Berichte
zur Polar- und Meeresforschung

640
2012

Reports on Polar and Marine Research

ARCTIC MARINE BIOLOGY

A workshop celebrating two decades of cooperation between Murmansk Marine Biological Institute and Alfred Wegener Institute for Polar and Marine Research

Edited by
Gotthilf Hempel, Karin Lochte, Gennady Matishov

HELMHOLTZ | GEMEINSCHAFT

ALFRED-WEGENER-INSTITUT FÜR
POLAR- UND MEERESFORSCHUNG
in der Helmholtz-Gemeinschaft
D-27570 BREMERHAVEN
Bundesrepublik Deutschland

ISSN 1866-3192

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— Expeditionsergebnisse (inkl. Dissertationen)
— wissenschaftliche Ergebnisse der Antarktis-Stationen und anderer Forschungs-Stationen des AWI
— Berichte wissenschaftlicher Tagungen

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Germany
www.awi.de

Editor:
Dr. Horst Bornemann

Assistant editor:
Birgit Chiaventone

Die "Berichte zur Polar- und Meeresforschung" (ISSN 1866-3192) werden ab 2008 als Open-Access-Publikation herausgegeben (URL: http://epic-reports.awi.de).

Since 2008 the "Reports on Polar and Marine Research" (ISSN 1866-3192) are available as web-based open-access publications (URL: http://epic-reports.awi.de)

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Please cite or link this publication using the identifier
hdl:10013/epic.38666 or http://hdl.handle.net/10013/epic.38666
ISSN 1866-3192

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Cover photo (preceeding page): Participants during the workshop

PREFACE

On 15 February 1991 in Bremerhaven, the directors of the Murmansk Marine Biological Institute of the Kola Scientific Centre of the Russian Academy of Sciences (MMBI KSC RAS) and the Alfred Wegener Institute for Polar and Marine Research (AWI), Academician RAS Professor Gennady G. Matishov and Professor Hempel, signed a Memorandum on Cooperation between their institutions. At that time, MMBI KSC RAS had a long-time record of Arctic studies, while the AWI had entered the scene only ten years before. They both shared the interest in a multidisciplinary approach to investigate polar marine ecosystems. Both institutions wanted to maximize the benefits of the new political situation and to set up a new pattern of bi- and multilateral research in the Arctic. Today, those goals remain unchanged.

Murmansk on the eve of the Workshop 13, February 2011,
air temperature -25 C. phot. Hempel

In February 2011, exactly twenty years later, the memorandum was renewed – now in Murmansk - reflecting the joint efforts of the institutions, also involving and embracing the Southern Scientific Centre of the Russian Academy of Sciences. On that occasion, a one-d bay symposium was held on marine research in the Western Arctic, particularly in the Barents Sea. The scientists of MMBI presented the main directions of past and on-going research of their institution, while the German participants briefly described the Arctic marine research of the AWI.

Subsequently, we decided to publish the symposium presentations as a special issue of the AWI's series "Reports on Polar and Marine Research" with the aim to take stock of research and to foster networking within the scientific community of polar researchers. The contributions are summary reports focusing on the scientific work of MMBI rather than covering the international literature in full.

Professor Hempel agreed to be the scientific editor of the issue. He made extra efforts to bridge the difference in Russian and German scientific writing. Roman Mikhalyuk together with MMBI translators endeavored to put the Russian texts into English.

On behalf of both institutions, we are grateful to the contributors and editors. We hope that this source of information will serve bilateral as well as multilateral future co-operation in polar marine studies.

Prof. Karin Lochte
Director
Alfred Wegener Institute for
Polar and Marine Research

Prof. Gennady G. Matishov
Director
Murmansk Marine Biological Institute
Kola Scientific Centre
Russian Academy of Sciences

CONTENTS

WORKSHOP

“OCEANOGRAPHIC RESEARCH IN THE ARCTIC”

12 - 16 February 2011, Murmansk, Russia

Murmansk Marine Biological Institute KSC RAS (MMBI), Southern Scientific Centre of the Russian Academy of Sciences (SSC RAS)

Alfred Wegener Institute for Polar and Marine Research (AWI)

Devoted to the 20-year Anniversary of Co-operation between MMBI KSC RAS and AWI

Monday, 14 February 2011, Workshop (Mass Media Coverage)

09.30-10.00	Registration
10.00-10.30	Welcome (MMBI Prof. G. Matishov; AWI Prof. K. Lochte)
10.00-13.00	Plenary (15-20 minutes each presentation with questions-answers)
10.00-10.20	Prof. G. Hempel “*A brief history of German polar research*”.
10.20-10.40	Prof. G. Matishov *“The Arctic Research in the context of MMBI KSC RAS - AWI co-operation: problems and prospects”*
10.40-11.00	Prof. K. Lochte “*Arctic Research at the Alfred Wegener Institute”*
11.00-11.20	Prof. G. Matishov, Dr. S. Dzhenyuk, Dr. V. Denisov, Dr. Zhichkin, PhD D. Moiseev *“Climate and oceanological processes in the Arctic seas”* (Speaker: Dr. S. Dzhenyuk)
11.20-11.40	Coffee/tea-break
11.40-12.00	Dr. E. Druzhkova, Prof. P. Makarevich *“Studies of the Laptev Sea phytoplankton: past and present”* (Speaker: Dr. E. Druzhkova)
12.00-12.20	Dr. E. Shipilov “*Currents issues of geotectonics and geodynamics of the Arctic Region”* (not given at the workshop)
12.20-12.40	Dr. S. Hain *“Future opportunities and challenges for Arctic research”*
12.40-13.00	Prof. G. Tarasov *“The history of joint AWI-MMBI KSC RAS sedimentological research”*

13.00-15.00	Lunch
15.00-17.40	Plenary (Cont’d)
15.00-15.20	Dr. G. Voskoboinikov, Dr. M. Makarov *“The results of macrophytes studies at the biostations in Dal’nie Zelentsy and Helgoland”* (Speaker: Dr. M. Makarov)
15.20-15.40	Dr. Yu. Krasnov *“The main directions of research on sea birds in the northern seas of Northern Europe”*
15.40-16.00	Dr. O. Karamushko *“Species composition and structure of the ichthyofauna of the Arctic seas of Russia and Eastern Greenland”*
16.00-16.20	Coffee/tea-break
16.20-16.40	Dr. S. Berdnikov, PhD D. Moiseev *“MMBI KSC RAS, SSC RAS, and NOAA approaches to the development of oceanographic database”*
16.40-17.00	Prof. N. Lebedeva *“Avi-vector of soil biota distribution to the polar regions: prospects of international co-operation”*
17.00-17.20	PhD A. Dvoretsky, PhD V. Dvoretsky *“Crustaceans of the Barents Sea”*
17.20-17.40	Discussions
17.40	Adjourn
19.00	Dinner (all participants)

Tuesday, 15 February 2011, Meetings at MMBI KSC RAS

10.00-13.00	Visits to MMBI KSC RAS Laboratories, meetings with researchers
13.00-14.00	Lunch
14.00-15.00	Signing of the new Memorandum of Understanding
15.00-17.00	Social events (Oceanarium)
18.00	Dinner

SIX PHASES OF GERMAN POLAR RESEARCH
A SKETCH, FOCUSSING ON MARINE BIOLOGY

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A historic overview of the six phases of research

The history of German polar research can be divided into six phases, stretching over more than two centuries (Reinke-Kunze, 1992; Lange, 1996, 2001; Fleischmann, 2005; Hempel, 2002, 2007, 2008): (1) The early participation of German scientists in foreign expeditions; (2) Exploratory expeditions in Arctic and Antarctic waters between 1867 and World War I; (3) Expeditions to Greenland and West-Antarctica between the World Wars I and II; (4) Participation in foreign expeditions; (5) Independent German polar research programmes of the FRG and the GDR since the mid 1970´s; (6) Unified German polar research as a part of the international polar science network.

Phase 1: German explorers serving in foreign expeditions

Since the 18th century, German polar scientists have been working in polar research as guests or employees of foreign scientific institutions and expeditions. Reinhold Forster and his son Georg participated in the second voyage of James Cook 1772 – 1775, during which the sea ice zone of the Southern Ocean was reached, and kept this expedition on record with a scientific report. The Forsters reported on whales, seals and penguins, which soon after this voyage became a desirable target of hunting expeditions.

Even before, Russian tsars had hired Dutch and German captains to explore whether a North-East Passage along the Siberian coasts exists and could be used. They invited German scientists to participate in expeditions to Siberia and Kamchatka, just to name Johann Gmelin and Georg Steller (the extinct giant sea cow is named after him), who were “driving forces” in the Great Nordic Expedition of 1733 to 1743. The German botanist and poet Adalbert von Chamisso kept hold of the Russian expedition 1815 – 1818 with a report, which became later on famous. In those times, just as today, there was an open and “global” science community within Europe offering a free market of the best and most courageous young scientists and explorers. The King of Denmark used the persuasive power of German protestant missionaries, who were bringing the Gospel to the Inuit people in his name. They did not only study the Inuit language and culture but explored Greenland as well, followed by German geologists serving under the Danish crown.

Phase 2: National expeditions before World War I

German whalers participated in whaling off Spitsbergen and moved in the 18th century stepwise to Greenland and Labrador. Those activities did not contribute notably to the public science, as the information gathered during whaling expeditions was largely kept confidential. In the second half of the 19th century national, scientific and commercial interests in polar regions grew substantially in Germany. August Petermann, a geographically interested journalist, was perhaps the strongest promoter of German explorers. He advocated the process of filling white spots on the polar maps and giving them German names. Germany possessed never any territory in the Arctic, but it was, nevertheless, interested in using the existing and finding new shipping routes from the German ports to the Far East. In those days, there was a widespread belief in the existence of an ice-free passage across the North Pole, as shown in the Petermann´s sailing order for the German North Polar expedition in the late 1860s. He thought that sea-ice is mainly derived from land and that this, therefore, would be largely attached to the continents, leaving the central Arctic Ocean mainly open waters. A first brief exploratory cruise took place under supervision of Carl Koldewey in 1868. His vessel *Grönland* (Fig. 1) is still under sail.

Fig. 1. Meeting of the Germany´s oldest and youngest polar research vessels in the mouth of river Weser in the 1990s. The RV *Grönland* was built in 1867/68 in Skanevik, Norway and undertook under Karl Koldewey the 1st German North Polar Expedition 1868; since 1973 operated by the German Maritime Museum, Bremerhaven). The RV *Polarstern* was built 1981/82 in Kiel and Rendsburg, Germany; operated by the Alfred Wegener Institute. AWI Archive

The second expedition in 1869/70 was carried out with two vessels, *Hansa* and *Germania*. They soon became trapped by the ice masses of the East Greenland Current and had to be abandoned. Nevertheless, the scientists managed to explore the major parts of the NE coast of Greenland. In 1871, the German Karl Weyprecht and the Austrian Julius von Payer undertook a scientific cruise to Spitsbergen and Novaya Zemlya and in 1872-1874 they led together the famous Austrian Expedition, which explored the Franz Josef Land. Their observations helped Nordenskjöld on *Vega* in 1879 to sail the Northeast Passage along the Siberian coasts. Most of those activities were privately funded, as the governments in Germany and Austria were reluctant to invest in polar expeditions (Hempel, 2002).

No German explorer participated in the sportive, nationalistic race to the North Pole. Weyprecht, supported by the geophysicist Georg von Neumayer (Fig. 2), was the first one to call for „research stations rather than research expeditions“. He developed plans for an international bi-polar network of observatories and uniform observation protocols. He became “the father” of the first International Polar Year 1882/83 with two German observatories, one in northern Canada and one in South Georgia.

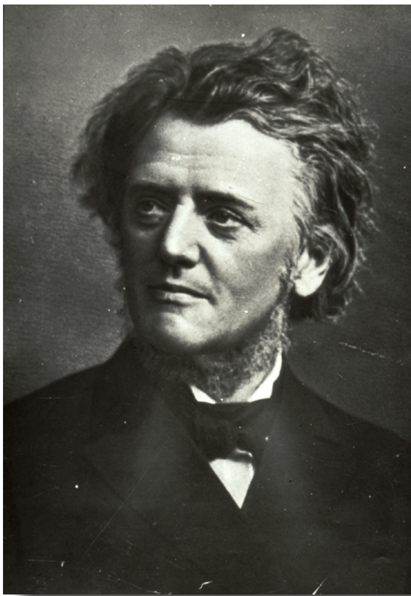

Fig. 2. Georg Balthasar von Neumayer (1826 – 1909), Hydrographer of the German Admirality was one of the strongest promoters of German polar research in the last quarter of 19th century. Archive IPOE

The German activities in the Southern Ocean and Antarctica started with a circumnavigation of the globe by *Gazelle* in 1874 – 1876 for geomagnetic, bathymetric, meteorological and navigational observations. During this expedition, an astronomical laboratory for the observation of the transit of Venus was established on Kerguelen Island. In the same year, the sealer and captain Eduard Dallmann mapped the western coasts of the Antarctic Peninsula. The staff of the Polar Year observatory on South Georgia explored and mapped the large island in some detail. Repeatedly and intensely, Georg von Neumayer, director of the German Marine Observatory in Hamburg, voted for a German Antarctic expedition to study geomagnetism and to explore Antarctica for mankind and German glory. The geophysicist and geographer Erich von Drygalski (Fig. 3) became the leader of the first German Antarctic Expedition 1901 - 1903 (v. Drygalski, 1989). He had visited West-Greenland in 1891 and overwintered there in 1892 - 1893. On the Antarctic expedition, his vessel *Gauss* (Fig. 6) was trapped by ice right off the coast, named by him “Kaiser Wilhelm II Land”, and the ship became freed only in the following summer. Nevertheless, the scientists on board carried out intensive studies, *inter alia* using tethered balloons. Half a century later, the Soviet Union created its first Antarctic Station *Mirny* in this area. The oceanographic, geophysical and biological results collected by *Gauss* in the Indian Sector of the Southern Ocean filled twenty volumes. While the German Emperor considered this expedition to be a flop, the scientific world still praises it as the first comprehensive scientific exploration of those waters. In 1910 - 1912, Wilhelm Filchner, more an explorer than a scientist in the strict sense, approached the Antarctic continent via the Weddell Sea. His vessel *Deutschland* reached the western ice-shelf, which was named later on after him, but could not land there. During the long ice drift on board the vessel, scientists gathered and brought home detailed oceanographic information on the structure of water masses of the Weddell Sea, including the detection of the Antarctic Bottom Water.

Fig. 3. Erich von Drygalski (1865 – 1949), professor of geography overwintered in Greenland and initiated and led the German Antarctic Expedition on board the *Gauss* in 1901 – 1903. Archive IPOE

Phase 3: Between the wars

The geophysicist Alfred Wegener (1900 - 1930) was the most important German Polar researcher (Fig. 4). He was indeed an outstanding scientist. Similar to Fridtjof Nansen, he was also an excellent skier with staying power and a world champion in balloon travelling as well. After his participation in the Danish Greenland Expedition 1906 – 1908 under leadership of Mylius-Erichsen he overwintered in 1912-1913 (together with the Dane Johann Peter Koch) for the first time on the inland ice of northern Greenland and traversed the ice cap at its widest and highest section. Those early expeditions convinced Wegener on the key importance of Greenland´s ice cap for the weather in Northern Europe and, hence, for the weather forecasting for shipping and future transpolar air traffic, as well as for iceberg drift. As a glaciologist, he was also keen to learn more about the thickness and dynamics of the ice shield. Soon after the 1st World War, Wegener developed plans for a major overwintering expedition combining glaciology and meteorology. Despite great financial constraints, a test expedition was carried out in 1929, followed by the main expedition in 1930 - 1931, with establishment of the overwintering observatory "Eismitte" on the top of the ice cap. Wegener died in November 1930 on the inland ice. The results of the expedition became particularly important for polar meteorology and for the understanding of the dynamics of the Greenland ice cap.

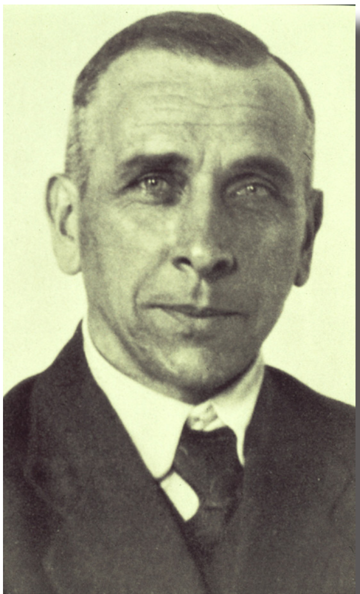

Fig. 4. Alfred Wegener (1880 – 1930), professor of geophysics and meterology, "father" of the continental drift theory (1914) studied the Greenland ice cap and its climate and meteorology at three expeditions between 1906 and 1930. Archive AWI

For the Antarctic, only two German activities are worth mentioning in the decades after the World War I: The „Meteor“ Expedition 1925-27, which covered the entire South Atlantic including the ice-free parts of the Atlantic sector of the Southern Ocean and provided the first comprehensive picture of its topography, water masses, current systems and biota. Right before the World War II, the Germany´s interest in Antarctic whaling resulted in Alfred Ritscher´s “Schwabenland”-expedition with marine biological studies and with aerial photogrammetry of the Queen Maud Land.

Phase 4, 1950 -1975: a slow recovery, partly again as guests of foreign expeditions

In the two decades after the World War II, polar research in the Arctic consisted only of minor activities in both parts of Germany. West German glaciologists and cartographers were engaged in two glaciological expeditions (EGIG I and II) studying in Wegener´s footsteps the Greenland ice cap in 1959 and 1967-1968. The EGIG (Expedition Glaciologique Internationale au Groenland) project was scientifically very successful and effective. It was the first joint undertaking of geoscientists of Denmark and their colleagues from the alpine countries Austria, Federal Republic of Germany (FRG), Switzerland and France (Fleischmann, 2005).

Because of its special legal status, Spitsbergen was freely visited both by teams from East and West Germany. Cartographers of the German Democratic Republic (GDR) under Wolfgang Pillewitzer worked in the Kongsfjorden area on Spitsbergen in 1962 and 1964-1965. Their hut still exists near Ny Ålesund. Julius Büdel, a West-German geographer, and his team studied periglacial phenomena on the Barents Island of the Svalbard archipelago in course of three expeditions between 1959 and 1967. Since those days, the islands became an eldorado for international cooperation with long-term joint programmes. Ny Ålesund is now a flourishing international research village including the German Koldewey station, which was merged with the French station into the French/German *AWIPEV* Arctic station in 2004.

The major German contribution to the International Geophysical Year (IGY) 1958/59 consisted of the inauguration of the International Polar Front Survey off East Greenland. This multi-ship survey of the International Council for the Exploration of the Sea (ICES) was coordinated by Günter Dietrich who afterwards edited the comprehensive data atlas. The only two ocean-going West-German research vessels of those days, *Gauss* and *Anton Dohrn,* participated with two long cruises each. Since then, the stratification and dynamics of water masses, the outflow of arctic water through the Fram Strait, its fate in the Greenland Sea and the formation of Atlantic deep water are key topics of German oceanography. The variability in water mass distribution was of great importance to the German fishery with respect to their traditional trawling grounds in the Nordic Seas. Particularly in the 1960s and 1970s, West-German research vessels were often active in the waters off Greenland, Iceland, Norway and Spitsbergen as long as they were more or less ice free. (Only since 1983 Germany operates the icebreaking research vessel *Polarstern.)*

The recovery of German Antarctic research took rather a long time, particularly in Western Germany. Only a few West-German scientists were guests in Antarctic activities, particularly of the US, in the course of the IGY 1958/59 and thereafter. German biologists took part in the whaling expeditions of the MS *Olympic Challenger* during the first half of the 1950s. The Soviet Academy invited its sister academy in the GDR to participate in Soviet Antarctic Expeditions already in 1959. This led to 35 years of uninterrupted collaboration in terrestrial and atmospheric geophysics and related fields of Antarctic research (Lange, 1996). For scientists of the GDR, it was a unique opportunity to work abroad and Soviet scientists welcomed the specific skills and instrumentation of their German colleagues. The Soviet-German cooperation started with field work on glaciers in Central Asia in 1958. In the following year two German meteorologists participated in the 5th Soviet Antarctic Expedition (SAE) and overwintered at the base *Mirny*. Since then every year a growing team of German meteorologists and geophysicists became member of the SAEs and stayed first primarily at *Mirny*, later also at *Molodoshnaya* station and occasionally at *Wostok* station in the centre of Antarctica. They participated in routine programmes of conventional and satellite meteorology, ionosphere observations, glaciology and geophysics of solid earth. The development of new instruments for geodesy and meteorology in cooperation with the high- tech industry of the GDR, like Carl Zeiss optics, became part of the programme too. In the 1970s German geologists studied the Prince Charles Mountains and the Shackleton Range using the facilities of the Soviet station *Drushnaya* on the Filchner Ice Shelf. Step by step and in full agreement with their Soviet partners, the German programme became more self-reliant. In 1974 the GDR became ordinary member of the Antarctic Treaty, long before the FRG.

Phase 5, 1975 – 1990: Fifteen years of polar research activities in divided Germany

In the mid 1970s political, scientific and economic interests in Antarctic research increased considerably in both parts of Germany. Scientifically, the polar regions became important for understanding and modelling of global circulation in the atmosphere and hydrosphere and in the study of plate tectonics. While the Arctic was largely closed to international cooperation, the Southern Ocean and Antarctica were accessible to all researchers. The political reasons for strengthening polar research were rather different in Western and Eastern Germany. In the GDR, there was a drive for international recognition competing with the FRG and combating the political isolation by the Western countries. In Western Germany, the warnings of the Club of Rome and the restrictions by the new United Nations Law of the Sea brought the potential resources of the Southern Ocean and Antarctica into focus. Some politicians felt that the FRG could "miss the train" in the same way as it happened at the conferences negotiating the Law of the Sea. Therefore, Western Germany aimed to obtain a consultative status under the Antarctic Treaty.

Development in Western Germany (Fleischmann, 2005)

In 1975-1976 and in 1977-1978 joint exploratory expeditions of the RV *Walther Herwig* and a factory trawler targeted demersal fish and krill in the Scotia and Weddell Seas. Geological and geophysical surveys in the Weddell Sea and in the North Victoria Land followed soon. In 1978 the West German government decided to apply for a consultative status at the Antarctic Treaty and for a membership in the Scientific Committee on Antarctic Research (SCAR), followed by the GDR in 1981. The Treaty, as well as the SCAR, stipulated a continuous and substantial scientific programme in Antarctica. For more than a hundred years, German polar research had suffered from the lack of centralised institutional support. After each expedition, the research vessel was sold and researchers went back to their various home institutions. The working up of the results lasted for decades and was rarely completed. The Antarctic research programme of 1979 included the establishment of a polar research institute (the Alfred Wegener Institute for Polar Research, see below), of an Antarctic overwintering research station and of an icebreaking research and supply vessel. The requirement of the Antarctic Treaty for obtaining a consultative status was commonly interpreted as a demand for running an overwintering research station in Antarctica. Thus, installing of an Antarctic base was the first step to be undertaken. The intention was to avoid building just one more, additional station in the „banana belt“ along the Antarctic Peninsula. Therefore, following an exploratory expedition to find a suitable location, the *Georg von Neumayer Station* (Fig. 5) was built in 1980/81 on the Ekström Ice Shelf of the eastern Weddell Sea. Scientific emphasis of the overwintering team of nine persons was on year-round atmospheric and geophysical observations. In summer, the station provided the logistic base for field work of glaciologists, geologists and biologists.

Fig. 5. The first *Georg von Neumayer-Station*, built underground on Ekström Ice Shelf near Atka-Bucht in 1981 for an overwintering team of 9 scientists and technicians. Archive AWI

In the 1970s, most of "the old boys" in Antarctic research and SCAR were geophysicists of the IGY 1958-1959. Just to be different, ocean research, including marine biology as a promising niche, became the dominating part of the West German polar programme. Right from the onset, the programme was truly bi-polar, although access to the Arctic waters was very narrowly limited in those days. The ice-breaking research and supply vessel *Polarstern* (Fig. 6), launched in 1982, was designed for year-round studies in ice covered waters. The vessel provides facilities for all kinds of marine and atmospheric studies and ample space for scientists of many countries and disciplines (Fütterer and Fahrbach, 2008).

Fig. 6. The ice-breaking RV *Polarstern* is since 1983 the backbone of German marine polar research and an important platform for international cooperation in Arctic and Antarctic waters. Archive AWI

By means of the *Polarstern,* the FRG was able to launch an ambitious multi-disciplinary programme in polar marine science. Every year since 1983, the Weddell Sea and other areas of the seasonally or permanently ice covered southern half of the Southern Ocean were visited. The major emphasis was placed on glaciology and biology of sea ice and its interaction with the atmosphere and the water column below. Basic information was gathered on the hitherto little known microbiology, plankton and benthos of those regions (reviews in Hempel and Hempel, 1995, 2009). The geological history was unveiled by the analyses of sediment cores and seismic profiles. All cruises of *Polarstern* were open to scientific researchers of many nations, particularly during the European Polarstern Studies (Hempel, 1993) and the Ecological studies of the Antarctic Sea Ice Zone (Arntz and Clarke, 2002).

The political and economic reasoning in the polar research policy of the FRG of the 1980s was leading away from investigating potential living and mineral resources towards global climate change and its interaction with polar ecosystems.

During the so-called "Cold War" period, West-German scientists did not get access to the parts of the Arctic Ocean under the control of the Soviet Union. Nevertheless, already right after her Antarctic maiden cruise, the *Polarstern* went to the Greenland Sea and to the Fram Strait. The international Marginal Ice Zone Experiment – MIZEX was the start to a series of regular Arctic cruises with numerous foreign participants. Sampling stations were established in the Fram Strait for year-round monitoring of the exchange of water masses and biota between the Arctic and North-Atlantic Oceans.

Until 1980, only few polar scientists were engaged by various federal institutes for applied research and at some universities in West Germany. In 1980 the Alfred Wegener Institute for Polar Research (the AWI, since 1986 called "The Alfred Wegener Institute for Polar and Marine Research") (Fig. 7) was established to run the permanent base / overwintering station in the Antarctic and to carry out basic research in various fields of polar sciences. Originally, the institute was planned for about 100 persons, now it has a staff of about 1000 employees (see details on the AWI and its activities, particularly in the Arctic, given in the contribution by Lochte and Hain in this volume).

Fig 7. The original main building of the Alfred Wegener Institute in Bremerhaven was inaugurated in 1986. In the course of enlargement of the AWI several additional buildings were constructed or reconstructed in various locations. Archive AWI

Polar scientists of other institutes, particularly in Kiel, benefited from the logistic and technical infrastructure of the AWI. Although the AWI quickly became the national centre of polar research, most of the existing groups in other institutions remained active and were supported financially by the federal government and logistically by the AWI. At Kiel University, an Institute for Polar Ecology (IPOE) was founded in 1982 that became an academic "nursery ground" for a new generation of polar biologists. Many of the former Ph.D. students of IPOE are now staff members of the AWI or went abroad to work at polar research institutes world-wide. In 1987, the GEOMAR research centre for marine geosciences was established in Kiel, and its director Jörn Thiede formed a strong group for geological studies in polar waters, particularly in the Arctic.

Development in Eastern Germany (Lange, 1996, 2001)

The growing interest of the GDR in Antarctica in the mid 1970s is reflected in the establishment of the *Georg Forster Station* near to the Soviet base *Novolasarevskaya* at the Schirmacher Oasis on the Princess Astrid Coast in Queen Maud Land (East Antarctica). The ionospheric observations carried out there demonstrated the development of the Antarctic ozone hole. Atmospheric chemistry on tropospheric aerosols and stratospheric trace gases became important contributions to the debates on global climate change. Multi-disciplinary surveys produced a comprehensive description of the Schirmacher Oasis and its surrounding glaciers and mountains, which had earlier been explored by the *Schwabenland* expedition. The *Georg Forster Station* (Fig. 8) was the first German overwintering base in Antarctica, five years before the West-German *Georg von Neumayer Station* was launched. At the same time, the East-German geologists used the Soviet station *Drushnaja* and biologists were guests at the Soviet station *Bellingshausen* on King George Island for studies on birds, seals and marine shallow water benthos. In the 1980s participation in SCAR workshops opened windows to the West. The growing research activities and international contacts strengthened the role of the Polar Secretariat in Potsdam, but for economic reasons it did not result in formation of a national polar institute of the GDR. The German „polarniki" still remained spread over a number of institutes mainly of the Academy of Science of the GDR and at the Meteorological Service of the GDR.

Fig. 8. The *Georg Forster Station* of the GDR built in 1976 was logistically to the Soviet station *Novolarasevskaya* at the Dronning Maud Land. Its year-round ionospheric observation greatly contributed to the detection of the "ozone-hole". The station served also as base for summer campaigns in the Schirmacher Oasis and its mountaineous surroundings. Photo Gernandt

Phase 6: The re-unified and internationally integrated German polar research since 1990

The emphasis of the GDR on terrestrial projects, mostly geophysics in their broadest sense, meant a substantial complement to the marine emphasis of polar research in Western Germany. Therefore the polar activities of the GDR and the FRG merged rather well. Most of the polar researchers of the GDR joined the AWI in 1991. A research department of the AWI was established in Potsdam focussing on periglacial research and on atmospheric physics and chemistry. Geologists found a new home in the Federal Institute for Geosciences and Natural Resources in Hannover. For financial and logistic reasons, the AWI had to abandon and dismantle the *Georg Forster Station*. The results of the multi-disciplinary study of the Schirmacher Oasis were published in two volumes (Borman and Fritzsche, 1995). The ionospheric research programme and some other activities of the *Forster* station are being continued at the *Neumayer* station.

Further Antarctic stations were established for temporary or only summer use on the Filchner Ice Shelf (for geodesy, glaciology), King George Island (shallow water biology) and in the inner Queen Maud Land (deep ice cores). Helicopters based onboard *Polarstern* are widely used in polar areas and the AWI operates two research aircrafts for atmospheric, glaciological and geodetic observations.

Russian-German cooperation in the Arctic since 1990

In 1987, President Gorbatschov offered in his well-known Murmansk speech Soviet cooperation to the Nordic neighbours. Immediately, both the AWI and the GEOMAR endeavoured to develop direct bilateral links to some Russian institutes, first of all to the Arctic and Antarctic Research Institute (AARI), to the Zoological Institute of the RAS, to the University in Leningrad (St. Petersburg), as well as to the Marine Biological Institute in Murmansk (MMBI) and the Polar Fisheries Institute (PINRO). In August 1990, the International Arctic Science Committee (IASC) was established with the Soviet Union as a strong partner. Soviet scientists visited the German institutes in Bremerhaven and Kiel and participated in Arctic cruises of the *Polarstern*. At the same time, the Russian partners helped their German colleagues to obtain permission to enter Siberian waters. Such political blessing was achieved by including marine and polar research into the governmental agreement on scientific and technical cooperation between the Russian Federation and Germany. Finally, in 1993 access to the Russian EEZ in the eastern Laptev Sea was admitted to the RV *Polarstern*. That was a milestone in the long and successful series of joint activities between Russian and German scientists. The projects included work on board the RV *Polarstern* and on board Russian vessels, sometimes supported by nuclear icebreakers. In terms of marine polar sciences, AWI with its *Polarstern* focussed on studies in offshore waters, often ice covered, while GEOMAR was particularly active in the shallow shelf seas. IPOE participated in both fields of research and had also a major programme in the polynyas off Greenland. RV Polarstern visited the North Pole three times and circumnavigated the Arctic Ocean through the North-West and the North-East passage in summer 2008.

The Otto Schmidt Laboratory (OSL) for Polar and Marine Research, situated at the AARI in St. Petersburg, is an impressive permanent joint Russian-German institution for polar sedimentology, biology and geochemistry. With the financial support of the Russian Ministry of Education and Science and the German Ministry of Education and Research, it operates since 2000 and serves as the central interface and base for cooperative polar research activities of both countries. The main goal of the well-equipped modern laboratory is the training of young scientists by Russian and German professors and advisors. Up to now, master students, graduated research assistants, and postdoctoral fellows from 280 research units of the Russian Federation have participated in the fellowship programmes of OSL. The AARI, AWI and IfM-GEOMAR are jointly executing the programme of OSL.

The Master Program in Applied Polar and Marine Sciences (POMOR) is an interesting new approach in bi-national training of students in polar environmental sciences. It is carried out jointly by the Saint Petersburg State University and various universities in northern Germany as well as AWI, IfM-GEOMAR and IOW (Institute for Baltic Sea Research Warnemünde). The Otto Schmidt Laboratory is participating in POMOR too and facilitates hands-on training in field work research. Over the past nine years 62 students have already graduated from POMOR.

”Russian-German cooperation in the Arctic environmental research” is the title of a recent publication by Polyakova et al. (2011). The work in the joint Laptev Sea Project and other activities of Russian and German teams are further reflected in several books in English or Russian language (e.g. Kassens et al., 1999, Kassens et al., 2009). The joint limno-geological and permafrost studies for the analysis of the paleoclimate in Siberia have a long tradition, including contributions by GDR scientists. The Potsdam branch of the AWI coordinates the various German activities in those fields. Since 1998, the German teams found a home base at the *Samoylov Station* in the Lena Delta.

Trends in polar marine biology in Germany

The present volume is devoted to recent biological work by the MMBI in the Barents Sea and adjacent waters. Therefore, the following very sketchy account is confined to the main lines of polar marine biology research in Germany. The literature quoted is just an arbitrary sample of relevant recent publications. For more details on German activities in polar marine biology, see the collection of review articles in Hempel and Hempel (1996, 2009) and Hempel et al. (2006). Plans for future activities in this field are also summarized in the article by Lochte and Hain in this volume.

German marine biology before World War I (phases 1 and 2) consisted mainly of studies in taxonomy, morphology and biogeography of marine organisms. The early description of diatoms in sea ice by Ehrenberg and Hooker dates back to the 1840s (Werner et al., 2009). The work by Victor Hensen and Karl Chun, culminating in the plankton expedition of the RV *National* (1889) and the deep sea expedition of *Valdivia* (1898/99), determined the architecture, lines and direction of development of the German marine biology for decades. Hensen took plankton samples at 100 stations between Greenland and the mouth of the Amazone, mapping the productivity of the Atlantic Ocean. Hans Lohmann and his students analysed the plankton samples of von Drygalski´s Antarctic expedition 1901 – 1903. They found the first nanoplankton in the houses of appendicularians. However, virtually no benthos was collected by Drygalski´s team in the Southern Ocean.

Between the wars (phase 3) in the course of works on board *Meteor* in the southernmost transatlantic section, scientists obtained polar plankton samples, which added to the overall picture of plankton distribution in the southern Atlantic drawn by Ernst Hentschel in conjunction with nutrient data. At the *Schwabenland* expedition in 1938/39 to the Lazarev Sea, studies in phytoplankton and krill were carried out, but relatively little was published during the war and post-war years. The same holds for the studies during pre-war and post-war whaling expeditions.

In the 1930s German fishery biologists worked in the Barents Sea. During the first three decades after the World War II (phase 4) in the arctic and subarctic waters off Greenland, Iceland and northern Norway, biological and oceanographic research was directly or indirectly related to fish and fisheries. Studies in primary productivity, phytoplankton biomass and nutrient budgets were high on the agenda of biological oceanographers in general. They slowly moved to polar waters of both hemispheres. For the Antarctic, estimates of krill production and potential harvests of krill were based on figures of primary production and on the guessed consumption of krill by whales prior to the onset of Antarctic whaling (Hempel, 1972).

As mentioned above, only a few West-German marine biologists participated in the Antarctic whaling expeditions in the early 1950s and later on in cruises of the RV *Eltanin* for primary productivity studies. Finally, in 1975, Southern Ocean ecology came into focus. The West-German exploratory fishing cruises, mentioned above, were used for a wide spectrum of biological and oceanographic research. Scientists of the federal Institute for Sea Fisheries under Sahrhage and students of the Institute for Marine Science in Kiel participated in studies of fish, krill, ichthyo- and other zooplankton, as well as oceanographic surveys. Target areas were the Scotia Sea, Bransfield Strait and the northern Weddell Sea. In addition to a large commercial mid-water trawl, the Rectangular Midwater Trawl (RMT) for the investigation of distribution, biomass, size composition and fecundity of krill was employed (Siegel, 1986). Behaviour, swimming and feeding of krill were also the topics of in-situ observations and experiments by Kils (1981). Extensive bottom trawling provided a comprehensive picture of the demersal fish fauna and of the size and age structure of the hitherto virgin stocks, which soon became (over) exploited by distant water fishing fleets, particularly of the USSR (Kock, 1992).

The widespread commercial interest in Antarctic krill and fish prompted El-Sayed and others in the US to develop plans for a large-scale census of the Antarctic marine resources. The BIOMASS Program (Biological Investigations Of Marine Antarctic Systems and Stocks) became the driver for a decade of concerted research efforts in pure and applied marine biology on a circum-Antarctic scale (Sahrhage, 1988, El-Sayed, 1994). The First and Second International BIOMASS Experiments in 1980-1981 (FIBEX) and 1983-1985 (SIBEX) were well-designed multi-ship surveys. The FRG was a strong participant in BIOMASS with cruises of the RV *Walther Herwig* and the RV *Meteor*. There was also a joint Anglo-German expedition on board the RV *John Biscoe* to the Scotia Sea in 1982. The large-scale programmes of those days attracted attracted - at least temporarily - several established German biological oceanographers and marine biologists and created a new generation of marine biologists in Germany.

The maiden voyage of the RV *Polarstern* in 1983 to the eastern Weddell Sea and adjacent waters, and subsequently to the Greenland Sea, meant a breakthrough in the true sense of the word. It opened the ice covered parts of the Southern Ocean and the Arctic Ocean to studies of life in the sea ice, the water layers and the sea bottom beneath, as well as in the polynyas of the Arctic and Antarctic. Since that time, every year the German national vessel visited Antarctic and Arctic waters to carry out research works in various disciplines including marine biology. Meanwhile all seasons have been covered, including the winter, with heavy ice cover and almost permanent darkness. Year-round collection of data and samples by moored instruments provided further information on the annual cycles of primary production and sedimentation. They were the forerunners of the large-scale and complex observation array *"Hausgarten"*, described by Lochte and Hain (this volume) in the Fram Strait.

The focal area in the Southern Ocean was the Weddell Sea. The Lazarev, Bellingshausen and Scotia Seas with the Bransfield Strait were also visited. In a number of zoogeographical and ecological studies the distribution and composition of macrozoobenthos, zoo- and phytoplankton and fish were described (e.g. Voß, 1988; Boysen-Ennen et al., 1991; Hubold, 1992), certain benthic groups attracted the attention of leading taxonomists and their students (Wägele and Sieg, 1994). The different strategies of copepods to cope with the drastic seasonality of food supply in polar waters became the theme for extensive field work in all seasons, as well as in experimental studies and in the analysis of reproduction cycles and energy stores in terms of various lipids (e.g. Bathmann et al., 1993; Schnack-Schiel and Hagen, 1994; Mumm et al., 1998; Hagen and Auel, 2001). Other ecophysiological studies were related to the adaptation of fish and invertebrates to temperatures near freezing (e.g. Pörtner, 2006).

The carbon cycle and biological pump in relation to primary production was studied by various groups of biogeochemists, phytoplanktologists, microbiologists and biogeochemists, as summarized early in various articles by Bathmann, Kirst, Lochte, Nöthig, Scharek, Smetacek, Tilzer and others in Hempel and Hempel, (1995). Later on, those studies yielded in large-scale iron fertilization experiments and a comprehensive by-programme in plankton ecology to investigate the role of iron in plankton productivity (e.g. Bathmann, 2005, Smetacek and Naqvi, 2008). Those experiments were designed to test the hypothesis of iron-limitation of phytoplankton production in the Southern Ocean. Acidification of polar surface waters and its effect on marine organisms is the topic of ongoing experiments in the laboratory and in mesocosms suspended in fjords at Svalbard. The concern about the potential impact of increased ultraviolet radiation caused by the ozone-hole triggered research in the UV-B effects on macroalgae, phyto- and zooplankton.

The Greenland Sea and the Fram Strait remained the key areas of the Arctic marine biology. However, the launching of RV *Polarstern* and the political opening of the Arctic Ocean meant a geographical expansion of German research activities into most parts of the Arctic Ocean with emphasis on the Western Arctic and the Russian shelf seas, particularly on the Laptev Sea. A huge amount of research work of German marine biologists was carried out on Russian, Canadian and US polar research vessels too.

The marine biological work encompassed the full spectrum from the description of fauna and flora of plankton and benthos to the synecology within the communities, and to the autecology, eco-physiology and genetics of key species. Of special scientific interest were vertical and horizontal distribution of zooplankton in relation to stratification of water masses and the structure of the current systems, particularly the inflow of Atlantic water through the Fram Strait and the Barents Sea. The sampling programmes and subsequent community analyses revealed gradients in composition and abundance of plankton and benthos, primarily echinoderms and demersal fish, from the shallow shelf to the continental slope and to the deep sea basins, as well as from the Fram Strait and Barents Sea into the Arctic Ocean proper (e.g. Hirche and Kosobokova, 2007; Piepenburg, 2005). Detailed analyses of seasonal variations in plankton were coupled with biochemical work on lipid composition and anti-freeze properties in plankton and fish (e.g. Hagen and Auel, 2001).

The *Koldewey Station* (Fig. 9) in Ny-Ålesund, Svalbard, provided opportunities for year-round field observations in the biota of Kongsfjorden and for sophisticated experiments on the reaction of polar marine organisms to various environmental stressors. The *Dallmann Laboratory* at the *Jubany Station* on King George Island had a similar function for work on Antarctic littoral fauna and macroalgae (Wiencke et al., 2005). The Northeast Water Polynya off NE-Greenland was a target area for joint physical, chemical and biological studies in 1991 – 1992. Its high productivity supports a substantial variety of pelagic and benthic organisms from fish to walruses as well as an Inuit hunting and fishing community.

The benthos work in both hemispheres was greatly advanced by the steady development of *in-situ* photo- and video cameras, mounted on remote operated vehicles (ROVs) and other platforms. They made it possible to systematically study Antarctic benthic diversity (Brey, 1994). Of special interests were the scouring effects of icebergs and the re-colonisation of the disturbed sea bed (Gutt et al., 1996). Along similar lines are the recent surveys of the bottom fauna of areas, which had been covered by floating ice shelf until the break-up of large parts of the Larsen Ice Shelf in 1995 and 2002. The evolution of the bottom faunas in the Arctic and Antarctic is still rather little-known. Arntz and his German and South-American co-workers made an extra effort in the comparison of the benthic fauna of the Magellan region with the Scotian Arc fauna (Arntz et al., 2005), while Brandt initiated a still ongoing major project for studies in Antarctic deep sea benthos as part of the Census of Marine Life (Brandt and Hilbig, 2004; Brandt et al., 2009).

Fig. 9. The Blue House of *Koldewey Station* in Ny-Alesund at Kongsfjorden; Spitsbergen is since 1991 the centre of German geophysical and chemical studies in the high Arctic atmosphere. Archive AWI

Polar seals and birds were not very high on the research agenda in Germany, nevertheless, some studies on diving / swimming performance and foraging of Antarctic seals, penguins and skuas were reported by Bannasch, Culik, Peter and Plötz in Hempel and Hempel (1995) and continued by the same authors and others. The old controversy of bottom- up or top-down control of ecosystem productivity became a new push by Smetacek´s (2008) “whale hypothesis”. He postulates that the depletion of whales and other top predators including fish are responsible for the decline in krill: less whales means less faeces as fertilizer for algal growth and, hence, less phytoplankton as food for krill and copepods.

Studies of the structure of Arctic versus Antarctic sea ice provided the background for an extensive programme of year-round investigations in the distribution and life history of ice-algae and in the broad spectrum of sympagig micro-, meio- and macrofauna within and underneath the ice and at the infiltration layer between the ice and the snow cover (e.g. Spindler, 1990; Kiko et al., 2008; Schünemann and Werner, 2005). The reaction to stress caused by extremely low temperature and high salinity in the brine channels was the topic of various experiments. The importance of sea-ice for the overwintering of krill, particularly its larvae, was studied in detail by ROVs and SCUBA-diving, linked with ecophysiological experiments (e.g. Marschall, 1988; Smetacek et al., 1990; Meyer, 2011). Sea ice is a “hanging garden” of high primary productivity and it serves as grazing ground and shelter for a large variety of heterotrophs from bacteria and protists to invertebrates and fish. It plays a key role in the functioning of the Arctic and Antarctic ecosystems.

Since the late 1980s the German polar marine biologists are keen to understand the potential consequences of any long-term changes in structure and seasonal extent of the sea ice cover on polar ecosystems in the Arctic and in the Antarctic (e.g. Smetacek and Nicol, 2005). Remote sensing, in-situ observations and numerical models are complementary tools in the study of sea ice extent, ice edge blooms and phytoplankton distribution in ice free waters. The actual and, even more, the potential effects of increased warming and CO_2 uptake by the ocean resulting in its acidification are currently the most important motivations for national and international funding of projects in marine biology, biological oceanography and biogeochemistry in polar regions. The assessment and protection of marine biodiversity comes second. Political directions, however, are not tight in German science funding and leave adequate room to maintain the broad spectrum of studies in marine biology and related fields (Bathmann, 2011). Trans-disciplinary thinking and inter-disciplinary cooperation became considerably stronger as well as international research projects. In fact, the majority of peer-reviewed German publications in those fields are co-authored by foreign colleagues.

Summary

The English abstract of an article in German (Hempel, 2008) might conveniently serve as a summary of the main lines of past and present German polar research as described in the present overview.

„The plans for the first major German arctic expeditions around 1870 were based on the erroneous assumption of existing of an ice-free passage from Europe to eastern Asia via the North Pole. The vessels got stuck in the ice masses off eastern Greenland. Similarly, neither Erich von Drygalski (1901-1903) nor Wilhelm Filchner (1912-1913) could reach the Antarctic continent, but their expeditions contributed greatly to Southern Ocean oceanography and biology. Carl Weyprecht promoted the First International Polar Year. Germany participated with geophysical observatories in Eastern Greenland and South Georgia. The most important contribution between World War I and II was the geophysical work by Alfred Wegener on the Greenland´s ice-cap.

From 1945 to 1990 polar studies in both parts of the divided Germany developed independently, but still showed similarities. For about 30 years activities were mostly restricted to individual scientists working on foreign invitations, mostly the US and the USSR, respectively. Major projects were confined to the participation by the FRG in the joint programme EGIG I and II in Greenland and to separate eastern and western German expeditions to Spitsbergen. In the 1970´s the governmental interest for a national involvement in polar activities increased in both parts of Germany. Western Germany initiated a polar programme with emphasis on the Southern Ocean and its resources, but also including geological work in North Victoria Land, East Antarctica and glaciological studies in the surroundings of the Weddell Sea. GDR scientists carried out mostly geophysical projects at the various Soviet stations in Antarctica. In the early 1980´s the FRG established the Alfred Wegener Institute for Polar Research in Bremerhaven and built an overwintering *station „Georg von Neumayer“ at the northeastern entrance to the Weddell Sea, not too far from the Georg Forster Station of the GDR at the Schirmacher Oasis. The icebreaking research vessel „Polarstern“ meant for research a breakthrough in the ice-covered sea and became an important platform for international cooperation in Arctic and Antarctic waters.*

In 1990, the eastern and western branches of German polar research joined mostly under the roof of the Alfred Wegener Institute, which built new laboratories in Potsdam. Since then studies in Siberia and in Siberian waters are high on the agenda. Over the recent 15 years, German Polar research gives priority to investigations on the impact of the Global Climate Change on polar regions and their ecosystems. The programme fosters inter-disciplinary and international co-operations as well as close links between the various institutes engaged in polar research in Germany”.

Reflecting on one and a half centuries of German polar research, we see that it was driven by scientific curiosity, as well as by political and commercial interests. After the early days of exploration under foreign flags, a succession of paradigms of polar research policy was noticeable. It started with geographical and nautical exploration, followed by waving the national flag. In the second half of 20th century, a focus on living and mineral resources of the Antarctic was followed since the late 1980s by another accent - by the increasing concern about the potential consequences of global climate change and loss of biodiversity. In recent years there is again a growing commercial interest in the Arctic, including non-living resources, fish and shipping routes. The history of polar research has always been influenced and impacted by the political climate, which at some times and regions fostered research and international cooperation, while at other times national interests interfered with freedom of research.

Right from the inauguration of the first International Polar Year, German polar scientists advocated international networks of observations and coordinated studies in both polar regions. There was also a keen interest in bilateral cooperation with the Soviet Union as shown in the long-lasting relations of Soviet and Russian polar research in Antarctica with the GDR. Over the past twenty years, German polar research institutes engaged in the Arctic cooperate closely with Russian polar research institutions in Saint Petersburg and Murmansk.

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Wägele JW, Sieg J (eds) (1994) Synopses of the Antarctic benthos. Koeltz Sci Books, Koenigstein, 155 p

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MAIN PROBLEMS OF ARCTIC MARINE ECOSYSTEM STUDIES OF MURMANSK MARINE BIOLOGICAL INSTITUTE

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The present review paper characterises the main research directions of the Murmansk Marine Biological Institute (MMBI) and introduces a detailed list of MMBI references in international journals for the last 15 years. The paper can be considered as an introduction and a summary of the Russian contributions collected in this volume.

Since its establishment in 1935 the institute has been active in integrated research on the environment and biota of the Barents Sea, at the coast of the polar archipelagoes of the Western Arctic. Originally, the institute´s premises and marine experimental facilities and tests were concentrated at the Dalnezelenetskaya Bay 200 km east of the Kola Bay (Scientific Events: the Biological Station at the Barents Sea (Anon. 1937)). Since 1990 the major part of the institute and its facilities, including marine aquarium, oceanarium, and research fleet (RVs *Dal'nie Zelentsy, Pomor*), are placed in Murmansk.

The MMBI regularly conducts ecosystem monitoring in the Arctic waters from Greenland to the Laptev Sea, though the focus of research is on the Barents and Kara Seas (Fig. 1). More than 40 winter surveys along the Northern Sea Route have been made on board the nuclear icebreakers. By those means, detailed information about the polar fauna and flora in winter and spring periods for the recent 20 years has been collected and accumulated. The MMBI researchers participated in many cruises of RVs *Polarstern*, *Aranda*, *Jan Mayen*, and other research vessels of western research institutes.

Expeditions on board the *Polarstern* in 1991-2004 have played an important role in co-operation with the AWI (Table 1). Bio-oceanographic material has been collected and accumulated in the Laptev, Kara, Barents, Greenland Seas, and others. Its analysis is presented in joint papers (Table 2).

Based on gained ecosystem knowledge and data, an integrated vision of the Barents Sea problems was introduced in 1991 for the first time (Matishov et al., 1992; Matishov and Weslawski, 1991). Like many other big marine research institutes, the MMBI possesses a full arsenal of means and technologies to study Large Marine Ecosystems (LME).

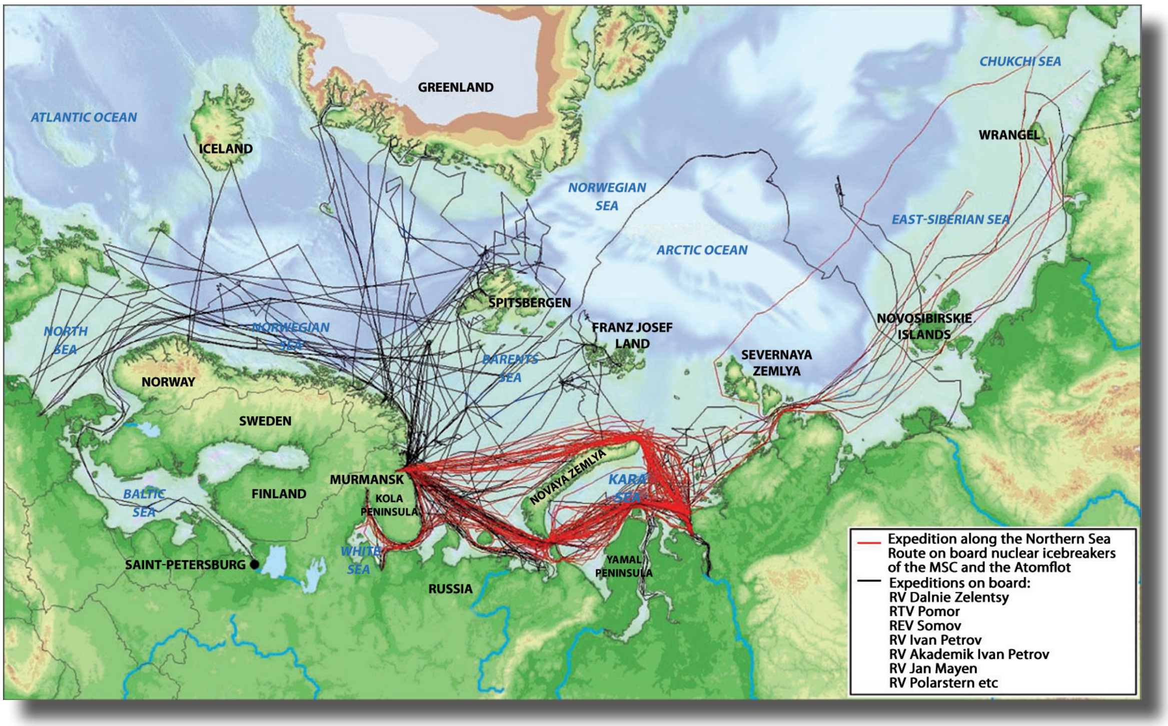

Fig. 1. MMBI Ecosystem monitoring of the Arctic seas (2000-2010)

Table 1. List of the MMBI participants in the joint expeditions on board the RV *Polarstern*

No.	Expedition	Regions	MMBI participants	AWI cruise leader
1	ARK-VIII/2–1991	Arctic Ocean, Barents and Greenland Seas	Matishov D., Petrov V., Chernova N., Ryzhov V., Shaban A., Timofeev S.	Rachor E.
2	ARK-VIII/3–1991	Arctic Ocean	Tarasov G.	Fütterer D.
3	ARK-IX/4-1993	Arctic Ocean, Laptev Sea	Timofeev S., Ilyin G.	Fütterer D.
4	ARK-XI/1–1995	Laptev Sea	Timofeev S., Anisimova N., Mitjaev M.	Rachor E.
5	ARK-XIII/2–1997	Yermak – Plateau area	Denisenko S. Mitjajev M.	Stein R.
6	ARK-XIV/1–1998	Arctic Ocean	Kukina N.	Jokat W.
7	ARK-XV/2–1999	Arctic Ocean, Fram Strait	Kukina N.	Jokat W.

No.	Expedition	Regions	MMBI participants	AWI cruise leader
8	ARK-XVI/1,2–2000	Nordic Seas	Kukina N., Larionov V.	Krause G.
9	ARK-XIX/1,2-2003	Arctic Ocean, Nordic seas and Barents Seas	Kukina N.	Schauer U., Kattner G.
10	ARK-XIX/3-2003	Nordic Seas, Atlantic Ocean	Kukina N.	Klages M.
11	ARK-XX/3–2004	Yermak – Plateau area, Fram Strait	Kukina N., Yanina Y.	Stein R.

Table 2. Joint publications by MMBI and AWI researchers

Bauch H.A., Pavlidis Y.A., Polyakova Y.I., Matishov G.G., Koc N. (eds) (2005). Pechora Sea Environments: Past, Present and Future. Berichte zur Polar- und Meeresforschung, 501, 247 p.

Denisenko S., Sandler H., Denisenko N., Rachor E. (1999). Current state of zoobenthos in two estuarine bays of the Barents and Kara Seas. ICES Journal of Marine Science, 56 (Suppl.), 187-193.

Detheleff D., Loewe P., Weiel D., Nies H., Kuhlmann G., Bahe C., Tarasov G. (1998). Winter expedition to the Southern Kara Sea – investigations on formation and transport of turbid sea ice. Berichte zur Polarforschung, 271, 40 p.

Fahl K., Herter J., Kassens H., Kukina N., Matthiessen J., Müller C., Musatov E. et al. (1999). Sea floor sediment sampling and description. In: Arctic'98: The Expedition ARK-XIV/1a of RV "*Polarstern*". Berichte zur Polarforschung, 308, pp. 47-49.

Fransz H.G., Hirche H.-J., Timofeev S.F. (1994). Zooplankton around Svalbard. European Week for Scientific Culture 1994: Polar Research – Still a Challenge. Bremerhaven: AWI. pp. 10-11.

Hanssen H., Timofeev S. (1994). Distribution of zooplankton and community structure. Berichte zur Polarforschung, 149, pp. 84-90.

Hass H.C., Birgel D., Didie C., Forwick M., Gussone N., Kukina N., Lensch N., Pirrung M. (2000). Geological sampling. Berichte zur Polarforschung, 368, pp. 40-45.

Hass H.C., Birgel D., Didie C., Forwick M., Gussone N., Kukina N., Lensch N., Pirrung, M. (2000). Marine Geology. Berichte zur Polarforschung, 368, pp. 27-29.

Hass H.C., Birgel D., Didie C., Forwick M., Gussone N., Kukina N., Pirrung M. (2000). Subbottom profiling using PARASOUND. Berichte zur Polarforschung, 368, pp. 29-39.

Birgel D., Matthiessen J., Daschner S., Kierdorf C., Kukina N., Langrock U., Vernaleken J. (2001). High-resolution reconstructions of Holocene warm water inflow into the Eastern Arctic Ocean. Berichte zur Polarforschung, 389, p. 26.

Khusid T.A., Korsun S.A. (1996). Modern benthic foraminiferal assemblages in the Kara Sea. Berichte zur Polarforschung. Reports on Polar Research, 212, pp. 308-315.

Korsun S., Hald M., Panteleeva N., Gerasimova M. (1999). Biomass of large foraminifera in the St. Anna Trough. Modern and Late Quaternary Depositional Environment of the St. Anna Trough Area, Northern Kara Sea. Berichte zur Polarforschung, 342, pp. 77-93.

Lubin P., Eckert C. (2001). Macrobenthos of the Yenisei and inner Kara Sea. The German-Russian Project on Siberian River Run-off (SIRRO): Scientific Cruise Report of the Kara-Sea Expedition "SIRRO 2000" of RV "*Akademik Boris Petrov*" and first results. Berichte zur Polarforschung, 393, pp. 72–75.

Carroll, J., Savinov V., Christensen G., Blakely P., Pettersen L., Sørensen K., Kjelstad B., Köhler H., Spitszy A., Hessen D. (2004). Material fluxes from the Russian Rivers Ob and Yenisey: Interactions with climate and effects on Arctic Seas (MAREAS). Berichte zur Polarforschung, 479, pp. 103–117.

Matthissen J., Boucsein B., Raun B., Finkenberger B., Korsun S., Muller C., Neumann K., Schoster F., Siebold M. (1998). Sedimentological investigations in the outer estuaries of the rivers Ob and Yenisey. Scientific cruise report of the Kara Sea expedition of RV "*Akademik Boris Petrov*" in 1997. Berichte zur Polarforschung, 266, pp. 40-42.

Bauch H.A., Pavlidis Yu.A., Polyakova E.I., Matishov G.G., Koç N. (2005). Past, modern, and future state of the Pechora Sea. Berichte zur Polarforschung, 501, pp. 1–6.

Rachor E., Denisenko S. (1997). Macrofauna: Quantitative Assessment. Berichte zur Polarforschung, 255, pp. 67-77.

Matthiessen J., Birgel D., Daschner S., Kierdorf C., Kukina N., Langrock U., Vernaleken J. (2001). Sampling program. Berichte zur Polarforschung, 389, p. 20.

Stein R., Drachev S., Fahl K., Herter J., Kassens H., Kukina N., Matthiessen J., Muller C., Musatov E. et al. (1999). Marine Geological Investigations. In: Arctic'98: The Expedition ARK-XIV/1a of RV "*Polarstern*". Berichte zur Polarforschung, 308, pp. 30-32.

Stein R., Kukina N., Matthiessen J., Muller C., Norgaard-Petersen N., Usbeck R. (1999). Lithostratigraphy. In: Arctic'98: The Expedition ARK-XIV/1a of RV "*Polarstern*". Berichte zur Polarforschung, 308, pp. 60-74.

Tarasov G.A., Stein R., Wahsner M., Nurenberg D., Mityaev M.V., Kukina N.A. (1998). Peculiarities of modern sedimentation in the northeastern Barents Sea and southwestern Kara Sea. Berichte zur Polarforschung, 287, pp. 55-69.

Tarasov, G., Nürnberg, D., Groth, E., Khasankaev, N. (1993). The bottom sediments, Reports on the international multi-disciplinary cruise to high-latitude archipelagoes of the Barents Sea (Frantz Josef Land and Novaya Zemlya, August - September 1992 (RV *Dal'nie Zelentsy*, cruise No. 68)) (G.G. Matishov (ed.). Murmansk Marine Biological Institute. pp. 22-26.

Tarasov G.A., Pogodina I.A., Matishov G.G., Bauch H.A., Kukina N.A. (2005). The Late Pleistocene history of the Pechora Sea. Berichte zur Polarforschung. 501, pp. 167–176.

Wahsner M., Ivanov G., Tarasov G. (1996). Marine Geological investigation of surface sediments in the Franz-Josef Land area and the St. Anna Trough. Berichte zur Polarforschung, 212, pp. 35-49.

Wahsner M., Müller C., Stein R., Ivanov G., Levitan M., Shelekhova E., Tarasov G. (1999). Clay-mineral distributions in surface sediments from the Central Arctic Ocean and the Eurasian continental margin as indicator for source areas and transport pathway: A synthesis, Boreas, 28, 215-233.

It is vitally important to cover all main human impacts on ecosystems and bio-resources (Fig. 2): from climate and fishing to aquaculture and socio-economy. The institute researchers continuously focus on this task.

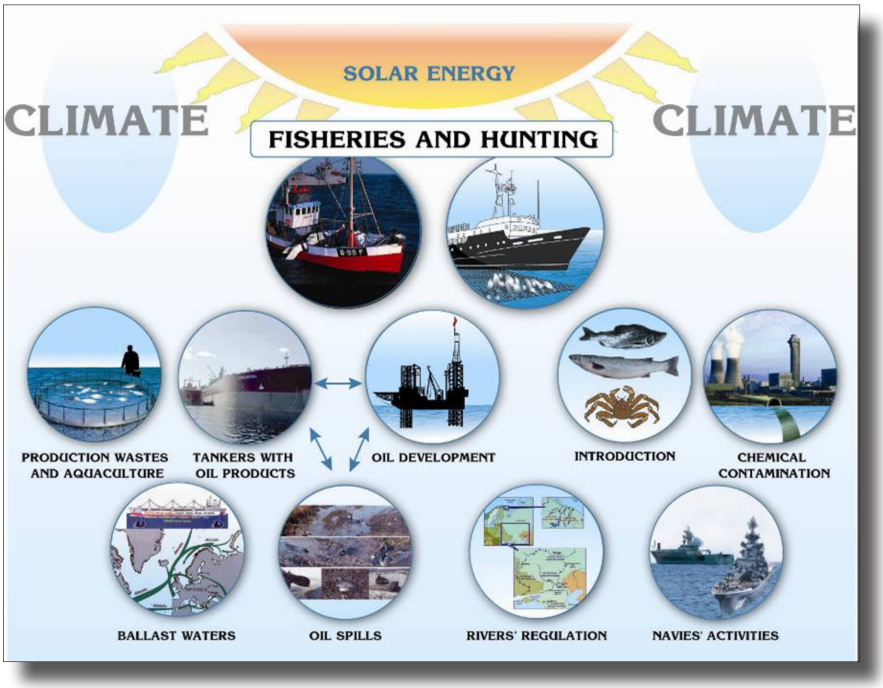

Fig. 2. Factors of impact on marine ecosystems and bio-resources

Climate and oceanology

Climate is a determining factor. To understand its dynamics, palaeoclimate reconstruction was conducted. Parts of the Northern Atlantic, the Arctic, and the Barents Sea, relatively recently, 18-20 thousand years ago, were covered by continental shelf ice and sea ice, as in the Antarctic nowadays. It took the ancient Scandinavian glacier 5 thousand years to melt (Taldenkova et al., 2010; Snyder et al., 2000; MacDonald et al., 2000; Forman et al., 1999). Since the first written reports on observations of the Arctic ice in the 15th century along the Russian coasts, there are no indications for a major and rapid ice retreat and melt. Based on our observations and the implemented research of the past decades, we think there are no grounds to suppose that the ice will dramatically retreat towards the pole. We assume that in case of the global warming, it might take the Arctic pack ice a thousand years to melt. The issue, definitely, requires further consideration and extended integrated studies. It goes without saying that the Antarctic ice should also be taken into consideration when developing any global climate model or scenario. We do not know enough about the dynamics of the Antarctic ice shield on the whole and the way it influences the Earth and the global climate, though most of the Globe´s continental ice is concentrated in the Antarctic, which is also the source of Antarctic Bottom Water found in much of the abyssal depths of the World Ocean. This research direction is of great interest and significance for the generations of researchers to come.

Mud flows rose in the Pleistocene during deglaciation periods when the ice shields of Scandinavia, Greenland, Iceland, and Canada melted. Those streams spread under water on abyssal plains forming a dense net of furrows and troughs. Oceanic periglacial developed outside the glacial shelves (Matishov et al., 1994; Matishov, 1999). Marine periglacial is typical of the modern Arctic shelves (Fig. 3). Periglacial processes impact the evolution of ecosystems directly or indirectly.

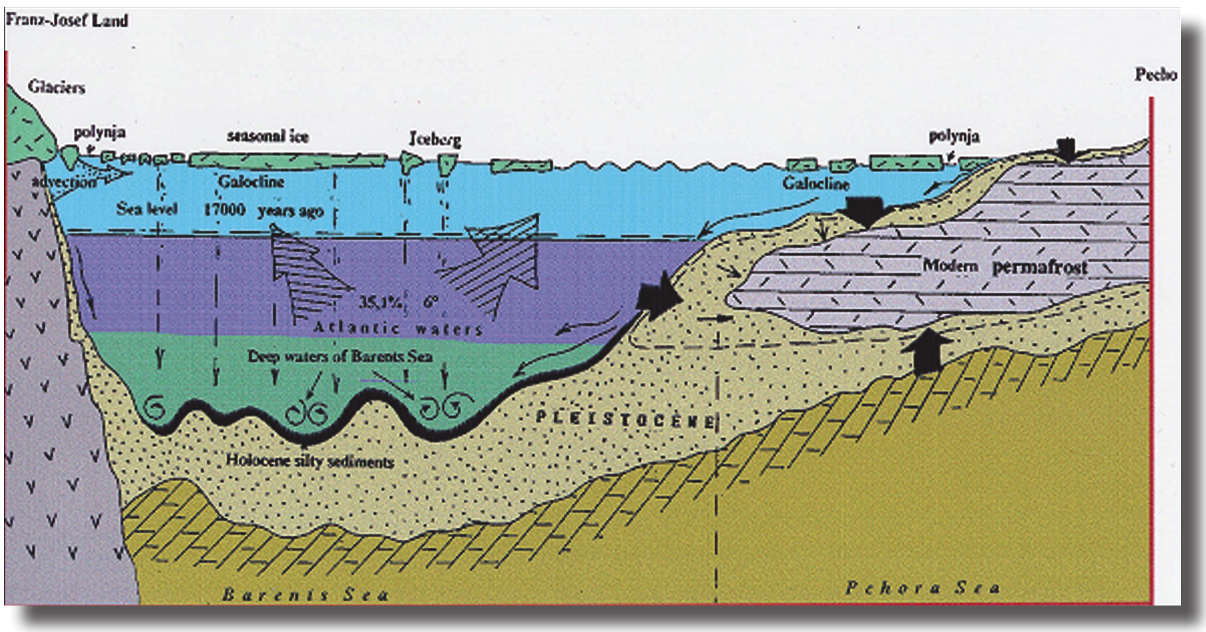

Fig. 3. Contemporary phenomenon of marine periglacial in the Barents Sea. Thin dotted lines - glacier sedimentation; thin lines - transports of sediments by river runoff and near bottom currents; thick black lines - flows of warmth causing degradation of underwater permafrost; thick shaded-dashed lines - flows of warmth and salt in the water column. Holocene silty sediments are indicated, sandstone and limestone are under them, left, under the FJL is granite.

The Arctic has been studied to such a degree that we face a situation when the more we learn, the more questions and discussions arise. The Barents Sea thermohaline regime has been studied unevenly, by both area and months, and its northern part has been studied very slightly. At the same time, everyone, in both practice and everyday life, requires reliable forecasts of weather and climate, circulation simulations and models of marine basins' hydrodynamics.

To solve such a task, the MMBI, jointly with the US NOAA, has been developing an electronic climate archive for twenty years already. Our database on the Arctic seas contains about 1 million measurements of T and S for 150 years (Matishov et al., 2004; Matishov et al., 2000; Matishov et al., 1998).

The Arctic climate is characterised by inner-secular cyclic pattern with a period of 30 years (Fig. 4). The Kola Bay is frozen once every 30 years (Levitus et al., 2009; Matishov et al., 2009; Smolyar and Adrov, 2003). Advection of warm Atlantic waters plays an important role in the development of the Arctic marine ecosystems (Fig. 3, 4). This phenomenon can be clearly observed and traced at the secular thermohaline and hydro-biological Kola Transect (Fig. 4, 5).

Warming was registered in the Arctic in the beginning of the 21st century, as well as in the 1930s. It was conditioned by a powerful advection of warmth from the Atlantic. It gave rise to the talks on the rapid and soon melting of the Arctic ice. However, most recently a climate vector changed beginning in 2007 (Fig. 5).

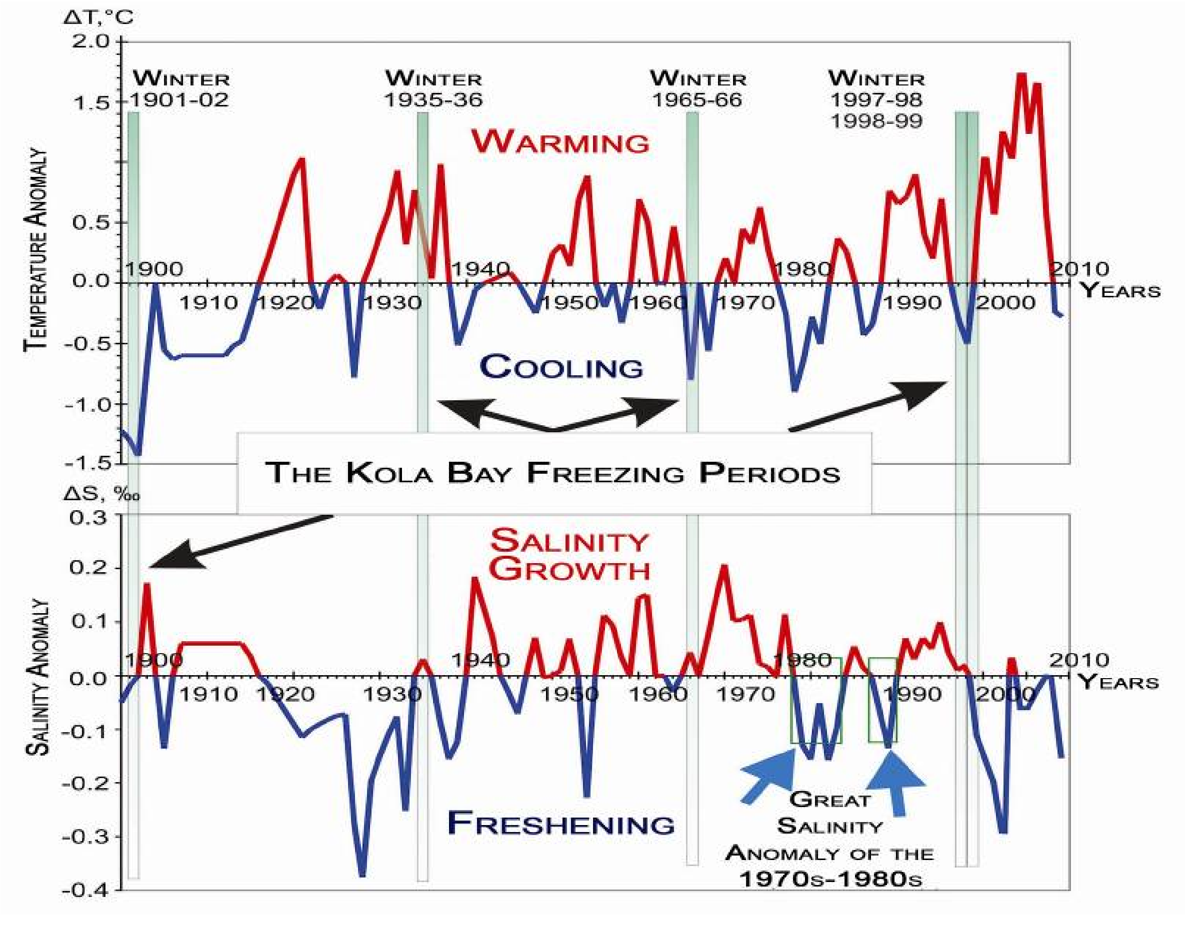

Fig. 4. Inner-secular cyclic pattern of climate

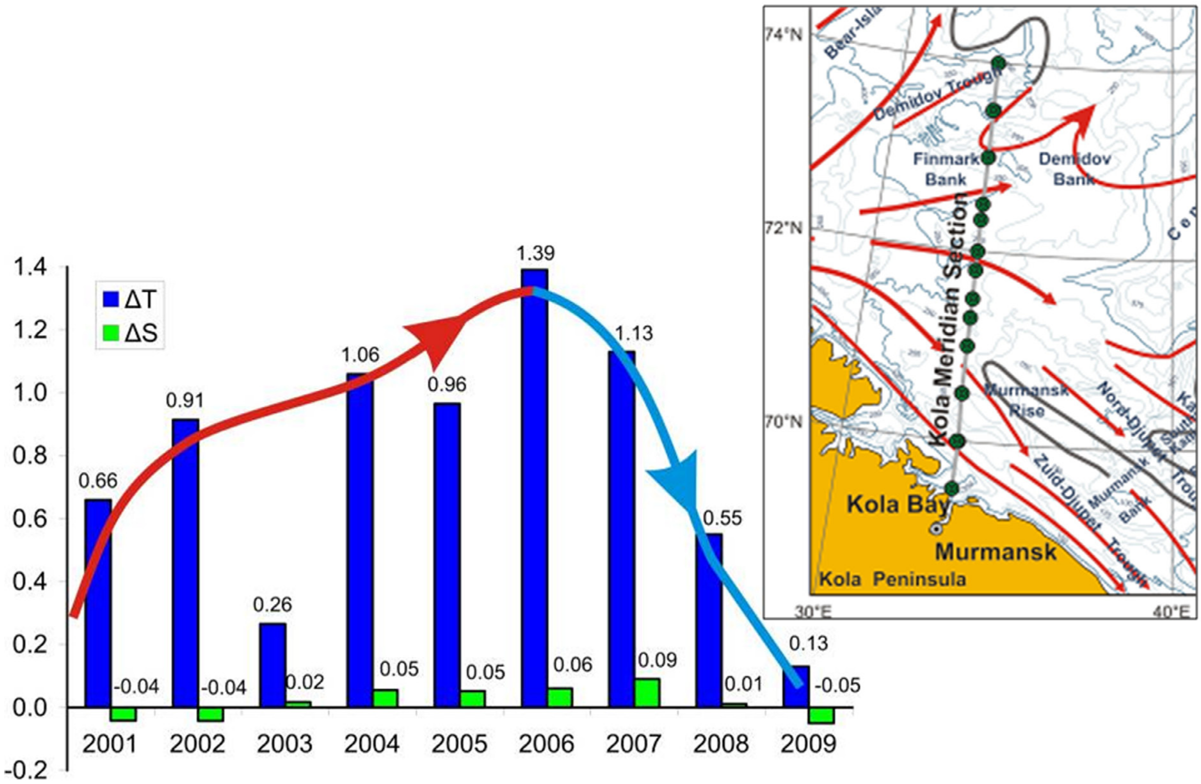

Fig. 5. Return to regular (averaged long-term) climatic conditions in 2007-2009

The thermohaline situation acquired characteristics of a standard regular year. A next cycle of cold years is probable in the near future. Location and boundaries of drifting sea ice is an important feature of climate dynamics. In 2009-2011, the ice edge and ice conditions (total freezing area) of the Barents Sea returned to standard usual location with increasing trend in the area.

For comparative reasons, it may be noted that winters of the early 21st century between the Azov-Black Seas and the Caspian Sea were cold. January 2006 turned out to be one of the most severe years for 100 years of observations. Winter 2011 in the Sea of Azov, as well as in the Gulf of Finland, was considered severe as well. A similar situation was in the Baltic in 2002-2003.

Development of criteria for climatic conditions' gradation for 150 years became an important result of the Barents Sea specific thermohaline features' analysis. Five grades of marine climate scale are as follows: abnormally cold, cold, standard (regular), warm, abnormally warm years. It so happened in scientific practice that everyone, by tradition, uses the Tantsyura chart of currents of the 1960s. Our new chart (Fig. 6) reflects the circulation of all the filaments of warm Atlantic current in a more factual and adequate way, considering the topography on the glacial shelf (Matishsov et al., 1995). This presentation of the current pattern is important to understand the migration of fauna, oil spills' drifts, etc.

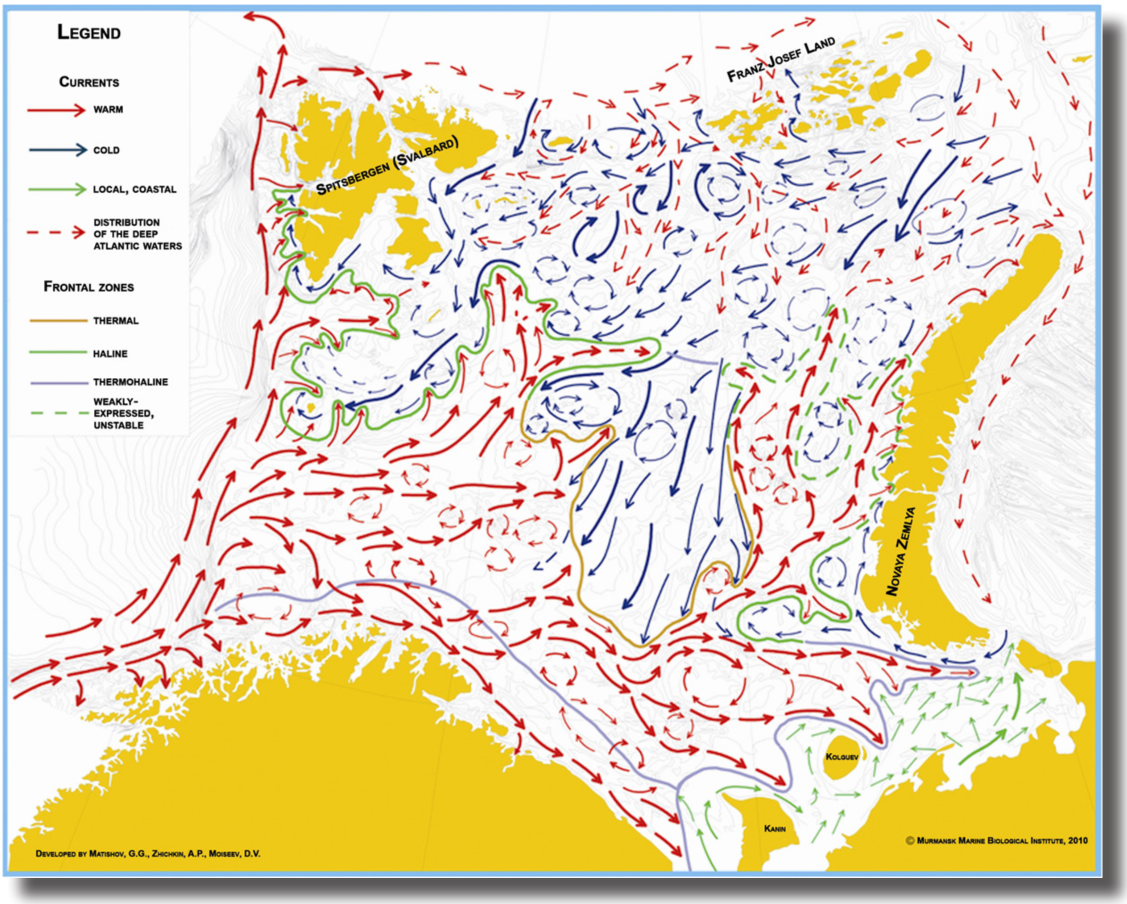

Fig. 6. Chart of the Barents Sea waters' circulation and location of climatic frontal zones

Climate forecast is necessary for effective commercial fishing and shipping, to understand the mechanisms and phenomena in Large Marine Ecosystems. Many zoobenthos species are perfect indicators of climate and sea pollution (Dahle et al., 2009; Jorgensen et al., 1999). In this respect, identification of species composition of fauna demands very high qualification.

Revision of zoobenthos has been carried out for the warming period in the early 21st century. By the change of biomass of polychaetes, mollusks, and some other species, our specialists ascertained that the bottom fauna does not immediately react to a vector of temperature anomaly. The response is delayed for 3-8 years.

Depending on abnormally cold or warm years, the migration pattern of cod and other commercial fish species changes dramatically. In warm years, cod naturally migrates for two thousand kilometers from the Lofoten Islands to the East, the Novaya Zemlya waters. And, vice versa, in cold years, cod migrates to the North, the Spitsbergen (Svalbard) waters.

Biological productivity

The synthesis of the primary organic matter, with phytoplankton being the main producer, forms the basis of the ecosystem pyramid. According to the most common assessments of primary production, the Norwegian Sea and Iceland Shelf LMEs are referred to as highly productive Arctic shelf areas (more than 300 g C/m^2 per year); the Chukchi Sea, Bering Sea, Faroe Plateau, and Southwestern Barents Sea are determined as areas with moderately high productivity (150 – 300 g C/m^2 per year). The rest of the Arctic water areas and the Arctic basin proper are considered as low productive.

Based on results of more than 40 MMBI cruises on board the nuclear icebreakers the functioning of detritus trophic chain in the Barents and Kara Seas coastal zones during the polar night has been studied. Plankton bacteriocenoses preserve its steady structure and high production activity under solid ice cover with temperatures close to seawater freezing point. Bacterioplankton in the winter season is the only food substrate for zooplankton organisms before the cryoflora vegetation becomes productive in spring.

There is a negative gradient in the productivity of key organisms of the plankton component of the trophic chain from the Barents, White, Kara, and Laptev Seas towards the East-Siberian Sea (Fig. 7). By our data, zoobenthos productivity varies depending on inner-secular climate fluctuations and bottom communities' succession stages. On average, the benthos of soft and mixed grounds produces around 70% of the total averaged biomass (P/B = 0.7) per year, while, the communities of hard grounds have a lower productivity (P/B = 0.6). In the open Barents Sea shelf, benthic somatic production is much lower with values of P/B-coefficient being 0.25 – 0.30 (Berezina, 1963; Konstantinov, 1967). Overall, the Barents Sea coastal bottom biocenoses production rates yield to such boreal seas as the Sea of Okhotsk and North Sea (where P/B-coefficients are 1.2 (Dulepova, 2002) and 1.5 (Dommasnes et al., 2001) correspondingly), but close to the Bering Sea indices (P/B = 0.9) (Dulepova, 2002)).

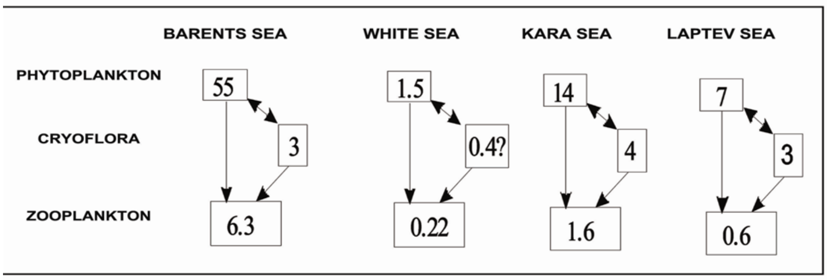

Fig. 7. Production (mln ton $C_{org.}$/year) of separate links of trophic chain in the ecosystems of the Barents, White, Kara, and Laptev Seas

When studying the Arctic LMEs it is important to assess quantitatively the role of every ichthyofauna species in the cycle of matter and transformation of energy in the ecosystems of the northern seas. Until recently, only tentative production values (P/B-coefficient) of 0.125–0.170 (Zenkevich, 1947) were applied for the Barents Sea fishes. Our research indicates they are significantly higher and for the Barents and White Seas cod, deepwater-redfish (perch), and Arctic cod are from 0.3 to 1.0.

Bio-geography of western Arctic waters

The main MMBI scientific forces are concentrated on the Arctic and Sub-Arctic marine biology (Timofeev, 2000; Makarevich, 2008; Timofeev, 2006; Timofeev and Selifonova, 2005; Timofeev et al., 2004; Timofeev, 2002; Dvoretsky and Dvoretsky, 2009; Makarevich, 2009; Dvoretsky and Dvoretsky, 2008; Smolyar et al., 2000; Deubel et al., 2003; Timofeev and Sirenko, 2002; Timofeev and Sklyar, 2001; Druzhkov and Druzhkova, 2000; Druzhkov et al., 2000). The strong school of systematic experts in phyto- and zooplankton, zoobenthos, macrophytes, and ichthyofauna has a long tradition (Christiansen et al., 2010; Matishov and Ognetov, 2011; Sukhotin et al., 2008; Zhuravleva and Minchenok, 2004; Zhuravleva et al., 2006; Mishin et al., 2001; Gudimov and Gudimova, 2002; Karamushko and Christiansen, 2002). The availability of marine aquarium and hydro-biological experimental facilities on the polar coast at all the stages of institute's history gave the MMBI a possibility to successfully conduct experimental activities on the physiology of animals, such as whales, seals, fishes, crustaceans, and mollusks (mussels). The studies focused on electroreception, chemoreception, biorhythms, and processes of adaptation to the Arctic environment. Expeditions on board the nuclear icebreakers under winter and polar night conditions resulted in the obtaining of principally new data for the arctic biology.

Long-term observations in the Kara Sea ice indicated that the zoo-geographical boundary of crested seal is not along the White Sea meridian, as it has been considered before, but at the Yenisei Bay traverse. Migration vector of the polar bears (Fig. 8) is in the direction of new cracks and polynyas in the Kara Sea. Our knowledge on migration patterns of marine mammals is based on aero-photo-surveys, surveys by commercial fishing and hunting vessels.

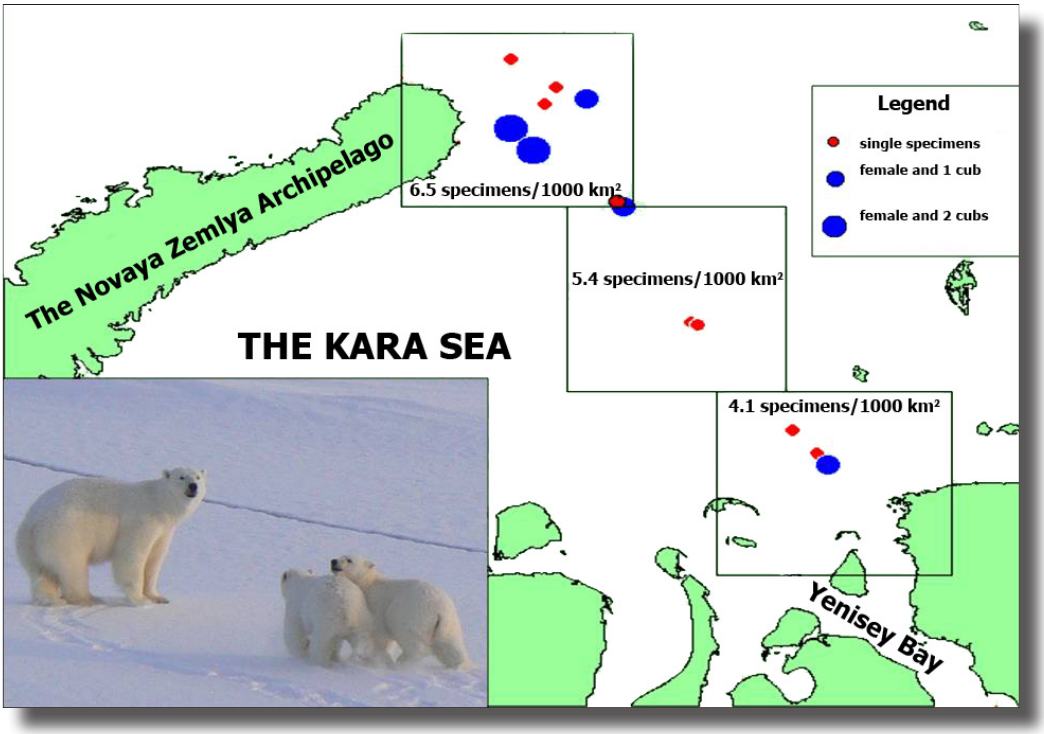

Fig. 8. Observations of polar bears of the Kara Sea in 2008.

Continuous daily satellite monitoring (Fig. 9) principally changed the previous ideas of life of gray and Greenland seals in the Barents Sea, from the birth to the first molting.

Birds in the Arctic, as well as biota they transport in the feathers and plumage were studied by MMBI researchers too. Exemplifying oribatidae mites, MMBI and SSC RAS researchers have described the ways soil biota takes to the sea birds colonies of the archipelagos in the Holocene (Krasnov et al., 2007; Barrett et al., 2008; Lebedeva and Lebedev, 2008).

The structure and diversity of ichthyofauna in the Arctic seas is largely determined by bottom temperature. Along 70° North latitude, the temperature ranges from -2° to +10° C in the Western Arctic waters. Taking these patterns into account, the list of species has been enlarged from previous 144 to 182 species of fish and subspecies. (Aschan et al., 2009; Matishov et al., 2004).

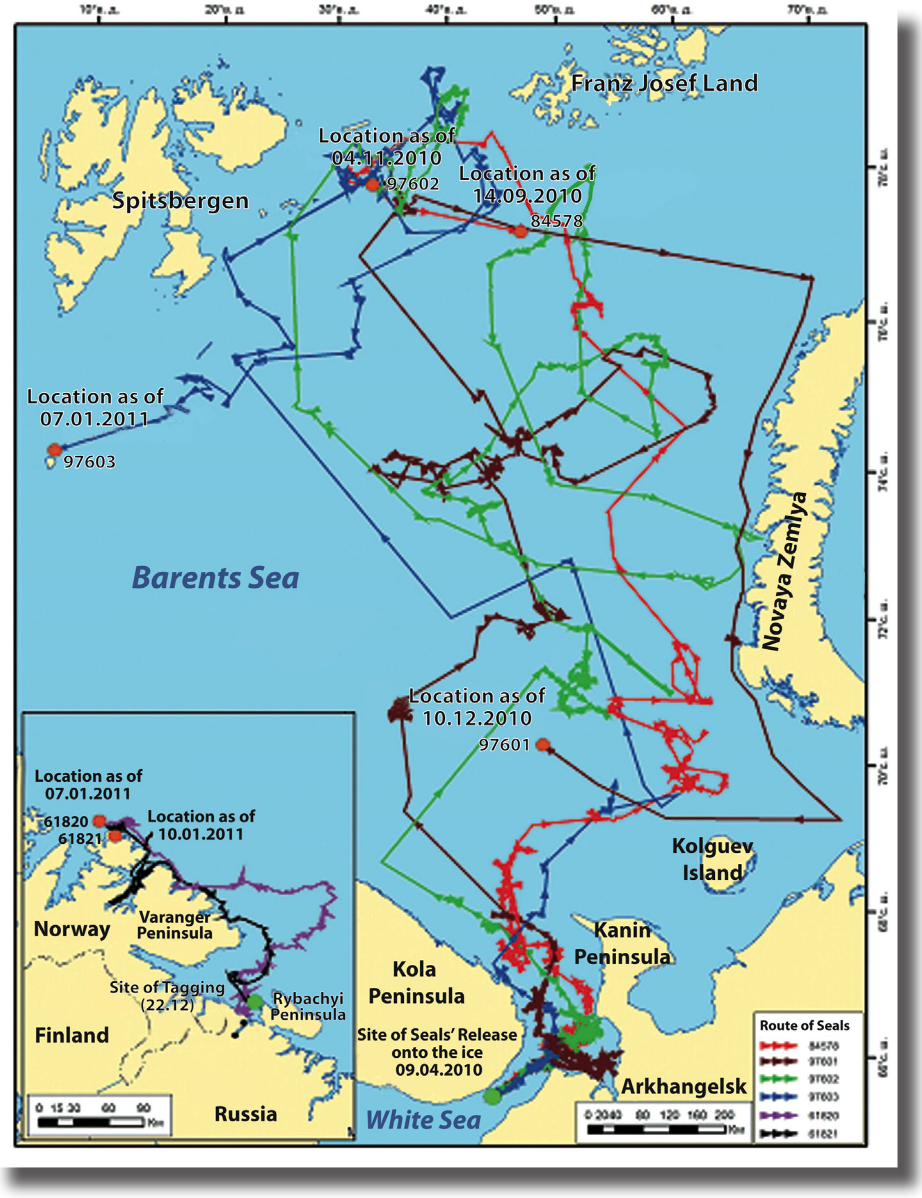

Fig. 9. Routes of satellite tagged Greenland seals in the White and Barents Seas (April 2010 – January 2011)

Human impacts

The issue of invasion or introduction of alien species is in a continuous focus of the MMBI. We consider alien fauna to be a biological pollution and divide it by its origin into: natural (climatic) migrants, alien biota of ballast waters, introduced species – a planned acclimatization of species, genetically modified species, including hybrids from aquaculture.

The introduction of biota from the Far East in the Soviet period proved to be ecologically dangerous (Dvoretsky and Dvoretsky, 2010; Dvoretsky and Dvoretsky, 2009; Dvoretsky and Dvoretsky, 2009; Dvoretsky and Dvoretsky, 2009; Dvoretsky and Dvoretsky, 2009; Dvoretsky and Dvoretsky, 2010; Dvoretsky and Dvoretsky, 2010; Britayev et al., 2010). The red king (Kamchatka) crab was introduced in the 1960s. Its abundance peak of 30 million specimens coincided with climate warming in the early 21st century. The crab stock became heavily overfished. Its extraction is only for research purposes now.

The Far East humpback salmon now inhabits the area from the coasts of Britain to the Ob Bay. The introduction of alien species from the Far East in the Soviet period was not only in the northern seas but also in the southern seas. The Far East haarder *Liza haematocheilus* (*Mugil soiuy* Basilewsky 1855), introduced into the Sea of Azov in the 1960-1970s, has now occupied the habitat of sturgeon and other valuable indigenous fish species. From the point of view of socio-economy, the red king (Kamchatka) crab, humpback salmon, as well as haarder are positive factors. From the ecosystem health point of view, they are obvious hazards. Introduction of alien species to the Barents Sea basin without making prognosis of ecosystem consequences made more harm than good.

Pollution from aquaculture is also dangerous for bio-geo-coenoses. Contamination of fjords and coastal waters with organic matter is caused by aquaculture. However, apart from the flow of organic matter, there is one more negative consequence. Up to three-four hundreds of millions of salmon specimens are annually cultured and maintained at the Norwegian fish farms with an annual production of up to 800 000 tons. During storms and accidents, fish specimens escape to the sea. Some of them end up in the Barents Sea (Fig. 10). The first catches of alien fish from the Norwegian fish farms were registered on Murman in 2001 (Fig. 10). The annual flow of invasive salmons

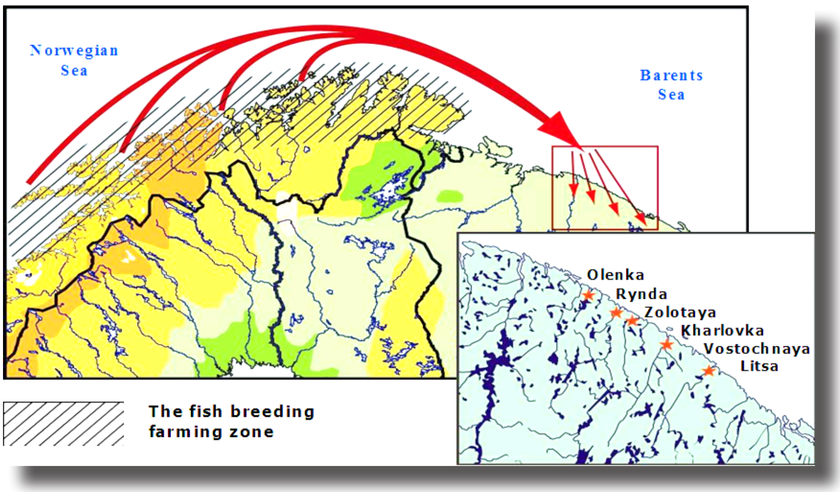

Fig. 10. Escapes of cultured salmon from the Norwegian fish farms

reaches many thousands of specimens. Genetically modified fish specimens supersede wild salmon in natural spawning areas in rivers of the Kola Peninsula.

Chemical and radioactive pollution of the Arctic marine environment is a priority issue in MMBI research (Sagerup et al., 2009; Dahle et al., 2006; Polder et al., 2004; Dahle et al., 2003; Muir et al., 2003; Savinov et al., 2003; Savinov et al., 2003; Skotvold and Savinov, 2003).

When it comes to chemical contamination, the Barents shelf is one of the cleanest among the northern seas (Fig. 11). Based on long-term research, MMBI proved that the existing background levels of pollutants do not harm marine bio-resources.

The decreasing trend in radioactivity continues in the early 21st century.

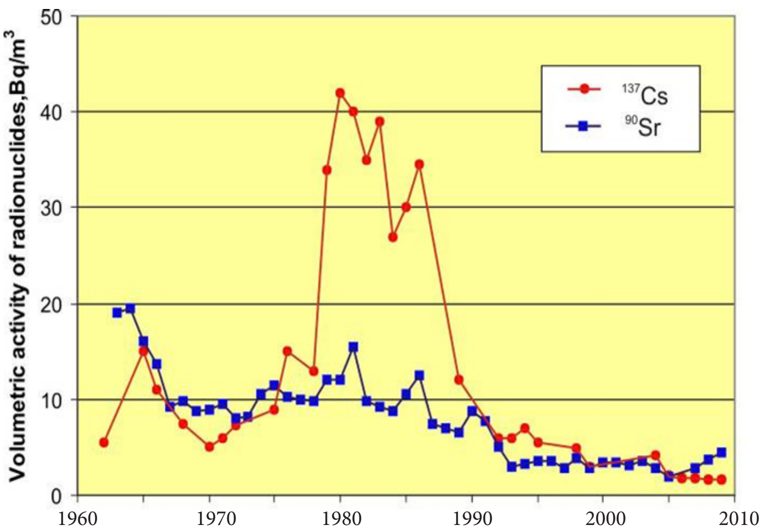

Fig. 11. Dynamics of Cs-137 and Sr-90 content in the Barents Sea water mass (1963-2009)

The maximum discharges from the Sellafield plants were in 1980-1985. Sharp reduction of radioactive wastes for the last 25 years resulted in the fact that advection of pollution from the Sellafield plants in the Barents Sea is practically not registered anymore (Matishov et al., 1994; Matishov and Matishov, 2004; Golubeva et al., 2003; Zauke et al., 2003; Matishov et al., 2002; Matishov et al., 2000; Savinov et al., 2000). There are practically no 137Cs and 90Sr in the Barents Sea. Practically no influence of the discharges from the nuclear bases of the Kola Peninsula has been traced.

Due to rapid development of oil and gas extraction on the Norwegian shelf, as well as tanker shipping of oil products along the Northern Sea Route, the accidents at platforms and accidental oil spills are possible and should be taken into account. That is why monitoring of pollution and studying of possible trajectories of pollutants' transport are necessary.

Socio-economic progress, to a great extend, is determined by results of studies and forecasts of climate, ice conditions, bio-resources, as well as rational exploitation of nature. The life and economy of the Far North directly depend on the scale of goods' transportation along the Northern Sea Route. In the post-Soviet period, a decrease to one quart of the earlier level is obvious (Fig. 12). The decreasing trend pauses now. Significant increase is only planned for the future.

The inhabitants of Murmansk and Archangelsk have been linking their future with the development of the Stockman hydrocarbon deposit off the Murman coast for three decades already. The entire socio-economic infrastructure was developed to meet the needs and requirements of the "project of the century". Today, no one may guarantee that the development of gas condensate will start in 2017. This means that new fields for employment should be found for the population of the Russian Far North.

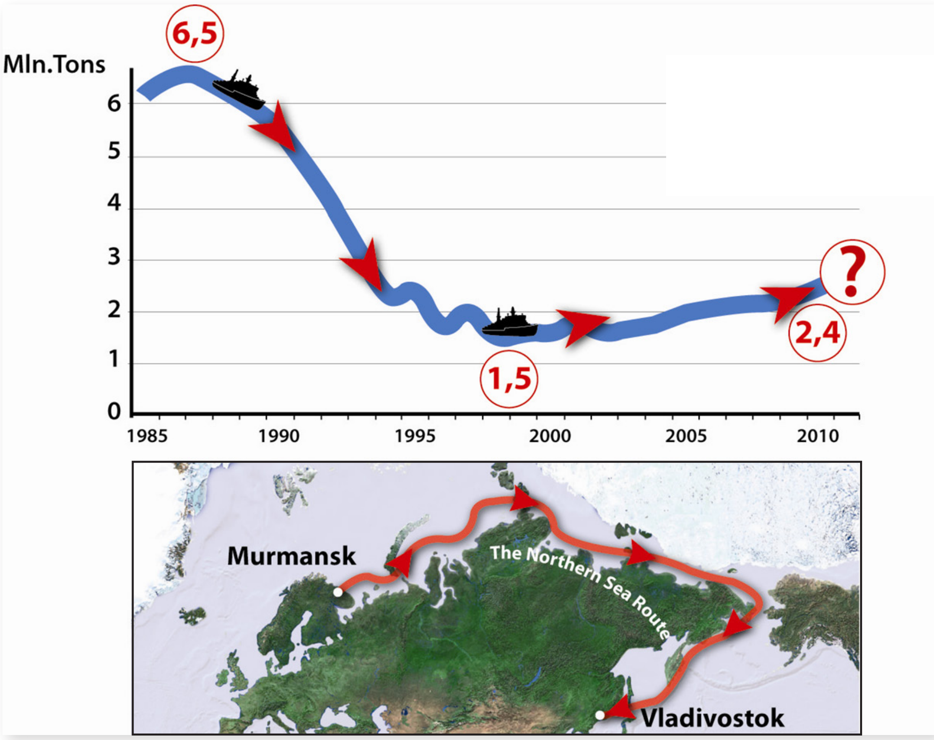

Fig. 12. Dynamics of goods transportation along the Northern Sea Route (million tons) in the period 1985 – 2010

Large Marine Ecosystems

Oceanography and marine ecology for fishing purposes nowadays, to a great extend, are based on the concept of Large Marine Ecosystems (LME). Seven LMEs border the Russian State in the Arctic. Their boundaries are well-defined (Denisov and Shavikin, 2005; Makarevich and Krasnov, 2005; Sherman et al., 2005; Matishov et al., 2003). The LME concept is a result of acknowledgement by researchers and practitioners (K. Sherman, G. Hempel, G. Matishov, etc.) that over-exploitation of bio-resources took place nearly everywhere in the fishing areas of the World Ocean.

Due to over-exploitation of fish like cod, the idea of fishing ban in the Barents Sea has been discussed more than once.

In the Barents Sea, we share the shelf with Norway as well as the same warm Atlantic Current, and have common migrating fish resources. In 2011, a new political boundary between Russia and Norway was determined and delineated. A desired division of the grey zone on shelf induced some Norwegian researchers (H-R Skjoldal, etc.) to go further into scientific reshaping of the Arctic. In particular, they proposed to reconsider the LME boundaries. Their new visions and approaches liquidate the East-Siberian Sea LME, merge part of the Barents Sea with the Kara Sea and so on. This issue, definitely, demands additional scientific studies and discussions at the Russian Academy of Sciences and at international scientific fora.

Concluding remarks

Scientific co-operation between the AWI and the MMBI in the Arctic was 20 years old in February 2011. Mutually beneficial co-operation was born in the "atmosphere" of Perestroika and Glasnost. The MMBI is interested in the *Polarstern* cruises' activities, joint research at the Helgoland Research Station, in the Laptev Sea and the Lena delta. It is reasonable to conduct a comparative analysis of climate fluctuations at the Kola Transect and the Helgoland secular transect that is in the Barents and North Seas.

The research plan of the MMBI for the years to come covers such research directions as: climate and palaeogeography of the Pleistocene, biodiversity, experimental physiology, cryopelagic studies and studies on the life in polynyas along the Northern Sea Route, modeling and forecast of ecosystem processes, rational nature exploitation, aquaculture biotechnologies, social and economic geography (socio-economy), Large Marine Ecosystems. Training of students and young researchers is part of the regular activities of the MMBI.

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ARCTIC RESEARCH AT THE ALFRED WEGENER INSTITUTE

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The Alfred Wegener Institute for Polar and Marine Research in the Helmholtz Association (AWI) and the Murmansk Marine Biological Institute (MMBI) are looking back on 20 years of fruitful collaboration. In February 1991 the first Memorandum of Understanding (MoU) was signed by Academician Professor Matishov and Professor Hempel for joint biological research in the Arctic. Due to foreseeable climatic changes and increasing exploitation and shipping, research in the Arctic region is becoming increasingly important. In particular, ecosystem shifts are to be expected in the Arctic and, therefore, the AWI and MMBI will continue their beneficial collaboration in a new MoU. Both institutes have a tradition, as well as strong potentials and future plans for multidisciplinary research in the Arctic, a key area for marine science, where multiple interactions of bio-, cryo-, hydro- and atmosphere take place. Research of this kind can only be sustainable and successful in international collaboration. In this contribution, an overview of the AWI, its Arctic research and an outlook towards future research foci will be given (see also http://www.awi.de/en/home/).

Overview of the Alfred Wegener Institute

AWI was established as a foundation under public law in Bremerhaven in 1980. Already in 1986 the Institute of Marine Research, Bremerhaven (IfMB) became part of the AWI. It had focused on ecology and on pollution issues in the North Sea and several of its scientists had become interested in Arctic marine research. In 1992 the polar research of the former GDR joined the AWI and a new branch was opened in Potsdam near Berlin, with emphasis on atmospheric and periglacial research. In 1998 the oldest marine research institution of Germany, the "Biologische Anstalt Helgoland" (BAH) became part of the AWI. Founded in 1892, the BAH is situated on the islands of Helgoland and Sylt with a focus on coastal ecology research in the North Sea and increasingly also in the Arctic. As a result of these historic developments, the AWI is distributed over four locations in Germany with headquarters in Bremerhaven (Fig. 1). The scientific mission comprises primarily research in both polar regions, the Arctic and the Antarctic, and in the North Sea. The AWI is member of the Helmholtz Association, receiving 90% of its funding from the German Federal Government (Ministry of Education and Science) and 10% from the Federal States (Bremen, Schleswig-Holstein and Brandenburg), in which the AWI research units are located (Fig. 1).

Fig. 1. Locations of the Alfred Wegner Institute for Polar and Marine Research in Germany (Bremerhaven, Potsdam, Helgoland and Sylt)

The AWI has currently (in 2010/11) over 970 staff, of which around half are scientists, and an annual budget of approximately 120 million Euro, including ca. 20 million Euro external funding. Approximately 30 percent of the budget are needed for running the major research platforms and infrastructure operated by the AWI (Fig. 2).

Fig. 2. Major research platforms and infrastructure operated by the AWI: Arctic (*AWIPEV*, Samoylov) and Antarctic (*Neumayer III*, *Kohnen*, *Dallmann Laboratory*) stations, research icebreaker *Polarstern,* three smaller ships and two aircrafts

The three scientific departments of the AWI (Geosciences, Biosciences and Climate Sciences) cover a broad range of research fields and topics. One of the advantages of the AWI is the availability and competence in most aspects of polar and marine research collectively within one institute, which facilitates excellent interdisciplinary work and new trans-disciplinary ideas. Research groups from the different departments and sections join forces to focus on topics of specific interest. For instance, investigations of polar ice shields and sea level rise are carried out by a multi-disciplinary team of geophysicists, oceanographers, climate scientists, paleoceanographers and modellers. Sea ice research incorporates oceanography, atmospheric and biological sciences, as well as modelling expertise. The research at the AWI includes the whole range from field observations and process studies to data analysis and modelling. Comprehensive research and polar system analysis in the Arctic and the Antarctic is a hallmark of AWI science. Long-term observations and time series serve as the basis for understanding and distinguishing between short-term variability and long-term trends in polar and temperate ecosystems.

The scientists are supported by efficient logistical and administrative departments and by excellent infrastructures for polar research (Fig. 2). AWI provides this infrastructure free of charge for the entire German scientific community and for international partners, based on applications and external evaluation. Many of those joint collaborative activities are part of large projects carried out under the auspices and with financial support of the EU and other funding agencies. All cooperative research projects are subject to independent international peer review in order to safeguard high scientific quality and relevance.

The most important infrastructure is the research icebreaker RV *Polarstern* that accommodates 50 scientists and operates for 310 days of research in both polar regions (Fütterer and Fahrbach, 2007). It is one of the busiest research vessels in the world, and RV *Polarstern* has travelled over 1.4 Million nautical miles since the launch in 1982. The transit cruises to and from the polar areas are used for ocean-wide studies en route. The vessel supplies the permanent German Antarctic research station *Neumayer* and is equipped for all scientific research in glaciology, physical and biological oceanography, atmospheric sciences, marine sedimentology, geophysics, chemistry and experimental marine biology, including microbiology. Smaller research vessels are available at the AWI for coastal work in the North Sea and European shelf seas. AWI scientists also have access to other large German research vessels, particularly RV *Meteor*, for carrying out comparative studies outside the polar areas. The institute is member of the European pool of research vessels: many foreign researchers use the opportunities provided by RV *Polarstern* expeditions (so far, more than 50 percent of the ship time was used by external scientists and 22 percent by international partners), while AWI scientists enjoy the hospitality of foreign vessels.

For atmospheric and ice studies, two converted and modernised DC-3 airplanes of the type Basler Bt 67, named *Polar 5* and *Polar 6*, are available. Depending on the research mission, their payload includes ice penetrating radar, magnetic and altimeter instrumentation for investigation of ice structure, thickness and surface characteristics, as well as special instruments and sensors for analysis of atmospheric chemistry.

A regional research focus is given by the location of the polar stations operated by the AWI. In the Arctic, the *AWIPEV Research Base* in Ny Ålesund on Svalbard, which is jointly operated with the French partner IPEV (L'Institut polaire français Paul-Emile Victor), provides a base for year-round atmospheric, geophysical and biological research. The joint German-Russian *Samoylov Station* is situated on the island of Samoylov in the Lena Delta (Siberia), close to the Laptev Sea. It serves for summer field research on permafrost and long-term observation of changes in the Arctic coastal environment.

In Antarctica, the permanently manned *Neumayer Station III* on the Ekström Ice Shelf of Dronning Maud Land is the central research station of the AWI. The first *Neumayer* station was opened in 1981 (see article of Prof. Hempel in this volume); now the third station is in operation, which was officially inaugurated in February 2009. The first two stations were tubular structures embedded in the ice shelf. Their life span was limited to 11 and 17 years, respectively, when pressure on the walls caused by the annual increase of ice and snow on top of the station made a further safe operation impossible. The new *Neumayer Station III* is built on hydraulic legs and is regularly lifted to accommodate the snow accumulation over time. This new station is expected to survive the harsh conditions of the Antarctic continent for more than 30 years, nearly three times as long as the previous stations. Around 560 kilometres southeast of the *Neumayer Station III* lies the *Kohnen Station*. Here geophysical, glaciological and atmospheric research is carried out during the austral summer. This station is supplied and reached via the *Neumayer Station III* by a traverse over the inland ice. It provides good facilities for drilling of ice cores for paleoclimate research. On King George Island at the Antarctic Peninsula, the *Dallmann Laboratory*, which is operated jointly with Argentinean partners at *Jubany Station*, is used for biological research again mostly during summer periods.

The two AWI island stations on Helgoland and Sylt in the North Sea are centers for coastal field work and for long-term observations of the ecosystem of the German Bight. Collection of temperature and salinity data started at Helgoland in 1873, with regular phytoplankton and zooplankton sampling and analysis commencing in 1962 and 1974, respectively. The unique data sets collected at these long-term observation sites are an important basis to analyse ecosystem changes and their driving forces, and are extremely valuable for comparison of climate change in the polar regions (especially the Arctic) with that observed in the temperate waters of the North Sea (Wiltshire et al., 2010; Vandepitte et al., 2010).

The coordination and the logistic / scientific support of polar research activities of German and foreign institutions are one of the prime tasks of the AWI. In order to fulfil this role, the AWI is part of a strong network of national and international research centres. The joint projects, which the AWI (often together with other German institutes, such as the Helmholtz Center for Ocean Research in Kiel GEOMAR) carries out in the Arctic in collaboration with MMBI and other Russian institutes, are outcome of this open policy. Right from the start, the AWI became engaged in academic lecturing and mentoring.

Most of the senior scientists teach as professors or lecturers at the University of Bremen or at other universities and hundreds of PhD students have carried out their theses at the AWI. At the beginning of October 2011 188 PhD students work at the AWI.

In the following an overview of only the Arctic research is given, but the overall research programme of the AWI includes also Antarctic and coastal research.

Arctic research at the Alfred Wegener Institute

The Arctic is an important driver of climate evolution and climate variability (Lemke et al., 2007, Gerdes et al., 2008). Over the last century the Arctic has experienced a temperature rise twice as high as the global average, and it can be considered as an early warning system for future global change (Lochte et al., 2010). Due to the steep temperature rise, the sea ice and ice sheets in the Arctic have decreased in extent and thickness substantially during the last decades (Kauker et al., 2009), and the chemical composition ("ocean acidification") of the Arctic Ocean is changing. If these temperature trends continue, studies by AWI and others (see overview in Denman et al., 2011) predict that the highly productive surface layers of the Arctic Ocean will become under-saturated with respect to essential carbonate minerals by 2032, and might be ice-free in summer by around 2070. Since the polar ecosystem is characterised by highly specialised and adapted species and food webs, the expected future changes will have profound effects not only in the physical environment, but also in the biological realm.

The processes and changes in the Arctic are not only of regional relevance, but they influence the climate and sea levels around the world. Therefore, it is the AWI's aim to provide high-quality scientific observations in the field, to improve data analyses and modelling, and to reduce error margins of forecasts for Arctic processes and their global effects. In the analysis of future change, it is important to understand the relative role of natural variability and anthropogenic influences. AWI's research thereby contributes to the assessment of the consequences of the ongoing changes in the Arctic that range from local to global scale.

The present research programme PACES (Polar Regions and Coasts in the Changing Earth System, 2009 - 2013), which is implemented by the AWI in collaboration with the Helmholtz Centre Geesthacht (HZG), includes four scientific topics:

1) The changing Arctic and Antarctic
2) Coastal change
3) Lessons from the past
4) Synthesis – The Earth system from a polar perspective

Arctic research is mainly dealt within topics 1 and 4, but Arctic issues are also part of the other topics.

One of the AWI's main Arctic research foci is the extent and change of the Greenland ice shield in past, present and future times, and the influence these changes have on the global sea level. The scientific analyses range from direct ice core measurements that investigate the structure of glacial ice and enable detailed paleoclimate reconstruction, to airplane measurements and satellite altimetry, which assess the mass balance and dynamic of the ice sheet (see, for example, Wake et al., 2009).

Furthermore, AWI scientists observe and model changes of the Arctic sea ice cover and its effect on the exchange between ocean – ice – atmosphere (Fig. 3).

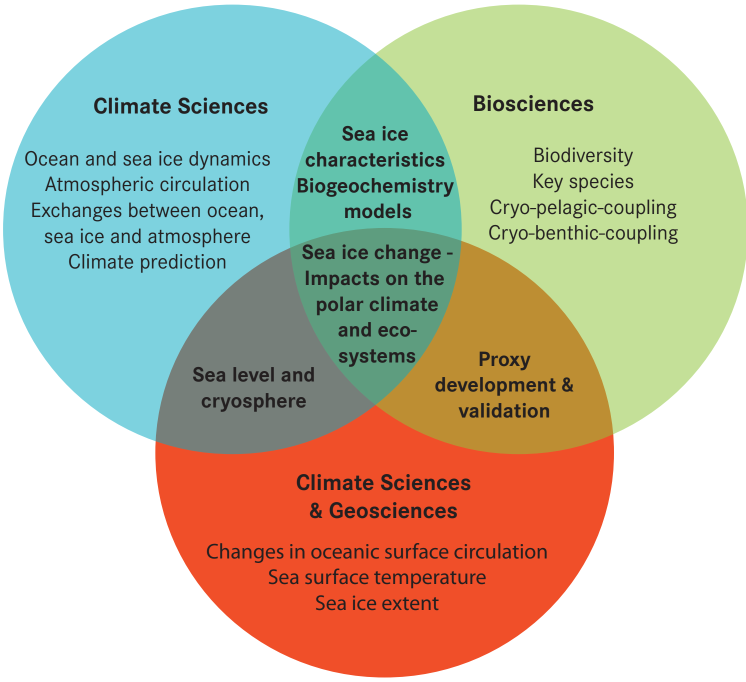

Fig. 3. The impact of sea ice change on polar climate and ecosystems (R. Gerdes, pers. comm.)

For instance, in 2009 a major international airplane campaign, PAM-ARCMIP, was carried out by *Polar 5* operating from Greenlandic, Canadian and US Arctic air bases to study sea ice thickness and atmosphere composition over a large region of the western Arctic (Fig. 4). These data are paramount to improve sea ice and atmospheric models (see, for example, Haas et al., 2010; Stone et al., 2010), and are important for considering the consequences on biogeochemical fluxes and marine ecosystems caused by sea ice retreat.

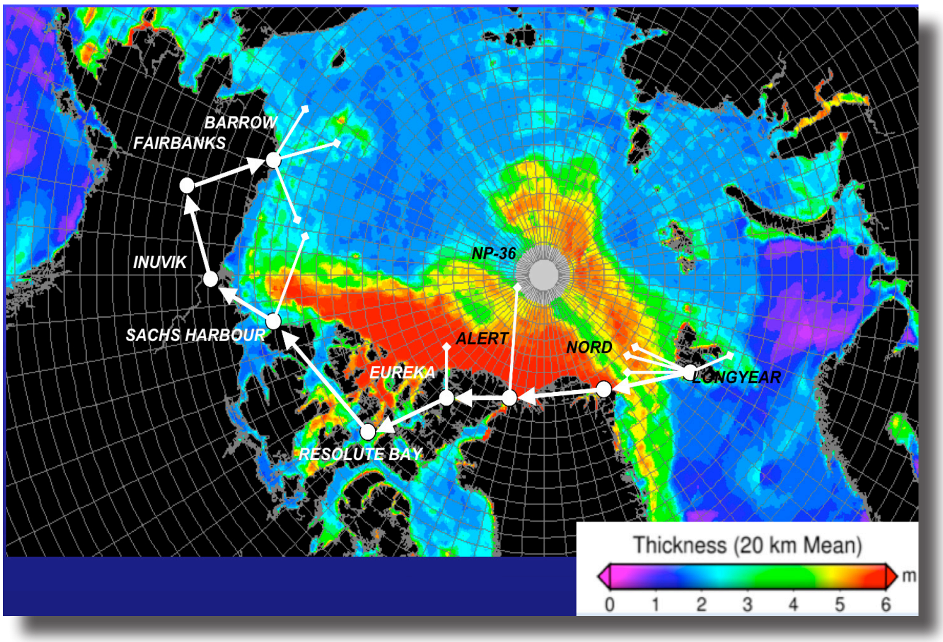

Fig. 4. Track of the PAM-ARCMIP flight of *Polar 5* for the investigation of sea ice thickness and atmospheric chemistry

Atmospheric research at the AWI analyses the dynamics and patterns of atmospheric circulation, as well as the chemical composition of the atmosphere. Important aspects are, for instance, long-time series of observations of aerosols and ozone concentrations in the Arctic. Recently, for the first time an Arctic ozone hole was observed and its origin could be attributed to increased atmospheric stratification due to warming of lower atmospheric layers (Manney et al., 2011). This type of research is part of an international teamwork and requires a well coordinated network of atmospheric observations in the Arctic. Scientists from the AWI Potsdam collaborate for such observations inter alia with Russian colleagues on the North Polar Drift Stations.

AWI investigates periglacial regions in Siberia and in Canada (Fig. 5), including submarine permafrost in the Laptev Sea. The latter is a remnant of permanently frozen terrestrial areas, which were flooded in the Holocene by sea level rise. For millennia, permafrost has preserved great amounts of organic carbon under frozen conditions. With rising temperatures, the release of these stores of organic carbon and of green house gases, such as methane, by thawing of permafrost is a major issue. Microbiological investigations of methane oxidation indicate that under suitable environmental conditions, this biological filter may convert the majority of released methane into carbon dioxide (Liebner et al., 2011). The global carbon cycle is substantially influenced by the release and turnover of carbon from degrading permafrost, but the fate of this organic matter and its deposition in the coastal ocean are still unresolved questions.

Fig. 5. Permafrost distribution in the northern hemisphere and main areas of AWI research
(Map: Hugues Lantuit, AWI; Source: International Permafrost Association)

The Fram Strait between Svalbard and Greenland is the only deepwater gateway between the North Atlantic Ocean and the Arctic Ocean. The outflow of Arctic water and ice determines largely the formation of dense, deep water, which drives the thermohaline circulation of the World's oceans. Around 80 to 90 percent of the water exchange between the Arctic and the other World oceans takes place through the 460 kilometres wide Fram Strait. On the eastern side, warm Atlantic water (the West Spitsbergen Current) flows from the Atlantic along the coast of Svalbard into the Arctic Ocean, while cold Arctic waters (the East Greenland Current) return on the western side of the Fram Strait. In order to study the processes going on in this crucial region, the AWI has established a long-term observation area, named "*Hausgarten*", with oceanographic moorings and biological and chemical study sites in the deep water of the Fram Strait (Soltwedel and Klages, 2009). It is the northernmost deep sea observation station worldwide and comprises 15 sampling stations from 1000 to 5500m water depth (Fig. 6). Regular, annual sampling and measurements by AWI scientists since 1999 revealed a constant, gradual increase in temperature by 0.06 to 0.08 °C at 2500 m water depth between 2000 and 2009 (Glover et al., 2010), and this trend continued in 2010 and 2011 (Fig.7).

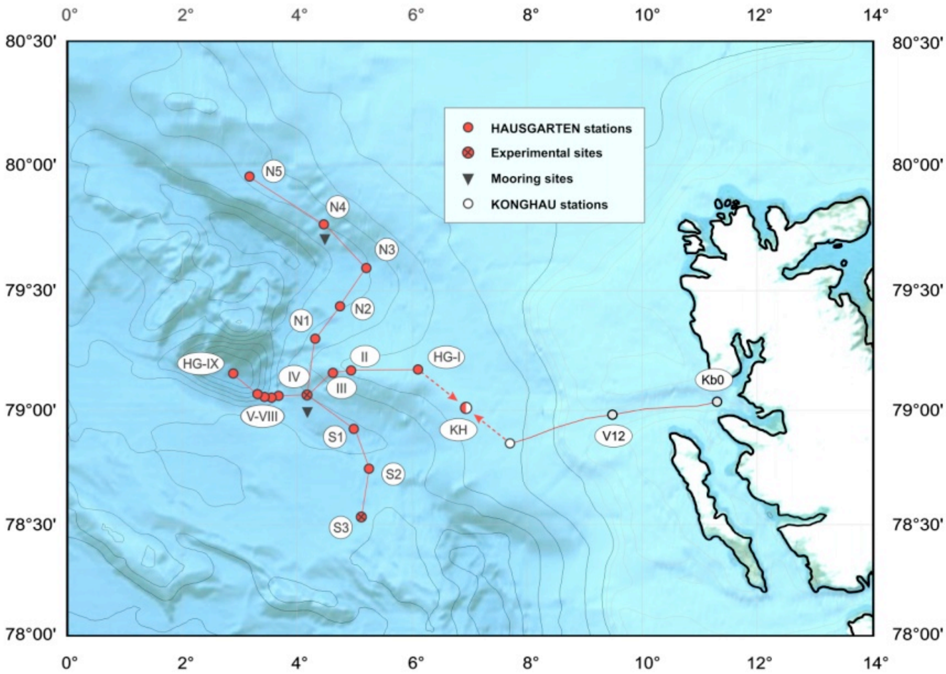

Fig. 6. Permanent sampling sites (HG-I – HG-IX, N1 – N5, and S1 – S3) at the AWI "*Hausgarten*" observatory area in the Fram Strait between Svalbard and Greenland

The observatory has been in operation since 1999 and is the northernmost deep sea site for long-term biological and physico-chemical observations. It covers an area of 110 km x 70 km and a depth range between 1000 to 5500m. Since 2007, the sites KH, V12, and Kb0 are repeatedly sampled within the German-Norwegian KONGHAU project.

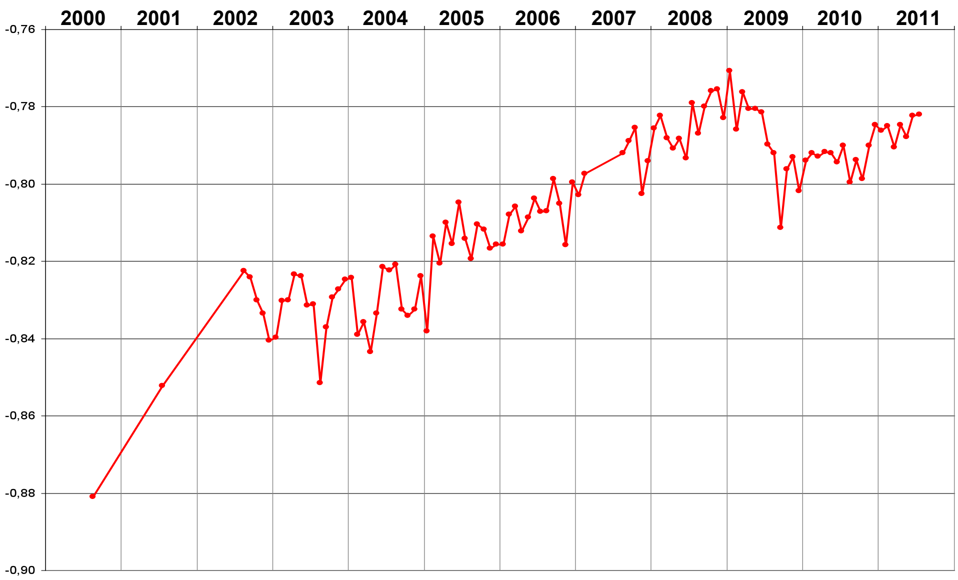

Fig. 7: Water temperature at the "*Hausgarten*" central station (HG IV) at 2500 m water depth from 2000 – 2011 (T. Soltwedel, pers. com)

A similar temperature rise has been observed at a deep-water station in the Norwegian Sea (Østerhus and Gammelsrød, 1999). Although this increase is very small, it is significant for the extremely stable deep-sea temperature regime and an indication of shifts in the exchange processes between the Atlantic and the Arctic Ocean. In the same period sea ice retreated constantly further north. This retreat affected the downward export of particulate organic carbon (POC) (Lalande et al., 2011) contributing to change in the planktonic community composition with Atlantic species replacing traditional polar Arctic species (Hirche and Kosobokova, 2007; Forest et al., 2010). At the sea floor concomitant changes over time in abundance and composition of the benthic communities were observed (van Oevelen et al. 2011). The "*Hausgarten*" station will be extended to become a central international research platform to observe also how changes in the physical environment will affect the biological processes and biodiversity. Processes that are studied in this key area may be used as indicators or examples for future developments within the Arctic system. It is planned to install new automatic observation systems and, if funding can be obtained, to connect the various sites of the observatory to Svalbard via a deep-sea cable. Apart from providing energy to the deployed sensor systems, such a cable connection would allow a constant data transfer to the laboratories, thereby enabling scientists and operators for the first time to observe and respond to important sporadic environmental changes in real time.

Development of research platforms and infrastructure

Despite the technological advances in the last decades, the remoteness, vastness and harsh conditions in the Arctic still pose major challenges for research. Effects of climate change on the Arctic environment differ considerably in time and space. This has to be taken into account in the planning of future research programmes and the development of suitable research platforms and infrastructure. Key areas in the Arctic, such as the Fram Strait mentioned above, have to be observed continuously, in order to detect sporadic events and follow variability and trends of environmental conditions and communities over time. This requires the development of new, innovative equipment and sensors, suitable to function reliably at very low temperatures. A special problem in the polar regions is the lack of year-round studies of marine and oceanic processes - often research at sea is limited to the summer months due to the shortage of research vessels, which are able to operate in Arctic winter conditions. Therefore, one of the major challenges in polar research is the development of international collaboration to coordinate and align observation strategies, to improve data exchange and to increase capacities of appropriate ships and observing infrastructure for collaborative research.

Future strategies and programmes for Arctic research

The climatic change in the Arctic poses many still unresolved questions. The research at the AWI contributes to establishing a baseline of the Arctic system and investigates the alteration of biological and biogeochemical processes, which control biodiversity, food webs, productivity and ecosystem services of the Arctic marine ecosystem. The anticipated future alterations are not only in response to change in the natural system. Also increased anthropogenic impacts are to be expected due to the potential exploitation of Arctic resources and enhanced shipping.

In 2009 the German government adopted a new overarching research programme "Research for sustainable development". This programme identifies, *inter alia,* the Arctic as a key region for strengthening research effort and infrastructure development, both at the national level and in the context of Germany's contributions to EU projects and programmes. In order to outline and guide further actions, a new Arctic research strategy has recently been developed. This document, entitled "Schnelle Veränderungen in der Arktis: Polarforschung in Globaler Verantwortung" (available in German only. The translation of the title would read 'Rapid Change in the Arctic: Global Responsibility of Polar Research'), was prepared under the lead of the AWI with contributions of the main members of the Arctic science community in Germany. It is published by the German Ministry for Education and Research (BMBF, 2011, in press) and summarises the focus areas to be addressed by Arctic research in the coming years under the following headings:

(i) Past, present and future climate change in the Arctic; (ii) contribution of the Greenland ice shield to sea level rise; (iii) decrease of Arctic sea ice; (iv) permafrost and gas hydrates as „unknowns" in the climate system; (v) adaptation of polar organisms to changes in the Arctic environment and (vi) opportunities and risks from increased economic use of the Arctic. For each of these foci and priority areas, the strategy lists the major goals and the central questions, which will drive and have to be addressed by future scientific research. The strategy identifies regional focus areas of the German Arctic research, such as the Fram Strait for deep-sea observations and Svalbard with the *AWIPEV* station for atmospheric and meteorological studies. The Laptev Sea and the Lena delta with the *Samoylov Station* will continue to be the major research localities for studying development / drift of sea ice and permafrost. Large-scale research across the Arctic Ocean is required for geological studies of evolution of the Arctic basin or for interdisciplinary studies of sea ice. In addition to identifying the key topics and questions for future scientific research in the Arctic, the strategy also highlights the need for improved scientific observations, synthesis analyses and predictions as regards the chances and risks resulting from Arctic change. The strategy recognises that the developments in the Arctic can have impacts far beyond the region itself, and, therefore, asks for science in support of a sustainable approach, the transfer of knowledge into society, technology transfer, and the continued support/promotion of young scientists.

The study and understanding of the complexity of the Arctic system, how this system has evolved and how it will be affected by and adapt to global change, will continue to play a major role in the scientific work carried out at the AWI. In the preparations of the new five-year research programme, which will succeed the current PACES programme from 2014 to 2018, the AWI has already identified the need to further investigate issues such as ice sheets dynamics, mass balance and sea level rise; the changing sea ice and the interaction with atmosphere, ocean and ecosystems; or the degrading permafrost landscapes, carbon turnover and gas exchange with the atmosphere. The new programme will also contain a special focus on the polar ocean dynamics, biodiversity of the deep Arctic Ocean and impacts on biogeochemical fluxes caused by changes in the Arctic ecosystem. The adaptation of ecosystems, of key species and behavioral patterns to environmental change will be an important research field in coastal and shelf areas.

The geo-, bio- and climate sciences divisions at the AWI with their multi- and interdisciplinary links to other national and international partners are well suited to address these issues and the challenges ahead. In order to communicate and enhance the impact of the results of this work, it is foreseen that the new programme will also include research into science-stakeholder interactions. One aspect, for example, will be the development of innovative information and knowledge management systems and platforms to transfer the research results effectively to policy makers, society and those who are directly affected by change in the Arctic region. The latter will be carried out in cooperation with partners in Arctic countries and in the context of international organisations, such as the International Arctic Science Council (IASC), as a contribution to the international arctic science policy framework.

International cooperation

The new Arctic research strategy also highlights the need for joint and coordinated action, especially at the international level. The various international projects and programmes carried out in the context of the International Polar Year 2007/8 have demonstrated the benefits of combining the expertise and data of many partners in the analysis of the environmental changes occurring in the Arctic and their regional and global effects.

The scientific cooperation between Russia and Germany has a long tradition (see article of Prof. Hempel in this volume). In 1987, their governments signed the first agreement on cooperation in science and technology, followed in 1995 by a specific agreement regarding the collaboration in marine and polar research. In the 1990s, this collaboration has been strongly fostered by the former AWI directors Gotthilf Hempel and Jörn Thiede and their colleagues in AWI and GEOMAR. Today, the AWI has bilateral collaborative agreements with all leading Russian marine and polar research institutes in support of joint scientific research and logistical operations in polar regions.

In this respect, the Otto Schmidt Laboratory in St. Petersburg (OSL, founded in 2000, see http://www.otto-schmidt-laboratory.de/) and the Master Program for Applied Polar and Marine Science (POMOR, founded in 2002, see http://www.pomor.de/) are prime examples for successful German – Russian collaboration. The OSL is located at the Arctic Antarctic Research Institution (AARI) and supported by the German Ministry for Education and Research, the Russian Ministry for Education and Science, the Russian Federal Service for Hydrometerology and Environmental Monitoring, as well as the AARI, AWI and GEOMAR. It provides state-of-the-art laboratory facilities for polar and marine research and logistical support for joint research projects of Russian and German teams. The Master programme POMOR is jointly taught by German and Russian lecturers in the field of polar and marine sciences at the St. Petersburg State University and the OSL.

These institutional collaborations are being supplemented by framework agreements and joint programmes between the Helmholtz Association and Russian counterparts, such as the Russian Academy of Sciences and the Russian Foundation for Basic Research. Young researchers are being supported by the 'Helmholtz – Russia Joint Research Groups' (HRJRG) supported jointly by German and Russian funds. In the context of the German - Russian Year of Education, Science and Innovation 2011/12, many new ideas and initiatives are being launched by science and research organisations, universities and companies in both countries to strengthen existing ties and identify new themes and issues for future collaboration.

The ongoing projects and new approaches / initiatives, described above, are based on freedom of research, mutual hospitality in research stations and on board research vessels, exchange of data and scientific and technical personnel, close cooperation in the publication of results and other information. These issues will in future become even more important, especially in the light of increasing interest in the Arctic region and the claims over extended continental shelf areas. In order to carry out research in Arctic waters under national jurisdiction, the AWI requires permits of the respective riparian country. Future research, therefore, needs to become even more internationally oriented and has to engage and involve partners from Russia and other Arctic countries actively in all stages of the project / expedition from the beginning to the final analysis and publication of results. Joint meetings / workshops, the exchange of personnel and ideas are ways of getting to know (and to learn from) each other. The Murmansk Symposium 2011 and the present publication volume are just two steps in this direction. As a next step MMBI and AWI plan to jointly analyse, compare and exchange the long-term, biological monitoring data obtained over more than 50 years by both institutes along the Kara transect and at the Helgoland roads station, respectively. We hope to derive new insights into long-term ecosystem changes in these regions and into potential linkages between arctic and temperate ocean processes. It is a good example of joint data analysis and of combining the complementary expertise of the two institutions.

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Further Reading

AWI Biennial Report 2008/2009 (in German & English) available at www.awi.de/de/aktuelles_und_presse/buecher_und_broschueren/broschueren

Biosciences at the Alfred Wegener Institute: Polar ecosystems in a changing climate available at www.awi.de/fileadmin/user_upload/News/Print_Products/PDF/Brochures/Polare_ecosystems_english.pdf

Climate Research at the Alfred Wegener Institute: The Polar Perspective - available at www.klimabuero-polarmeer.de/fileadmin/user_upload/Pictures/Downloads/The%20Polar%20Perspective-e.pdf

CLIMATE AND OCEANOGRAPHIC PROCESSES IN THE BARENTS SEA

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Abstract

Results of the Barents Sea climate system studies in the 20th – early 21st centuries are introduced. Characteristics of current climate trends of water temperature and ice cover anomalies in the Barents Sea are given. They serve as the main indicators of the European Arctic marine ecosystems' state. A conclusion is made on the near end of the present warm phase and return of the Barents Sea ecosystem functioning to the mean long-term state. It has been suggested that further changes in climate system will be of cyclic character, with a period close to 30 years.

Introduction

Climate changes in marine ecosystems are one of the major issues in modern oceanography. Climate anomalies are the most important external impact factor directly affecting biological productivity and biological resources in the sea. In polar waters the associated variability of ice cover determines the living conditions of marine organisms at all trophic levels. In present times of expanding economic activity in the western Arctic seas, the importance of integrated natural research increases, among which the study of regional features of thermohaline and ice conditions and their climate variability is of significant relevance.

The Barents Sea is one of the most important areas for monitoring climatic changes in the Western Arctic during the 20th – early 21st centuries. This extreme northeastern extension of the North Atlantic current ("Gulf Stream") is notable for significant spatial and temporal variability of thermohaline and ice characteristics (Hydrometeorology and hydrochemistry of USSR seas, 1990). The most complete assessment of this variability was achieved by using observations at the standard hydrological section VI along 33° 30 'E (the so-called "Kola Transect"). The relative regularity of these observations allows performing systematic assessments at different time scales.

In this paper specific features of thermohaline and ice conditions' climate variability observed in the Barents Sea in the 20th – early 21st centuries are considered.

Materials and methods

The study of climate dynamics in the Barents Sea was carried out based on the MMBI oceanographic database, with the data received during the institute's expeditions for more than 75 years and as the results of international exchange. Arrays of thermohaline data on regularly repeated sections of the Barents Sea have more than 220 thousand hydrological stations for the period from 1900 to 2010 (Matishov et al, 2004, 2005, 2009). Practically all observations to 2000 were performed using standard bathometric series. Data for summer seasons of 2001-2010 were obtained within the framework of annual MMBI expeditions on board the RV *Dal'nie Zelentsy*. Overall, more than 750 stations were performed within the first decade of the 21st century in the study area applying the CTD-profiler SEACAT SBE 19plus. Mean values and anomalies of temperature were calculated for the whole period of observations. A water temperature anomaly is a difference between the temperature value registered during the observations and its average long-term value (norm) calculated by depth with an interval of 5 m for every station for the month of observations. The monthly norms of water temperature were calculated on the basis of a renewed database (Matishov et al., 2004) for the middle date of each month.

Analysis of the Barents Sea ice coverage (sea area covered with ice relative to the entire area of the Barents Sea), regardless of ice concentration and ice conditions dynamics, was based on combined data of ship observations and aerial surveys from 1960 onwards and since 1977, particularly on satellite images. The electronic database of the Barents Sea ice cover and conditions, formed by the MMBI, contains time series of ice area monthly values for 1960 – 2010, and 408 monthly ice charts for the period of 1977 – 2010. Calculations of the ice cover area during the period of 1977 – 2010 were made at the MMBI Laboratory of Oceanography and Radioecology applying GIS software MapViewer. For monthly charts' construction, data of remote sensing from the AARI Ice Center were used (Review ice maps of the Arctic Ocean 2000-2009, 2011).

Results and discussion

Among the factors, which determine the climate of the western Arctic seas, the advection of warm water by the North Atlantic current plays a important role. In the Barents Sea a frontal zone separates Atlantic waters entering the non-freezing southwestern part of the Barents Sea from the rest of the water area with transformed by processes of convection water mass and seasonal ice cover (Fig. 1). The distribution of the Atlantic waters along bottom troughs leads to considerable spatial variability of water temperature. So, for understanding of climate trends, averaged characteristics should be used (Matishov et al., 1998, 2009).

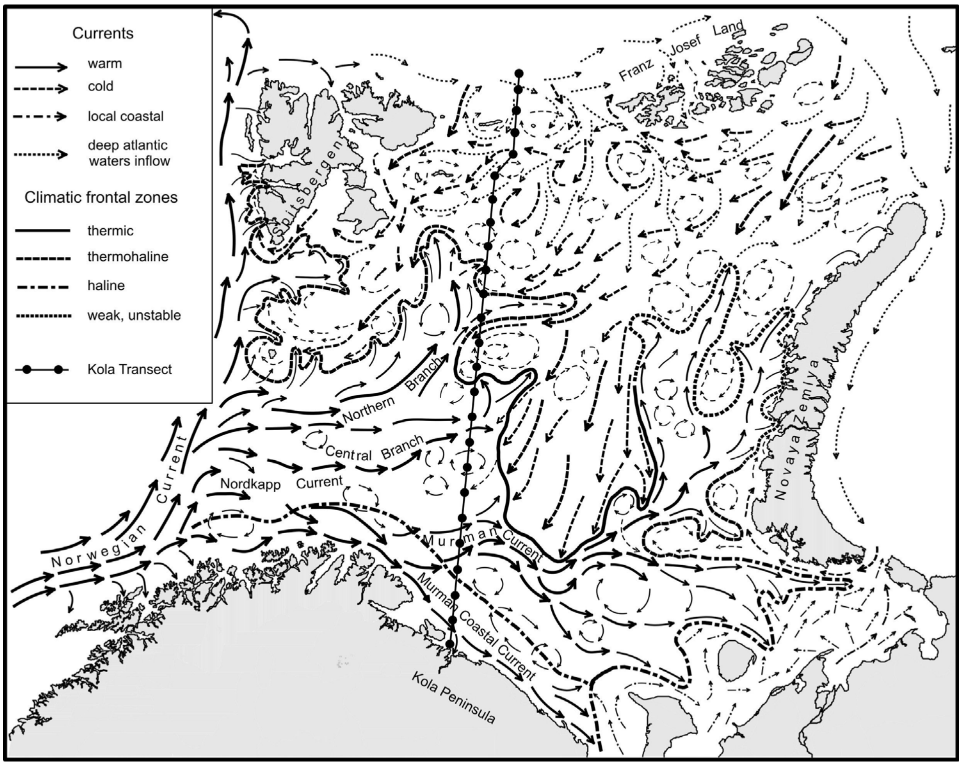

Fig. 1. Currents and frontal zones of the Barents Sea and location of the Kola Transect: 1-3 - currents (1 - warm 2 - cold, 3 - local coastal), 4 - distribution of the deep Atlantic waters, 5-8 - climatic frontal zones (5 - thermal, 6 – thermohaline, 7 - haline, 8 - weakly expressed, unstable), 9 – the Kola Transect

The inflow of Atlantic water to the Barents Sea, which is the main factor of climate variability, can be calculated using the direct measurements of current velocities and directions. However, such time-series are not numerous at present and totally absent for the past periods. So, the long-term dynamics of oceanological processes can by assessed only by variations of water temperature and (to a lesser degree) of salinity (Levitus et al., 2009). The thermohaline structure of water masses at standard sections is also affected by geomorphology of glacial bottom (Matishov, 1984; Matishov et al., 2009).

The Kola Transect along 33º30' E (Fig. 1) is unique because of its long observation period, which began in 1900, was interrupted in 1907-1920 and 1942-1944, and is available in continuous series since 1945. In most cases, only the southern part of the section up to 74º N is regularly examined (Karsakov, 2009). However, thermohaline structure to the north of 74º N latitude is much more interesting, as it allows exploring all Atlantic water streams flowing into the Barents Sea from the west and the polar front (Fig. 1). Average temperature of the Atlantic water in the layers of 0-50 and 0-200 m remains a commonly used indicator of climatic variability of the Nordic Seas and of the Barents Sea in polar oceanography, as it respectively reflects the processes in the surface layer of the sea and throughout the water column (Matishov et al., 2007).

On a secular scale of climate dynamics, warm cycles were observed repeatedly. The warm phase in the 1920-30s was strongly marked (Fig. 2). It was linked to the climatic phenomenon of the first half of the 20th century, known as "the warming of the Arctic," which manifested itself also in air temperature increase at coasts and islands and reduction of seasonal ice cover in the Arctic seas (Zubov, 1945; Vinje, 2001). At the Kola Transect two warm periods were registered, with temperature anomalies up to +1,0 °C in the early 1920s and again for most of the 1930s.

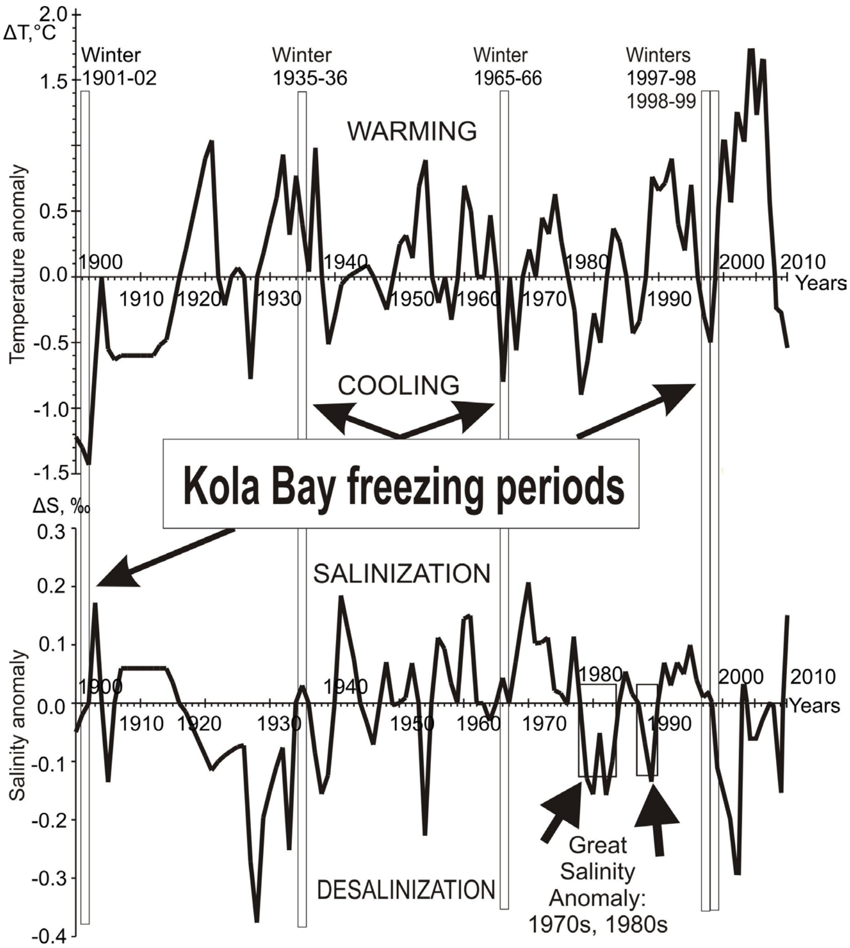

Fig. 2. The mean yearly anomalies of water temperature (ºC) and salinity (‰) at the Kola Transect in 0-50 m layer from 1900 to 2010 (the Great Salinity Anomaly is according to: Belkin et al., 1998)

A similar warming period, which has begun in the late 1980s (and still goes on), is revealed at the Kola Transect. As evidenced by salinity data, this increase in temperature is mainly caused by strong advection of Atlantic water (Matishov et al., 2009). Short-term cooling of 1997-1998 was observed against the background of long-term warming (Matishov et al., 1999; Bushev et al., 2001).

In the early 21st century warm anomaly in the Barents Sea in the 0-50 m layer reached its peak between 2001 and 2007. In 2008-2010 it was followed by a cooling trend. The water temperature anomaly changed from plus 1.85 ºC in 2004 to minus 0.18 ºC in 2010 (Fig. 3).

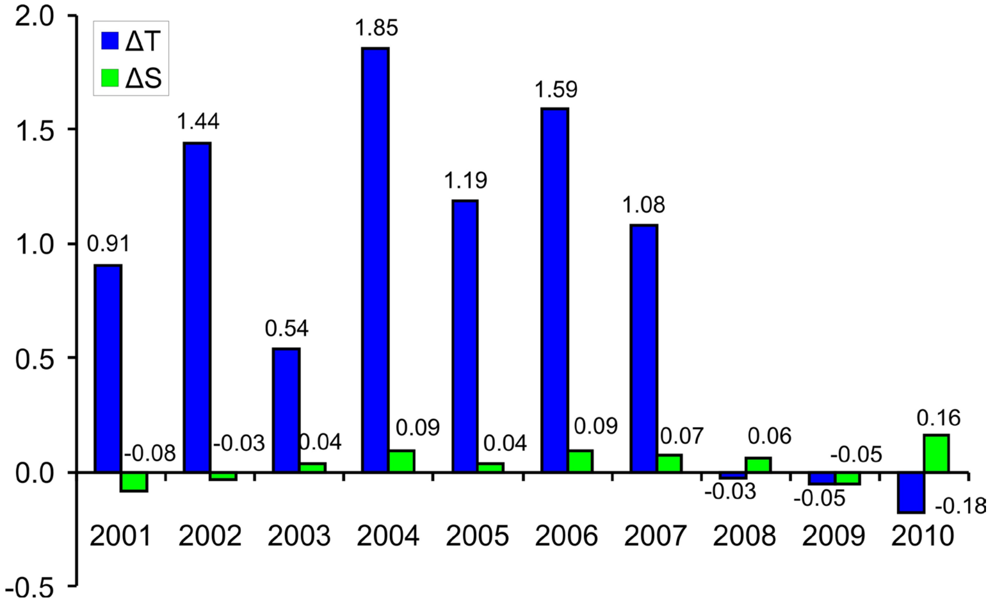

Fig. 3. Summer (July-August) anomalies of temperature (°C) and salinity (‰) in the 0-50 m layer at the Kola Transect south of 78° N in 2001-2010 according to the data from expeditions on board RV *Dal'nie Zelentsy*

Our data refer to summer months, but they can be reasonably extended to all seasons, as summer thermal regime is the most variable. So, according to the research handbook (Hydrometeorology and hydrochemistry of USSR seas, 1990) standard deviation of monthly average surface layer temperature varies in different areas of the Barents Sea from 1 to 3 °C in summer, whereas in winter it ranges from 0.5 to 1.0 °C.

Changes of air temperature at the western Arctic sea coasts during the second half of the 20th – beginning of the 21st century follow the same patterns as the surface waters, although inter-annual variability of mean annual air temperature is much higher (anomalies of opposite sign alternate with 1-2 years intervals). Results of average annual air temperature series analysis made by similar methods for stations of Murmansk (Kola Bay: development and rational nature management, 2009) and Malye Karmakuly on the southern island of Novaya Zemlya (Zubakin and Buzin, 2008) are presented in recent publications. In both cases identified trends vary considerably depending on time interval: for 50-60-year series the trend is close to zero, in 1980-2005 it was in both cases increasing at a rate of about 0.5 °C / 10 years.

The air temperature monthly values' anomalies in Murmansk since 1919 showed that the chronological distribution of anomalies is close to uniform, including the last two decades, when a pronounced warming trend was traced in many parts of the world. Preponderance of positive anomalies was registered only for 2003-2008.

Sea ice coverage and conditions were calculated by annual or monthly averaging over the entire Barents Sea. The Barents Sea is characterised by considerable inter-annual and intra-annual fluctuations of sea ice cover and conditions in any month in contrast to the Norwegian-Greenland Basin, where ice conditions change only little from year to year, and the Kara Sea, where variations are significant only during a short summer-autumn period (Zhichkin, 2010; Koenigk et al., 2009; Vinje, 2001). Ice coverage is closely related to sea water temperature. So, for the Barents Sea, correlation coefficient between ice coverage in August and water temperature at the Kola Transect the same month for the period 1960-1998 is -0.83 ± 0.03 (Hydrometeorology and hydrochemistry of USSR seas, 1990). However, ice cover and temperature series are not free of seasonal and monthly gaps in time and systematic uncertainties in methods, and for an objective assessment of climatic trends both types of information should be used in parallel.

Long-term and seasonal variability analysis of ice regime of the western Arctic seas was previously made by Zubakin (2008) and Mironov (2004). New data on sea ice cover and conditions in individual regions of the Barents Sea are presented in (Buzin, 2008; Zubakin, 1987) and on the current changes of the entire Arctic Ocean ice cover – in (Alekseev et al., 2007). To perform our own assessment of climate trends, we used MMBI electronic database of the Barents Sea sea ice coverage and conditions for 1960-2010, referred to above. These data provided the base for calculations of monthly and mean annual norms and anomalies of the Barents Sea ice cover and conditions over the indicated period.

The entire 50-years period is divided into two intervals by the mean ice extent variability and changes: before 1990 - a period with heavy ice conditions domination, since the beginning of the 1990s to our days – a period with favourable conditions (Zhichkin, 2010). Throughout the period a gradual decrease in ice area to the minimum values in 2006-2007 took place. However, in 2008-2010 a tendency to ice area increase was registered (Fig. 4).

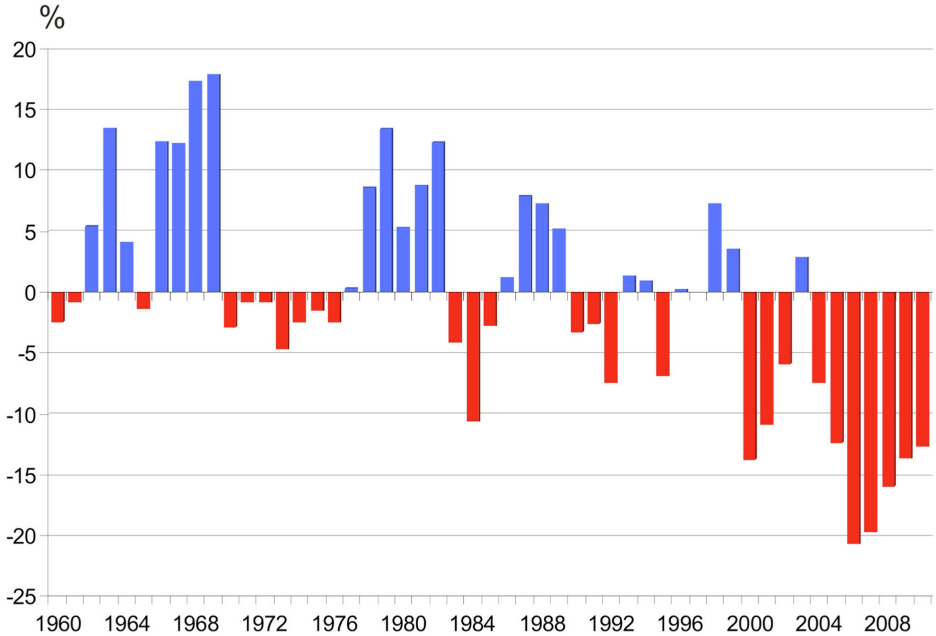

Fig. 4. The mean annual anomalies (%) of sea ice cover in the Barents Sea for the period of 1960-2010

The largest positive anomaly (high ice cover) over the past half a century was observed in 1969 (+18%), while the largest negative (low ice extent) – in 2006 (-21%).

Ice cover anomalies are characterised by high inertia in comparison with those of water temperature. According to our records, periods of increased ice cover (not below the norm in any of the months) longer than one year were observed in: January 1963 – October 1964 (22 months), January 1966 – January 1968 (25 months), March 1968 – December 1969 (22 months), November 1979 – August 1981 (22 months), December 1981 – December 1982 (13 months), and December 1986 – March 1989 (26 months). After 1990 duration of increased ice cover periods does not exceed 6 months and after 2000 there was only one case, when it lasted for 5 months (November 2002 – March 2003). It is noteworthy that after excluding minor anomalies of opposite sign in February 1968, a record-long period of heavy ice conditions was observed, from the beginning of 1966 to the end of 1969.

Duration of continuous abnormal light ice conditions in the 1960s did not exceed 7 months. Later on, some periods lasted for more than one year: August 1972 – September 1973 (14 months), January 1984 – March 1985 (15 months). Between 1985 and 2000, ice cover reduction was frequent but relatively short-term; from December 1999 to October 2001, reduced ice cover was for 23 months. Then, after some stabilization (the average value for 2003 exceeded the norm by 2%), an unprecedented period of reduced ice cover took place, from February 2004 to December 2008. In the series of average values, the years of 2006, 2007, and 2008 were the least ice covered – 17, 18, and 22% respectively.

Complete ice extinction in the Barents Sea for one month and longer for the considered period was registered 10 times. All the cases were in August-October. In 1972, 1984, and 2000 ice-free period lasted up to three months, whereas in 2004 and subsequent years with abnormally light ice conditions, its duration did not exceed two months.

Indicators and values, averaged within hydrographic boundaries of the seas, do not always give a complete picture of the specific features of ice conditions, which are important for marine ecosystems functioning. Ice conditions in coastal areas are of great importance for the western Arctic seas. There are three types of coastal zones in the area: 1) non-freezing coastal zone of the Barents Sea, where, nevertheless, ice could possibly be formed in isolated bays and tidal plains as well as freshwater ice could be imported with riverine runoff; 2) coast of the White and southeastern Barents Seas, including the Barents Sea coast of the Novaya Zemlya, where a regular alternation of ice and ice-free periods takes place; 3) the Franz Josef Land and Spitsbergen Archipelagoes (except Spitsbergen's warm southwestern coast), where ice cover is possible all year round and short ice-free periods from July to September are irregular.

In the south-western Barents Sea, ice conditions of the Kola Bay (where not less than 90% of human population and nearly total civilian turn over of shipping of the Russian part of the Barents Sea coastal zone are concentrated) are most important to marine activities. Drift ice from the open sea areas was never registered in the Kola Bay during the entire observation history. Formation of ice directly in the bay is possible due to more severe winter conditions as compared to the open coast and abundant river runoff. In winters close to norm, there is only floating ice in the bay, which is constantly taken out to the sea by tidal and runoff currents. In abnormally cold winters of 1901/1902, 1935/1936, 1965/1966, 1997/1998, and 1998/1999, the bay area until its middle part (Salnyi Island) was covered by fast-ice for more than a month (Kola Bay: development and rational nature management, 2009; Matishov, 2008). The cases coincided with significant negative anomalies of air temperature and with the absence of pronounced anomalies of temperature, salinity and ice cover in the open sea areas.

Ice season in the White Sea lasts normally from December to May. In these months, there is considerable spatial and temporal variability of ice conditions in the open areas, but they are relatively stable in the coastal areas. In the Southeastern Barents Sea, seasonal ice cover does not vary much from year to year. Its formation usually begins in November in the Pechora and Khaipudyrskaya Bays, and then it extends to the entire coastline from the Kanin Nos Cape in the west to the Kara Gate Strait in the east and further along the Barents Sea coast of the Novaya Zemlya within a very short period of time. From January to April, the entire coastal zone is constantly ice-covered. The ice edge slowly shifts to the Central Barents Sea, reaching the maximum western location (40 ° E) usually in April. Reduction and destruction of ice is usually in June. Ice in the southeastern Barents Sea remained at least for 4 months (January – June) over the entire period, according to ice charts, and only in abnormal seasons of 2007/2008 and 2008/2009, solid ice cover in the Southeastern Barents Sea was finally formed in February. However, in the late 2009 its formation time approached the norm.

Arctic archipelagoes are constantly surrounded by ice from October to June, but during a short warm period, ice conditions in their coastal waters are extremely variable. For example, a set of situations is possible for the Franz Josef Land (FJL) in August – September from complete closure of all islands to complete clearing of the coastal zone. In June – July (and even, as an exception, in May), there may be stable flaw polynyas, both on the southern and northern coasts of the FJL (Environment and ecosystems of the Franz Josef Land (archipelago and shelf), 1994). Such situations have become much more frequent since 1997.

In most years the FJL coastal zone is partially ice-free for 2-3 months, from July or August to September. A remarkable exception was the period from 1993 to 1999. In 1993, 1996, and 1999, such light ice conditions were observed only in September, and in 1994, the coastal zone was completely ice-covered during all the months. However, in 1997 and 1998 certain areas were ice-free from May to September.

Complete clearing of the FJL coastal waters occurred in some months only as an exception: in September 1984 and 1985, in August and September 2000, in September 2005 and 2008. October 2009 was dramatically abnormal when ice edge remained steadily to the north of the FJL. In November-December 2009, ice conditions of the FJL returned to their normal, but abnormally light conditions remained in the Barents Sea.

Apart from that only exception, complete freezing of the FJL coastal waters was always registered in September or October. Periods of ice fracture were more variable and during the considered period shifted to earlier ones. While in 1987-

1997, ice destruction began no earlier than in June, since 2000 it has systematically been observed in May – June (although this might be explained by more complete polynyas identification on satellite maps).

Thus, in general terms ice conditions in the Barents Sea during the last four decades of the 20th century varied with no clear trend. Then a dramatic decrease of the total ice cover of the Barents Sea occurred. It was accompanied by positive temperature anomalies of the surface layer. Changes of ice conditions in different coastal areas were more complicated.

Conclusion

The combined analysis of temperature and ice conditions shows that a period of warming began in the Barents Sea in the late 1980s and continued with short interruption (cooling of 1997-1998) till 2007. This warming of the Barents Sea somewhat exceeded the well-known warming of the 1920-30s by intensity and was comparable by duration. Since 2008 the climatic system seems to return to a cooler state. There are reasons to believe that further changes in the climate system will be of cyclic character and a further warming is less probable than return to the long-term cyclic pattern.

The concept of the anthropogenic warming supposes the upward trend of water temperature and downward trend of ice cover. However, the temperature anomaly of 1920-30s can be explained only by natural variability. Although we have not a comparable set of ice cover data on the Barents Sea, it is known that ice conditions in the Russian Arctic Seas were favourable for shipping along the Northern Sea Route during 1930s.

The next 3-5 years will show, whether the present cooling is a part of a multiyear cycle or just an interlude to a long-term warming.

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THE LAPTEV SEA PHYTOPLANKTON STUDIES: PAST AND PRESENT

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The history of phytoplankton studies in the Laptev Sea is more than hundred years old. It began with Adolf Erik Nordenskjöld's expedition on board the *Vega* in 1878-1879 and Fridtjof Nansen's expedition on the *Fram* in 1893-1896. Simultaneously, information about the shores of Siberia and their surrounding waters, insufficiently studied at that time, were collected and water samples for studying aquatic microorganisms were taken. The Russian Polar Expedition on board the schooner *Zarya* in order to find the Sannikov Land occurred under the leadership of Baron Eduard Toll in 1900-1903. In 1910-1915 an integrated Russian hydrographic expedition under the leadership of Boris A. Vilkitsky on the icebreakers *Taimyr* and *Vaigach* took place. Attempts to pass the Northern Sea Route were the main purpose of those expeditions, i.e. to make voyage through the Arctic Ocean from the Atlantic to the Pacific along the coasts of Europe and Asia, vainly sought for three centuries. The first systematic sampling of biota of the Laptev Sea, in particular, plankton algae, was carried out during the expeditions aboard the schooner *Polyarnaya Zvezda*, organised by the Academy of Sciences of the USSR in 1926 and 1927. The results of those studies were presented in a monograph entitled "Studies of the USSR Seas (Ed. K.K. Deryugin)" (Kiselev, 1932). The Russian studies increased in intensity and effectiveness since the early 1990s within the framework of various international programmes, specifically by the joint Russian-German project "The Laptev Sea System". The project aimed at investigating the causes and mechanisms of climate fluctuations in the environment of the Laptev Sea system during the last 10.000 years in order to understand current environmental changes and predict future ones.

The main research directions cover:

- state and development of modern cryosphere;
- assessment of freshwater and energy balance of tundra;
- geomorphologic studies of the Lena River delta;
- studies of coastline erosion;
- emission and green gases fluxes;
- soil studies;
- volume and distribution of river runoff and deposits;
- hydrological and hydrobiological studies of the Laptev Sea.

It should be noted that despite a large scale of efforts applied, there are still many white spots in the Laptev Sea studies. This is primarily due to very harsh climatic conditions in the region. Of all the marginal seas of the Arctic, the Laptev

Sea is influenced the least by the warm Pacific and Atlantic currents. The polar night lasts for about 3 months in the south and about 4 months in the north. The negative air temperatures remain for 11 months in the Northern Laptev Sea and 9 months in the Southern Laptev Sea. The average air temperature in the coldest month January is from —26 to —28°C in the south and from —31 to —34°C in the north with an absolute minimum of —61°C. The average temperature in the warmest month August does not exceed 5—7°C in the south and 1 °C in the north. Along with low winter temperatures typical of all Siberian shelf seas, the Laptev Sea differs by a wide shelf and abundant river runoff, above all, of the Lena River (about 700 km^3 per year).

The Laptev Sea is ice covered most of the year (from October to May). Ice formation begins simultaneously throughout the sea in late September. Extensive fast ice with thickness of up to 2 meters develops in its shallow eastern part until 25 meters isobath in winter. A stable zone of drifting ice is located to the north of the fast ice edge. Ice is carried away from fast shore ice constantly moving under the influence of offshore wind and currents and forming large areas of open water – flaw polynyas – a unique phenomenon under severe polar winter conditions. Flaw polynyas are currently allocated as a separate type of the polar sea landscape with its specific features of plankton community organization. Vertical water circulation activity in polynyas, high concentrations of and absence of ice cover would eventually allow a higher productivity of phytoplankton in these areas. The entire system of polynyas is formed in the Laptev Sea, with the Eastern Severozemelskaya, Taimyr, Lena and Novosibirskaya polynyas being singled out. All these polynyas are parts of the huge quasi-stationary Siberian polynya.

Thus, all above-indicated environmental factors define the structure and functional features of phytoplankton communities in the Laptev Sea water area.

More than hundred scientific expeditions were carried out in the Laptev Sea waters over the last 120 years. In recent times they were integrated expeditions, by the research vessels *Akademik Fedorov, Kapitan Dranitsyn, Kapitan Danilkin, Polarstern*, as well as nuclear icebreakers along the Northern Sea Route (by MMBI KSC RAS employees). However, it should be noted that up today there are only few, mostly taxonomic studies on the Laptev Sea phytoplankton in summer and autumn. These are Gran's work (Gran, 1904) based on the results of Nordenskjöld's expedition, Kiselev's work as a result of expedition of 1926-1927 (Kiselev, 1932), Sorokin's work on chlorophyll and primary production (Sorokon and Sorokin, 1996), and Tuschling's works (Tuschling, 2000; Tuschling et al., 2000) devoted to seasonal micro-phytoplankton dynamics studies in the Southeastern Laptev Sea – fast ice formation area. During the last 10 years some results were presented at different conferences including workshops on the Russian-German Cooperation System Laptev Sea. Furthermore, we should mention the work by Vetrov, Romankevich, and Belyaev (2008) on chlorophyll, primary production and organic carbon in the Laptev Sea where data are presented of SeaWiFS and MODIS satellite-borne observations and data on chlorophyll content collected during expeditions of 2004-2006.

Micro-phytoplankton of the Laptev Sea caught by net >20µm numbers 199 species, 82 of which are represented by diatoms. Plankton flora in the major part of the water area is typically marine (73 taxa are marine and brackish-water forms), with predominance of neritic forms, which are typical for the arctic seas (Timofeev, 1998). A typical component of pelagic algocenosis (phytoplankton community) is boreal species of microalgae, observed in the deep-water Northern Laptev Sea due to the influence of the Atlantic waters. High abundance of cryopelagic forms is registered in polynyas and shore leads.

Spring season begins in April and is characterized by the formation of spring planktonic micro-algae with a maximum of up to 1.6 x 10^6 cells/l with biomass up to 85 µg C/l), and blooming begins under solid ice cover (with thickness more than 2 meters) in the zone of fast ice in the part of the water area outermost of the Lena Delta (Fig. 1). It is interesting to note that the phenomenon of under-ice blooming was described by MMBI researchers also for the Barents Sea (the Pechora Sea area) and the Kara Sea (the Ob-Yenisei shallow area) (Makarevich, 1998).

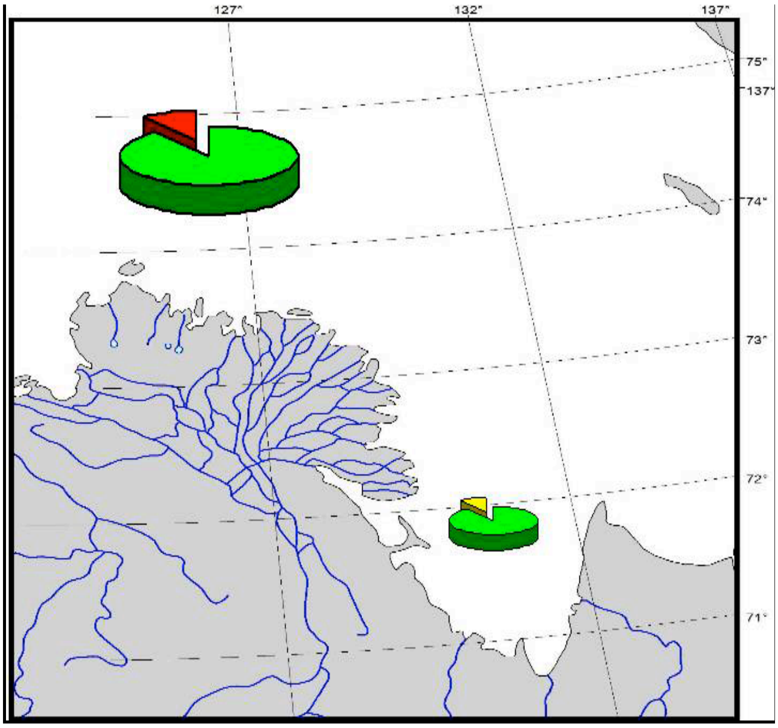

Fig. 1. Structure of phytoplankton communities in spring period. (Diatoms are in green, dino-flagellates – in red, chloro- and crysophytes – in yellow)

The minimum values of biomass (0.8 µg C/l) were registered in the same period in the coastal areas, particularly, in Buor-Haya Bay. The spring micro-phytoplankton blooming peak is formed by diatoms, which account up to 90 % of the total community biomass. The dominance of diatoms in spring is typical of all the arctic seas in general. At the same time, the structural organization of microphytoplankton community (pelagic phytocenosis) differs qualitatively in some areas of the Southeastern Laptev Sea. Besides the dominant diatoms, the rest of the community in the seaward area is represented by dinoflagellates, while in the bay chloro- and crysophytes are replacing the dinoflagellates. The latter fact indicates a constant influence of the river runoff on the structural organization of microplankton community. Moreover, freshwater and euryhaline forms prevail in the composition of diatoms in the bay area. Levels of phytoplankton biomass registered during under-ice blooming are quite comparable to summer phytoplankton biomass of open water. The maximum annual values are registered in spring during the breakup of Siberian rivers and the maximum of river runoff.

During summer period (Fig. 2) strict density stratification is set up in the zone of freshwater runoff influence, and thickness of freshened layer reaches 15-20 meters. At the same time, the upper 30-50 meters in the northeastern water area are occupied by cold desalinated water masses, formed as the result of sea ice melting. The biomass maximum (> 200 μg C/l) is observed in the coastal areas where the community of microalgae is formed by freshwater diatoms with a substantial proportion of green and blue-green algae. Phytoplankton biomass decreases the further it is away from the shore together with a relative increase in the proportion of autotrophic dinoflagellates in the community (Tuschling, 2000).

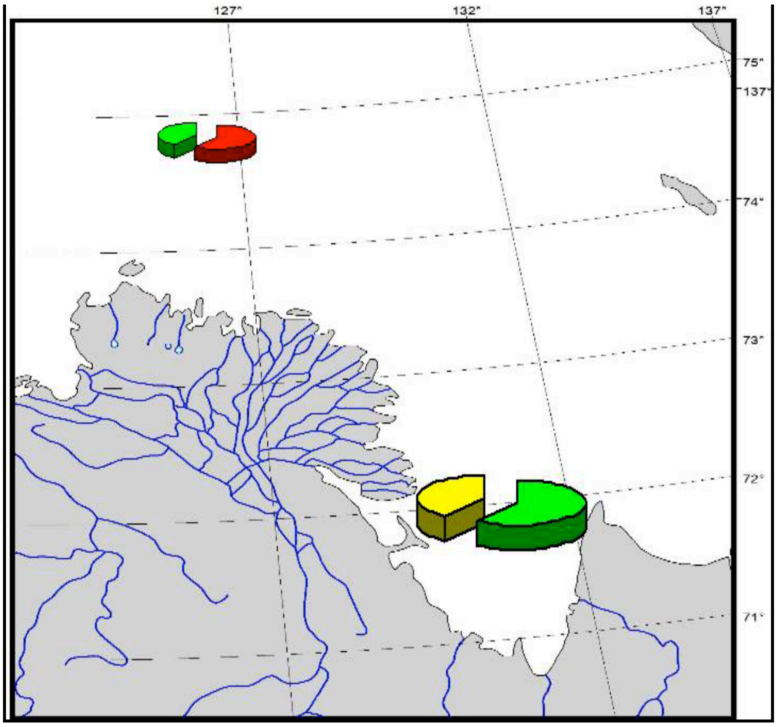

Fig. 2. The composition of phytoplankton communities in summer. Legend – see Fig. 1

The biomass of micro-phytoplankton is low in autumn (from < 0.1 to 5.7 μg C/l); the minimum values are registered along the very coast. The autumn period is characterized by a sharp decrease of light conditions and the beginning of sea ice formation. The qualitative composition of the community during the period is rather heterogeneous: diatom algae dominate spatially in the surface horizon in the northern areas, and dinoflagellates (including heterotrophic and mixotrophic forms) – in the subsurface layers. Green algae are to be found in the area influenced by river runoff, and blue-green algae are associated with the ice being formed.

The structure of micro-phytoplankton community of flaw polynyas differs greatly from the above-described one. The early spring phytoplankton community usually starts to bloom in late February – March. The total number of phytoplankton in the open water areas is about 1 thousand cells/l at the end of the winter season (according to the data of A. Gukov, 1999), it is one order of magnitude lower than in the ice. It reaches 65 thousand cells/l in early April, with biomass being of about 50 μg C/l. Comparing flaw polynya with the above-described fast ice zone, it is possible to note that spring activation of the micro-phytoplankton community starts at the same time over the entire area regardless of ice cover presence. Plankton algocenosis during the spring blooming in the flaw polynyas consists mainly of pennate and, in some water areas, centric diatoms. The period of early spring enhance of micro-phytoplankton in polynyas is very short and ends before the beginning of blooming in the areas of fast ice. In comparison to the zones of ice formation, in the flaw polynyas diatoms remain dominant throughout the year, reaching their seasonal development peak in September, when their average abundance is 1.2 million cells/l and biomass – > 300 μg C/l (Gukov, 1999).

Phytoplankton biomass > 20 μm expressed in carbon, etc. (see above) showed significant inter-annual variability, which is primarily due to changes of environmental conditions. For example, in the period of 1985-1990, according to the calculations made (Timofeev, 1998), a decrease trend in phytoplankton biomass dynamics was clearly observed in the Lena polynya of the Laptev Sea. This phenomenon might be related to the global factor of climate change, which resulted in the change of hydrological regime of the Arctic Ocean. Response to climate changes in 1980-1990 revealed large-scale anomalous salinity decrease, caused by the intensification of freshwater runoff; in the same period, there was an increase of frequency of positive temperature anomalities (Alekseev, 1994; Sy et al., 1997). Thus, continuous increase of freshwater runoff of Siberian rivers, including the Lena River in the 1980s (Alekseev, 1994), inevitably led to the salinity decrease in the Southern Laptev Sea. Therefore, phytoplankton biomass decrease in 1985-1990, probably, was also related to the Southern Laptev Sea desalination, as a significant decrease of concentrations of nutrients, such as nitrogen and phosphorus, was also linked with that process (Gukov, 1995). According to conference materials for the Program of an International Polar Decade (4 – 7 October 2010, Sochi) Arctic warming has intensified since mid 1990s and reached its maximum in 2007. There was a sharp reduction of ice-covered sea area in late summer. Positive temperature anomaly of subsurface water of Arctic origin has spread widely, and fresh-water distribution in the uppermost layer has changed. Positive trends in both winter and summer-autumn runoff are revealed in Lena river basin (by 10-30% over past 20-25 years) according to the analysis of the Russian assessment of annual, seasonal and monthly runoff of 300 rivers over the recent 50-year period (Anon., 2008). However, between 1998-2007 positive trends of phytoplankton production were revealed in the Arctic seas using satellite and field data, which range from 3.7% to 18% per year (Vetrov and Romankevich, 2009). This fact may be explained by the decrease in the ice cover areas and the gradual increase in the vegetation period caused by the climate warming.

Most recently a new cooperation programme has been set up by Russian and German scientists. The MMBI took part in biological field research within the project "Lena 2010" from 28 July to 10 August 2010. The main purpose of research was to characterize plankton communities and food chains dynamics in the Lena River delta. In order to achieve the goal the following tasks were focused on:

- Characteristics of plankton communities (micro-phytoplankton, micro-mesozooplankton) along the salinity gradient in river, estuarine and marine areas of the Lena delta;

- Analysis of biotic (fluorescence, chlorophyll-A, pigment, etc.) and abiotic parameters (nutrients, temperature, etc.) along the salinity gradient;

• Dynamics of food chains in the delta area: impact of methane emissions from permafrost on various components of benthic and planktonic food chains;

• Analysis of cyst and resting stages of planktonic algae to determine the role of deposits in the life cycle of algae.

During the study period, 45 samples of phytoplankton were taken at 15 stations in the Buor-Hai Bay. So far, there are only very preliminary results. It should be said that the microalgae community is rather homogeneous over the entire bay. In the apex of the bay the number is primarily formed by freshwater diatoms, while the main biomass of the phytoplankton community is formed by dinoflagellates. Throughout the bay area there is a high proportion of green and blue-green algae.

Concluding this brief review, it should be noted that the described pattern of the Laptev Sea phytoplankton community is of most general character. Until now, there are extremely insufficient data on phytoplankton in available literature. The authors would like to express hope that the raised issues may serve as a stimulus for further development of co-operation between the MMBI and the AWI in the field of studying the current state of the Laptev Sea phytoplankton community.

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SEDIMENTATION PROCESSES AND GLACIAL HISTORY IN THE WESTERN ARCTIC OCEAN

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This report is dealing with the results of joint Russian (Murmansk Marine Biological Institute, MMBI) and German (Alfred Wegener Institute, AWI and IFM-GEOMAR) studies on Arctic Ocean sediments. In the first part accomplishments of the MMBI/AWI cooperation are introduced, whereas in the second part outcomes of the MMBI and the IFM-GEOMAR studies are presented.

I. Joint MMBI-AWI studies of Arctic Ocean sediments

Introduction

Reconstructing the marine paleoenvironment of the Eurasian Arctic margin and the central Arctic Ocean in the Quaternary period is impossible without studying unconsolidated (soft) sediments. In a geographical sense, the Eurasian shelf area has specific natural features: being ice-covered for more than 10 months per year, proximity of modern mountain glaciers that cover archipelagoes, variable bottom topography with relatively large depths of the shelf (e.g., Barents Sea) and very shallow depths (e.g., inner Kara Sea), as well as the presence of extended deeply cut-in troughs (e.g., Barents and Kara seas). The latter, as shown by Matishov et al., (1993), determine the distribution of water masses and fundamental physical, chemical and biological characteristics including bio-productivity. All these factors directly affect modern sedimentary processes. Thus, the characterisation and understanding of these main natural processes and their mirror in bottom sediments become fundamentally important. Conducting field studies is not always possible in these areas due to severe ice conditions. Therefore, it is extremely important to obtain unique undisturbed sediment material, which may allow to study and reconstruct the geological history of the region. Due to specific lithological features, surface bottom sediments may contain detailed information about the natural environment in which the accumulation of different sediment deposits occurred. These studies have been carried out by MMBI scientists together with colleagues from the AWI (Germany) during marine expeditions aboard the AWI and the MMBI vessels.

Material and methods

MMBI specialists were involved in marine field studies carried out on board the RV *Polarstern* as part of the AWI research programme, and AWI sedimentologists took part in MMBI research cruises (Table 1). Such co-operation of scientific work solved complex organisational issues: obtaining core material in marine expeditions and carrying out efficient laboratory processing of sediment samples using AWI and MMBI analytic facilities.

As it is shown in Table 1, the major activities were carried out on the RV *Polarstern* in the Arctic Ocean close to the North Pole (Fig. 1, 2), in the north of the Greenland Sea (Yermak Plateau and the Fram Strait), as well as in the Laptev Sea (e.g. Berichte zur Polarforschung 107/1992, 120/1993, 226/1997, 255/1997, 308/1999, 368/2000, 517/2005).

Table 1.: Joint MMBI/WI activities in high Arctic sedimentical investigations

	Expedition	**Region**	**MMBI**	**AWI**
1.	ARK-VIII/3 - 1991 RV "*Polarstern*"	Arctic Ocean	G. Tarasov	D. Fütterer
2.	ARK-XI/I - 1995 RV "*Polarstern*"	Laptev Sea	M. Mitjaev	E. Rachor
3.	ARK-XIII/2 - 1997 RV "*Polarstern*"	Yermak - Plateau area	S. Denisenko M. Mitjaev	R. Stein
4.	ARK-XIV/I-1998 RV "*Polarstern*"	Arctic Ocean	N. Kukina	W. Jokat
5.	ARK-XV/2-1999 RV "*Polarstern*"	Yermak - Plateau area	N. Kukina	R. Stein
6.	ARK-XX/3 - 2004 RV "*Polarstern*"	Yermak - Plateau area, Fram Strait	N. Kukina, Y. Yanina	R. Stein
7.	RV "*Dal'nie Zelentsy*" - 1992	Franz Josef Land, Novaya Zemlya	G. Tarasov S. Korsun et al..	D. Nürnberg E. Grot
8.	RV "*Akademik Golitsyn*" - 1994	Franz Josef Land, St. Anna Trough	G. Tarasov N. Kukina et al.	M. Washner M. Polterman
9.	INTAS 2000-2002	The Pechora Sea - Late Pleistocene paleogeography, present state of the shelf and costal zone and forecast 21th century	G. Matishov G. Tarasov I. Pogodina N. Kukina	H. Bauch

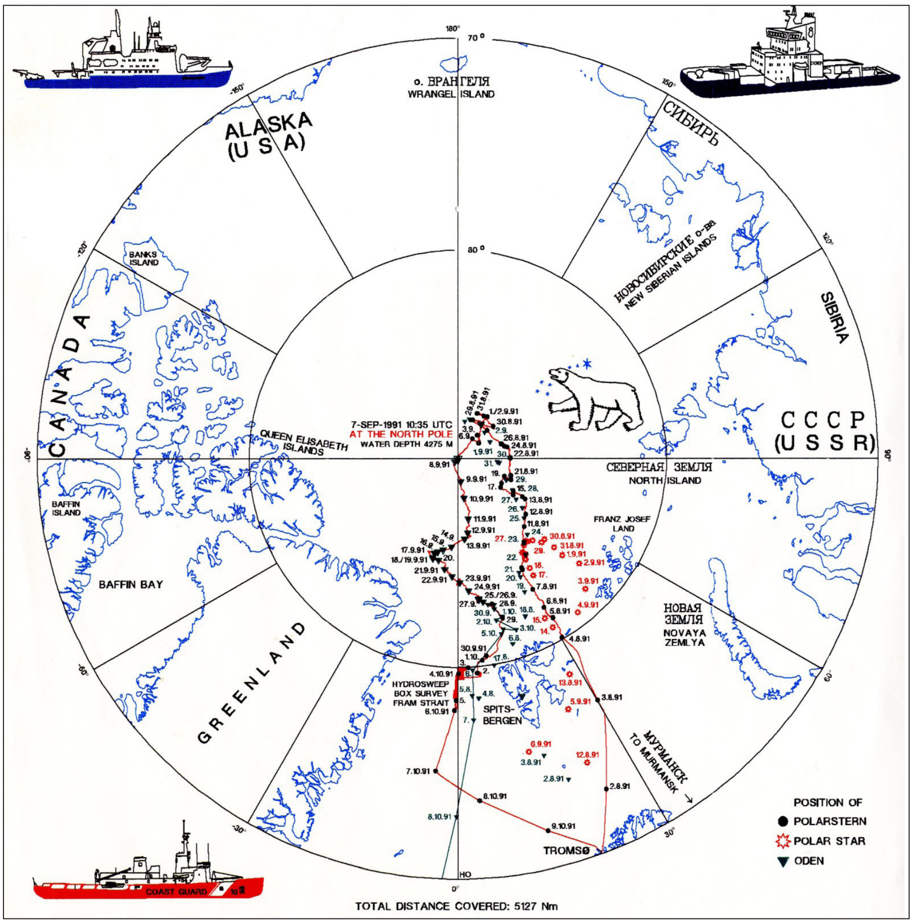

Fig. 1. Route of the expedition ARK-VIII/3 of RV *Polarstern* in 1991 (Fütterer, 1992)

Fig. 2. Participants of the expedition ARK-VIII/3 of RV *Polarstern* in 1991 at the North Pole

On the Russian research vessels work was conducted in the northern Kara Sea, in the St. Anna Trough and in the straits of the Franz Josef Land Archipelago, as well as in the coastal area of the Novaya Zemlya Archipelago.

In order to obtain actual field data and sediment material, various types of samplers were used on research vessels:

- Giant box corer (GKG) with a box size of 50 cm x 50 cm x 50 cm (Fig. 3);
- Box-type gravity corer (KAL; Kastenlot) with 30 cm x 30 cm section and a core barrel of about 10 m in length;
- Gravity corer (SL; Schwerelot) with a core barrel of 120 mm in diameter and 5 to 15 m in length;
- Multi-corer (MUC) for sampling the undisturbed surface layer bottom sediments down to 50 cm sampling depth with 12 tubes of 6 cm in diameter.

Fig. 3. Sediment sampling by box-corer (KAL; Kastenlot)

During these expeditions the recovered sediment cores were logged for obtaining physical property data (magnetic susceptibility, wet bulk density and p-wave velocity), opened, described for identifying different lithologies and for getting a lithostratigraphic framework (Fig. 4; visual core description, smear-slide analysis), photographed, and sampled for later shore-based studies in the home laboratories in Murmansk and Bremerhaven. Ship-board results of each expedition were published immediately after the expeditions as cruise reports in the AWI journal "Berichte zur Polarforschung" (107/1992; 120/1993; 176/1995; 212/1996; 255/1997; 271/1998; 287/1998; 342/1999), as well as in the MMBI preprints on expeditions conducted on the Russian vessels (Fig. 5, 6). Furthermore, the main results of sedimentological studies were presented in several articles of national and international journals (Tarasov et al., 1992, 1995, 1999, 2000; Nürnberg and Groth, 1993; Stein et al., 1994a, 1994b, 1994c, 2001, Wahsner et al., 1996, 1999; Schubert and Stein, 1996, 1997); Tarasov and Matishov, 1998; Andreeva et al., 1999; Kukina et al., 1999; Levitan et al., 1999; Stein, 1999, 2008; Stein and Knies, 1999; Knies et al., 2000; Levitan et al., 2000; Müller and Stein, 2000; Pogodina and Tarasov, 2000; Schoster et al., 2000; Stein, 2000; Stein and Fahl, 2000; Pogodina and Matishov, 2001; Stein et al., 2001; Vogt et al., 2001; Levitan et al., 2002; Matishov and Kukina, 2002; Tarasov and Pogodina, 2002; Yanina et al., 2005 a, b; for most recent review see Stein, 2008).

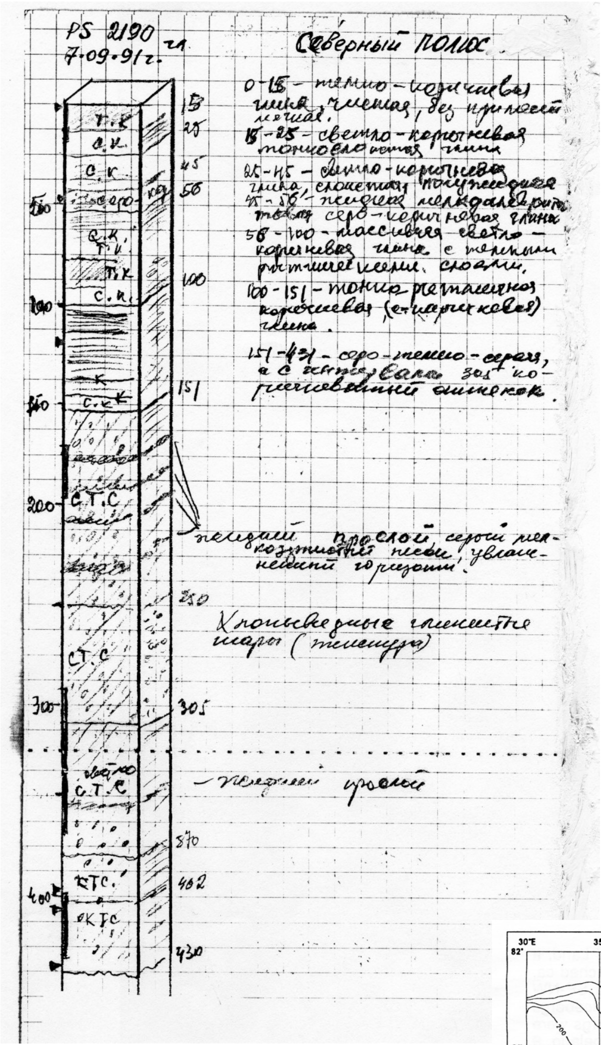

Fig. 4 (above). Lithological structures of "*Polarstern*" Core PS2190, recovered at the North Pole (G. Tarasov's sketch)

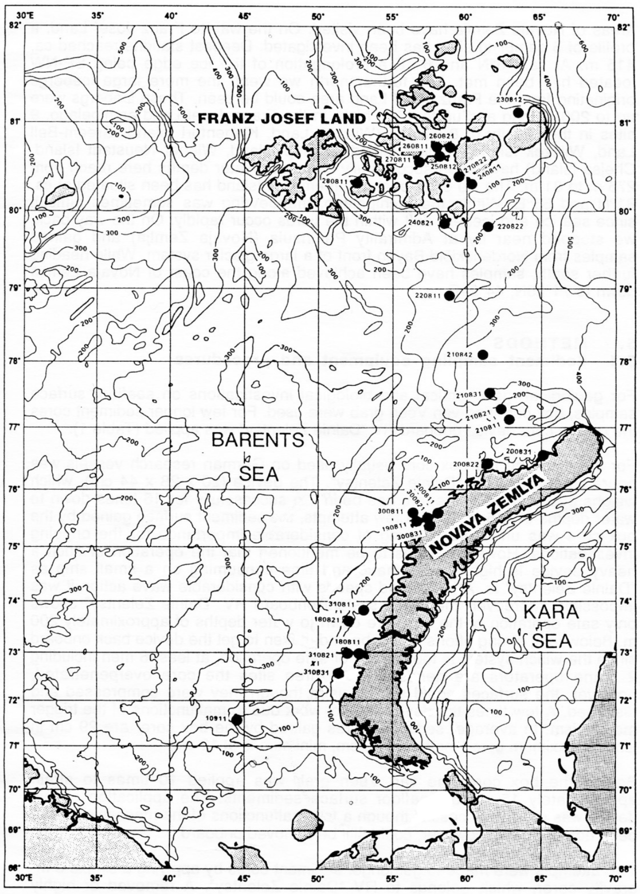

Fig. 5. Location of geological stations in the Novaya Zemlya and Franz Josef Land Archipelago areas (RV *Dal'nie Zelentsy* cruise 68; 14.08 – 05.09.1992)

Fig. 6. Ice transport of rock fragments (Franz Josef Land Archipelago)

Results and discussion

Two types of areas, i.e. coastal-island and open sea, can be distinguished by sediments' distribution type and the main composition features in the studied Barents-Kara region.

The Coastal-Island Area

On a first view, modern surface sediments hardly differ from the open sea areas. The composition of the sediment is very similar; the only difference is in grain packing and rate of sedimentation. In fjords and bays with calm hydrodynamic environment, intensive deposition of unsorted terrigenous material of near-by transport takes place without apparent processing of particles. As a rule, these are products of coastal zone hard rock destruction by modern exogenic processes. The effect of sedimentary material transport by streams and rivers originated from the modern outlet glaciers is of dominant importance. This melt water flow is strongly saturated by moraine mineral suspension. For example, in the Gulf of Nordenskjold on the western coast of the northern island of Novaya Zemlya in mid-summer (22 July 1990), a flow of melt water, rich in terrigenous suspension, rising from outlet glacier, spreads over the lower part of the bay close to the open sea for more than 20-30 km. According to data by Medvedev and Potekhina (1990), suspension concentration in the apex (upper part) of the Nordenskjold Bay is

304.2 mg/l, near the open sea – 49.0 mg/l, and in the open sea 10 km away from the coast – 6.1 mg/l. Accordingly, the major part of mineral suspension is deposited within the bay, and only small part of it is transported to the open sea. In this case, the volume of terrigenous material and its transportation distance from the front of outlet glacial depend on intensity of glacial melting, and in its turn, on summer temperature conditions. Much larger amount of mineral sediments is transported in warm summers than in cold ones.

The near surface sediments are composed of greenish-grey, brownish-red or brown fine-silts, with common bioturbation as reflected in numerous polychaetes tubes. A distinguishing feature of surface sediments from sections near melting glaciers is the presence of a monotonous layer of gray and greenish-gray plastic fine-silts, which are rather faunally poor and a product of "glacial milk" deposition. The sediments of the upper 0 to 5 cm of the 1 to 3 m thick sedimentary sections obtained in the Nordenskjold Bay (stations DZ-32, 33, 34), are soft, dark-grey, olive-grey almost homogeneous fine-silts. Sediment density increases from top to bottom in all columns. A section of horizontally laminated fine-silts is traced under the upper semi-liquid layer. Thickness of light (grey and olive) layers ranges from 1 to 10 cm, and dark ones from 1 to 5 mm. Tarasov et al. (1993) assume that light layers are accumulated in summer and dark ones in winter. Layer thickness depends on sedimentation rate per year; the thicker the layer is the more intense is glaciers' melting and transport of suspended terrigenous matter by thawing streams. Sedimentary material deposited during summer remains in semi-liquid-suspension condition for the first year. Inflow of sedimentary material dramatically reduces in winter with sea ice covering the bay. In fact, winter deposits consist only of suspension contained in the water column, which did not deposit during summer-autumn season, as well as dead organic matter generated as suspension after spring bloom of phytoplankton and ice algae, which are also in the water column. The process of compaction in the surface semi-liquid layer takes place in winter due to aggregation of terrigenous particles. The previous year sediments of semi-liquid horizon reach down to the underlying fine-silts already the following summer with the increased inflow of sediment material. The process of sediment compaction and layer thinning continues each subsequent year.

In comparison, the process of modern sedimentation in the Novaya Zemlya bays is the same as on West Spitsbergen, for example, in the Hornsunn Fjord with outlet glaciers (Tarasov et al., 2000). We observe quite a different situation in the bays and straits of the Franz Josef Land Archipelago (FJL), which has a more severe climate with essentially short summer (July – August) and "colder" glaciers. These factors, together with specific geological and geomorphologic features of the FJL Archipelago and bottom geomorphology of the adjoining shelf areas, predetermine basic features of modern sedimentation and favor formation of non-typical fine-grained sediments, the same ones as in the open sea. Long cores with lengths up to 3 m were recovered in bays and straits protected from the near bottom dynamics of the water column (stations: Gol-12, 13, 14; DZ-14, 19, 20, 29). They consist of grey, dark grey homogenous fine-silts with abundance of hydrotroilite traces. There is a clear predominance of aleurite fractions in the granulometric composition. For example, the content of aleurite in a one meter core section at Gol-13 station, located at the depth of 234 m in the Austrian Strait of the FJL, ranges from 41.8% to 73.6%, on average – 50.1%. In this case, the medium aleurite fraction dominates.

The content of gravel-pebble material from non-gravel rock fragments of adjacent land and shores is relatively low. In some cores, its quantity reaches up to 10%. It is scattered more or less evenly along the column length. Such distribution of gravel-pebble material in the section of bottom sediments indicates the constancy of their ice thawing in summer period as a result of ice drift and melting.

The Open Sea Area

The distribution of grain-size composition in the surface sediments indicates their distinct dependency on bathymetric position and seabed geomorphology. Sediments of medium- and fine sands occur down to 120 m. As a rule, these are shelf sediments of coastal shallow areas or bottom highs. They are of grey or greenish-grey colour when wet, and are of bog-grey and greyish-green colour and become loose when dry. The presence of shell matter up to 8% is a common characteristic feature of the material composition of sand deposits. Average degree of sorting is typical of sands. Sorting coefficient varies within the range of 1.7-3.2.

Fine sediments, i.e. fine silts and aleurite-clayey silts, occur in deeper parts of the area. The colour of the sediments is greenish-grey with ocher-brown inclusions. Light-brown and brown varieties are also observed. Clayey silts are composed of fine homogenous mass with an admixture of aleurite and fine-sand materials. They are usually non-calcareuos and contain insignificant amounts of organic remains. Terrigenous sediment particles are up to 40% quartz angular grains, 20% plagioclases, and 11-22% rock fragments. High content of iron and manganese oxides is found (Fe_2O_3 – 5.6-5.8%; FeO – 3.7-4.1; MnO – 0.2-1.5). Oxides and hydroxides of iron are of goethite, limonite, and occasionally martite (Kukina et al., 1999). They are in a form of rounded grains, colloform and yellow or ocher earthy aggregates. Rare rock fragments from gravel to large pebble size are registered in the surface sediments.

A homogeneous sediment structure is observed in the long sediment cores of up to 3 meters in length. They are mainly soft aleurite-clayey sediments with no visible change in granulometric composition. Sediment colour varies from light brown to dark brown one.

Underwater slopes of the Novaya Zemlya and Franz Josef Land archipelagoes (stations DZ – 12, 13, 16 (1992); Gol – 1, 2, 3 (1994); DZ – 4, 6 (1996)) are characterised by layered sediments. The upper layer is mainly brown, greenish-yellow, soft, sometimes semi-liquid fine-silt or aleurite-clayey silt. Then there is a dark grey, dark green thin layer (15-40 cm) of fine-silt with lots of gravel material. The bottom layer is composed of dark grey diamicton-like compacted sediments.

The study of the mineralogical composition of the light fraction showed that quartz, potassium feldspar, plagioclase and muscovite are the main minerals. The presence of chlorite, glauconite, opal and volcanic glass is also observed. Frequently, also rock fragments (sericite-chlorite rocks) and ferruginated clay aggregates occur, which frequently may become predominant in the sample.

The main mineral of the light fraction is quartz with average content of 40.4%. The highest concentration of quartz is observed at station PL-94-08 and is up to

80%. At stations PL-94-60 and PL-94-64, the content of quartz decreases with increasing depth, and, approximately in the range of 200-320 cm, clay aggregates become the leading components.

Feldspars are plagioclases and potassium feldspars. Plagioclases are often milky-white with a shape close to plate prismatic. Their content unevenly ranges from 3% to 19%. Potassium feldspars (pfs) are intensively pellitised and have numerous inclusions of the basic plagioclase, quartz, and biotite. The average content of pfs is 2.5-8.5% (Kukina et al., 1999).

Kukina's determination shows that muscovite has slightly yellowish, irregular form, as determined by smear-slide analysis. Most likely it is epimagmatic and develops in plagioclase way. Muscovite is registered rarely, accounting for only 0.2-2%. The most common mineral of mica group is chlorine, its content varies from the actual 0 (PL-94-08 station) up to 17% (PL-94-08 station). Grains are light green or grey-greenish, elongated columnar, and have high relief and medium orange surface. Specific feature of coarse silt's light fraction at PL-94-08 station is the prevalence of chlorite over muscovite as well as its increased content.

Biogenic residues are registered in great amount in the way of debris and well-preserved shells of foraminifera (*Neogloboquadrina pachyderma*) and red algae particles.

Studying of quartz particles' roundness showed the presence of large number of angular shape grains with a roundness score of 1-2 by Khabakov scale (Khabakov, 1946) in the fraction of 0.5-0.25 mm. Perfectly rounded grains with smooth surface (score 4) are rare, which explains such a low coefficient of roundness of 1.6 to 2.2. A distinctive feature of the quartz grains is their transparency and clearness. They have practically neither inclusions nor red-stained films.

Thus, our studies of sediment cores indicate a periodic variability of sedimentation processes in the past. Primarily, this is related to warm-cold climate variability on different time scales, an annual cyclicity (short-term climate fluctuations) and long-term oscillations, which cover climate change cycles of tens or hundreds years. Glaciers and ice entrained with terrigenous detrital components are the main suppliers of sedimentary material into the marginal seas.

In the north of the Barents-Kara Sea region, icebergs, fast shore ice, and often pack ice drifting constantly into the open Arctic Ocean, melt fast during summer times, releasing their sediment load settling towards the sea floor. This process lasts the entire short Arctic summer and slows down with the formation of new ice in October. In the zone of ice drift unconsolidated fine-grained sediments, with an admixture of gravel-pebble material, are formed predominantly. Large fragments of hard rock can also enter the sea. For example, during the RV *Akademik Golitsyn* Expedition, we registered floes and icebergs laden with stone-blocky material, certain pieces of which weighted up to 100 kg, at the outlet of the Austrian Strait of the Franz Josef Land Archipelago (Fig. 6).

Bottom sediments related to ice transport are not always characterised by stratification. Influx of sedimentary material under ice cover suspends in winter, and a semi-liquid (near-bottom) layer may be formed due to suspended matter, though it may not be deposited at all due to transport by bottom currents. The next portion of ice-transported sedimentary material of the following year easily passes through winter semi-liquid layer and adheres to the old formation. In such cases, stratification is practically not observed. Such a situation is registered throughout the area and depends on many factors. Thin-layered sediments with distinct annual layers are registered locally. In some columns layer thickness is rather uniform, while in the others there is a notable alternation of thick and thin layers. This is, probably, the way of sedimentation when volume and rate of sediment material entry dramatically changes from year to year. Consequently, melting of ice and reduction of glaciers is more intensive in warm summers than in cold ones. In general, the sequence of layers in section strata, its consistency by capacity and composition are determined by stability and persistence of climatic conditions.

Under-glacier streams of melt water, saturated with terrigenous material, strongly influence sedimentation in the areas of modern glaciers. This factor is decisive near outlet glaciers, giving an avalanche character to sedimentation. The impact of melt water flows on the general course of sedimentation decreases the further from the shores. Nevertheless, this factor is of decisive importance in modern sedimentogenesis.

II. Joint MMBI – IFM-GEOMAR studies on Arctic Ocean sediments within the INTAS project research

“The Pechora Sea – Late Pleistocene paleogeography, present state of the shelf and coastal zone and forecast for the 21 century” (Pogodina and Matishov, 2001; Pogodina and Tarasov, 2001; Pogodina, 2002; Tarasov and Pogodina, 2002; Tarasov et al., 2000, 2002).

Introduction

This project is for the Pechora Sea development prognosis with a glance to “anthropogenic pressure” amplification and possible environmental changes. Authors of the project support the view of cyclical development of natural conditions associated with changes of earth climate in Pleistocene and Holocene. Method of analogies allows usage of data of natural environment conditions in the past to produce models of natural environments in the future. We believe that Holocene, including modern period, represents the beginning of next interglacial period in earth’s history. Therefore, for predictions we can use natural environmental data of previous warmer interglacial period, which was separated from Holocene by the last glacial period.

Material and methods

Determination of sediment composition of offshore well drilling sections (Fig. 7), literature data, and new radiocarbon datings of the sediments allow the reconstruction of shelf sediment thicknesses, as well as paleoenvironmental conditions. Authors of the project compiled large amounts of new data derived from scientific and engineering researches. These include sediment sampling data and materials of offshore well drilling, as well as data on modern sediments distribution in the Pechora Sea as habitat for benthic organisms.

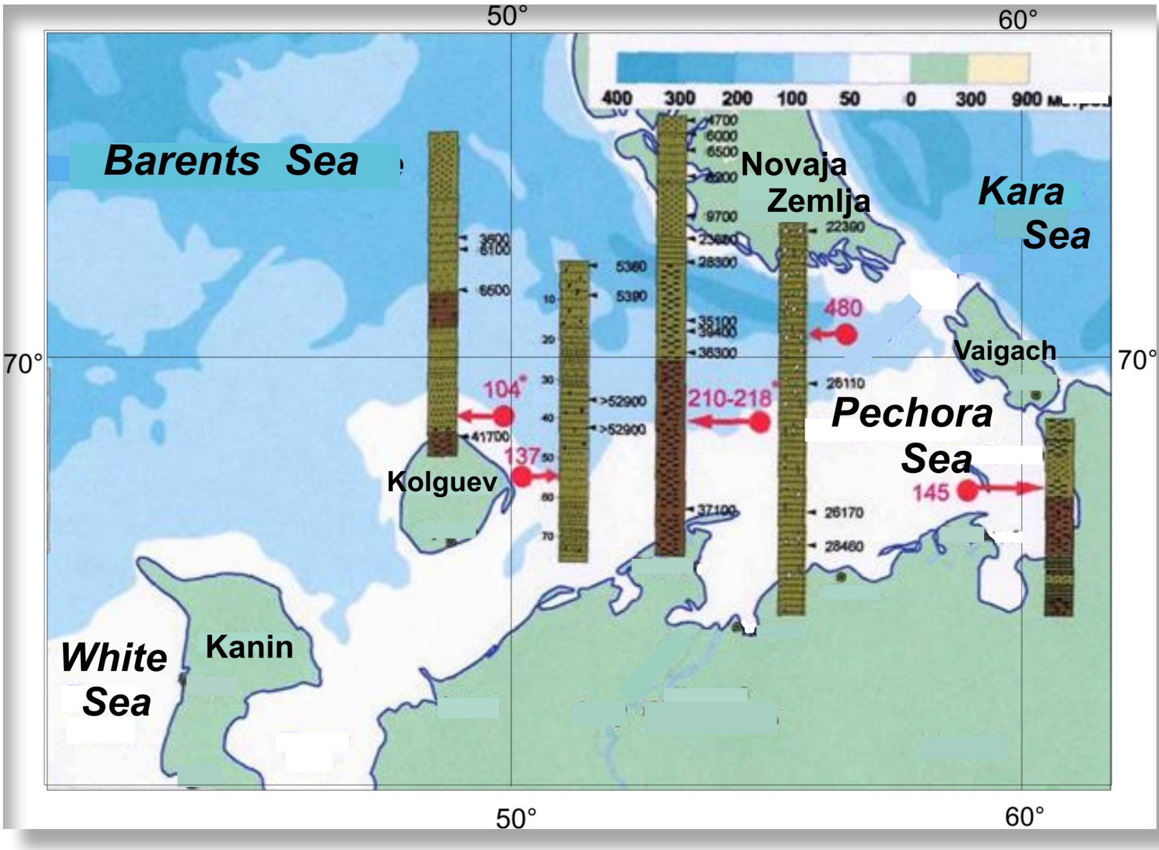

Fig. 7. Location of studied wells of offshore drilling (OJSC "AMIGE") in the Pechora Sea

As actual material and data, the Pechora Sea bottom sediments' samples, obtained during the expeditions on board the RV *Dal'nie Zelentsy* in the 1980-1990s, applying ground corers and dredger, were used in the project. At the same time, faunal samples were taken during those cruises. The cores of sea drilling wells by the Arctic Marine Engineering and Geological Expedition (AMIGE) on board the drilling vessel *Bavenit*, kindly provided by V.N. Bondarev, director of the above-indicated institution, were an important material for our studies. Processing of bottom sediments' samples (granulometric composition, mineralogy, chemical analyses) was carried out according to standard methods both at the MMBI and other organisations (AMIGE, MAGE, IO RAS, etc.). Absolute age determination (C-14) was at the Geological Institute RAS (Moscow, Russia) and at Kiel University (Kiel, Germany).

Results and discussion

The Quaternary Pechora Sea shelf sediments were formed by repeating glacio-eustatic fluctuations of the global sea level, when marine environments were replaced by continental ones and were accompanied by the development of powerful ice cover. As a result, extremely complicated Pleistocene strata, consisting of moving morainic and interglacial deposits overlapped by marine Holocene sediments, was formed on the shelf. Determining the age of moraines is rather complicated, but presence of glaciers on the Pechora Sea shelf in the Early-Middle Pleistocene is indisputable, as a number of moraine deposits overlapped by marine Mikulinsk (MIS 5e) sediments were discovered in a series of wells (Tarasov et al., 2000).

The Gulf Stream penetration into the Eastern Barents and Pechora Seas was obviously more powerful in the Late Quaternary (Mikulinsk) period than today. This is suggested from the composition of foraminifera in the Late Quaternary (Mikulinsk) sediments recovered in well 145 drilled at Varandey area in the central part of Medynsky shaft (Fig. 8). In dark-grey clayey strata containing rare inclusions of pebbles interbedded with fine-grained well-sorted sand, a foraminifer complex is registered, which has no analog in the modern fauna of the Pechora Sea (Pogodina and Tarasov, 2001, 2002). High species diversity with large percentage of boreal species and absence of dissolution traces on shells indicate normal salinity of marine waters, i.e. a hydrochemical regime of near bottom waters suitable for shell preservation and burial. Pollen of woody plants predominate in the spore-pollen composition (Sharapova, 1996).

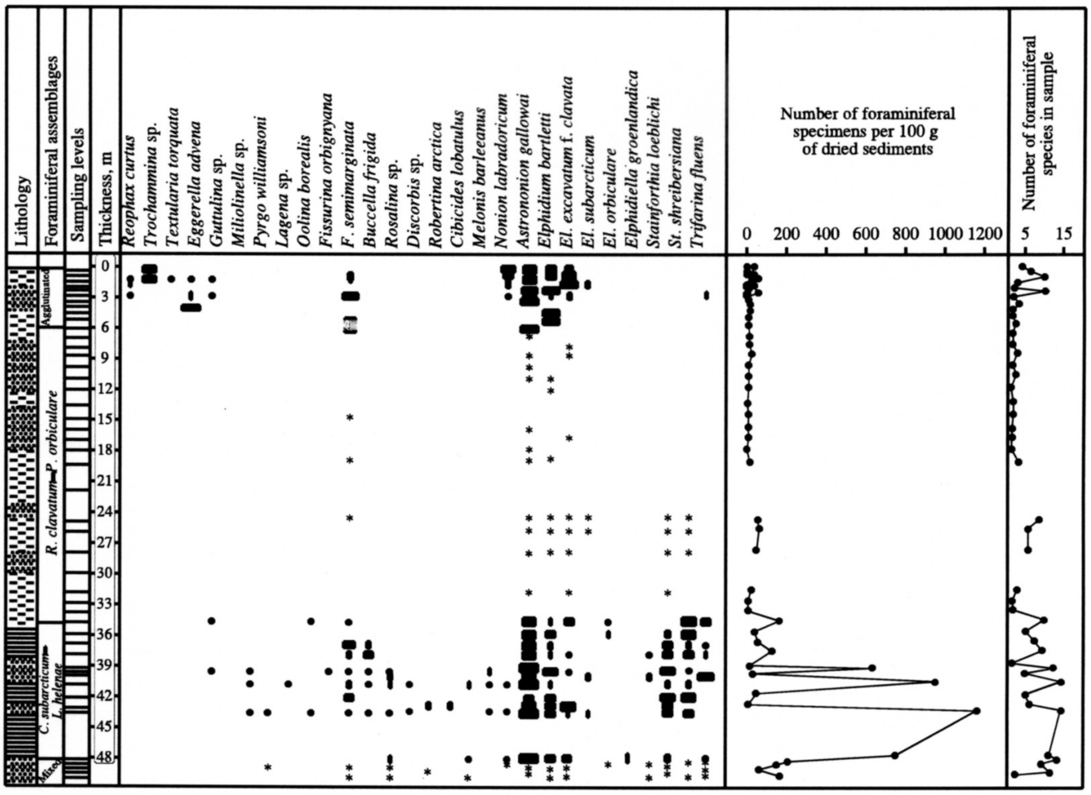

Fig. 8. Micro-paleontological characterisation of sediments of well 145 (Pogodina, 2002)

The Early Valdai (MIS 5d) cooling led to formation of distinct ice sheets, which covered the area of the Pechora Sea and descended to the Pechora lowland. Considerable part of marine sediments of the Late Quaternary (Mikulinsk) period was redistributed by glacial streams. Deposits of this period are dense dark-grey loams with inclusions (lenses) of coarse deposits and single faunal remains of autochthonous origin and contain neither Quaternary spores nor pollen.

The revision of drilling and seismic profiling materials and applying modern chronostratigraphic methods, showed that the Pleistocene loam deposits in the southeastern part of the Pechora Sea are overlapped with some laminated dark-grey aleurite. Its lower 10 meters contain significant amount of foraminifers, mollusks, and ostracods, which are indicators of open-marine interstadial conditions. Trees pollen forms significant percentage in palynological spectra of these sediments. According to the radiocarbon analysis, the uncorrected age of these deposits is 39-35 thousand years. Tarasov and Pogodina (2002) assume that complete deglaciation of the Pechora Sea shelf took place in the Middle Valdai (MIS 5a). These data agree with the results of postglacial sediments from the Pechora Plain and the Yamal Peninsula, dated by radiocarbon and thermoluminescence methods (Mangerud et al., 1999; Forman et al., 1999). Significant sea transgression is registered according to micropaleontological data obtained from Pleistocene deposits of the Kola Peninsula in the Karginsk period (40-35 and 30.7-24.1 thousand years ago). The Karginsk transgression invaded coastal lowlands and penetrated into the near-mouth areas of rivers. The size of the basin during the Karginsk stage was significantly less than the size of the basin during the Mikulinsk stage and, probably, the present stage. Tarasov et al. (2000) and Pogodina and Tarasov (2001) believe that the southeastern part of the shelf may have been a land area. Marine layers enriched with faunal remains were not discovered at well 145 located in the extreme south-east. A different nature of marine fauna in the Karginsk and Mikulinsk horizons is registered. The Karginsk paleo-faunal composition is of Arctic character, indicating a colder basin similar to the modern one.

The sea level lowering and establishment of continental conditions took place after a short interstadial period with normal marine conditions. The Pleistocene loam sediments in the southern part of the Pechora Sea are overlain by grey rhythmically laminated aleurites with almost no faunal remains. Pollen of herbaceous plants, primarily worm wood (*Artemisia*), dominates in the spore-pollen composition of these sediments. The absence of microfauna and the increase of grass pollen content indicate the transition to shallow marine pro-deltaic conditions, lowering of sea level, and proximity of the coastline. Significant part of the Pechora Sea during that period was a land in a form of low marine, alluvial-marine, and alluvial-lacustrine plains where permafrost was formed and various cryogenic processes actively proceeded. The Late Valdai Novaya Zemlya ice sheet probably occupied only the northern Pechora Sea without reaching the Pechora lowland.

Later on, during the Holocene transgression, the shelf underwent intensive treatment, i.e. abrasion under the advancing marine conditions. The Holocene sediments of the Pechora Sea shelf are ubiquitous. They lie on the eroded surface of the Pleistocene sediments identified by a gravel-pebble horizon. The Holocene sediment thickness in the study area varies from some meters to 50 m. The thickness increase coincides with neo-tectonic depressions. The Holocene section with thickness of 44.2 m of sands in the upper part and aleurites and clays in the bottom part was opened by an offshore drilling well (104) near the eastern coast of Kolguev Island. Similar sediments were recovered in the nearby well 137, where prominent sandy-clayey sediments were deposited during a very short period of time. The ages of mollusks *Montacuta maltzani* at depths of 9.4-9.5m and 1.4-1.5m were 5390+30 thousand years (KIA 16841) and 5360+30 thousand years (KIA 16840), respectively.

An area of increased thickness of Holocene sediments was observed between 52° and 58° E. The Holocene thickness exceeds 5 m and at two sites even 10 m in the Novozemelskyi/Novaya Zemlya Trough and in the Pomorsky Strait (the area of Kolguev Island). Holocene sediment thicknesses decrease with decreasing water depths. This decrease in sedimentation is probably caused by decreasing energy of wave impact on sediments and their related deposition. The energy of prevailing currents is only sufficient for further transport of finer particles of suspension.

The sequence of Holocene sediments can be divided into three intervals: transgressive sands formed approximately 8-10 thousands years ago, marine silty clay with microfossils deposited approximately 5-8 thousand years ago, and marine sands enriched in malacofauna, formed during the last about 5 thousand years ago. A pack of sediments is distinguished by a complex of microfauna belonging to the Holocene Optimum.

Well 480, located near the Kara Gate Strait, is of great interest because at this site a 100 meter thick sequence of plastic frozen argillaceous dark-grey sediments with no visible lithological boundaries was recorded (Fig. 9). Sediment temperature was uniform at about -1.0-1.5°C. Ice content of sediments has its maximum in the near-surface sediments (up to 60%) and decreases down-core to 5-10%. Ice schlieren (i.e. inclusions of ice in frozen ground forming various cryogenic textures) are irregular, often angular in shape and up to 3 cm in diameter. The ice is transparent, without visible inclusions. Thin (up to 30 cm) clay layers with preserved net cryo-structure have been observed. Mesh cryostructure (cryostructure of the second order – mesh like, with distance between the schlieren being 2-3 cm) occur all over the section. Micropaleontological analyses have shown the presence of significant amounts of plant detritus throughout the section. Single micro-scleres of sponges are common faunal remains throughout (Pogodina, 2002). Absolute age dating suggests pre-glacial nature of the well formation (Tarasov and Matishov, 2005).

In summary, the maximum Quaternary warming in the Pechora Sea region was recorded during the Mikulinsk Interglacial (MIS 5e). Based on our data, this period differs evidently from the Holocene. Significant advancement of woody vegetation towards the north and remarkable changes in the hydrological characteristics of water masses are registered during the Mikulinsk Interglacial. The Early Valdai cooling (MIS 5d) led to the formation of extensive ice sheets covering the territory of the Pechora Sea and descending to the Pechora lowlands. Complete deglaciation of the Pechora Sea took place in the Middle Valdai, approximately 35-40 thousand years ago (MIS 5a). The Karginsk warming (MIS 3) differed by even moderately cold climate close to modern. After a short interstadial period, the sea-level decrease took place and the establishment of continental conditions occurred. The Pechora Sea shelf was of low marine, alluvial-marine, and alluvial-lacustrine plains, where permafrost rocks formed and various cryogenic processes actively developed. The Late Valdai (MIS 2) Barents Sea ice sheet probably occupied only the Northern Pechora Sea, not reaching the Pechora lowlands. Later on, during the Holocene transgression, shelf underwent abrasion. Modern lithodynamic conditions in the Pechora Sea, to the greater extent, determine the formation of sand-aleurite sediments.

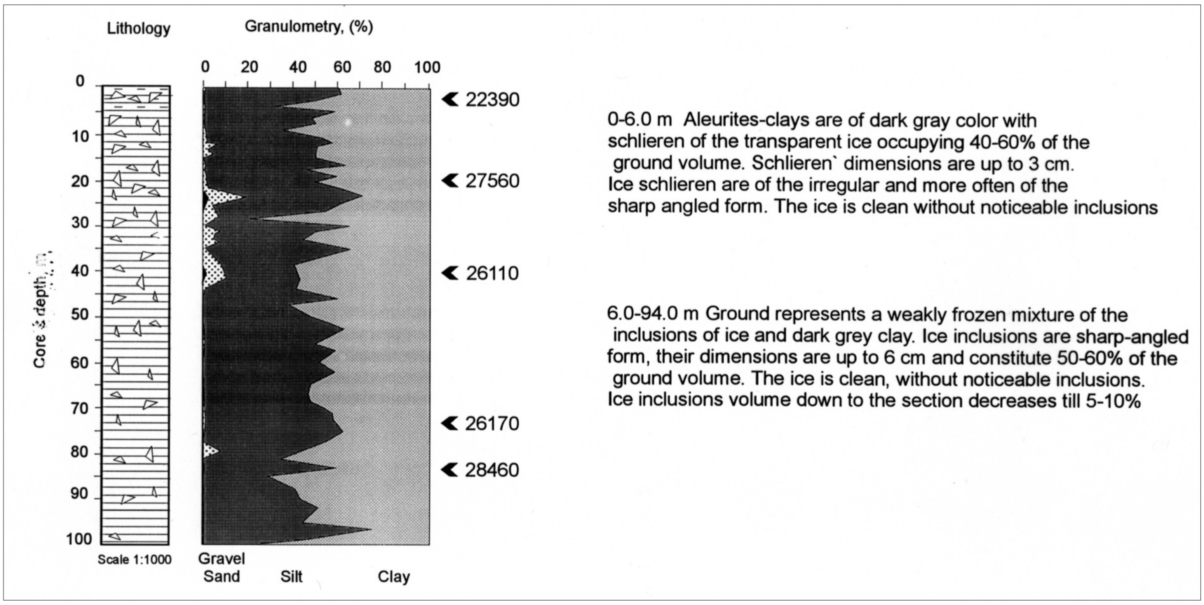

Fig. 9. Lithology of well 480 section

The glaciers of the southern island of Novaya Zemlya, Vaigach Island, and Pai-Khoi during the Late Valdai period, most likely, were small and little active. Permafrost on the shelf of the Pechora Sea was developed during the Late Pleistocene regression when the entire shelf plain of the Pechora Sea was drained to 120-130 m. The Southeastern Barents Sea during the Late Valdai (MIS 2) accordingly, developed under periglacial conditions with active cryogenic processes.

Acknowledgements

The data discussed in Part I were obtained under the Cooperation Agreement No 03F08GUS between the MMBI (Activities Supervisor Dr. G.A. Tarasov) and the AWI (Project Coordinator Dr. R. Stein) of 17 March 1995 on current sedimentary processes and paleoenvironment on the shelves around Franz Josef Land, the northeastern Barents Sea and the northwestern Kara Sea. The agreement envisaged joint research in 1995-1997 based on sediments and data obtained from expeditions on board RVs *Polarstern, Akademik Golitsyn* and *Dal'nie Zelentsy*.

The data discussed in Part II were obtained within a joint MMBI - IFM-GEOMAR INTAS research project (2000 – 2002) composed of two sub-projects:

"The Pechora Sea – Late Pleistocene paleogeography, present state of the shelf and coastal zone and forecast for the 21 century" (Project Co-coordinator: Dr. H.A. Bauch).

"The reconstruction of paleoenvironmental conditions of the Pechora Sea region during specific time intervals of the Late Pleistocene and Holocene" (Project Co-cordinator Prof. G.G. Matishov with team scientists Prof. G.A. Tarasov, Dr. N.V. Denisenko, Dr. I.A. Pogodin and Dr. N.A. Kukina).

I gratefully acknowledge the input of Dr. Rüdiger Stein to the present publication in reviewing it and sincerely thank him for his efforts.

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EFFECTS OF LIGHT AND TEMPERATURE ON THE BARENTS SEA MACROALGAE

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Marine macroalgae are one of the main primary producers and sources of organic matter and oxygen in coastal areas. They largely determine the state of shallow water marine ecosystems and interact with many kinds of animal and plant organisms.

Most of the marginal seas of Russia are located North of the Arctic Circle (Polar circle). Algae living there are exposed to both low temperatures and poor light conditions during the polar day and the polar night. During the course of the year, the daily dose of solar radiation, the light intensity, and spectral light composition change significantly with day length due to the varying sun altitude above the horizon, the tidal height, the ice cover, the concentration of plankton organisms, dissolved organic and suspended matter, etc.

Exposed to environmental factors which are subject to seasonal changes, algae need to be capable of endogenous regulation of physiological processes. Some of its manifestations are noticeable, for example, the beginning of growth in the middle of the Polar night in certain species (Makarov et al., 1999), others can be hidden due to the combined effects of short-term (the daily change of light, the tidal cycle) and long-term (the Polar day – the Polar night) impacts (Lüning, 1990).

Despite of more than two centuries of study, many specific physiological features of Arctic marine macroalgae, are still insufficiently investigated. Issues of biodiversity and algal capability to propagate in high latitudes also remain relevant. Among a large number of theories describing the basics of biodiversity and distribution of terrestrial and marine organisms (see review by Willig et al., 2003), only a few of them consider the mechanisms enabling algal distribution and leading to the evolutionary formation of new species (Perestenko, 1998; Howe and Brunner, 2005). This brief review presents findings of our long-term field observations and experiments. They suggest that the adaptation of algae to the changing light conditions during the Polar day and the Polar night also affects their distribution. This confirms a recent hypothesis, of a complex barrier controlling the bio-geographic distribution of algae (see reviews by Campana et al., 2009; Gomez et al., 2009; Wulff et al., 2009; Zacher et al., 2009).

1. The effect of light intensity

The effective operation of the photosynthetic apparatus is restricted to the species-specific range of light intensity and thus partly determines the lower and upper vertical distributional limit of a species on the shore. The process of high light-mediated photodamage occurs at the upper vertical limit, whereas early developmental stages are generally adapted to a lower light level if compared with adult plants. The phototaxis of spores and gametes of green algae facilitates their movement towards the area with optimal light conditions, while brown algal zoospores rather rely on chemotaxis (Makarov, 1987). Therefore, to understand the processes of algal adaptation to environmental conditions it is necessary to examine the responses and the physiological state of the organism at all stages of ontogeny.

1.1. The impact of light intensity on early life-history stages of *Saccharina latissima*

The developmental processes in gametophytes and early sporophytes of laminariales have been studied for over a century. A great contribution to this research field was made in 1982 -1997 years by V.N. Makarov at the Murmansk Marine Biological Institute (MMBI KSC RAS). We have investigated the influence of light intensity on the settling rate, germination and development of spores, gametophytes, and early *Saccharina latissima* sporophytes of the Barents Sea. The light coverage ranged from 0.5 to 100 W/m^2. It corresponds to the natural conditions during the release of spores (our unpublished data).

Results of experiments with moving zoospores indicated that the movement pattern and their settling rate do not depend on light intensity. Zoospores stability may be related to the fact that their photosynthetic apparatus has not yet completely been formed. In contrast, high light exposure (75 W/m^2 and higher) of subsequent developmental stages may result in lethal destruction of the photosynthetic apparatus. The stability depended on the duration of the light exposure: embryospores survived for up to 2 days, early sporophytes for up to 10 days.

The range of tolerance and the light optimum zone differ for different *Saccharina* species or for species growing under different conditions. For the development of gametophytes of *Saccharina japonica* from the Far East the light intensity of 30 W/m^2 or even higher is optimal (Yabu, 1964), although other data indicate a range of 120 – 250 W/m^2 (Maltsev, 1978). For the White Sea *Saccharina latissima* the light intensity of 5 – 30 W/m^2 is optimal (Makarov, 1987). Results of our research indicated that for the Barents Sea *Saccharina latissima* the optimum is within the light range of 10 – 50 W/m^2. Differences are apparently related to the light conditions in natural habitats of these species.

1.2. Seasonal changes in the photosynthetic apparatus of algae

The possibility of algal growth under polar light conditions depends on the adaptive capacity of their photosynthetic apparatus. Our research has shown that adaptation occurs at different organizational levels and is expressed by the different size of photosynthetic membranes, the content and ratio of photosynthetic pigments, the size of light-harvesting complexes (LHC), and the content of UV-shielding and absorbing agents (Makarov, 2010).

Investigation of chloroplast ultrastructure of the green alga *Ulvaria obscura* showed that in winter if compared with summer the partial volume of thylakoid membranes greatly increases per unit area of the chloroplast stroma. Thylakoids are more densely packed in winter. The number of ribosomes in the stroma is reduced. Similar changes are observed in other algal species. For example, in *Fucus vesiculosus* the ratio of the size of the chloroplast section and length of photosynthetic membranes increases by more than six times from summer to winter. In spring, a larger area of photosynthetic membranes and high activity of the photosynthetic apparatus is associated with active growth of algae.

In all algal species investigated, the maximum content of photosynthetic pigments (Fig. 1) and the largest size of light-harvesting complexes were also observed in April and November-December, the minimum was observed in July and August.

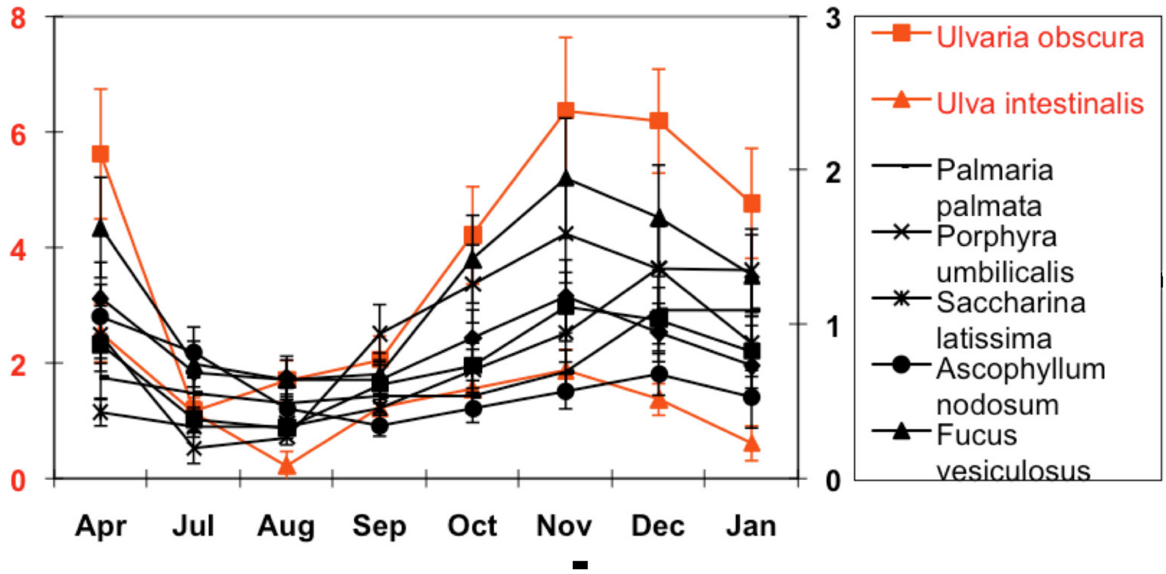

Fig. 1. The content of algae photosynthetic pigments (the sum of chlorophylls and carotenoids) during a year, microgram per gram of wet weight. Left Y-axis is for *Ulvaria obscura* and *Ulva intestinalis*, right one is for the other species

The analysis of LHC size during a year (Table 1) revealed that the photosynthetic apparatus of red algae is subject to great changes due to the destruction of phycobilin pigments in summer, and that of the brown algae is more stable. Besides, the size of LHC depends on the water depth of algal growth: the smallest changes are observed in sublittoral species.

The analysis of carotenoid pigments showed that all studied algal species contain a sufficiently large number of them. According to the Chl/Car ratio, algae are distinctly divided into taxonomic groups. In brown algae this index is about

2 and stable during the year. In green and red algae the ratio is about 2 during summer too, but in green algae the ratio increases up to 3.5 in January, in red algae - up to 5 in the winter-spring period.

Table 1. Changes of relative size of algal LHC during a year

Division/Species			Changes (%)*
Red algae	**Green algae**	**Brown algae**	
Porphyra umbilicalis			68.2
Palmaria palmata			67.4
	Ulva intestinalis		66.0
	Ulvaria obscura		43.2
		Ascophyllum nodosum	38.6
		Fucus vesiculosus	32.2
		Fucus distichus	30.8
		Fucus serratus	27.0
		Saccharina latissima	24.4

* determined according to a formula: (Max-Min)/Max$_*$100%

Our studies revealed structural and functional reorganizations of the photosynthetic apparatus enabling algae in the Barents Sea to function effectively throughout the year under significant changes of light intensity. Different algal species showed similar responses. This may be due to their adaptation to the high latitudes.

1.3. Mechanisms enabling algae existence during the permanent darkness in Polar winter

On the Murman coast of the Barents Sea the Polar night lasts for about 1 month, the average intensity of PAR (photosynthetically active radiation) in mid-December in the afternoon is 3 W/m^2. At the latitude of Spitsbergen (Svalbard), the Polar night lasts for about 4 months, of which during 2 months lighting is completely absent.

Our studies indicated the presence of physiological activity in macroalgae during the Polar night (Voskoboinikov et al., 2004; Tropin and Makarov, 2004; Matishov and Makarov, 2004; Voskoboinikov et al., 2006; Makarov et al., 2006). On the Murman coast, photosynthetic activity in most algal species during the daytime is several times greater than respiration (although respiration prevails if to convert to the daily production).

To study the functional state of the algae during the Polar night, a special light-tight container to be placed in the sea was developed. Various mechanisms allowing algae to survive during the unfavorable period were identified. It was shown that the duration of their existence in the absence of light depends on the structure of the thallus and the type of the meristematic zone.

One-year weeds under the lack of lighting are at a resting stage. Most species survive winter in the form of microscopic life stages (gametophytes or spores) (Breeman, 1988; tom Dieck, 1993).

Perennial green and red macroalgae with thin-lamina thallus and diffuse way of growth (lack of differentiated growth zone) are the most sensitive to the lack of lighting. Duration of their existence is limited by a number of intracellular storage compounds and is about 30 days.

Higher organized brown algae, apart from consumption of reserve substances, have additional mechanisms enabling their existence in the absence of light due to the physiological differentiation of different thallus parts. The structure of their thallus determines heterotrophic feeding pattern of inner cell layers deprived of photosynthetic carbon assimilation.

During a long period of light absence (up to 60 days) the photosynthetic apparatus of *S. latissima* and cells of the external phototrophic layer remain intact. With a lack of lighting, the area of growth preserves due to short-range transport of reserve substances from heterotrophic cell layers of the central part and distant transport of assimilates from disintegrating cells of the marginal and the distal parts of the lamina (Makarov et al., 2006). This mechanism even allows running the growth processes during the Polar night (Dunton and Schell, 1986; Makarov et al., 1999).

The growth zone of fucoid algae is apical, and they cannot actively use organic substances produced during the thallus autolysis like the Laminariaceae. However, we showed that *F. vesiculosus* is capable to remain viable up to 9 months under the absence of light. After 6 months of the algae being in the dark, its photosynthetic apparatus remained in the intact state, the number and ratio of photosynthetic pigments remained unchanged. The rate and intensity of photosynthesis and respiration changed insignificantly, the level of photosynthesis was 6-8 times higher than that of respiration. A decrease in size and decrease of the electron density of polysaccharide granules, the increase of the specific proportion of mitochondria and cristae in mitochondrias were observed at the ultrastructural level.

The possibility of long-term existence of fucoids under the absence of lightning relates to their ability to absorb dissolved organic matter (Khailov, 1971; Khailov and Firsov, 1976; Khailov and Monina, 1977). Most probably, organic matter is used by macrophytes to maintain energy exchange, as we have shown absorption of carbonate-ions in the absence of CO_2 light fixation (Tropin and Makarov, 2004), which was also observed for the other species of algae (Titlyanov et al., 1972; Bykov, 2003; Kolmakov, 2005; Trusova, 2009).

The study of the ultrastructure of cells and tissues of *Fucus vesiculosus* revealed the presence of solitary bacteria on the algae surface in the summer period (Fig. 2 *a*). In the apical part of thallus a large number of dividing cells are registered. Nuclei of these cells differ by ultrastructure depending on the division stage. Chromatin is at various condensation degrees: from dispersed to gathered in the way of lumps. In the cytoplasm, there is a large number of ribosomes, both free and attached to membranes of the reticulum. Membranes of the rough reticulum are well distinguished. These features indicate active protein synthesis processes.

In the peripheral cell rows, there is a large number of electron-dense granules, which are apparently physodes covering 30% of the cells cut. Chloroplasts are oval, up to 12 µm, and locate mainly parietally. The outer membrane of many chloroplasts contacts membranes of smooth reticulum. Photosynthetic membranes of chloroplasts are well distinguished: complexes of three thylakoids lay in parallel rows across the chloroplast. In the stroma, a large number of ribosomes is visible.

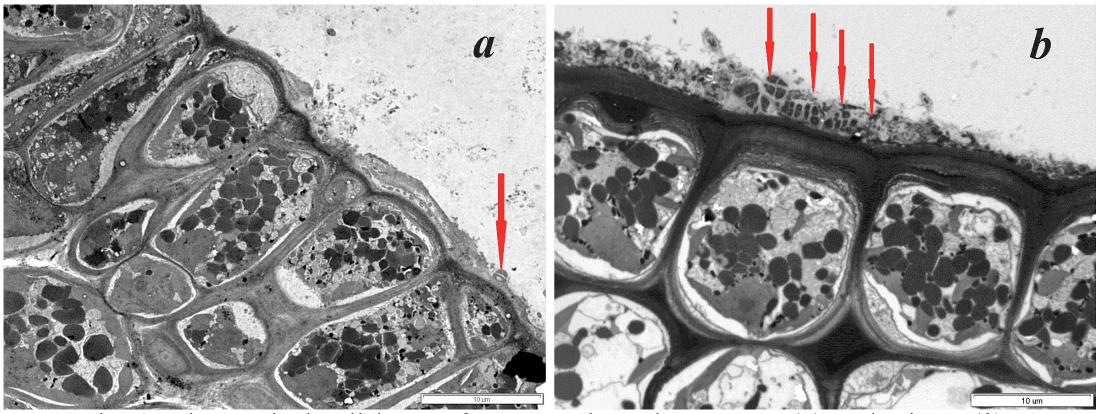

Fig. 2. The cortical cell layer of *F. vesiculosus* in summer (*a*) and winter (*b*). Arrows point at bacteria

After a 3-month stay in the dark, the outer surface of algae becomes covered with a layer of bacteria (Fig. 2 *b*). The penetration of bacteria into the intercellular space and inside cells was not registered. Dividing cells are absent. However, a segregation of chromatin in the nuclei of most cells was registered, as well as a reduction of a number of ribosomes in the cytoplasm and the predominance of membranes of smooth reticulum over the ones of rough reticulum. In some cells of the apex periphery, physodes occupy up to 50% of the volume. Chloroplasts do not differ in shape, size, and location in the cell from the algae chloroplasts in summer, but in winter, the amount of photosynthetic membranes greatly increases (Fig. 3). In cells there were no signs of degradation of any structures.

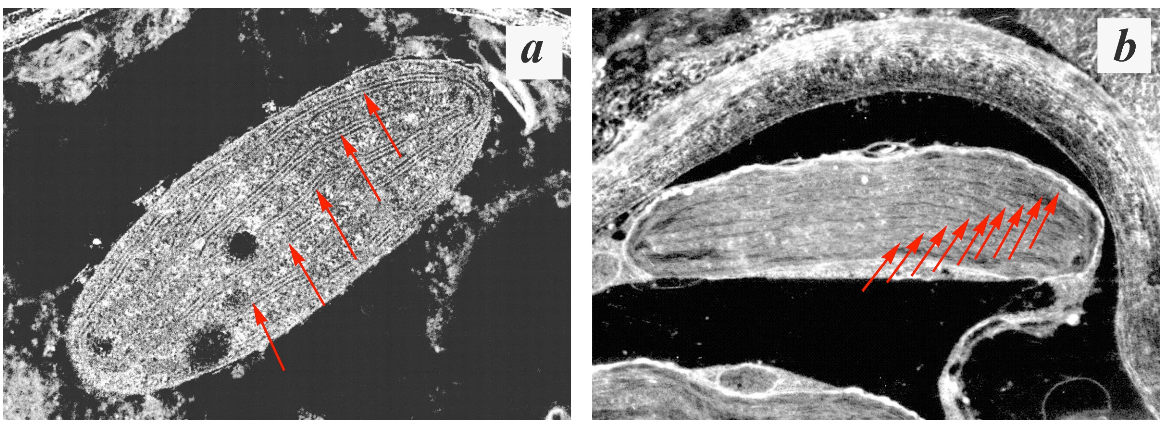

Fig. 3. Chloroplasts *F. vesiculosus* in summer (*a*) and winter (*b*). Arrows point at photosynthetic membranes

Thus, after 3 months in darkness (both under experimental and natural, near the Spitsbergen (Svalbard), conditions), *F. vesiculosus* retained viability with no signs of cells damage. Morphological characteristics indicate slowing down of its functional activity.

Our studies indicated that capability of algae living on the Murmansk coast during the Polar night was provided by the adaptation of the photosynthetic apparatus to a lower light level. Algae of the higher latitudes survive during a period of light absence due to the consumption of reserve substances, products of autolysis of the thallus, and the external dissolved organic matter. This may be an important condition for algal propagation to the high latitudes.

2. The spectral composition of light

2.1. Effects of spectral light composition on the light-harvesting complex of *Fucus vesiculosus*

There are many studies on the effects of spectral light composition to algae (so-called chromatic adaptation of algae). However, a large amount of contradictory data and the complexity of their interpretation make it difficult to understand the occurring processes. A quite detailed comparison of specific and nonspecific light and chromatic adaptation is given by Litvin and Zvalinskiy (1983).

Our studies showed rearrangements in the light-harvesting complex of the littoral brown algae *Fucus vesiculosus* in response to changes in the spectral light composition with increasing growth depth.

The light-harvesting complex of brown algae is called the FCPA (Fucoxanthin-Chlorophyll-Protein Assembly) or "xanthosoma". The complex consists of seven identical protein subunits of 54 kDa, each containing 13 molecules of Chl *a*, 3 - Chl *c*, 10 - fucoxanthine and 1 - violaxanthine. Migration of absorbed in xanthosomas energy is in 2 independent ways different in speed, but not the efficiency: from fucoxanthine to Chl *a* and Chl *c* to Chl *a* (Alberte et al., 1981; Katoh et al., 1989; Mimuro et al., 1990). However, the ratio of pigments may vary depending on species affinity (Barrett and Anderson, 1980; Katoh et al., 1989; 1993; Mimuro et al., 1990; Passacuet et al., 1991; Douady et al., 1993).

For higher plants and green algae the chlorophyll content in the LHC is represented by the ratio of Chl *a*/ Chl *b* (Lichtenthaler, 1987). Since the ratio of brown algal pigments in LHC is not known, the distribution of Chl *a* in pools of LHC or photosystems can be roughly determined by the ratio of Chl *a*/ Chl *c* + fucoxanthine. On the analogy of green algae, the lowest value of this indicator will indicate the maximum size of the LHC.

Chl *a* and Chl *b* act as the major light-harvesting pigments in the LHC composition of higher plants and green algae. Therefore, only the changing of LHC size, not its structural rearrangement, can be identified when the spectral composition of light changes. In the red algae, bearing phycobilisomes, LHC structure, includes 2 pigment-protein complexes: phycoerythrin and phycocyanin with absorption maxima in different spectral ranges. All studies on chromatic adaptation of red algae indicate the changing ratio of these pigments. Thus, phycobilisome restructuring is revealed here.

Our studies showed that in summer about 80% of PAR is absorbed by the first meter of water column off the Barents Sea coast (Zelenetskaya Bay). 6% of PAR reach 5 m depth, about 0.4% reach the depth of 15 meters. In September, water transparency increases, and 1% of PAR reaches the depth of more than 30 meters. UV radiation is absorbed by upper water layers, the light intensity in the red (700 nm) and blue (400 nm) spectral ranges reduces considerably as well. Green (545 nm), yellow (580 nm) and to a lesser extent orange (620 nm) light penetrates the maximum depth.

To determine adaptive reorganizations of photosynthetic apparatus of *F. vesiculosus* collected from the littoral zone were placed at the depths of 0 to 15 m, where they remained for a month. Adaptation of plants' FSA to reduced light intensity may occur by increasing the xanthosoma size. Its maximum size (the minimum ratio of Chl *a*/ Chl *c* + fucoxanthine) was observed with plants located at a 2-meter depth and it decreased together with the further increase of depth. The accumulation of photosynthetic pigments continued down to the depth of 5-10 m (Makarov et al., 2010).

Xanthosoma resizing was accompanied by a rearrangement of its structure. The ratio Chl *a*/ Chl *c* and Chl *a*/ fucoxanthine changed, changes were in antiphase (Fig. 4 *a*). The content of Chl *a* changed mainly, the fucoxanthine content remained more stable. A functional specialization of these pigments is possible. The energy of light quanta from fucoxanthine is largely transferred to PS I, from chlorophyll *c* to PS II. Findings of the study of the photosynthetic apparatus and photosystems functioning of *F. vesiculosus* from the Baltic and Norwegian Seas confirm this finding (Gylle et al., 2011).

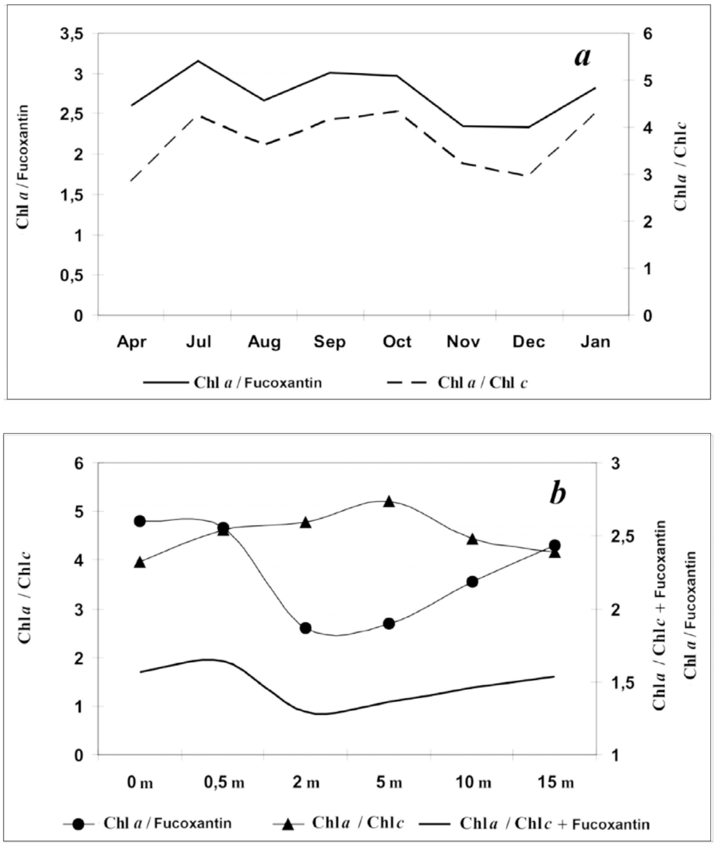

Fig. 4. The size of xanthosoma and the ratio of light-harvesting pigments depending on the depth (*a*), seasonal changes in the ratio of pigments compounding *F. vesiculosus* xanthosoma (*b*)

During adaptation to light intensity varying throughout the year, resizing of *F. vesiculosus* xanthosoma is without rearrangement of its structure: the ratio of Chl *a*/ fucoxanthine and Chl *a*/ Chl *c* changes simultaneously (Fig. 4 *b*).

The study showed that the light-harvesting complex of brown algae adapts to both the intensity and spectral light composition. The structural rearrangement of xanthosoma is mainly due to changes in the Chl *c* content, which may be associated with the priority of maintaining PS II function under stress conditions.

2.2. Impact of ultraviolet radiation

The ultraviolet part of the solar spectrum is largely absorbed by upper water layers. However, even its reduced number impacts significantly. Experiments on various parts of the UV radiation clipping using selective filters showed that the rate of algal growth is maximal in its absence. It remains at the same level or is slightly reduced under UV-A influence and decreases considerably when exposed to UV-B (Makarov, 1999). UVB radiation affects seaweed physiology and ecology and, thus, shapes the coastal environment by affecting the spatial, species and functional structure of seaweed communities (Bischof et al., 2006).

Species with a lamellar thallus organization inhabiting the lower littoral and upper sublittoral zones are the most sensitive, which is likely due to disruption of photosynthetic and protein-synthesizing apparatus (Harm, 1980; Dohler, 1984; Karentz et al., 1991; Jordan et al., 1991). The degree of different species resistance to UV-B depends on the content of shielding and UV-absorbing pigments, and on the activity of repair processes (Makarov, 1999; Steinhoff et al., 2011).

The exposure of sporogenous tissue of *Saccharina latissima* with UV-B causes the paraphyses death. This leads not only to the output of both mobile (active) mature and immature spores and to detachment of the entire sporangia. At high levels (1.2 W/m^2, which corresponds to the natural level of UV-B in the Arctic on a clear summer day), the output started 4 h after exposure. The mortality rate of zoospores also directly depends on the UV intensity.

UV exposure of *Saccharina latissima* zoospores did not exert significant influence on their germination, whereas the irradiation of embryospores caused a delay or developmental disorder. This finding can probably be explained by an active state of DNA and protein synthesis apparatus of embryospores unlike the zoospores.

Our studies have thus shown that the ultraviolet radiation is a factor having a significant impact on the algal reproduction and recovery processes (Makarov andVoskoboinikov, 2001).

3. Photoperiod

The studies conducted so far revealed the influence of photoperiod on the growth rate, the dry matter content, and the state of photosynthetic apparatus of the Barents Sea macroalgae.

Prolonged photoperiod contributed to the algal growth in the autumn-winter period and did not affect or hinder the growth during the spring and summer. Experiments also revealed that under constant lightning the growth rate of most algae species is higher than during the 12/ 12 light/darkness photoperiod. Nevertheless, under the natural conditions with constant light (Polar day) and the increase of water temperature algal growth slowed down. This indicates endogenous rhythms of seasonal algae development (Makarov et al., 1999). Similar data were also obtained for the other algal species from the seas of moderate latitudes (Fortes and Lüning, 1980; Lüning 1991, 1993; tom Dieck, 1991; Lüning and Kadel, 1993; Schaffelke and Lüning, 1994).

The response of the photosynthetic apparatus to the duration and intensity of light varies. Under long day conditions, a general reduction of photosynthetic pigments without changing the ratio of chlorophylls and carotenoids was found.

Under short day conditions, accumulation of carotenoids performing the role of both sunscreen and light-harvesting pigments is optimal: while under high light intensities at midday carotenoids protect chlorophylls from photodestruction, they may act as “light accumulators” under low light conditions at allow solar angle, thereby increasing a period of effective light energy use.

Reduction of light duration causes an increase of the dry matter content in algal thalli. Apparently, photoperiod is a signal switching physiological processes of algae from growth to the accumulation of reserve substances, which is an important adaptive trigger to prepare for the environmental constrains during the Polar night.

Our research has confirmed the conclusion by K. Lüning (Lüning, 1993) that photoperiod is the regulator synchronizing endogenous rhythms of algae with environmental conditions. This is especially true for algae of the Polar seas where temperature and light conditions vary considerably during the year.

4. Temperature

Temperature is one of the main factors determining biogeographical boundaries of algal growth (Hoek, 1982a, b, 1984; Lüning, 1984; Perestenko, 1998; Cambridge et al., 1990; Novaczek and Breeman, 1990; Howe and Brunner, 2005; Verbruggen et al., 2009). However, despite numerous experimental studies on algal temperature tolerance, mechanisms of their heat resistance and cold resistance (being especially relevant for the Northern seas) are not entirely understood.

The results of our experiments show that for the majority of the Barents Sea algae the optimum temperature for vegetative growth is 10-15°C, rarely 5-10°C, and 20-22°C for single species (Table 2). Among them, there are eurythermic species, the majority of littoral algae belong to, and stenothermic species, able to exist within a narrow temperature range. Eurythermic algae are adapted to considerable temperature fluctuations. Similar results were obtained for the other algal species as well (Grintal, 1965; Lüning, 1990; Shoshina et al., 1996; Voskoboinikov et al., 1996, 1997).

The air temperature on the Barents Sea coast experienced by littoral algae during a low tide period can drop to -25ºC in winter and reach +30ºC in summer. The lowest water temperature (to -1.5ºC) is registered in February-March. The maximum temperature at the water surface in the Barents Sea bays reaches 12ºC in September, and does not rise above 5ºC at a 10-meter depth (Chernov, 1957).

Table 2. Effect of temperature on the viability of Barents Sea macroalgae

	Temperature, ºC										
Species	-20	-15	-10	-5	-2.5	+10	+15	+20	+27	+30	+35
Acrosiphonia arcta	+	+	+	+	+	+	+	+/- (20/80)	-	-	-
Cladophora rupestris	-	+/- (30/70)	+/- (50/50)	+	+	+	+	+	+/- (80/20)	+/- (20/80)	-
Ulva intestinalis	+	+	+	+	+	+	+	+	+/- (50/50)	+/- (30/70)	-
Ascophyllum nodosum	+	+	+	+	+	+	+	+	+/- (30/70)	+/- (20/80)	-
Fucus vesiculosus	+	+	+	+	+	+	+	+	+/- (50/50)	+/- (20/80)	-
Fucus serratus	+	+	+	+	+	+	+	+	+/- (20/80)	-	-
Pylaiella littoralis	-	+	+	+	+	+	+	+	+	-	-
Saccharina latissima	-	-	+	+	+	+	+	-	-	-	-
Laminaria digitata	-	-	-	+	+	+	+	-	-	-	-
Delesseria sanguinea	-	-	-	-	+	+	+	-	-	-	-
Phycodrys rubens	-	-	-	+/- (40/60)	+	+	+	-	-	-	-
Palmaria palmata	+	+	+	+	+	+	+	+	-	-	-
Porphyra sp.	+	+	+	+	+	+	+	+	+	-	-
Chondrus crispus	-	-	-	+/- (40/60)	+	+	+	-	-	-	-
Polysiphonia arctica	-	-	-	+	+	+	+	+	+	-	-
Dictyota dichotoma	-	-	-	-	+	+	+	+	+	-	-
Membranoptera alata	-	-	-	-	+	+	+	+	+	-	-

Legend: “+” alive, “-” died, “+/-” partially survived (the ratio of alive and dead, %)

Our studies have shown that the algae in the Barents Sea can exist within a month at a temperature of -1.5ºC. First injuries of *Phycodrys rubens* and *Saccharina latissima* were registered at -2.0°C, but some of them were reversible. The formation of crystals inside the sublittoral algae cell starts at a temperature below -1.8°C (a seawater freezing point). With further temperature decrease, the number of damaged cells increases reaching its maximum at -5ºC for *Phycodrys rubens* and -6.5ºC for *S. latissima*. *Fucus vesiculosus* indicated the highest resistance to low temperatures. Irreversible damages began to occur at a temperature of -20ºC. At -20ºC only single fragments of *Palmaria palmata* and *Porpyra umbilicalis* remained viable (Voskoboinikov et al., 1996). A wide range of *F. vesiculosus* temperature tolerance was registered also for the White Sea fucoids (Feldman et al., 1963).

The resistance of algae to freezing is probably a consequence of the synthesis and accumulation of cryoprotectants (glycerol, proline, mannitol, fucoidan, etc.). However, this hypothesis is valid only for a limited number of species able to synthesize these substances. For instance, brown algae, such as *S. latisima* with significantly higher mannitol content, compared to many littoral algae, are significantly inferior in resistance to low temperatures.

An excretion of fucoidan polysaccharide by littoral fucoid algae enables the formation of a hull (ice box) on the outer part of the algae. It prevents macrophytes from death during low tides in winter. Cells of fucoids contain a large amount of phenol compounds serving as antifreeze.

During low tide periods, littoral algae lose up to 40-70% of water. The ability of dehydration without losing viability possibly also ensures the safety of tissues of some littoral algae species in winter. Recent experiments carried out by means of high dielectrometry, nuclear paramagnetic resonance, indicated a large percentage of bound water in the cells (Parshikova et al., 2000). In *Palmaria palmata* and *Porphyra sp*. it was shown that the temperature decrease causes the increase in the concentration of polyunsaturated fatty acids in algae (Kayama et al., 1985; Khotimchenko, 2003) contributing to cell membranes fluidity. The presence of other mechanisms contributing to survival of littoral algae under cold conditions is possible (Gapochka, 1981; Klimov, 2001).

The range of low-temperature resistance was developed for fucoid algae *Fucus vesiculosus*> *F. distichus*> *F. serratus* based on experimental data collected applying a freezing facility as well. The range coincides with the vertical position of algae in the littoral zone.

Macrophytes in the Barents Sea show a significant difference in the resistance both to negative and positive temperatures. We have shown that the green algae *Cladophora rupestris* and *Acrosiphonia arcta* being close in systematic affiliation, thallus structure, and habitat preferecnes, are quite different in temperature growth optima and boundaries of resistance to positive temperatures. The maximum growth rate of *A. arcta* is at +8-10°C, and the temperature of +18-20°C causes mortality. The growth rate of *C. rupestris* is maximal at 20-22°C, and its mortality is at 30°C. This phenomenon can be explained by the alga´s geographical origin: While *A. arcta* is of Arctic origin, *C. rupestris* is a tropical one (Voskoboinikov et al., 1997). On the ground of the obtained data we concluded that algal temperature tolerance is genetically conditioned.

Conclusions

Thermal conditions in the high-latitude Arctic areas of the Barents Sea are quite severe for the existence of living organisms. In addition, lighting conditions due to the photoperiod change from the Polar day to the Polar night also have a significant impact on plant organisms. While terrestrial higher plants are able to shed leaves and go into hibernation in winter, algae are deprived of this capability and have to adapt to low temperatures and lack of lighting. The results of conducted studies suggest that the adaptation to a prolonged absence of light and low temperatures during the Polar night allowed the algae to propagate beyond the Arctic (Polar) Circle.

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MAIN DIRECTIONS OF SEABIRD RESEARCH OF MURMANSK MARINE BIOLOGICAL INSTITUTE IN ARCTIC SEAS OF EUROPE

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Abstract

The main directions of ornithological research of the Murmansk Marine Biological Institute (Russia) in the seas of Northern Europe are considered in this paper. The major results of seabird research at sea and in areas of mass breeding on islands and coasts of the northern seas are presented. The use of aviation facilities in monitoring wintering and molting areas, and migration stopover sites, as well as studies of sex-age structure of some species of seabirds are discussed. Essential outcomes of studying the trophic links of the seabirds of the Barents and White Seas are introduced.

Introduction

Seabirds are species, which spend most of their annual cycle at sea and are land related during breeding season only. In the Soviet Union the surge of interest in research on marine avifauna in the 1920-40s coincided with the beginning of active exploration and development of the Arctic and was closely connected to the organisation of polar stations and nature reserves (Demme, 1934; Kaftanovskiy, 1938; Uspenskiy, 1941). The focus of research in those years was on nesting biology and ecology including the development and improvement of methods of abundance recording in breeding places. The implication was that such research should ensure creation of a scientifically based rational system of seas bird exploitation in the national economy's interests (Belopolskiy, 1957). For this reason, the first ornithological reserves *Kandalaksha* and *Semi Ostrovov* (subsequently united) were established. They were almost the only centers for seabird studies in the European part of the country for decades (Bianki et al., 1993). Sea birds were studied mainly on land in the places of their mass reproduction. In the open sea areas only few fragmentary observations on distribution specific features and trophic behavior of some species were conducted (Belopolskiy, 1933).

Studies of seabirds at that time were only little linked to studies of the other parts of marine ecosystems. In the mid 1980s, however, the majority of experts started to consider seabirds as truly marine organisms. In the early 1990s the Murmansk Marine Biological Institute (MMBI) began active research in the field of marine ornithology with a distinct ecosystem approach.

Studies of seabirds in the open sea areas

The information about nesting biology and ecology of seabirds began to increase rapidly in the 1970-80s. It became obvious that many basic tasks, such as studying birds' role in marine ecosystems, were impossible to solve without a complete set of information obtained in the open sea areas. Issues of estimation of birds' abundance at sea became most important.

Those estimations had to be carried out year round in the Barents, Kara, and White Seas, in order to determine inter-annual variability in abundance and distribution of avifauna in some areas of these seas.

Detailed and the most extensive ornithological information in the open sea areas can be obtained by observations from vessels. MMBI experts organized regular ornithological observations in winter on board the icebreakers in the Barents, White, and Kara Seas. It resulted in obtaining information about winter avifauna of the Eastern Barents Sea and Western Kara Sea. During those cruises the wintering area of thick-billed guillemot (*Uria lomvia*) in polynyas and water-streaks near the Northwestern coast of the Novaya Zemlya was discovered (Krasnov et al., 2007). Near the southwestern coast of the archipelago, wintering birds are concentrated in some years only perhaps influenced by ice conditions. In general, a series of observations from icebreakers showed that the abundance of sea birds near the western coast of Novaya Zemlya from December to January is relatively low. It begins to increase gradually already in February reaching its maximum in April. This is due to a return of hundreds of thousands marine colonial birds to colonies of the western coast of the Novaya Zemlya. Before going to nesting, birds are battened in edge-side areas and polynyas, where an increased productivity of zooplankton is found. Concentration of thick-billed guillemots, black guillemots (*Cepphus grille*), little auks (*Alle alle*), and black-legged kittiwakes (*Rissa tridactyla*) with high values of abundance was registered in those areas during the period (Krasnov et al., 2007).

The internationally developed and standardized traditional methods of marine avifauna research in the open water areas by shipboard observations (Mehlum, 1989; Isaksen, 1995; Camphuysen et al., 1995, Tasker et al., 1984; Gould and Forsell, 1989) are not free of a number of deficiencies (Krasnov et al., 2004). Aviation observations from aircraft-laboratories do not have that defect and allow avoiding ship surveys' difficulties because speed of aircraft is much higher than the speed of the observed birds have. Moreover, aerial surveys seem to be the only way to obtain correct information on the birds' abundance in fishing areas in case of a concentration of a large number of fishing vessels.

Aerial birds' counting surveys started nearly half a century ago (Isakov, 1952; Kishchinskiy, 1973). The research areas are usually limited to lakes, bays, straits, and coastal waters because exclusively light aircrafts are used worldwide (Webb et al., 1990; etc.). A team of professionals from the MMBI, PINRO and AARI for the first time in the history of ornithology developed a method of seabirds' registration from the board of flying laboratories carrying out research in the open areas of the Arctic seas. The aircraft-laboratory is equipped with specific windows (blister windows), computer complex and remote sensing facilities, which provide a comprehensive information pool: speed and flying altitude above sea level, course, as well as survey track, coordinates of observed objects were recorded automatically by GPS directly into PC) (Krasnov et al., 2004). The use of aircraft-laboratories allows promptly to determine the abundance and distribution of seabirds over vast areas, for example, over the entire Barents Sea (Fig. 1).

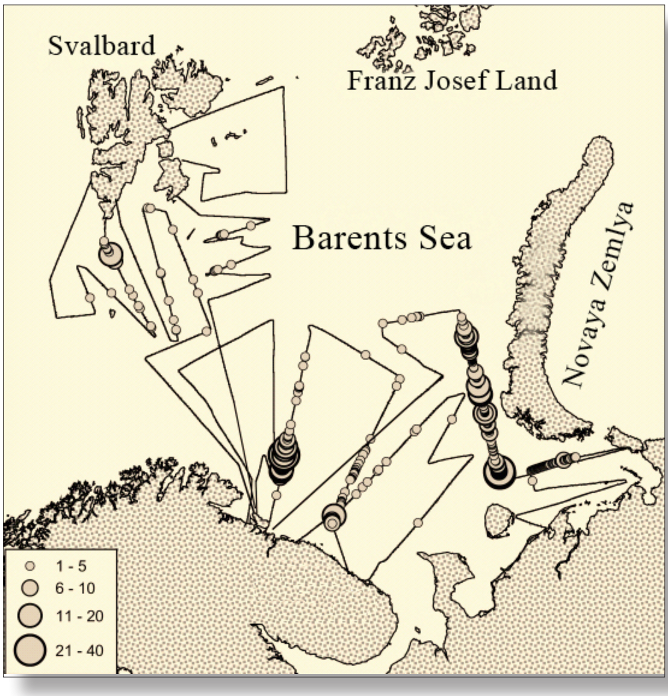


Fig. 1. Distribution and abundance of guillemots in the Barents Sea according to air-observation data in September 1997. Circles represent number of specimen along transect

Both observation methods (aircraft and ship) supplement each other. Overall, the observation results illustrated that the behaviour and distribution of seabirds in the open areas of the Arctic seas may vary within wide limits depending on climatic and weather conditions, as well as on location, distribution and amount of feed resources available for birds. The highest numbers of seabirds in the open sea areas are to be found in places of dense concentrations of small pelagic fish and zooplankton, particularly near the ice-edge.

Since the mid 1990s ornithologists of MMBI in close collaboration with those of the AARI, NINA and Norsk Polar Institutt began a series of aerial observations from helicopters in the coastal areas of the Kola Peninsula and the White Sea (Nygard et al., 1995; Krasnov et al., 2004a; Krasnov et al., 2006). This allowed us to identify most of the current wintering and molting areas of sea ducks in these areas and to get information about the abundance of individual species.

For example, 250 thousand individuals of 24 bird species were counted during aerial observations in March 2009 in collaboration with the Norwegian Ornithological Society (NOS) off the coast of the Kola Peninsula and in the White Sea. Of these, the vast majority refers to four species: common eider (*Somateria mollissima*), king eider (*Somateria spectabilis*), Steller's eider (*Polystricta stelleri*), and black-legged kittiwake (*Rissa tridactyla*). The major concentrations of wintering sea ducks are registered in the Barents Sea – off the Murman coast; in the White Sea – in the northeastern part of the Tersky coast, in shallow waters of the Solovetsky Islands and in the Western Onega Bay (Fig. 2). More than 50 thousand specimen of common eider were registered in the White Sea. During observations in 2009 we found the wintering area of Steller's eider and king eider in the White

Sea to include the Onega Bay. It has been ascertained that the distribution pattern of sea ducks in the White Sea depends on location, thickness and specific features of ice cover.

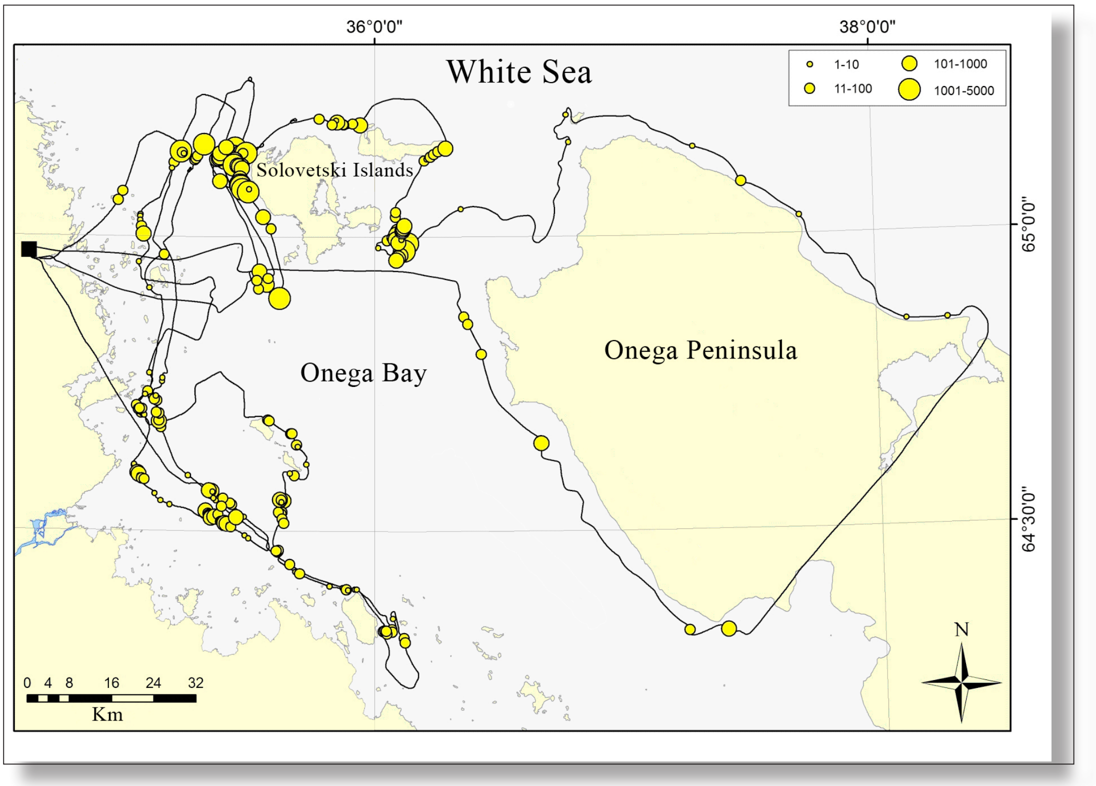


Fig. 2. Distribution and abundance of common eider (*Somateria mollissima*) in the Onega Bay of the White Sea in March 2009. Circles represent number of specimen along transect

Studies of seabirds in nesting areas

Ornithologists of MMBI conduct surveillance in large colonies of seabirds on the southern coast of the Barents Sea in order to identify the main factors determining the development of specific populations. Our research in these areas aims to define the current state of nesting populations of black-legged kittiwakes and guillemots, number of breeding birds and analysis of trends in population development in the Southern Barents Sea. Studies conducted during the period of 1995-2010 demonstrated that in accordance with changes in food supply in the coastal zone of Murman, both guillemots and kittiwakes experienced periodic fluctuations in abundance (Fig. 3; Krasnov et al., 2007a). At the same time, stocks of schooling pelagic fish near the coasts of Murman fluctuated strongly, and occasionally their abundances were extremely low. During those periods, conditions for development of guillemot and kittiwake populations were extremely unfavourable.

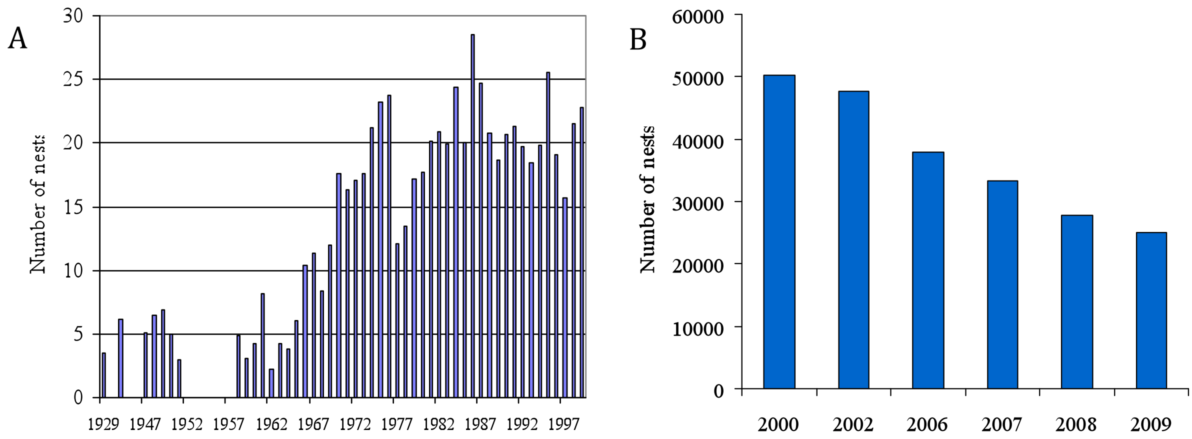
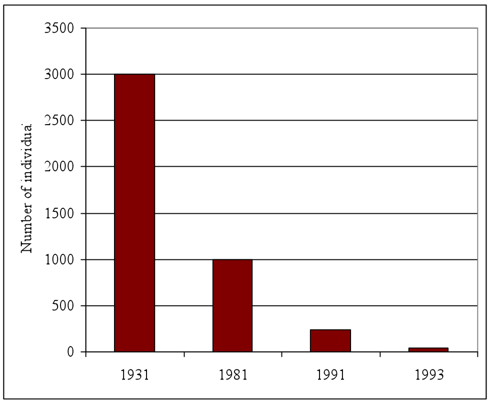


Fig. 3. Number of kittiwakes (*Rissa tridactyla*) on the northern coast of the Kola Peninsula
Legend: A – Kharlov Island, B – Gorodetskiy Cape

Studies of hitherto poorly investigated areas of seabirds' breeding in the Russian Arctic Novaya Zemlya and Franz Josef Land are of special interest. These areas are difficult to access for researchers. Nevertheless, we have both archival material and original information about birds of these areas (Fig. 4).



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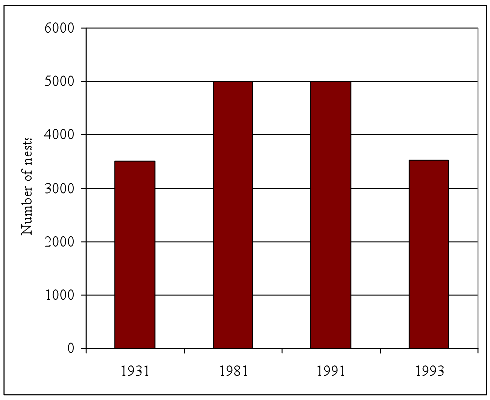

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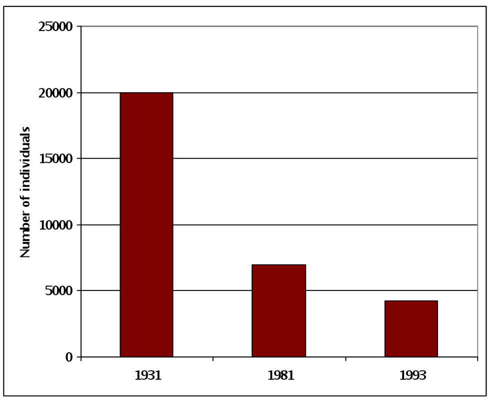

C

Fig. 4. Number of birds in Rubini Rock Colony, Hooker Island (the Franz Josef Land)
Data used: N.P. Demme (1934);
S.E. Belikov and T.E. Randla (1984);
M. Skakuj (1992)
Legend: A – northern fulmar (*Fulmarus glacialis*), B – kittiwake (*Rissa tridactyla*), C – Brunnich's guillemot (*Uria lomva)*

The development of seabird populations was retrospectively analyzed for some large colonies of Novaya Zemlya (Krasnov, 1995) and Franz Josef Land (Krasnov, 1995a). Ornithological studies are carried out rather regularly in the Southeastern Barents Sea, on Kolguev and Vaigach Islands (Krasnov, 2004; Krasnov et al., 2008). For example, in recent years actual abundance and distribution pattern of seabirds and water birds were determined off the western coast of Vaigach Island and adjacent waters of the Barents Sea. Catastrophic decline of common eider abundance on the western coast of Vaigach and in the adjacent areas and, conversely, a multiple increase of breeding and molting Barnacle geese (*Branta leucopsis*) have been demonstrated. The abundance of the first mentioned species decreased by approximately 10 times since the first detailed survey in 1960 (Karpovich and Kokhanov, 1967).

Studies of seabirds' migrations

In our studies on the migration routes of seabirds in the Arctic seas we summarized the results of dominant bird species' ringing and we mapped the flyways and migration stop-points, as well as the birds' molting and wintering areas (Krasnov and Goryaev, 2001). Kittiwake's wintering areas were studied by an international research group using GPS-recorders (loggers) in 2009-2010.

Studying of seabirds' trophic links

The trophic links of dominant seabird species, especially of guillemots and kittiwakes, are of great ecological interest. Our research showed that feeding composition of adult kittiwakes and guillemots was variable and diverse during the last decades in all the studied colonies. One or the other species of schooling pelagic fish periodically dominated in birds' diet. High occurrence level of small crustaceans, particularly euphausiids, was registered in kittiwakes' diet with rare dominance of capelin (*Mallotus villosus*).

Analyses of faeces in the Barents Sea region showed extremely high variability of common eider (*Somateria mollissima*) diet even within one geographical area, for example, in one bay of the White Sea. Even greater geographical variability of common eider diet is registered when sampling over greater distances (Fig. 5). In common eider diet on the Murman coast, mollusks, crustaceans (*Balanus balanus, B. crenatu*), and sometimes sea urchins *Strongilocentrotus droebachiensis* are of great importance. Species composition of common eiders diet is more limited and variable in the northern areas of the Barents Sea on the Franz Josef Land Archipelago. Crustaceans (*Onisimus glacialis*) or mollusks, particularly double-leaf *Mya truncata*, could form the basis of common eiders' diet in the studied areas of Franz Josef Land. High variability in common eider diet was registered on the western coast of the Spitsbergen Archipelago in the Fram Strait. (Krasnov et al., 2008a; Nikolaeva et al., 2010).

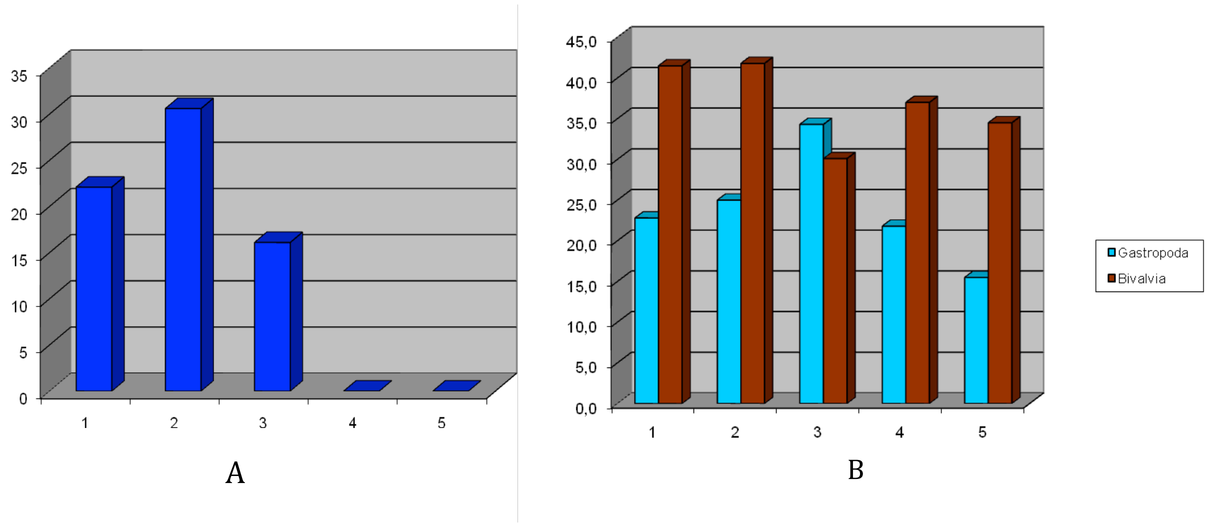

Fig. 5. Mussel (A) and other mollusks content (B) in common eider's diet (*Somateria mollissima*) in the Barents and White Seas
Legend: 1 – the White Sea, 2 – the Southwestern Barents Sea, 3 - Murman, 4 – Spitsbergen, 5 – Franz Josef Land

It has been demonstrated that common eiders' feeding behavior is characterized by certain plasticity allowing them to extract efficiently not only abundant forms of benthic organisms but also moving objects like fish. In each specific situation, a bird chooses the most abundant type of food. The geographic variability of food composition can be so great that they mask seasonal and sexual aspects of species trophic links. Qualitative and quantitative composition of common eider diet in winter period within the White Sea is largely determined by the presence and distribution pattern of ice cover. Therefore, the "ice factor" finally determines the conditions and survival of birds wintering in the area.

Collaborative research of the White Sea Biological Station of the Zoological Institute RAS and the Murmansk Marine Biological Institute KSC RAS revealed the trophic conditions for stable long-term existence of molting and migratory aggregations of king eider near Dolgiy Island and the western coast of Vaigach Island in the Southeastern Barents Sea. This is one of the most important areas of water birds' concentration in Northern Europe (Krasnov et al., 2002). The presence of attractive food like aggregated sublittoral mussel beds (*Mytilus edulis*) determines the key significance of this area for sea ducks (Sukhotin et al., 2008).

Studying of population structure of common eider (*Somateria mollissima*) as a model species

Common eider is the most abundant species of sea ducks in the Barents and White Seas and is the most interesting object for studying the population structure in the region as well. The significant size and high number of this sea duck define its important role in ecological functioning of the basin. There was a suggestion that the White Sea (endemic) population of common eiders lives in a settled-down way in the Western White Sea (Bianki, 1993), while birds belonging to the Murmansk population nest on islands along the Tersky coast within the Voronka and Gorlo areas of the northern White Sea.

Our observations in nesting periods showed that common eiders of the Murman population indeed nest on islands along the Tersky coast of the White Sea (within the Gorlo and Voronka areas), while the endemic White Sea population breeds and nests in the Kandalaksha and Onega Bays of the White Sea. Our studies conducted in the White Sea in the post-nesting period indicated that both populations are most widely distributed during the molting period of adult males.

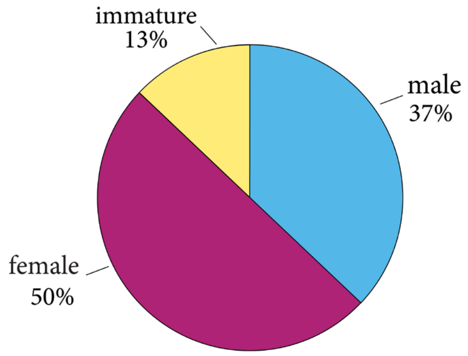

Fig. 6. Sex-age structure of the White Sea population of common eider (*Somateria mollissima*)
Data used: Krasnov et al. (2010)

Common eiders of the endemic population are most vulnerable in winter period, as they mostly winter in polynyas of rather limited shallow areas of the Onega Bay and sometimes of the Dvina Bay.

The current abundance of the White Sea population of common eider is more than 50 thousand individuals according to data of joint research by the MMBI, AARI, and NOF in 2009. There was practically no information published until recently about the sex-age structure of the population. Sex and age of almost 40 thousand individuals of common eider were determined, based on the analyses of more than three hundred photographs of wintering birds' concentrations of this species made from helicopter in the polynyas of the Onega and Dvina Bays of the White Sea, using digital photographic gadgets (Krasnov et al., 2010). This is more than 77% of the total population. Males (59%) are almost twice as abundant as females (30%). Immature individuals make up 11% of the total population abundance (Fig. 6, Krasnov et al., 2010). Thus, the number of the White Sea mature common eiders exceeds by more than twice the number of breeding individuals of the Western White Sea even in most favourable years (Karpovich, 1987). This means that there is a significant reserve of mature birds in this population.

Research on synanthropic groups of birds

In the mid 1980s seabirds experienced an acute shortage of fish feed, especially in their most sensitive breeding season, due to large-scale changes in the heavily exploited fish stocks in the Southern Barents Sea (Krasnov et al., 1995; Krasnov, Nikolaeva, 1998). Species with plastic feeding behavior, such as European herring gull, facing the shortage of fish feed in the vicinity of their traditional nesting sites were leaving them and formed thousands of non-nesting congestions in cultural landscape around Murmansk city dumping grounds, urban neighbourhoods, animal-breeding sovkhozes, and port facilities (Tatarinkova, Krasnov, 1984; Paneva, 1989). Nesting of European herring gull's couples on the roofs of residential buildings was first observed in the mid 1990s. In 2006 the city group of herring gulls consisted already of 1300 breeding pairs (Goryaeva, 2007). This "urban population" exists decoupled from processes in marine ecosystems.

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STRUCTURE OF ICHTHYOFAUNA IN THE ARCTIC SEAS OFF RUSSIA

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Abstract

This paper analyses the diversity and structure of fish communities in the Russian Arctic seas. The inventory of species composition was carried out based on all Russian reports over the entire historical period of observations. The number of species has been considered within geographic boundaries of the Russian Arctic seas. From the Barents Sea to the Chukchi Sea 286 species inhabiting the area and belonging to 161 genera, 64 families, 28 orders, and 5 classes were registered. The number of fish species and subspecies was determined for certain seas. The structure of ichthyofauna has been assessed by geographic habitat, affiliation to biotopes, and trophic preferences of fishes.

Introduction

The study of ichthyofauna of the Arctic region along the northern coasts of Russia started earlier, but detailed information on the general fish species composition in general, as well as for all six seas, was offered only in the middle of the last century (Andriyashev, 1954). Before and after only some data on certain seas or larger areas were published (Knipovich, 1897; Esipov, 1940, 1952; Altukhov et al., 1958; Russ, 1949, 1995; Dolgov, 2004; Karamushko, 2008). Some information on the Arctic ichthyofauna composition is to be found in review papers of high-latitude regions and the Russian waters in general (Parin, 2004; Reshetnikov, 2007a, b). The annotated catalogues of fishes from all Russian seas made invaluable contributions to the current understanding of ichthyofauna of the area under consideration (Andriyashev and Chernova, 1994; Parin, 2001, 2003; Parin et al., 2002; Evseenko, 2003; Vasil'eva, 2003; Fedorov, 2004). Nevertheless, after the appearance of the classical work by Andriyashev (1954), the quantitative composition of ichthyofauna of the seas along the northern coasts of Russia was not considered, although during the past 56 years the number of species and subspecies of fishes recorded here has increased significantly. Structural characteristics, describing the ratio of fishes and the geographic range, biotopes and trophic groups, have never been considered. Therefore, in this paper an attempt is made to briefly fill up the gap.

Materials and methods

To determine the quantitative species composition and the structure of ichthyofauna community of certain seas (the Barents, White, Kara, Laptev, East Siberian, Chukchi seas) data of expeditions and from the literature were used.

The results presented in this paper were obtained by expeditionary research during 1984-2010. Material for the analysis of species composition and structure of the ichthyofauna was collected from vast waters of the Arctic region within the Russian Economic Zone and beyond its boundaries. Scientific and commercial, specialized and multidisciplinary cruises were carried out to meet the goals. During the entire period of studies 31 scientific cruises and 10 coastal expeditions were carried out. The author was directly involved in 18 of them. He also provided biological guidance to 97 combined scientific-commercial cruises.

Bottom trawls DT / TV with a mesh size of 125-135 mm were mostly used. Fish catching from the RV *Dal'nie Zelentsy* in the Barents, White and Kara Seas was carried out with fine-mesh bottom trawl (mesh in wings of 24-80 mm, bag 12 mm). One trawling lasted from 10-20 minutes (fine-mesh trawls) up to 3.5 hours (fisheries trawl).

Besides open sea studies in 2002-2010, studies on the diversity of fishes were carried out in littoral and sublittoral zones of bays and bights of the Barents Sea coast of the Kola Peninsula. For that purpose, dragnets of 16 m in length, 2.5 m in height, mesh in wings and mouth of 5 mm, belly ends of 4 mm were deployed. The area fished at one station was about 700 m^2.

To determine the current quantitative composition of the ichthyofauna in the Laptev, East Siberian and Chukchi Seas, all available published data were used. We also included all data from annotated catalogues of fishes of the Russian seas. Data on quantitative composition of the global ichthyofauna was taken from the Eschmeyer's catalogue (Eschmeyer, 2011). The terms to describe the peculiarities and specific features of the geographical range and fish relations with the bottom or pelagial were adopted from Andriyashev and Chernova (1994). The species association to any of these characteristics was made after annotated lists and catalogues of fishes (Andriyashev and Chernova, 1994; Parin, 2001, 2003; Parin et al., 2002; Evseenko, 2003).

Results

The inspection of species composition and structure of ichthyofauna of the Russian Arctic seas revealed that from the Barents Sea to the Chukchi Sea there are 286 species inhabiting the area and belonging to 161 genera, 64 families, 28 orders and 5 classes. Fish species composition was also determined for certain seas (Table 1).

Table 1. Taxonomic structure of ichthyofauna in the Arctic seas of Russia

Taxonomic rank	Seas					
	Barents	White	Kara	Laptev	East-Siberian	Chukchi
Species and subspecies	182	82	93	70	51	103
Genera	127	65	62	43	36	68
Families	58	31	27	22	19	26
Orders	28	18	16	14	11	13
Classes	5	3	3	2	2	3

Without taking into account semi-anadromous, anadromous, and freshwater species constantly registered in seas, the number of marine species and subspecies amounts to 154 for the Barents Sea, 50 for the White Sea, 60 for the Kara Sea, 50 for the Laptev Sea, 26 for the East-Siberian Sea, and 78 for the Chukchi Sea. Representatives of the freshwater ichthyofauna are most numerous in the White and Kara Seas, where 19 species of freshwater fish are recorded. There are 9 of these species in the Barents Sea, 7 – in the Laptev Sea, 8 – in the East Siberian Sea, and only 5 – in the Chukchi Sea.

The share of the Arctic species increases steadily from the Barents Sea (28%) to the Laptev Sea (67.1%), and then decreases making a little less than a half of this parameter (33%) in the Chukchi Sea. The number of the Arctic-boreal species, a share of which in the Barents Sea is rather low (2.2%), gradually increases eastward to the East Siberian Sea (7.8%). The smallest number of boreal species is in the Laptev Sea (24.3%), while the maximum one is in the White Sea. This is associated with a high proportion of freshwater species (Fig. 1). The major biotope for fishes from all the Arctic seas is near-bottom layers and the bottom itself, where 36.6- 67% of all species live permanently depending on the area (Fig. 2).

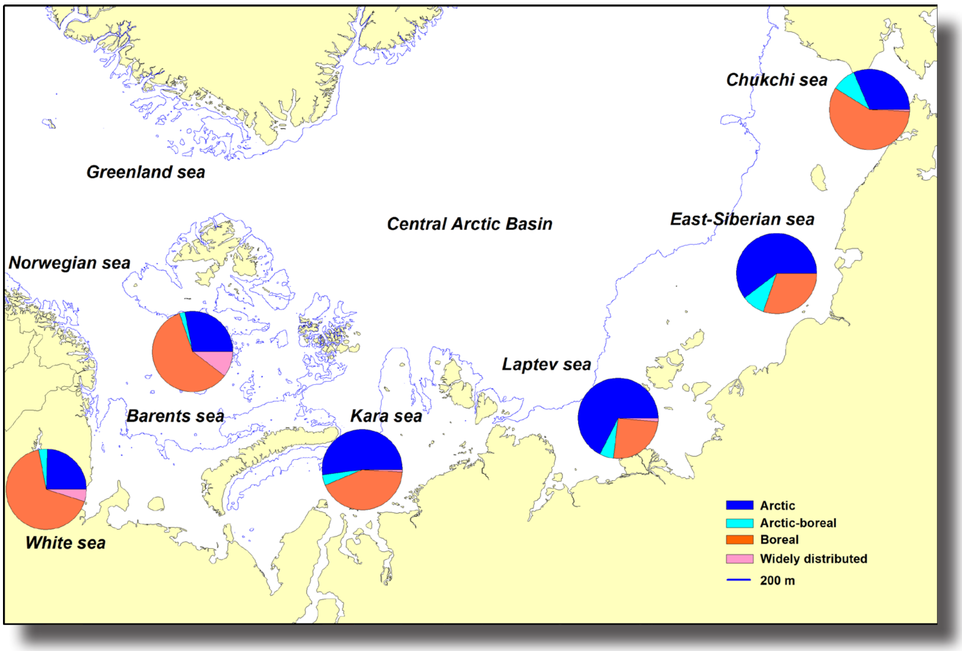

Fig. 1. The structure of the Arctic seas ichthyofauna by geographical area

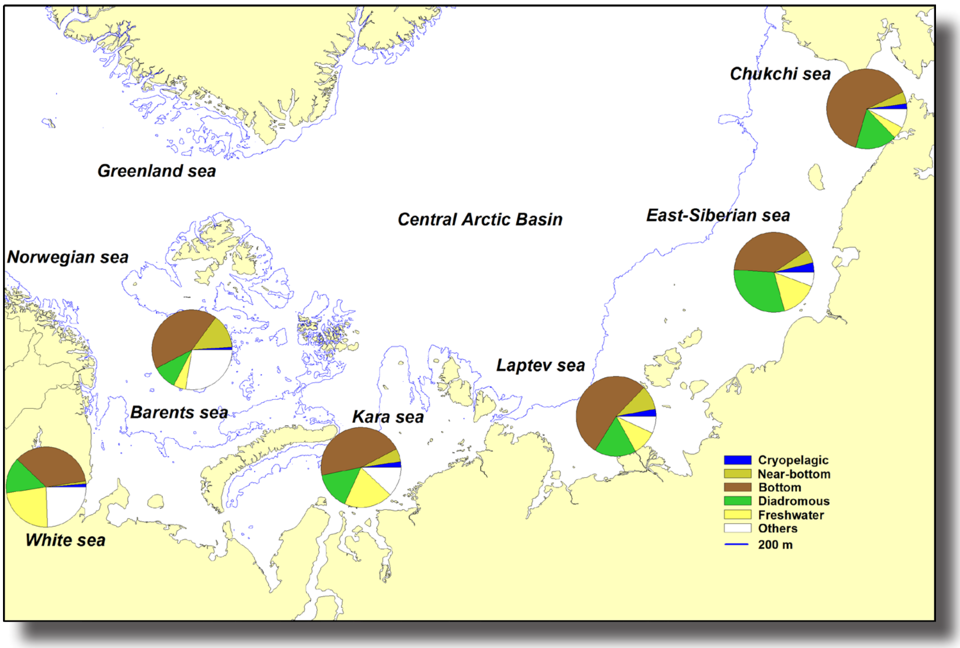

Fig. 2. The structure of the Arctic seas ichthyofauna by biotop peculiarities and specific features

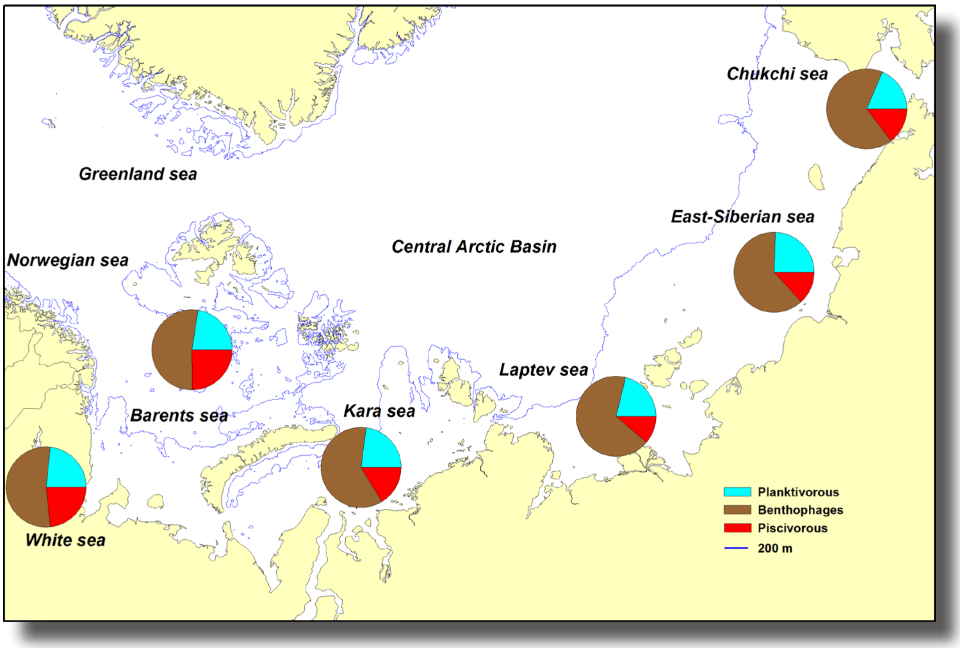

Fig. 3. The structure of the Arctic seas ichthyofauna by diet

The major trophic fish group in the high-latitude seas of Russia is benthophages. Their share in various seas varies from 52.2% (the Barents Sea) to 67.1% (the Laptev Sea). The relative amount of plankton-eaters varies in the majority of water bodies to a lesser degree and makes 21.4-23.7%. Only in the Chukchi Sea it amounts to 17.5% (Fig. 3). The greatest number of predator species inhabits the Barents Sea (24.7%), while the minimum is in the Laptev Sea (11.5%). In general, the ratio of plankton-eaters and predators in each of six seas is quite similar, and only in the Laptev Sea the number of predators is two times less.

Discussion

To view the quantitative composition and structure of the ichthyofauna of the Arctic region as a whole and of the Arctic seas, in particular, we applied three principles:

1. The quantitative ichthyofauna composition considers registered catches of all fish species in waters of corresponding seas;

2. The quantitative composition and structure of ichthyofauna is considered within the geographical boundaries of the Arctic seas (Atlas of the Oceans, 1980);

3. Freshwater species as a permanent element of fish communities of certain sea areas are included in the ichthyofauna composition.

It should be noted that freshwater fishes constantly registered in seas (coastal areas, bays, inlets and estuarine areas) are to be included in lists of species, because, for instance, a calculation of productivity, being a functional characteristic of a fish community, is not possible without these species being considered. These species use marine food resources for 2-8 months and in some cases during the entire year. In some areas, such as the Gulf of Dvina, the Gulf of Ob, Taz Bay, the Yenisei Gulf and others, freshwater species make up to half or more of the local ichthyofauna – *Leuciscus idus* (Linnaeus, 1758), *Leuciscus leuciscus* (Linnaeus, 1758), *Rutilus rutilus* (Linnaeus, 1758), *Esox lucius* (Linnaeus, 1758), *Lota lota* (Linnaeus, 1758), *Gymnocephalus cernuus* (Linnaeus, 1758), *Perca fluviatilis* (Linnaeus, 1758). These species are not only observed in the area but live there all the year round and are of local economic (commercial) importance. In the most recent annotated catalogues (Parin, 2001, 2003; Parin et al., 2002) freshwater species are included in the lists of ichthyofauna of the Russian seas. In fact, this confirms the need for appropriate accounting of freshwater fish in marine areas.

Compared with the list of fishes represented in Andriyashev (1954), the relative number of species and subspecies in some Arctic seas increased since the middle of the last century by 26.4% in the Barents Sea, 54.7% in the White Sea, 66.1% in the Kara Sea, 75.0% in the Laptev Sea, 96.2 % in the East-Siberian Sea, and 178.4% in the Chukchi Sea. There was a clear eastward trend in the rate of new records. In the Barents Sea and partially in some other seas, the main increase of fish species composition occurred due to the revision of some genera (*Liparis, Careproctus, Gymnelus*). In some other areas it was a result of finding species previously not registered and the inclusion of freshwater representatives.

In general, this is a small amount when compared to 4249 new species described in the global ichthyofauna during the last 10 years (Eschmeyer and Fong, 2011).

The number of higher taxonomic groups consistently decreases from the Barents Sea to the East Siberian Sea (from the west to the east), and then increases slightly (Table 1). Almost the same situation exists in relation to species, with the only exception being the White Sea. There the environmental conditions are significantly more severe than, for instance, in the Northwestern Kara Sea, where rather many species are registered.

The analysis of such indicators of taxonomic structure as the average number of species in the genus or family, the average number of genera in the family, showed for various Arctic seas that the ratio indices of species/genera were 1.26-1.63, species/family - 2.64-3.96, genera/family - 1.87-2.62. These are significantly lower than the indices for the global ichthyofauna (6.7, 57.8 and 9.3 respectively). These figures of latitude-zone diversity show that taxonomic organization of the Arctic ichthyofauna is poor against the world average values.

Representatives of three orders (Salmoniformes, Scorpaeniformes, Perciformes) constantly dominate in all seas. Number of species is highest in the families Zoarcidae and Cottidae. There are no endemic genera, not to mention the higher rank taxa in the ichthyofauna of the Russian Arctic seas. This is due to the relatively short history of the Arctic basin existence as a cold-water region, and its incomplete geographical isolation.

Considering the high-latitude location of the seas having quite harsh habitat conditions for fishes, of special interest is the structure of fish communities by the geographic area. The least amount of Arctic species inhabits the Barents, Chukchi, and White Seas, which is primarily due to their oceanographic characteristics. For the Barents and Chukchi Seas the most important of them is the inflow of warm water from the nearby boreal areas. In the Kara, Laptev, and East Siberian Seas, life conditions of fish are more severe. They determine the ichthyofauna composition where representatives of a limited number of genera *Coregonus, Salvelinus, Careproctus, Liparis, Gymnelus, Lycodes* dominate.

In general, there were 11 categories defined in the biotopical structure of the Arctic seas ichthyofauna – cryopelagic, epipelagic, neritopelagic, bathypelagic, epibenthic-pelagic, epibenthic (near-bottom), benthic (bottom), semi-anadromous, anadromous, catadromous, and freshwater). Some fish species deserve a special attention. These are, first of all**,** cryopelagic polar cod *Boreogadus saida* and Arctic cod *Arctogadus glacialis*. Within shelf areas, polar cod keeps near ice sparsely. Instead, it lives almost constantly in near-bottom layers where it is exploited by bottom trawling. Getting into the central Arctic basin, or other deep-water areas, those fish are forced to concentrate at the sea-ice, because, according to our observations (near Greenland), bottom habitat deeper than 800 m is not suitable for them. The same is applicable to the Arctic cod.

All fish species in the Arctic seas of Russia can be divided into four groups by their preferred nutrition – detritophages, zooplankton-eaters, benthophages, and predators (the overwhelming majority are ichthyophages). With few exceptions, this division is rather conditional, since most species could be considered euryphagous. Unstable habitat conditions determined by the varying intensity of heat advection and discontinuous regional climate variations have a significant impact on both the number and distribution of food objects, and on feeding areas of fishes. Under such circumstances, it is not possible to feed on one food type permanently or for a long time. At the same time, whenever it is possible to choose, each kind of fish prefers some certain food, which, as a rule, is reflected in the long-term data on their feeding.

Detritophagous *Chelon labrosus* was noted only in the Barents Sea sporadically, so this group may be disregarded. The remaining three groups are at Figure 3. Regardless of the area, the main trophic group is benthophages. Under the more severe conditions of eastern seas their share is significantly higher than in western ones.

It is commonly known that a structure of the fish part of communities can vary in time and space. The major abiotic factors of diversity in the Arctic seas are temperature and salinity, which have a direct influence on the formation of fish population. In the Barents and the White Seas fishing is the dominant factor impacting the fish fauna. In northern ecosystems characterized by a high degree of dominance of a limited number of fish species and relatively low indices of natural diversity, an increase in fishing intensity increases the diversity due to the alignment of shares of other community representatives. Therefore, in such ecosystems as the Barents Sea an increase in diversity, and particularly a sharp one, may be an indicator of over-exploitation of dominant fish populations.

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JOINT MMBI, SSC RAS AND NODC NOAA APPROACH TO OCEANOGRAPHIC AND HYDRO-BIOLOGICAL DATABASE ORGANISATION FOR THE ARCTIC AND SOUTHERN SEAS OF RUSSIA

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Objective assessment of present climate changes largely depends on the availability and completeness of databases containing information about the environment and biota. Since the early 1990s the Murmansk Marine Biological Institute (MMBI) of the Kola Scientific Center (KSC), that is a part of the Russian Academy of Sciences (RAS), in collaboration with the National Oceanic and Atmospheric Administration (NOAA, USA), operating the National Oceanographic Data Center (NODC), has been working on rescuing and archiving of oceanographic and biological data (Matishov et al., 1998, 2000, 2004; Golubev and Zuev, 2005a,b). In 2003 the Southern Scientific Centre (SSC) RAS joined this work. As a result, a series of climatic and biological atlases of the Arctic seas and Sea of Azov was published (Matishov et al., 1998, 2000, 2004, 2006, 2009c).

The first known instrumental water temperature monitoring in the Arctic at the surface and various depths was done by the British whaler William Scoresby at 76°16' N, 9°00' E on the 19th of April 1810 (Piterman et al., 1871). Since then an enormous amount of physical, hydrochemical and hydro-biological data has been accumulated as a result of research on scientific and commercial vessels of Russia (the USSR), Germany, Norway, France, the Netherlands, the UK, the USA, and other countries (Golubev and Zuev, 2005a).

Oceanographic observation data were accumulated in archives of oceanography institutions in the form of tables, logbooks and aircraft observations records for a long time (Golubev and Zuev, 2005a). Development of modern instruments and methods of oceanographic research has led to rapid increase in information quantity. The so-called "silicon or digital revolution" has made it possible to obtain in-situ, enter, process and analyse huge amounts of data. Since the 1980s the MMBI participates in those technological developments.

Earlier approaches to oceanographic databases organisation at the MMBI were described in detail by Zuev and Golubev (1999), Matishov et al. (2003b,c) Golubev and Zuev (2005a,b).

Series of atlases

In the course of developing the oceanographic database, MMBI, SSC and NODC have published the following atlases:

1. **Climatic Atlas of the Barents Sea 1998** (Matishov et al., 1998). This atlas contains 74,256 stations (temperature, salinity, oxygen) carried out during 1898-1993 (Fig. 1).

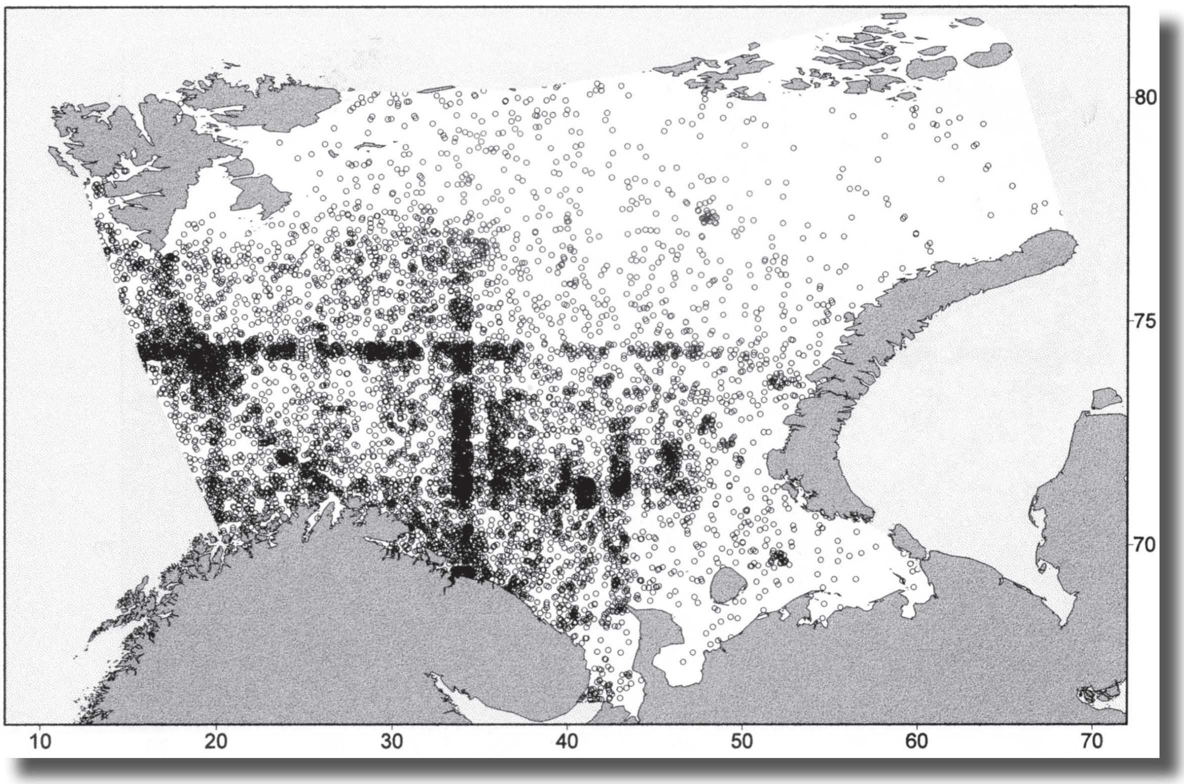

Fig. 1. Distribution of oceanographic stations in the Climatic Atlas 1998

2. **Biological Atlas of the Barents and Kara Seas in 2000** (Matishov et al., 2000). This atlas provides physical and biological (phytoplankton and zooplankton) data of 158 cruises of research vessels for the years 1913-1999, as well as data on phytoplankton collected in 1994-1999 during the voyages of Russian nuclear icebreakers from the Barents Sea to the Kara Sea (Fig. 2). Lists of phytoplankton and zooplankton species of the Arctic seas are presented. Ecological and geographical characteristics are given for each phytoplankton species. Photos of living cells are presented for dominant species of phytoplankton.

3. **Climatic Atlas of the Arctic seas 2004** (Matishov et al., 2004). This atlas presents data on meteorology, oceanography, and hydrobiology, collected during 1810-2001 in the Arctic seas by specialists from many countries. The primary data are compiled on a DVD. Data on plankton, benthos, fish, seabirds and marine

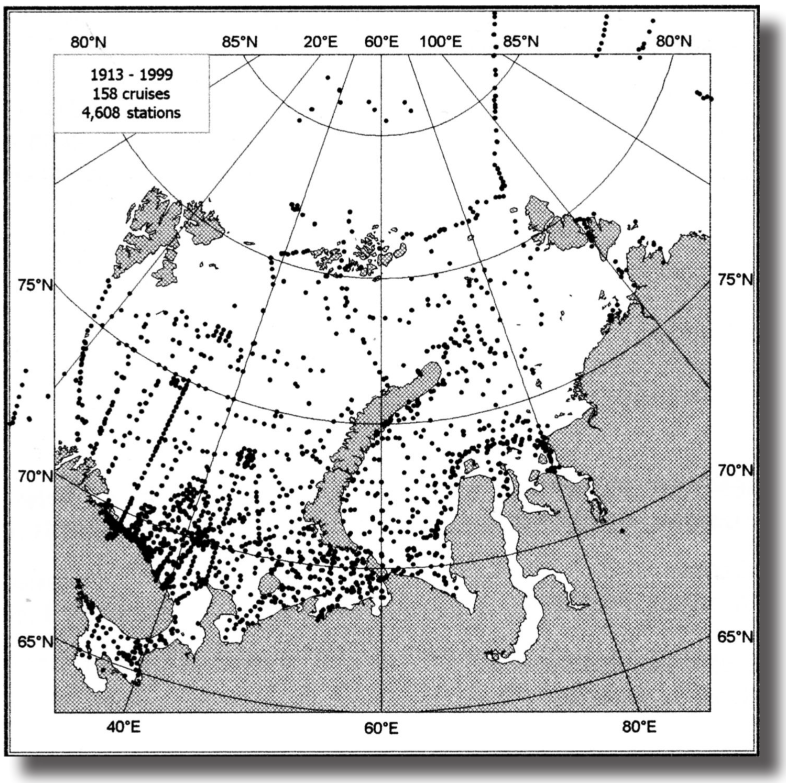

Fig. 2. Distribution of plankton stations in the Biological Atlas of the Barents and Kara Seas 2000

mammals are presented in different formats. The entire data set is divided into one-degree squares. For each square mean monthly averages of climatic parameters were calculated. Distribution of temperature and salinity was shown in maps for various depths layers and on vertical profiles (Fig. 3).

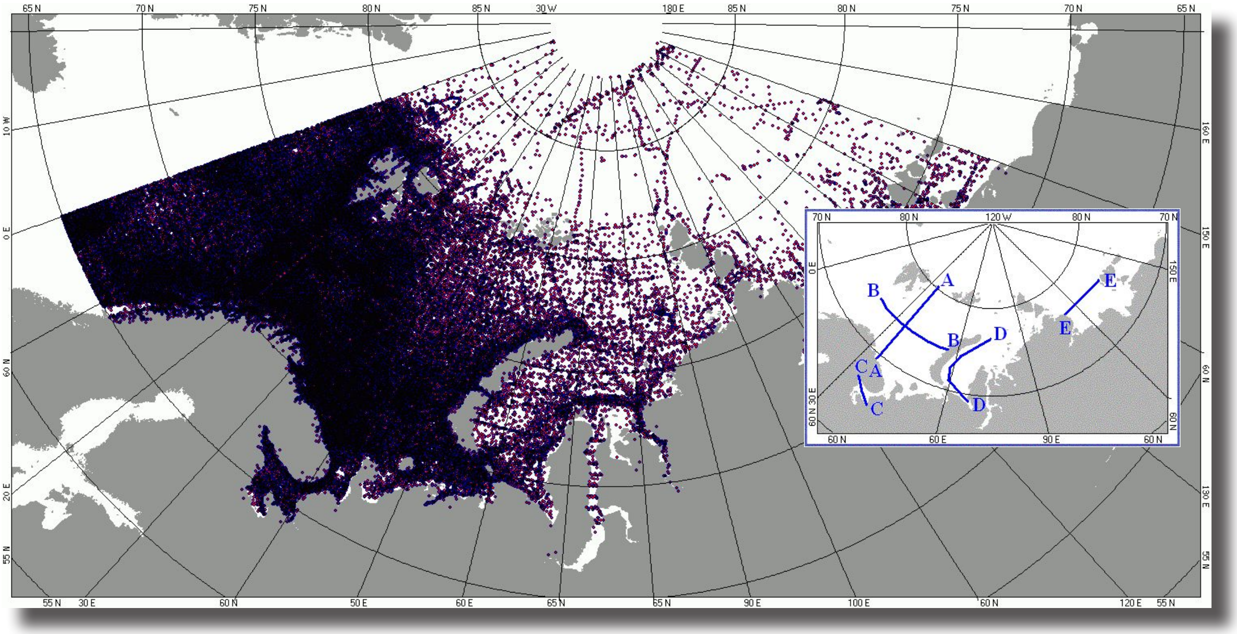

Fig. 3. Main map: Distribution of 478,000 hydrological and hydro-biological stations in the Climatic Atlas of the Arctic seas (2004). Inset map: Position of sections in the Arctic seas is shown

4. **Climatic Atlas of the Sea of Azov 2006** (Matishov et al., 2006). This atlas with a CD-ROM disc contains data on water temperature and salinity collected by various maritime and oceanographic institutions in the Sea of Azov and adjacent part of the Black Sea during 1913-2004 (Fig. 4).

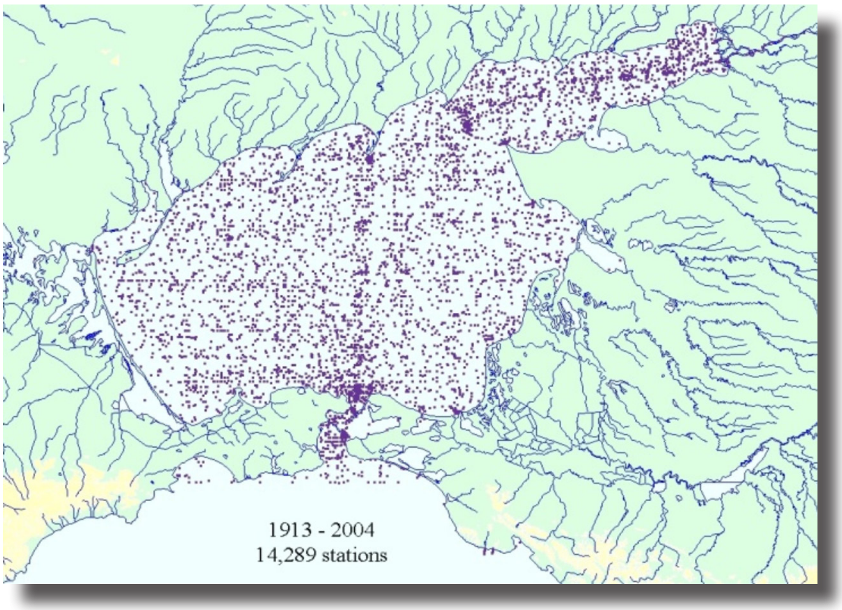

Fig. 4. Distribution of stations in the Climatic Atlas of the Sea of Azov 2006. The total of 14,289 stations

5. **Climatic Atlas of the Sea of Azov 2008** (Matishov et al., 2009c). The Atlas contains primary oceanographic data presented on a CD-ROM and at the website http://www.nodc.noaa.gov/OC5/AZOV2008/start.html. Data were collected in the Sea of Azov and the Kerch Strait during 1891-2006 by specialists of the Academy of Sciences, Ministry of Fisheries and Hydrometeorological Service of Russia (Fig. 5). The Atlas provides annual monthly data distribution maps, monthly climate vertical sections of temperature and salinity and maps of temperature and salinity at the surface and horizons of 5 and 10 meters. Inter-annual changes in air temperature adjacent to the Sea of Azov area during 1885-2006 are discussed, in terms of describing the trends of climate change in the region. The Atlas includes rare books and articles in electronic format on the history of the Sea of Azov exploration and development, studies of its climate, as well as photos that give an idea of the nature of the region and its history.

Currently, the SSC RAS and the Azov Branch of MMBI prepare a Climatic Atlas of the Caspian Sea (Fig. 6). Primary information from 41,189 marine stations for the period from 1904 to 1991 has been accumulated into an oceanographic database of the Caspian Sea. Besides, more than 600 marine stations were worked by the SSC RAS in the Russian sector of the Caspian Sea for the period from 2004 to 2010. Overall, there are 168,576 temperature measurements and 144,289 measurements of salinity. The database presents the results of field research by the Institute of Water Problems RAS, the Lomonosov Moscow State University, the Northern Caucasus Hydrometeorological Service, the Hydrometeorological Service of Azerbaijan and the Caspian Research Institute of Fisheries.

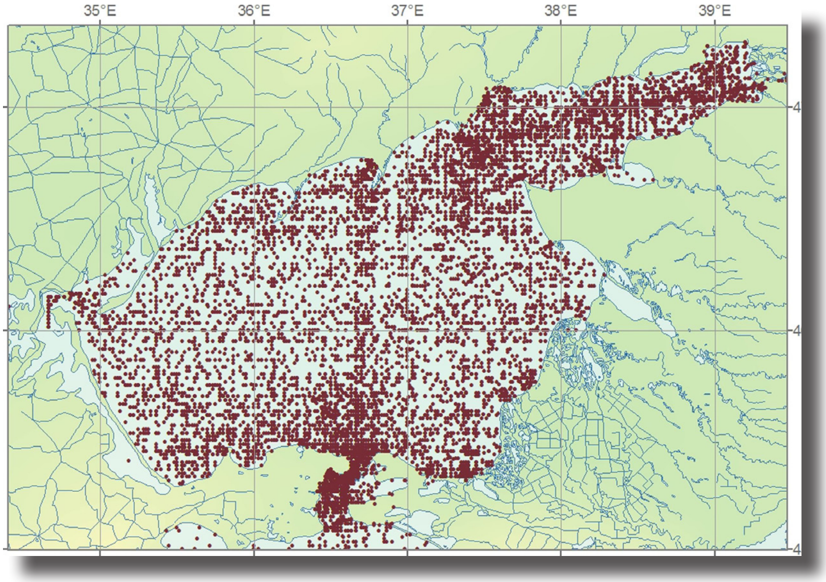

Fig. 5. Distribution of stations in the Climatic Atlas of the Sea of Azov 2008. The total of 35,417 stations and 89,203 coastal measurements, 1891-2006

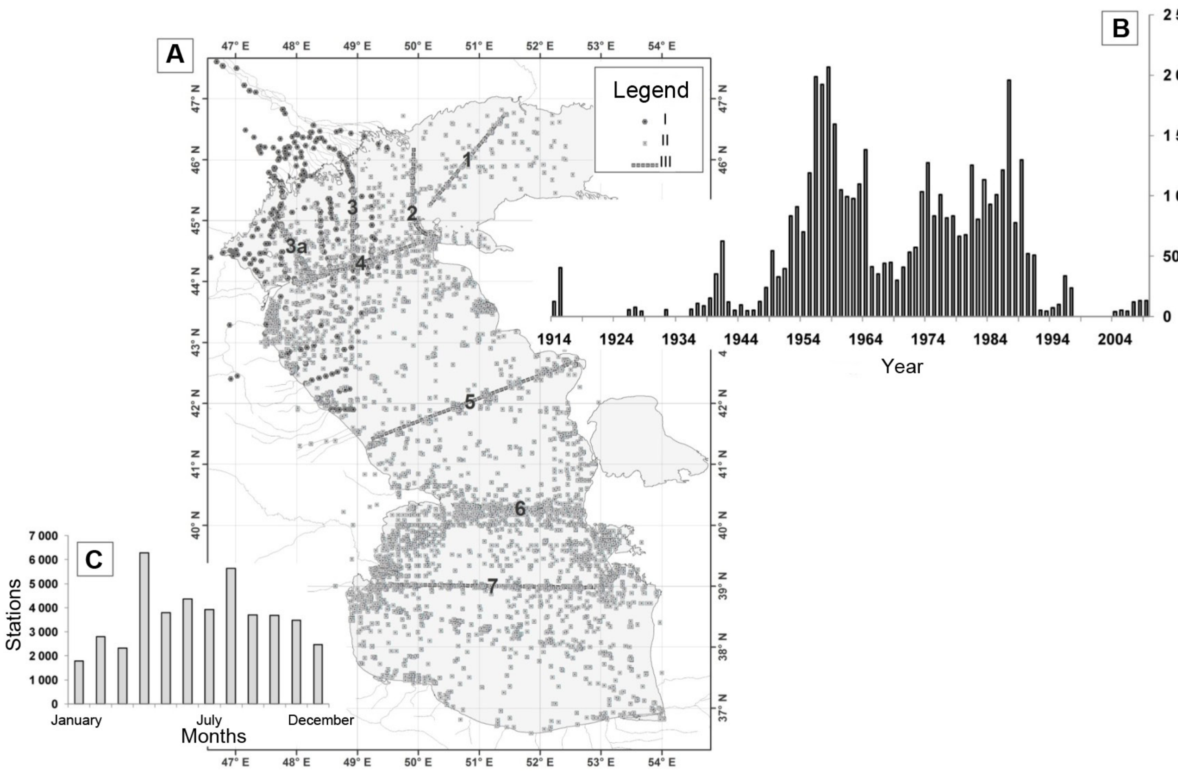

Fig. 6. Oceanographic data base of the Caspian Sea. A: I - SSC RAS expeditions (2004-10). > 600 stations; II - Historical data (1904-1991). > 41,000 stations; III - "Secular" oceanographic sections. B – Stations' distribution by year. C – Stations' distribution by months

Methods of formatting and data archiving

The Arctic seas

During expeditions to the Arctic seas different types of data were collected. Regular reports, in addition to traditionally collected meteorological and oceanographic data, also contain data on *inter alia* marine mammals, birds, fish, benthos, plankton, geology and many other data.

The data format developed by the MMBI (Matishov et al., 2000; Golubev and Zuev, 2005a) consists of two blocks STATION and TYPE. The STATION block contains information about location and time of data collection (Fig. 7). TYPE block contains the observational data themselves. It consists of the following elements - Meteorology, Hydrology (Fig. 7), Zooplankton, Phytoplankton (Fig. 8), Benthos, Birds, Marine Mammals, Ichthyology, Geology, Paleontology, etc. It is necessary to restore the coordinates of stations in course of formatting of historical data, as cruise reports are in terms of local geographic sites and places (e.g. 3 miles north of the Island of Kildin).

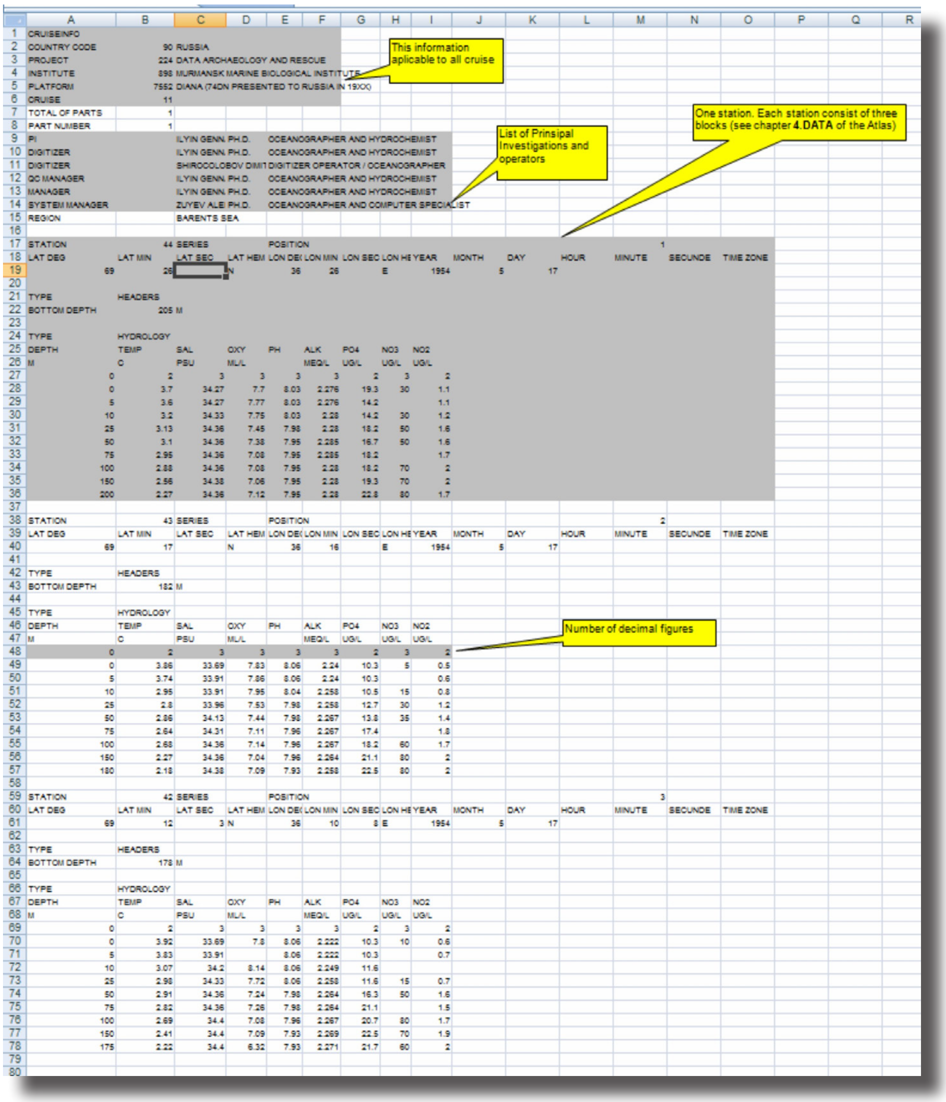

Fig. 7. Blocks "Station" and Type "Hydrology"

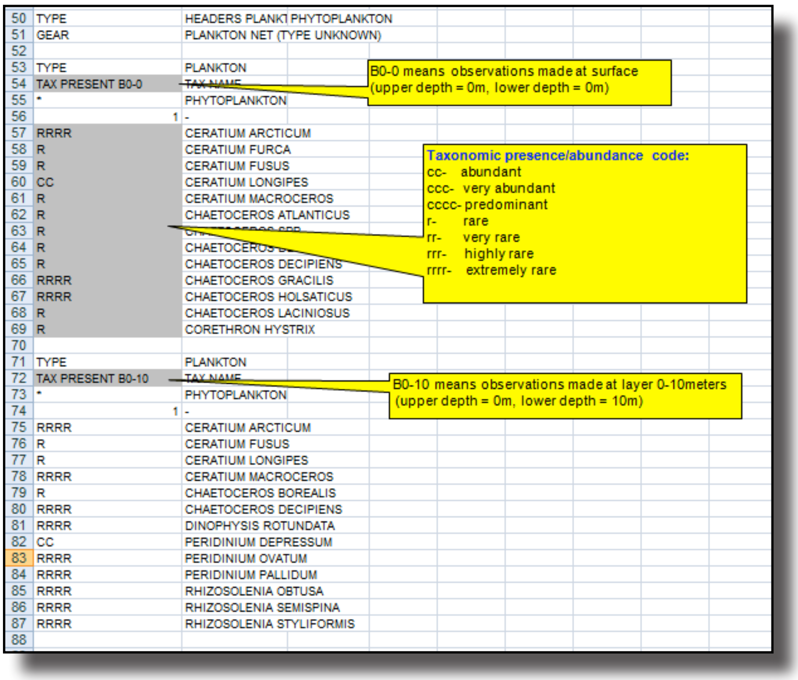

Fig. 8. Block “Type Phytoplankton”

This is a typical situation for the Arctic seas, because many expeditions took place in the late 19th – early 20th centuries and were carried out relatively close to the coast, so it was easy for a navigator to locate a vessel in terms of the shoreline. For individual cruises of that period, up to 50-70% of stations’ coordinates needed restoration.

Errors and uncertainties in ship location determination are part of the evaluation of data quality in general. Therefore, information about restored coordinates should be provided to the database user in terms of restoration parameters both of quality of information and instrumental methods. Presence of COORD DETERM = DESCRIPTION parameter indicates the fact of coordinates’ restoration. If this parameter is missing, the location coordinates of the vessel are determined by instrumental methods.

Southern seas

- Since 2004 the SSC RAS has been working on oceanographic observations database for the Sea of Azov, the Caspian and Black Seas. This oceanographic database is divided into three categories depending on where and how measurements were made:
- In-situ measurements of meteorological, hydrological and hydrochemical characteristics performed at stations in the sea (Fig. 9);
- Measurements of meteorological, hydrological and hydrochemical characteristics performed at the coastal hydrometeorological stations (Fig. 10);
- Measurements performed applying the towed CTD probes (Fig. 11).

	A	B	C	D	E	F	G	H	I	J	K	L
1	CRUISEINFO											
2	COUNTRY	RUSSIA										
3	PROJECT	AZOV SEA										
4	INSTITUTE	898	MURMANSK MARINE BIOLOGICAL INSTITUTE									
5	SHIP	PROFESSOR PANOV NIS										
6	CRUISE											
7	AREA	Sea of Azov										
8												
9												
10	STATION	279										
11	LAT DEG	LAT MIN	LAT SEC	LAT HEM	LON DEG	LON MIN	LON SEC	LON HEM	MONTH	DAY	YEAR	
12	46.8661			N	37.3517			E	4	26	2006	
13												
14	HEADERS											
15	TIME	13	54		zone -3							
16	BOTTOM DEPTH	8.7	M									
17	RELIABILITY FLAG	0										
18	SAL METHOD	titration										
19	TS PROBE	BOTTLE										
20	WATER SAMPLER	BATHOMETER MOLCHANOVA										
21	AIRTEMP	7.2	C									
22	BARPRESS	1015	MBAR									
23	SURF TEMP	10.1	C									
24	TRANSPARENCY	1.1	M									
25	WINDDIR	NW	COMPASS									
26	WINDSP	6.2	M/SEC									
27												
28	DETAILS	DEPTH	CL	OXY	PH	SAL	PO4	NO2	NO3			
29	units	M	MG/L	MG/L			UG/L	UG/L	UG/L			
30	decimal places	1	1	2	2	1	0	0	0			
31		0.5	112.5	11.59	8.47	7.4	49	42	28			
32		5	112.5			7.4						
33		7.5	125	11.54	8.29	8.2						
34												
35												
36	STATION	270										
37	LAT DEG	LAT MIN	LAT SEC	LAT HEM	LON DEG	LON MIN	LON SEC	LON HEM	MONTH	DAY	YEAR	
38	46.8672			N	37.5002			E	4	26	2006	
39												
40	HEADERS											
41	TIME	16	56		zone -3							
42	BOTTOM DEPTH	8.7	M									
43	RELIABILITY FLAG	0										
44	SAL METHOD	titration										
45	TS PROBE	BOTTLE										
46	WATER SAMPLER	BATHOMETER MOLCHANOVA										
47	AIRTEMP	7.2	C									
48	BARPRESS	1014	MBAR									
49	TRANSPARENCY	1	M									
50	WINDDIR	N	COMPASS									
51	WINDSP	5.8	M/SEC									
52												
53	DETAILS	DEPTH	CL									
54	units	M	MG/L									
55	decimal places	1	0									
56		8	105									

Fig. 9. In-situ data from the marine stations

	A	B	C	D	E	F	G	H	I	J	K
1	CRUISEINFO										
2	COUNTRY	USSR									
3	PROJECT	MARIUPOL									
4	INSTITUTE	HYDROMETEOROLOGICAL SERVICE									
5	SHIP	COASTAL OBSERVATIONS									
6	CRUISE										
7	SOURCE DOCUMENT	Sea hydrometeorological MB									
8	AREA	Sea of Azov									
9											
10											
11	STATION	Mariupol									
12	LAT DEG	LAT MIN	LAT SEC	LAT HEM	LON DEG	LON MIN	LON SEC	LON HEM	MONTH	DAY	YEAR
13	47.0919			N	37.6089			E	10	1	1975
14											
15	HEADERS										
16	TIME	9	0		LOCAL						
17	RELIABLE	2									
18	AIRTEMP	13.8	C								
19	CLOUD DOWN	0	CODE10								
20	CLOUDAMAT	0	CODE10								
21	REL HUMID	55	PERCENT								
22	WINDDIR	NE	COMPASS								
23	WINDSP	8	M/SEC								
24											
25	DETAILS	DEPTH	TEMP								
26	units	M	C								
27	decimal places	0	1								
28		0	18.4								
29											
30											
31	STATION	Mariupol									
32	LAT DEG	LAT MIN	LAT SEC	LAT HEM	LON DEG	LON MIN	LON SEC	LON HEM	MONTH	DAY	YEAR
33	47.0919			N	37.6089			E	10	1	1975
34											
35	HEADERS										
36	TIME	15	0		LOCAL						
37	RELIABLE	2									
38	AIRTEMP	17.9	C								
39	CLOUD DOWN	0	CODE10								
40	CLOUDAMAT	0	CODE10								
41	REL HUMID	42	PERCENT								
42	WINDDIR	NNE	COMPASS								
43	WINDSP	10	M/SEC								
44											
45	DETAILS	DEPTH	TEMP	CL							
46	units	M	C	PCU							
47	decimal places	0	1	2							
48		0	18.1	7.03							
49											
50											
51	STATION	Mariupol									
52	LAT DEG	LAT MIN	LAT SEC	LAT HEM	LON DEG	LON MIN	LON SEC	LON HEM	MONTH	DAY	YEAR
53	47.0919			N	37.6089			E	10	1	1975
54											
55	HEADERS										
56	TIME	21	0		LOCAL						
57	RELIABLE	2									
58	AIRTEMP	13.8	C								
59	CLOUD DOWN	0	CODE10								
60	CLOUDAMAT	0	CODE10								
61	REL HUMID	48	PERCENT								
62	WINDDIR	NE	COMPASS								
63	WINDSP	10	M/SEC								
64											
65	DETAILS	DEPTH	TEMP								
66	units	M	C								
67	decimal places	0	1								
68		0	17.8								
69											
70											

Fig. 10. Data from the coastal hydrometeorological stations

	A	B	C	D	E	F	G	H	I	J	K	L
1	**CRUISEINFO**											
2	COUNTRY	RUSSIA										
3	PROJECT	AZOV SEA										
4	INSTITUTE	MURMANSK MARINE BIOLOGICAL INSTITUTE										
5	SHIP	PROFESSOR PANOV NIS										
6	AREA	Sea of Azov										
7	INSTRUMENT	CTD: ZGP-2004 (RUSSIA) zond										
8												
9												
10						TIME		LAT DEG	LON DEG	DEPTH	TEMP	SAL
11	#	MONTH	DAY	YEAR	HOUR	MINUTE	SECOND	N	E	M	C	
12	1	6	17	2005	13	40	31	46.98097	38.61665	0.6	25.771	0.849
13	2	6	17	2005	13	40	36	46.98093	38.61647	0.6	25.846	0.85
14	3	6	17	2005	13	40	41	46.98085	38.6162	0.6	25.841	0.854
15	4	6	17	2005	13	40	46	46.9808	38.61603	0.6	25.898	0.849
16	5	6	17	2005	13	40	51	46.9807	38.61578	0.6	25.852	0.858
17	6	6	17	2005	13	40	56	46.98063	38.61562	0.6	25.908	0.858
18	7	6	17	2005	13	41	1	46.98052	38.61538	0.6	25.985	0.862
19	8	6	17	2005	13	41	6	46.98045	38.61523	0.6	26.002	0.864
20	9	6	17	2005	13	41	11	46.98035	38.61498	0.6	25.979	0.865
21	10	6	17	2005	13	41	16	46.98028	38.61482	0.6	26.062	0.869
22	11	6	17	2005	13	41	21	46.9802	38.61455	0.6	26.031	0.866
23	12	6	17	2005	13	41	26	46.98013	38.61438	0.6	26.07	0.87
24	13	6	17	2005	13	41	31	46.98007	38.61412	0.6	26.083	0.874
25	14	6	17	2005	13	41	36	46.98002	38.61393	0.6	26.089	0.875
26	15	6	17	2005	13	41	41	46.97997	38.61367	0.6	26.091	0.875
27	16	6	17	2005	13	41	46	46.97993	38.61348	0.6	26.104	0.876
28	17	6	17	2005	13	41	51	46.9799	38.6132	0.6	26.149	0.878
29	18	6	17	2005	13	41	56	46.97988	38.61302	0.6	26.212	0.883
30	19	6	17	2005	13	42	1	46.97987	38.61273	0.6	26.176	0.884
31	20	6	17	2005	13	42	6	46.97985	38.61253	0.6	26.127	0.882
32	21	6	17	2005	13	42	11	46.9798	38.61227	0.6	26.109	0.886
33	22	6	17	2005	13	42	16	46.97977	38.61208	0.6	26.23	0.889
34	23	6	17	2005	13	42	21	46.97973	38.6118	0.6	26.228	0.886
35	24	6	17	2005	13	42	26	46.9797	38.61162	0.6	26.146	0.89
36	25	6	17	2005	13	42	31	46.97965	38.61133	0.6	26.147	0.892
37	26	6	17	2005	13	42	36	46.97963	38.61115	0.6	26.204	0.893
38	27	6	17	2005	13	42	41	46.97962	38.61087	0.6	26.088	0.892
39	28	6	17	2005	13	42	46	46.9796	38.61067	0.6	26.031	0.894
40	29	6	17	2005	13	42	51	46.9796	38.61037	0.6	26.1	0.895
41	30	6	17	2005	13	42	56	46.9796	38.61018	0.6	26.103	0.893
42	31	6	17	2005	13	43	1	46.97962	38.60988	0.6	26.047	0.894
43	32	6	17	2005	13	43	6	46.97963	38.6097	0.6	25.807	0.892
44	33	6	17	2005	13	43	11	46.97962	38.60942	0.6	25.798	0.895
45	34	6	17	2005	13	43	16	46.9796	38.60923	0.6	25.602	0.897
46	35	6	17	2005	13	43	21	46.97953	38.60897	0.6	25.769	0.894
47	36	6	17	2005	13	43	26	46.97947	38.6088	0.6	25.815	0.894
48	37	6	17	2005	13	43	31	46.97937	38.60857	0.6	25.702	0.904
49	38	6	17	2005	13	43	36	46.97928	38.60842	0.6	25.915	0.907
50	39	6	17	2005	13	43	41	46.97917	38.6082	0.6	25.958	0.906
51	40	6	17	2005	13	43	46	46.97908	38.60805	0.6	25.971	0.909

Fig. 11. Data from the towed CTD probe

Oceanographic database is implemented in DBMS Microsoft Access. The main objects of the database, isolated from the subject area, are: cruises, stations, and various types of research. A "cruise" refers either to a specific oceanographic voyage or to offshore or coastal surveillance stationary observations. Studies of different nature are carried out at the station: meteorological, hydrological, hydrochemical, of qualitative and quantitative characteristics of plankton, benthos, etc.

The concept of data quality control provides information storing about observation conditions and sampling techniques (tools, methods), as well as professionals selecting and processing samples. An object in database is selected for each type of research, containing information about materials and methods – methodological data and fixed conditions of research (observations), tools and equipment used when carrying out relevant studies and characteristics of these technical facilities. Since most of these data is textual information, a handbook was compiled for each type of information. Development of references and handbooks was based on international standards, covering handbooks developed by the World Meteorological Organization (WMO) and the NOAA (USA).

The increase in the amount of data increases the number of incorrect information. Therefore, there are greater demands to data verification procedures. It should be noted that high quality and comprehensive data verification is possible only if meta-information about conditions of measurement, methods of data collection and processing is available. High degree of domain uncertainty cannot fully automate the process of data quality control, i.e. it is not possible to make a decision about data quality without participation of specialists. In connection with this procedure quality control of oceanographic data is presented in the form of an iterative process, each iteration consists of two phases:

- Automated stage of objective data quality control;
- Stage of subjective analysis implemented with the participation of one or more specialists.

Stage of interactive subjective control includes construction of climate norms and anomalies, maps of individual characteristics' distribution and identification of spatial-temporal statistical characteristics. For this purpose, a set of specialised tools, carrying out activities with spatial data in GIS and enabling us to construct distribution fields and vertical sections of various characteristics of marine environment was developed (Arkhipova et al., 2009).

Modernisation of oceanographic database at the MMBI (Matishov et al., 2010b)

Activities on the Climatic Atlas of the Arctic seas were resumed in 2009 after a break of several years. In addition to information base's replenishment, the goal of upgrading the database management system (DBMS) was set up.

Using Microsoft Access as the database software, as well as the programming language Borland Delphi, individual CSV format data files were collated into the single file format in a text form. Information about methods and means of obtaining the primary data was recorded into the second text file associated by the key field. Furthermore, these files were finally imported into DBMS Access, which represents two related relational tables. Such an approach allows taking into account different methods of obtaining initial data and avoiding appearance of erroneous assessments, when "old" and "new" data are used in calculations.

Selections of temperature and salinity at standard sections No. 6 (The Kola Transect or the Kola Meridian 33° 30' E), 29 (from the west to the east along the Earth parallel 74° 30' N), 3+19 (Transect via Nordkapp – Bear Island – Spitsbergen) were made. Vertical profiles of thermohaline structure distribution along the section for summer and winter seasons, for 1950 to 2001, were obtained by means of automation of cartographic material processing and interpolation of thermohaline characteristics in the nodes of a regular grid with a built-in product Golden

Software Surfer Visual Basic language (Fig. 12). Primary analysis of temperature and salinity distribution graphs at the sections showed high convergence with climatic characteristics of the Barents Sea, with geography of currents, as well as already previously published materials.

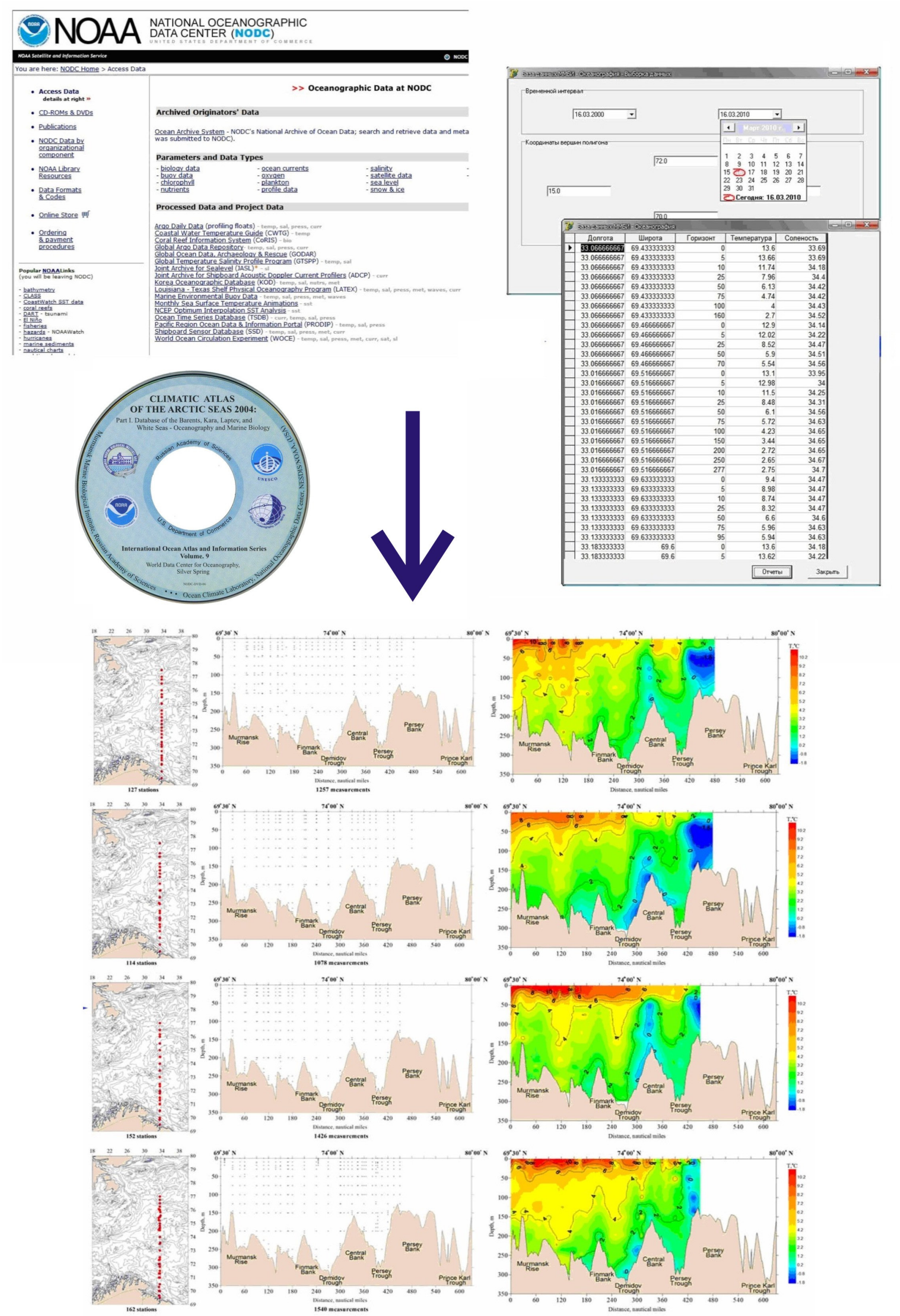

Fig. 12. Scheme of automated data retrieval and plotting of temperature or salinity distribution at standard sections

GIS and geo-portal "Ecological study of marine ecosystems of the South of Russia"

A geographic information system containing data on ecological study of marine ecosystems in southern Russia was developed by the SSC RAS in order to assess the completeness of field research and for the organisation of future expeditions. It provides information about the SSC RAS and the Azov Branch of MMBI marine expeditions to the Sea of Azov, the Black and the Caspian Seas for the period 1997-2010 (Fig. 13). Remote access to relevant spatial data is through geo-portal (http://geoportal.sfedu.ru/api/index.html).

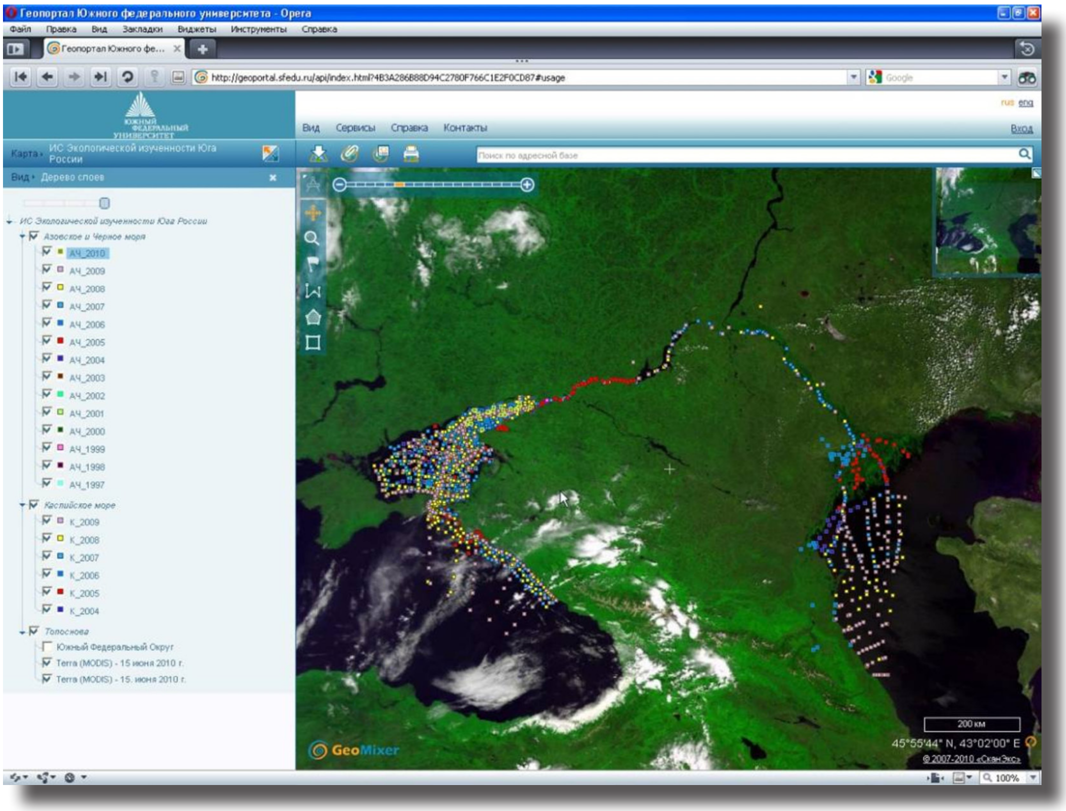

Fig. 13. Publication of the Internet version of "GIS ecological study of the South of Russia" at the site of the Southern Federal University for teaching students

Practical use of atlases

The total combination of factual data obtained in the sea in a single database on common methodological positions allows appearing of new perspectives for paleoecological reconstruction, short- and long-term climate prediction, sea ice conditions, biological productivity, and fishery yields, isolating of anthropogenic component in the global variability. Therefore, database of atlases is widely used by the MMBI, SSC RAS and other institutions when implementing climate and ecosystem research (Levitus et al., 2009; Matishov et al., 2003a, 2008, 2009a,b, 2010a; Smolyar and Adrov, 2003). First of all, it concerns temperature and salinity norm (long-term mean values) calculations for horizons and sections. Anomalies of each observation period and each cruise are estimated on the norm basis. Calendar of the Barents Sea anomalies is compiled with highlighting of warm, normal and cold periods for 5 gradations (Atlas of the Barents Sea water temperature and salinity anomalies in 1951-2001, 2008). Plankton database currently is used in EC FP7 Project Greenseas in modelling for projecting future marine ecosystem states. Estimates of heat water content are made for the Sea of Azov (Matishov et al., 2008, 2009b). Long-term salinity dynamics, which changes as a result of rivers overregulation by hydroelectric dams and affects ecosystem conditions of brackish waters, was calculated for the Azov and Caspian Seas. See also the chapter "Climate and oceanographic processes in the Barents Sea" by Matishov et al in this issue.

Acknowledgements

The following MMBI, SSC RAS and NOAA experts, together with the authors, were involved in the development of oceanographic and hydro-biological databases in various periods of time: Sydney Levitus, Dr. Igor Smolyar, Prof. Dr. Dmitry Matishov, Dr. Alexey Zuev, Valery Golubev, Prof. Dr. Pavel Makarevich, Prof. Dr. Vladimir Denisov, Prof. Dr. Sergey Timofeev, Prof. Dr. Leonid Kuznetsov, Dr. Oleg Karamushko, Dr. Lyudmila Dashkevich, Dr. Olga Arkhipova, Julia Lychagina (Sladkova), Sergei Ivanov, Prof. Dr. Yury Gargopa, Dr. Nicholai Adrov and others.

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ORIBATID MITES TRANSPORTED BY BIRDS TO POLAR ISLANDS A REVIEW

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One of the most basic problems of biogeography is the specific feature of the island fauna formation (MacArthur and Wilson, 1967). However, the understanding of local faunas, including island ones, is impossible without the understanding of factors forming species diversity. This requires determination of mechanisms of island colonization by different species. Mechanism of bird's settlement to new territories, separated by ice or water areas, deserts, mountain ranges, and other geographic barriers, is more or less clear, whereas ways of remote islands' colonization by inactive representatives of soil fauna remain unknown.

Soil animals, microarthropods, which were the subject of our study, are representatives of microfauna, i.e. have dimensions less than 1.0 mm. The task of finding the penetration ways of soil microarthropods to the remote Arctic archipelagos was solved in two directions. Attempts to prove their random long-range transport by wind and ocean waters were taken (Coulson et al., 2002a, 2002b, 2003). Charles Darwin (1859) demonstrated that some plant seeds could survive many months in the soil around the roots of driftwood etc. However, a hypothesis about a possible transport of microarthropods by driftwood washed up to the island shores was not being supported by factual material from the Arctic. There are evidences that one of the powerful factors of species distribution in the present period is a human being, who can bring species with domestic animals and imported materials to the developing territories (Majka et al., 2007). This factor may be important for the polar regions, but explains only modern invasions of some (individual) species, not the formation of polar island fauna overall.

It seems obvious that for colonization of islands, remote from the mainland, by sedentary small organisms there should be "transmitting-vectors", possessing the ability to travel great distances in short periods and to transport animals. This is the way, for example, the parasites spread, being completely provided with food by their hosts. One of the transport mechanisms for non-parasitic animals can be phoresy. Phoresy (transport of one organism by another or the use of the other organism as a means of transport) allows sedentary species to spread over distances many times greater than those they can cover independently. Phoresy is a customary phenomenon for some groups of mites with special morphological adaptations for fixing up on a host (Evans, 1992). Insect phoresy (32 species) was registered for 22 species of oribatid mites (Acari: Oribatida), despite the mites defaulted special morphological structures for such a distribution (Norton, 1973). Phoresy of gamasid mite *Tinoseius spinosus* on different littoral dipterans is regularly found (Lindroth et al., 1973). A fact of oribatid mite *Diapterobates notatus* phoresis on ectoparasite fly *Cynomya mortuorum* was registered on the Spitsbergen (Svalbard) (Coulson, 2009), as well as deutonimph *Thinoseius spinosus* (Acari, Eviphididae) on another form of parasitic flies *Protophormia terraenovae* (Gwiazdowicz and Coulson 2010). Those findings allowed authors to discuss a possibility of soil animals introduction to the archipelago by means of insects. However, the transport on parasitic flies is possible only with the host. Phoresis by non-parasitic insects is unlikely for the remote Arctic archipelagos. The possibility that oceanic birds could be a more significant and likely factor in dispersal of viable organic units, either plants or animals, was discussed by Falla (1960). However, proofs of dispersal of non-parasitic invertebrate via birds were absent.

Our hypothesis about the Arctic archipelagos' colonization by soil microarthropods is based on the role of the avian vector. It has been suggested that immediately after climate warming and ice retreat in the Arctic archipelagos about 12-10 thousand years ago, birds began to visit the islands and bring soil animals to them (Lebedeva and Krivolutsky, 2003). It is unlikely that any organism could have had survived the last glacial period on Svalbard: during the maximum of the Weichselian (Weichsel) glaciation (Brochmann et al., 2003) the entire Spitsbergen Archipelago was almost completely covered by ice shield, only some small areas remained ice-free (Landvik et al., 2003). Modern fauna began to conquer the island after glacier retreat only during the last 10000 years.

Targeted search showed that plumage of many bird species is inhabited by soil microarthropods, including oribatid mites (Krivolutsky and Lebedeva, 1999, 2003, 2004a, 2004b). Different bird species, living in the Russian Arctic, were also investigated for carrying oribatid mites (Lebedeva and Krivolutsky, 2003; Lebedeva et al., 2006, Lebedeva and Lebedev, 2008a, 2008b). 44 species of oribatid mites of 74 species known for this region were recorded on birds on the Russian Arctic archipelagos (Krivolutsky et al., 2003). Overall, the plumage of around 5000 birds of 180 species registered in the Palaearctic, Arctic, and Antarctic was examined in 1998-2010. More than 190 species of oribatid mites and other microarthropods at different life stages were registered (Krivolutsky and Lebedeva, 1999, 2003, 2004a, 2004b; Lebedeva et al., 2003, 2006; Lebedeva, 2005; Lebedeva and Lebedev, 2005, 2007).

To prove our avian vector hypothesis a model territory had to be chosen. A model territory should correspond to certain criteria: to be relatively young in terms of landscape formation history, have powerful separation barrier between itself and other territories, and with small diversity of studied species. From this perspective, the most interesting sector is the Russian Arctic, which is quite different from the Canadian one, where distances between islands in the high Arctic remain disproportionately smaller than the distances between the mainland and archipelagos in the Russian sector. Diversity of soil biota on the Arctic islands and archipelagos was formed within a relatively short geological period of time after the last glaciations. The main attention was paid to species diversity of oribatid mites. Oribatid mites are one of the dominant groups of soil organisms in tundra and arctic soils. Their abundance and biomass are relatively high.

Studying microarthropods in the soils of the Russian Arctic began in the late 19th century. The first scientific expedition to the Arctic took place in 1878-1879 under the leadership of Nordenskjöld en route from the Atlantic to the Pacific Ocean on board the *Vega*. Later on, the materials on soil mites, collected in that expedition, were processed by K.L. Koch, who recorded 12 species of the Arctic oribatid mites, including 8 new species for sciences (Koch, 1879). Then, the polar expeditions of the Russian (1885-1886, 1990-1903, 1912), Scandinavian (1881-1924), and British (1894-1899) researchers provided further material., In the late 19th – early 20th centuries the first papers were published by Kulczynski (1908a, 1908b), Trägårdh (1900, 1904, 1928), Thor (1930), devoted to the study of soil micro-arthropods of the archipelagos of Franz Josef Land, Svalbard, Novaya Zemlya, and the New Siberian Islands. Some publications on the Spitsbergen oribatid mites (Karppinen, 1967; Niedbala, 1971; Solhøy, 1976; Seniczak and Plichta, 1978) appeared in the second half of the 20th century. However, in general, during 100 years of research in the high-latitude Arctic, European and American researchers discovered overall about 30 species of oribatid mites (Danks, 1981; Behan-Pelletier, 1999). Then active research in the high-latitude Arctic resumed 25 years ago.

In August 2000 we began to study microarthropods inhabiting the plumage of birds, nests and soils, their breeding and resting sites on the Arctic shore of the Barents Sea. Most of the material was gathered around the biological research station of Murmansk Marine Biological Institute *Dal'nie Zelentsy* on the Eastern Murman coast (the Kola Peninsula, 69°N 36°E). Further samples of birds, nests and soil were obtained from Longyearbyen (78°12'N 15°36'E) and Barentsburg (78°07'N 14°25'E) vicinities on Spitsbergen (Svalbard). For our study we used bird skins sampled by MMBI staff for studying helminthofauna, as well as birds specially quarried and caught for studying soil microarthropods in their plumage. Several individuals were collected at our request by G.I. Ivanov on Novaya Zemlya (72°90'N 53°23'E). Some birds collected during the Russian Antarctic Expeditions in 1996-1999 near the Russian polar stations of *Mirnyi* and *Bellingshausen* (66° 30'S, 93°00'E) were transferred to us from the Arctic and Antarctic Research Institute (Saint-Petersburg) to study soil micro-arthropods in the feathers. Besides, in the Russian Arctic we investigated non-parasitic micro-arthropods from both birds' plumage and nests and ornithogenic soils. Overall, around 100 nests, 245 bird individuals of 41 species were examined in the polar latitudes.

Many researchers who studied birds by traditional parasitological methods did not record soil micro-arthropods in bird's plumage. There were no publications about such findings before 1999. This, on the one hand, could be due to parasitologists' focus on ectoparasites only, ignoring other objects that fell in sight, and, on the other hand, due to research method limitations. The new view at birds' plumage as a possible substrate for soil micro-arthropods demanded the application of a new method for studying plumage. D.A. Krivolutsky proposed the application of a method traditional for soil zoology – microarthropods extraction, the so-called "modified extraction method" by Berleze-Tullgren (Gilyarov, 1941). A skin of a small bird (or the entire carcass with feathers), or part of the skin of a large individual was placed on the funnel (feathers down) and kept for 5-6 days or more under electric illumination. Some skins were kept in refrigerator in advance at 4° C or -20° C as exceptional cases. Part of the microarthropods probably died during the storage, but even after several years of storage, we extracted alive oribatid mites and other representatives of soil microfauna. This can be explained by high resistance of some Arctic species to low temperatures. The fact was confirmed by studies of Coulson and Birkemoe (2000), who investigated springtails and oribatid mites from soil samples collected on Spitsbergen and stored for 4 years at a temperature of -20°C. It turned out that even after four years of freezing some soil fauna species can survive.

Composition analysis of non-parasite microarthropods found in birds' plumage on the Eastern Murman coast, Spitsbergen, and Novaya Zemlya showed that both oribatid mites (60%) and other soil inhabitants, such as Prostigmata, Gamasida, Trombidiformes, Acaridia mites, and springtails, might be found in feathers. Collembolans were the second most abundant group of soil microarthropods, found in bird's plumage. Sufficiently abundant were non-parasitic Gamasida mites (14% and 11% respectively). In birds' plumage, apart from the species indicated, we also registered spiders as well as small insects, and their larvae.

Distribution of oribatid mites recorded on one bird is asymmetric and corresponds to the Poisson distribution for rare events. In one third of the surveyed birds, soil microarthropods, including oribatid mites, were absent. Generally, 1-2 individuals of oribatid mites were recorded on the same bird, with the maximum figure being 21.

Analysis showed that with increase of bird size, the number of individuals and species of oribatid mites in its plumage increased as well (Fig. 1). This trend was statistically confirmed. Thus, the average number of species and oribatid mite specimens in waterfowl plumage increased in the series "ducks - geese - swans" (Lebedeva, 2005) and "passerines - shorebirds - seabirds - ducks" (Lebedeva and Lebedev, 2008b).

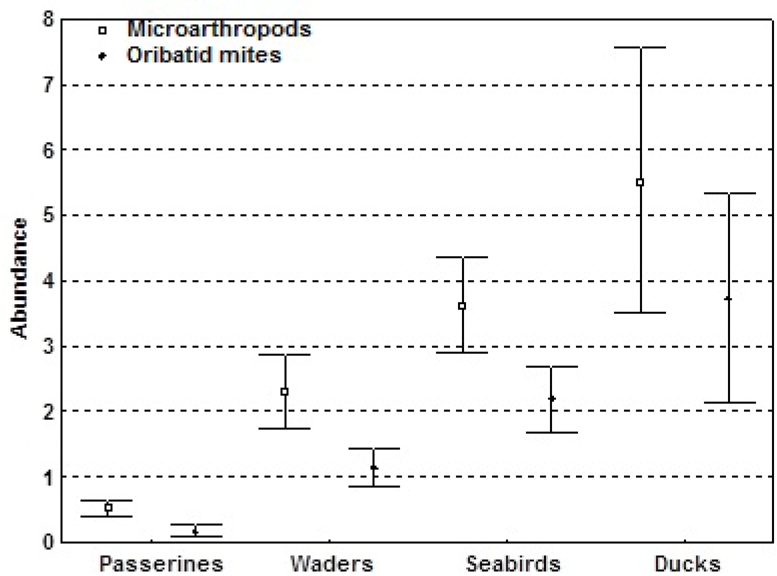

Fig. 1. Average (points) and standard errors (whiskers) of microarthropods and oribatid mites' abundance per one bird for different groups of birds in Barents Sea region (by Lebedeva and Lebedev, 2008b)

Conducting research on the mainland coast of the Barents Sea, we recorded 53 species of oribatid mites in the plumage of birds, whereas birds living on the Spitsbergen (Svalbard) had only 17 species (Lebedeva and Lebedev, 2005; Lebedeva et al., 2006). These species of oribatid mites were founded in plumage of the short-distance (Fulmar *Fulmarus glacialis*, Common eider *Somateria mollissima*, gulls, guillemots) and long-distance migrants (geese, skuas, Arctic tern *Sterna paradisaea*, and snow bunting *Plectrophenax nivalis*). When studying oribatid mites on the Svalbard Archipelago, we also focused our attention not only on studying bird's feathers, but also on studying microarthropods of nests and soils in bird's concentration sites and their nests. The places, where the so-called "ornithogenic soils", the most enriched with organic matter, are formed, were of the greatest interest to us.

It is interesting to note that the concentration of efforts towards the study of substrates related to birds helped significantly to enrich the list of archipelago oribatid mites. There were 45 known archipelago species of oribatid mites before the beginning of our study. We managed to recorder 20 species new for local fauna on the archipelago, with the majority of newly registered species being on birds and in ornithogenic soils. Our research helped to increase a list of oribatid mites of the Spitsbergen (Svalbard) by one third (up to 65 species) (Coulson and Refseth, 2004; Coulson, 2007). The idea of avian vector (Lebedeva and Krivolutsky, 2003) drew attention to the study of birds' nests substrates on the Spitsbergen (Coulson et al., 2009) and other islands of the Arctic (Makarova et al., 2010).

In general, together with Krivolutsky and colleagues (Krivolutsky et al., 2003), we increased the list of oribatid mites species of the Russian Arctic up to 74, of which only 28 species were described during the previous 100 years of research.

Many species of oribatid mites feed on bacteria or are mycophages. Thus, they can find food resources in bird's plumage for their long stay in such a substrate. In recent years the community of microorganisms in feathers, bacteria in particular, has been thoroughly studied (Bisson et al., 2007).

We recorded mites of all life cycle stages on Arctic birds. For example, on the birds of Eastern Murman, the ratio of oribatid mites at different stages of their life cycle (adults, nymphs, larvae) was 60%: 35%: 5%, respectively. In bird's plumage on the Spitsbergen (Svalbard) nymphs of oribatid mites were found frequently (21% of all oribatid mites).

Number of species of oribatid mites in the plumage differed greatly between the 21 bird species in the Arctic. One mite species per bird species was recorded on Steller's eider *Polysticta stelleri*, Ruff *Philomachus pugnax*, Arctic tern, Bluethroat *Luscinia cvecica*, White wagtail *Motocilla alba*, Red-throated pipit *Anthus cervinus*, and Snow bunting. Fulmar, gulls (Glaucous gull *Larus hyperboreus*, Great black-backed gull *L. marinus*, Herring gull), and waders (Ringed plover *Charidrius hiaticula*, Purple sandpiper *Calidris maritima*, Dunlin *C. alpina*, Little stint *C. minuta*) had from 2 to 15 species of oribatid mites in plumage. The highest oribatid mite diversity was observed in the Kittiwake *Rissa tridactyla* (19 species) and Common eider (26 species). Oribatid mites species uneven abundance can be partly due to sample size of the surveyed birds, partly by bird's size (see above), but it is possible to find a further explanation. It is known that microarthropods prefer moist biotopes (Gilyarov and Krivolutsky, 1995), so they can find enough comfortable habitats in the plumage of birds, especially waterfowl, sea and wetland. This might explain the high number of mite species in the plumage of waterfowl, gulls (shorebirds), and sandpipers (waders), which have close ecological relationship to marine habitats.

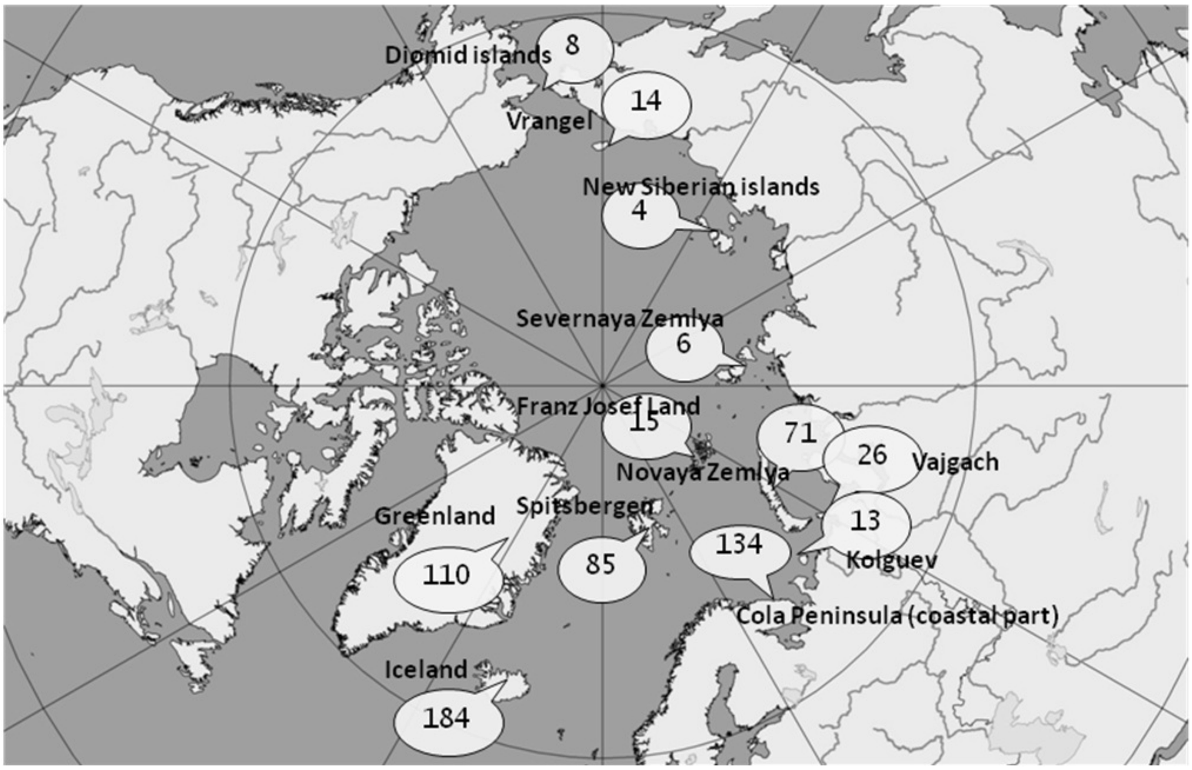

Fig. 2. Distribution of known numbers of oribatid mite species in the eastern Arctic islands and archipelagos (by Krivolutsky et al., 2003; Lebedeva et al., 2006; Coulson, 2007; Lebedev, 2009; Makarova and Böcher, 2009; and our unpublished data)

In the plumage of certain Antarctic birds, we also found non-parasitic invertebrates (Krivolutsky et al., 2004), including one new species of oribatid mites belonging to the *Cosmohthonius* genus. It should be noted that over 40 years of research in the Antarctic and Sub-Antarctic, the British Antarctic Survey described 156 species of oribatid mites, but representatives of *Cosmohthonius* genus were not recoded. Only one species of this genus from Australia was known. Even Emperor penguins, which throughout their life cycle are not associated with land, had small soil invertebrates in the plumage. This confirms that exchange of invertebrates can be on rookery and in colonies and in birds' concentrations via dead organic matter and guano. Some bird species besides penguins are common in the Antarctic penguin rookeries, including the Antarctic Skua (we also studied its plumage), which has a sufficiently wide habitat and is able to migrate far to the north during the Antarctic winter period.

As it is shown in our studies, birds are able to carry various and sometimes quite abundant soil microfauna in its plumage, spreading in its plumage both oribatid mites and other groups of non-parasitic micro-arthropods: Gamasida predatory mites, springtails, Acaridia mites, and spiders. Consequently, when studying diversity of harsh habitats' soil fauna, attention should be paid to soil types around and in bird's colonies and rookeries. Colonies, most likely, are the center of formation of soil biota diversity in the high-latitude Arctic. Birds guano accumulated in island bird colonies, is a good substrate for naturalization of microarthropods.

On one hand, birds can be considered as a random factor of soil microarthropods transport. On the other hand, this is a directed vector, because birds regularly migrate from breeding grounds to wintering grounds and back, and some stop during migrations, long enough to restore fat reserves. One of the most important, yet not fully implemented, research tasks is the understanding of relationships of soil micro-arthropods habitats and migratory routes of birds. This will help to understand the pathways of soil inhabitants to remote islands and get a better idea of soil micro-arthropods fauna of poorly studied areas, as well as to understand a geographical pattern of formation of soil invertebrates' local faunas. We have managed to show the transport of some oribatid mites' species by birds by from temperate to high latitudes and vice versa. However, these studies need to be continued together with the studies of many other aspects of soil micro-arthropods recorded in bird's plumage.

A new international scientific project AVIFauna (Avian Vectors of Invertebrate Faunas) began in June 2011. Researchers from Russia, Norway, Poland and the Netherlands address a theme of current interest; namely how did and how do wingless invertebrates colonise remote arctic islands? What is the role of avian vector in dispersal and colonization of Svalbard archipelagos by the soil microarthropod community? Undoubtedly, there will new interesting facts and publications on avian vector of soil biota in the near future.

Acknowledgements

Avi-vector Project "AVIFauna (Avian Vectors of Invertebrate Faunas)" is supported by the Norwegian Research Council (project number 196172 / S30). The author is very grateful to Professor Gotthilf Hempel and Dr. Steven J. Coulson for important remarks to this manuscript, and to Roman Mikhalyuk for English translation.

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CRUSTACEANS OF THE BARENTS SEA: RECENT STUDIES OF MURMANSK MARINE BIOLOGICAL INSTITUTE

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Abstract

The paper is devoted to the analysis of research findings of the Barents Sea planktonic and benthic crustaceans carried out by the Murmansk Marine Biological Institute KSC RAS (MMBI) in the past few years. Spatial variations of zooplankton biomass, life-cycle specific features, dynamics of abundance, biomass and production of the dominant plankton copepod *Oithona similis* in the Kola Bay and zooplankton biodiversity were studied, as well as groupings of species were singled out for the Barents Sea. Some biological features of the large benthic crustacean – the red king crab *Paralithodes camtschaticus* - as invasive species were investigated. A high level presumably of illegal crab catching was revealed based on the analysis of lib injuries. The major symbionts and foulers of the red king crab were studied, molting hormone concentrations were identified, peculiarities of the crab size increment were investigated in the course of aquaria observations.

Introduction

Crustaceans are dominant in all marine ecosystems of the World Ocean (Forest and von Vaupel Klein, 2004, 2006). In the polar regions they form the basis of pelagic and benthic fauna food webs (Clarke, 1983; Raymont, 1983; Arntz et al., 1994; Matishov et al., 2000, 2004; Piepenburg, 2005).

The Barents Sea is the largest one among the shelf seas of the Arctic Ocean. It occupies about 30% of the whole shelf of the World Ocean. About 49% of the primary production of the arctic shelves falls on the Barents Sea (Wassmann et al., 2006). The Barents Sea is ice-free throughout the year in the south and south-west, it is not affected by freshwater runoff in the center and in the north, and its hydrological regime is largely determined by waters of Atlantic origin (Matishov et al., 2009). Moreover, it is also the most important fishing area in the Arctic.

Russian scientists intensively studied the Barents Sea plankton and benthic communities, especially in the first half of the 20th century (Linko, 1907; Deryugin, 1915; Brotskaya and Zenkevich, 1939; Jashnov, 1940; Manteifel, 1941; Kamshylov, 1955, 1958; Zelikman and Kamshilov, 1960; Zenkevich, 1963). Since the 1970s they studied mainly the specific distribution features of plankton and benthos as well as the formation of bio-productivity zones, commercial fish stocks were assessed (Kuznetsov, 1970; Antipova, 1975; Degtereva, 1973, 1979; Fomin 1977, 1978; Drobysheva, 1979; Timofeev, 1997). At the present stage international research in the Barents Sea has attained a multidisciplinary character. Models of the Barents Sea ecosystem are developed based on the data obtained, flows of organic matter in pelagic and benthic communities are assessed (e.g. Piepenburg et al., 1995), attempts to reveal the effect of climate change on ecosystem and bio-oceanological processes are made (Wassman et al., 2006; Sakshaug et al., 2009).

The alien red king crab *Paralithodes camtschaticus* (Tilesius, 1815), introduced in the 1960s, plays a special role in the Barents Sea benthic communities. Since 1974 large crabs have been regularly observed in the coastal zone. In recent years the crab began to extend actively out of the coastal waters towards the North up to 71°30’ N, to the Finnmark fishing grounds in the West and the southern slope of Gusinaya fishing grounds in the east (Karsakov and Pinchukov, 2009). In the east its distribution boundary shifted to Kolguev Island, 51°E. In coastal waters the crab has reached the Voronka area of the White Sea (Zolotarev, 2010). At present, the resource potential of this species in its new habitat has reached a level allowing the opening of significant commercial catches (Sokolov, 2006; Sokolov and Milyutin, 2006).

The purpose of the study is to make a review of the recent MMBI works on pelagic and benthic ecosystems of the Barents Sea. An emphasis is made on plankton copepods, which form the basis of the secondary production of the sea, as well as on the largest benthic crustacean, red king crab, which plays an important role in the benthic system and in the formation of the commercial potential of the area.

1. Plankton crustaceans

1.1. Zooplankton distribution in the Eastern Barents Sea

Mesozooplankton in the Barents Sea was to the fullest studied in its southern and southwestern parts (Degtereva, 1979; Timofeev, 2000; Dalpadado et al., 2003; Wassmann et al., 2006). The eastern sector of the sea was explored less, with basic data obtained on the qualitative composition and distribution of large dominant copepod species (Timofeev, 1995). Zooplankton samples were taken with the Juday net in the water column from the bottom to the surface or in the upper 100m during the cruise of the RV *Dal’nie Zelentsy* in August 2006. The samples were processed according to a standard technique (Dvoretsky and Dvoretsky, 2009d). The number of copepods was counted for 1 m^2.

The mesozooplankton numbers ranged within 4704-85103 specimens/m^2, biomass ranged within 382-7377 mg dry weight/m^2 (Fig. 1). Copepods and nauplii were the dominant group accounting for 79–98 and 61–98% of the total abundance and biomass respectively (Dvoretsky and Dvoretsky, 2009d). There were 12 copepod species observed in the area. *Calanus finmarchicus, Oithona similis* and *Pseudocalanus* (*P. minutus* and *P. acuspes*) were the most abundant species at all stations. Large *Calanus* (C. *finmarchicus* and *C. glacialis*) dominated everywhere in terms of the total biomass.

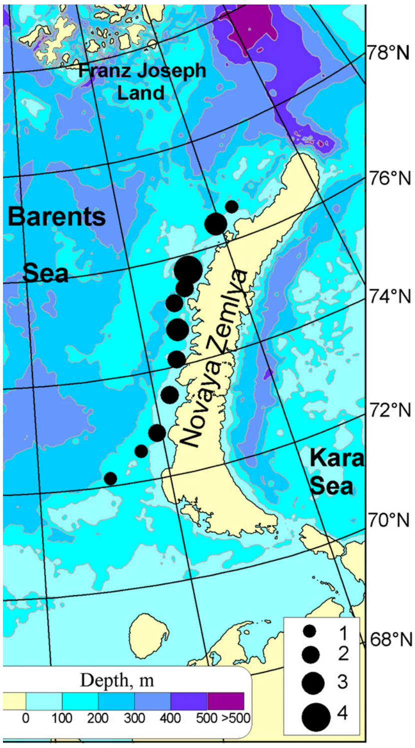

Fig. 1. Distribution of copepod biomass (mg dry mass m^{-2}) near Novaya Zemlya (the Eastern Barents Sea) in August 2006. 1 – <1000, 2 – 1000–2000, 3 – 2000–3000, 4 – >3000

The composition of copepod community off the Novaya Zemlya Archipelago coasts in 2006 was largely consistent with the previous studies carried out in the Southeastern Barents Sea and in the Western Kara Sea (Timofeev, 1995). The number of copepod species depends on the research area, biological seasons and hydrological factors. For example, the coastal areas exposed to freshwater runoff are often characterized by high species diversity. The number of species in spring is higher than in other seasons, and in years with significant increase of the North Cape current warm-water copepods often appear in plankton. High homogeneity of copepods' composition in the Novaya Zemlya vicinity is most likely associated with the presence of a closed circulation around the archipelago (Timofeev, 1995). The population structure of copepods indicates that these copepods propagate successfully within the eastern part of the sea.

In warm years the total biomass of mesozooplankton in the Eastern Barents Sea increases substantially due to the massive development of the large copepods *Calanus* spp. and *Metridia longa*. It is important to stress that in 2006 *C. finmarchicus* were dominant near Novaya Zemlya. Even in the northern part, where *C. glacialis* is usually dominating, the warm-water species *C. finmarchicus* comprised a major part of the copepod biomass. This phenomenon is most likely associated with a strong influx of the warm Atlantic waters into the Barents Sea in 2006 (Matishov et al., 2009).

1.2. The life cycle and production of *Oithona similis*

The cyclopoid *Oithona similis* Claus, 1866 can be regarded as the most numerous representative of plankton crustaceans of the Barents Sea. During some seasons the species may exceed *Calanus finmarchicus* both in the abundance and biomass. Its small size but high stock biomass make *O. similis* an important food item for other crustaceans and fish larvae. In cold years *O. similis* is the main food resource for adult plankton-eating fish as well.

Zooplankton samples were taken 2–3 times per month in the Kola Bay (the southern part of the Barents Sea) in 2004–2005 at a fixed station (33º02'E and 68º58'N). Zooplankton was collected with a Juday net from near the bottom to the surface. The total daily secondary production for the period was calculated as the sum of productions of all stages. Daily production capacity of female *O. similis* was obtained by multiplying the biomass of females with the specific egg production. The rate of the individual egg production of *O. similis* was calculated basing on water temperature (Ward and Hirst, 2007). The secondary daily production rates of copepodites and *O. similis* males were calculated by multiplying their biomass and the average growth rate according to methods published by Hirst and Bunker (2003).

From December 2004 to the early May 2005, the total number of copepodites and adults fluctuated within a narrow range. The minimum number was registered in March. Since mid-May the massive reproduction of *O. similis* was noted (Dvoretsky and Dvoretsky, 2009e,i), the abundance reached 4562 specimens/m^{-2}. During this period, younger copepodites dominated (Fig. 2a). Later on their number declined. From mid-July to mid-September there was an increase in the abundance of all investigated stages up to the annual maximum of 7541 specimens/m^{-2}. The annual average abundance was 2764 ± 290 specimens/m^{-2}. The seasonal dynamics of the total biomass of copepodites and adult stages of *O. similis* was characterized by two peaks – in May (1.37 mg C m^{-2}) and September (3.29 mg C m^{-2}) (Fig. 2b). The annual average value was 1.25 ± 0.12 mg C m^{-2}.

During the study period three production peaks were registered in May, August and October 2005 (Fig. 2c). In general, the lowest production values were observed in winter (16-30 μg C m^{-2} d^{-1}). The annual production of *O. similis* was 7181 μg C m^{-2} yr^{-1} (Dvoretsky and Dvoretsky, 2009i).

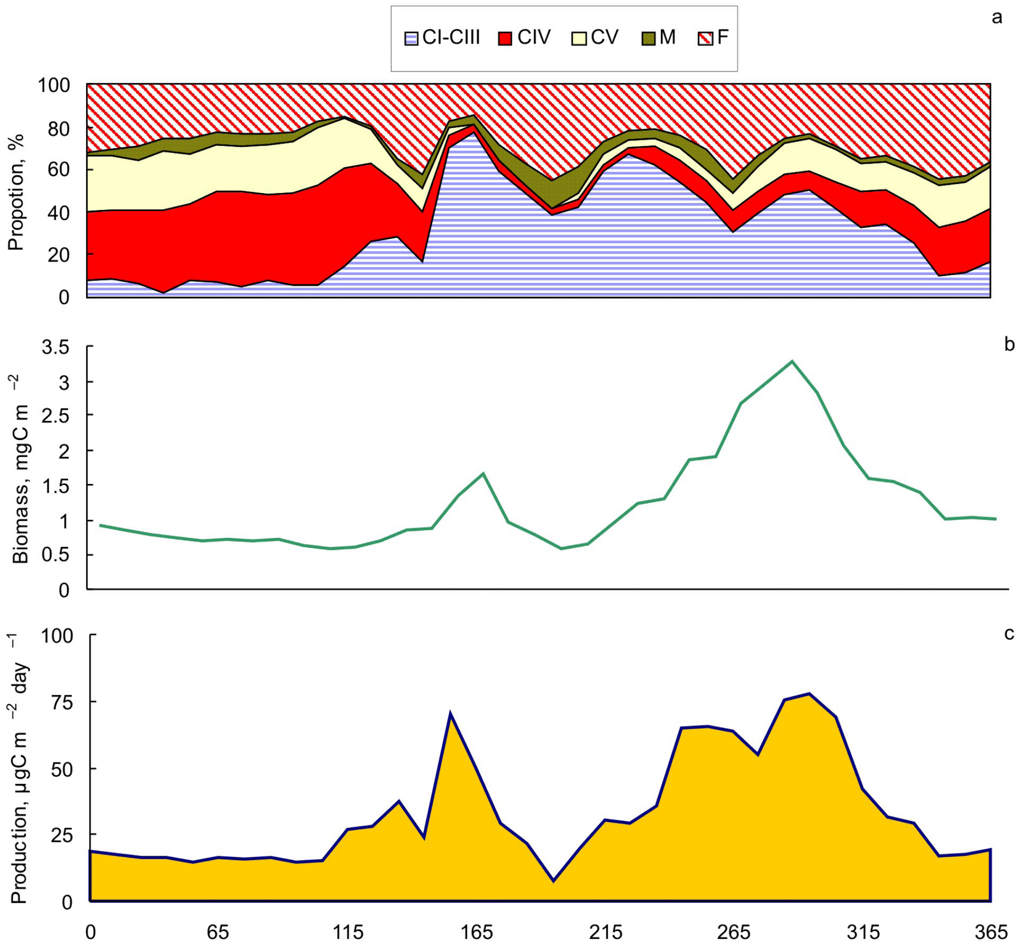

Fig. 2. Dynamics of stage structure (a), biomass (b), and production (c) of *Oithona similis* in the Kola Bay from end of December 2004 to begin of December 2005 (n = 365). CI–CV – copepodites I–V, F – females, M – males

1.3. Morphological variability of *Oithona similis* in the Barents Sea

As the Barents Sea is characterized by a wide range of hydrological factors, it is possible to compare morphological characteristics of crustaceans from different environments. The distribution of *O. similis* in the Barents Sea by size classes varied depending on the area. In the southern part males were mostly of 625 microns length, females with a body length of 775 and 825 microns predominated. In the central and eastern parts males were evenly distributed among three size classes of 675, 700, and 725 microns. Among female specimen with a body length of 825 microns predominated. In the northern and northeastern parts of the sea most of the males and females belonged to the size classes of 750 microns and 850 microns respectively. The average body length of both sexes increased from the South to the North. The maximum average length of *O. similis* was observed in the Northern Barents Sea (the Franz Josef Land Archipelago), the minimum average length in the Southern Barents Sea. A clear decrease in the total length of antennules in the latitudinal direction from the south to the north was noted (Dvoretsky and Dvoretsky, 2009f).

Morphological indicators of *O. similis* were well correlated with water temperature. An inverse relationship between water temperature and the average body length was observed. In colder areas crustaceans had shorter antennules. Thus, in our case, it is possible to speak of intraspecific-groups (sub-populations) of *O. similis* in the Southern, Central, and Northern Barents Sea (Fig. 3). Moreover, the analysis of reproductive characteristics all in all confirmed the validity of such a subdivision (Dvoretsky and Dvoretsky, 2009g). Two different size-morphological forms of *O. similis* have been delineated by Shuvalov (1980) based on the analysis of size compositions and body configurations. The Atlantic-White Sea group includes the North Atlantic population with a modal body size for females of about 730 μm and White Sea population with a modal female body size of 700 μm. The Arctic-Okhotsk Sea group consists of Arctic populations with a modal body size of 970 μm and an Okhotsk Sea population with a modal body size of 850 μm. We found that 3 intraspecific groups of *O. similis* could be distinguished in the southern, central and northern sectors of the Barents Sea (Fig. 3). In the southern region of the Barents Sea, the *O. similis* population is intermediate in female prosome modal size between the small boreal form and the large Arctic form. Populations of northern and north-eastern regions of the Barents Sea approximate the Arctic-Okhotsk Sea group. Populations of the east and center of the Barents Sea are in between the north and south sector populations (Shuvalov 1980). The populations of the Eastern and Central Barents Sea occupy an intermediate position (Fig. 3). It is possible to assume that the identified size-morphological groups (forms) differ in eco-physiological requirements for the environment, as the variability of copepods depends primarily on temperature and food conditions (Raymont, 1983).

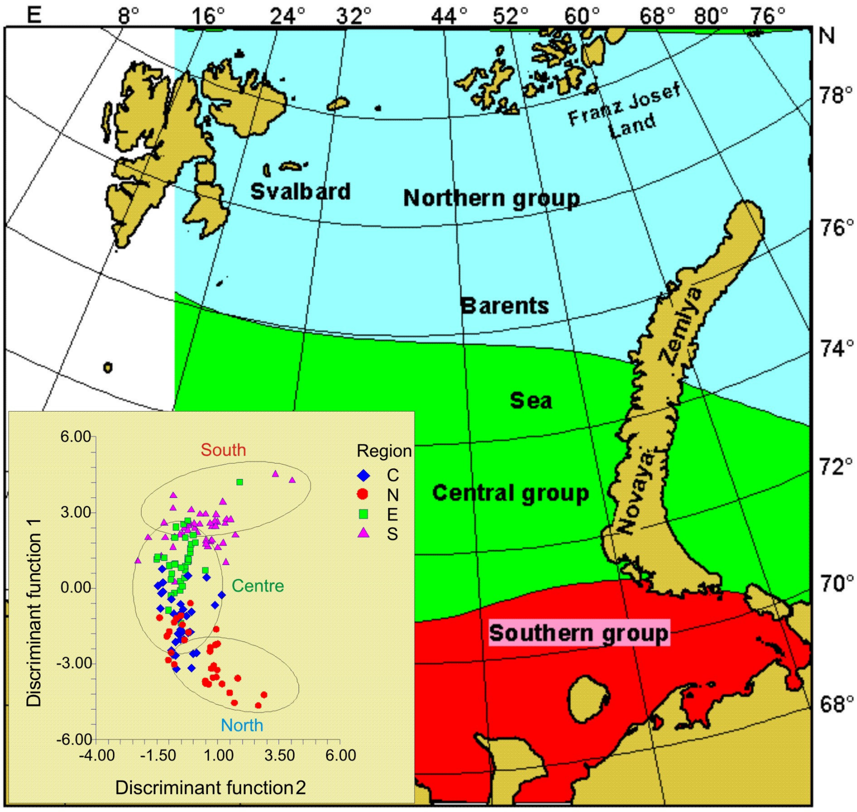

Fig. 3. Morphological groups of *Oithona similis* in the Barents Sea

1.4. Biodiversity of the Barents Sea plankton crustaceans

More than 450 samples taken in the Barents Sea in 1999–2010 as well as a number of literature sources were used in the study of plankton biodiversity (Dvoretsky and Dvoretsky, 2008, 2009d, h; Dvoretsky and Dvoretsky, 2010d, f). A review of published data supplemented by our research, suggests the presence of more than 374 taxa of animals, which can be detected in plankton samples, among the Barents Sea zooplankton (Dvoretsky and Dvoretsky, 2010e). The list of species, genera and higher taxonomic categories of the Barents Sea includes a considerable number (more than 70%) of zooplankton species registered in the Arctic seas.

Multi-cellular organisms make more than 89%. Crustaceans reach the greatest diversity (247 taxa, 73.1%), with copepods dominating among them (Fig. 4). Animals with body sizes of 0.5–3.0 mm (mesozooplankton) dominate in the composition of community (226 taxa, 59.6% of the total number of taxa or 66.9% of the total number of taxa of multi-cellular animals). Crustaceans (201 taxa) and coelenterates (11 taxa) are the most widely represented ones among them. Larger organisms (macrozooplankton) amount up to 86 taxa. The most abundant groups are again Crustacea (46 taxa) and Cnidaria (24 taxa).

Comparison of the Barents Sea taxonomic diversity with that of the other arctic and subarctic regions is of definite interest. According to published data (Pertzova and Kosobokova, 2000), zooplankton fauna of the White Sea comprises only 142

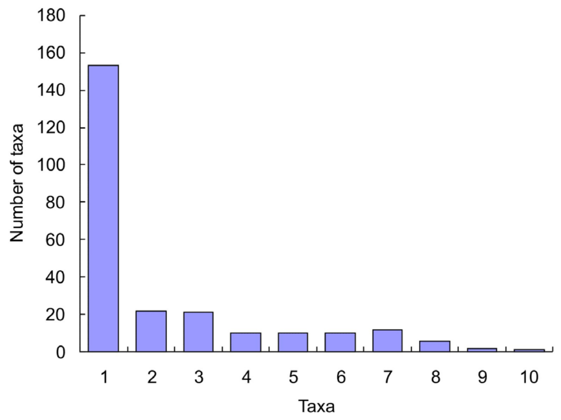

Fig. 4. Diversity of crustacean fauna in plankton samples from the Barents Sea. 1–Copepoda, 2–Cladocera, 3–Decapoda, 4–Ostracoda, 5–Amphipoda, 6–Cirripedia, 7–Mysidacea, 8–Euphausiacea, 9–Cumacea, 10–Isopoda

taxa (50 species of crustaceans). This can be explained by the fact the White Sea is a semi-closed water area, which borders only with the Barents Sea. In the Southern Kara Sea, including river basins, 155 taxa of zooplankton, including 86 crustacean species, were registered (Timofeev, 2000). About 165 taxa of zooplankton were described for the Laptev Sea, more than 65% of them were Crustacea (Timofeev, 2000). About 103 taxa of multi-cellular zooplankton are known for the Fram Strait and the Kongsfjorden. Crustaceans make up about 73% of the total number of species (Hop et al., 2006). The observed differences may be due to two main reasons. Firstly, the diversity of zooplankton is strongly dependent on varying environmental conditions. The Barents Sea is characterized by considerable diversity of habitats – from marine to estuarine, from the cold Arctic waters to the warm Atlantic, from oligotrophic to mesotrophic, from the shallow water sites to the deepwater troughs, from the ice-covered waters to the ice-free ones throughout the year. In the other Arctic areas, no similar diversity of environmental conditions was observed. Secondly, the zooplankton fauna of some Arctic waters (seas of the Russian Arctic and Siberian seas) was less studied than relatively easily accessible areas as the Barents Sea.

2. Benthic red king crab

Material for the study of the red king crab was received during summer periods from 2002 to 2010 in Dalnezelenetskaya Bay of the Barents Sea (36º06'E and 69º07'N). Crabs were caught by diving in shallow water (5-40 m deep). Our analysis of biology included determination of sex, maturity stages of females and molting, carapace length (CL), and limps integrity. Crabs were divided into two groups: immature (CL <100 mm) and mature (CL> 100 mm) according to Sokolov and Milyutin (2006). We accounted also the injury rate – the ratio of the number of individuals with at least one injured limb to the total number of analyzed crabs.

Fouling organisms and symbionts were collected right after crabs' catching. The material was fixed in 4% formalin for subsequent analysis. Foulers and symbionts were collected from different parts of the host's body: abdomen (including the eggs clutch), gills, carapace, limbs and mouth parts.

In the study of a molting hormone we collected crabs hemolymph, which was fixed in alcohol and frozen. Analysis of the samples and determination of the molting hormone concentrations were performed at the laboratory of the Institute of Biology of the Ural Branch RAS (Syktyvkar) by the procedure of Volodin et al. (2002).

The study of molting growth of crabs was based on the comparison of the ratios of the red king crab size parameters: the carapace width (CW), the carapace length (CL), the length of merus of the third right peraeopod (ML) within 0.1 mm accuracy before and after molting (Donaldson and Byersdorfer, 2005). The data were obtained during observations of molting during coastal expeditions and by aquaria studies of crabs in artificial sea water.

2.1. Injury rate of the red king crab limbs

Injury of immature crabs during the study period was approximately constant. For mature individuals, an increasing trend of the occurrence of individuals with damaged limbs was registered (Fig. 5) (Dvoretsky and Dvoretsky, 2009a). Injury of small crabs' limbs is caused by predators, primarily different fish species (Kuzmin and Gudimova, 2002). It should be noted that the rate of damaged limbs of mature crabs registered in the Dalnezelenetskaya Bay was significantly higher than at greater depths, where limbs injury usually did not exceed 20% (Pinchukov, 2006). The abnormally high occurrence of crabs with missing limbs is explained by a high level of anthropogenic pressure on the red king crab subpopulation in the Dalnezelenetskaya Bay. A high activity of recreational diving for crab catching was registered in the area. It is known that by the attacks of predators (to whom the divers can be attributed), the crab loses a limb it has been seized by and tries to escape to greater depth. So, the amateur divers should be considered as a factor impacting the crab limbs' injury. The number of divers increased significantly during the study period. It may explain the observed dynamics of the red king crab limbs injury very well (Dvoretsky and Dvoretsky, 2009a).

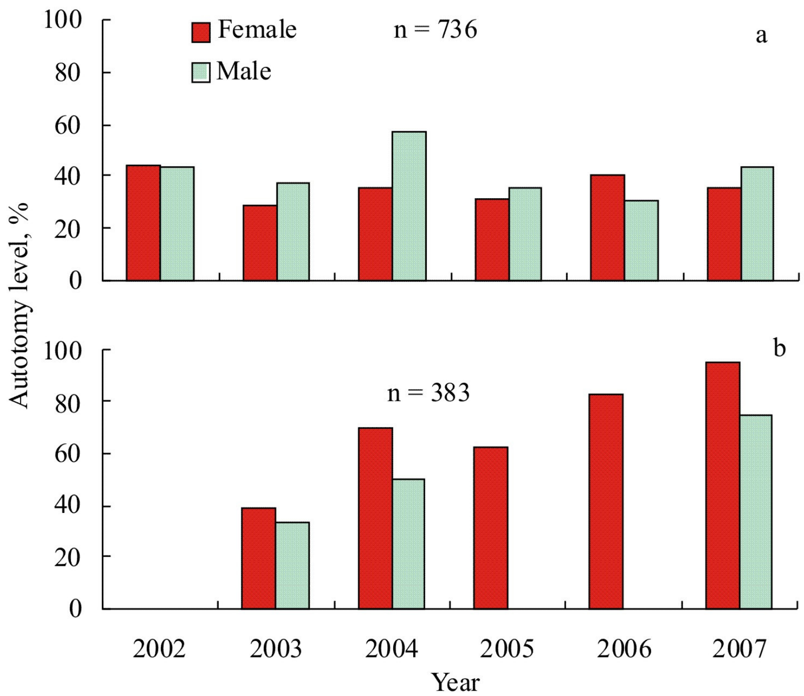

Fig. 5. Inter-annual variability in *Paralithodes camtschaticus* autotomy levels in the Dalnezelentskaya Bay, 2002–2007;
juveniles (a), adults (b)

2.2. Symbionts and foulers

In the course of the long-term research, macro-symbionts and foulers of the red king crab in the coastal areas of the Barents Sea were studied. The list of animals associated with the host includes more than 45 taxa (Dvoretsky and Dvoretsky, 2009b, 2010a). Barnacles *Balanus crenatus* (Fig. 6), mussels *Mytilus edulis*, and hydroids *Obelia* can be attributed to the primary fouling organisms. Among macro-symbionts amphipods *Ischyrocerus commensalis* (Fig. 6), fish leeches *Johanssonia arctica*, polychaetes *Harmothoe imbricata* dominate. All organisms registered on the red king crab are native inhabitants of the Barents Sea. It evidences a lack of invasion of alien crab parasite species into the Barents Sea. However, the crab introduction affected the distribution of amphipods and fish leeches. High indices of host species occupancy by these species and their high prevalence corroborate the fact (Dvoretsky and Dvoretsky, 2010a). Most of the species do not to impact the crab negatively. Amphipods *Ischyrocerus commensalis* are an exception, as they are rather often registered on the gills of the host (Fig. 6). At higher concentrations of these symbionts, the gas exchange of the host may become reduced. Such effects may lead to exhaustion of crabs and inhibition of growth, and in some cases, it may lead to death (Dvoretsky and Dvoretsky, 2009c). Other amphipods present on egg clutches of female crabs might consume the eggs. However, experimental works showed that the amphipod *I. commensalis* does not impact the eggs mortality rate and cannot be considered a specialized eggs predator (Dvoretsky and Dvoretsky, 2010b).

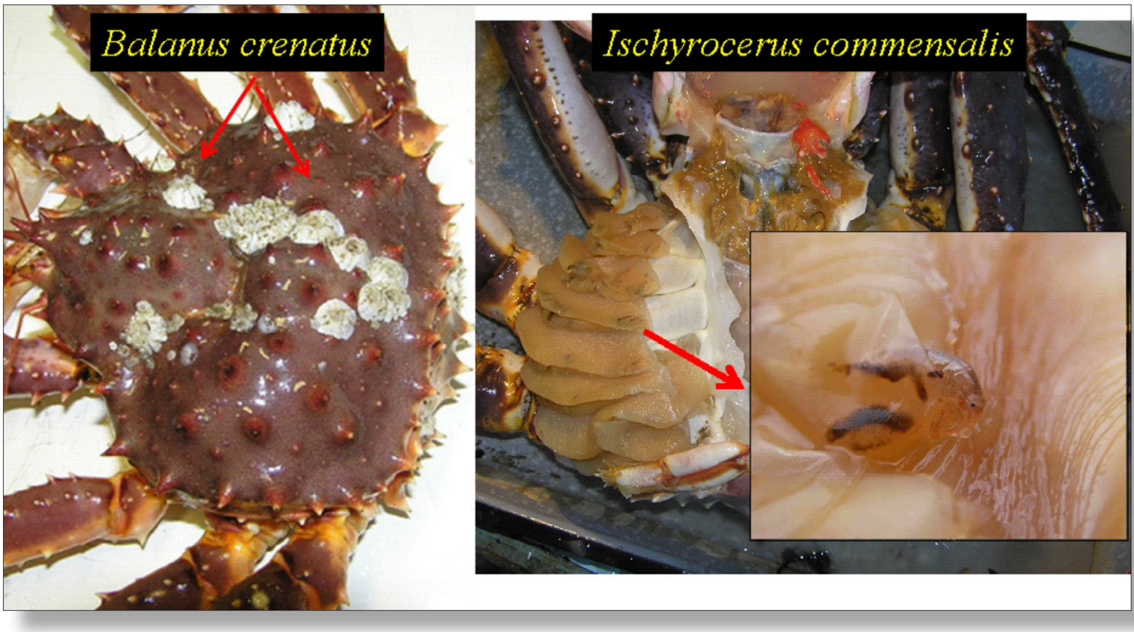

Fig. 6. Common epibionts and symbionts of the red king crab in the Barents Sea: the cirripedian *Balanus crenatus* and the amphipod *Ischyrocerus commensalis*

2.3. Molting hormones of the red king crab

The molting hormones of the red king crab from three coastal areas of the Barents Sea were studied for the first time. Two hormones responsible for crabs' molting were identified (ecdysone and 20-hydroxyecdysone). Their concentrations ranged from 0 to 190 mcg/ml and from 0 to 13 mcg/ml (Dvoretsky and Dvoretsky, 2010c) (Fig. 7) respectively. These concentrations are significantly higher than those in other decapod species. According to statistical analyzes, concentrations of ecdysteroids were similar in male and female crabs and in individuals with different numbers of damaged limbs. Also, the molting hormone levels were significantly higher in immature crabs when compared with mature ones (Dvoretsky and Dvoretsky, 2010c). The obtained data provide the basis for further research in the growth of crabs and in the development of technologies of cultivation of this species.

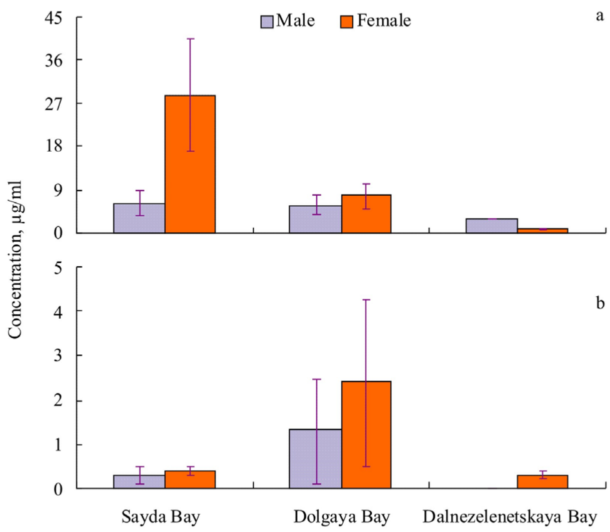

Fig. 7. Concentration of molting hormones in the red king crab in different regions of the Barents Sea:
a – 20-hydroxyecdysone,
b – ecdysone

2.4. Molt growth of crabs

During observations on the crab biology both in natural (during coastal expeditions) and artificial conditions (in aquaria), 34 cases of molt were registered. The survival rate of crabs during molting was 85.8%. Our data do not exceed similar patterns obtained for other species. During the study of the blue king crab *Paralithodes platypus* molting in running sea water, survival rates of 90% were registered (Otto and Cummiskey, 1990). The determination of the size-weight characteristics of juvenile red king crabs has shown a regular body size increase as a result of juvenile crab molting. Such increases of CL were observed during experiments of other researchers too (Matsuura and Takeshita, 1989; Jorstad et. al., 2001). The data analysis showed no significant sex dependent differences in the growth increase of the studied parameters. This confirms the idea that among juvenile crabs no significant differences in size characteristics exist among males and females (McCaughran and Powell, 1977). Molt growth of crabs had a linear dependence with a high coefficient of regression (Fig. 8). Similar linear relationships for the CW and CL were obtained by other authors when studying red king crab molting (Jorstad et. al., 2001). The data obtained are again of importance for the development of cultivation technologies of the red king crab in artificial systems and for forecasting the growth increase of individuals.

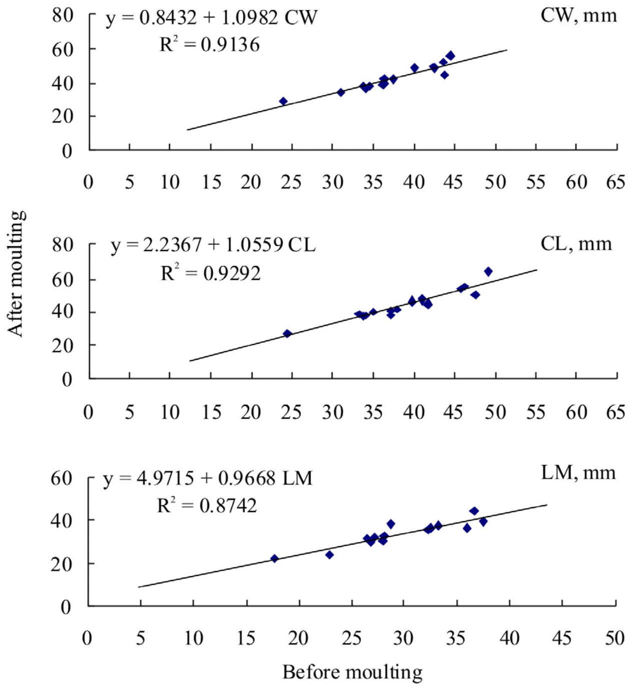

Fig. 8. Features of increment of the linear sizes of the red king crab during molting. CW – carapace width, CL – carapace length, LM – length of merus of the third right peraeopod

Acknowledgements

The authors would like to thank S.A. Kuzmin and T. A. Britaev for assistance in conducting field works, processing of the results and data compilation; N.N. Panteleeva, E.A. Frolova, E.N. Nikulina, S.Yu. Utevsky, and O.S. Lubina for help in species identification of symbionts and foulers; V.V. Volodin and S.O. Volodina for determining the concentrations of crab molting hormones. We express our gratitude to all colleagues from the MMBI Laboratory of Plankton for assistance in sampling. Special thanks are due to D.V. Moiseev for providing oceanographic data.

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CURRENT ZOOBENTHOS MONITORING AT THE KOLA TRANSECT IN THE BARENTS SEA

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Abstract

Benthic fauna at the Kola Transect (South-east of the Barents Sea) sampled in September 1995, May 1999, September 2000, April 2001 by grabs using standard techniques is analysed. Maximal species diversity connects with Warm Current at stations No 2 and No 8. Biomass of zoobenthos varies from 4.2 to 447 g per m^2. It increases along the section from the south to the north. Abundance ranges from 500 to 5100 individuals per m^2. At the Kola Transect, the Boreal-Arctic fauna (52%) dominates by number of species. The warm (Boreal) species are about 12%, the cold (Arctic) species – 8%. The highest number of warm-water species was registered in the zone of the coastal branch of the Murmansk Current. Five species assemblages were revealed at the investigated area, using cluster analysis with Bray-Curtis similarities. Assemblages distribution connects with environmental conditions, e.g. water temperature.

Basic monitoring of zoobenthos conducted at the Kola Transect indicated that benthic communities respond to changes in environmental state, by changes in quantitative characteristics and species composition.

Introduction

The Southwestern Barents Sea, where the Kola Transect is situated, is one of the main gates of the Atlantic water penetrating into the Arctic. The intensity of the Atlantic jet flow and its heat content vary from year to year (Piechura and Walczowski, 2009), determining the variability of environmental conditions in the area and the entire Barents Sea. This area is most interesting for long-term observations, since the biological processes in the marine ecosystem are closely connected to environmental parameters (Nesis, 1960).

The north/south Kola Transect is located at 33° 30' E. Its southern part crosses the coastal (69° 30' -70° 30' N) and main (70° 30' - 71° 30' N) branches of the Murmansk Current. The section also crosses a small branch of the Norwegian (Nord Cape) current to the North of (73° 30' N) (Nesis, 1960). The regularly investigated part of the Kola transect covers depths from 150 to 330 m. Minimal depths are found on the southern part of the Kola Transect (Murman Rise) and the greatest depth is found in the north. Long-term monitoring along such section allows to estimate changes in the sea ecosystem.

Long-term observations of zoobenthos at the Kola Transect started in the early 1890s (Deryugin, 1924, 1925). First samples of zoobenthos on the section were obtained mainly by semi-quantitative methods using Sigsbee trawl and bottom-grabs (Deryugin, 1924; Tanasiichuk, 1927; Nesis, 1960). A large volume of information and data was compiled and analysed by Nesis (Nesis, 1960). Unfortunately, the benthos data of long-term observations are only poorly comparable because of the variety of collection techniques employed. Nevertheless, the results are useful for studying the variability of benthic communities due to variability in climatic conditions (Nesis, 1960).

The present report focuses on the current time series of zoobenthos monitoring at the Kola Transect, which has been started by a scientific team of the Murmansk Marine Biological Institute (MMBI) in 1995 with support by the Alfred Wegener Institute (AWI) and which continues today (Denisenko et al., 2000; Frolova et al., 2007). At this stage of research, sampling is entirely by quantitative methods using bottom-grabs (Frolova et al., 2007). The present data allow not only to analyse changes in species composition, but also to assess the variability of their biomass and abundance in space and time, including the impact of climate fluctuations on the benthic community.

Materials and methods

Zoobenthos samples were taken at the Kola Transect in September 1995, May 1997, September 2000, and April 2001 by a 0.25 m^2 Ocean grab with two replicates at each station and by a 0.1 m^2 Van Veen grab with five replicates at each station (Table 1, Fig. 1). Washing of zoobenthos samples was through a 0.75 mm mesh sieve. The samples were fixed in 4% formaldehyde buffered by borax. The benthic organisms were sorted into major taxonomic groups and transferred into 70% alcohol. Laboratory analysis includes determining species composition, number and weight of each taxon in each sample. The alcohol wet weight (including mollusks shells and polychaete tubes of *Spiochaetopterus typicus,* (M. Sars 1856)) was used. Data from the replicate samples were averaged for each station. Species composition and diversity were determined by summing of taxa in all replicate samples at station. Common abundance and biomass of the benthic organisms on the Kola section were obtained by averaging data from nine regular stations (from 70° 00' – 74° 00' N). The level of the variability of quantitative data was assessed applying the variation coefficient (Ivanter and Korosov, 2003).

Faunal groups were determined by cluster analysis applying the Bray-Curtis similarity coefficient based on quantitative data. Clustering was performed by pairwise addition. Species registered in the material less than twice were excluded from the analysis (Clarke and Warwick, 1994). Calculations were performed in the "PAST" program for paleontology statistics (Hammer et al., 2001).

Table 1. Benthic stations sampled on the Kola section for the time 1995 -2001

No. st.	Date	N.	E	H, m	Sediment	Grabe, number of replicates
RV "*Yasnogorsk*" September, 1995						
1	02.09.95	74˚30.1	33˚29.7	260	silt, clay	2 samples Ocean 0.25
2	03.09.95	74˚00.1	33˚29.2	325	silt, clay	2 samples Ocean 0.25
3	03.09.95	73˚30.4	33˚29.5	295	silt, clay	2 samples Ocean 0.25
4	03.09.95	72˚59.8	33˚31.7	215	silty sand, pebble	2 samples Ocean 0.25
5	03.09.95	72˚30.2	33˚29	290	clayey silt, pebble	2 samples Ocean 0.25
6	03.09.95	71˚59.8	33˚30.3	265	clayey silt	2 samples Ocean 0.25
7	03.09.95	71˚30.1	33˚29.4	280	clayey silt, pebble	2 samples Ocean 0.25
8	04.09.95	70˚59.7	33˚29.2	225	clayey silt, pebble	2 samples Ocean 0.25
9	04.09.95	70˚30.1	33˚31.8	255	clayey silt, pebble	2 samples Ocean 0.25
10	04.09.95	69˚59.9	33˚28.3	155	sandy silt	2 samples Ocean 0.25
RV "*Pomor*" May, 1997						
1	22.05.97	74˚30.341	33˚30	270	sandy silt	5 samples van-Veen 0.1
2	23.05.97	73˚59.06	33˚28.314	330	silt, clay	5 samples van-Veen 0.1
3	23.05.97	73˚29.06	33˚30	283	sandy silt, clay	5 samples van-Veen 0.1
4	23.05.97	72˚59.7	33˚30	214	silt, clay	5 samples van-Veen 0.1
5	23.05.97	72˚29.98	33˚29	288	sandy silt, clay	5 samples van-Veen 0.1
6	23.05.97	72˚00.147	33˚29.06	266	silt, clay, pebble	5 samples van-Veen 0.1
7	24.05.97	71˚30	33˚29.87	283	sandy silt, clay	5 samples van-Veen 0.1
8	24.05.97	71˚00.09	33˚31.11	221	silt, clay, pebble	5 samples van-Veen 0.1
9	24.05.97	70˚29.99	33˚31.32	251	sandy silt, clay	5 samples van-Veen 0.1
10	24.05.97	69˚59.32	33˚30.88	150	silt, clay , spicules	5 samples van-Veen 0.1
RV "*Dal'nie Zelentsy*" September, 2000						
1	10.09.00	69˚30.015	33˚42.125	270	silt, clay	5 samples van-Veen 0.1
2	28.09.00	70˚00.05	33˚30.05	141	silt, clay , spicules	5 samples van-Veen 0.1
3	28.09.00	70˚28.289	33˚34.223	239	silt, clay , sspicules	5 samples van-Veen 0.1
4	29.09.00	71˚00.3	33˚29	216	sandy silt, clay	5 samples van-Veen 0.1
5	29.09.00	71˚29.364	33˚31.737	272	sandy silt,clay	5 samples van-Veen 0.1
6	29.09.00	72˚00.1	33˚29.8	254	silt, clay	5 samples van-Veen 0.1
7	29.09.00	72˚30.04	33˚27.916	276	silt, clay	5 samples van-Veen 0.1
8	30.09.00	73˚00.9	33˚26.8	210	silt, clay, pebbles	5 samples van-Veen 0.1
9	30.09.00	73˚31.293	33˚29.332	280	silt, clay	5 samples van-Veen 0.1
10	30.09.00	74˚10.8	33˚28	317	silt, clay	5 samples van-Veen 0.1
11	30.09.00	74˚31.743	33˚32.362	254	silt, clay	5 samples van-Veen 0.1
12	01.10.00	75˚00.8	33˚31.2	149	silt, clay, pebbles, stones	5 samples van-Veen 0.1
RV "*Dal'nie Zelentsy*" April, 2001						
1	13.04.01	69˚17.308	37˚55.427	221	silt, clay	5 samples van-Veen 0.1
5	16.04.01	69˚36.815	37˚43.464	111	silty sand, shells, clay	5 samples van-Veen 0.1
8	18.04.01	73˚58.9	33˚25.6	301	silt, clay	5 samples van-Veen 0.1
9	18.04.01	73˚28.952	33˚24.015	277	sandy silt	5 samples van-Veen 0.1
10	19.04.01	72˚59.874	33˚28.806	212	silt, clay, stones	5 samples van-Veen 0.1
11	19.04.01	72˚30.675	33˚28.743	275	silt, clay	5 samples van-Veen
12	19.04.01	72˚00.9	33˚32.9	264	sandy silt	5 samples van-Veen 0.1
13	20.04.01	71˚29.878	33˚29.412	271	sandy silt, clay	5 samples van-Veen 0.1
14	20.04.01	70˚59.124	33˚28.937	211	sandy silt, clay	5 samples van-Veen 0.1
15	20.04.01	70˚30.016	33˚30.277	241	sandy silt, clay	5 samples van-Veen 0.1
16	20.04.01	69˚59.4	33˚32.859	138	sandy silt, spicules	5 samples van-Veen 0.1
17	20.04.01	69˚29.836	33˚29.122	251	sandy silt	5 samples van-Veen 0.1

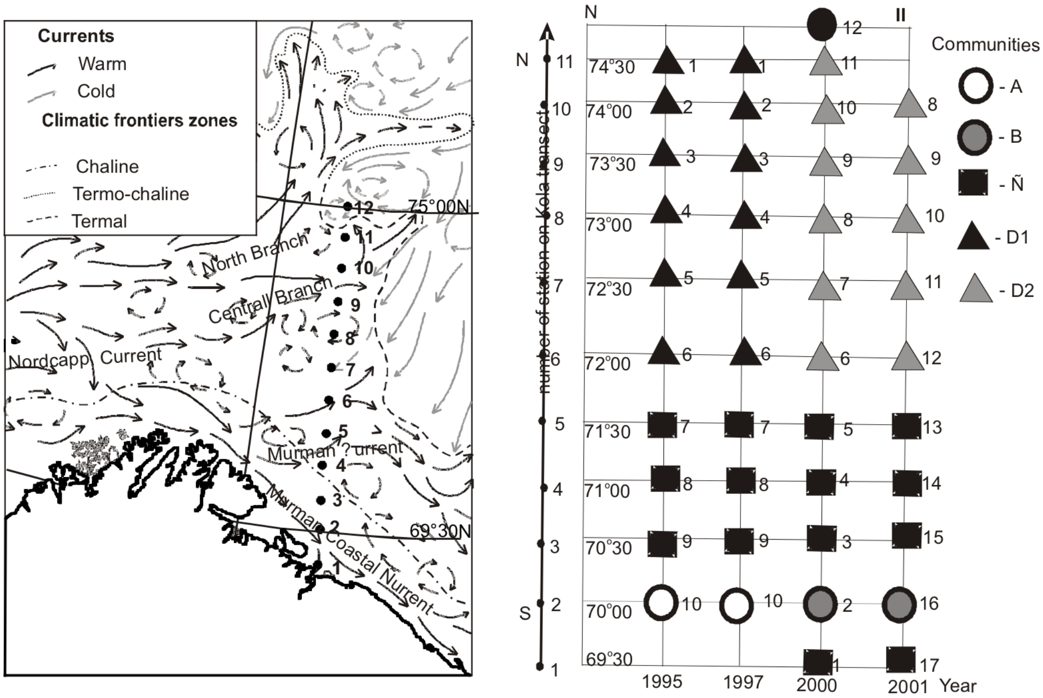

Fig. 1. Scheme of the Kola Transect (Currents scheme by Matishov et al., 2010) (left): monitoring scheme at the section, (right): distribution of zoobenthos associations (five community complexes) (explanations in text)

Water temperatures at the Kola Transect in the different years were taken from Matishov et al. (2010).

Zoogeographical status of benthic organisms was detected according to the principles of zoogeographical zonations of Golikov (1990).

Results and conclusions

652 taxa of benthic organisms were identified at the Kola Transect during the period of observation, of which there were 495 identified species of 29 classes, 76 orders, and 187 families.

Quantitative distribution of zoobenthos along the Kola Transect

Species richness in the studied area includes on average 87.4 species at a station. It varies moderately along the section (with a variation coefficient on average of 24%). Station No. 2 and station No. 8 at the Kola Transect were characterized by a high level of species richness according to long-term data (Fig. 2 A). Station No. 2 is located at small depths (140-150 m) in the area of the coastal branch of the Murmansk Current. Station No. 8 is located in the core of the main branch of the Norwegian Current. The peaks of species richness were well-expressed in years of positive anomalies of sea surface temperature in 1995, 2000, and 2001 (Matishov et al., 2009; Matishov et al., 2010) (Fig. 2A). In the "cold" year 1997, the maximums shifted from the north to the south, and all peaks of species diversity were expressed weakly (Fig. 2A). The number of species at the stations varies moderately over the time (with a variation coefficient of 22%). The number of species strongly increased in 2000 (Fig. 2B).

The average biomass of zoobenthos at the section is 35 g per m^2 and varies from 4.2 to 447 g per m^2 (coefficient of biomass variation on average is 21%). Biomass increases along the section from south to north (Fig. 3A). The minimum is recorded at the mouth of the Kola and Motovskiy Bays (station 1), and the maximum at the northernmost station of the section. Clear patterns of biomass distribution along the section were not registered in different years of monitoring. The maximum average biomass of zoobenthos at the section was recorded in September 2000, and the minimum in April 2001 (Fig. 3B) (coefficient of variation in time is 20%).

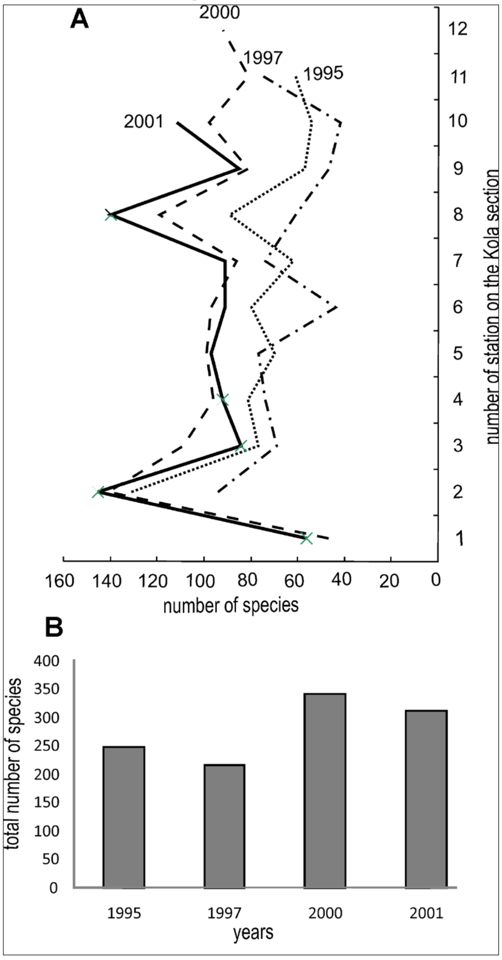

Fig. 2. Distribution of zoobenthos species diversity (richness) along the Kola Transect in different years of observations (A), fluctuations of the total number of taxa encountered in the study period (B)

The average abundance of benthic organisms is 1900 specimens per m^2 and ranges from 500 to 5100 individuals per m^2 (coefficient of variation in space is 38%). Diagram of the abundance variation is similar to the curve of species diversity variation (Fig. 4A). The minimum abundance of zoobenthos was recorded in May 1997, and the maximum – in September 2000 (Fig. 4B) (coefficient of abundance variation in time is 36%).

Analysis of zoobenthos distribution along the section revealed a greater variability in space than in time. Species diversity and biomass of zoobenthos vary moderately both in space and time. These characteristics can be considered quite stable. Abundance is strongly associated with biological seasons and therefore varies greatly in the course of the year. This means that biomass and species diversity are the most typical characteristics for evaluation of long-term changes in benthic communities.

Frolova et al., (2007) found a linear correlation between fluctuations of the averaged biomass of individual zoobenthos species in the *Spiochaetopterus typicus* community and changes of the mean annual temperatures at the Kola Transect in the layer of 0-200 m. It was shown that biomass of warm-water species increased together with the temperature increase, while cold-water ones decreased. The biomass change manifested itself with a delay of 3-7 years (Frolova et al., 2007).

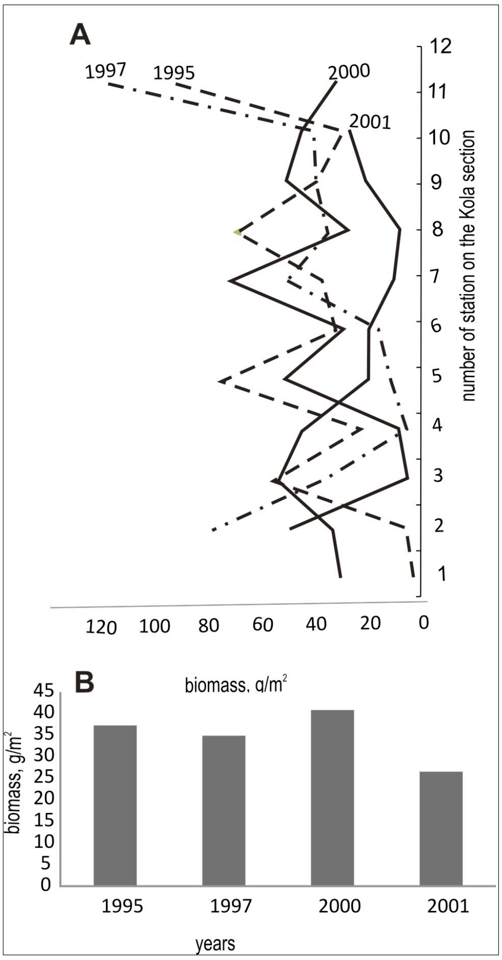

Fig. 3. Distribution of benthic biomass along the Kola Transect in different years of monitoring (A), fluctuations of averaged benthic biomass at the Kola Transect during the monitoring period (B)

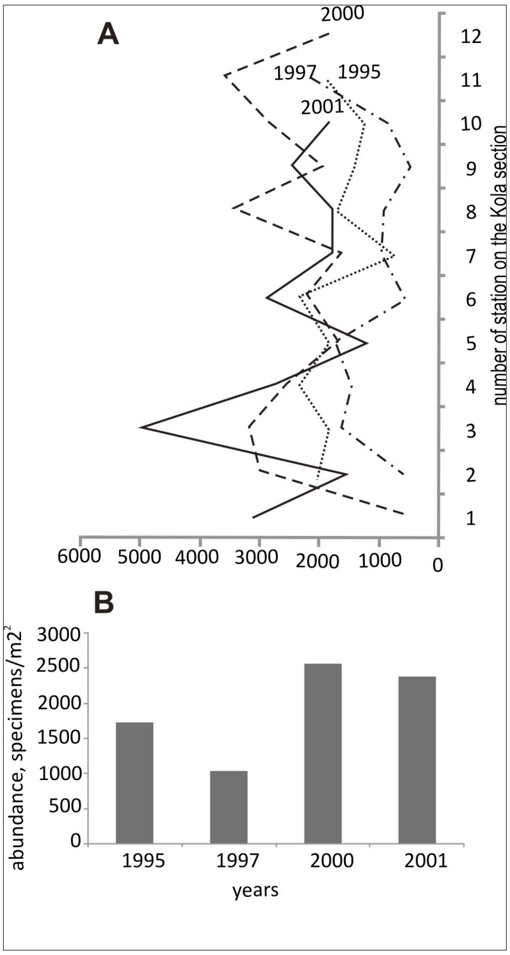

Fig. 4. Distribution of benthos abundances along the section in different years (A), fluctuations of averaged numbers of benthos at the Kola Transect during the monitoring period (B); see Fig.2

The period varies in different species. The delay time depends on longevity of the organisms and their reproduction features (Nesis, 1962; Denisenko, 2000; Frolova et al., 2007). Many warm-water fauna elements with plankton larvae have greater settlement potentials than cold-water ones (often without pelagic larvae) (Nesis, 1962).

Zoogeographical composition

The temporal variability of fauna structure was studied by comparing percentage ratio of warm water (Boreal) and cold water (Arctic) species (Nesis, 1960) at the various stations. Both types of species are on the border of their temperature tolerance, and therefore are the most sensitive to fluctuations of environmental parameters.

At the Kola Transect, the Boreal-Arctic fauna (52%) dominates by the number of species. The warm (Boreal) species are about 12%, the Arctic species – 8%. Zoogeographical status was not detected for 26% species. These species were excluded from the analysis.

The highest number of warm-water species (A) was registered at station No. 2, located in the zone of the coastal branch of the Murmansk Current. The maximum of cold-water species (B) shifted along the section in different directions during the study period (Fig. 5).

The Boreal species are more diverse at the Kola Transect than Arctic species. Relative diversity of warm and cold-water species at the section is shown in figure 5. Diversity of warm-water species was higher in 1995 and 1997, whereas share of cold-water species increased in 2000. It seems that temperature of the preceding period determined the ratio of warm and cold-water species.

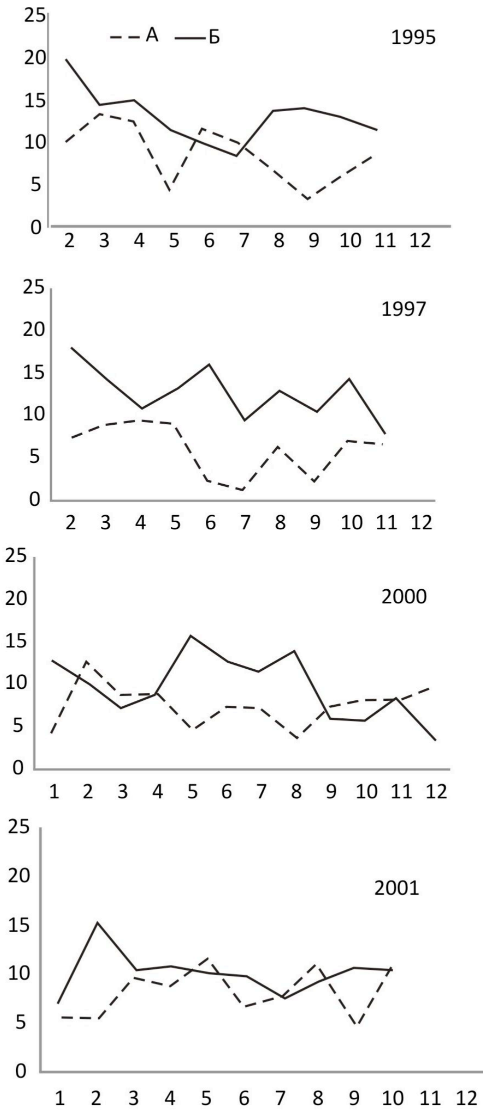

Fig. 5. Distribution of percentages of Boreal (A) and Arctic (B) species of the total number of species at stations in different years of monitoring

The results show that peaks of species richness at stations No. 2 and 8 were due to both warm-water species and cold-water elements of fauna evolving in those areas during the periods of lower diversity of Boreal species. Probably not only the water temperature determines high levels of species diversity, but also other habitat conditions, such as the depths, variety of types of bottom sediments, bottom micro-relief.

Analysis of the results confirmed a response delay of zoobenthos to changes in environmental conditions. Thus, the effect of the "cold" period of the late 1990s (1997-1999) became visible in the appearance of benthic fauna during the subsequent "warmer" period in 2000 and 2001. Distribution of the Boreal and Arctic species at the section during different monitoring periods indicates the cyclical pattern of the zoogeographic structure of fauna associated with climate variability.

Distribution of benthic communities

Five species complexes were allocated during the observation period at the Kola Transect (Fig. 1, 6).

Complex A. Samples taken at station No. 2 of the section in 2000 and 2001 were combined into the complex A (Fig. 1, 6). Sponges have high values in biomass here (35%), as well as the bivalve *Astarte crenata* (Gray, 1842) (12%). Most abundant species here are bivalve *Mendiucula ferruginosa* (Forbes, 1844), polychaetes *Notoproctus oculatus* (Arwidsson, 1906), *Pseudoscalibregma longisetosum* (Theel, 1879), *Chone murmanica* (Lucash, 1910), cumacean *Leucon nasica* (Kroyer, 1841). 174 species are registered in this complex. Species number is very high, 143 species per station on average. Abundance of zoobenthos on average is 2700 specimens per m^2, biomass is 14 g per m^2. The Boreal-Arctic species dominate in this complex by number, biomass and abundance (Fig. 7). Boreal species surpass the share of the Arctic species by all quantitative indices (Fig. 7).

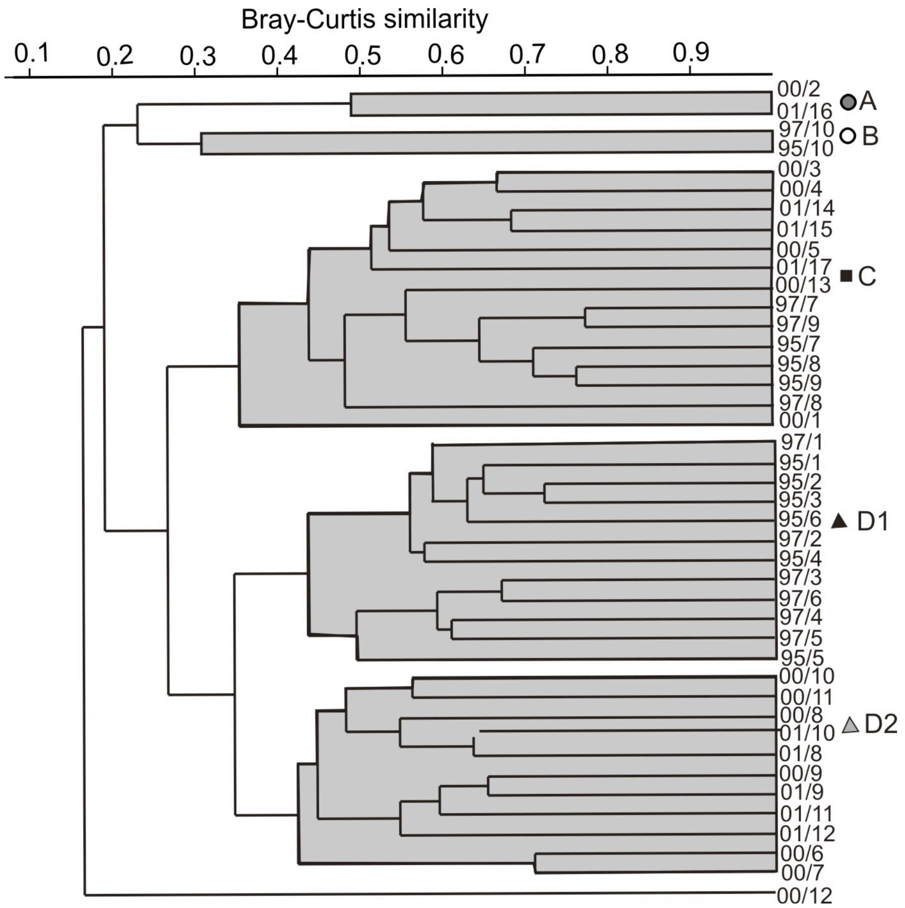

Fig. 6. Dendrogram of Bray-Curtis similarity of zoobenthos at the stations of the Kola Transect (explanations in text)

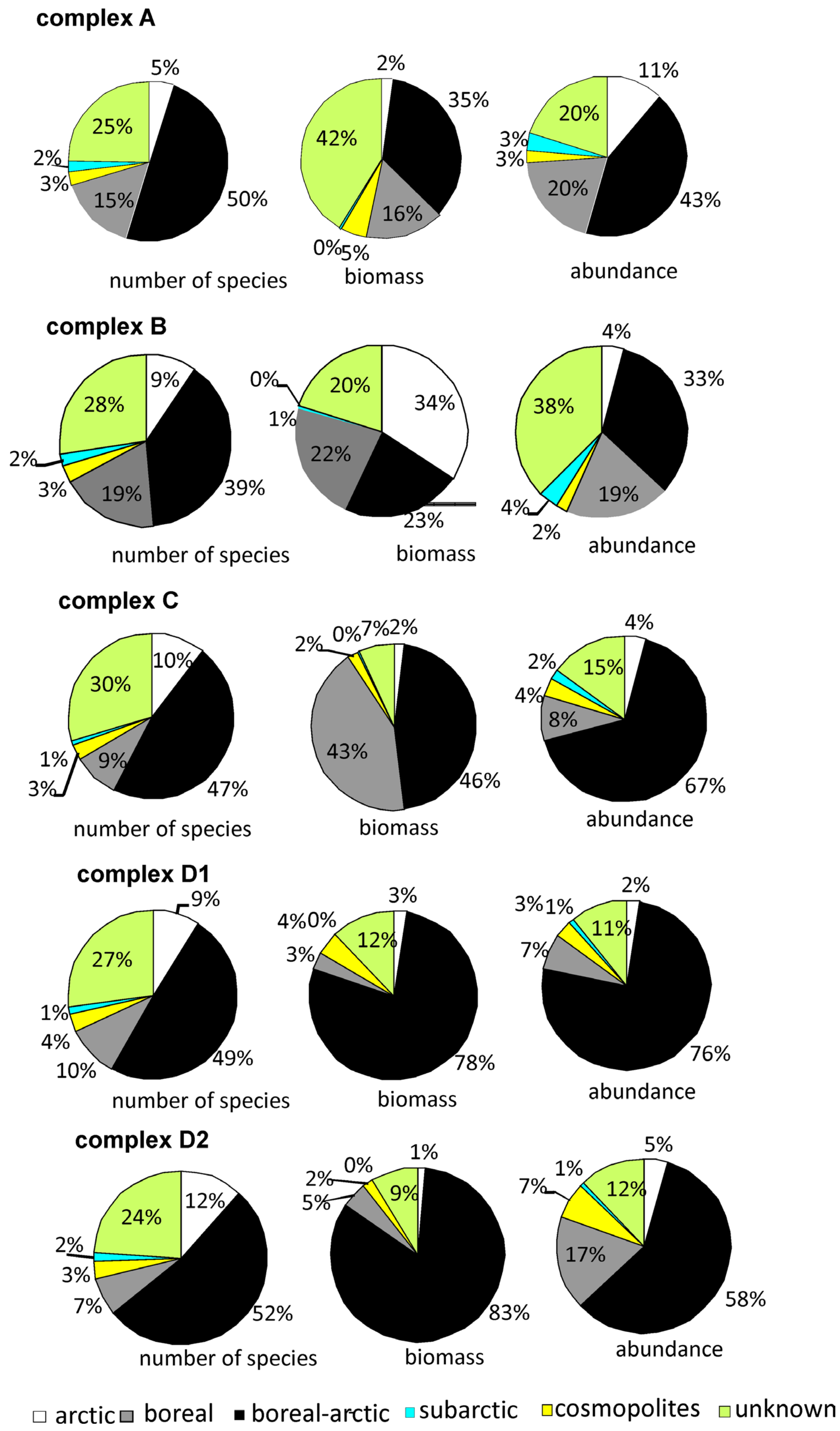

Fig. 7. Biogeographic structure of zoobenthos associations at the Kola Transect stations in the years of monitoring

Complex B. In 1995 and 1997 the species composition at station No. 2 was grouped into complex B (Fig. 1, 6). The holothurian *Molpadia borealis* (M. Sars, 1859) (32%) and the irregular sea urchin *Brisaster fragilis* (Duben & Koren, 1846) (18%) dominate by biomass in the complex. The most important in abundance are polychaetes of the genus *Chone* (23%), *Notoproctus oculatus* (4%), and the brittle star *Ophiura sarsi* (Lutken, 1855) (4%). There are 138 species here. Species number is on average 112 species per station. Biomass is on average of 60 g per m^2, abundance – 1300 specimens per m^2. The Boreal-Arctic species dominate by number of species and number of individuals (Fig. 7). The Arctic species stand out by biomass due to the dominance of the large cold-water holothurian *Molpadia borealis (*M. Sars, 1859). Besides, warm-water species are important when it comes to biomass due to the irregular sea urchin *Brisaster fragilis* (Fig. 7).

Complex C is relatively stable in space and time for the entire specified period. It was localized in 69° 30' N in 2000 and 2001 and from 70° 30' to 71° 30' N along the section (Fig. 1, 6). *Mendicula ferruginosa* (Forbes, 1844), the polychaetes *Maldane sarsi (*Malmgren, 1867), *Asychis biceps* (M. Sars, 1861), *Scoloplos armiger* (Muller, 1776), *Paramphinome jeffreisii* (McIntosh, 1868), and a group of species of *Cirratulidae* have high constancy of occurrence. The irregular sea urchin *B. fragilis* (39%) and the polychaete *Spiochaetopterus typicus* (M. Sars, 1856) (13%) have great importance in biomass. Most abundant in the association are *Maldane sarsi* (21%) and *Mendicula ferruginosa* (19%). There were 233 species registered in the complex. Species diversity is 81 species per station on average, abundance is 2000 specimens per m^2, biomass is 25 g per m^2. The Boreal-Arctic species dominate by all quantitative indices. Diversity of the Arctic species is slightly higher than Boreal ones. Boreal species, in contrast, dominate in terms of biomass (Fig. 7).

Complex D is localized from 72° to 74° 30' N of the section. Differences in the structure of dominance in the complex are observed in different years (Fig. 1, 6).

Complex D1 was registered in 1995 and 1997. Constant species here are: the polychaetes *Spiochaetopterus typicus* (M. Sars, 1856), *Aglaophamus malmgreni* (Theel, 1879), *Galathowenia oculata* (Zachs, 1923), *Maldane sarsi* (Malmgren, 1867), *Paramphinome jeffreisii* (McIntosh, 1868), *Scoloplos armiger* (Müller, 1776), *Terebellides stroemi* (Sars, 1835), the starfish *Ctenodiscus crispatus* (Retzius, 1805), and nemerteans. The polychaete *Spiochaetopterus typicus* dominates by biomass (40%) and abundance (34%). 169 species were registered in the complex. Species diversity was 62 species per station, biomass was 45 g per m^2, and abundance was 1300 specimens per m^2. The Boreal-Arctic species dominate in the faunal complexes by all quantitative indicators. The differences in shares in biomass, abundance, and species diversity of the Arctic and Boreal species are negligible (Fig. 7).

Species complex D2 was registered at the section in 2000 and 2001 within the same localization boundaries as complex D1 (Fig. 1, 6). This fauna complex is similar in constant species composition. Polychaete *S. typicus* dominates in biomass and abundance (34% and 11% respectively). Bivalve *Mendicula ferruginosa* (Forbes, 1844) is very important when it comes to its abundance (13%). 239 species were registered at the complex. Species diversity of zoobenthos was 98 species per station, biomass was 44 g per m^2, and abundance was 2700 specimens per m^2. The Boreal-Arctic species dominate here by all quantitative indicators. Diversity of the Arctic species in the complex is higher than of the Boreal ones (Fig. 7).

Results of zoobenthos studies in the open sea indicate a decisive role of bottom sediments, bottom topography, and depth on species composition (Zienkiewicz, 1963; Heip et al., 1992; Anisimova et al., 2010; Reiss et al., 2010; Denisenko, 2006). Importance of water masses upon the formation of associations of benthic organisms was stressed with the fjords of the Spitsbergen (Svalbard) being exemplified (Wlodarska-Kovalczuk and Pearson, 2004; Lyubina et al., 2010). The reviewed observations of zoobenthos at the Kola Transect also showed the role of oceanographic conditions, such as water temperature, for the species composition of zoobenthos communities. So changes of the dominant species complex at the north part of the Transect expressed prevailing warm water species by diversity in 1995, 1997 and increasing number of cold-water species in 2000, 2001 validate this statement. It can be assumed that the first half of the study period reflects the "warm phase" prior to 1995 with delay, but in 2000-2001 the effect of the cold late 1990s.

The unique complexes at station No. 2 are typical for the area of the warmest Coastal branch of the Murmansk current in silty soils with spicules of sponges. Here zoobenthos differ by the maximum of species diversity. Probably, habitat conditions allow increasing of species richness here. A great number of warm- and cold-water species were registered in the area. However, the influence of warm coastal currents water masses upon the increase of diversity of species cannot be excluded. Rare and new warm-water species for the fauna of the Barents Sea were registered in the area (Lyubina, 2009).

Zoobenthos complexes had high constancy of species composition in the central part of the Kola Transect during the entire observation period. These complexes can be considered as transitional, since there is a large proportion of species with different bio-geographic distribution.

Human impacts

We did not consider possible human impacts on the sea area, which can also affect the bottom fauna. Impoverishment of benthic communities in the area of station No. 1 of the section, located in the mouth of the Kola and Motovskiy bays, can probably be due to high levels of sediment pollution (Anon., Information bulletin, 2007). In addition, there is intensive fishery in the Southwestern Barents Sea, which should also influence the composition and abundance of zoobenthos (Denisenko, 2007). All our samples were taken by bottom-grabs. It is known that bottom-grabs adequately exploit relatively small and buried organisms, while the bottom trawls used in commercial fishery mainly destroy large epifauna species (Jorgensen et al., 2008). The issue requires more detailed consideration and analysis of the greater continued data series.

Basic monitoring of zoobenthos conducted at the Kola Transect indicated that benthic communities respond to changes in environmental state, not only by changes in quantitative characteristics, but also by species composition. We assume that quantitative indices of zoobenthos from the Kola Transect may be important for studying the climate change effects on bottom populations.

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ACKNOWLEDGEMENT

The present volume deserves a special acknowledgement from its guest editor. As already stated in the preface, the decision to produce the volume was made rather ad hoc, at the end of the short workshop on Arctic marine biology and related Arctic studies held in Murmansk one year ago. On the German part, we were gratefully impressed by the efforts of our Russian colleagues in reporting comprehensively about their work in the broad field of Arctic marine biology and related subjects. Many of those results had already been published in the Russian scientific literature and quite a number of the original data derived from long-time series of observations had also been incorporated in atlases recently published by the MMBI in co-operation with the US NOAA. Nevertheless, we felt that the international awareness of the research programmes carried out by the MMBI and other Russian institutes working in Arctic waters needs to be fostered and raised. We assume that publishing the inputs to the workshop in English in „Berichte zur Polar- und Meeresforschung / Reports on Polar and Marine Research" may further contribute to this aim.

Academician Gennady Matishov and his staff members kindly submitted English versions of their presentations on a rather short notice. It so happened that traditionally, the Russian science community has its own way of scientific writing, therefore the manuscripts required considerable editorial adaptation to the style of an international series like the „Reports on Polar and Marine Research". More details in terms of methods and of quantitative data were needed; quotations and references as well as figures and tables and their legends had to be refined. Through my friend Roman Mikhalyuk on the Russian side and through Elena Tschertkowa-Paulenz in Bremerhaven, I pestered the Russian colleagues with endless detailed questions. I would like to express my sincere gratitude to the authors for their understanding, patience and precision adjustments. Some manuscripts were reviewed and commented for amendments by external specialists. Their assistance is also highly appreciated both by the authors and the editor.

My thanks also go to Elena Tschertkowa-Paulenz and to the staff of the series „Berichte zur Polar- und Meeresforschung", editor in charge Dr. Horst Bornemann and assistant editor Birgit Chiaventone, for their meticulous and skillful way of turning the manuscripts into a handsome publication.

International research projects and joint publications in international journals and other series pave the way to international exchange of concepts, knowledge and data, and, what is more, to the understanding and common thinking. The present volume is expected to help the international dialogue and to be one of those bridges, which are essential to make marine sciences truly global. Without globalisation, our scientific understanding of the World Ocean and its polar seas will be piecemeal and its application to answering burning questions of human society will remain fragmentary.

English is a foreign language for all contributors of the present volume: authors, scientific editor, translators and editorial staff as well. Despite our combined efforts, the publication retains some of the Russian English with a light German flavour. Hope you will like the endeavour. We did not aim for the language perfection.

Gotthilf Hempel, 9. February 2012

Die "Berichte zur Polar- und Meeresforschung" (ISSN 1866-3192) werden beginnend mit dem Heft Nr. 569 (2008) als Open-Access-Publikation herausgegeben. Ein Verzeichnis aller Hefte einschließlich der Druckausgaben (Heft 377-568) sowie der früheren **"Berichte zur Polarforschung** (Heft 1-376, von 1982 bis 2000) befindet sich im Internet in der Ablage des electronic Information Center des AWI (**ePIC Reports**) unter der URL http://epic-reports.awi.de. Durch Auswahl "Reports on Polar- and Marine Research" (via "browse"/"type") wird eine Liste der Publikationen sortiert nach Heftnummer innerhalb der absteigenden chronologischen Reihenfolge der Jahrgänge erzeugt.

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