into the Kara Sea. One of his opponents, V.S. Zarkhidze, previously distinguished only marine deposits in the Pliocene-Pleistocene sections; but, in his new maps sometimes he points to glaciers.

Before the 1990s, the emphasis of research was on the North Atlantic to west of the Barents Sea, whereas since the beginning of the last decade the studied area has expanded to north and east, and geological surveys have been conducted in the Kara and the Laptev Seas. Thorough investigations are searching for oil and gas fields as well as for probable pipeline constructions. In this connection the scientific directions of the geological studies have changed; at present, special geo-ecological investigations generalizing both old and new data are necessary.

Bottom sediments and the reconstruction of glacial shelves in the West Arctic during the last 20,000 years have traditionally been studied in the MMBI. In addition, geo-ecological studies of the bottom sediments were initiated, such as investigations on transportation and distribution of radionuclides and heavy metal concentrations (Matishov et al., 1993, 1994). Spiridonov et al. (VSEGEI; 1986, 1992) considered the new ideas on the geo-ecological mapping and genesis classification of glacio-marine deposits on the glacial shelves in the Russian north-western seas in connection with large-scale marine surveying. This classification proposed to distinguish taxa of three levels including local facies at the lowest level, determined by the distance from glacier margin, intensity of detrital rock matter importation, pattern of gravitation processes etc. The genetic criteria for the identification of glacio-marine deposits formed the basis of this stratigraphic scheme and of palaeogeographic conclusions concerning the eastern part of the Barents Sea. The main conclusion postulates that a discontinuos glacier shield was absent from the Barents Sea by the end of the Pleistocene. Several individual centres could only exist at the mainland.

By the beginning of 1990s, complex sections in Quaternary deposits have been studied in hundreds of bore-holes made in the Barents Sea and the Kara Sea with the drilling vessels „Bavinit" and „Kimberlit" (AMIGE). These studies provided new data on thickness, composition and age of the younger deposit sequences. Seismostratigraphic approaches (Krapivner et al. 1986; Gritsenko, Krapivner, 1989) formed baselines for the stratigraphic division of the latest sediments. The various seismostratigraphic sediment complexes were connected with five regional cycles of relative fluctuations of the sea level in the West Arctic basin, namely:
late Miocene - middle Pliocene (6,600 to 3,800 ka ago),
middle Pliocene - late Pliocene (2,800 to 1,700 ka),
early Pleistocene - late Pleistocene (400 to 72 ka),
late Pleistocene (72 to 18 ka), and
late-Pleistocene to modern (18 ka up to date).

In this decade, the German Alfred-Wegener-Institut for Polar and Marine Research, Bremerhaven, and the GEOMAR research institution, Kiel, carried out multidisciplinary investigations in Russian Arctic seas. German-Russian expeditions on board of RV „Polarstern" (1991, 1993, 1995, 1996, 1997, 1998) and RVs „Ivan Kireyev" (1993), „Prof. Multanovskiy" (1994), „Kapitan Dranitsyn" (1995) and „Akademik Boris Petrov" (1997) sampled bottom sediments, biological material and hydrological data in the Barents, Kara and Laptev Seas under, sometimes, hard ice conditions (Fütterer, 1992, 1994; Nürnberg et al., 1995; Kassens & Karpiy, 1994; Kassens & Dmitrenko, 1995; Rachor, 1997; Augstein, 1997; Kassens, Dmitrenko, Timokhov & Thiede, 1997; Stein & Fahl, 1997; Matthiessen & Stepanets, 1998). German sedimentologists obtained unique bottom sediment samples by using modern sea floor samplers. The expeditions and the subsequent treatment of the obtained material were carried out within a number of bilateral Russian-German projects. The results of these expeditions have given the baselines for many publications on the Russian Arctic shelf sedimentology.

The Institute of Oceanology of the Russian Academy of Sciences (IOAN) has also carried out co-operative investigations in the Arctic seas. Besides research inside the outer estuaries of the Lena, Ob and Yenisei Rivers, sedimentological studies in the Kara Sea, especially in the marginal zone of mixing of river and sea waters were carried out in 1993-94 (Lisitsyn, 1994).

Interest in the Arctic seas has very much increased in the recent years. New plans of large-scale, often multidisciplinary, investigations are formulated for the next decade. Many western countries including the U.S.A. are going to become active partners of these projects.
The geological and geophysical data which were collected in the last two decades both in the Russian Arctic shelf zone and in other regions of the Arctic enable us to revise the traditional ideas on the geology and evolution of the Arctic Ocean and its continental margins. To carry out theoretical studies of the numerous problems of Arctic marine geology and palaeo-oceanology, the Centre of Arctic Marine Geology was established in Murmansk in December 1995, according to a decree of the Kola Scientific Centre of the Russian Academy of Sciences. Prominent Russian scientists - Acadêmicians Gennadii G. Matishov and Felix P. Mitrofanov have promoted the organization of the Centre. The main field of the Centre activity is to cover the complex studies of main problems of the geological structure of the Arctic marine regions.

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## Abstract

History of studies of the bottom relief and sediments in the Russian Arctic seas

Matishov, G.G., Tarasov, G.A., Samoilovich, Yu.G.:

The history of research on bottom sediments and bottom morphology of the Russian Arctic seas is analysed (with emphasis on the Barents Sea region). Directions of work of leading home and foreign institutions and individual scientists, past and present ways of sampling and data processing are elucidated.

# Peculiarities of modern sedimentation in the northeastern Barents Sea and southwestern Kara Sea

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## Introduction

From the standpoint of geography, the shelf in the north of the Barents-Kara-Sea region has some specific environmental peculiarities: It is covered with ice for more than 10 months the year, adjacent to the modern glaciers of Franz Josef Land and Novaya Zemlya archipelagoes; it is rather deep with its bottom relief being extremely diverse; and it comprises stretched, deeply cutting trenches. The latter (Matishov et al., 1992) determine the distribution patterns of water masses and their main physico-chemical components. Taking into account that all these conditions influence directly the modern sedimentogenesis, it is extremely important to distinguish the principal natural processes, which criteria might be used for the typification of sediment genesis.

Despite the fact that data on bottom sediments have been published since Klenova (1960), this region remains poorly known. Although scientific interest in this high-latitude Arctic region does not decrease, natural reasons (short Arctic summer and difficult ice conditions) sometimes prevent investigations. Expeditions into this region have become annual after building of the Biological Station of the Murmansk Marine Biological Institute at Hooker Island (Franz Josef Land archipelago) in 1990. Preliminary results of these expeditions have already been included in some recent publications (MMBI, 1992: Compl. Intern. Exped.; Matishov et al., 1993; Forman et al., 1993; Nürnberg & Groth, 1993; Tarasov et al., 1993; Alekseev et al., 1993; Matishov et al., 1994).

## Material and methods

Material obtained by the MMBI expeditions (68th cruise of the RV "Dalnie Zelentsy", 1992, and 80th cruise of the RV "Akademik Golitsyn", 1994) have created the basis for this work. General information on the station distribution is given in Table 1 and Figure 1.

Sampling of the superficial bottom sediments (down to 20 cm beneath the bottom surface) was carried out by box-corer, multi-corer, and the bottom grab "Okean-50". Two to three m long sediment cores were obtained using percussion tubes. The primary treatment of the samples on board included visual lithological description and layer-by-layer sampling for further laboratory studies of the qualitative composition and microfauna. Later, the samples were used for sedimentological investigations at the Murmansk Marine Biological Institute (Russia) and the Alfred-Wegener-Institute for Polar and Marine Research (Germany).

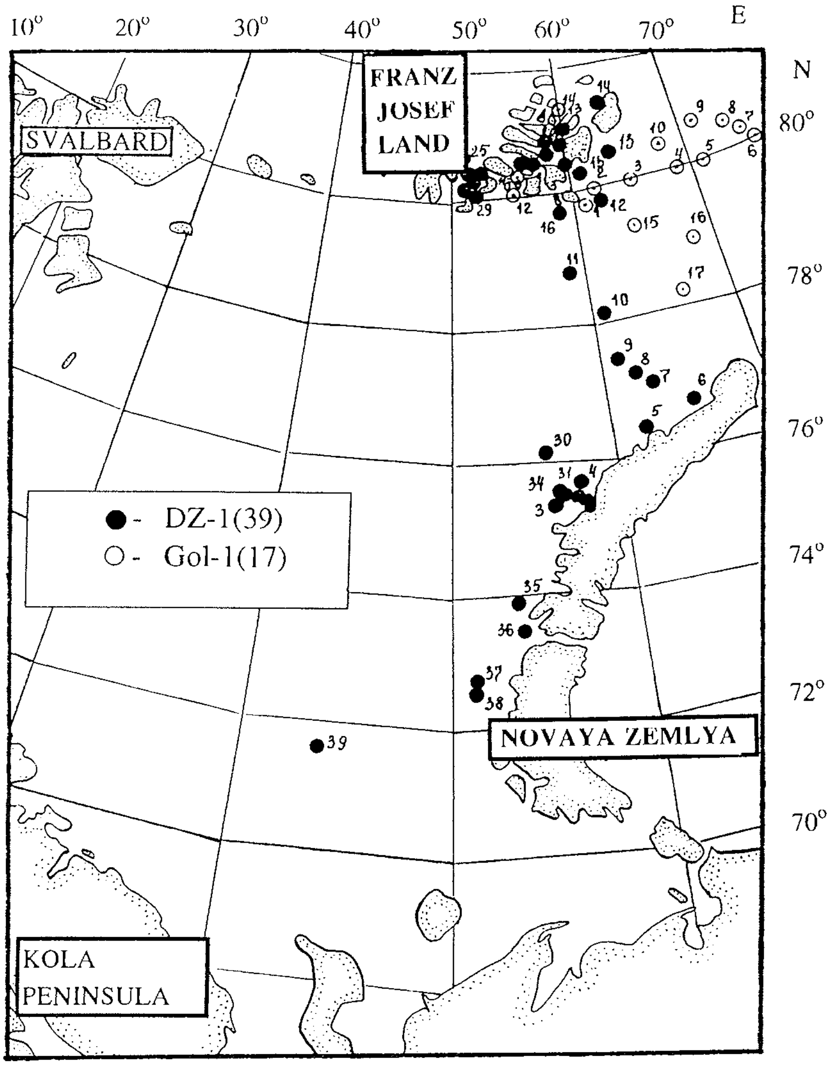


Fig. 1. Sites sampled during the espeditions of RV "Dalnie Zelentsy" (1992) and RV "Akademik Golitsyn" (1994).

## Results and discussion

In the surface sediments of the Barents-Kara-Sea region, fine aleurite and clayey muds of green-yellow, light brown, and light grey colours predominate. With respect to the sediment distribution and main component features, the studied part of the Barents-Kara-Sea region may be divided into two areas: the coastal-insular zone and the open-sea zone.

*Coastal-insular sediments*

On a first view, the surface sediments do not differ from those in the open-sea regions. Their composition and texture are very similar; some difference is only recorded in grain packing and sedimentation rates. It has been observed that in fjords and bays with calm hydrodynamics a pronounced sedimentation of the unsorted terrigenous matter after short transportation takes place without apparent modifications of the particles. As a rule, the material originates from destruction of coastal rocks by current processes. The influence of the sediment transportation with rivers and springs originating from the modern outlets of glaciers in the fjord heads, however, is of greatest importance. This flow of melt water is greatly enriched with moraine mineral suspensions. Figure 2, based on satellite photograph data, gives the transportation pattern of the suspended mineral matter in the Nordenshield Bay (west coast of the northern island of Novaya Zemlya archipelago) in summer (July 22, 1990). Here, the melt water flow enriched with terrigenous suspension, expands from the bay into the open sea by more than 20 to 30 km. According to Medvedev and Potekhina (1990), the concentration of suspension makes up 304.2 mg/l in the Nordensköld Bay head, 49.0 mg/l just in front of the outlet into the sea, and 6.1 mg/l at 10 km distance from the coast line. Consequently, the major part of the mineral suspension falls out in the limits of the bay, and only an insignificant part enters into the open sea. The amount of the transported terrigenous matter and the transportation distance from the outlet glacier border depend on the glaciers' melting rates and, therefore, on the summer temperature conditions. In warmer summers the amount of the transported mineral sediment matter is greater than in colder summers.

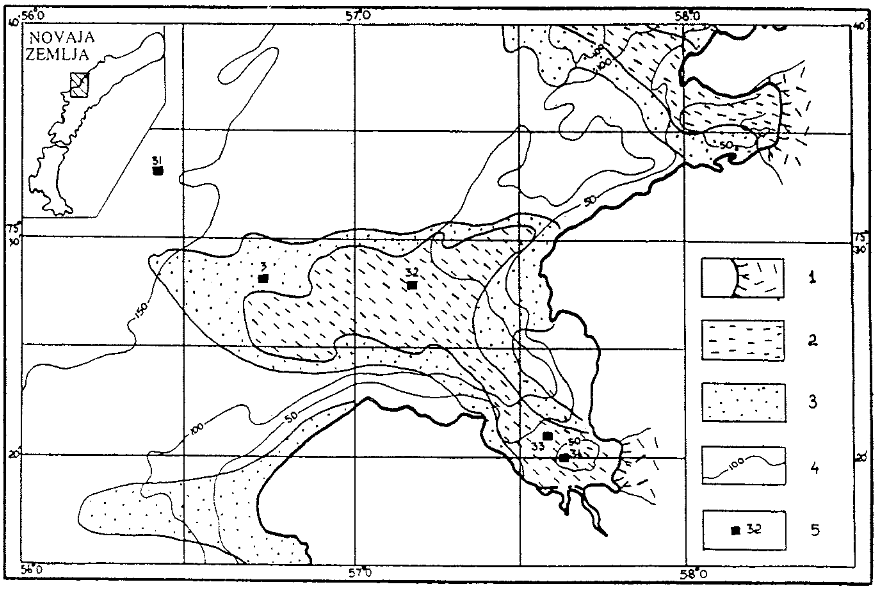


Fig. 2. Tracing of the suspension in the under-glacier melt water flows in the Nordensköld Bay (Novaya Zemlya archipelago) from satellite images: 1 - active outlet glacier; 2-3 - zones of high (2) and low (3) concentrations (s. text); 4 - isobaths (m); 5 - sampling sites.

Studies of sections of sediment cores have shown that surface deposits consist of fine aleurite muds of green-grey or brown colours, perforated with numerous polychaete tubes. The specific feature of the bottom sediments adjacent to melting glaciers is the presence of a homogenous layer of grey and green-grey plastic fine aleurite muds with poor fauna. These muds result from glacier milk sedimentation. In the 1 to 3 m long cores sampled in the Nordenskïold Bay (stations DZ-32, 33, 34; Fig. 2) the sediments consist of soft dark grey, olive-grey, and green-grey homogenous fine aleurite muds. In all cores the sediment density increases from top to bottom. Underneath the upper semi-liquid layer (0 to 3 cm) a zone of fine aleurite muds with horizontal stratification is visually observed, but the granulometric composition does not change. The thickness of the light (grey or olive) layers ranges between 1 and 10 cm, that of the dark layers varies from 1 to 5 mm. According to Tarasov et al. (1993), the light layers are accumulated during summer seasons, whereas the dark ones during winter seasons.

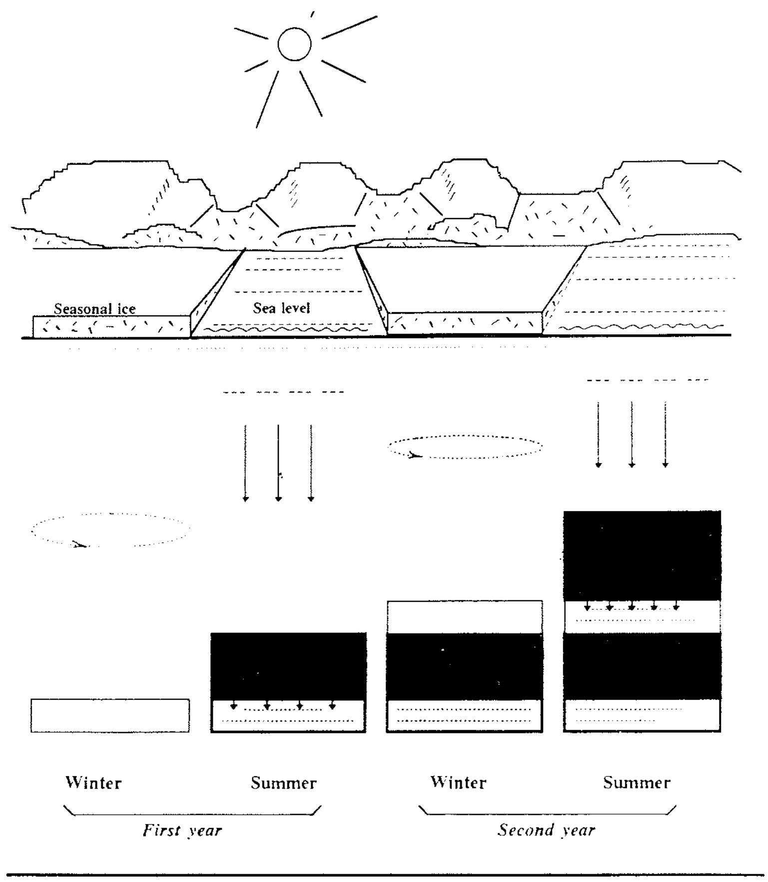


Fig. 3. Formation of laminar sediments

In addition, the layer thickness depends on the annual sedimentation rate: the thicker the layer, the more intensive was glacier melting and transporting of terrigenous suspen-ded matter with melt water. The sediments fallen out during summer form semi-liquid suspended matter in the first year. In winter, after formation of the ice cover in the bay, the import of sediment matter decreases drastically. In reality, only suspensions remaining in the water after the summer-autumn season and dead organic matter derived from spring phytoplankton blooms and also suspen-ded in the water column, fall out. In winter, due to ad- and cohesion between the terrigenous particles, the upper semi-liquid layer hardens. In the next summer, with increase of suspended matter transportation, the sediments of the previous year from a semi-liquid consistence pass to the underlaying layers (fine aleurite mud), see Fig. 3. Sediment hardening continues for several years.

The modern sedimentation in the Novaya Zemlya bays is similar to other regions (for example, West Svalbard, outlet glaciers in the Hornsund (Hornsoon) Fjord (Tarasov et al., 1993). Processes observed in bays and sounds in Franz Josef Land archipelago are, however, different. Here the climate is more severe, summer is very short (July-August), and glaciers are "colder". The mentioned peculiarities together with geological and geomorphological features of the Franz Josef Land archipelago and the bottom geomorphology of the adjacent shelf determine the main features of the modern sedimentation and promote formation of atypical fine-granular sediments (like in the open sea). Cores of maximum length were obtained in bays and sounds protected against bottom dynamics by water turbulence (Gol-12, 13, 14; DZ-14, 19, 20, 29). They consist of grey and dark grey homogenous fine aleurite muds enriched with hydrotroilite. The aleurite fraction predominates apparently in the granulometric composition (Table 2, Fig. 4). In a 1 m core section at the station Gol-13 (234 m of water depth, Austria Strait), aleurite concentrations range between 41.8 and 73.6%, and averages at 50.05%. The middle aleurite fraction predominates.

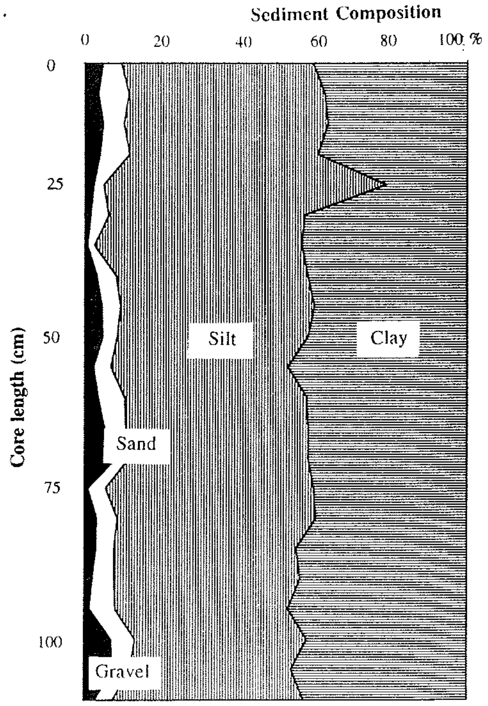


Fig. 4. Granulometric composition of bottom sediments in the core section from station Gol-13.

The content of gravels and pebbles resulting from rough fragments of rocks forming the coasts, is rather low. It reaches 10% in some core samples. This coarse material is distributed more or less uniformly over the core length. This occurrence and the layering of gravel and pebbles in bottom sediments point to a constant sedimentation due to ice drift and melting during summer seasons.

*Sediments in the open sea*

The sediment particle size distribution in the surface layer shows an obvious dependence on the bathymetric position and bottom morphology. Accordingly, sandy deposits composed of fine and middle sands expand at depths down to 120 m. As a rule, they are situated in the shelf zone and are connected with coastal shallow waters or bottom elevations. Under wet conditions, they are of grey and grey-green colour; under dry conditions, they have green-grey, khaki, and grey-green colours. A specific feature of the sandy matter is the permanent presence of coquina matter (up to 8%). The sorting index ranges between 1.7 and 3.5. The main mineral is quartz, constituting 30 to 65%. Feldspar content reaches lower values (34.8%).

In the deeper areas of the region, fine sediments (fine aleurite and aleurite-clayey muds) predominate. Under wet conditions, the sediments are semi-liquid, whereas with drying they become more solid. They are of grey-green colour with blue shade and with ochre-brown spots. Light brown and brown inclusions are also recorded. The clayey muds are composed of homogenous fine-granular (hydromica-peach or hydromica) matter containing aleurite and fine sand admixtures. Usually, carbonates are almost absent, and the sediments contain an insignificant amount of organic substances. The terrigenous sediment particles mainly consist of polygonal quartz grains (up to 40%), plagioclase (up to 20%), and rock fragments (11 to 22%). The contents of ferric, ferrous and manganese oxides are high ($Fe_2O_3$ - 5.58 to 5.78 %; FeO - 3.71 to 4.14 %; MnO - 0.23 to 1.51 %). Ferric oxides and hydroxides are represented by goethite, limonite, and, less common, martite). They form round grains, pseudo-oolites, collomorphous and sallow conglomerates of yellow and ochre-yellow colours. Single rock fragments ranging from gravels to large pebbles, occasionally occur on the bottom surface.

The sections of the up to 3 m long sediment cores show heterogenous structures of the sediments. In trenches and depressions, modern (Holocene) deposits were not recovered in the cores. Here, sediments are composed of homogenous soft fine aleurite-clayey deposits. The sediment density increases with depth, and its colour changes from light brown to dark brown. Laminated sediments are typical for under-water slopes of the archipelagoes (Stations DZ-12, 13, 16, Gol-1, 2, 3; Franz Josef Land; and DZ - 4, 6; Novaya Zemlya) and for elevation slopes in the open sea (St. DZ - 9, 10; Gol - 6, 8) (Fig. 5). The surface sediment layer (0 to 3 cm) is mainly brown, green-yellow, soft, and sometimes semi-liquid, and is composed of fine-aleurite or aleurite-clayey hardened mud. The transformation to the underlying layer is marked with an apparent hardening of the sediments. The next layer is dark grey or dark green, 15 to 40 cm in thickness, and composed of fine aleurite mud (sometimes of clayey or sandy-clayey mud) containing large amounts of gravel. The lowermost layer is represented by dark grey hardened diamicton-tye deposits ("ancient clay").

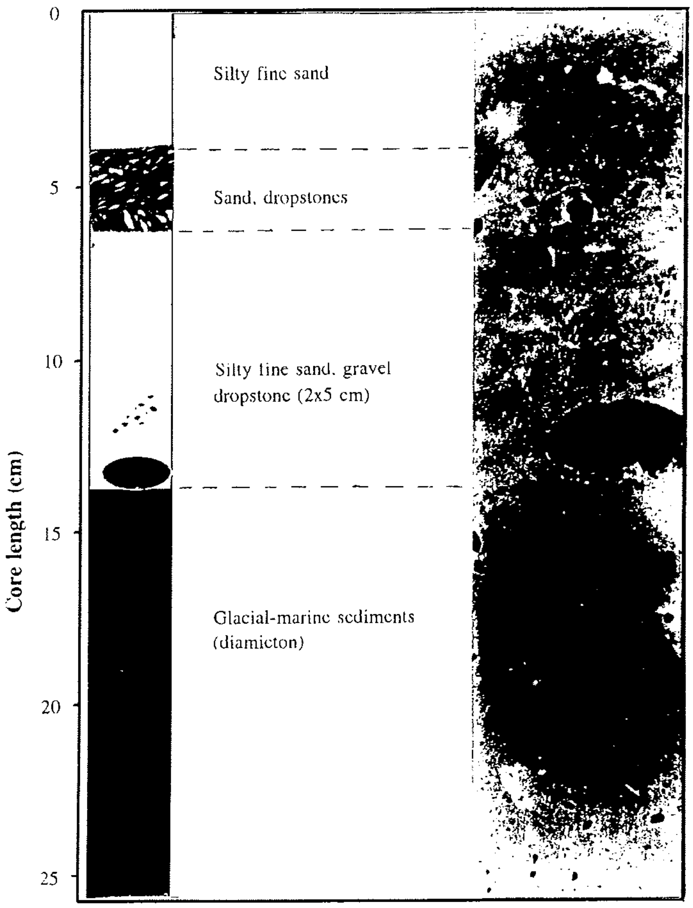


Fig. 5. Typical pattern of sediment structures in regions with slow sedimentation rates. X-ray record of the sediment Core DZ-9.

Sediments not similar to the above-described ones are recorded in the St. Anna Trough (Fig. 6). They consist of alternating layers of dark brown, dense aleurite-clayey muds, or, less common, of coarser sandy-aleurite deposits containing concretions of ferric and manganese oxides and hydroxides.

In Figure 7, roundness values of quartz grains of the fraction 0.25 to 0.125 mm from the top layer (20 cm) of the bottom deposits are presented. To estimate the roundness, the bottom sediments were sampled at every 2 cm of the core. In general, polygonal quartz grains occur. This picture is very typical for the coastal zone, as far as substances resulting from the frost and other physical weathering of coastal rocks and fine moraine matter fall out mainly here. Quartz grains of intermediate roundness ($K_{ok}$ more than 2) are only recorded in the St. Anna Trough (St. Gol-9, 10, 17). As the main flow of particulate matter moves in this region along the trench to the central Arctic Ocean, quartz particles in the course of their transportation change their initial shape by smoothing of angles. Here, transparent quartz particles devoid of inclusions and thin coatings are found.

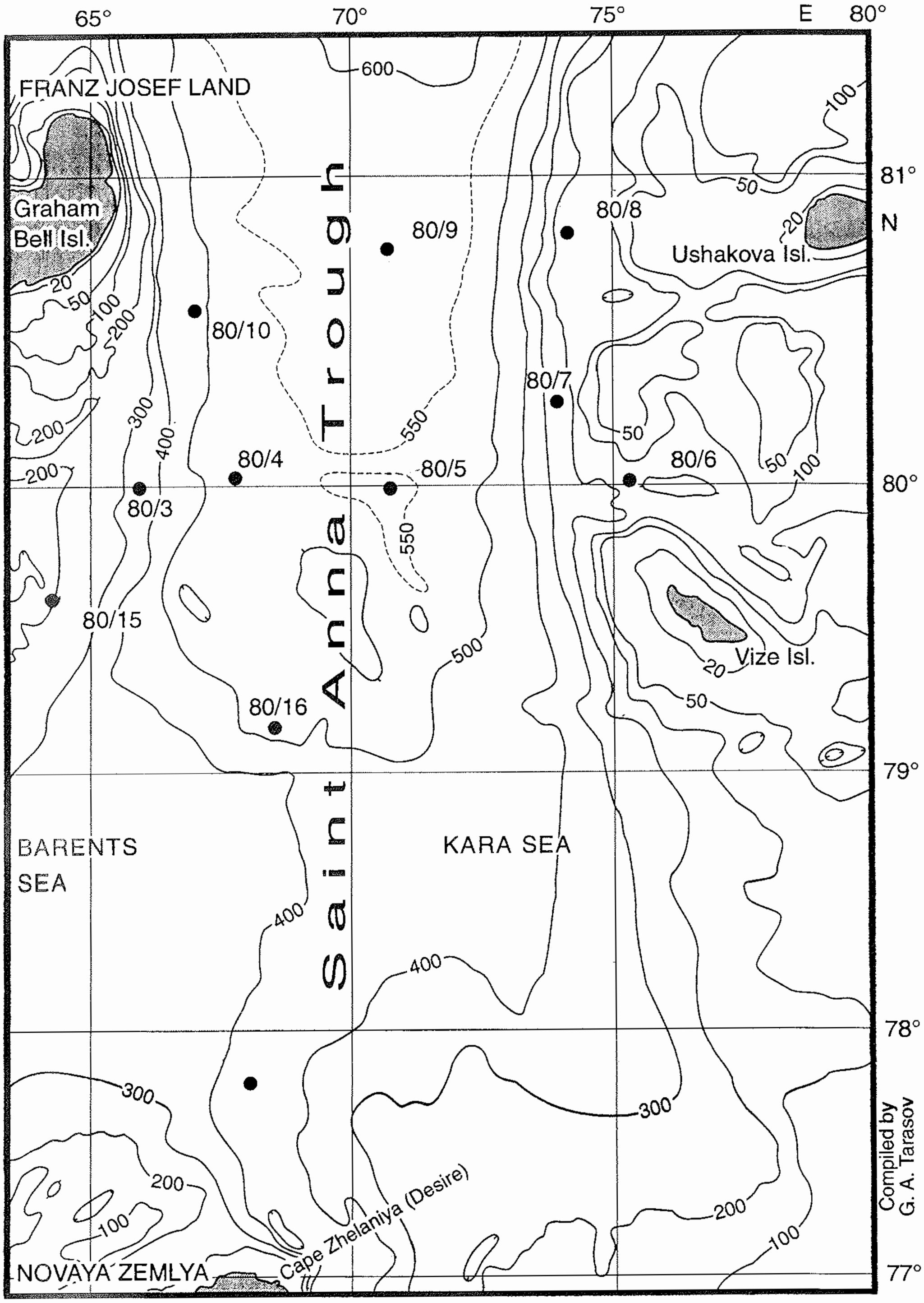


Fig. 6. Bathymetric map of the St. Anna Trough showing sampling sites.

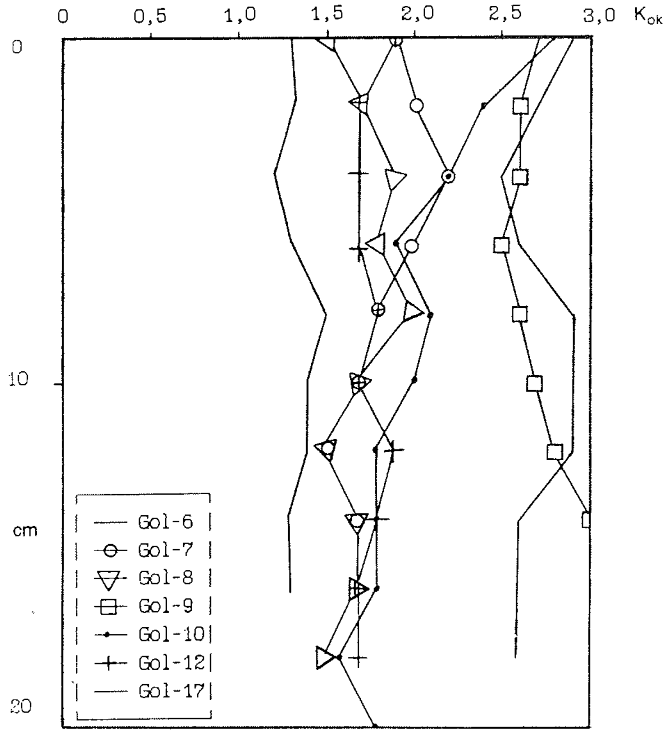


Fig. 7.
Distribution curves of roundness values of quartz grains in samples obtained during the 1994 expedition of RV "Akademic Golitsyn"

## Conclusions

The studied sediment cores from the Barents-Kara-Sea region show a regular variability of the sedimentation processes in the past. First of all, this results from weather and climate fluctuations: repeating of warm and cold periods in an annual cycle (short-term fluctuations) and long-term cycles covering tens and hundreds of years. These climate fluctuations are connected with dynamic peculiarities of the sea-ice cover in high latitudes. Glaciers and ice loaded with terrigenous matter, are main sources of the Barents-Kara-Sea sediments.

In the northern area of the Barents-Kara-Sea region drifting icebergs, fast ice, and sometimes Arctic pack ice melt quickly in summer and cover the sea floor with sediments. The melted ice gives place to new ice masses. This process continues during the short Arctic summer and becomes slower with the formation of new ice. In the zone of drifting ice, a layer of loose deposits is formed, mainly composed of fine-grained sediments containing gravel and pebbles. Transport of large fragments of coastal rocks must not be ruled out. Accordingly, during the RV "Akademik Golitsyn" expedition in the Austrian Sound (Franz Josef Land) we observed ice fields and icebergs containing big stones, some of them weighed more than 1 ton (Fig. 8). In bottom sediments resulted from ice transport, laminar structures may be absent. As during winter transportation of terrigenous material becomes slower under the ice cover, at the sea floor a semi-liquid layer is formed by suspended substances. However, this process may be hampered or stopped by water currents removing deposits from the bottom surface. This semi-liquid is only recorded in some places and depends on many reasons.

Fig. 8.

Ice transportation of big rock fragments, Austrian Sound (Franz Josef Land).

The usual amount of deposits of ice origin of the next year passes easily through the winter semi-liquid layer and joins the old layer. In such cases we do not record laminar structures. Sediments showing thin layers of apparent annual cycles are recorded in some places. In some cores, regular thicknesses of the layers occur, whereas in others an irregular alternation of thick and thin layers was observed. Probably, the latter results from drastic changes in both amount and rate of sediment matter transportation from year to year. During warm summers, ice melting and glaciers retreat take place more intensively than during colder ones, and, consequently, the transportation rate of sediments is greater. In general, the distribution of layers over the core and their thickness and composition are determined by the stability of climatic conditions.

In the regions of the modern glaciers, sedimentation is greatly influenced by under-glacier flows of melt water enriched in terrigenous material. Near the glacier outlets this factor becomes prevalent and transforms sedimentogenesis into "avalanche"-like processes. The influence of melt water on the bulk sedimentation rate decreases with increasing distance from the coastline. Nevertheless, this factor plays an important role in the modern sedimentogenesis in the northern Barents-Kara-Sea region.

Table 1: List of stations

| Station numbers | Date | Latitude N | Longitude E | Water depth m |
|---|---|---|---|---|
| DZ/68-1 | 18.08.92 | 72° 58' 5" | 53° 03' 74" | 28 |
| DZ/68-2 | 18.08.92 | 73° 36' 04" | 52° 16' 02" | 137 |
| DZ/68-3 | 19.08.92 | 75° 28' 03" | 56° 44' 17" | 139 |
| DZ/68-4 | 20.08.92 | 75° 35' 60" | 57° 58' 9" | 56 |
| DZ/68-5 | 20.08.92 | 76° 25' | 61° 22' | 57 |
| DZ/68-6 | 20.08.92 | 76° 28' 50" | 65° 11' 8" | 150 |
| DZ/68-7 | 21.08.92 | 77° 08' 60" | 62° 52' 3" | 100 |
| DZ/68-8 | 21.08.92 | 77° 19' 40" | 62° 16' 9" | 219 |
| DZ/68-9 | 21.08.92 | 77° 33' 20" | 61° 30' 7" | 320 |
| DZ/68-10 | 21.08.92 | 78° 07' | 61° 18' | 410 |
| DZ/68-11 | 22.08.92 | 78° 54' 50" | 59° 00' | 260 |
| DZ/68-12 | 22.08.92 | 79° 50' | 61° 29' | 145 |
| DZ/68-13 | 23.08.92 | 80° 33' 60" | 64° 30' 3" | 70 |
| DZ/68-14 | 24.08.92 | 81° 05' 50" | 63° 32' 5" | 275 |
| DZ/68-15 | 24.08.92 | 80° 20' | 60° 20' 2" | 37 |
| DZ/68-16 | 25.08.92 | 78° 52' 87" | 58° 40' 17" | 43 |
| DZ/68-17 | 26.08.92 | 80° 37' 2" | 58° 05' 5" | 27 |
| DZ/68-18 | 26.08.92 | 80° 44' 3" | 57° 53' 8" | 29 |
| DZ/68-19 | 26.08.92 | 80° 43' 9" | 58° 52' 9" | 160 |
| DZ/68-20 | 26.08.92 | 80° 42' | 57° 50' 7" | 217 |
| DZ/68-21 | 26.08.92 | 80° 36' 5" | 55° 46' | 75 |
| DZ/68-22 | 26.08.92 | 80° 35' 3" | 55° 45' | 340 |
| DZ/68-23 | 26.08.92 | 80° 30' 4" | 56° 43' 8" | 214 |
| DZ/68-24 | 27.08.92 | 80° 23' 9" | 59° 37' 4" | 43 |
| DZ/68-25 | 28.08.92 | 80° 19' 92" | 52° 50' | 47 |
| DZ/68-26 | 28.08.92 | 80° 18' 7" | 52° 37' 7" | 164 |
| DZ/68-27 | 28.08.92 | 80° 18' 3" | 52° 34' | 140 |
| DZ/68-28 | 28.08.92 | 80° 17' | 52° 15' 8" | 230 |
| DZ/68-29 | 29.08.92 | 80° 05' 8" | 51° 50' 6" | 340 |
| DZ/68-30 | 30.08.92 | 76° 20' | 56° 22' | 73 |
| DZ/68-31 | 30.08.92 | 75° 33' 3" | 56° 26' 6" | 165 |
| DZ/68-32 | 30.08.92 | 75° 28' 5" | 57° 10' | 120 |
| DZ/68-33 | 30.08.92 | 75° 21' 5" | 57° 35' 8" | 45 |
| DZ/68-34 | 30.08.92 | 75° 20' 3" | 57° 38' 2" | 38 |
| DZ/68-35 | 31.08.92 | 73° 50' | 53° 00' 00" | 120 |
| DZ/68-36 | 31.08.92 | 73° 43' | 52° 32' 00" | 120 |
| DZ/68-37 | 31.08.92 | 71° 00' | 51° 54' | 52 |
| DZ/68-38 | 31.08.92 | 72° 37' | 51° 20' | 76 |
| DZ/68-39 | 1.09.92 | 71° 35' 1" | 44° 24' 7" | 85 |
| Gol/80-1 | 13.08.94 | 79° 47' 28" | 60° 53' 53" | 265 |
| Gol/80-2 | 13.08.94 | 79° 58' 94" | 62° 13' 89" | 253 |
| Gol/80-3 | 14.08.94 | 79° 56' 65" | 65° 54' | 300 |
| Gol/80-4 | 14.08.94 | 79° 59' 90" | 67° 45' 70" | 560 |
| Gol/80-5 | 14.08.94 | 79° 55' 60" | 70° 46' 21" | 586 |
| Gol/80-6 | 15.08.94 | 80° 00' 60" | 75° 29' 30" | 143 |
| Gol/80-7 | 15.08.94 | 80° 14' 40" | 74° 00' | 256 |
| Gol/80-8 | 15.08.94 | 80° 50' 50" | 73° 59' 80" | 160 |
| Gol/80-9 | 16.08.94 | 80° 46' 30" | 70° 45' 20" | 608 |
| Gol/80-10 | 16.08.94 | 80° 37' | 67° 03' 10" | 497 |
| Gol/80-11 | 18.08.94 | 80° 22' 30" | 55° 52' 30" | 26 |
| Gol/80-12 | 19.08.94 | 80° 20' | 55° 40' 00" | 450 |
| Gol/80-13 | 21.08.94 | 80° 52' | 59° 15' 00" | 234 |
| Gol/80-14 | 22.08.94 | 81° 02' 30" | 59° 36' 40" | 267 |
| Gol/80-15 | 26.08.94 | 79° 36' 42" | 64° 15' 32" | 238 |
| Gol/80-16 | 26.08.94 | 79° 09' 80" | 68° 26' 40" | 530 |
| Gol/80-17 | 27.08.94 | 78° 21' | 56° 08' 00" | 380 |

Table 2: Results of granulometric sediment analyses
(all values in per cent of dry sediment weights).

| Station Numbers | Depth of sed. layer (cm) | Peb. | Gravel | | | Sand | | | Silt | | (%) | sum | sum | sum | sum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 20000 | 10000 | 5000 | 2000 | 1000 | 500 | 250 | 100 | 50 | 10 | Grav | Sand | Silt | Clay |
| | | 10000 | 5000 | 2000 | 1000 | 500 | 250 | 100 | 50 | 10 | 5 | | | | |
| | | (µm) | | | | | | | | | | | | | |
| Gol/80-1 | 0-1 | 0 | 0 | 2.3 | 3 | 6.1 | 12 | 21.5 | 16 | 2.3 | 12 | 5.3 | 39.9 | 31 | 23.8 |
| Gol/80-1 | 1-6 | 0 | 0 | 0 | 2.3 | 2 | 5.5 | 17.4 | 16 | 6.7 | 6 | 2.3 | 24.9 | 28.6 | 44.2 |
| Gol/80-1 | 6-11 | 0 | 0 | 0 | 1.2 | 2.4 | 2.9 | 6.7 | 6.9 | 2.5 | 12 | 1.2 | 12 | 21.4 | 65.4 |
| Gol/80-1 | 11-17 | 0 | 0 | 0 | 1.3 | 2.5 | 4.9 | 10.9 | 8 | 5.7 | 8 | 1.3 | 18.3 | 21.7 | 58.7 |
| Gol/80-1 | 17-23 | 0 | 0 | 0 | 0 | 1.5 | 1.8 | 4 | 3.6 | 4.9 | 7 | 0 | 7.3 | 15.5 | 77.2 |
| Gol/80-2 | 0-2 | 0 | 0 | 0.3 | 1 | 1.6 | 3.9 | 7.5 | 8.2 | 9.4 | 10 | 1.3 | 13 | 27.6 | 58.1 |
| Gol/80-2 | 2-5 | 0 | 0 | 0.1 | 1 | 1.1 | 3.8 | 6.8 | 8.8 | 10 | 10 | 1.1 | 11.7 | 29.2 | 58 |
| Gol/80-2 | 5-11 | 0 | 0 | 0 | 0 | 0.9 | 2.8 | 5.9 | 9 | 10 | 12 | 0 | 9.6 | 31 | 59.4 |
| Gol/80-2 | 11-13 | 0 | 0 | 0 | 2.1 | 6 | 5.6 | 8.2 | 8 | 11 | 10 | 2.1 | 19.8 | 28.9 | 49.2 |
| Gol/80-2 | 13-19 | 0 | 0 | 5 | 7.8 | 11 | 16 | 15 | 8.7 | 8.8 | 1.8 | 12.8 | 41.7 | 19.3 | 26.2 |
| Gol/80-2 | 19-26 | 0 | 0 | 0 | 1 | 0.7 | 3.4 | 7.9 | 7.5 | 10 | 8.3 | 1 | 12 | 25.8 | 61.2 |
| Gol/80-3 | 0-5 | 0 | 0 | 0 | 0 | 1.4 | 5.6 | 14.6 | 18 | 10 | 9.6 | 0 | 21.6 | 37.3 | 41.1 |
| Gol/80-3 | 5-10 | 0 | 0 | 0 | 0 | 1.1 | 8.5 | 15.9 | 23 | 18 | 24 | 0 | 25.5 | 64.4 | 10,1 |
| Gol/80-3 | 10-15 | 0 | 0 | 0 | 0 | 0.5 | 1.1 | 4.8 | 17 | 10 | 10 | 0 | 6.4 | 37.1 | 56.5 |
| Gol/80-3 | 15-18 | 0 | 0 | 0 | 0 | 0.3 | 0.6 | 7.4 | 20 | 13 | 13 | 0 | 8.3 | 46 | 45.7 |
| Gol/80-3 | 18-25 | 0 | 0 | 0.5 | 1.2 | 1.5 | 9.2 | 15.7 | 25 | 9.2 | 9.2 | 1.7 | 26.4 | 43.5 | 28.4 |
| Gol/80-3 | 25-27 | 0 | 0 | 3.9 | 2.8 | 2.2 | 1.5 | 8.1 | 24 | 11 | 13 | 6.7 | 11.8 | 47.6 | 33.9 |
| Gol/80-4 | 0-5 | 0 | 0 | 0 | 0 | 0.4 | 2.8 | 14.5 | 22 | 10 | 8.7 | 0 | 17.7 | 40.8 | 41,5 |
| Gol/80-4 | 5-10 | 0 | 0 | 0 | 0 | 0.1 | 0.2 | 0.8 | 1.5 | 2.7 | 7.3 | 0 | 1.1 | 11.5 | 87.4 |
| Gol/80-4 | 10-15 | 0 | 0 | 0 | 0 | 0.1 | 0.4 | 2 | 5 | 3.7 | 11 | 0 | 2.5 | 20 | 77.5 |
| Gol/80-4 | 15-22 | 0 | 0 | 0 | 0 | 0.1 | 0.3 | 1.4 | 2.8 | 1.1 | 8.2 | 0 | 1.8 | 12.1 | 86.1 |
| Gol/80-5 | 0-2 | 0 | 0 | 0 | 0.2 | 1 | 8.9 | 15.2 | 8.6 | 13 | 19 | 0.2 | 25.1 | 41.1 | 33.6 |
| Gol/80-5 | 5-20 | 0 | 0 | 0 | 0 | 0.6 | 10 | 17.3 | 7.2 | 2.1 | 13 | 0 | 27.9 | 22.4 | 49.7 |
| Gol/80-5 | 5-20 | 0 | 0 | 0 | 0 | 0.2 | 0.2 | 0.1 | 1.1 | 3.1 | 12 | 0 | 0.5 | 16.1 | 83.4 |
| Gol/80-5 | 5-20 | 0 | 0 | 0 | 0 | 0.1 | 0.3 | 5.7 | 13 | 18 | 30 | 0 | 6.1 | 61 | 32.9 |
| Gol/80-5 | 5-20 | 0 | 0 | 0 | 0.5 | 0.8 | 14 | 19.5 | 17 | 15 | 20 | 0.5 | 34.7 | 52.2 | 12.6 |
| Gol/80-5 | 5-20 | 0 | 0 | 0 | 0 | 0.1 | 1.2 | 3.7 | 3.8 | 7 | 8.7 | 0 | 5 | 19.5 | 75.5 |
| Gol/80-5 | 13-16 | 0 | 0 | 0.2 | 0.4 | 1.1 | 0.4 | 1.6 | 2.6 | 3.4 | 5.8 | 0.6 | 3.1 | 11.8 | 84.5 |
| Gol/80-5 | 16-18 | 0 | 0 | 0 | 0 | 0.3 | 1 | 3.8 | 4.8 | 4.2 | 6.5 | 0 | 5.1 | 15.5 | 79.4 |
| Gol/80-5 | 18-19 | 0 | 0 | 0.3 | 1.9 | 2 | 14 | 9.2 | 4.9 | 4 | 5.4 | 2.2 | 24.8 | 14.3 | 58.7 |
| Gol/80-6 | 0-2 | 0 | 0 | 0 | 0 | 0.7 | 3.2 | 39.5 | 44 | 0.7 | 3.7 | 0 | 43.4 | 48.4 | 8.2 |
| Gol/80-6 | 2-4 | 0 | 0 | 0 | 0.2 | 0.9 | 4.1 | 50.7 | 5.6 | 9.9 | 8.3 | 0.2 | 55.7 | 23.8 | 20.3 |
| Gol/80-6 | 4-6 | 0 | 0 | 0.2 | 0.2 | 0.9 | 3.7 | 38.5 | 24 | 11 | 5.1 | 0.4 | 43.1 | 39.5 | 17 |
| Gol/80-6 | 6-9 | 0 | 0 | 0 | 0.2 | 0.6 | 2.3 | 45.7 | 21 | 9.5 | 4.5 | 0.2 | 48.6 | 34.6 | 16.6 |
| Gol/80-6 | 9-11 | 0 | 0.3 | 0.7 | 0.1 | 1 | 3.1 | 36.5 | 21 | 11 | 5.7 | 1.1 | 40.6 | 37 | 21.3 |
| Gol/80-6 | 11-14 | 0 | 0 | 0.5 | 0.2 | 1.1 | 2.5 | 26 | 21 | 16 | 7.4 | 0.7 | 29.6 | 43.6 | 26.1 |
| Gol/80-6 | 14-16 | 0 | 0 | 0 | 0 | 0.8 | 1.5 | 22 | 22 | 17 | 7 | 0 | 24.3 | 46.5 | 29.2 |
| Gol/80-6 | 16-18 | 0 | 0 | 0 | 0 | 0.4 | 2.4 | 29.6 | 22 | 15 | 6.3 | 0 | 32.4 | 43.4 | 24.2 |
| Gol/80-6 | 18-20 | 0 | 0 | 0 | 0.1 | 0.2 | 2.3 | 29.2 | 23 | 17 | 5.4 | 0.1 | 31.7 | 45.6 | 22.6 |
| Gol/80-7 | 0-2 | 0 | 0 | 0 | 0.5 | 0.9 | 5.3 | 38.1 | 21 | 7.1 | 9.4 | 0.5 | 44.3 | 37.5 | 17.7 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gol/80-7 | 2-4 | 0 | 0 | 0.3 | 0.2 | 0.5 | 4.2 | 33.7 | 20 | 9.8 | 11 | 0.5 | 38.4 | 40.1 | 21 |
| Gol/80-7 | 4-6 | 0 | 0 | 0.7 | 0.5 | 0.9 | 5.5 | 20.3 | 25 | 8.1 | 17 | 1.2 | 26.7 | 50.4 | 21.7 |
| Gol/80-7 | 6-8 | 0 | 0 | 0.4 | 0.2 | 1.4 | 5 | 42.8 | 18 | 8 | 5.6 | 0.6 | 49.2 | 31.9 | 18.3 |
| Gol/80-7 | 8-10 | 0 | 0 | 0.3 | 0.2 | 1.3 | 4.5 | 38.2 | 20 | 10 | 6 | 0.5 | 44 | 35.8 | 19.7 |
| Gol/80-7 | 10-12 | 0 | 0 | 0.3 | 0.2 | 0.9 | 4.5 | 38.5 | 19 | 9.6 | 6.4 | 0.5 | 43.9 | 35.4 | 20.2 |
| Gol/80-7 | 12-14 | 0 | 0 | 0.2 | 0.1 | 1.3 | 3.8 | 30.8 | 20 | 15 | 7.3 | 0.3 | 35.9 | 41.5 | 22.3 |
| Gol/80-7 | 14-16 | 0 | 0 | 0.2 | 0.4 | 4.3 | 6.6 | 23.6 | 16 | 15 | 8.1 | 0.6 | 34.5 | 39.8 | 25.1 |
| | | | | | | | | | | | | | | | |
| Gol/80-8 | 0-2 | 8.1 | 3.8 | 2 | 0.3 | 1.2 | 9.9 | 34.5 | 9.7 | 8.1 | 4.1 | 6.1 | 45.6 | 21.9 | 18.3 |
| Gol/80-8 | 2-4 | 6.6 | 2.3 | 2 | 0.4 | 1.1 | 7.9 | 35.2 | 9.2 | 7.6 | 5.3 | 4.7 | 44.2 | 22.1 | 22.4 |
| Gol/80-8 | 4-6 | 5.2 | 1.1 | 1.4 | 0.5 | 1.2 | 11 | 37.9 | 17 | 4.5 | 3.8 | 3 | 49.7 | 25.6 | 16.5 |
| Gol/80-8 | 6-8 | 0 | 2 | 1.2 | 0.6 | 1.4 | 11 | 41.1 | 21 | 4.9 | 2.8 | 3.8 | 53.7 | 28.9 | 13.6 |
| Gol/80-8 | 8-10 | 14.9 | 5.2 | 1.8 | 0.5 | 0.8 | 7.4 | 34.3 | 11 | 5.9 | 1.2 | 7.5 | 42.5 | 17.6 | 17.5 |
| Gol/80-8 | 10-12 | 0 | 2.4 | 5.7 | 0.7 | 1.7 | 9.5 | 36.6 | 12 | 6.9 | 4.6 | 8.8 | 47.8 | 23 | 20.4 |
| Gol/80-8 | 12-14 | 2.7 | 0.4 | 0.9 | 2.5 | 0.7 | 4.2 | 29.7 | 14 | 12 | 7.1 | 3.8 | 34.6 | 33.2 | 25,7 |
| Gol/80-8 | 14-16 | 0 | 0.4 | 0.5 | 0.3 | 0.5 | 3.1 | 22.1 | 15 | 14 | 7.8 | 1.2 | 25.7 | 36.1 | 37 |
| Gol/80-8 | 16-18 | 0 | 0 | 0 | 0.3 | 0.8 | 3.5 | 20.7 | 15 | 15 | 9.3 | 0.3 | 25 | 39.3 | 35.4 |
| Gol/80-8 | 18-20 | 0 | 0.8 | 0.3 | 0.2 | 0.6 | 2.8 | 20.3 | 14 | 17 | 11 | 1.3 | 23.7 | 42.3 | 32,7 |
| | | | | | | | | | | | | | | | |
| Gol/80-9 | 0-2 | 0 | 0 | 0 | 0.5 | 1 | 0.5 | 0.5 | 10 | 19 | 25 | 0.5 | 2 | 54.7 | 42.8 |
| Gol/80-9 | 2-4 | 0 | 0 | 0 | 0.3 | 0.5 | 0.6 | 0.9 | 7.5 | 25 | 28 | 0.3 | 2 | 60.1 | 37.6 |
| Gol/80-9 | 4-6 | 0 | 0 | 0 | 0.3 | 0.5 | 0.5 | 0.8 | 4.9 | 13 | 19 | 0.3 | 1.8 | 37.5 | 60.4 |
| Gol/80-9 | 6-8 | 0 | 0 | 0 | 0.7 | 0.8 | 0.4 | 0.8 | 5.8 | 13 | 21 | 0.7 | 2 | 39.7 | 57.6 |
| Gol/80-9 | 8-10 | 0 | 0 | 0 | 0 | 0 | 0 | 0.5 | 1.1 | 6.4 | 18 | 0 | 0.5 | 25.9 | 73.6 |
| Gol/80-9 | 10-12 | 0 | 0 | 0 | 0 | 0.8 | 3.4 | 0.5 | 6 | 6.8 | 23 | 0 | 4.7 | 35.3 | 60 |
| Gol/80-9 | 12-14 | 0 | 0 | 0 | 0 | 0 | 0.4 | 0.5 | 7.4 | 13 | 18 | 0 | 0.9 | 38.2 | 60.9 |
| Gol/80-9 | 14-16 | 0 | 0 | 0 | 0.3 | 0.3 | 1.5 | 3.4 | 2.5 | 18 | 18 | 0.3 | 5.2 | 38.7 | 55.8 |
| Gol/80-9 | 16-18 | 0 | 0 | 0 | 0.7 | 0.5 | 0.9 | 1.9 | 3.8 | 12 | 18 | 0.7 | 3.3 | 34.1 | 61.9 |
| | | | | | | | | | | | | | | | |
| Gol/80-10 | 0-2 | 0 | 0.4 | 0.2 | 0.2 | 0.3 | 1.1 | 4.1 | 4.8 | 19 | 16 | 0.8 | 5.5 | 40 | 53.7 |
| Gol/80-10 | 2-4 | 0 | 0 | 0 | 0.3 | 0.7 | 0.8 | 4.4 | 8 | 17 | 19 | 0.3 | 5.9 | 44.1 | 49.7 |
| Gol/80-10 | 4-6 | 0 | 0 | 0 | 0.7 | 0.3 | 1 | 4.6 | 11 | 16 | 17 | 0.7 | 5.9 | 43.9 | 49.5 |
| Gol/80-10 | 6-8 | 0 | 0 | 0 | 0.7 | 0.2 | 0.8 | 4.6 | 9 | 17 | 14 | 0.7 | 5.6 | 40 | 53.7 |
| Gol/80-10 | 8-11 | 0 | 0 | 0 | 0 | 0.1 | 0.8 | 6.2 | 7.4 | 20 | 14 | 0 | 7.1 | 40.7 | 52.2 |
| Gol/80-10 | 11-14 | 0 | 0 | 0 | 0 | 0.1 | 0.9 | 10.7 | 15 | 25 | 11 | 0 | 11.7 | 50.8 | 37.5 |
| Gol/80-10 | 14-16 | 0 | 0 | 0.3 | 0.4 | 0.2 | 1.3 | 9.9 | 14 | 23 | 13 | 0.7 | 11.4 | 50.2 | 37.7 |
| Gol/80-10 | 16-18 | 0 | 0 | 0 | 0.2 | 0.4 | 1 | 9.4 | 16 | 18 | 14 | 0.2 | 10.8 | 48.6 | 40.4 |
| Gol/80-10 | 18-20 | 0 | 0 | 0 | 0.5 | 0.5 | 1.4 | 13.7 | 16 | 19 | 10 | 0.5 | 15.6 | 44.6 | 39.3 |
| Gol/80-10 | 20-23 | 0 | 0 | 0 | 0.5 | 0.8 | 1.1 | 13.7 | 13 | 25 | 7.6 | 0.5 | 15.6 | 45.7 | 38.2 |
| Gol/80-10 | 23-26 | 0 | 0 | 0 | 0.5 | 1 | 1.3 | 12.4 | 16 | 27 | 1.7 | 0.5 | 14.7 | 45.3 | 39.5 |
| | | | | | | | | | | | | | | | |
| Gol/80-11 | 0-5 | 0 | 0 | 0 | 0 | 0.1 | 0.8 | 52.8 | 8 | 32 | 0.7 | 0 | 53.7 | 40.5 | 5.8 |
| Gol/80-11 | 5-10 | 0 | 0 | 0 | 0.1 | 0.3 | 0.6 | 51.6 | 23 | 16 | 2 | 0.1 | 52.5 | 40.7 | 6.7 |
| Gol/80-11 | 10-15 | 0 | 0 | 0 | 0 | 0.2 | 0.9 | 77.2 | 16 | 2.6 | 0.2 | 0 | 78.3 | 19.1 | 2.6 |
| | | | | | | | | | | | | | | | |
| Gol/80-12 | 0-2 | 0 | 0 | 0 | 0.3 | 1.2 | 1.2 | 1.9 | 63 | 5.9 | 9.5 | 0.3 | 4.3 | 78.5 | 16.9 |
| Gol/80-12 | 2-4 | 0 | 0 | 0 | 1.1 | 0.7 | 1.2 | 2.3 | 7.7 | 22 | 17 | 1.1 | 4.2 | 46.3 | 48.4 |
| Gol/80-12 | 4-6 | 0 | 0 | 1.1 | 0.7 | 0.7 | 1.2 | 1.9 | 10 | 23 | 14 | 1.8 | 3.8 | 46.6 | 47.8 |
| Gol/80-12 | 6-8 | 0 | 0 | 2.3 | 0.6 | 0.9 | 1.1 | 1.9 | 17 | 13 | 15 | 2.9 | 3.9 | 45.1 | 48.1 |
| Gol/80-12 | 8-10 | 0 | 4.4 | 1.1 | 0.8 | 0.9 | 0.9 | 1.6 | 6.7 | 18 | 16 | 6.3 | 3.4 | 40.3 | 50 |
| Gol/80-12 | 10-12 | 6 | 3.3 | 1.2 | 0.3 | 0.4 | 1.1 | 1.6 | 3.2 | 20 | 13 | 4.8 | 3.1 | 35.4 | 50.7 |
| Gol/80-12 | 12-14 | 0 | 1.3 | 2.6 | 0.7 | 0.7 | 0.6 | 1.7 | 9.5 | 15 | 16 | 4.6 | 3 | 40.6 | 51.8 |
| Gol/80-12 | 14-16 | 0 | 2.7 | 3.5 | 0.8 | 1.1 | 1.1 | 1.8 | 17 | 15 | 12 | 7 | 4 | 43.6 | 45.4 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gol/80-12 | 16-18 | 0 | 0.5 | 2.3 | 0.9 | 1 | 1.1 | 1.9 | 9.7 | 15 | 13 | 3.7 | 4 | 37 | 55.3 |
| Gol/80-12 | 18-20 | 0 | 0 | 2.3 | 2 | 1.6 | 1.1 | 1.9 | 13 | 17 | 13 | 4.3 | 4.6 | 42.9 | 48.2 |
| | | | | | | | | | | | | | | | |
| Gol/80-13 | 5-10 | 0 | 1.8 | 2.5 | 0.5 | 0.6 | 1.1 | 3.2 | 7.6 | 30 | 13 | 4.8 | 4.9 | 49.8 | 40.5 |
| Gol/80-13 | 10-15 | 0 | 0.8 | 2.3 | 0.6 | 0.6 | 2.2 | 5.1 | 6.5 | 32 | 13 | 3.7 | 7.9 | 51 | 37.4 |
| Gol/80-13 | 15-20 | 0 | 1.2 | 3 | 0.7 | 0.9 | 1.3 | 3.3 | 7 | 32 | 14 | 4.9 | 5.5 | 53.1 | 36.5 |
| Gol/80-13 | 20-25 | 0 | 0 | 3.2 | 0.8 | 0.7 | 2.2 | 4.9 | 4.8 | 32 | 12 | 4 | 7.8 | 49 | 39.2 |
| Gol/80-13 | 25-30 | 0 | 0.9 | 1.2 | 0.3 | 0.3 | 0.8 | 1.5 | 51 | 16 | 6.2 | 2.4 | 2.6 | 73.6 | 21.4 |
| Gol/80-13 | 30-35 | 0 | 0 | 1.3 | 0.3 | 0.4 | 1.3 | 3.1 | 9.4 | 27 | 15 | 1.6 | 4.8 | 51 | 42.6 |
| Gol/80-13 | 35-40 | 0 | 0 | 0.5 | 0.2 | 0.3 | 1.1 | 0.5 | 9.7 | 30 | 14 | 0.7 | 1.9 | 54 | 43.4 |
| Gol/80-13 | 40-45 | 0 | 0.4 | 2.3 | 0.5 | 0.8 | 1.2 | 3.1 | 9.8 | 27 | 13 | 3.2 | 5.1 | 49.9 | 41.8 |
| Gol/80-13 | 45-50 | 0 | 0.7 | 3.2 | 0.7 | 0.7 | 1.4 | 2.9 | 10 | 28 | 13 | 4.6 | 5 | 50.4 | 40 |
| Gol/80-13 | 50-55 | 0 | 1.5 | 2.7 | 0.6 | 0.7 | 1 | 2.2 | 13 | 26 | 11 | 4.8 | 3.9 | 49.6 | 41.7 |
| Gol/80-13 | 55-60 | 0 | 1 | 0.8 | 0.6 | 0.7 | 1 | 2.9 | 6.6 | 26 | 14 | 2.4 | 4.6 | 46 | 47 |
| Gol/80-13 | 60-65 | 0 | 0 | 2.6 | 1 | 1.1 | 1.6 | 4.3 | 6.4 | 27 | 14 | 3.6 | 7 | 47.3 | 42.1 |
| Gol/80-13 | 65-70 | 0 | 1 | 3.4 | 0.9 | 0.9 | 1.3 | 3.4 | 6.6 | 27 | 14 | 5.3 | 5.6 | 47.5 | 41.6 |
| Gol/80-13 | 70-75 | 0 | 5.5 | 2.4 | 0.6 | 0.5 | 0.8 | 2.1 | 5.9 | 25 | 16 | 8.5 | 3.4 | 46.4 | 41.7 |
| Gol/80-13 | 75-80 | 0 | 0 | 0 | 0.9 | 0.8 | 1.1 | 2.8 | 11 | 28 | 15 | 0.9 | 4.7 | 54.2 | 40.2 |
| Gol/80-13 | 80-85 | 0 | 2.3 | 0.6 | 0.4 | 0.5 | 1.2 | 3.8 | 7 | 27 | 18 | 3.3 | 5.5 | 51.6 | 39.6 |
| Gol/80-13 | 85-90 | 0 | 0 | 2.4 | 0.7 | 0.7 | 1.1 | 3 | 4.1 | 32 | 11 | 3.1 | 4.8 | 47.3 | 44.8 |
| Gol/80-13 | 90-95 | 0 | 0 | 1.6 | 0.6 | 0.9 | 0.9 | 3.9 | 11 | 24 | 14 | 2.2 | 5.7 | 48.4 | 43.7 |
| Gol/80-13 | 95-100 | 0 | 0 | 0.7 | 0.7 | 1.1 | 1.7 | 4 | 3.9 | 28 | 14 | 1.4 | 6.8 | 44.9 | 46.9 |
| Gol/80-13 | 100-105 | 5.3 | 0 | 1.4 | 0.5 | 0.6 | 1.7 | 3.9 | 5.4 | 28 | 12 | 1.9 | 6.2 | 44.7 | 41.9 |
| Gol/80-13 | 105-110 | 0 | 3.5 | 3.5 | 0.6 | 0.6 | 1.4 | 2.6 | 1.8 | 28 | 12 | 7.6 | 4.6 | 41.8 | 46 |
| Gol/80-13 | 110-115 | 0 | 0.7 | 1.7 | 0.5 | 0.5 | 1.3 | 2.9 | 7.6 | 29 | 13 | 2.9 | 4.7 | 49.6 | 42.8 |
| | | | | | | | | | | | | | | | |
| Gol/80-14 | 0-2 | 0 | 0 | 0 | 0.6 | 0.9 | 1.1 | 2.4 | 16 | 15 | 17 | 0.6 | 4.4 | 47.8 | 47.2 |
| Gol/80-14 | 2-6 | 0 | 0 | 0.4 | 0.4 | 0.8 | 0.8 | 1.7 | 7.4 | 27 | 17 | 0.8 | 3.3 | 52 | 43.9 |
| Gol/80-14 | 6-10 | 7.8 | 0.2 | 1.7 | 0.6 | 0.5 | 0.5 | 1.1 | 1.8 | 29 | 15 | 2.5 | 2.1 | 44.9 | 42.7 |
| Gol/80-14 | 10-14 | 0 | 0.1 | 1 | 0.3 | 0.4 | 0.4 | 0.8 | 6.7 | 29 | 16 | 1.4 | 1.6 | 51.4 | 45.6 |
| Gol/80-14 | 18-22 | 0 | 0 | 0.9 | 0.9 | 0.6 | 0.8 | 0.8 | 9.5 | 29 | 21 | 1.8 | 2.2 | 59.2 | 36.8 |
| Gol/80-14 | 22-24 | 0 | 0 | 1.1 | 0.2 | 0.5 | 0.5 | 0.9 | 4.4 | 32 | 14 | 1.3 | 1.9 | 49.9 | 46.9 |
| | | | | | | | | | | | | | | | |
| Gol/80-15 | 5-13 | 0 | 3.4 | 8.2 | 2.3 | 2.3 | 2.9 | 9.2 | 8.5 | 16 | 14 | 13.9 | 14.4 | 38.5 | 33.2 |
| Gol/80-15 | 13-18 | 0 | 0 | 0 | 1 | 0.7 | 1.3 | 13.3 | 12 | 19 | 13 | 1 | 15.3 | 43.9 | 39.8 |
| Gol/80-15 | 18-23 | 0 | 0 | 0 | 0.7 | 0.3 | 0.9 | 13.8 | 17 | 18 | 12 | 0.7 | 15 | 46.5 | 37.8 |
| Gol/80-15 | 23-28 | 0 | 0.9 | 0.6 | 0.4 | 1.7 | 2 | 10.2 | 15 | 20 | 9.8 | 1.9 | 13.9 | 45.4 | 38.8 |
| Gol/80-15 | 28-33 | 0 | 0 | 1 | 0.8 | 1.3 | 1.4 | 9.2 | 13 | 20 | 12 | 1.8 | 11.9 | 43.7 | 42.6 |
| Gol/80-15 | 33-38 | 0 | 1.8 | 1.2 | 0.7 | 1.2 | 2.1 | 10.1 | 11 | 18 | 13 | 3.7 | 13.4 | 41.9 | 41 |
| Gol/80-15 | 38-43 | 0 | 0.2 | 2.2 | 1 | 2.6 | 1.9 | 8.5 | 13 | 18 | 11 | 3.4 | 13 | 42.2 | 41.4 |
| Gol/80-15 | 43-48 | 0 | 2.1 | 3.4 | 1 | 2.1 | 1.8 | 7 | 15 | 17 | 10 | 6.5 | 10.9 | 42.3 | 40.3 |
| Gol/80-15 | 48-53 | 0 | 1.1 | 1.9 | 1.4 | 3.8 | 2.8 | 10.7 | 1.2 | 20 | 12 | 4.4 | 17.3 | 33.3 | 45 |
| Gol/80-15 | 53-58 | 0 | 0.2 | 1.5 | 0.9 | 2.3 | 2.6 | 13.1 | 11 | 18 | 11 | 2.6 | 18 | 40.1 | 39.3 |
| Gol/80-15 | 58-63 | 1.3 | 0.6 | 2.2 | 0.8 | 2.2 | 2.1 | 10.3 | 17 | 18 | 11 | 3.6 | 14.6 | 46.1 | 34.4 |
| Gol/80-15 | 63-68 | 0 | 0.5 | 0.5 | 0.6 | 0.5 | 1.2 | 14.1 | 17 | 20 | 9.6 | 1.6 | 15.8 | 46.5 | 36.1 |
| Gol/80-15 | 68-73 | 0 | 0.5 | 5 | 2.2 | 3.9 | 2.6 | 8.9 | 8.7 | 19 | 10 | 7.7 | 15.4 | 38.2 | 38.7 |
| Gol/80-15 | 73-78 | 0 | 0 | 1.6 | 1 | 2.2 | 2.2 | 11.3 | 14 | 19 | 12 | 2.6 | 15.7 | 45.5 | 36.2 |
| Gol/80-15 | 78-83 | 0 | 0.7 | 2 | 0.9 | 1.1 | 1.6 | 10.7 | 9.5 | 21 | 13 | 3.6 | 13.4 | 43.5 | 39.5 |
| Gol/80-15 | 83-88 | 0 | 0 | 2.3 | 1.6 | 1.3 | 1.5 | 7.5 | 39 | 13 | 7.7 | 3.9 | 10.3 | 59.3 | 26.5 |
| Gol/80-15 | 88-93 | 0 | 0 | 2.2 | 1.2 | 1.4 | 3 | 13.7 | 13 | 19 | 12 | 3.4 | 18.1 | 43.2 | 35.3 |
| | | | | | | | | | | | | | | | |
| Gol/80-17 | 0-2 | 0 | 0 | 0 | 0.1 | 0.4 | 0.9 | 3 | 11 | 23 | 22 | 0.1 | 4.3 | 55.4 | 40.2 |
| Gol/80-17 | 2-4 | 0 | 0 | 0 | 0.3 | 0.4 | 0.8 | 2.3 | 17 | 20 | 24 | 0.3 | 3.5 | 61.3 | 34.9 |
| Gol/80-17 | 4-6 | 0 | 0 | 0 | 0.1 | 0.4 | 0.8 | 2.9 | 12 | 24 | 24 | 0.1 | 4.1 | 59.1 | 36.7 |
| Gol/80-17 | 6-8 | 0 | 0 | 0 | 0.7 | 0.6 | 0.5 | 2.7 | 7.9 | 15 | 21 | 0.7 | 3.8 | 43.7 | 51.8 |
| Gol/80-17 | 8-10 | 0 | 0 | 0 | 0 | 0 | 0.4 | 3.5 | 5.4 | 19 | 16 | 0 | 3.9 | 40 | 56.1 |
| Gol/80-17 | 10-12 | 0 | 0 | 0 | 0.4 | 0.4 | 0.4 | 0.3 | 11 | 15 | 17 | 0.4 | 1.1 | 43 | 55.6 |
| Gol/80-17 | 12-14 | 0 | 0 | 0 | 0 | 2.4 | 0.5 | 3.4 | 3.7 | 17 | 17 | 0 | 6.3 | 37.5 | 56.2 |
| Gol/80-17 | 14-16 | 0 | 0 | 0 | 0 | 0.4 | 1.2 | 4.5 | 6.9 | 16 | 18 | 0 | 6.1 | 40.8 | 53.1 |
| Gol/80-17 | 16-18 | 0 | 0 | 0 | 0.3 | 0.3 | 0.9 | 4.3 | 8 | 18 | 15 | 0.3 | 5.5 | 41 | 53.2 |
| Gol/80-17 | 18-20 | 0 | 0 | 0 | 0 | 2.2 | 0.3 | 3.1 | 4 | 19 | 17 | 0 | 5.6 | 39.3 | 55.1 |

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## Abstract

### Peculiarities of modern sedimentation in the northeastern Barents Sea and southwestern Kara Sea

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Some results of investigations of surface sediments in the northern part of Barents-Kara region are presented. The composition of the sediments, the character of their distribution in the basin, their origin with special regard to glaciers, and possible ways of transportation as well as early changes of the surface sediment structures are discussed.

# Reproduction of the chaetognath *Eukrohnia hamata* (Möbius, 1875) in the Arctic Ocean

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## Introduction

*Eukrohnia hamata* (Möbius, 1875) is an oceanic species distributed in meso- and bathypelagic layers in subtropical and equatorial regions, but rising to epipelagic levels or even to the surface in the coldest seas.

There are a few reports about the reproduction of *E. hamata* in the Arctic regions (Bogorov, 1940; Richter, 1994). However, no knowledge is available about the breeding characteristics of these chaetognaths, because they are difficult to culture and most individuals are damaged by collection.

This short paper includes information about the reproductive features of *E. hamata* collected in the Arctic Ocean.

## Materials and methods

The chaetognaths *E. hamata* were collected at two Stations northwest of Franz-Josef-Land in August 1993 during the expedition ARK IX/4 of the German RV "Polarstern": Station 27/019 (18 August; at 82° 45,2' N and 40° 12,5' E; 2984 m total water depth) and Stat. 27/020 (19 August; 82° 23,0' N, 40° 55,4' E; 1977 m depth). Samples were obtained with vertical tows by a Kiel Multinet equipped with 5 nets (150 µm mesh gauze). Sampling intervals were 1500-700-200-100-50-0m.

The collections were preserved in 4% borax-buffered formaldehyde.

## Results and Discussion

*E. hamata* were found over all the depth; however, immature specimens of 3-22 mm length (9 mm modal class) predominated in the surface layers (Hanssen & Timofeev, 1994). Animals from 26 to 36 mm length with different rates of gonad development and carrying egg sacs were found only in the deepest layers (1500-700 m).

Such vertical distribution is typical for *E. hamata* in the Arctic and Antarctic Oceans (Bogorov, 1940; Hagen, 1985; Richter, 1994) and indicates the existence of spawning migrations, i.e. the largest and ripest specimens descend to lower layers to reproduce. Since the layer from 100-150 m to 900-1000 m in the Eurasian Arctic Ocean is occupied by Atlantic waters with temperatures of near to 0°C and salinities of 34.8-34.9 (Fig. 1), the maturation and reproduction in *E. hamata* are suggested to be completed in these Atlantic waters.

Data, characterising the chaetognaths' length, development of gonads and fecundity, are given in Table 1. In mature specimen female or male gonads are available, but, no simultaneous maturation of ovary and testis occurs. This supports our general knowledge of chaetognath reproductive biology, i.e. that a successive (protandrous) hermaphroditism exists also in *E. hamata*. Accordingly, their mode of fertilization is presumably allomixis.

Fig. 1.
Vertical distribution
of temperature and salinity
at the Station 27/019,
19 August, 1995

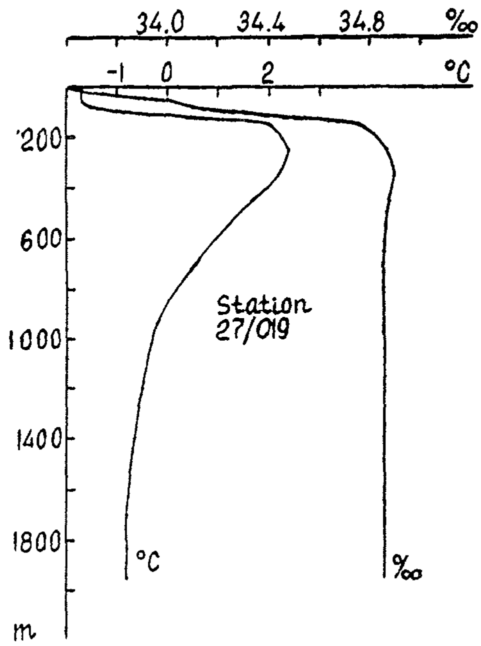


Table 1: Reproductive characteristics of *Eukrohnia hamata* in the Arctic Ocean

| Body length mm | Gonad length, mm female | male | Marsupial sac | Fecundity state |
|---|---|---|---|---|
| Station 27/019: | | | | |
| 25.0 | | | no | no eggs |
| 26.9 | 4.5 | | yes | 144 (69+75) |
| 27.7 | 3.5 | | yes | no eggs |
| 28.4 | 6.3 | | yes | no eggs |
| 28.9 | 5.2 | | yes | no eggs |
| 30.3 | | 10.7 | no | no eggs |
| 31.5 | | 9.0 | no | no eggs |
| 32.4 | 7.8 | | no | no eggs |
| 33.7 | | 9.7 | no | no eggs |
| 34.4 | | 9.9 | no | no eggs |
| 35.7 | 8.7 | | no | no eggs |
| Station 27/020: | | | | |
| 26.0 | 6.4 | | yes | 140 (72 + 68) |
| 26.1 | | | no | no eggs |
| 26.6 | 8.3 | | no | no eggs |
| 27.5 | | | no | no eggs |
| 30.5 | 4.7 | | yes | 151 (77 + 74) |
| 31.5 | 7.0 | | yes | 120 (58 + 62) |
| 31.5 | | 8.8 | no | no eggs |
| 32.0 | | 9.5 | no | no eggs |
| 32.7 | | | no | no eggs |
| 33.5 | | | no | no eggs |
| 34.2 | | 9.7 | no | no eggs |
| 34.3 | 7.0 | | no | no eggs |
| 34.7 | 9.0 | | no | no eggs |
| 34.8 | | 10.2 | no | no eggs |
| 36.0 | | | no | no eggs |

Among the animals caught, only seven specimens had egg sacs and only four of them eggs (Table 1). *E. hamata* with egg sacs, but lacking eggs, were the smallest adult specimens (27.7-28.9 mm body length), however, with well developed female gonads. Probably, those were the animals ready to start their reproduction in the nearest future.
The eggs of spherical shape (500-625 mm diameter) are concentrated in the egg sacs as solid mass. Approximately equal numbers of eggs, ranging from 120 to 151, were found in each pair of egg sacs.

Data on the fecundity of species of *Eukrohnia* are summarized in the Table 2. The egg size is dependent on body length. However, the fecundity does not relate to this characteristic; and it is probably determined by the depth of dwelling. In spite of the fact that the mature specimens of *E. hamata* have been found in great depths (bathypelagy), the main portion of the population, as juveniles, inhabits the epipelagial (0-100 m). Thus, if this species is regarded in the Arctic Ocean as, for its main part, epipelagic, however, by migrating to greater depths for reproduction, its fecundity, when compared within the *Eukrohnia* genus, is not reduced, while other species, living at greater depths, produce less eggs.

Table 2: Body length, depth distribution, fecundity and eggs size in chaetognaths of the genus *Eukrohnia*

| Characteristics | *E. bathypelagica* | *E. fowleri* | *E. hamata* |
|---|---|---|---|
| Area | 50° N, 145° W | 50° N, 145° W | 82.5° N, 40.5° E |
| Depth, m | 250-500 | below 1000 | 0-700-1000 |
| Body length, mm | 15-24 | 32-40 | 25-36 |
| Egg diameter, mm | 480 | 900 | 500-625 |
| Fecundity | 38-60 | 10-12 | 120-151 |
| References | Terazaki & Miller, 1982 | Terazaki & Miller, 1982 | present study |

## Conclusion

In the Arctic Ocean young specimens of *E. hamata* inhabit the epipelagial, whereas mature specimens occur in the meso- and bathypelagial. Maturation and reproduction of *E. hamata* take place in the waters of Atlantic origin (temperature is above 0° C and salinity around 35 ‰). Fecundity of *E. hamata* in the Arctic Ocean reaches 120-151 eggs in one specimen. Egg size in the genus *Eukrohnia* is dependent on the animals' body lengths, whereas fecundity is determined by the depth of (main) inhabitation.

## Acknowledgements

I thank the Alfred-Wegener-Institute for Polar and Marine Research for organizing and making possible my research activities in Arctic waters on board RV "Polarstern". I also thank the crew of the ship and Drs. H. Hanssen (Kiel) and K. Kosobokova (Moscow) for ensuring successfull field operations.

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## Summary

### Reproduction of the chaetognath *Eukrohnia hamata* (Möbius, 1875) in the Arctic Ocean

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The reproduction of the chaetognath *Eukrohnia hamata* sampled in the Arctic Ocean in August 1993 during the expedition ARK IX/4 of the German RV "Polarstern" was studied. In the Arctic Ocean, young specimens of *E. hamata* inhabit the epipelagial, whereas mature animals occur in the meso- and bathypelagial. It is suggested that the maturation and reproduction of *E. hamata* take place in the Atlantic water (temperature mainly above 0° C and salinity around 35 ‰). The fecundity of *E. hamata* in the Arctic Ocean comes to 120-151 eggs during one spawning of a female.

# Meroplankton in Spitsbergen waters

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## Introduction

Meroplankton research of waters washing the Spitsbergen Archipelago, is an almost unexplored field in the Arctic marine hydrobiology. Some information is available only for the Hornsund (Wiktor et al. 1986; Weslawski et al. 1988; Koszteyn and Kwasniewski 1989) and Storfjord (Koszteyn and Kwasniewski 1989; Timofeev and Shaban 1992). Besides, some data were published about meroplankton from the Victoria Island and Franz Josef Land areas (Shuvalov and Pavshtiks 1977).

This paper is the first one in which the larvae of bottom invertebrates are specially considered as a component of plankton community in the waters around Spitsbergen.

## Materials and methods

Material was obtained during the international Arctic EPOS cruise of RV "Polarstern" in June - July 1991 (s. Rachor, 1992, and map Fig. 1 of contribution Androv and Matishov, this volume). Zooplankton was collected by Bongo-net from 100 m depth to the surface. Speed of a net lifting was about 1 m/sec. Samples were preserved in 4 % neutral formalin.

## Results

The portion of bottom animal larvae in the total zooplankton abundance of Spitsbergen waters, independent of the area, is relatively uniform (Table 1). The section in the Barents Sea, where the relative value for meroplankton does not exceed 15 %, is an exception; and the lowest absolute abundance value for these organisms is noted here. Maximum meroplankton abundance was found in Storfjord. Larvae of Echinodermata (mainly Ophiurida) were predominant almost over the whole area studied, and only in the Kvitøya section the nauplii of Cirripedia prevailed (Table 2). Larvae of Decapoda were found only in the Barents Sea section (*Pandalus* spp.) and in the Storfjord (*Pagurus* spp.), larvae of Ascidiacea - only in the first of these areas. Juveniles of Bivalvia were caught in the Storfjord and along the Yermak Plateau section, while Gastropoda were restricted to the northern and northeastern waters. For more details see Table 2.

Table 1: Abundance of holo- and meroplankton in waters around Svalbard

| Area, Station | Depth m | Holoplankton | | Meroplankton | |
|---|---|---|---|---|---|
| | | ind./m$^2$ | % | ind./m$^2$ | % |
| *Barents Sea* | | | | | |
| 19/040 | 195 | 6075 | 96.2 | 240 | 3.8 |
| 19/041 | 156 | 6765 | 72.5 | 2565 | 27.5 |
| 19/044 | 227 | 8775 | 93.6 | 600 | 6.4 |
| 19/045 | 250 | 23685 | 79.4 | 6120 | 20.6 |
| *Storfjord* | | | | | |
| 19/052 | 185 | 10875 | 28.8 | 26985 | 71.2 |
| 19/057 | 142 | 11940 | 29.8 | 28215 | 70.2 |
| 19/064 | 216 | 13680 | 93.9 | 885 | 6.1 |
| *Kongsfjordrenna* | | | | | |
| 19/078 | 1811 | 4005 | 95.4 | 195 | 4.6 |
| 19/079 | 1242 | 14505 | 92.5 | 1170 | 7.5 |
| 19/081 | 297 | 9390 | 38.8 | 14820 | 61.2 |
| 19/082 | 334 | 8595 | 46.8 | 9780 | 53.2 |
| *Yermak Plateau* | | | | | |
| 19/086 | 571 | 6123 | 97.0 | 184 | 3.0 |
| 19/088 | 502 | 6270 | 30.2 | 14461 | 69.8 |
| 19/090 | 169 | 13745 | 85.8 | 2260 | 14.2 |
| *Sjuøyane* | | | | | |
| 19/094 | 220 | 37980 | 57.2 | 28370 | 42.8 |
| 19/098 | 2759 | 12926 | 91.8 | 1159 | 8.2 |
| 19/100 | 875 | 12240 | 78.5 | 3345 | 21.5 |
| 19/101 | 530 | 6615 | 68.6 | 3030 | 31.4 |
| *North-Eastern Slope* | | | | | |
| 19/104 | 266 | 2305 | 82.3 | 495 | 17.7 |
| 19/105 | 395 | 3405 | 56.3 | 2640 | 43.7 |
| 19/108 | 2542 | 2838 | 76.4 | 878 | 23.6 |
| 19/110 | 1930 | 5707 | 93.4 | 401 | 6.6 |
| 19/111 | 1441 | 25725 | 75.5 | 8354 | 24.5 |
| 19/112 | 995 | 14080 | 80.4 | 3435 | 19.6 |
| 19/115 | 237 | 2085 | 66.5 | 1050 | 33.5 |
| *Kvitøya* | | | | | |
| 19/116 | 107 | 11757 | 58.0 | 8497 | 42.0 |
| 19/124-2 | 411 | 2595 | 52.0 | 2390 | 48.0 |
| 19/129 | 100 | 6870 | 64.0 | 3855 | 36.0 |

# The Laptev Sea Zooplankton: a Review (1996)

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## Introduction

In respect of the zooplankton fauna, the Laptev Sea is almost the least studied Arctic sea (except the East Siberian Sea, which is almost „mare incognitum" for zooplanktonologists). At the present time even waters of the Central Arctic Basin have been studied better and more completely. The reasons of this disproportion of the research efforts are rather simple. The "Golden Age" of the study of Siberian Seas zooplankton was in the 1930-s, during the developing of the Northern Sea Route. In this period a great number of expeditions were conducted. Hydrobiologists (planktono-logists) took part in many of them. The rather low-power ice-breakers of that time made more severe demands to ice fore-casts and needed a more detailed estimation of the ice-situation. That also promo-ted biological investigations as one alternative approach of the ice situation forecast. In the 1950-s, 1960-s and later, the importance of biological parameters has descreased sharply as, on the one hand, data obtained by airplanes (and then by satellites) and giving more operative information have been used for ice fore-casting and ice situation evaluation, and, on the other hand, powerful ice-breakers (with both atomic and traditional power-plants) appeared.

Fishery in this region is of local character and is connected with river mouths. Moreover, its output is insignificant, and, accordingly, it does not provoke investigations of zooplankton as its forage reserve.

All these above mentioned reasons together with the bad accessibility have resulted in insufficient and only non-obligatory investigations of the Laptev Sea zooplankton (like the Second Arctic Underwater Expedition of the Zoological Institute of the Academy of Sciences of the U.S.S.R. in 1973). On the contrary, the study of the central Arctic Basin in that time has continually gained in scope, especially in connection with the organization of stations drifting on ice-floes during several years. These stations permitted to get unique data on the structural and functional organization of pelagic communities of this region (Vinogradov and Melnikov 1980; Melnikov 1989).

In spite of their scanty number, data on the Laptev Sea zooplankton allow to write a rather complete review. Another reason forcing us to write this review is the bad availability of the information on the Laptev Sea zooplankton in editions of books and journals which have become rare even in scientific libraries. Moreover, in recent years new international and bilateral expeditions to Siberian waters were initiated, for which basic knowledge is required.

## Short physical-geographical description of the Laptev Sea

The Laptev Sea was named in 1935 after two cousins, participants of the Great Siberian Expedition (1736-1742), D.Yu. Laptev and H.P. Laptev (former names: the Siberian Sea, the Nordenskjöld Sea). The sea is defined as the area between Severnaya Zemlya in the west, the mainland coast, and the New Siberian Islands in the east, and by a northern border line from 81°16′ N (in the west) to 76°12′ N (in the east). It is an open marginal, high-Arctic, to its main extent epi-continental sea. Its main part is covered with ice the whole year round; and only in summer the coastal and some adjacent parts are released from it (Zenkevitch 1963; Nikiforov et al. 1974; Dobrovolskii and Zalogin 1982; Sookhovei 1986; Muromtzev and Gershanovitch 1986). The Laptev Sea area is about 672 000 $km^2$; its volume is about 363 000 $km^3$; average depth is 540 m, the maximal one 2980 m. There are many islands, especially in the western part; their total area makes up 5 900 $km^2$. Many rivers fall into the sea; their annual run-off is 730 $km^3$. The biggest rivers - the Lena and the Yana (the former gives 77 % of the mainland runoff) - form deltas; the mouths of other, smaller rivers are estuaries. The Laptev Sea is situated mainly on the mainland shelf; depths from 50 m to 100 m predominate (70 % of the total sea area), while depths of more than 1 000 m occupy not more than 18 % of the aquatory. The bottom morphology of the southern (shelf) part of the sea is complicated: shallows, banks, numerous depressions, of both, erosive and tectonic origin, and continuations of submerged valleys of present rivers are typical for it. The mainland slope is cut by the deep-water Sadko Trough (with depths maximal for the sea), which passes further to the north into the Nansen Basin.

The character of the grounds in the Laptev Sea is in accordance with the distribution of depths. In the deep-water regions, the bottom is covered with mud. In the shallow regions, bottom sediments largely consist of boulders and pebbles. In the coastal zone, sediment-formation is influenced by the rivers, carrying great amounts of suspended matter (the Lena - 11.3 millions tons per year, the Yana - 6.2 millions tons per year). In the coastal zone both, accumulation of sediments and abrasion of shores, result in a sedimentation speed making up even 25 cm per year. In the eastern part of the Laptev Sea (near the New Siberian Islands) relict (fossil) ice occurs under the layer of sediments (permafrost).

In respect of climate, the Laptev Sea is one of the most inclement Arctic seas. In winter it is influenced by three pressure components: the crest of the Siberian anticyclone from the south-east, the ridge of the Arctic anticyclone from the north, and the low of the Icelandic cyclone from the west. The influence of the Siberian anticyclon predominates. In this period, calm and low-nebulous weather prevails above the sea; sometimes it is disturbed by cyclones moving to the south of the Laptev Sea. In summer, the Siberian anticyclone is replaced by lowered pressure; the Icelandic cyclone's low is filled. Weak northern and north-eastern winds predominate.

The hydrological regime of the Laptev Sea is primarily determined by the presence of ice during the major part of the year and by mainland run-off. Especially during winter, extended wind-driven polynyas are of great influence for ice formation and hydrology. Superficial currents, as in other Arctic seas, form cyclonic rotations (Fig. 1). Waters move from west towards east along the mainland shore and towards south-east in the south-eastern part of the sea. The discharge current, strengthening the total coastal flow, moves from the River Lena's mouth towards north-east. The greater part of this flow takes the northern turn along the New Siberian Islands (the New Siberian Current ), and the smaller part enters the East Siberian Sea through the Sadko Strait.

In the north of the Laptev Sea, the New Siberian Current takes the north-western turn and enters the Transarctic Current of the Central Arctic Basin. At the northern extremity of the Severnaya Zemlya archipelago, the East-Taymir-Current branches off the Transarctic Current and moves towards south along the eastern shores of Severnaya Zemlya and the Taymir Peninsula. The speeds of the currents forming the circulation are low and do not exceed a few cm per second. Sometimes, strong winds may cause non-periodic currents with high speeds, the directions of which differ from those of the prevailing currents.

The tidal wave enters the Laptev Sea from the Arctic Basin. Floods are mainly semi-diurnal, and amplitudes are, on an average, about 1 m. In the bays and inlets, wind-induced fluctuations of the water level do not exceed 2.5 m. The vertical stratification of the waters is caused by winter cooling and convection, summer heating, run-off, influence of Atlantic waters entering the intermediate layer and of bottom waters from the Central Arctic Basin, entering the Sadko Trough. Autumn-winter convection is more prominent in the western part of the sea than in the eastern one. The latter is entered by the river Yana, and, as a result, great vertical salinity and density gradients prevent the development of convection. In the end of winter, homothermy (by conversion of the water temperature to the temperature of freezing) arises, due to desalting of superficial waters, which results from both, ice-forming and drifting of cooled waters from shallows along the bottom slopes into depths of 50-60 m. Below 50 to 60 m, the temperature is increasing with increasing depth.

In the northern part of the sea, where salinity stratification of the waters is less prominent, convection reaches 100 m depth (homothermy with negative temperatures over the whole water column from the surface down to 100 m is being stated). Here, the temperature increase begins below 100 m; the highest temperature (about 1.5°C) is recorded in the layer 250 to 300 m (Atlantic waters). Bottom water with the temperature -0.8° C from the Central Arctic Basin is found below the Atlantic water layer (< 300 m). In summer, in the ice-free aquatory, the water temperature is positive; but, this layer does not exceed 10 to 15 m. Below it, the temperature decreases sharply and reaches the value of freezing at 25 m.

In regions with depths till 50 to 60 m, this cold water stretches down to the bottom. The vertical subdivision of the water column into several hydrological structural layers (which is true at least for the northern part of the Laptev Sea) permits to classify this sea as heteromixtic (accordingly, the type of water is intermixing; Semenov 1988a), i.e. as reservoir with separate intermixing of waters of each structural layer (Semenov 1988b, 1989).

The horizontal distribution of the superficial layer temperatures in summer-time is given in Fig. 1. In ice-free bays and inlets, water is heated up to 8 to 10° C. Waters of the western part of the Laptev Sea, diluted by the Arctic Basin cold waters brought by the Taymir Current, are colder (2 to 3° C) than the waters of the eastern part (4 to 6° C), heated by waters running off the mainland. The temperature in the central part of the sea is 0 to 2° C, and in the northern area and nearby the marginal ice zone 0 to -1° C.

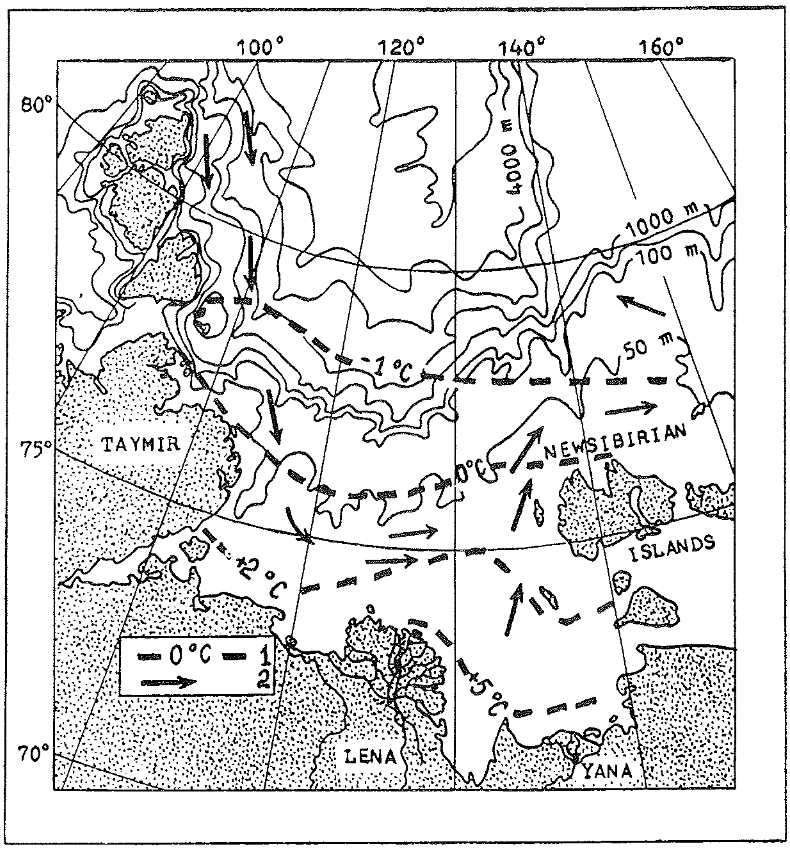


Fig. 1. Map of the Laptev Sea.
1 - surface temperature in summer, ° C ; 2 - surface currents.

The salinity distribution of the Laptev Sea is greatly influenced by the run-off. In general, salinities from 20 to 30 ‰ prevail. The cyclonic system of the residual water circulation results in always higher salinities in the western part of the sea than in the eastern one. Altogether, horizontal salinity gradients are significant, especially in the southern part of the sea: The salinity near the Lena mouth is 1 to 2 ‰ only, whereas it exceeds 34 ‰ in the north. The strongly pulsed inflow of river waters during the year (90 % of the mainland run-off occurs in June-September, among them 35 to 40 % are recorded in August) results in prominent seasonal fluctuations: In summer, freshening of the sea takes place (most obvious in the south-eastern part). But, only a thin upper water layer (5 to 10 m) is freshening; salinity increases sharply below it. Sometimes, the gradient can reach 20 ‰ per 1 m. Below the discontinuity layer, salinity changes rather insignificantly. Near the bottom, salinity is 32 ‰ in regions with depth of 50 to 60 m, and increases up to 34 ‰ at depth from 50 to 300 m.

## Ecological-biogeographical description of the Laptev Sea fauna

In general, the Laptev Sea fauna is a typical Arctic one. But, in spite of that, due to some peculiarities of the climate and hydrological conditions, it is composed by several groups, the representatives of which have different origin and demands to the environment. First of all, these are three large groups of animals: marine, brackish- and fresh-water. The ratio of their representatives determines the type of fauna in each region of the sea (e.g. Sirenko et al., 1995).

The biogeographical division of the Laptev Sea, in spite of terminological differences between researchers, in general may be shown as follows:
The northern part of the sea is a part of the Arctic pelagic and deep-water province (Nesis 1987; abyssal Arctic subarea, Zenkevitch 1963; deep Arctic province, Scarlato and Golikov 1985). The central regions are included in the West-Siberian and Chukotka-Canadian high-Arctic shelf-bathyal province (Nesis 1987; Siberian region of high-Arctic shallow marine province, Zenkevitch 1963; superficial Arctic province, Scarlato and Golikov 1985, while the southern coastal part of the sea is termed as high-Arctic shallow salt-water province (Zenkevitch 1963; estuarine-Arctic interzonal province, Scarlato and Golikov 1985).
Although the biogeographical divisions on the basis of the bottom fauna and the pelagic one are generally in accordance, some differences are noted, caused by the greater dependence of plankton on the distribution and variability of water bodies. They are manifested in more "hazy" and "flexible" boundaries between the biogeographical provinces distinguished by the pelagic fauna analysis (Zenkevitch 1963).

## Short history ofthe study of the Laptev Sea zooplankton

The first hydrobiological studies of the Laptev Sea were apparently conducted more than 100 years ago, by the Swedish expedition headed by A.E. Nordenskjöld on the vessel "Vega" in 1878-1879. Animals were mainly collected in the western part and near the coast (Popov, 1932).

Then, during the famous drift of "Fram" (the Norwegian Northern Polar Expedition of 1893-1896, headed by F. Nansen) hydrobiological investigations were conducted at two stations (78° N, 136° E; 80° N, 134° E) in the north-eastern part of the Laptev Sea. G.O. Sars (1900) studied samples of plankton crustaceans from these stations and described several new species.
In 1900-1903, the Russian Polar Expedition headed by baron E.V. Tolli worked on the yacht "Zarya" in the Laptev Sea. The biologist A.A. Byalynitzkii-Birulya collected zooplankton at 54 stations, which were mainly situated in the western part of the sea and near the New Siberian Islands. The samples were analysed and described by A.K. Linko (1908, 1913). Linko did not confine himself to the enumeration of collected animals and to the description of new species, but gave probably the first scheme of a biogeographical division of the Eurasian part of the Arctic Ocean on the base of the distribution of plankton fauna.
Moreover, he attempted to connect the occurrence of species of Atlantic origin (for example, the euphausiid *Thysanoessa longicaudata* Krøyer) in the Arctic seas with the penetration of Atlantic water bodies into these regions.

In 1913-1915, the Marine Polar Expedition headed by A.I. Vilkitzkii worked on the vessels "Taymir" and "Vaigatch" near the Siberian shore. The physicians of the expedition, E.A. Arngold and L.M.Starokadomskii, collected a lot of material in different parts of the Laptev Sea. Unfortunately, besides short reviews by Arngold (1913a,b; 1915a,b) and Starokadomskii (1914, 1915, 1916) and reports of the director of the Zoological Museum in St. Peterburg, N.V. Nasonov (1911, 1914, 1916), no other publications about the zooplankton collected by that expedition have appeared (see also Popov, 1932).
In 1918-1920 and 1921-1924, a Norwegian expedition worked in the Laptev Sea on the boat "Mod", but its contribution to the plankton investigation was small (Popov, 1932).

During 1926-1927 - the Yakut Commission of the Academy of Sciences conducted investigations in the south-eastern part of the Laptev Sea and near the New Siberian Islands. The hydrologist P.K. Khmyznikov collected zooplankton at 11 stations in the Tiksi Bay (Lena delta) in 1926; and in 1927, the hydrobiologist A.M. Popov on board "Polyarnaya Zvezda" collected 28 zooplankton samples in different parts of the sea. The collections of this expedition were treated by M.A. Virketis (1932).

In the 1930-s, zooplankton in the Laptev Sea was collected in 1932 (boats "Rusanov" and "Taimir": western Shokalskii and Vilkitskii Straits) (Khmyzni-kova 1935, 1937), in 1937 (on board ice-breaker "Litke" (Jaschnov 1939; Bogorov 1944), and on boat RV "Sadko" (Jaschnov 1940)). The drifting expedition of the ice-breaker "G. Sedov" in 1937-1939 collected large amounts of material in different parts of the sea, including some material from the area north of Severnaya Zemlya (Bogorov, 1946).
Later, the Laptev Sea zooplankton was studied only in the Lena and the Yana deltas, for purposes of the fishery of valuable fish species (of Arctic cisco - *Coregonus autumnalis*, and east Siberian cisco -*Coregonus sardinella,* mainly) (Lutsyk et al. 1981; Pirozhnikov 1985). Very seldom (for example, in 1973) the investigated area was extended to the north up to the New Siberian Islands (Lutsyk et al., 1981).

The Second Arctic Underwater Expedition of the Zoological Institute Acad. Sci. U.S.S.R. (Leningrad), headed by Prof. A.N. Golikov in August-September, 1973, should be especially mentioned. On the New Siberian Islands shelf, at 10 stations, zooplankton was collected; the analysis of these samples has significantly broadened the knowledge on the Laptev Sea pelagic zone (Pavshtiks, 1977, 1978, 1990).
In recent years, several Russian-German expeditions, e.g. with RV "Polarstern", have contributed to the zooplankton investigations of the Laptev Sea (e.g. Hanssen & Timofeev, 1994; Kosobokova, 1994; Petryashev et al., 1995; Kosobokova et al., 1995; Timofeev, 1995; Kosobokova et al. 1997).

A number of reviews attempting to generalize the available knowledge on the Laptev Sea plankton should also be mentioned. First of all, these are works of the A.M. Popov (1932), V.A. Jaschnov (1940, 1946), V.G. Bogorov (1944), M.A. Virketis (1946), L.A. Zenkevitch (1951, 1963), S.A. Mileikovskii (1970), E.A. Romankevitch et al. (1982), O.A. Scarlato and A.N. Golikov (1985), and E.A. Pavshtiks (1987). Besides them, there are several publications considering certain taxonomic groups of plankton animals, including those inhabiting the Laptev Sea. This list is rather long and cannot be presented in this review.

## Taxonomic composition and zonation

The Laptev Sea zooplankton has been studied unequally in different regions. Before the middle of the 1930-s, only qualitative sampling was conducted; later, most of the investigations were connected with the south-eastern part of the sea and the shelf of the New Siberian Islands. Accordingly, a list of species is the only information available for the comparative analyses of different Laptev Sea regions (Table 1). The general list for the whole sea includes 81 forms, which number is similar to the Kara Sea (Timofeev, 1989), but more than two times less in comparison with the Barents Sea (Kamshilov and Zelikman, 1958; Fomin, 1978). E.A. Pavshtiks (1987) recorded 18 Copepoda-Calanoida species, whereas our list contains 20 species. This divergence results from the neglection of fresh-water species occurring in the Lena and the Yana deltas in Pavshtiks' list. The list of taxa of the Laptev Sea zooplankton may apparently be broadened after additional investigations, owing to, mainly, larvae of the benthic animals, and new sampling equipment.

Table 1 shows that various parts of the Laptev Sea have different zooplankton compositions. I calculated Sörensen indices (Sörensen, 1948) to estimate the degree of both, similarity and divergence of the plankton fauna; the obtained results are given in Fig. 2. Three regions are distinguished according their zooplankton composition:

At first, the northern part (area N 1 in Table 1 and in Fig. 2), which obviously results from the peculiarities of the hydrological structure of this region: great depth (more than 1000 m), influxes of Atlantic (warm) and Arctic bottom (cold) waters possessing specific inhabitants. The presence of zooplankton species connected with the Atlantic water body and of batypelagic species determines both low indices of similarity (less than 25 %) and the rather high independence of this northern fauna of the zooplankton of other regions of the sea.

| areas | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| 1 | X | 22.2 | 19.5 | 18.6 | 00.0 | 18.2 | 6.0 |
| 2 | | X | 50.9 | 52.6 | 26.4 | 62.0 | 49.1 |
| 3 | | | X | 71.0 | 31.0 | 50.8 | 46.2 |
| 4 | | | | X | 33.3 | 52.3 | 44.4 |
| 5 | | | | | X | 32.7 | 32.0 |
| 6 | | | | | | X | 80.0 |
| 7 | | | | | | | X |

0-25 % 25-50 % 50-75 %

75-100 %

Fig. 2. Similarity of zooplankton communities between different areas of the Laptev Sea. (NN = areas - see Table 1).

Table 1: List of zooplankton species (taxa) in different areas of the Laptev Sea

| Taxa | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Coelenterata, Cnidaria - Hydrozoa: | | | | | | | |
| Perigonium vesicarium | | | | | | | |
| (Catablema campanula) | - | - | - | - | - | + | + |
| Calycopsis (Sibogita) birulai | - | - | - | - | - | + | + |
| Rathkea octopunctata | - | - | - | - | - | + | + |
| Obelia flabellata | - | + | - | - | - | + | + |
| Obelia sp. | - | - | - | + | - | - | - |
| Euphysa flammea | - | + | - | - | - | - | - |
| Sarsia sp. | - | - | - | + | - | - | - |
| Halitholus cirratus | - | - | - | - | - | + | + |
| Perigonimus joldia-arctica | - | - | - | - | - | + | - |
| Ptychogena lactea | - | + | - | - | - | - | - |
| Ptychogastria polaris | - | + | - | - | - | - | - |
| Homoeonema platygonon | - | - | + | - | - | - | - |
| Aglantha digitale | - | - | - | + | - | - | - |
| Aeginopsis laurentii | - | + | + | + | + | + | + |
| Dimophyes arctica | - | + | + | + | - | - | - |
| Cnidaria - Scyphozoa: | | | | | | | |
| Cyanea sp. | - | - | - | - | - | + | - |
| Acnidaria - Ctenophora: | | | | | | | |
| Mertensia ovum | - | - | - | - | - | + | - |
| Beroe sp. | - | + | + | - | + | + | + |
| Rotatoria: | | | | | | | |
| Synchaeta sp. | - | - | + | + | + | - | - |
| Asplanchna sp. | - | - | - | - | + | - | - |
| Asplanchna priodonta | - | - | - | - | + | - | - |
| Polyarthra sp. | - | - | - | - | + | - | - |
| Trichocerca (s.str.) pusilla | - | - | - | - | + | - | - |
| Trichocerca marina | - | - | + | + | - | - | - |
| Keratella quadrata | - | - | - | - | + | - | - |
| Keratella cochlearis | - | - | - | - | + | - | - |
| Notholca acuminata | - | - | - | - | + | - | - |
| Notholca bipalium | - | - | - | - | + | - | - |
| Kellicottia longispina | - | - | - | - | + | - | - |
| Anuraeopsis fissa fissa | - | - | - | - | + | - | - |
| Annelida - Polychaeta: | | | | | | | |
| Polychaeta spp. (larvae) | - | + | + | + | + | + | + |
| Thyphloscolex muelleri | + | - | - | - | - | - | - |
| Pelagobia longicirrata | + | - | - | - | - | - | - |
| Arthropoda - Crustacea: | | | | | | | |
| Daphnia longispina | - | - | - | - | + | - | - |
| Bosmina longirostris | - | - | - | - | + | - | - |
| Bosmina sp. | - | - | - | - | + | - | - |
| Calanus glacialis | + | + | + | + | - | + | + |

Continuation Table 1

| Taxa | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Calanus hyperboreus | + | + | + | + | - | + | - |
| Pseudocalanus minutus | - | + | + | + | + | + | + |
| Pseudocalanus major | - | + | + | + | + | + | + |
| Microcalanus pygmaeus | - | - | + | + | - | - | - |
| Scaphocalanus magnus | + | - | - | - | - | - | - |
| Limnocalanus grimaldii | - | - | - | + | + | + | - |
| Pareuchaeta glacialis | + | - | + | + | - | - | - |
| Metridia longa | + | + | + | + | - | + | - |
| Gaidius tenuispinus | + | - | - | - | - | + | - |
| Chiridius armatus | - | + | - | - | - | + | - |
| Chiridius obtusifrons | - | - | + | - | - | - | - |
| Heterorhabdus norvegicus | + | - | - | - | - | - | - |
| Drepanopus bungei | - | - | - | + | + | + | + |
| Jaschnovia tolli | - | - | + | - | - | + | + |
| Acartia longiremis | - | + | + | + | - | + | + |
| Eurytemora hirundoides | - | + | - | - | - | - | - |
| Eurytemora lacustris | - | - | - | - | + | - | - |
| Eurytemora raboti | - | - | - | - | - | + | - |
| Eurytemora gracilis | - | - | - | - | + | - | - |
| Mormonilla minor | + | - | - | - | - | - | - |
| Oithona atlantica | - | - | + | - | - | - | - |
| Oithina similis | - | + | + | + | + | + | + |
| Oncaea conifera | + | + | - | - | - | - | - |
| Oncaea borealis | - | - | + | + | - | - | - |
| Acanthocyclops bisetosus | - | - | - | - | + | - | - |
| Cyclops strenuus | - | - | - | - | + | - | - |
| Microsetella norvegica | - | - | + | + | + | + | + |
| Cirripedia spp. (larvae) | - | + | - | + | - | + | + |
| Conchaecia elegans | - | - | - | + | - | - | - |
| Hyperia galba | - | - | - | - | - | + | + |
| Parathemisto abyssorum | - | - | - | + | - | - | - |
| Decapoda spp. (larvae) | - | + | - | - | - | + | + |
| Thysanoessa longicaudata | - | - | + | - | - | - | - |
| Mollusca - Gastropoda: | | | | | | | |
| Clione limacina | - | - | + | + | - | - | - |
| Limacina helicina | - | - | + | + | - | - | - |
| Chaetognatha: | | | | | | | |
| Sagitta elegans | - | + | + | + | + | + | + |
| Eukrohnia hamata | - | - | + | - | - | - | - |
| Echinodermata: | | | | | | | |
| Ophiopluteus | - | + | + | + | - | + | - |
| Ophiura spp. juv. | - | + | - | + | - | - | - |
| Echinopluteus | - | - | + | - | - | - | - |

Continuation Table 1

| Taxa | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Chordata - Appendicularia: | | | | | | | |
| Fritillaria borealis | - | + | + | + | - | + | + |
| Fritillaria polaris | - | - | - | + | - | - | - |
| Oikopleura labradoriensis | - | - | + | + | - | + | - |
| Oikopleura vanhoeffeni | - | + | - | - | - | + | + |

1 - northern part (78°33' N, 118°30' E) (by Jaschnov, 1940);
2 - open sea region (by Linko, 1913 and Jaschnov, 1940);
3 - Shokalsky Channel (by Linko, 1913 and Khmyznikova, 1937);
4 - Vilkitsky Channel (by Linko, 1913 and Khmyznikova, 1937);
5 - Jana river mouth (Jana Bay) (by Linko, 1913, Virketis, 1932 and Lutsyk, Silina, Lutsyk, 1981);
6 - New Siberian Islands Archipelago (by Linko, 1913, Virketis, 1932, Lutsyk, Silina, Lutsyk, 1981 and Pavshtiks, 1978, 1990);
7 - north off the New Siberian Islands (by Linko, 1913 and Jaschnov, 1940).

The second zone, which is situated in the north off and around the New Siberian Islands (N 7, N 6 in Table 1 and in Fig. 2) and has an intermediate degree of isolation (indices of similarity 25 to 50 %) from all other areas. The relative isolation of the zooplankton of this region is probably explained by the fact that the New Siberian Islands, as a whole, are considered to be the boundary between biogeographical provinces (Nesis 1982,1983) or subprovinces (Scarlato and Golikov, 1985).

And, at last, the south-eastern part of the Laptev Sea, influenced greatly by fresh-water from Lena's and Yana's run-off (N 5 in Table 1 and in Fig. 2). Marine species are completely absent here; euryhaline and fresh-water species predominate, while exclusively brackish-water formes are rare.

Not regarding the New Siberian Islands' region, the highest degree of fauna similarity (71 %) is recorded in waters of the western straits (Shokalskii's and Vilkitskii's Straits; N 3 and N 4 in the Table 1 and in the Fig. 2), as the waters of both these straits are included in the Taymir Current (Fig. 1).

As it was mentioned above, the Laptev Sea fauna includes marine, salt-water and fresh-water species. V.A. Jaschnov (1940, 1946) already suggested the existence of three zones arranged parallely to the coast line: The first zone adjoins the shore and is inhabited by a typical fresh to brackish water adapted fauna; the second zone takes a more offshore position and is characterized by marine, mainly euryhaline, species; the third zone is a transitional one between the second and the true marine region outside the Laptev Sea.

For the most studied south-eastern region of the sea it is possible to trace the spatial succession of different zooplankton groups from the river mouths towards the open sea (Lutsyk et al., 1981): Near the river mouths (where water either is fresh or of insignificant (1-2 ‰) salinity), the plankton fauna consists exclusively of fresh-water forms. With moving away from the coast and with increasing salinity, conditions to form communities of brackish-water species, are appearing. Farther, in more open areas of the sea, the marine forms dominate in the number of species, while the brackish water ones prevail in abundance. To V.A. Jaschnov's (1940) mind, this structure is common for the superficial water layers of the main part of the Laptev Sea. Recurring to the south-eastern part, it should be noted that here the brackish-water species constitute the basis of the zooplankton fauna, while the shares of marine and fresh-water forms depend on the actual circulation of water masses. Altogether, the boundaries of the distinguished complexes are extremely flexible and are determined by hydrological conditions (Lutsyk et al., 1981).

The brackish-water complex consists of individuals of a great number of species, although 4 species predominate: *Pseudocalanus major, Limnocalanus grimaldii, Drepanopus bungei* and *Jaschnovia tolli*; the two latters are endemic of the Arctic seas (Jaschnov, 1947; Markhaseva, 1980; Brodskii et al., 1983). The area of the distribution of all four species is considered to be the area of the whole brackish-water complex (Bogorov, 1944; Jaschnov, 1946). Consequently, the thorough analysis of these species' distribution is of great interest. Literature data (Bogorov, 1944; Jaschnov, 1940, 1946, 1947; Lutsyk et al., 1981; Pirozhnikov, 1985) confirm that maximal occurrence and abundances of these species are connected with different salinity ranges: *L. grimaldii* - less than 12 ‰, *P. major* and *D. bungei* - 17 to 20 ‰, *J. tolli* - 20 to 25 ‰. Consequently, the above-described scheme of the plankton fauna zonation from river mouths towards offshore waters may be supplemented with detailing of the brackish-water complex. In conclusion, this scheme has the pattern indicated in Fig. 3.

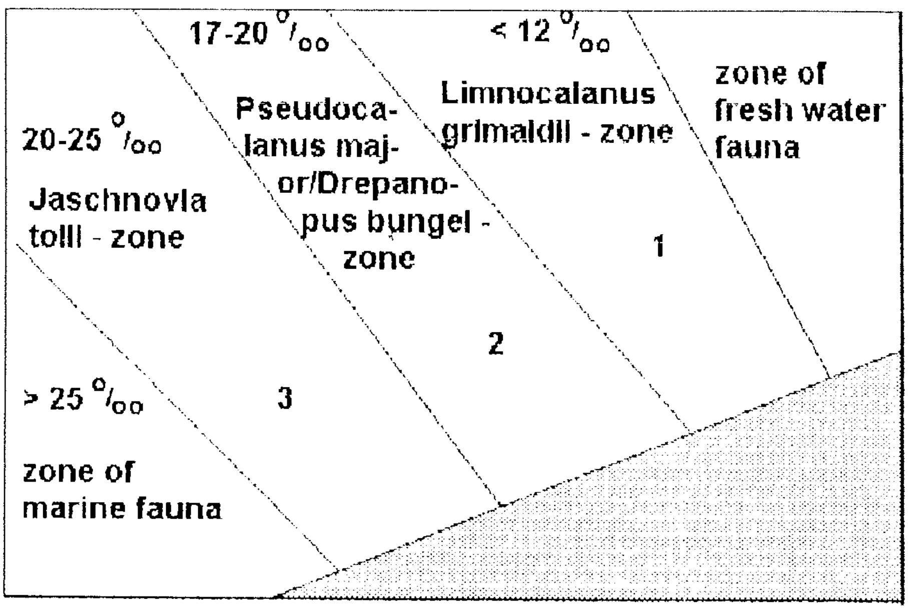


Fig. 3 Zonality of pelagos in the Laptev Sea.

## Vertical distribution

The peculiarity of the hydrological structure of the Laptev Sea must have strong effects on the vertical distribution of zooplankton. Nevertheless, this problem is a completely unstudied feature of the Laptev Sea ecology. Almost all expeditions working in this region sampled zooplankton by un-stratified catches of the whole water column from the bottom up to the surface. There are only two publications (until 1993) considering in short form this vertical distribution: an article by V.L. Khmyznikova (1937) and the monography of V.A. Jaschnov (1940).
Khmyznikova sampled in the Vilkitzkii Strait by Tchelyuskin's Cape on September 2, 1932 (diurnal station). In spite of the qualitative treatment of the samples and the absence of hydrological data, the information obtained by Khmyzhikova permitted approximately to reveal the vertical distribution of mass species (*Pseudocalanus elongatus, Oithona similis, Microsetella norvegica, Sagitta sp., Fritillaria borealis*). All forms except *M. norvegica* had their abundance maximum in the lower layers (45 to 25 m; total depth in the place of sampling being 45 m) at 6 and 12 o'clock, i.e. in the morning and daylight hours; at 18 and 24 h the maximum moved towards the surface (10 to 0 m). Thus, a zooplankton migration over the whole water column during 24 hours may be postulated; but, the lack of hydrological data does not permit to explain unbiassedly the reasons of this phenomenon. Khmyznikova suggested that thelight rate may induce it. The abundance of *M. norvegica* was maximal near the surface during all the investigation time.
The data on zooplankton vertical distribution given in Jaschnov's (1940) book were based on the analysis of samples collected in the northern part of the Laptev Sea (78°33' N, 118°30' E; depth 2381 m) in the following water layers: 800-500, 500-250, 250-150, 150-50 and 50-0 m. The 150-0 m layers were cool, with temperatures below 0°C (-1.4 to -1.7°C); between 500-150 m - was the warm (up to +1.11°C) stratum of Atlantic waters; and beneath 500 m cold Arctic water was found. The composition of the zooplankton of the upper layers differed only insignificantly from the populations of more southern stations. *Calanus glacialis* predominated (60 to 70 % of the biomass); and in general, the zooplankton biomass made up 102 $mg/m^3$ in the layer 50-0 m and 69 $mg/m^3$ in the layer 150-50 m (on an average for the whole upper cold layer - 80 $mg/m^3$, s. Table 2). The Atlantic water zooplankton differed drastically from that of the upper layers: *C. glacialis* dissappeared, and species, typical for waters of Atlantic origin, became prevalent (*Scaphocalanus magnus, Gaidius tenuispinosus, Oncaea conifera, Pelagobia longicirrata* etc.). In these layers the plankton biomass was small (s. Table 2). In the layer 800-500 m, with the smallest biomass value (4 $mg/m^3$), only single individuals of different species were revealed. Most of them were forms, the distribution of which is connected with Atlantic water.

The scanty data on the zooplankton vertical distribution, especially for the central (shelf), south-eastern and eastern (New Sibrian Islands shelf) parts of the Laptev Sea permit no final conclusions. This is especially true for aquatories with depths less than 100 m. The vertical distribution in the northern deep-water regions, however, has trends and regularities, similar to those of the Central Arctic Basin plankton communities (Vinogradov and Melnikov, 1980).

## Biomass

Due to the scarcity of quantitative samples, data on the zooplankton biomass are found only in a few published articles. The results of the literature analysis are summarized in the Table 2.

V.A. Jaschnov (1940) paid a great attention to zooplankton productivity and calculated that the total biomass of zooplankton organisms in the water mass under 1 km$^2$ made up 5 to 6 tons in the northern deep-sea part, 2 to 3 tons in the shallows, and 3.1 tons on an average for the whole Laptev Sea. According to Jaschnov, 3 millions or more tons of zooplankton are produced in the Laptev Sea each year. In comparison with 40 million tons in the Barents Sea and even 5 millions tons in the Kara Sea, this low biomass value permitted Jaschnov to conclude that the Laptev Sea is significantly less productive than more western. The shorter duration of the vegetative period was considered by him as a main reason of that.

Table 2: Biomass of zooplankton in different regions of the Laptev Sea

| Region | Biomass (mg/m$^3$) | | Author |
|---|---|---|---|
| Northern part (78°33′ N, 118°30′ E) | 102 | (50-0 m) | Jaschnov, 1940 |
| | 69 | (150-50 m) | |
| | 12 | (250-150 m) | |
| | 8 | (500-250 m) | |
| | 4 | (800-500 m) | |
| Central part | 24-200 (average 72) | | Jaschnov, 1940 |
| Jana river mouth (Jana Bay) | 134-470 | (summer) | Lutsyk et al., 1981 |
| | 120-261 | (winter) | |
| Shelf of the New Siberian Islands | to 950 | (summer) | Lutsyk et al., 1981 |
| Shelf of the New Siberian Islands | 71-1122 | (August) | Pavshtiks, 1978 |
| | 47-1636 | (September) | Pavshtiks, 1990 |

Further investigations of Yana Bay and of the New Siberian Islands region have shown that plankton biomass in these rather shallow regions may apparently exceed the value obtained by Jaschnov (Table 2). So, according to E.A. Pavshtiks' calculations, zooplankton biomass by the Stolbovoi Island made up approximately 17 tons per 1 km$^2$ in the end of August, 1973. Moreover, the zooplankton biomass in Yana Bay in winter is comparable with that obtained by Jaschnov in summer-time in the open sea. Accordingly, it is possible to suggest that the Laptev Sea zooplankton productivity is several times higher than it was considered previously (by Jaschnov').

The south-eastern regions of the sea, where either influx of river fresh water or other sources of energy exist (the New Siberian Islands shelf, Lena and Yana mouths) are considered to be "oases of life", providing a rather high level of zooplankton productivity. In general this is in accordance with the hypothesis, according to which in Arctic seas the greatest productivity is recorded in regions, where an influx of additional energy occurs (in the forms of warmth, biogenic and dissolved organic substances, etc.; Timofeev 1988).

The lack of seasonal observations is a serious obstacle preventing calculations of the annual productivity of zooplankton as well as of other components of the Laptev Sea pelagic communities. In this connection the data on winter zooplankton of Yana Bay (Lutsyk et al. 1981) are of special value. Although they don't permit a reconstruction of seasonal dynamics of biomass, they at least show an approximate ratio between summer and winter biomasses. Accordingly, the zooplankton biomass made up 134 to 470 $mg/m^3$ in summer, while it was 120 to 260.6 $mg/m^3$ in winter (Table 2), i.e. a slight (no more than 2 times) decrease took place. In contrast, in the southern part of the Barents Sea, summer and winter zooplankton biomasses differ approximately 10 times. And that is considered to be a peculiarity of the functioning of Arctic pelagic communities (Zelikman, 1977). However, the scanty data do not permit to final conclusions about either accordance or dicrepancy of the observed seasonal variation of the zooplankton biomass in Yana Bay to conventional notions. Thorough investigations of both river mouths and other sea regions are required.

## SOME ASPECTS OF THE BIOLOGY OF *DREPANOPUS BUNGEI* AND *JASCHNOVIA TOLLI*

*Drepanopus bungei* Sars, 1898 - was described from samples collected in the river Yana mouth. This species of typically Arctic origin (endemic of High Arctic) occurs in the Kara, Laptev and East Siberian Seas. Relict populations of D. bungei were revealed in Canadian Arctic fjords and in the Tuborg Lake (Elsmer's Land; Brodskii et al., 1983). In addition, this species occurs in the western part of the Chukchi Sea (Stepanova, 1937) and in the Pechora Sea (the eastern part of the Barents Sea; Zelikman, 1961).

*Jaschnovia tolli* (Linko, 1913) - was described by A.K. Linko as *Scolecitrix tolli* from samples collected in the East Siberian Sea nearby the New Siberian Islands. Jaschnov (1947) had distinguished this species as a separated (monotypic) genus *Derjuginia*, and later, in 1980, Markhaseva redescribed it as *Jaschnovia*. *J. tolli* as *D. bungei* is an endemic species of the High Arctic and occurs only in epicontinental waters of the Arctic Ocean: from the western coast of the Yamal Peninsula till the Beaufort Sea (Linko 1913; Jaschnov 1947; Brodskii 1950; Markhaseva 1980). Single *J. tolli* individuals can occur in other parts of the Arctic, for example, in the Pechora Sea (Zelikman, 1961).

Despite the fact that individuals of these two species constitute the base of the pelagic salt-water complex of the Siberian Seas and, accordingly, of the whole zooplankton, their biology is studied insufficiently. At present, the only work containing some information, is a short article by E.A. Pavshtiks (1977), in which

he analyses data of the Second Arctic Underwater Expedition of the Zoological Institute Acad. Sci. U.S.S.R. (August-September, 1973). Near the New Siberian Islands the highest values of both, numbers and biomass (204 mg $m^3$), of *D. bungei* were recorded in the beginning of August, when the water salinity was 18 ‰. The maximal abundance of *J. tolli* (biomass made up 1467 mg/$m^3$) was recorded in the beginning of September (salinity - 19 ‰). Pavshtiks concluded that, in spite of co-occurrence, individuals of these species bred in different periods, which resulted in a temporal divergency of their abundance maxima. That probably permits *D. bungei* and *J. tolli* the better use of the forage reserve during the short vegetation period. In addition to this asynchronous development, the existence of other mechanisms reducing (or even prohibiting) the competition for forage reserves between these species may be supposed. The critical food concentration for copepoda is known to be in direct dependence on the sizes of both, of crustaceans themselves and of their food particles (Krylov, 1986). Accordingly, animals of different sizes have optimal conditions for feeding at different concentrations and sizes of food particles.
The body length of *D. bungei* makes up 0.75 to 1.10 mm in males and 1.10 to 1.30 mm in females, while *J. tolli* is two times larger - 2.20 to 2.40 mm in males and 2.50 mm in females. Consequently, the size differences also make a contribution to allow these species' co-existence under severe limitation of the forage amount. Unfortunately, there are no data on phytoplankton development and on the concentrations of both, organic and mineral substances suspended in the Laptev Sea water. Thus, we have no opportunity to test our suggestions. Moreeover, it should not be forgotten that the zooplankton communities may also function by using the microalgae connected with ice as a main food source. In waters of the Canadian Arctic this way predominates and provides the existence of rich life both in the water column and at the bottom (Conover and Huntley, 1991; Conover et al., 1991).

## Conclusions

The analysis of the literature devoted the Laptev Sea zooplankton (until the beginning of the 1990-s), which is given in the present article, permits to draw the following conclusions:

1. The taxonomic composition and productive potential of the zooplankton in each region of the sea are mainly determined by the peculiarities of the water bodies and their circulation.

2. According to its zooplankton composition, the Laptev Sea may be subdivided into several zones parallel to the shore line (Fig. 3):
- the zone of brackish-water fauna, subdivided into several subzones (fresh to brackish-water fauna off the river mouths with predomination of *Limnocalanus grimaldii*; with *Pseudocalanus major* and *Drepanopus bungei* at 12-20 ‰ salinities; and with *Jaschnovia tolli* predomination at 20-25 ‰);
- the zone of marine euryhaline species, mediating between the brackish-water zone and that of the true marine fauna;
- the zone of true marine fauna.

3. The main association determining the level of the zooplankton productivity is probably the salt-water complex represented by endemic species of the High Arctic (*Drepanopus bungei* and *Jaschnovia tolli*) and by euryhaline marine species (*Pseudocalanus major* and *Limnocalanus grimaldii*).

4. According to investigations of the 1970-s, the values of zooplankton biomasses in the eastern Laptev Sea were up to 10 times higher than in the central and northwestern parts in the 1930-s, and might reach 1 g per $m^3$ and more in summer-time.

However, it should be recognized that the level of our knowledge on zooplankton and on plankton in general even for the best studied regions of the Laptev Sea is low and has not permitted any sufficiently serious conclusion about the structural-functional organization of its pelagic communities until the early 1990-s. Complex investigations on these characteristics are required, and special attention should be paid to the study of life-cycles of mass zooplankton species and of the forms and mechanisms of their adaptations to exist under the severe conditions of the high Arctic shelf.

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## Summary

### The Laptev Sea Zooplankton: a Review (1996)

Timofeev, S. F.

The Laptev Sea zooplankton data published mainly in Russia have been analysed, and the following conclusions are drawn:

1. The taxonomical composition and productive potential of the zooplankton are mainly determined by the circulation of the water masses.
2. The Laptev Sea may be subdivided into several zones and subzones parallel to the shore line.
3. The main association determining the level of zooplankton productivity is the brackish-water complex, represented by endemic species of the high Arctic and by euryhaline marine species.
4. The zooplankton biomass might reach 1 g per $m^3$ and more in summer-time.

# Long-term changes in the distribution of molluscs in the Barents Sea related to the climate

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## Introduction

Climate is one of the major factors determining the state of the biosphere, conditions of life and economic activity of man. In the seas of the world's oceans climatic fluctuations that have a strong impact on temperature and salinity, direction and speed of currents and other constituents of the hydrological and hydrochemical regimes, are also related to significant long-term fluctuations of fauna and flora.

The long-term changes of bottom fauna are understood as processes lasting for several years or decades; in this case events that have taken place in the past 100-150 years are considered. Nevertheless, in spite of their often relatively short duration, these processes may lead to notable changes in the qualitative and quantitative composition of fauna and flora, distribution boundaries of several species and groups of species, biocoenosis structure and production. Studies of these phenomena, on the one hand, permit to determine dependences of marine organisms on the climate, and, on the other hand, to use them as biological indicators of the climate and its variability.

Among the Russian seas, the Barents Sea is most promising for studies of long-term changes of the fauna. It is situated in the high latitudes; its major part is the transition area between the Arctic and Atlantic Boreal biogeographical regions. Owing to its transitional location the bottom fauna of the sea is represented by a relatively large number of species belonging to Arctic, Boreal-Arctic, Boreal, and subtropical-Boreal forms, which in their origin are divided into Atlantic and Pacific representatives.
At the same time the Barents Sea is the most completely studied part of the Arctic Ocean; investigations of its bottom populations on relatively large scales have been conducted for the more than one hundred years. As a result, vast materials have been accumulated in the form of collections, published and archive data that provide sufficiently full pictures of the bottom fauna and conditions of its existence in different periods.

Molluscs representing one of the three major groups of the Barents Sea benthos were chosen for the analysis of the long-term climate-induced changes of the fauna. Molluscs are abundant and possess shells allowing to determine their ages; this permits to relate different periods of mollusc life with climatic changes.

Studies of the long-term processes related to climatic fluctuations were started in 1908 by K.M. Derjugin (1915) and further on continued by scientists of Russia and other countries. They permitted to describe many changes in the composition and distribution of bottom organisms of the Barents Sea that occurred during the 1920's through the 1960's. These studies, however, were not systematic and did not cover the entire complex of phenomena related to these processes, and were often restricted to mentioning particular cases. Therefore, the problem of long-term changes of the fauna, which is, no doubt, of great scientific and practical importance, requires a further more profound elaboration. This is all the more needed, considering the vast material that has been accumulated meanwhile.

## The history of investigations of long-term climate-related changes of the Barents Sea bottom fauna

The studies of the long-term changes the Barents Sea fauna were initiated by K.M. Derjugin (1915) who, after finding several new Boreal and Arctic species in the Kola Bay in 1908 and 1909, related them to the fluctuations of temperature regime and pointed out the need for further investigations of these phenomena. However, this problem was not elaborated until 1921, when new thermophilic organisms were found in the Barents Sea as the temperature increased owing to the "warming of the Arctic". N.M. Knipowitsch (1921) was the first to note the importance of research about these phenomena; he showed that analyses of the temperature and faunistic changes were not only of scientific, but also of great economic value. In the same year (1921), a study of these processes was developed by K.M. Derjugin (1924, 1925) and his disciples (Gurjanova, 1927; Ushakov, 1926, and others). He described the appearance of new Boreal species while the Arctic forms retreated and suggested a periodicity of these phenomena. Vast materials on the changes of bottom fauna were collected by the staff of the Murmansk Biological Station in Polyarnoe (Tanasijchuk, 1929), who collected benthos on a section along the Kola Meridian not less than 15 times in 1921-1930. Unfortunately only a small part of the data was published; the rest were lost after closing of the station. L.S. Berg (1935) published a brief report on the changes in the distribution of fish and invertebrates in the 1920'.

In the 1930's, when the rise of temperature attained the highest level, a series of observations were conducted by V.I. Zatsepin and Z.A. Filatova (Zatsepin and Filatova, 1945; Filatova, 1938). In 1936, the Murmansk Biological Station was organized again in Dalnie Zelentsy. Its task was to conduct "systematic observations on the fauna and flora in terms of the general fluctuations of the climate and hydrological conditions" (Ushakov, 1948, p. 12). With reference to the material of 1934-1939 and collections of 1946-1956, V.I. Zatsepin (1962) showed the warming-induced change in the composition of a bottom fauna community of coastal Murmansk waters. A review of these phenomena noted for the Barents Sea in the 1920's-1930's and later was published by L.A. Zenkevitch (1963), who pointed out three pathways for these processes: changes of biocoenotic structures, displacements of boundaries of the distribution of species and groups of species, and fluctuations in abundance and biomass.

Consequences of the cooling of 1940-1942 that caused reverse movements of Boreal and Arctic species were described by E.F. Gurjanova (1947) and V.T. Tscheremisina (1945).

Material collected in the 1950's permitted to correlate the distibution of bivalve molluscs in the southern part of the Barents Sea with the data collected in the 1920's (Galkin, 1964) and to compare the distributrion of some echinoderms, decapods, and sponges in the region of Bear Island and Spitsbergen with their distribution in the same area during 1878 to 1931 (Blacker, 1957, 1965). Changes in the relation of Boreal and Arctic bottom animals on the section along the Kola Meridian were traced by K.N. Nesis (1960).

Benthos sampling covering nearly the entire Barents Sea and performed in 1968-1970, showed declines in the biomass of benthos and in the numbers of Boreal organisms (Antipova, 1975; Bryazgin, 1973). The successive changes in the distribution of 11 species of bivalves depending on their age were considered with reference to the same material and to collections from the Kara Sea (Antipova, Neyman, 1988). A comparison of samples collected in 1945 and 1975 in the south-western part of the Kara Sea and materials from the north-eastern part of the Barents Sea suggested notable climate-induced changes in the composition and arrangement of the biocoenoses (Semenov, 1989).

In 1978-1981, a repeated study was performed off Bear Island and Spitsbergen of indicator species collected there in 1878-1931 and in the 1950's (Dryer et al., 1984). After investigations conducted in 1977-1985 by Polish scientists off the coasts of south-western Spitsbergen, several thermophilous molluscs that had not been reported for that area before, were found (Rozycki, 1987).

Russian studies of long-term changes in the bottom fauna have not been restricted to the Barents Sea and have been conducted also in the White, Baltic, Black, Azov, Caspian, Japan, and Okhotsk Seas. Foreign authors, too, carried out many observations e.g. in the North and Baltic Seas, the English Channel, the Skagerrak, the Kattegat and in other parts of the European seas and put special emphasis on long-term changes induced by the climate and other factors. Analogous studies were conducted in the waters off North America.

## Material, methods and groupings

Materials have been considered for this study that were obtained in the Barents Sea and adjoining areas of the Norwegian, Greenland, White, and Kara Seas and the Arctic Ocean during the investigations conducted in 1773-1982. Collections of the Zoological Institute of the Russian Academy of Sciences accumulated during 1837-1973 and also data from 250 articles and reviews on the material collected in 1773-1982 and eventually unpublished archive materials for the period from 1921 to 1973 were used for that purpose. The archive materials included mostly catalogues on particular stations from scientific records of the Zoological Institute RAS, PINRO, and Moscow State University as well as personal documents of Z.A. Filatova and also T. V. Antipova, V.I. Zatsepin, and T.A. Matveeva.

Between 1773 and 1982, more than 10,000 stations were sampled in the above mentioned regions, accompanied by collecting of benthos. I had the opportunity to obtain and use data referring to 7,700 of these stations, 3,400 of them being represented by collections, 2400 by literature data, and 1,900 by archive material. The major studies, i.e. analyses of relations of fluctuations in the climate and the hydrological regime with the changes in distribution and abundance of molluscs, were based on materials obtained during the 100-year period from 1870 to 1970. This was determined by the fact that more or less significant collections of benthos were not initiated until the 1870's and that the last large survey covering nearly the entire Barents Sea was made in 1970. From that period, data of 7300 stations were analyzed; 3300 of them were extracted from collections, 2100 taken from literature, and 1900 from archive material. The arrangement of these stations is shown in the figures given below.

Analyses of relationships between climate and fauna were performed for 96 species and 7 subspecies of molluscs belonging to the classes Gastropoda (30 species, 6 subspecies) and Bivalvia (66 species, 1 subspecies) from 20,400 samples. 8200 of these were collection samples including 85 thousand specimens. They were supplemented by literature data (7150 samples) and archive data (5050 samples); thus, the amount of material used increased two-fold. The period 1870-1970 was represented by 19,600 samples including 8150 collection samples with 84 thousand specimens.

As these materials were examined, taxonomic position, origin, biogeography, and ecological characteristics of individual molluscs were determined. The species composition of Buccinidae was determined by A.N. Golikov in earlier years (1963, 1980). Maps of distribution in separate years have been prepared for all species and subspecies; in addition, total depth, most common depth (75-85 % of findings), mean distribution depth, temperature and salinity in the localities of habitation were determined. This permitted to specify the type of origin and biogeographic position of a number of forms. The ages of *Lepeta caeca* (1330 specimens) and *Iothia fulva* (23 specimens) were calculated from annual growth rings on the shell. From age-size graphs given by A.N. Golikov (1980), the ages of most gastropods belonging to the genus *Buccinum* were determined. The calculation of the ages allowed to establish the time of appearance of separate generations of these species in particular areas.

It should be noted that different groups of molluscs occurring in the Barents Sea were fairly well represented in the examined material. The species examined belonged to 2 classes, 6 subclasses, or superorders, 36 families, and 63 genera. All representatives of the lower gastropods belonging to subclasses Cyclobranchia and Scutibranchia, and also Arctic forms of the family Buccinidae were analyzed; two thirds of the Bivalvia species inhabiting the Barents Sea were studied.

Seventy eight species and subspecies (76%) belonged to forms of Atlantic origin and 25 (24%) to Pacific ones. In terms of biogeography, 28 molluscs (27%) were Arctic, 22 (22%) Boreal-Arctic, 23 (22%) Boreal, and 30 (29%) subtropical-Boreal. Of them, the following bivalve molluscs have been considered: all Arctic, Boreal and subtropical-Boreal, and also 10 of 39 Boreal-Arctic species. The mode of embryonic development was determined for 75 species based on literature data and by analogy with closely related taxa. 33 species (44%) had planktonic larva, 15 (20%) a very short planktonic stage if any, 25 (33 %) direct development, and 2 (3%) were viviparous. 82 species were assigned to trophic groups, which classification was closely related to the velocity of bottom currents and the type of ground. Four species (5%) were phytophages, 39 (47%) - sestonophages (suspension feeders), 23 (28%) detritophages (deposit feeders), 3 (4%) xylophages, and 13 (16%) predators and necrophages.

## General distribution patterns

The areas inhabited by the studied species covered the entire Barents Sea. But, while forms of Atlantic origin occupied mostly the western and northern parts of the sea and did not occur in its far south-eastern part, Pacific molluscs lived further east and particularly in the south-eastern regions and in coastal waters of Spitsbergen. The molluscs occupied all depths of the sea; Boreal and subtropical-Boreal forms were noted in all levels from the littoral down to the upper bathyal, whereas Arctic and even boreal-Arctic species were virtually lacking in the littoral and in the uppermost sublittoral. Atlantic species were connected with greater depths than Pacific ones, which is valid for both, Bivalvia and lower Gastropoda. Thus, Atlantic bivalve molluscs were spread mostly at depths of 100-275 m, Pacific bivalves between 5 and 70 m; and lower gastropods were mainly found at depths of 20-160 m and 10-110 m, respectively.

There were differences between Atlantic and Pacific molluscs also in terms of habitat temperature and salinity. Pacific species inhabit regions with low salinity and wider ranges of seasonal temperature fluctuations with relatively high summer and low winter temperatures. Accordingly, salinities in the places of their findings were lower, and temperatures, at least in the summer, were higher than in the areas preferred by Atlantic species. Bivalve molluscs occurred at higher temperatures than those preferred by gastropods.
Temperature limits of separate biogeographic groups were well-defined. The same was even true for Boreal-Arctic species, all of which are regarded by some authors as eurythermal; but, they are distinctly different from Arctic and Boreal species in their temperature-dependent zonations.

## Climatic changes

Relationships between climate and fauna were revealed by means of correlation of changes in the distribution and abundance of the studied species on the one hand and fluctuations of the climate and hydrological regime on the other. For this, water temperatures in the layer 0-200 m along the Kola Meridian section were used. Reconstruction of temperatures for the period 1814-1920 was made on the basis of initial data and formulas presented by Yu.A. Bochkov (PINRO) and A.A. Dementyev (AARI). Average annual temperature anomalies were calculated based on the mean long-term temperature for 1814-1990 equal to 3.8° C.

The time considered can be divided into two periods: the cold period - from the 1860's until 1918, when the average anomaly of water temperature along the Kola Meridian was -0.2°, and the warm period - from 1919 until 1970, characterized (at least until the middle of the 1960's) by the process of the "warming of the Arctic" with an average anomaly equal to 0.2° (Fig. 1). Within these periods, temperature fluctuated periodically. In the first period, apart from strong coolings in 1892-1893, 1899-1903, and 1912-1918, there was a slight warming in 1905-1908; in the second period, apart from the most pronounced warmings in 1920-1921, 1930-1939, and 1943-1962, there were some coolings in 1926-1929, 1940-1942, and 1965-1969. The main causes of these temperature fluctuations in different years were changes either in the inflow of warm Atlantic waters into the Barents Sea or in the degree of autumn-winter cooling of water masses under the influence of low air temperatures. The different water currents greatly affected the distribution and abundance of molluscs (Fig. 2).

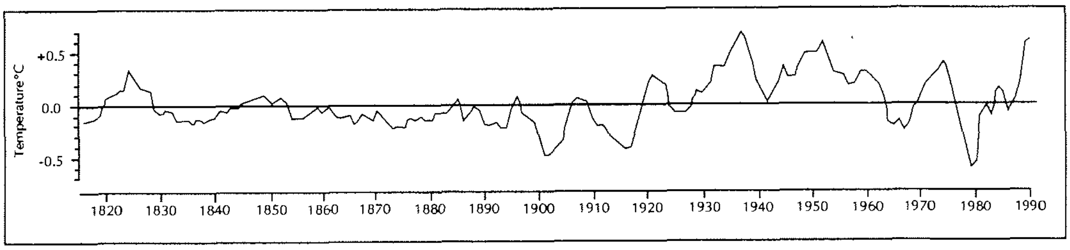



Fig. 1. Running average 5-year anomalies of water temperature in the layer 0-200 m in the section along the Kola Meridian in 1816-1990.

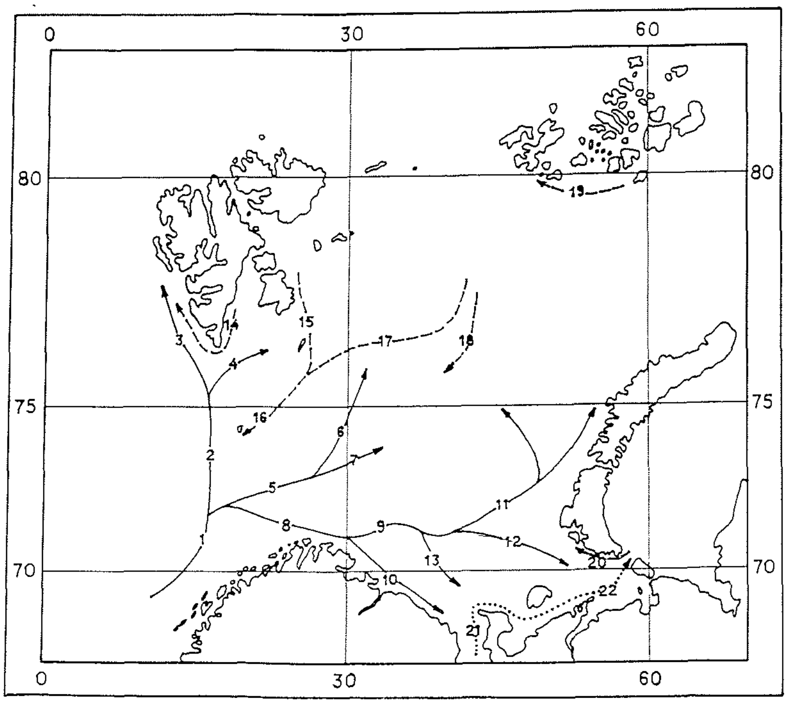



Fig. 2. Scheme of surface currents in the Barents Sea (according to Tantsyura, 1973). - *Warm currents:* 1 - The Norwegian Current, 2 - The Spitsbergen Current, 3 - The West Spitsbergen Current, 4 - The South Spitsbergen Current, 5 - The North Cape Current, 6 - The Northern branch of the North Cape Current, 7 - The Central branch of the North Cape Current, 8 - The South (coastal) branch of the North Cape Current, 9 - The Murmansk Current, 10 - The Murmansk Coastal Current, 11 - The Novaya Zemlya Current, 12 - The Kolguev-Pechora Current, 13 - The Kanin Current. - *Cold currents:* 14 - The South Cape Current, 15 - The Barents Current, 16 - The Bear Island Current, 17 - The Persey Current, 18 - The Central Current, 19 - The Coastal Current of Franz Josef Land, 20 - The Lithke Current.
*Outflow currents:* 21 - The White Sea Current, 22 - The Pechora Current.

## The course of the long-term changes of the climate and of the mollusc fauna

The second half of the 19th century and the beginning of the 20th century were characterized by cold climate. During a long period, mean annual temperatures of sea water in the Barents Sea except a few years were lower than the average long-term temperature. The anomaly of water temperature in the layer 0-200 m along the Kola Meridian section in 1860-1905 was -0.2° C, rising during a slight warming in 1886-1890 to 0.0° and falling during the cooling periods in 1892-1893 and 1899-1903 to -0.6 and -0.5°. Species belonging to the Arctic biogeographic group had their maximum advantage in their distribution and abundance, which is confirmed by high frequency of occurrence (number of findings divided by the number of stations and multiplied by 100) of Arctic molluscs in the southern part of the Barents Sea. In bivalve molluscs of Atlantic origin in Murman coastal waters (68-71° N, 30-40° E) this index was equal to 21 % at that time, and in south-eastern part of the sea (67-72° 30'N, 40-60° E) it was 12%. Unfortunately, relatively few stations were sampled in northern regions of the Barents Sea (except Spitsbergen) during that period (Fig. 3), which did not permit a sufficiently complete mapping of mollusc distribution in these areas.

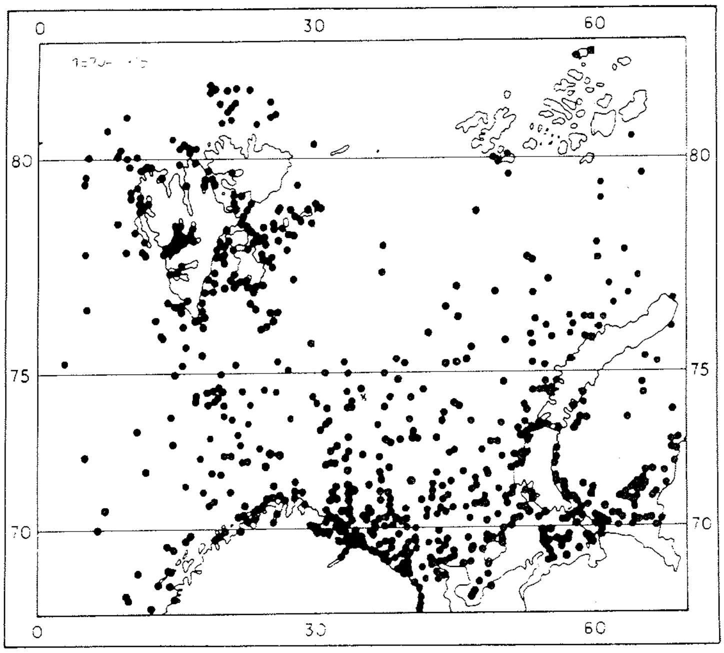



Fig. 3. Map of benthic stations sampled during 1870-1915.

The composition and distribution of molluscs in that period were as follows: Arctic Atlantic species were represented by two groups; the first one included high Arctic forms that were low in numbers, inhabited the northern part of the Barents Sea and seldom occurred in its southern part: *Margarites groenlandicus umbilicalis, M. vahlii, Yoldiella symmetrica, Limatula hyperborea (Fig. 4), Thracia myopsis devexa, Astarte acutocostata* (Fig. 5), *Diplodonta torelli*.

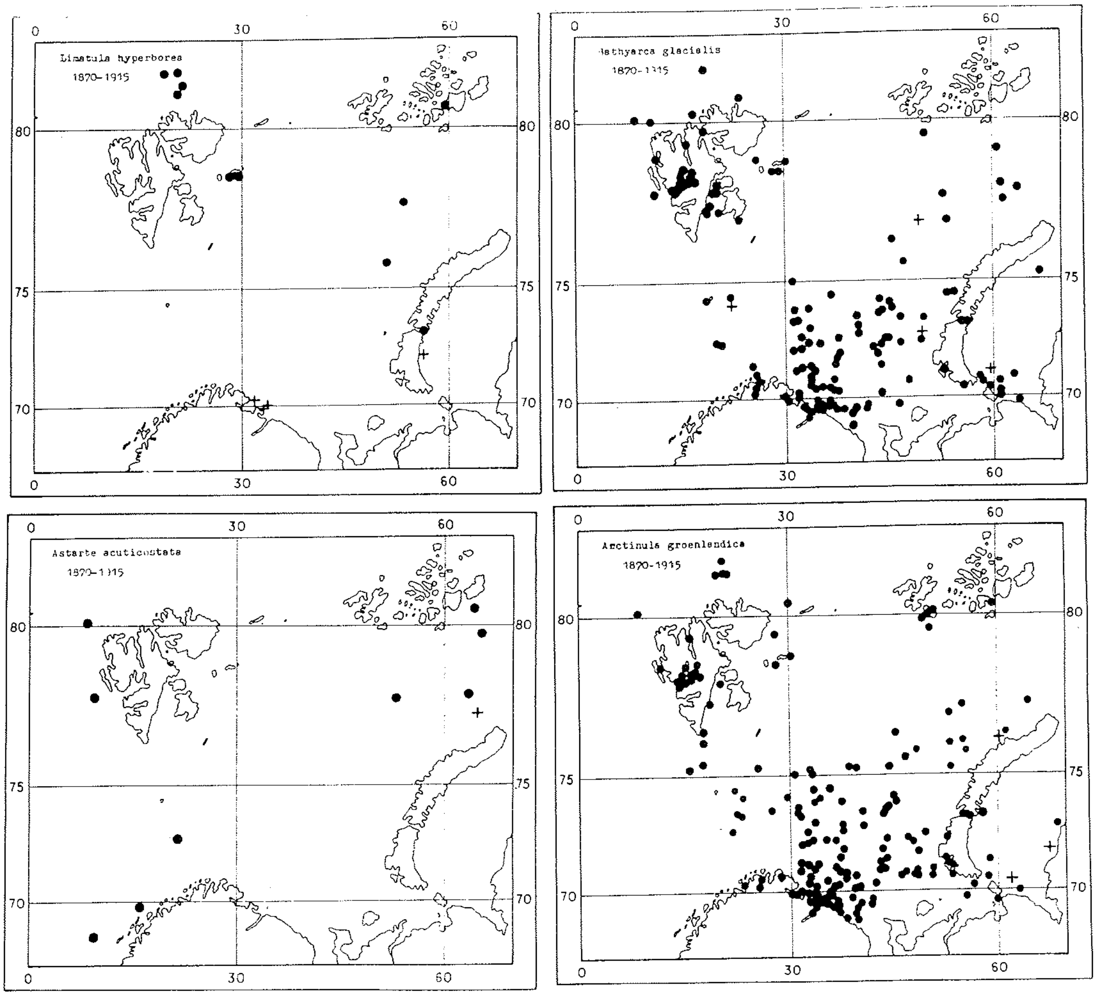
The second group included widespread and mostly abundant species occurring in all parts of the sea, except its south-eastern part: *Neptunea denselirata, Buccinum ciliatum sericatum, B. hydrophanum, B. micropoma, B. nivale, B. belcheri, Yoldiella intermedia, Y. lenticula, Y. frigida, Bathyarca glacialis* (Fig. 6), *Arctinula groen-landica* (Fig. 7), *Astarte crenata, Cuspidaria arctica, C. subtorta.* In the south-western part of the sea these species were nearly lacking in the warmest areas of open sea adjoining the North Cape; they inhabited fjords, because they found Arctic conditions for their existence there. They passed beyond the limits of the Barents Sea, occurring in the bathyal and fjords of north-western Norway and sometimes spreading further south, as for instance, *A. groenlandica*, which in 1892 was noted in Trondheimfjorden (63° 25'N).

The group of Arctic molluscs of Pacific origin included *Margarites costalis sordidus, Buccinum maltzani, Portlandia arctica* (Fig. 8), *P. aestuariorum, Thracia septentrionalis* (Fig. 9), *Montacuta maltzani, M. spitzbergensis*, that inhabited mostly the south-eastern part of the sea along coasts and in bays of Novaya Zemlya and also in fjords and coastal waters of Spitsbergen. However, two of these species, *T. septentrionalis* and *M. maltzani* , were noted off southern coasts further west than in the period that followed, which was evidently related to weakening of Atlantic water flow and cooling. This apparently allowed the former to settle along the Murman coast up to the Rybachiy Peninsula (33° E) and the latter - to appear in the Varangerfjorden (30° E).

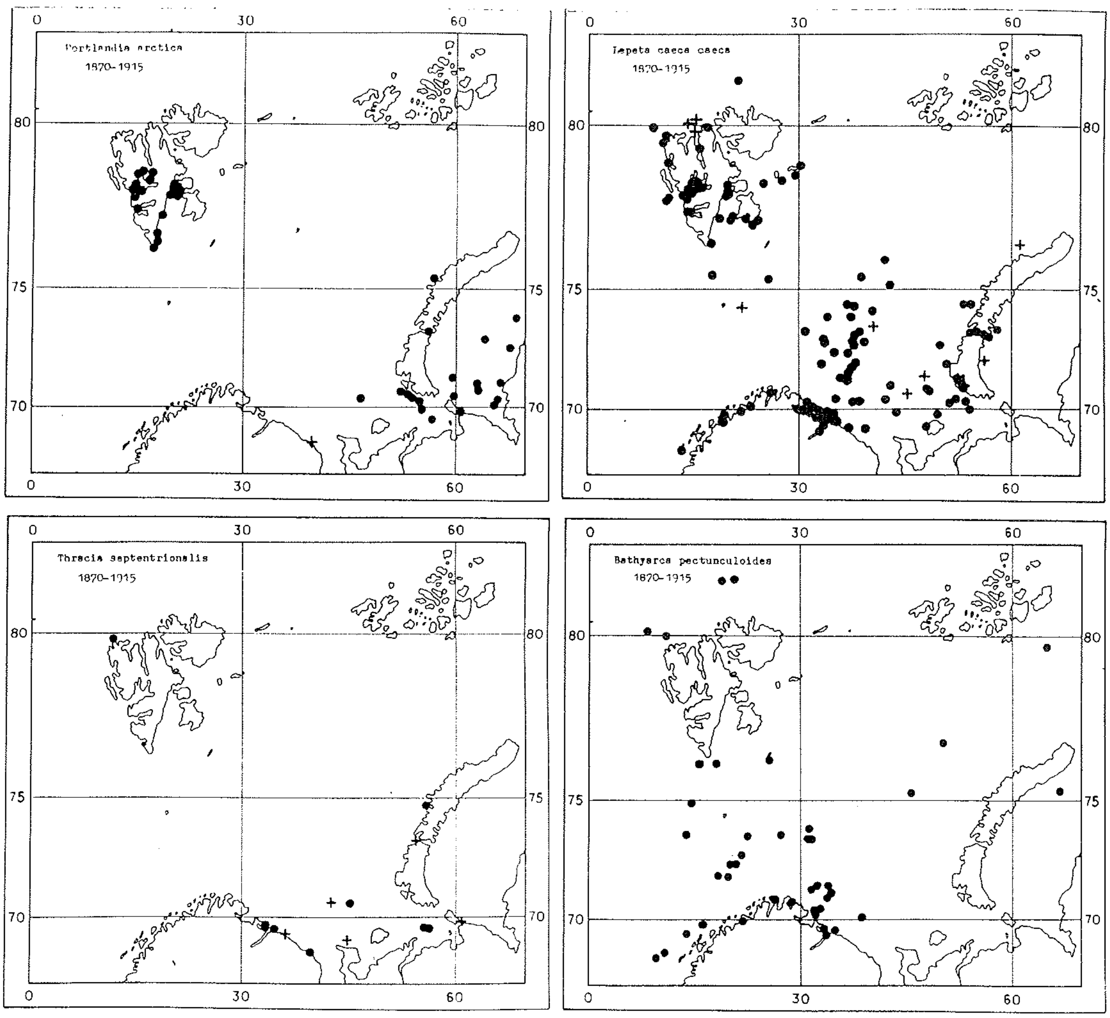
The Boreal-Arctic Atlantic species *Scissurella crispata, Lepeta caeca caeca* (Fig. 10), *Margarites olivaceus olivaceus, Moelleria costulata, Ganesa basistriata, G. laevigata, Dacrydium vitreum, Bathyarca pectunculoides* (Fig. 11), *Cyclopecten imbrifer, Panomya arctica* occurred in all regions of the sea, but were particularly abundant in its southern part. In waters of Murman, the mean frequency of occurrence of *L. caeca, D. vitreum*, and *B. pectunculoides* was 11% in that period, and in the southeastern part of the sea 10%. Pacific Boreal-Arctic molluscs including *Erginus rubellus, M. giganteus, M. olivaeus marginatus, Solariella obscura obscura, S. obscura intermedia, S. varicosa* (Fig.12), *Lyonsia arenosa, Pandora glacialis, Thracia myopsis myopsis, Serripes groenlandicus* (Fig. 13), *Macoma torelli, Liocyma fluctuosa* were noted as well as Arctic species, mostly in the south-eastern part of the sea, and off Novaya Zemlya and Spitsbergen.

Moreover, they inhabited in great numbers coastal waters of Murman and further westwards, particularly *S. obscura obscura* and *S. varicosa*, and were spread along the Norwegian coasts at much greater distances. They were not restricted to fjords, but inhabited also open waters. Thus, while *M. giganteus, M. olivaceus marginatus, M. torelli* and *L. fluctuosa* in the southern part of the sea did not penetrate beyond its south-eastern part, *P. glacialis* was noted up to the entry into the Motovskiy Bay (33° E), *S. obscura intermedia, S. varicosa*, and *S. groenlandica* up to Vadso (30° E), *E. rubellus* up to Tromsø (19° E), *Th. myopsis myopsis* Bodø (67 N), *L. arenosa* - the Oslofjorden, and *S. obscura obscura* reached waters beyond the Norwegian Sea in the Atlantic Ocean. The frequency of occurrence of Boreal-Arctic Pacific bivalvia was 3 % in coastal waters of Murman and 12 % in the south-eastern part of the sea in those years.

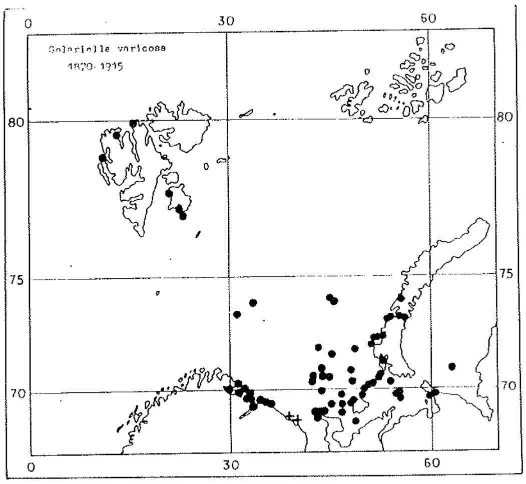
In the following Figs, locations of living molluscs are marked with circles and locations of empty shells with +.

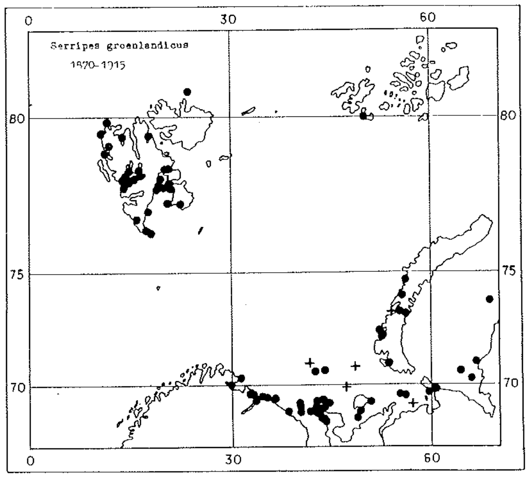



Figs. 4. - 7. Distributions of *Limatula hyperborea, Astarte acuticostata, Bathyarca glacialis* and *Arctinula groenlandica* during 1870-1915.

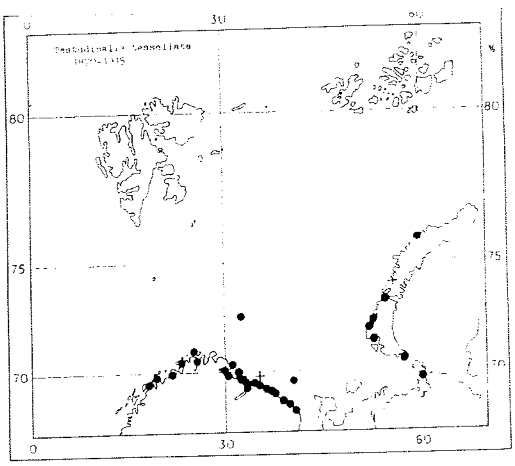


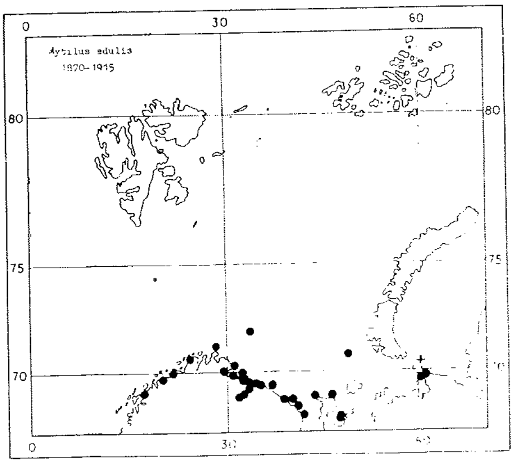

Figs. 8. - 11. Distributions of *Portlandia arctica, Thracia septentrionalis, Lepeta caeca caeca* and *Bathyarca pectunculoides* during 1870-1915.




Figs. 12. -13. Distributions of *Solariella varicosa* and *Serripes groenlandicus* during 1870-1915.

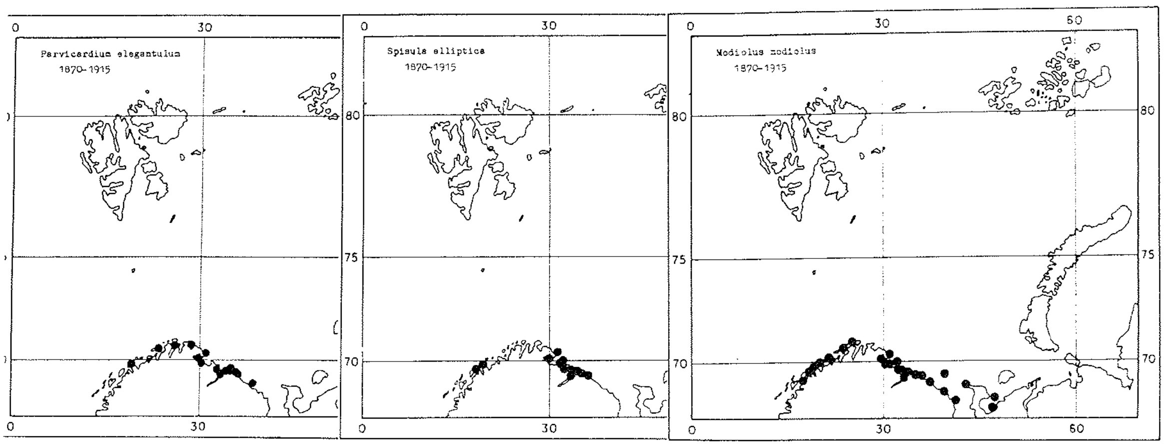



Figs.14. - 15. Distributions of *Testudinalis tessellata* and *Mytilus edulis* during 1870-1915.

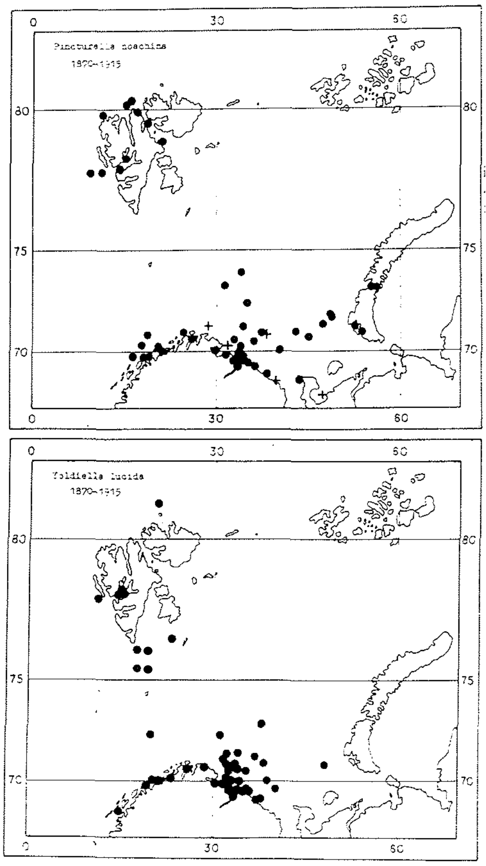
Boreal molluscs were divided into three groups according to their distribution. The first, including the Atlanic species *Testudinalia tessellata* (Fig. 14), *Margarites helicinus, Cerastoderma edule, Mya arenaria* and the (originally Pacific) *Mytilus edulis* (Fig. 15) and *Macoma balthica* inhabited mostly the littoral. They were found at the coast of Northern Norway and Murman, and their distribution eastwards was restricted to the area off Svyatoy Nos (40° E; *C. edule* even only to Ura Inlet, 33° E). Moreover, *T. tessellata* was noted on Yugorskiy Shar and on the western coast of Novaya Zemlya up to 76° N, and *M. helicinus* - in the Yugorskiy Shar, Novaya Zemlya, Spitsbergen, and Franz Josef Land. In these regions, however, they inhabited depths of 5-10 m and more, and were noted in the littoral only in a few cases. *M. edulis* and *M. balthica,* apart from Norway and Murman occurred even in the south-eastern part of the Barents Sea and penetrated through the Yugorskiy Shar in the adjoining part of the Kara Sea, also by descending to the upper sublittoral.

The second group included molluscs inhabiting coastal waters and fjords of Norway and Murman: Atlantic *Iothia fulva, Gibbula tumida, Calliostoma formosa, Yoldia amygdalea, Parvicardium elegantulum* (Fig. 16), *Arctica islandica, Spisula elliptica* (Fig. 17), *Zirfaea crispata,* and Pacific *Buccinum ciliatum ciliatum* and *Modiolus modiolus* (Fig. 18). In that period, they did not occur in the open sea except *C. formosa* (farther than 5-10 miles from the coast). Their distribution in the eastern direction was restricted to the following limits: *Y. amygdalea* - Porsangerfjorden (25° E), *G. tumida* - Vayda Inlet (32° E), *I. fulva* - 34° E, *C. formosa* -35° E, *S. elliptica* - 36° E, *P. elegantulum* - 38° E, *A. islandica* - 40° E; and only the Pacific *M. modiolus* was found in the Cheshskaya Inlet (47° E). The boring mollusc *Z. crispata* was noted in the Kola Bay in 1909. The Pacific species*B. ciliatum ciliatum* inhabited the south-eastern part of the sea, and, apart from that, was found off southern Spitsbergen and Bear Island. The average frequency of occurrence of the Atlantic *P. elegantulum, A. islandica, S. elliptica* in the region of Murman was 5% in these years.




Figs. 16. - 18. Distributions of *Parvicardium elegantulum* ,*Spisula elliptica* and *Modiolus modiolus* during 1870-1915.

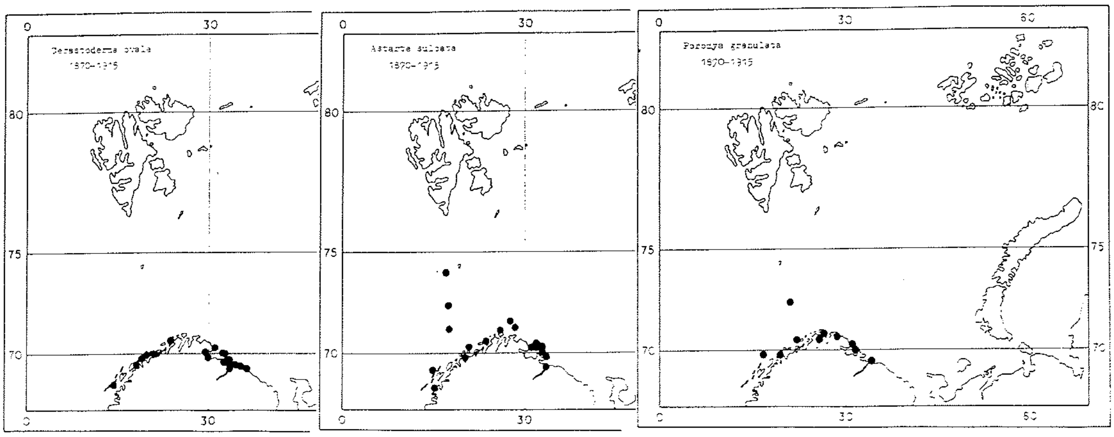
The third group contained the Atlantic species *Puncturella noachina* (Fig. 19), *Margarites groenlandicus groenlandicus, Solariella obscura bella, Yoldiella lucida* (Fig. 20), *Heteranomia squamula, H. aculeata*, and the Pacific *M. costalis costalis*. As the previous group, this group inhabited coastal Norwegian and Murman regions, and, partly, the south-eastern part of the sea. The frequency of occurrence of such bivalvia was 13% in the waters of Murman and 1.5% in the south-eastern region. At the same time, species of this group were widely represented in the open sea where they occupied areas with higher temperatures. *P. noachina, M. groenlandicus groenlandicus, M. costalis costalis, Y. lucida* were noted off western and northern Spitsbergen in areas affected by the West Spitsbergen Current; *P. noachina, S. obscura bella, Y. lucida, H. squamula, H. aculeata* were found in the central part of the Barents Sea, where the Central Branch of the North Cape Current approaches; and *P. noachina* and *M. groenlandicus groenlandicus* were also collected between Murman and Novaya Zemlya and off Novaya Zemlya, i.e. in the area warmed by the Murman and Novaya Zemlya currents. *M. groenlandicus groenlandicus* was found off Novaya Zemlya even up to 75° N. Moreover, in that period, Boreal molluscs did not occur in the central part of the sea farther north than 73-74° N. Off Bear Island *M. groenlandicus groenlandicus* and *M. costalis costalis* were found in small numbers, and off the Murman coast both these species ascended up to the littoral zone.




Figs.19. -20. Distributions of *Puncturella noachina* and *Yoldiella lucida* during 1870-1915.

Subtropical-Boreal molluscs, in spite of the northern location of the Barents Sea, are represented in its fauna by a large number of species. In the class Bivalvia they are second in the number of species after the Boreal-Arctic category and have more species than the Arctic complex. But, the overall abundances of separate subtropical-Boreal molluscs are low in the Barents Sea, because their distribution is restricted mostly to its small south-western area. Within the studied period, 22 species were noted here, although a reservation should be made that this figure may have been over-estimated, because it was often based on the numerous data published as long ago as the end of the past century. All these species, except for *Turtonia minuta*, belonging apparently to Pacific forms, were molluscs of Atlantic origin. As well as Boreal species, subtropical-Boreal molluscs were subdivided into three groups: The first group, including *T. minuta*, *Helcion pellucidus*, and *Gibbula cineraria*, inhabited the littoral and the uppermost horizon of sublittoral. The dispersal of the Pacific *T. minuta* eastwards, to the less warmed areas, reached 39° E, while the distribution of the other two species was restricted to the region of Vadsø in the Varangerfjorden (30 - 31° E).

The second group consisted of forms inhabiting mostly fjords and coastal waters: *Modiolula phaseolina, Palliolum tigerinum, Pseudamussium septemradiatum, Notolimea sarsi, Anomia ephippium, Lucinoma borealis, Parvicardium scabrum, P. minimum, P. (Cerastoderma) ovale* (Fig. 21), *Chamelea striatula, Timoclea ovata, Spisula subtruncata, Psiloteredo megotara, Cuspidaria lamellosa, C. obesa. P. minimum* and *C. lamellosa* did not penetrate into the Barents Sea farther than Porsangerfjorden (26° E); *P. ovale* was found at a maximal distance in the eastern direction, off Gavrilovo and in the Podpakhta Inlet (36° E). Apart from that ship worm, *P. megotara* was found in the Ura Inlet (33° E) in those years. In other species, the distribution eastwards did not go beyond the limits of the western part of the Varangerfjorden (Vadsø, Vardø, Longfjorden, Elvenes - 30-31° E).



Figs. 21. -23. Distributions of *Parvicardium ovale*, *Astarte sulcata* and Poromya *granulata* during 1870-1915.

The third group comprised molluscs occurring not only in fjords and coastal waters, but also in the open sea: *Tectura virginea, Limopsis minuta, Delectopecten vitreus, Astarte sulcata* (Fig. 22), *Poromya granulata* (Fig. 23). In the south-western part of the Barents Sea and adjoining part of the Norwegian Sea they moved away from the coast, which was determined by the direction of warm currents; *T. virginea, L. minuta, P. granulata* migrated to a distance of not more than 110 -130 miles, *A. sulcata* of 250 miles. The farthest dispersal northwards with the waters of the Spitsbergen Current was noted for *A. sulcata* which occurred at 74° N, south-west of the Bear Island; and maximal dispersal eastwards with the Murman Current was noted for *T. virginea* found at 33° 30' E.

In the years described, unlike in the subsequent periods, water temperature fluctuations were relatively small. But, periods of cooling and warming were observed also during that time, the second half of the 1880's being particularly warm. These periods of temperature rise could have been responsible for the short appearance of thermophilous Boreal species, for instance *Calliostoma formosa*, found in 1880 in Teriberka (35° E) and *Cerastoderma edule*, noted in Port Vladimir (Ura Inlet) in 1888-1889.

A pronounced cooling began in the Barents Sea in 1899; it continued until 1918 with an interruption in 1905-1908. Anomalies of average annual water temperatures on the section along the Kola Meridian in 1899-1904 and 1911-1918 were -0.5 and +0.4°. The lowest temperatures were observed in 1917, when the anomaly fell to -1.0. There are scanty data on the influence of such temperature declines on the fauna, because only few stations were sampled after 1901 in the open sea. But, their effects on the distribution and abundance of molluscs are confirmed by the data obtained in 1921-1925. The cooling led to the migration of Arctic and Boreal-Arctic species in the south-western direction and, thus, a decrease of the inhabited areas and the numbers not only of Boreal and subtropical-Boreal, but also of Boreal-Arctic molluscs. This is confirmed, in particular, by the increase in the numbers of *Lepeta caeca* in the south-western regions; in 1921, it was found at 5 stations of the section along the Kola Meridian, whereas it was found at only 2 stations in 1900-1901.

A slight warming in 1905-1908, when the temperature anomaly along the Kola Meridian was 0.0°, also affected the fauna to some extent. It was responsible for the appearance of several subtropical-Boreal species in the Kola Bay, such as *Palliolum tigerinum* and *Xylophaga dorsalis*, together with the sea urchin *Echinus esculentus*, the holothurian *Labidoplax buskii*, and the fish *Chirolophis ascanii*, that were observed there by K.M. Derjugin (1915, 1925). However, these animals were not precursors of warming (as he had assumed), but on the contrary, testified to the past temperature rise. The same warming apparently caused a gradual increase in the numbers of *Lepeta caeca* off the north-western coast of Novaya Zemlya (which was revealed through collections made in 1921) and also a further migration of *Calliostoma formosa* eastwards. The latter was found in 1913 off Murman coast at 37° 30' E, 50 miles away from the site where it was previously discovered off Teriberka in 1880.

The next phases of long-term changes of the bottom fauna were related to the process of the "warming of the Arctic" that began in the Barents Sea in 1919. Positive average annual anomalies of the temperature observed on the section along the Kola Meridian were 0.3° in 1919-1922 and in 1924, with a rise to 0.6° in 1921.

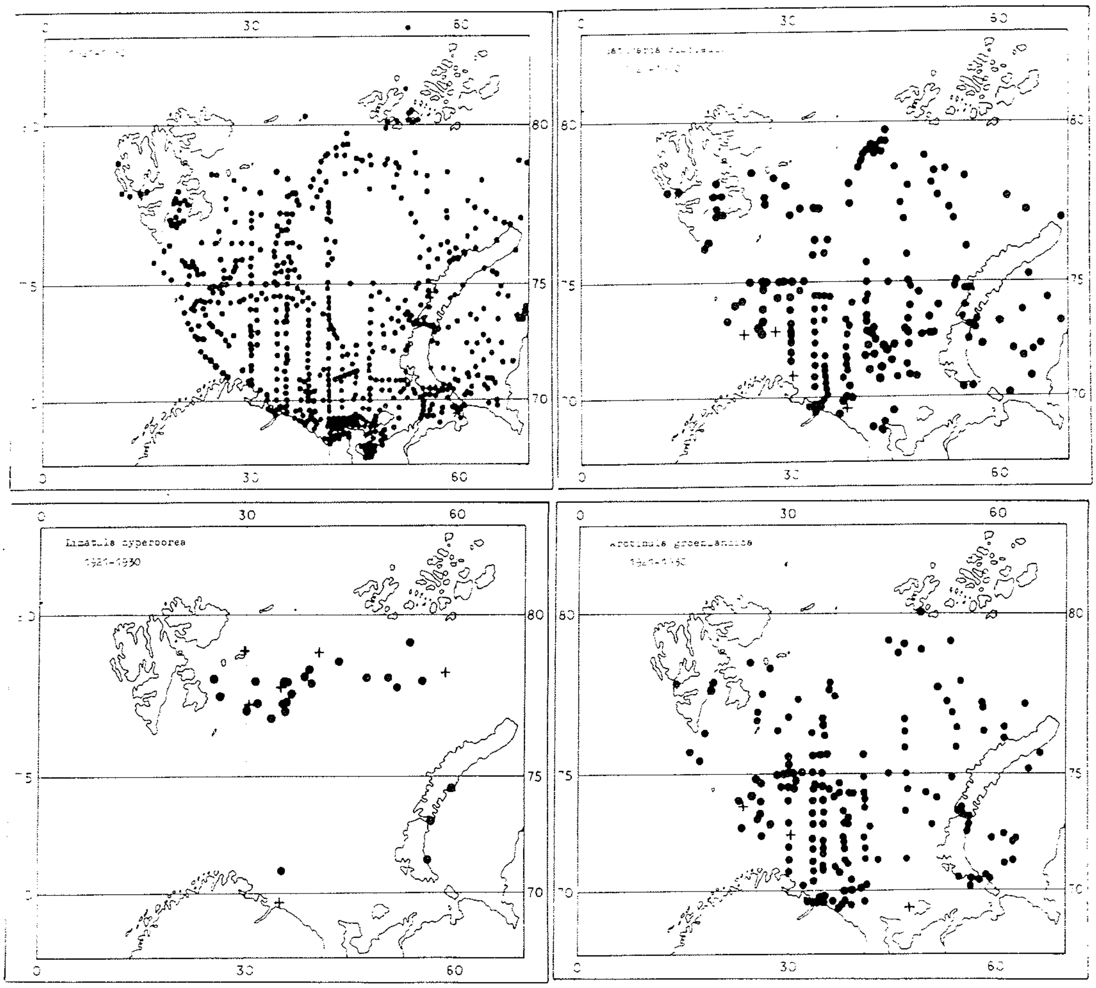



Fig. 24. Map of benthic stations sampled during 1921-1930.
Figs. 25. - 27. Distributions of *Limatula hyperborea*, *Bathyarca glacialis* and *Arctinula groenlandica* during 1921-1930 (cf. Figs 4, 6, 7).

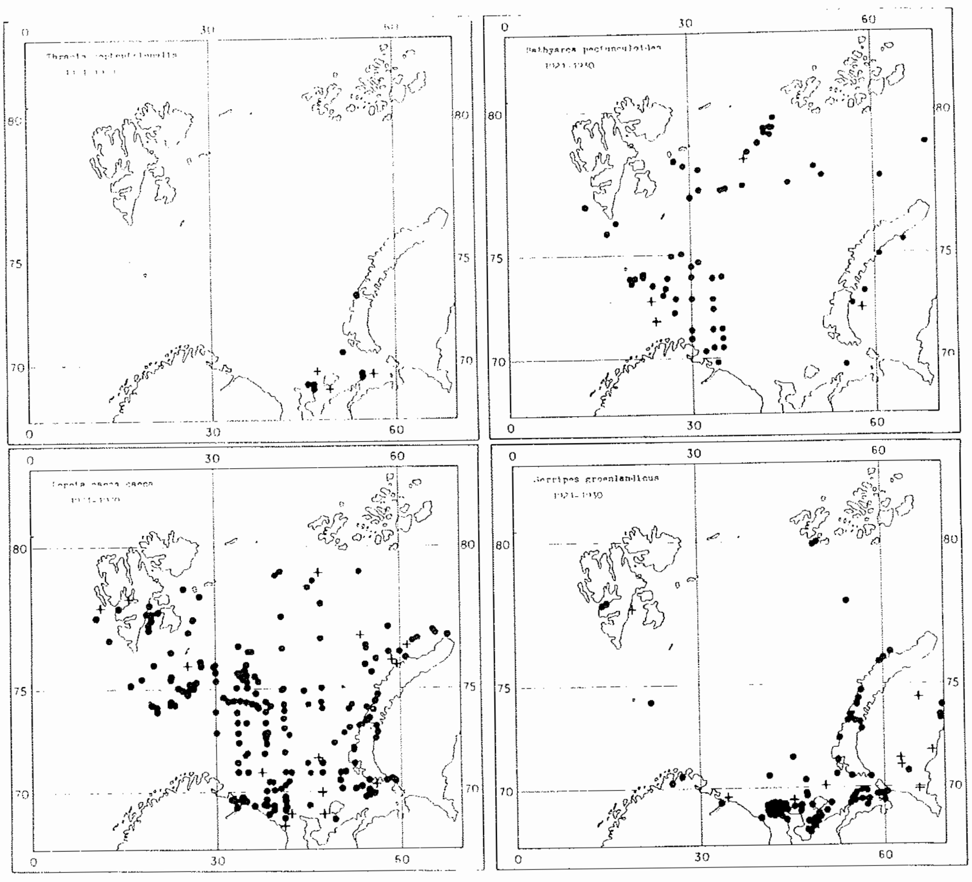
In 1923 and 1925-1929, short coolings occurred, during which the anomaly -0.1°. As a result of these moderate fluctuations, water temperature in the 1920's was nearly equal to the average long-term temperature (in 1919-1929 = 0.0° C).

Collections made in the 1920's were more complete (Fig. 24) as compared to the previous period, because a larger number of stations were sampled not only in the southern part, but also in the northern part of the sea. This allowed to make a more detailed analysis of distribution of molluscs in the North (Fig. 25, 26, 27).

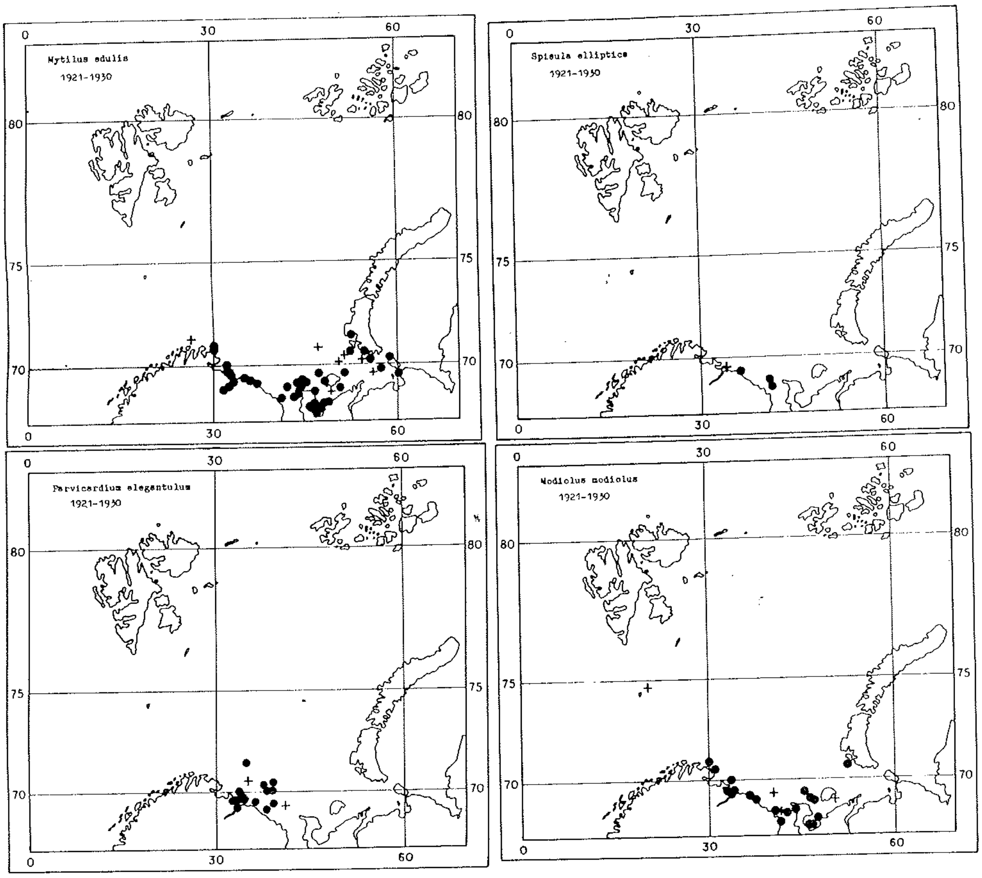
Warming was accompanied by corresponding changes in the distribution of molluscs, i.e. increase in the numbers of thermophilous forms and their dispersal to new areas. However, as materials collected in the first half of the 1920's included mostly specimens that emerged and grew during the previous strong cooling, naturally, indices of abundance of Arctic species remained high. This explains, for instance, the high frequency of occurrence of Arctic Atlantic bivalvia during that period, which in coastal waters of Murman was kept on the same level as in 1898-1901, i.e. 21%. Meanwhile, in the 1920's, the Arctic *Margarites vahlii* was not noted in the southern part of the Barents Sea, and *M. costalis sordidus* and *Thracia myopsis devexa* were not noted in its central part, as the southern border of their distibution shifted northwards.

In the south-eastern part of the sea, in the area of the Kolguev-Pechora Current (see Fig. 2), the Atlantic species *Neptunea denselirata* and *Buccinum hydrophanum* moved 100 and more miles eastwards. Changes occurred also in species of Pacific origin. It was only in that region that *Thracia septentrionalis* (Fig. 28) was observed during those years; in the previous years it was noted also in Murman coastal waters. The southern boundary of the distribution of *Portlandia arctica* shifted 20-60 miles farther north, and the minimal depth of its habitation increased from 16 to 100 m. In the most remote south-eastern shallow area living individuals of *B. maltzani* were only found at a depth of 13-28 m, whereas empty shells were found at depths of 35-39 m. In all probability, the extinction of molluscs at this depth horizon was related to the intensification of flow of salty and heavier Atlantic waters, which, moving in the near bottom layer, displaced *B. maltzani* to shallower depths.

Areas and abundances of Boreal-Arctic species increased in the 1920's (Figs. 29, 30), which was obviously related to the above-described characteristics of the temperature regime. The temperature rise in the beginning of this period led to an increase in abundance of these molluscs in the northern part of the sea. The slight cooling that followed, permitted them to retain their abundances at a relatively high levels also in southern regions. As these processes occurred during a relatively short period that did not exceed ten years and, in most cases, did not exceed the limits of life duration of one generation, Boreal-Arctic animals had an opportunity of forming more dense settlements both in the northern and southern areas, which led to a total increase in their numbers and biomass. This is confirmed by the fact that the frequency of occurrence of Atlantic bivalvia increased from 6 to 18% in coastal waters of Murman in that period. Moreover, in the south-eastern part of the sea, some species, i.e. *Lepeta caeca*, *Dacrydium vitreum*, *Panomya arctica* and also the Arctic Buccinidae, moved further east in the Kolguev-Pechora Current waters. The frequency of occurrence of Pacific Boreal-Arctic bivalvia in the Murman region remained on nearly the same level (3 and 4%), but, in the south-eastern part of the sea it increased on the average two-fold,



Figs. 28 - 31. Distributions of *Thracia septentrionalis, Lepeta caeca caeca, Bathyarca pectunculoides* and *Serripes groenlandicus* during 1921-1930 (cf. Figs. 9-13)



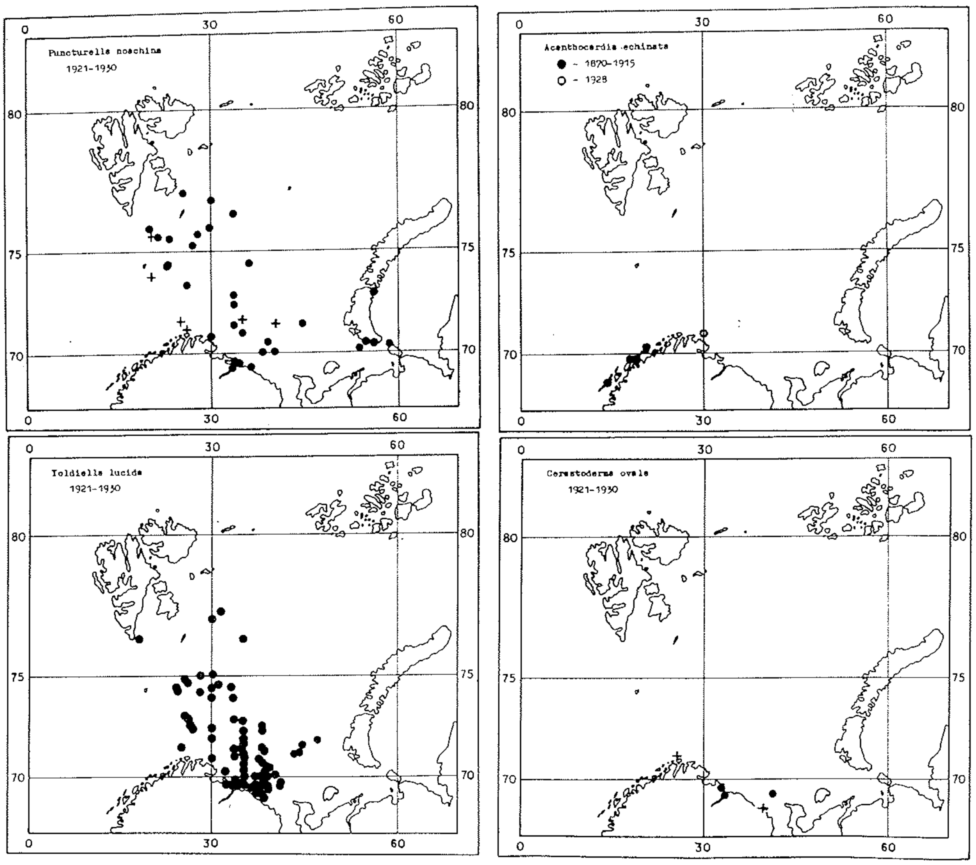

Figs. 32 - 35. Distributions of *Mytilus edulis, Parvicardium elegantulum, Spisula elliptica* and *Modiolus modiolus* during 1921-1930 (cf. Figs. 15-18).

from 12 to 21%, and in*Macoma torelli* and*Liocyma fluctosa* to a still greater extend. Meanwhile, in the Murman coastal waters only single specimens of *Scissurella crispata* were observed, *Moelleria costulata* was not found; and the number of findings of *Serripes groenlandicus* (Fig. 31) was less, although Porsangerfjorden and Laksefjorden (25-27 E) were noted as the westernmost areas of its distribution.

Boreal species moved far northwards during that period, and also to the north-east and east occupying new habitats, their dispersal being closely connected with warm currents. *Cerastoderma edule* inhabiting littoral and upper subittoral waters, was found in the Kola Bay in 1921, whereas it was not found east of the Ura Inlet in earlier years. *Mytilus edulis* was found in many stations in the south-eastern part of the sea (Fig. 32, cf. Fig. 15). Of the coastal forms, *Gibbula timida* was also found in 1921 in the Kola Bay; it moved to south-east from the previous habitat in the Vaida Inlet on the Rybachiy Peninsula (32° E) by a distance of 50 miles. The other species, *Parvicardium elegantulum,* noted in the past in Murman waters up to 38° E, but only in the coastal zone, was found in the open sea at a distance of 100 miles from the coast in the area where the Murmansk Current gives way to the Kanin Current (Fig. 33). *Spisula elliptica* that did not occur east of 36° E in previous years, was noted in the northern part of the Throat of the White Sea at 41° 30' E in 1927 (Fig. 34); and *Modiolus modiolus* was found 40 miles off the northern coast of the Kanin Peninsula (Fig. 35).

The greatest changes in distribution were observed in molluscs inhabiting the open sea. The coastal species *Iothia fulva* and *Calliostoma formosa* were the first to invade the open sea; they appeared in the latitude of Bear Island (74° 30' N) in areas warmed by the Spitsbergen Current and the Northern Branch of the North Cape Current. Now, they appeared 250 miles farther north than the nearest place of their previous habitation off the Norwegian coast. *Puncturella noachina* (Fig. 36) occurred in the zone of action of the South Spitsbergen Current, where it had not been found before; and *Yoldiella lucida* (Fig. 37) migrated 120 miles north-eastwards into that region up to 77° 30' N. The dispersal of *Margarites groenlandicus groen-landicus, M. costalis costalis, Solariella obscura bella, Y. lucida,* inhabiting the central part of the Barents Sea, 150-300 miles northwards, from 71-74° to 75 -78° 30' N, was related to the Northern Branch of the North Cape Current. In the area of the Central Branch of the North Cape Current *P. noachina* spread 35 miles towards north-east; it appeared also in the region of the Karskie Vorota, which, in all probability, was connected with the enhanced influence of the Kolguev- Pechora Current. The same factor was obviously responsible for the appearance of the Boreal *M. costalis costalis* in the south-eastern part of the sea, where it began to replace the Arctic *M. costalis sordidus.* Via the Novaya Zemlya Current, *Y. lucida* penetrated 180 miles north-east up to the Gusinaya Bank, and *P. noachina* and *S. obscura bella* penetrated 90-140 miles northwards up to 74° 30'N.
*M. groenlandicus groenlandicus* and *S. obscura bella* spread along the coast of Novaya Zemlya from 76° N up to the Zhelaniya Cape.

The warming of the 1920's was not only responsible for the expansion of the areas inhabited by Boreal molluscs, but also for increases of their abundance. Thus, the frequency of occurrence of Atlantic Boreal bivalvia in Murman waters increased from 9 to 19%; and in the south-eastern part of the sea, in Pacific species, this index increased up to 2-3-fold.




Figs. 36 - 39. Distributions of *Puncturella noachina, Yoldiella lucida, Acanthocardia echinata* and *Parvicardium (Cerastoderma) ovale* during 1921-1930.

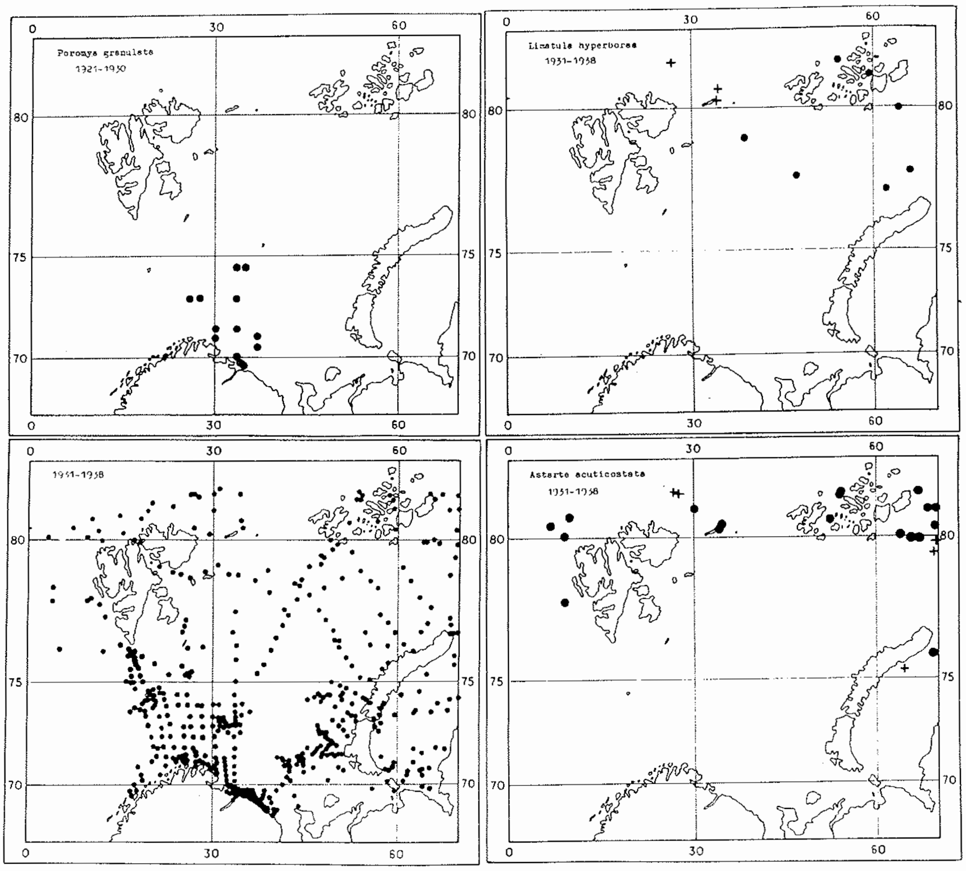
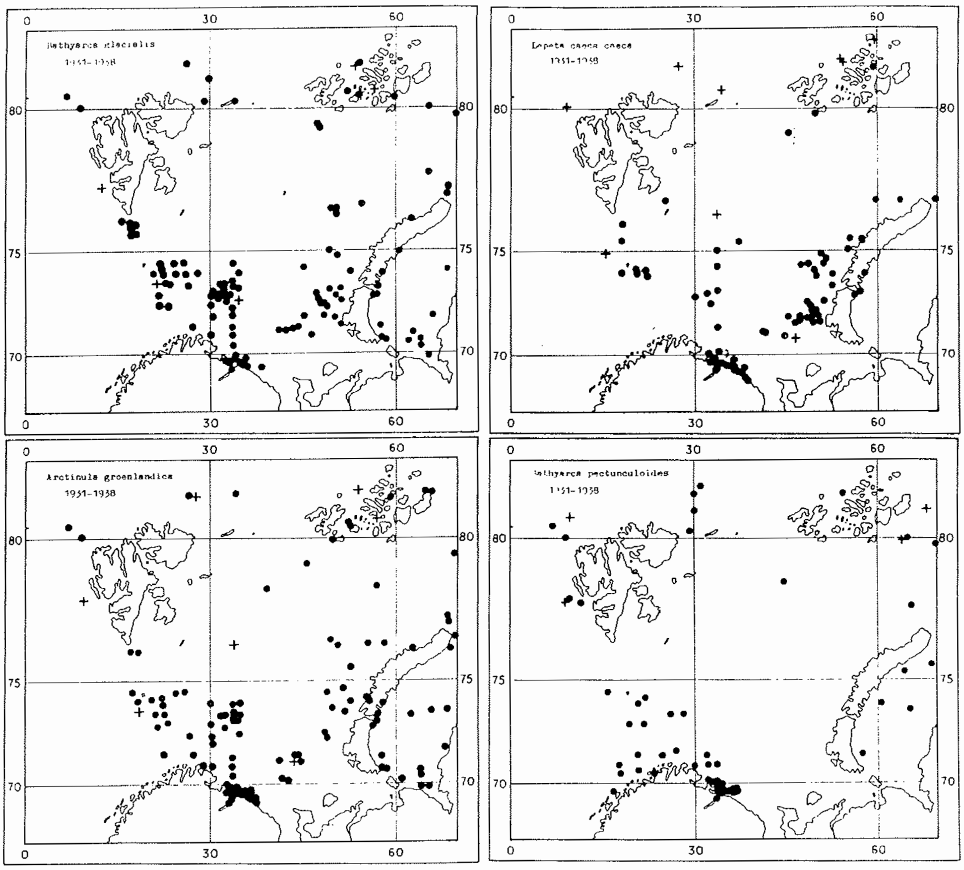



Fig. 40. Distribution of *Poromya granulata* during 1921-1930 (cf. Fig. 23).
Fig. 41. Benthic stations sampled during 1931-1938. - Figs. 42 - 43. Distributions of *Limatula hyperborea* and *Astarte acuticostata* during 1931-1938 (cf. Fig. 25).

Two new coastal species appeared in the group of subtropical-Boreal molluscs of the Barents Sea, i.e. *Limatula subauriculata* and *Acanthocardia echinata* (Fig. 38). The areas of approximately a half of other forms increased, as they spread farther north- and eastwards. Among the mostly littoral forms, *Turtonia minuta* was noted at a depth of 13 m in the Cheshskaya Inlet, 180 miles east of the littoral Murman site, where it was found before; and the coastal species *Parvicardium ovale* moved 110 miles eastwards to the northern part of the Throat of the White Sea (41° E; Fig. 39). Among species of the open sea, *Tectura virginea* was found in the Porchnikha Inlet in the Eastern Murman, 70 miles east of its earlier location in the Kola Bay. *Delectopecten vitreus* moved northwards up to 73° N with the Spitsbergen Current, *Limopsis minuta* moved with the North Cape Current 100 miles to north-east, and *Poromya granulata* (Fig. 40) moved by 290 miles. The other subtropical-Boreal molluscs listed above among the coastal species in the new areas were no longer found within their previous habitats.

The climatic (and especially the temperature) fluctuations occurring in the 1920's manifested as a warming and a subsequent slight cooling, with the average temperatures for the entire period being equal to the long-term average temperatures. These fluctuations undoubtedly had favourable influences on the mollusc fauna of the Barents Sea. There were no essential changes in the numbers of Arctic species at least in the first half of the 1920's. At the same time, the distribution areas and numbers of many species, Boreal-Arctic, Boreal, and subtropical-Boreal, increased considerably. Therefore, the 1920's were an optimal period of existence not only for molluscs, but also for other groups of the bottom communities of the Barents Sea. Accordingly, the indices of benthic fauna biomass established for these years after the „Persey" expeditions in 1924-1931 (Brotskaya, Zenkevitch, 1939), were high.

In 1930-1939 a new, much stronger warming occurred in the Barents Sea when temperatures attained the maximal values noted during the "warming of the Arctic". The average anomaly of water temperature along the Kola Meridian was 0.5°, rising in 1938 up to 0.9° (Fig. 1). Owing to the high temperature rise and long duration of this warming, its influence on the fauna was much greater than in the 1920's. It led to translocations of distribution boundaries of bottom animals towards north and east and to notable decreases of habitats and abundances not only of Arctic, but also of Boreal-Arctic species (Fig. 41). During this warm period and in the subsequent years, the high Arctic *Diplodonta torelli* was no longer found in the Barents Sea. The Arctic species and subspecies *Margarites groenlandicus umbilicalis, M. costalis sordidus,* and *M. vahlii* were noted only in the northern-most part of the sea, in the region of Eastern Spitsbergen and Franz Josef Land, and *M. costalis sordidus*, also in the south-eastern part of the sea and off the western coast of Novaya Zemlya. The high Arctic *Limatula hyperborea* and *Astarte acuticostata* (Figs. 42, 43) disappeared from the southern part of the sea; they inhabited mostly areas north of 75 N, although in the 1920's single individuals occurred in the areas situated farther south. There was a notable decline in the numbers of *Buccinum hydrophanum* in the Motovskiy Bay in the western Murman and in the adjoining waters, where it was common in 1899-1901. In collections from the eastern Murman this species is represented for these years mostly by empty shells, which testifies its extinction as a result of rising temperatures.



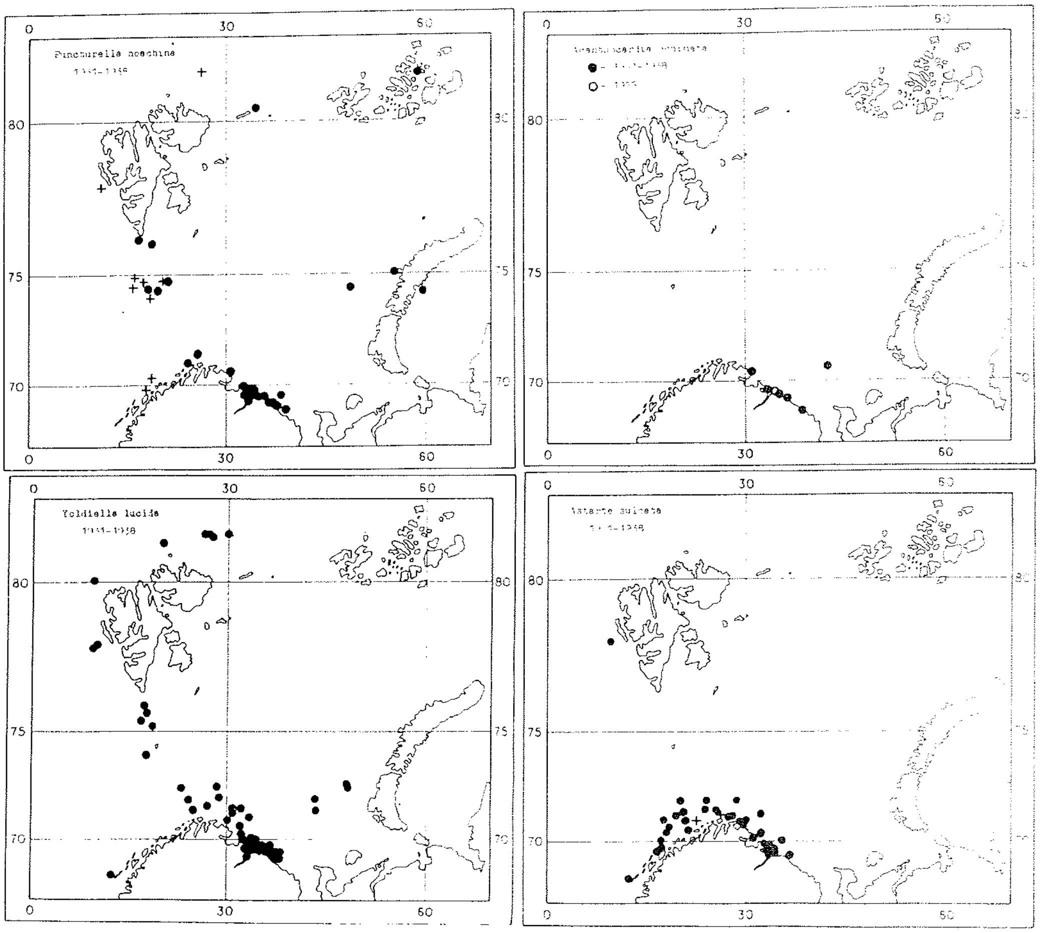

Figs. 44 - 47. Distributions of *Bathyarca glacialis, Arctinula groenlandica, Lepeta caeca caeca* and *Bathyarca pectunculoides* during 1931-1938.

In the south- western part of the sea there was a decline in the numbers of such widespread Arctic species as*Yoldiella intermedia, Y. lenticula, Y. frigida, Bathyarca glacialis* (Fig. 44), *Arctinula groenlandica* (Fig. 45) and *Cuspidaria arctica*. In the coastal waters of Murman, the frequency of occurrence of Arctic Atlantic bivalvia decreased from 21 to 11%, but, at the same time, this index slightly increased from 8% to 10% in the south-eastern part of the sea, which was probably related to the inflow of waters of Atlantic origin.

Among Boreal-Arctic species there was a notable decline in the numbers of *Lepeta caeca* (Fig. 46) and *Margarites olivaceus olivaceus* inhabiting central parts of the sea. The frequency of occurrence of *L. caeca* in the open sea declined from 23 to 13%. The species *Scissurella crispata, Ganesa basistriata, G. laevigata*, and *Moelleria costulata*, small molluscs and low in numbers, disappeared from the southern part of the sea. Then, they were noted only off Spitsbergen and Franz Josef Land. *M. olivaceus olivaceus* was not found in Murman; and the frequency of occurrence of *Dacrydium vitreum* and *Bathyarca pectunculoides* (Fig. 47) decreased from 18 to 7%. However, for *L. caeca* this index in Murman waters increased from 21 to 35 % and in the south-eastern part of the sea from 19 to 23 %. The frequency of occurrence of Pacific gastropods and bivalves in both regions declined during the 1930's.

The dispersal of Boreal molluscs in the Barents Sea continued. The mainly littoral (intertidal) *Testudinalia tessellata* and *Margarites helicinus* were found off the western coast of Novaya Zemlya from 76 15' N up to the Zhelaniya Cape at depths of 1-11 m. The coastal (nearshore subtidal) species*Calliostoma formosa* was found in the south-western part of the sea at 90 miles distance from the coast; along the Murman coast it shifted from 35 to 36° E. Of the species occurring in the open sea, *Puncturella noachina* (Fig. 48) and *Margarites costalis costalis* migrated around northern Spitsbergen with the extension of the West Spitsbergen Current and were found off Kvitoya Island, situated between Spitsbergen and Franz Josef Land. In the waters of the Arctic Ocean north off Spitsbergen the number of findings of *Yoldiella lucida* increased (Fig. 49). In the zone of the Novaya Zemlya Current, *P. noachina* migrated 300 miles north-eastwards, up to 75° N, and *Y. lucida* northwards from 72° to 76° 40' N. In the south-eastern part of the sea *Parvicardium elegantulum* moved 120 miles eastwards to the area of the Kolguev-Pechora Current, to 46° 20' E. In Murman coastal waters the frequency of occurrence of Boreal species remained nearly the same, having declined from 19% to 17 %.

In the 1930's, the subtropical-Boreal mollusc fauna of the Barents Sea was enriched by 3 species. These were *Chlamys sulcata* found off the Murman coast at 36°35' E, *Pododesmus patelliformis*, found off the Rybachiy Peninsula, and the ship worm *Nototeredo norvagica*, noted up to the Teriberka (eastern Kola Peninsula). A number of such subtropical-Boreal molluscs continued their dispersal along the Murman coast. They reached the following longitudes: *Delectopecten vitreus* - 33°18'E, *Acanthocardia echinata* - 33°23' (230 miles east of of its previous finding), *Modiolula phaseolina* - 33°30' (70 miles), *Limopsis minuta* - 33° 50' (60 miles), *Palliolum tigerinum* - 34°15 (15 miles), *Astarte sulcata* - 36° E (50 miles). Apart from that, 3 specimens of *A. echinata* were caught in an area to which their larvae had been apparently brought by the Murmansk Current, i.e. 150 miles from the coast and 255 miles east of the previous location (Fig. 50).




Figs. 48 - 51. Distributions of *Puncturella noachina, Yoldiella lucida, Acanthocardia echinata* and *Astarte sulcata* during 1931-1938 (cf. Figs. 19, 20, 22)

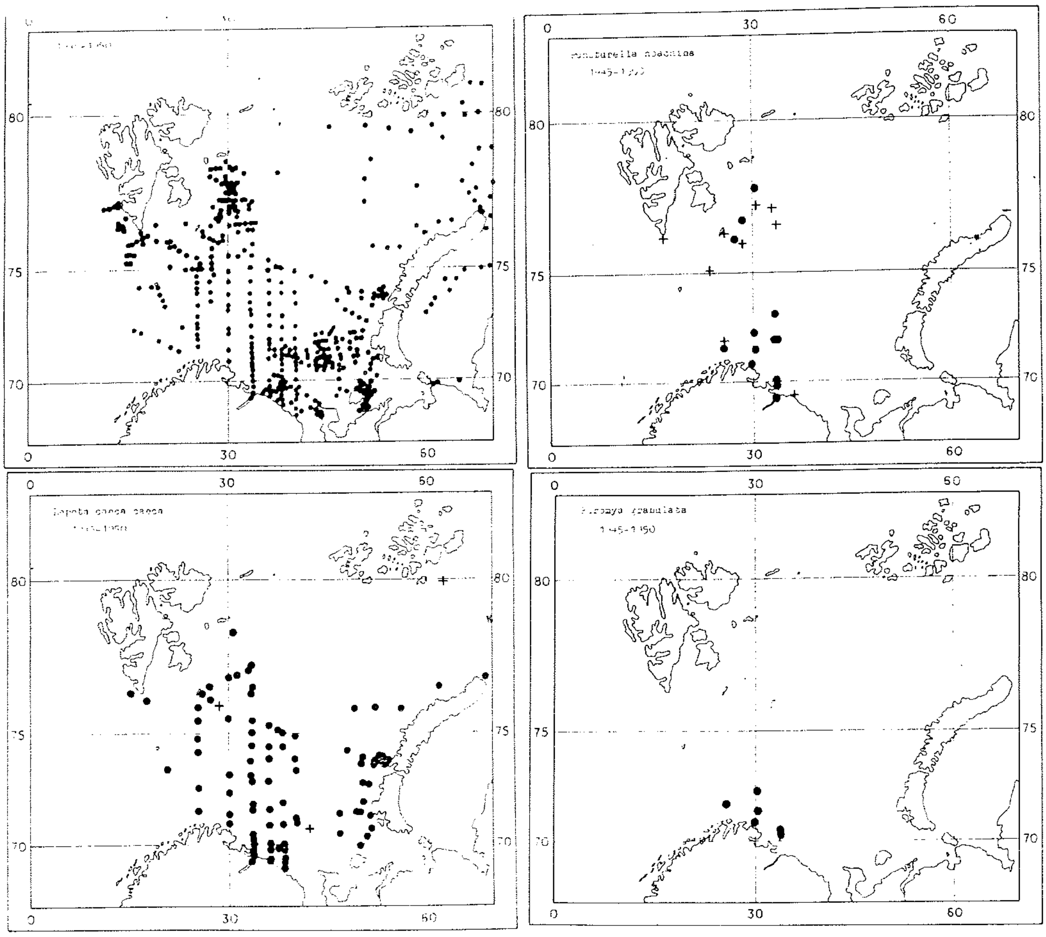



Fig. 52. Benthic stations sampled during 1945-1950.
Figs. 53 - 55. Distributions of *Lepeta caeca caeca, Puncturella noachina* and *Poromya granulata* during 1945-1950 (cf. Figs. 46, 48, 51).

In the region of action of the Spitsbergen and West Spitsbergen currents, *Tectura virginea* was found off Bear Island at 74° 34'N and *Astarte sulcata* off Western Spitsbergen at 78° N (Fig. 51). In the first case, the northern border of distribution shifted by 250 miles, in the second, by 450-550 miles. At the same time, even the considerable rise of temperature in the 1930's did not result in a notable increase of the areas inhabited by many subtropical-Boreal molluscs (*Helcion pellucidus, Gibbula cineraria, Pseuda-mussium septemradiatum, Notolimea sarsi, Lucinoma borealis, Parvicardium scabrum, P. minimum, Chamelea striatula, Spisula subtuncata, Cuspidaria lamellosa, C.obesa),* found only in Porsangerfjorden and Varangerfjorden in the second half of the 19th century. One can assume that they persisted there throughout all subsequent years. However, no data are available in the literature except for *H. pellucidus* and *P. scabrum* in the 1920'-1930's. This, however, may be explained by the lack of benthos collections in the fjords or by the possibility that findings were not published in the following years.

Warming of the 1930's gave way to cooling in 1940-1942 during which the mean anomaly of water temperature along the Kola Meridian was -0.3°, falling in 1941 and 1942 to -0.4° (Fig. 1). This brought about reverse migrations of many species to southern and western directions as is shown by the collections of 1945-1950 (Fig. 52). The fall of temperature could have been responsible for the increase of the frequency of occurrence of the Arctic *Yoldiella intermedia* in Murman waters from 16 to 22%, and for the occurrence of the high Arctic *Y. symmetrica* in the southern half of the sea along the Kola Meridian at 71° 30 N. In the same period there was a notable increase in the numbers of the Boreal-Arctic *Lepeta caeca* in the central part of the sea (Fig. 53), and it appeared in the coastal region of Murman in the areas where the core of the Murmansk Coastal Current passes and where this animal was previously lacking. Thereafter, in 1947, *L. caeca* occurred at nearly all stations along the Kola Meridian, except the stations 4 and 5, where the Murman Current passes. Moreover, there was a slight increase in the numbers of *Margarites olivaceus olivaceus* in the central part of the sea. In the region between Spitsbergen and Hopen Island there was a slight increase in the numbers of the Pacific *Solariella obscura obscura* and *S. varicosa*. In the Murmansk Region, the increase of the frequency of occurrence of the Boreal-Arctic Pacific S. *obscura obscura, S. varicosa, Lyonsia arenosa, Pandora glacialis* and *Serripes groenlandicus* was presumably related to cooling, too. At the same time this index declined for Boreal Atlantic bivalvia from 17 to 10 %. This may be partly attributed to the fact that very few stations with depths of less than 100-150 m, inhabited by these species, were sampled in those years. Collections of 1945 revealed an abrupt decline of *Cerastoderma edule* in the littoral of the Kola Bay while large numbers of its empty shells were found. To judge by the age of living young individuals found in that area, the shells belonged to molluscs which died in 1941-1942. Apparently, the cooling led to extinction of not only *C. edule*, but also of *Puncturella noachina* inhabiting the Bear Island Bank and the area north of it, between 75 and 78° N (Fig. 54). This is evidenced by empty shells of this mollusc found at 7 stations in 1948, whereas living individuals were detected at only three stations.

The cooling of 1941-1942 had an even greater impact on subtropical-Boreal species. In the 1940's and subsequent years *Modiolula phaseolina, Palliolum tigerinum, Limatula subauriculata* and *Pododesmus patelliformis* were no longer found in coastal waters of the south-western part of the Barents Sea and off

Murman. But, it is hardly probable that they did no longer exist in the Barents Sea, as they presumably persisted in large fjords between the North Cape and Murman (Porsangerfjorden, Laksefjorden, Tanafjorden and Varangerfjorden), where *M. phaseolina* and *P. tigerinum* were noted already in the second half of last century. As regards other subtropical-Boreal species, *Limopsis minuta* and *Astarte sulcata* no longer occurred off Murman coast, while the average frequency of occurrence of this group of species decreased there from 3 to 1%. The eastern boundary of *Parvicardium ovale* distribution in that region shifted 75 miles westwards, from 39 to 36° E; and *Tectura virginea* was not noted in the open sea. The northern distribution boundary of *A. sulcata* in waters off Western Spitsbergen shifted 80 miles southward from 78 to 76° 40' N and that of *Poromya granulata* in the central part of the sea 120 miles from 74 30' (in 1927) to 72 30' N (Fig. 55) .

In 1943, a new, much more prolonged warming began; it lasted 20 years until 1962. As compared to the previous one it was not so strong (with an average annual anomaly of water temperature along the Kola Meridian section of 0.4°, compared to 0.5° in the 1930's). Moreover, this warming was interrupted several times, in 1948, 1953, 1956, and 1958, when water temperatures fell below the average long-term value (anomalies in these years fluctuating between -0.1 and -0.3°). However, owing to its long duration and the high temperatures observed in 1950 and 1954 (when the anomaly increased to 0.9°), the warming had a notable impact on a considerable share of the Barents Sea fauna.

Changes brought about by the warming were noted already in the 1940's, when the frequency of occurrence of the Arctic *Yoldiella lenticula* in Murman waters decreased from 23 to 16%. The Boreal-Arctic *Lepeta caeca* disappeared from the southern part of the central Barents Sea, subjected to the influence of the Central Branch of the North Cape Current in that time (see Fig. 2). *Bathyarca pectunculoides* migrated to the north-east from the Murman coast; it was found in the open sea 150 miles from the coast, along which *Cyclopecten imbrifer* migrated up to 34 E. The Boreal *Iothia fulva* appeared off north-western Spitsbergen at 80° N, 330 miles from the place of the previous finding off the Bear Island. In the Northern Branch of the North Cape Current, *Puncturella noachina* moved 60 miles up to 78 N; and in the same time, there was a notable increase in its numbers in the south-western part of the sea. *Solariella obscura bella* dispersed with the Novaya Zemlya Current from 72° 45' to 74° N along Novaya Zemlya coast. In subtro-pical-Boreal species, changes were noted in *Anomia ephippium* and *Timoclea ovata. A. ephippium*, which had been found in Varangerfjorden in 1890, was collected in the open sea 40 miles off the Varanger Peninsula in 1947; and *T. ovata* migrated along the Murman coast up to 37° E and was caught 175 miles away from the place of its 1874 finding in the Vardø region at 30° E.

The continued warming led to a decline in the frequency of occurrence of Arctic Atlantic Bivalvia in coastal waters of Murman from 12 to 9% and its increase in the south-eastern part of the sea from 13 to 16% in the 1950's (Fig. 56 ff). In the eastern Murman, the southern boundary of the distribution of *Buccinum hydrophanum, B. ciliatum sericatum, B. nivale, Yoldiella intermedia, Y. lentticula, Arctinula groenlandica*, situated 5-10 miles from the coast in the 1930's, was shifted into the open sea by 10-20 miles from the coast. And for *Neptunea denselirata* the place of its southernmost finding was as far away from the coast line as 120 miles. The distribution boundary of *Montacuta spitzbergensis* in the south-eastern part of the sea moved 40-80 miles northwards, as compared to the 1920's; and the boundary of *Y. lenticula* in the zone of the Kolguev-Pechora Current shifted 70 miles to the east. But, at the same time, *N. denselirata* and *B. hydrophanum* migrated 65-95 miles westwards in that region, probably also as a result of the warming.

In Boreal-Arctic species, the rise in temperature brought about a notable decline in the numbers of *Lepeta caeca* in the south-western region of the sea (Fig. 57). On the the Kola Meridian section this mollusc was found in only two locations at 75° and 75° 30' N; in the open areas of the sea its frequency of occurrence declined from 30 to 27%. *Margarites olivaceus olivaceus* was not found in the waters of Murman. Increases in the numbers of the Atlantic species *L. caeca, Dacrydium vitreum, Bathyarca pectunculoides, Cyclopecten imbrifer* were noted in this region; and their frequency of occurrence rose from 12 to 18%. *C. imbrifer* spread along Murman and appeared 45 miles farther east, at 35°15'E. The frequency of occurrence of the Pacific *Solariella obscura obscura* and *S. varicosa* decreased there from 7 to 4% at the same time; the former was no longer found west of 36 E, and the latter not west of 34 E (Fig. 58). As regards other Pacific Boreal-Arctic species, *Lyonsia arenosa* and *Serripes groenlandicus* (Fig. 59) were only found in the Teriberskaya and Yarnyshnaya inlets in East Murman, whereas *Pandora glacialis* was not noted there. The penetration of the Atlantic *Moelleria costulata* eastwards became stronger. In the south-eastern part of the sea *D. vitreum* migrated with the Kolguev-Pechora Current 110 miles eastwards, and *B. pectunculoides* with the Novaya Zemlya Current 60 miles to the north. In the same region the numbers of the Pacific *Erginus rubellus* and *M. giganteus* increased somewhat. The frequency of occurrence of *S. obscura obscura* and *S. varicosa* went up considerably, i.e. from 14 to 42%; but *Liocyma fluctuosa* was found only in the most south-eastern area, whereas, in the 1920's, it was found 300 miles farther west, off the northern coast of the Kanin Peninsula.

There was an increase in the numbers of Boreal molluscs in the 1950's, while their dispersal into the northern and eastern directions continued. In 1955, *Iothia fulva* appeared also off south-western Spitsbergen. In the area between the Bear Island and Spitsbergen (at 74-77° N and 17-26° E) the frequency of occurrence of *Margarites groenlandicus groenlandicus* and *M. costalis costalis* increased from 18 and 11% to 30%. In the Murman region, the dispersal of *I. fulva* and *Calliostoma formosa* into the open sea continued; they were found 100-105 miles from the coast. At the same time, the Boreal molluscs dispersed along the Murmansk coast: *I. fulva* up to 36° 40' E, *C. formosa* to 37° 30' E, and*Yoldiella lucida* to 39 E, 50 miles east from its previous record (Fig. 60). *Spisula elliptica* migrated up to 40° E; it was found 35 miles north of the Cape Svyatoy Nos (Fig. 61). The mean frequencies of occurrence of the Atlantic *Y. lucida, Heteranomia squamula, H. aculeata, Parvicardium elegantulum, Arctica islandica, S. elliptica* increased from 10 to 14%, and that of the Pacific *M. costalis costalis* from 4% to 8%. *Puncturella noachina* was found 180 miles north-east of eastern Murman and reached 44° E (Fig. 62). *A. islandica* was found off the Cape Kanin Nos, 105 miles from its previous distribution area. The distribution boundary of *P. elegantulum* in the area of Gusinaya Bank shifted 75 miles northwards as compared to the 1930's. The Pacific *Modiolus modiolus* extended 40 miles eastward, from the Kanin Peninsula up to the western coast of the Kolguev Island.

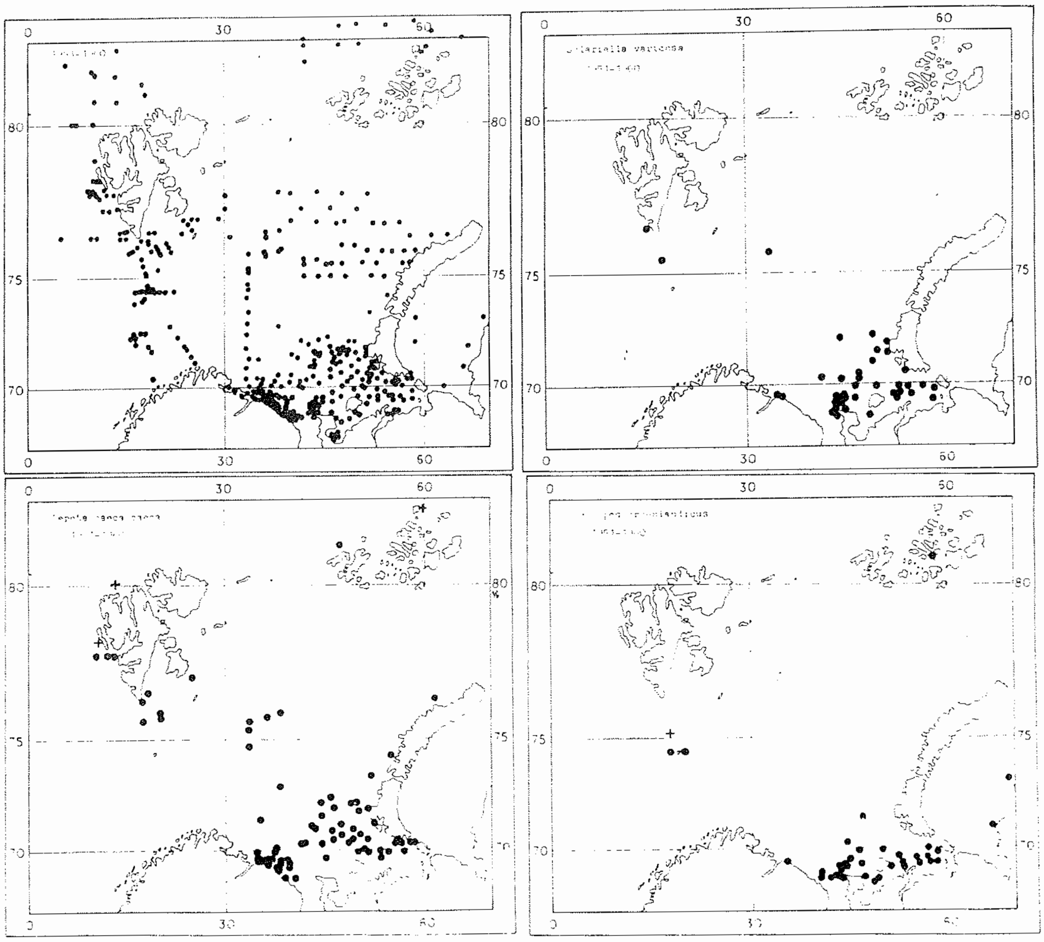
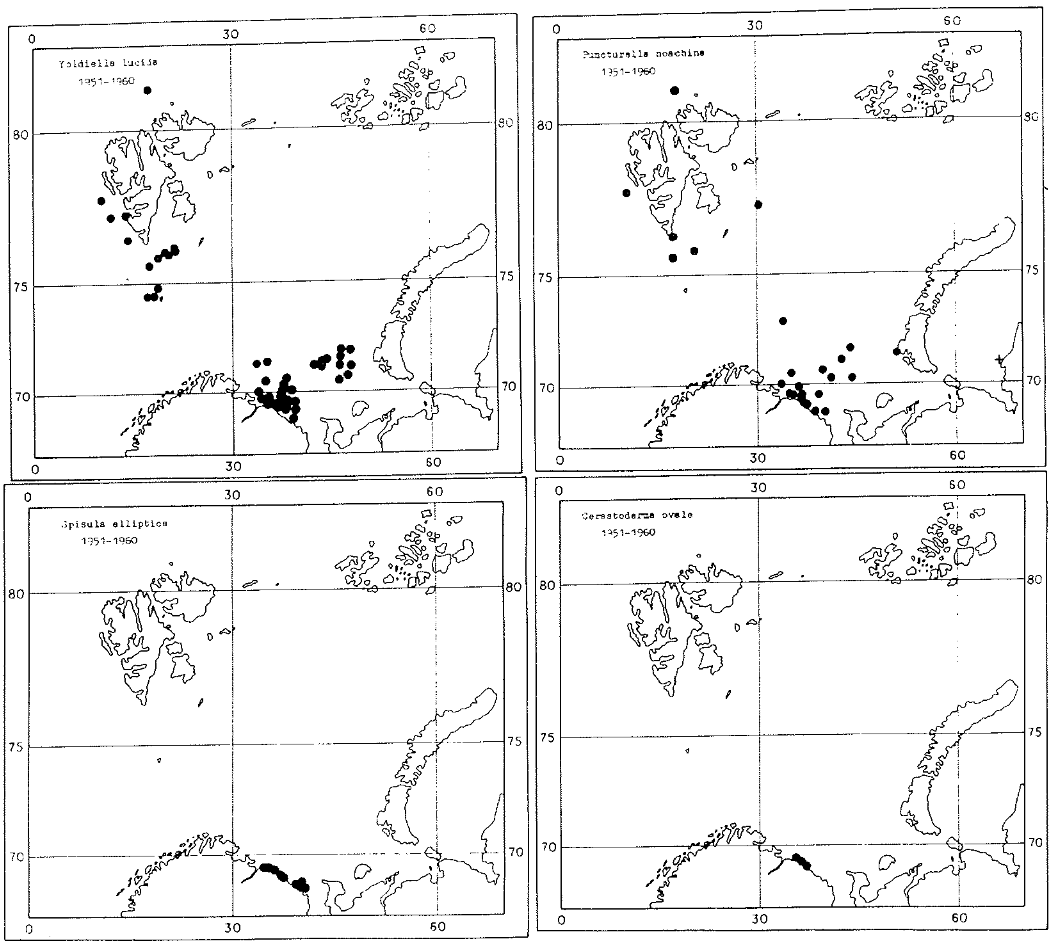


Fig. 56. Map of benthic stations sampled during 1951-1960.
Figs. 57 - 59. Distributions of *Lepeta caeca caeca, Solariella varicosa* and *Serripes groenlandicus* during 1951-1960.




Figs. 60 - 63. Distributions of *Yoldiella lucida, Spisula elliptica, Puncturella noachina* and *Cerastoderma ovale* during 1951-1960.

But, in the same period, the number and sizes of areas inhabited by subtropical-Boreal species continued to decrease in spite of the warming. The species *Limopsis minuta, Anomia ephippium, Astarte sulcata,* and *Timoclea ovata* were not noted in the coastal waters of Murman, although a large number of stations were sampled there. The distribution boundaries of a number of species in that region moved back westwards: *Chlamys sulcata* from 36° 23' to 35° 43' E (30 miles), *Acanthocardia echinata* from 38° 23' to 34° 15' E (100 miles), and *Cerastoderma (Parvicardium) ovale,* which migrated from 39 to 36° E (90 miles) as compared to the 1930's. The distribution boundary of *L. minuta* in the open sea retreated 45 miles southwards from 72° 15' to 71° 30' N. However, the littoral *Turtonia minuta* was still found in the Cheshskaya Inlet as in 1926, whereas a few others, evidently less thermophilous molluscs, continued their north- and eastward dispersals: *Poromya granulata* reached Western Spitsbergen having migrated 240 miles from the area of Bear Island (from 74 to 78° N; Fig. 64). *Tectura virginea* which occurred off the Murmansk coast up to 36° E appeared at 37° 40' (35 miles eastwards), while *Delectopecten vitreus* migrated from 33°18' up to 35°45' E (55 miles).

The warming from the 1940's until the 1960's ceased in 1962. After two transitional years, during which the temperatures were first lower and then higher than the average long-term temperature, a new cooling occurred (Fig. 1). It lasted from 1965 until 1969, with an average annual anomaly of water temerature of -0.3°. In 1966, the water temperature even fell to its lowest value in the past one hundred years (anomaly -1.0°). A new warming began in 1970, lasting until 1976.

The basic evidence concerning the 1960's was collected in 1968-1970 (Fig. 65). It was represented mostly by molluscs that appeared and spent most of their life during the previous warming, and, to a lesser extent, by individuals that appeared in the years of cooling. Accordingly, their distribution reflected primarily the conditions typical of the period of high temperatures.

The warming undoubtedly brought about the continuing retreat of Arctic Buccinidae from the eastern Murman to the north-east. Accordingly, *Buccinum hydrophanum* that previously occurred at a distance of not more than 10 miles from the coast, was found only at a distance of 50 miles; *Neptunea denselerata, B. micropoma,* and *B. nivale* which lived not closer than 120, 100, and 20 miles to the coast line, moved away from it up to 160, 140 and 150 miles. *Arctinula groenlandica* retreated to north of 71° N (Fig. 66). The frequency of occurrence of Arctic Bivalvia in coastal waters of Murman fell from 9 to 7%; in *Bathyarca glacialis* from 9 to 6%. In the south-eastern part of the sea, in the zone of the Kolguev-Pechora Current, *N. denselirata* moved 95 more miles westward, whereas *B. hydrophanum* again moved eastwards to the zone where it was found already in 1924. The minimal depth inhabited by the Pacific *Portlandia arctica* in the Novaya Zemlya Trench in the 1920's was 100 m, in the 1960's - 150 m (Fig. 67). The second representative of this group, *B. maltzani,* retreated to the most south-eastern part of the sea and migrated from depths of 13-28 m to depths of 12 -14 m.

The temperature rise led to a shift of the major area inhabited by the Boreal-Arctic *Lepeta caeca* in the central part of the sea to north of 75° N (Fig. 68) This was accompanied by a decline in the numbers, because conditions in the northern part of the Barents Sea were unfavourable for the cold-adapted bottom fauna, which is evidenced by low biomasses of benthos (Brotskaja, Zenkevitch, 1939).

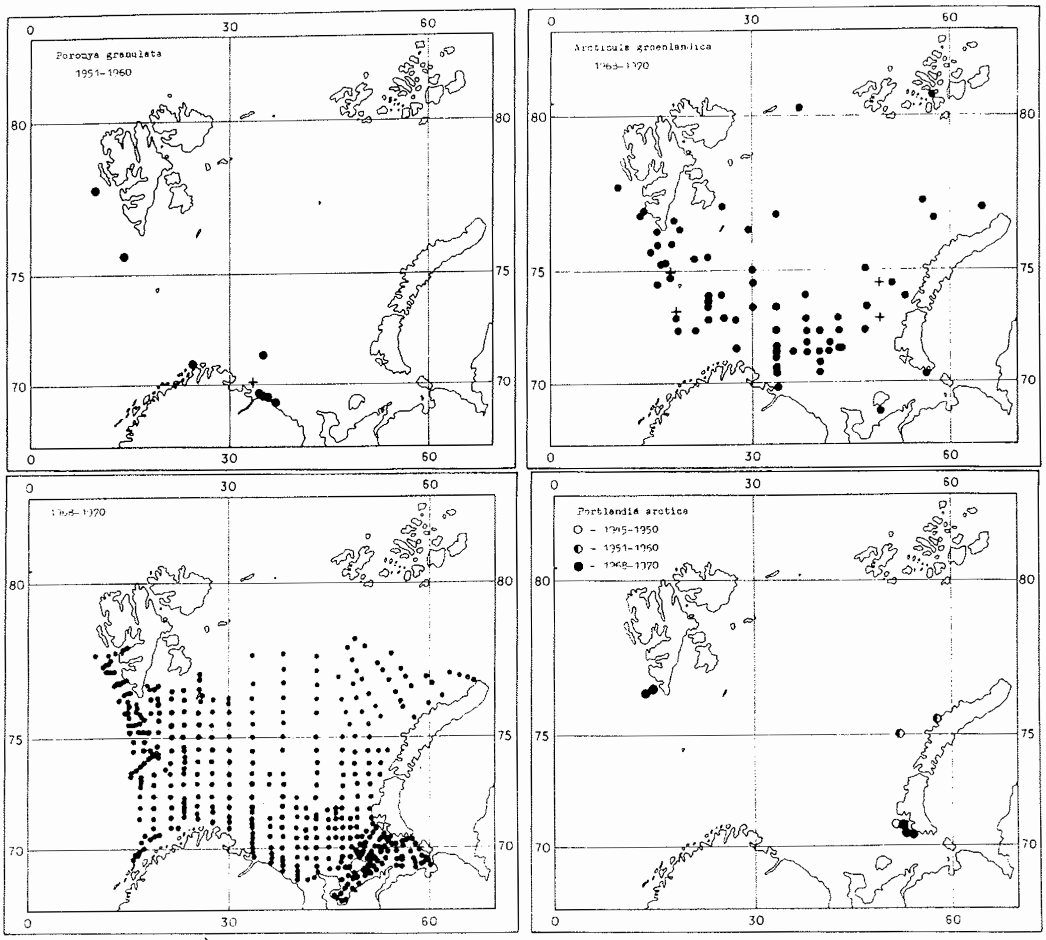
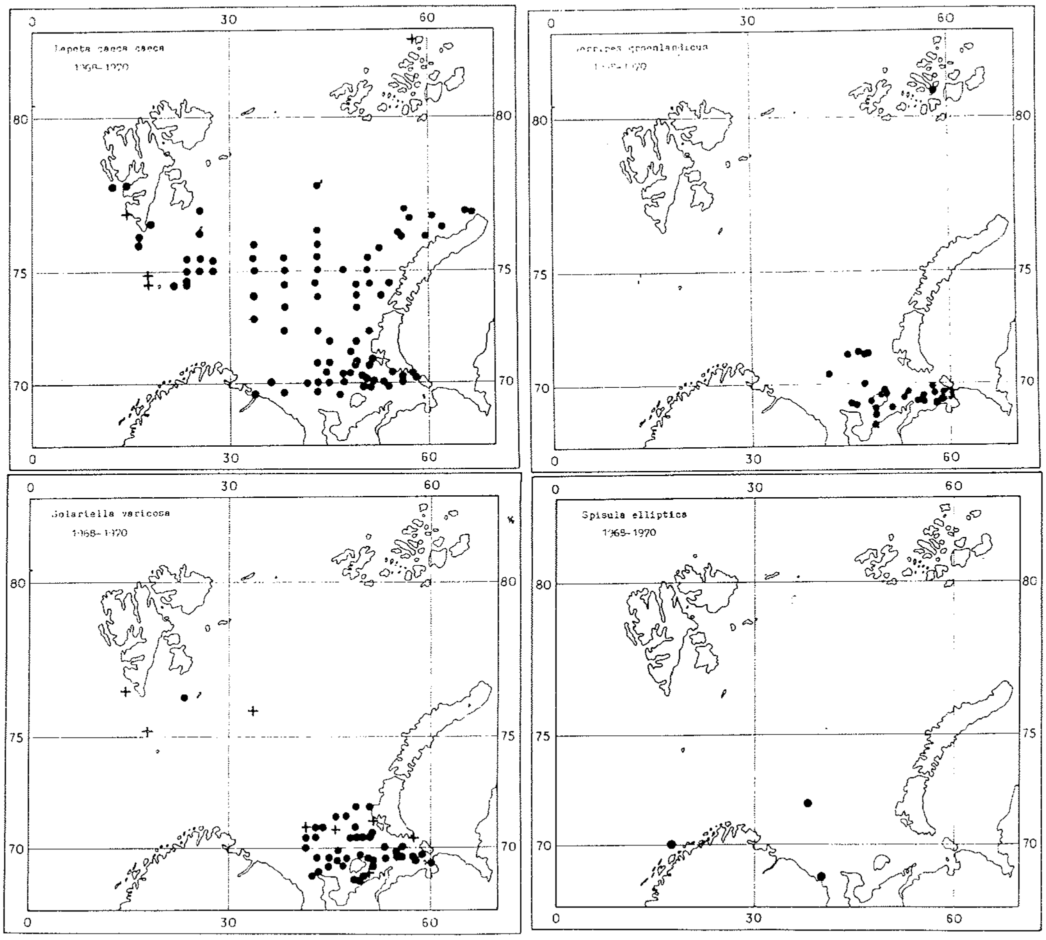



Fig. 64. Distribution of *Poromya granulata* during 1951-1960).
Fig. 65. Benthic stations sampled during 1968-1970. - Figs. 66 - 67. Distributions of *Arctinula groenlandica* and *Portlandia arctica* during 1968-1970.




Figs. 68 - 71. Distributions of *Lepeta caeca caeca, Solariella varicosa, Serripes groenlandicus* and *Spisula elliptica* during 1968-1970.

In coastal Murman waters the frequencies of occurrence of Boreal-Arctic species of Atlantic and Pacific origins also decreased. In *L. caeca* frequency fell from 17 to 2%, in the Atlantic Bivalvia - from 12 to 9 %, in the Pacific *Solariella obscura obscura* and *S. varicosa* from 3 to 1%, and in the Pacific Bivalvia from 2 to 1 %. Collections of 1971 showed that *S. obscura obscura* and *S. varicosa* were already found there almost exclusively in the inlets situated east of 38° E (Fig. 69). The process of a decline in the numbers touched also the south-eastern part of the sea, where the frequency of occurrence of *L. caeca* reduced from 40 to 18%, of *S. obscura obscura* and *S.varicosa* - from 42 to 21%, and of Pacific Bivalvia - from 12 to 5%. Moreover, a number of species in this region shifted eastwards, e.g. the Atlantic *Arctica islandica* (appearing off Kolguev Island) by 155 miles, *Panomya arctica* (in the Kolguev-Pechora Current) by 125 miles, the Pacific *Lyonsia arenosa* by 150 miles, and *Pandora glacialis* by 120-150 miles. Moreover, in the 1960's, *Serripes groenlandicus* (Fig. 70) and *Macoma torelli* were not noted in the region of the Cape Kanin Nos; and *Liocyma fluctuosa*, which occurred farther west between the Cheshskaya Inlet and the Kolguev Island in the 1920's, during that period was represented by only two samples in the most south-eastern part of the sea. *Margarites giganteus*, which previously occurred farther west, was found in the same area for the first time in 1970.

Among the Boreal species, the discovery of *Testudinalia tessellata* (at a depth of 3-10 m) and *Margarites helicinus* in the Cheshskaya Inlet seemed to a certain extent related to the warming, although, in all probability, both species also lived there earlier in smaller numbers. In the region of Bear Island and Spitsbergen the frequency of occurrence of *Margarites groenlandicus groenandicus* increased from 30 to 46%,while that of *M. costalis costalis* declined from 30 to 15%. Both these phenomena were evidently determined by the rise of temperature, which had a positive effect on the Atlantic *M. groenlandicus g.* population, but a negative impact on that of the Pacific *M. costalis c* .

Collections of 1968 in eastern Murman covered mostly depths of 150-270 m, whereas the Boreal Atlantic bivalves *Parvicardium elegantulum, Arctica islandica, Spisula elliptica* live, as a rule, at a depth of less than 100-150 m in this region. Therefore, it is not possible to judge of their distribution and abundance from the data available. It should be noted, however, that *S. elliptica* was included in the general process of migration into the open sea during that time, indicated by one specimen found at 38° E at a distance of 170 miles from eastern Murman (Fig. 71). Similarily, *Modiolus modiolus* was found in the south-eastern part of the sea, 45 miles north-west of Kolguev Island.

In the 1960's, the mollusc fauna of the Barents Sea was enriched by one more subtropical-Boreal species, namely the littoral *Patella vulgata*. Earlier, it was known only on the western coast of Mageroy Island, North Cape being its northern limit. But, in the 1960's, this species appeared off its eastern coast in the Barents Sea. It is not possible to make any conclusions about the distribution of subtropical-Boreal molluscs along the Murman coast for lack of collections, as shown with Boreal species. It is only known that *Tectura virginea* was found there in the Sidorovka Inlet at 38° 06' E in 1971, 20 miles farther east than in the previous years. *Limopsis minuta* and *Chlamys sulcata*, molluscs inhabiting the open sea, were found north of the North Cape at the latitude of Bear Island, whereas they were noted only 120-130 miles farther south in the 1930's.

The cooling in 1965-1969 was also responsible for some changes in the mollusc fauna of the Barents Sea. It allowed the Arctic *Margarites groenlandicus umbilicalis* to appear in the southern part of the sea. One individual of this species that recruited, judged by its size, in the cold waters of 1963 or 1965, was found in 1968 (see Fig. 74 , double circle). The appearance of egg-clusters of the Arctic Buccinidae found in 1968-1969 in the areas affected by normally warm currents was obviously also related to the fall of temperature; these were egg-clusters of *Buccinum hydrophanum* found 20 and 50 miles north of the North Cape, of *B. maltzani* found - between Bear Island and Spitsbergen, and of *B. nivale* - off Western Spitsbergen. The cooling may also have been responsible for the decline of the frequency of occurrence of the Boreal *M. costalis costalis* from 17 to 8% in the south-eastern part of the sea. And eventually, the cooling could have brought about the southward retreat of the subtropical-Boreal species *Poromya granulata* from the offshore waters of Western Spitsbergen from 78 to 74 N (Fig. 72).

Further on after 1969, the alternation of periods of rise and fall of temperatures con-tinued. Periods of temperature rises were noted in 1970-1976 and 1983-1984, and of lowered temperatures - in 1977-1982 and 1985-1988. A new warming began in 1989 and has continued up to the mid nineties. The distribution of molluscs after 1970 is not considered in detail. However, based on the given results from earlier periods, we can gain an impression of the population changes which may have occurred in these years.

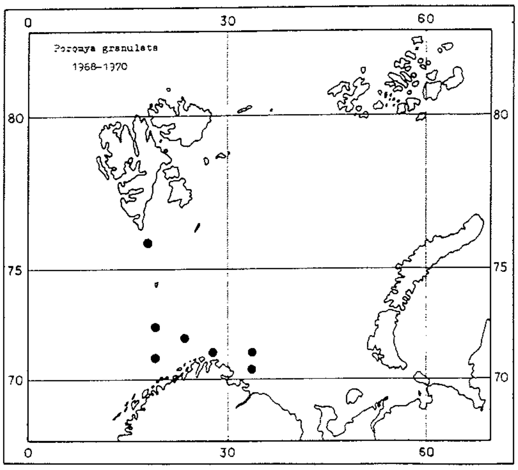



Fig.72. Distribution of *Poromya granulata 1968*-1970.

## Ways of the changes of distribution boundaries

The changes in the boundaries of distribution of individual species in the Barents Sea are primarily related to the fluctuations in their abundances. This is the major way of „dispersal" and „retreat", as it is important not only in the forms with direct embryonic development, constituting the bulk of the mollusc fauna, but also in species possessing pelagic larva. Its essence are increases or declines in the densities of some populations under certain conditions resulting in the appearance of their offspring or in their extinction in particular, especially marginal areas, which leads to shifts of their distribution boundaries. However, in most cases the resulting shifts may be perceived to be more apparent than real, since the molluscs may continue to inhabit these areas.

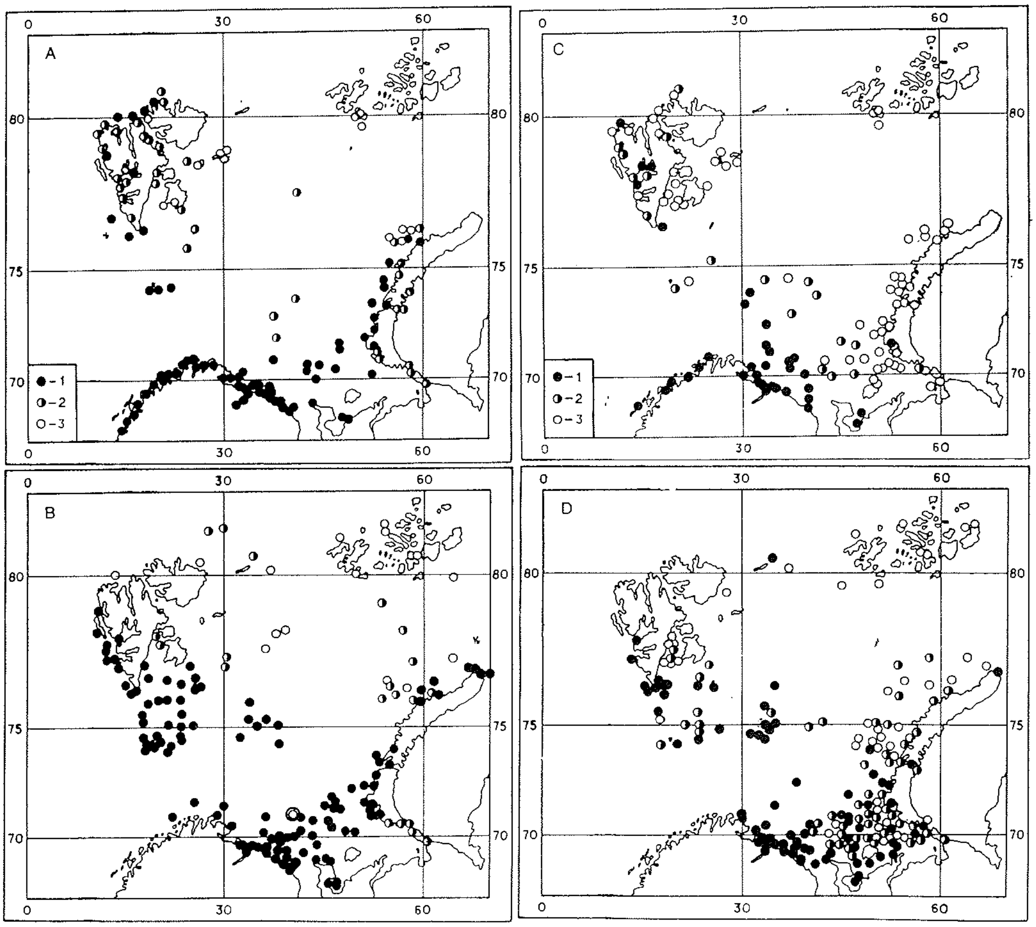
But, their abundances dropped to such an extent that they are no longer caught by the normal sampling gear. Accordingly, there was a decline in numerical abundances of Arctic and even Boreal-Arctic species in the south-western part of the sea during warming. They were not found in certain areas, although a low number of them remained there, shown by sudden outbreaks of their densities during a subsequent cooling.

The second way of changing the boundaries is the dispersal of pelagic larvae with currents to new areas, where they may form permanent settlements under favourable conditions. This way is also of great importance for the Barents Sea: For instance, among such Bivalvia whose type of reproduction is known, 40% have pelagic larvae. These are primarily subtropical-Boreal and Boreal species; but, this mode is important also for Boreal-Arctic molluscs like such abundant forms as *Ciliatocardium ciliatum, Serripes groenlandicus* and possibly *Macoma calcarea.*

The third way is the dispersal of reproductive products, larvae, and adult molluscs together with a substrate by water movements, e.g. on drifting algae, pieces of wood and other objects. It is found in a small number of species and is typical primarily of such forms as *Margarites helicinus* or *M. groenlandicus* which permanently inhabit macrophytes throughout a certain period of life and lay egg-clusters on them. This is also true for boring molluscs *Nototeredo norvegica* and *Psiloteredo megotara,* the existence of which is related to floating ships or pieces of wood.

Apart from these three ways of boundary shifts, there is in all probability one more way. Its essence is that in some species represented by what may be subspecies belonging to different biogeographic groups, the type of development towards the dominance of one or another form is determined apparently by temperature. Boreal varieties of these molluscs develop with warming, and Arctic ones with cooling. This phenomenon was traced in a study of changes in the distribution of *Margarites groenlandicus* and *M. costalis* which are represented each by two "subspecies" in the Barents Sea: the Boreal *M. groenlandicus groenlandicus* and *M. costalis costalis* and the Arctic *M. groenlandicus umbilicalis* and *M. costalis sordidus*. These forms differ well not only in their distribution and ecology, but also in their shells. Only the existence of continuous transition between them does not permit to regard them as separate taxa.

The areas of distribution of the different "subspecies" of *M. groenlandicus* and *M. costalis* are not permanent; they change with the climate and temperature regime (Figs. 73-76).
The boundaries between these Arctic and Boreal subspecies passed the southern part of the sea during the cold period of the end of the 19th and the beginning of the 20th century, and shifted 150-300 miles northwards into the northern half of the sea in the 1920's-1960's, during the "warming of the Arctic". In cold years, the Arctic *M. c. sordidus* was the main representative of these varieties in the south-eastern part of the Barents Sea; but, in the period of warming, its former area was considerably reduced and inhabited by the Boreal *M. c. costalis*. Most of the area, however, was occupied by the transitional form between these two "subspecies".




Figs. 73 - 74. Distribution of *Margarites groenlandicus* in the cold period (A, samples of 1875 - 1923 are combined) and in the warm periods (B, 1924 - 1970 combined): 1 - *M. groenl. groenlandicus*; 2 - transitional forms; 3 - *M. groenl. umbilicalis*.
Figs. 75 - 76. Distribution of *Margarites costalis* in the cold period (C, samples of 1875 - 1923 are combined) and in the warm periods (D, samples of 1924-1970 combined): 1 - *M. costalis costalis*; 2 - transitional forms; 3 - *M. costalis sordidus*.

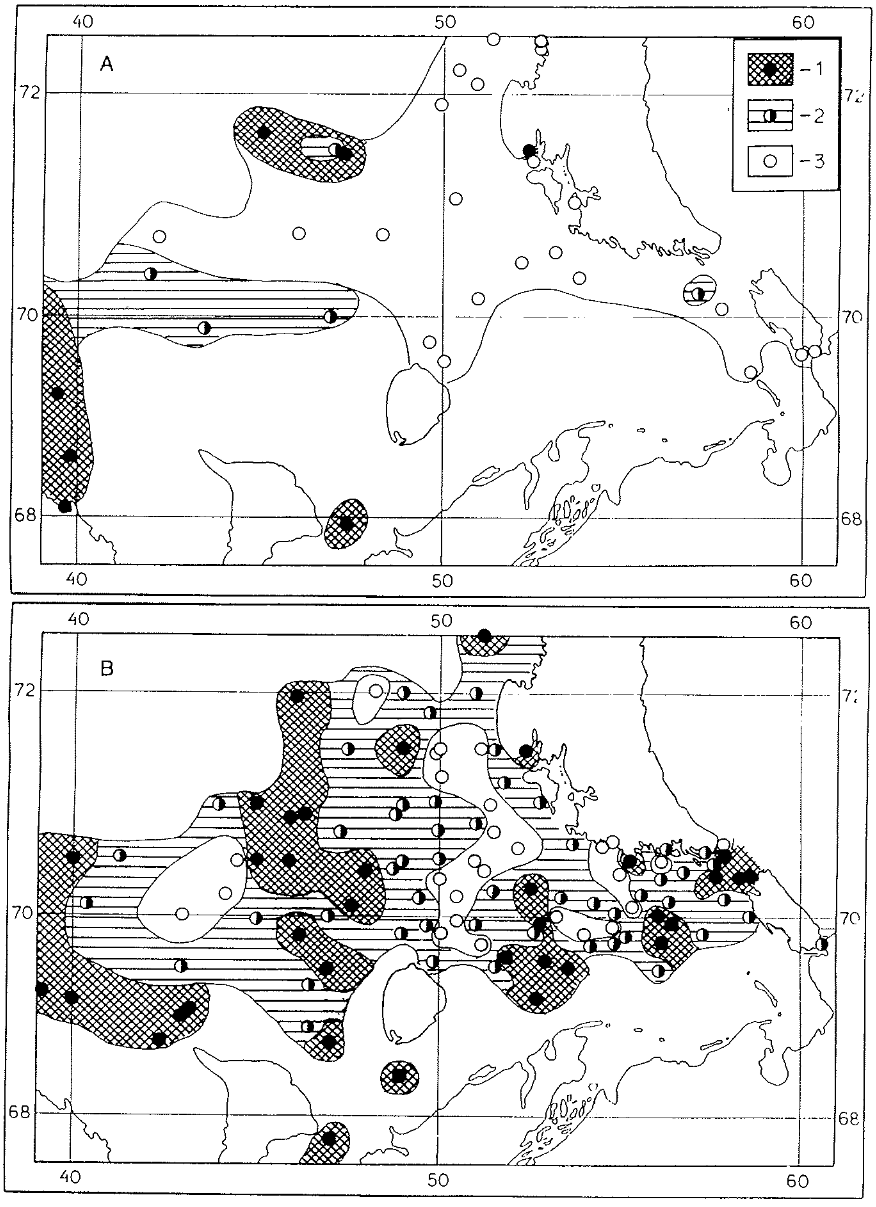



Fig. 77 - 78. Distribution of *Margarites costalis* in the south-eastern part of the Barents Sea in the cold (A, 1875 - 1923) and in the warm periods (B, 1924-1970). 1 - *M. costalis costalis*; 2 - transitional forms; 3 - *M. costalis sordidus*.

Thus, the change in the distribution areas of different varieties of these molluscs occurred by means of replacement of their Arctic by Boreal forms. Both these species have direct development without a pelagic larval phase (Thorson, 1935). Accordingly, the described phenomenon cannot be attributed to larval transfer, and a possible explanation may be a relationship between the development of these molluscs and temperature. Some of their varieties differ well in the shape of their shells in a very early phase, and it may be assumed that their development towards one or the other form is determined during embryogenesis or even in gametogenesis. This process is completed by the formation of the Boreal variety with a temperature rise and by the formation of the Arctic variety with a temperature fall.

These patterns are typical not only of these molluscs, but also of other bottom invertebrates having, what are regarded, subspecies belonging to different biogeographic groups. One may assume that future investigations will confirm this experimentally. It is very likely that these qualities may be revealed in polymorphic bivalve molluscs in the phase of subspecies formation, such as *Astarte crenata, Tridonta borealis, Nicania montagui,* and also *Thracia myopsis.*

Unlike *Margarites groenlandius* and *M. costalis,* whose subspecific differences become distinct at an age of one year and a shell height of 1.5 mm, such features become noticeable in other species at an older age. Thus, in *A. crenata* and *T. borealis* collected in the southern part of the Barents Sea in 1957-59, it is only possible to identify forms to the "subspecies" *A.c. crenata* or *A.c. crebrirostrata, T.b. borealis* or *T.b. placenta* with shell lengths of more than 10 mm. Also, in *Thracia myopsis* collections of 1860-1970, it was only possible to determine whether its individuals belonged to Arctic or Boreal-Arctic "subspecies" at shell lenghts of more than 5 mm. Hence, it is possible that these molluscs are differentiated to subspecies-like forms at a greater age than the *Margarites* species.

## Conclusions

The study of long-term changes in the mollusc fauna of the Barents Sea permitted to describe the processes related to climatic variations within 100 years from 1870 to 1970. The initial state of the fauna during 1870-1918 in the cold climatic period was considered, and changes observed in the subsequent years during the "warming of the Arctic" were traced.

The long-term changes of the fauna are periodic, as was noted already by K.M. Derjugin (1924), which is related to cyclicity of climatic fluctuations and the temperature regime and alternation of warm and cold periods. Such faunistic changes may be large-scale events, but occur within quite short periods lasting several decades or only some years.

The widest distribution and the highest abundance of Arctic species were noted in the cold period from 1870 till 1918. In Boreal-Arctic molluscs, these values attained the highest levels in the 1920's, when temperatures were near their average long-term values, while they declined during the warmer periods. The widest distribution and the highest abundance of Boreal species were related to the periods of rising and higher temperatures from the 1920's to the 1960's. During the period of the "warming of the Arctic" the mollusc fauna of the

Barents Sea was enriched by 6 new subtropical-Boreal species. A thriving of this group was registered in the 1930's. But then, in spite of the new warming, a decline in the numbers and areas of these species began. For example, 6 species of this group were lacking in samples taken after 1940. One Arctic mollusc species also disappeared in these years.

The boundaries of distribution of individual species are closely related to the spreading and position of water masses and currents. The changes of these boundaries in the Barents Sea are based primarily on fluctuations in abundance which lead to appearance and disappearance of molluscs in certian areas. The habitats (and areas) of species of Atlantic and Pacific origins were shifted in different ways.

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## Abstract

### Long-term changes in the distribution of molluscs in the Barents Sea related to the climate

Yuri I. Galkin

Long-term changes of the mollusc bottom fauna in the Barents Sea related to climatic fluctuations are examined. The data used for this purpose include collections, published material, and scientific archives. They were obtained at 7700 stations in the Barents Sea and adjacent areas of the Norwegian, Greenland, White, and Kara Seas and the Arctic Ocean between 1773 and 1982. The main conclusions have been based on the material of the 100-year period from 1870 to 1970. Approximately 20,000 samples comprising 96 species and 7 subspecies of molluscs have been analyzed; and changes in the distribution of molluscs are described. Regularities determining the character of these long-term, climate-induced changes are discussed, and a periodicity of these phenomena is confirmed. It is shown that these changes seem to be large-scale events. Ways of changes in the distribution boundaries of individual species and biogeographic groups are determined. Differences in the changes of distribution boundaries of molluscs of Atlantic and Pacific origins are revealed, and maps of species distributions in different periods are presented.

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