

Biological Atlas of the Arctic Seas 2000: Plankton of the Barents and Kara Seas

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PREFACE

Both the Barents Sea and the Kara Sea have been the focus of historical studies performed by many generations of Russian researchers. Because Russia has sent expeditions to this area since the 19th century, a large amount of physical, hydrochemical, and hydrobiological data have been collected from this region. These data are useful for the study of a broad range of fundamental problems in oceanography, particularly since the Barents Sea is the final element in the Atlantic Ocean water transformation through the Gulf Stream system. For better understanding of the nature of the processes in this region of the Arctic basin and their prediction, the Gulf Stream system from the Florida Peninsula to the Novaya Zemlya archipelago should be considered as a whole. These reasons outline the long-term objectives in cooperation between the Murmansk Marine Biological Institute, Russian Federation (MMBI) and the World Data Center for Oceanography, Silver Spring (WDC) for generating an oceanographic database and its utilization for ocean studies.

The Biological Atlas of the Arctic Seas 2000 is the second stage in the joint study performed by the MMBI and the WDC within the framework of the GODAR Project (Global Ocean Data Archaeology and Rescue). The first study *Climatic Atlas of the Barents Sea 1998: Temperature, Salinity, Oxygen* was published in 1998 with copies forwarded to different scientific centers, including Murmansk schools. We are planning to distribute the present publication in a similar way. We believe that this will stimulate an interest in young generations for further examination of the ocean and its biological resources.

This Atlas and associated data are being distributed internationally without restriction via CD-ROM, and the Internet in accordance with the principles of the World Data Center system of the International Council of Scientific Unions and the UNESCO Intergovernmental Oceanographic Commission.

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ACKNOWLEDGMENTS

Several generations of Russian investigators, observers, and mariners collected hydrobiologic data in the Arctic Seas during the period 1910-1950. These data represent a basic tool for the study of the Arctic Seas. Many scientists involved in this research added to their knowledge, expertise and skill in making marine surveys thanks to the historic investigations of A. Linko, K. Deryugin, B. Manteifel, M. Kamshilov, E. Zelikman, and scientists of other generations.

Over the years, the efforts of the crewmembers of the R/V *Pomor* and the R/V *Dalnie Zelentsy* of the MMBI, provided unique opportunities for data collection over the Arctic seas, often facing the severe weather conditions of the polar latitudes.

Special gratitude should be expressed to the crewmembers of the nuclear icebreakers *Arktika*, *Sovetsky Soyuz*, *Vaigach*, and *Rossiya* as plankton information collected during their cruises provided data for the study of regions previously inaccessible for investigations.

The Kola Scientific Center of the Russia Academy of Sciences, the NOAA Climate and Global Change Program, and the NOAA Environmental Science Data and Information Management program have supported aspects of this work on the development of an oceanographic database and the computation of the plankton characteristics of the Arctic Seas.

A large amount of data has been rescued through the efforts of the UNESCO International Oceanographic Commission (IOC) which sponsors the GODAR project. The NOAA Central Library (Silver Spring, MD, USA), the Slavic and Baltic Division of the New York Public Library (New York, NY, USA), the Dartmouth College Library (Hanover, NH, USA), and the Slavic Library (Helsinki, Finland) served as sources for the valuable data used in this work.

We are indebted to staff of the MMBI and especially to D. Moiseev, T. Kuznetsova, E. Druzhkova, M. Gromov, L. Matyusheva, D. Shirokolobov. We are also indebted to the staff of NODC and the World Data Center for Oceanography (Silver Spring), J. Antonov, T. Boyer, M. Conkright, C. Forgy, S. Phillips, R. Gelfeld, D. Johnson, C. Sazama, C. Stephens, and G. Trammell, who have contributed significantly to the database generation. We acknowledge E. Makarenko for the Russian-English translation of this text.

We would like to express our special gratitude to E. Markhaseva, Ph.D., Zoological Institute (S. Peterburg, Russia), S. Drobushcheva, Ph.D., Polar Institute of Fisheries and Oceanography (Murmansk, Russia), P. Murphy, Ph.D., and Anthony R. Picciolo, Ph.D., NODC/NOAA (Silver Spring, USA) for editing this publication.

ABSTRACT

Presented are (a) physical and biological data collected during 158 scientific cruises carried out in the period 1913-1999 and (b) data on phytoplankton collected in 1994-1999 during cruises of nuclear icebreakers in the region extending from the Barents Sea to the Kara Sea. Listed are phytoplankton and zooplankton species of the Arctic Seas. Ecological and geographic characteristics are given to each individual species. Pictures of live cells illustrate the dominant species. Based on

the pattern of the annual cycle of the plankton variability, proposed criteria are presented for the quality control of phytoplankton and zooplankton data. The methods of objective analysis are used for mapping the distribution of physical and biological characteristics of the Barents and Kara Seas. Changes in the plankton community structure between the 1930's, 1950's, and 1990's are discussed. It is demonstrated that observed differences substantially exceed the error resulting from the use of various methods for plankton sampling.

1. INTRODUCTION

Plankton is a biological component of the World Ocean and a major food source for a variety of marine life. This fact makes the problem of plankton investigation an important part of the study of the Ocean and its biological resources.

Hydrobiological investigations of the Barents Sea and the Kara Sea were launched in the second half of the 19th century. Peak studies occurred between 1960 and 1990 when dozens of scientific research vessels were carrying out monthly collections of physical and hydrobiological data in this region. These data are potentially useful for a variety of oceanological, biological, and fishery problems. In practice, utilizing these data has been problematic because they have not been compiled systematically into a single database accessible to the broad scientific community. Compiling the data is a challenging project for several reasons. The data collected in the 1920's-1950's are available only as manuscripts, many of which are written in Russian. Additionally, the methods of collection and sample processing have changed over time. Unless the methods were extremely well documented, it is very difficult to evaluate the comparability of the data collected, and to obtain a coherent dataset.

The goal of this work was to implement the information of the plankton communities of the Arctic Seas into the study of the ocean climatic system. To reach this goal we needed to solve the following problems:

- a) develop an electronic plankton database for the Barents and Kara Seas;
- b) document the variation in the plankton communities over periods of time.

As an information data source we used the observations of MMBI performed during 1953-1999, and data presented in Russian and U.S. publications during the period 1913-1964. These publications are available in the NOAA Central Library (Silver Spring, MD, USA.), the Slavic Library (Helsinki, Finland), the New York Public Library (New York, USA), and the Dartmouth College Library (Hanover, NH, USA).

The section *Photographs of Phytoplankton Living Cells* was prepared by P. Makarevich, Ph.D., based on materials collected in 1998-1999. The section *Methods of continuous observations* was prepared by A. Shavykin, Ph.D., based on the information acquired during cruise 72 of R/V *Dalnie Zelentsy*.

2. THE HISTORY OF HYDROBIOLOGICAL INVESTIGATIONS

Many countries have been carrying out hydrobiological investigations in the Barents Sea and the Kara Sea. The results of many Norwegian, English, German, and other scientific cruises are published in English and are accessible to the scientists of many countries, whereas the papers of Russian scientists have been published mainly in Russian, which makes them almost inaccessible to English readers. This section references papers of Russian scientists, giving special emphasis to the description of the annual cycle of plankton, which could serve as a basis for synthesis of

hydrobiological data quality control criteria. All publications cited in this section are presented in [references](#).

2.1 Phytoplankton

Barents Sea

The study of Barents Sea phytoplankton started in the 1870's ([Palibin](#), 1903-1906; [Deryugin](#), 1915; [Linko](#), 1907). Only factual material without any detailed analysis was accumulated during this first stage that came to an end by 1910.

At that time, scientists from Austria, England, Belgium, Germany, Denmark, Norway, and Sweden also began carrying out hydrobiological observations in the Barents Sea. During this stage 300-500 stations were sampled.

The early 20th century was characterized mostly by scientists studying the phytoplankton of the Barents Sea ([Manteifel](#), 1938; [Mosentsova](#), 1939; [Schultz, Wulf](#), 1929). At that time a great volume of data on species composition and distribution allowed for the first theoretical conclusions ([Kiselev](#), 1928; [Usachev](#), 1935). These papers resulted in a list of species of Arctic phytoplankton giving details of its taxonomic content. Studies were performed mostly by scientists of the Institute of the Northern Studies (Russia). Later the leadership transferred to the Polar Institute of Fisheries and Oceanography (PINRO). During that period, data from 20 expeditions (nearly 800 stations) were collected.

Valuable work begun in 1950-1960 by M. Roukhiyainen initiated the systematic study of phytoplankton at MMBI. Her papers ([Roukhiyainen](#), 1956, 1960, 1961a, 1962b, 1967) considered and discussed taxonomic composition, spatial distribution, dynamics of seasonal variability (the succession system) of phytoplankton communities and the coastal waters of the Kola Peninsula. Of extreme importance was that Roukhiyainen's study resulted in the compilation of the most complete taxonomic list of the Barents Sea phytoplankton ([Roukhiyainen](#), 1966a), and revealed general ecological mechanisms of the vertical distribution of the pelagic marine algae ([Roukhiyainen](#), 1966b).

Among all the other scientific papers published during the 1950's-1960's, emphasis should be given to the papers of N. Kashkin ([1963](#), [1964](#)) on the ecology and biogeography of several algae species, of [G. Barashkov](#) (1962) on the biochemical composition of phytoplankton cells, and of [M. Kamshilov](#) (1950) on the spatial distribution of several diatom species. The papers of A. Solovieva and her colleagues ([Solovieva](#), 1973, 1975, 1976; [Sokolova, Solovieva](#), 1971; [Vedernikov, Solovieva](#), 1972; [Sokolova](#), 1972; [Solovieva, Churbanova](#), 1980) published in the 1970's considered a wide range of problems on taxonomic composition, primary production, chlorophyll concentration, and the dynamics and spatial distribution of phytoplankton. In 1970-1980, a number of papers of Ryzhov gave high priority to the seasonal and geographic groups of phytoplankton, the effect of frontal zones on phytoplankton distribution, and on using phytoplankton species as bioindicators of various water masses in the Barents Sea ([Ryzhov](#), 1976, 1985, 1986; [Ryzhov, Syuzeva](#), 1974; [Ryzhov et al.](#), 1987).

In 1950-1980, more than 2,000 stations were sampled during 100 scientific cruises. In the second half of the 1980's another generation of hydrobiologists started their work in the MMBI, and opened a new stage of the Barents Sea phytoplankton study. Their investigations were focused on the examination of phytoplankton taxonomic composition ([Larionov](#), 1995; [Makarevich](#), 1996, 1997; [Makarevich, Larionov](#), 1992; [Druzhkov, Makarevich](#), 1999), spatial structure ([Druzhkov, Makarevich](#), 1989, 1996; [Larionov](#), 1992, 1993, 1997), productivity characteristics of phytoplankton

([Bobrov](#), 1985; [Kuznetsov et al.](#), 1994; [Savinov](#), 1997), the succession system, and the seasonal effect on phytocenosis ([Druzhkov, Makarevich](#), 1991; [Druzhkov, Makarevich.](#), 1996).

In the 1990's, the attention of scientists was focused mostly on the nearshore waters of Novaya Zemlya, Franz-Josef Land, Spitsbergen, and St. Ann Trough in the Arctic Ocean, Pechora and Kara Seas. Most of these regions had never been examined before. Cruises of nuclear icebreakers from the Barents to Kara Sea and back during winter allowed for the collection of phytoplankton data in ice covered regions.

During the 1990's, investigations of Barents Sea phytoplankton were carried out by the Polar Institute of Fisheries and Oceanology, Murmansk, the Institute of Oceanology, Moscow, the Botanical Institute, St. Petersburg, and the Murmansk Hydrometeorological Service.

From the 1980's until the present, more than 100 scientific cruises were carried out, collecting about 3,000 samples. In addition to almost all the Arctic Seas, the region of investigation covers the Norwegian Sea, the North Sea, and the White Sea, with thorough study of individual fjords and bays of both the Barents Sea and the Kara Sea. In Dal'nezemel'skaya Bay multi-year complex ecological monitoring was carried out ([Druzhkov et al.](#), 1990).

A list of publications of the Barents Sea phytoplankton and the stages of phytoplankton study of the Barents Sea by Russian scientists are presented in the "[Review by region](#)" and "[History references](#)" sections.

Kara Sea

The history of phytoplankton studies of the Kara Sea started from the scientific cruise of A. Nordensheld in 1875. The Kara Sea is distinguished by severe weather conditions. It is covered with ice for 8-9 months, and as a result during 1900-1980 the number of scientific cruises did not exceed several dozens. The Arctic scientific cruise of Moscow State University (MSU), conducted in 1974 focused on microflora of the northwest Kara Sea and resulted in 25 stations and 148 samples.

The present stage of studies, started in 1980, is focused on large-scale examinations of the Kara Sea phytoplankton. During this time the plankton studies are analyzing more aspects, expanding the territory of examination, and adding data from more years and seasons. The use of nuclear icebreakers for scientific purposes makes it possible to conduct scientific cruises in inaccessible regions of the Kara Sea in winter and spring. Examination of this region is conducted mainly by the MMBI ([Bobrov et al.](#), 1989, [Makarevich](#), 1993, 1994, 1995). Scientific work in the Kara Sea was also carried out by the Institute of Oceanology, Moscow ([Vedernikov et al.](#), 1994), the Arctic and Antarctic Research Institute, St. Petersburg, and some other institutions. About 20 scientific cruises, providing 1,200 samples, have already been conducted during this period. The major portion of this material is used in the present review.

2.2 Zooplankton

Barents Sea

The history of study of the Barents Sea zooplankton started with the Murmansk Scientific and Fisheries Expedition organized by N. Knipovich in 1898. The expedition functioned effectively until World War I (1914) and had accumulated annual material characterizing the zooplankton community development in different regions of the Barents Sea (mostly in its coastal zone and in the Kola Bay). The results obtained during that series of investigations were presented in monographs by [Linko](#) (1907) and [Deryugin](#) (1915). Zooplankton studies performed during the expeditions were targeted

at forecasting for fishermen, giving them information when "bait fish" were approaching the coast (mostly capelin were used as a "bait fish" during fishing of cod). The same data were used for forecasting migrations of white whale following shoals of cod along the coastline. There were 15-20 expeditions with zooplankton data, with 300-500 samples collected.

The next stage in the study of the Barents Sea zooplankton was targeted at providing data on the herring fishery (1930-1950). During this period, quantitative methods for collection and analysis of plankton were developed (Bogorov, [1927](#), [1933](#), [1934](#), [1938a, b](#), [1939a, b](#), [1940a](#)), and an observation network for the Barents Sea was developed. The paper of [Manteifel](#) (1941) can be considered as an encyclopedia of zooplankton study in the Barents Sea during that period.

In 1950, scheduled (annual) sampling of zooplankton was launched using standard methods and stations. Since 1953, the data on abundance of euphausiid crustaceans was collected ([Drobysheva](#), [1979](#), [1988](#), [1994](#); [Drobysheva, Nesterova](#), 1996). Since 1959, the material on zooplankton was accumulated ([Degtereva](#), 1979; [Degtereva, Nesterova](#), 1985; [Nesterova](#), 1990). Samples of euphausiids were taken in winter, and sampling of mesozooplankton was done twice a year (April-May, May-June). During the same period (1953-1959), a program of more detailed examination of zooplankton in the coastal zone of Murmansk ([Kamshylov et al.](#), 1958; [Zelikman, Kamshylov](#), 1960; [Zelikman](#), 1977) as well as in the southwest Barents Sea ([Zelikman](#), [1961a](#), [1966](#); [Myaemets, Veldre](#), 1964) was conducted. The focus was on the seasonal dynamics of plankton, the effect of "predator-prey" relationships, inter-year and intra-year variability in zooplankton abundance, and the biology of dominant species of zooplankton ([Kamshylov](#), [1951](#), [1952](#), [1955](#), [1958a, b](#); [Zelikman](#), [1958a, b](#), [1961a, b, c](#), [1964](#); [Petrovskaya](#), 1960; [Rzhepishevsky](#), [1958a, b](#), [1960a, b](#)). During this period, 60 to 80 expeditions were carried out and 3,000 to 4,000 zooplankton samples were collected.

In the history of Barents Sea zooplankton studies, the years, from 1960-1990 were valuable for providing information on food stocks for the larvae and juveniles of dominant commercial fishes ([Antipova et al.](#), 1974; [Degtereva](#), 1979; [Degtereva, Nesterova](#), 1985; [Nesterova](#), 1990). Moreover, data on zooplankton, very important for the capelin fishery forecast, were collected ([Degtereva et al.](#), 1990). In 1982-1993, the zooplankton state was examined annually in the Central Barents Sea ([Tereshchenko et al.](#), 1994), where similar surveys had not been previously performed.

In 1976-1984, scientists of the MMBI recommenced studies on the seasonal dynamics of zooplankton ([Fomin](#), [1978](#), [1991](#); [Fomin, Chirkova](#), 1988; [Druzhkov, Fomin](#), 1991), the life cycle of *Calanus finmarchicus* ([Fomin](#), 1995), and euphausiid crustaceans ([Timofeev](#), 1996a).

In the 1980's, samples of zooplankton were collected in the Kola Bay during environmental monitoring by the Murmansk Regional Hydrometeorological Service ([Glukhov et al.](#), 1992).

The number of expeditions during the period 1950-1990 were 90-100, with 10,000-15,000 samples collected.

In the history of investigations of the Barents Sea zooplankton, the 1990's are characterized, by large-scale sampling of zooplankton, and also by enhanced southeast Barents Sea monitoring ([Timofeev](#), 1992a; [Timofeev, Shirokolobova](#), 1996; [Makarevich, Druzhinina](#), 1997; [Stogov, Antsulevich](#), [1995](#), [1996](#)). The latter was associated with the detection of oil deposits in the Pechora Sea. Previously, as a result of the navaga fishery, zooplankton was studied in that region by the Arkhangel branch of the Polar Institute of Fishery and Oceanology ([Chuksina](#), 1971; [Zalesskikh](#), [1986](#), [1990](#)). During the same period, the MMBI continued investigations of zooplankton in the Kola Bay and the Motovsky Bay ([Ilin et al.](#), 1992; [Timofeev, Shirokolobova](#), 1993; [Druzhinina](#), 1997;

Timofeev, [1997a](#), [1998a](#)). Valuable data on zooplankton were provided by 1,000-2,000 samples collected during approximately 20 cruises.

Zooplankton studies were started in the 1990's by Norwegian scientists who primarily examined the fjords of the northern Norway, mostly in Balsfjord ([Hopkins](#), 1981). During 1980-1990, studies of zooplankton were moved to the central Barents Sea and focused mostly on two projects (1984-1989, *PRO MARE*; 1990-1994, *MARE NOR*). Their results were published in the materials of some symposia ([Sakshaug et al.](#), 1991; [Skjoldal et al.](#), 1995). Again, the study of zooplankton, both in Norway and Russia, was associated with the capelin and herring fishery.

Most of the data collected during 1950-1998 are generalized and presented in "[Review by Region](#)" and "[History references](#)" sections.

Norwegian scientists published on the topics:

- Zooplankton biomass dynamics in the central Barents Sea during 1979-1984 ([Rey et al.](#), 1987);
- Dynamics of the abundance of pelagic hyperiids during 1982-1993 ([Dalpadado et al.](#), 1994);
- Dynamics of abundance of the euphausiid crustaceans during 1982-1993 ([Dalpadado and Skjoldal](#), 1995).

Kara Sea

The first information on the Kara Sea zooplankton was presented in the reports of scientific and fisheries expeditions: the Russian Polar cruise of 1900-1903, and the Marine Polar cruise of 1910-1915 ([Linko](#), [1908](#), [1913](#); [Milekovsky](#), 1970; [Evgenov](#), [Kupetsky](#), 1985). The papers of that period emphasized studies on zooplankton species composition, and the biogeographical and ecological characteristics of dominant species. Almost 100 plankton samples were collected during these scientific cruises.

In 1920-1940, zooplankton sampling was carried out during most cruises, examining both the Kara Sea and the Laptev Sea. Zooplankton distribution and abundance was estimated, and the possibility of using zooplankton as an indicator of water masses of different origins was illustrated ([Rossolimo](#), 1927; [Jashnov](#), [1927](#), [1940](#); [Bernshtein](#), [1931](#), [1934](#); [Khmyznikova](#), [1931](#), [1935](#), 1936 a,b, 1946; [Bogorov](#), 1945; [Ponomareva](#), [1949](#), [1957](#)). In 1920-1940, 10 to 15 cruises examining zooplankton collected nearly 1,000 samples.

In 1950-1970, zooplankton of the open Kara Sea was poorly examined. Studies were conducted only in the fjord of the Ob Gulf, the Yenisey Bay and some other nearshore Kara Sea waters ([Greze](#), 1957; [Leshchinskaya](#), 1962; [Leleko](#), 1985; [Pirozhnikov](#), 1985; [Chislenko](#), [1972a](#), b). Of the most interest were the results of seasonal observations on zooplankton carried out in the Yenisey Bay and the Dixon Bay ([Chislenko](#), 1972 a, b).

In 1981 and 1982, the MMBI conducted two scientific cruises (300 samples total) in the southwestern Kara Sea. Information on zooplankton biomass distribution became available. Zooplankton biomass distribution was considered as a function of water column hydrological structure. Data on the distribution and abundance of dominant species were collected, and

characteristics of the life cycles of some species were analyzed (Timofeev, [1983](#), [1985](#), [1989a](#), [1990a](#), [1995](#); [Fomin et al.](#), 1984; [Fomin, Petrov](#), 1985; [Fomin](#), 1989a; [Zubova](#), 1990).

In 1990, an intensive study in the southwestern Kara Sea was launched, induced by exploration of oil and natural gas stocks detected in that region. The zooplankton study was conducted within the framework of complex ecological monitoring of the Kara Sea ecosystem and made available some new information on distribution, abundance, and biomass of zooplankton, and on the life cycles of the dominant species ([Novoselov](#) 1993; [Vinogradov et al.](#), 1994 a, b; [Vinogradov](#), 1995; [Scientific Report](#), 1996; [Vozzhynskaya et al.](#), 1997; [Druzhinina](#), 1998). In all, 10 scientific cruises on zooplankton studies were conducted and about 300 samples were collected.

***Calanus finmarchicus* in the Barents Sea**

A. Linko was the first Russian scientist to investigate the Barents Sea. He summarized plankton samples collected during the Murmansk scientific and commercial cruises during 1898-1906 (headed by Knipovich and Breifus), and presented them in a monograph ([Linko](#), 1907). Linko established that *C. finmarchicus*, a dominant species in the Barents Sea zooplankton, and could be used as an indicator of the waters of Atlantic origin. He pointed out that the vertical distribution of *C. finmarchicus* in the nearshore zones and open sea was determined by the water column vertical structure. These crustaceans were observed in the Barents Sea in a temperature range of +1.8 to +10.6 °C and salinity range of 32.12 to 35.08 pss.

Taxonomic analysis

[V. Jaschnov](#) (1939a) established that the region north of 75°N was inhabited by an endemic population of *C. finmarchicus*, unrelated genetically to the population dwelling in the southern Barents Sea. This conclusion stimulated to do more precise morphological studies. In 1955, V. Yashnov published his review on *Calanus* systematics, which described a new species, *C. glacialis*, distinct from *C. finmarchicus*. In the late 1950's, Yashnov ([1955](#), [1957](#), [1958](#)) published a set of papers scrutinizing basic aspects of the morphology, distribution, and systematics of *Calanus finmarchicus* s.l.

[Brodsky](#) ([1959](#), [1967](#) , [1972](#)) continued the morphological studies. He used more features than [Jaschnov](#) and drew the conclusion that *C. finmarchicus* and *C. glacialis* could not be considered as a separate species. He assumed that both were subspecies of the same species existing under various ecological conditions. [Brodsky](#) ([1972](#)) supposed that the complicated group of *C. finmarchicus* s.l. was in the stage of "incomplete species formation". By the early 1980's, after publication of [Frost's](#) paper ([Frost](#), 1974), [Jaschnov's](#) viewpoint became dominant and thus, both *C. finmarchicus* and *C. glacialis* were considered as "good species". These ideas were published in the latest monograph of K. [Brodsky](#) ([Brodsky et al.](#), 1983), where *C. finmarchicus*, *C. glacialis*, and *C. marshallae* were termed as "sibling species".

It should be mentioned that accurate species identification for *C. finmarchicus* and *C. glacialis* is still a serious problem, especially in the regions of joint occurrence of both species. The species were determined by size criteria ([Mumm](#), 1991) or by using the concept termed "mixed population" developed [Vinogradov et al.](#), ([1995](#), [1996](#)).

Despite the existing problems, it is important to give an accurate species identification for both *C. finmarchicus* and *C. glacialis*, otherwise there exists a risk of erroneous conclusions on the tendency of zooplankton community variation. For example, [S. Novoselov](#) (1993) made a comparison between zooplankton of the fjord Baidaratskaya Guba (the Kara Sea) for different time periods: 1945-1946 and 1991. The presence of a large number of *C. glacialis* in samples of 1991 and their absence in

the samples of 1945-1946 ([Ponomareva 1957](#)) allowed for the conclusion that cooling of the Arctic seas had caused substantial changes in zooplankton fauna. This assumption was based on the knowledge that *C. glacialis* related to Arctic species. The conclusion of S. Novoselov on the Arctic cooling in the early 1990's was in contradiction with the real situation as exactly during that period the Arctic warming occurred ([Carmack et al., 1997](#); [Morison et al., 1998](#)). This contradiction can be explained by an assumption that S. Novoselov did not take into account the fact that in 1945-1946 *C. glacialis* was not distinguished from composite species *C. finmarchicus s.l.*

Distribution

Until the 1950's, when V.Jaschnov ([1955](#), [1957](#), [1958](#)) demonstrated the composite character of the superspecies, *C. finmarchicus s.l.*, *Calanus* was identified as oceanic, open sea species widely distributed in the waters of the Northern Hemisphere ([Brodsky 1950](#)). After some revisions of the superspecies, the area of *C. finmarchicus* itself had been reduced sufficiently, and at present *Calanus* is usually considered as a boreal North Atlantic species abundant as well in the waters of the west Arctic basin, where *C. finmarchicus* is a good indicator of Atlantic waters ([Jaschnov 1955](#), [1958](#), [1961](#), [1966](#); [Abramova 1956](#); [Kashkin 1962](#); [Sushkina 1962](#); [Brodsky 1965](#); [Brodsky et al., 1983](#)).

Biomass, abundance, production

[Jaschnov \(1939b\)](#) determined that 84% of plankton biomass in the southwest Barents Sea consists of *Calanus*. The average biomass of *C. finmarchicus* comprised 24 ton/km²; with a minimum biomass value (8.5 ton/km²) in March and April, and a maximum in August. V. Yashnov estimated the annual production of *C. finmarchicus* to be 65 ton/km², and from the data of the PINRO (1950-1970) the crustacean production comprised 77.5 ton/km² ([Degtereva, Nesterova, 1985](#)).

In the nearshore waters, the impact of *Calanus* on zooplankton biomass comprises 60-64% ([Manteifel, 1939](#); [Fomin, 1978, 1995](#)) and during some years its impact can decrease to 13-34% ([Kamshilov et al., 1958](#)). Seasonal dynamics of *C. finmarchicus* biomass in the nearshore Barents Sea is characterized by the presence of one maximum that usually occurs in June and July ([Kamshilov et al., 1958](#); [Zelikman, Kamshilov, 1960](#); [Fomin, 1978, 1995](#)). The annual production of *C. finmarchicus* in the coastal zone is less than in the west Barents Sea and comprises 277.3 mg/m³ ([Kamshilov 1958a](#)).

Since the late 1950's the PINRO has been conducting annual spring and summer cruises during which the information on zooplankton, mostly of the western Barents Sea, is collected ([Degtereva, 1979](#); [Degtereva, Nesterova, 1989](#); [Degtereva et al., 1990](#)). Data on the number of eggs, nauplii, and copepodite stages of *C. finmarchicus* were presented at two transects conducted in 1959-1983 at North Cape - the Bear Island and the *Kola Meridian* section. The relationship between the number of *Calanus* nauplii and water temperature in spring was determined as follows:

$$Y = 774.6$$

$$X - 2035.2,$$

in which: **Y** is nauplii abundance in the Murman drift in the layer of 0-50 m (individuals/m³); **X** is temperature in the Murman drift in the layer of 0-50m (°C).

Life cycle

The first information on the life cycle of *C. finmarchicus* of the Barents Sea was obtained by Bogorov (1932, 1939b), Manteifel (1939, 1941), and Jaschnov (1939a). As a result, the *C. finmarchicus* life cycle can be presented as follows:

- During winter *C. finmarchicus* is at depth and concentrated in streams of the Nordkapp drift;
- In late March, *C. finmarchicus* rises to surface;
- April-May is a period of reproduction, starting mostly in the southwest and then distributing gradually to the east and northeast. Spawned specimens descend to deeper water layers, where they die or are used as a food by predators;
- In July-September, as a result of a water temperature rise in the upper layers (up to 6-7°C), *C. finmarchicus* descends to near-bottom layers. During this period it stops growing and changes its color (red becomes yellow and white). Starting from the second half of August, *C. finmarchicus* initiate their diurnal vertical migrations;
- In October-November *C. finmarchicus* is concentrated in deep-water parts of the Barents Sea and gradually stops its diurnal vertical migrations.

Such a life cycle suggests that over most of the Barents Sea, *C. finmarchicus* is monocyclic but during some years the second generation of *C. finmarchicus* comes from the West (specimens hatched in nearshore northwest Norwegian waters). The young of this generation do not spread farther East than 33°30' E. Appearance of *C. finmarchicus* specimens of the second generation in the southwest Barents Sea (Manteifel, 1939, 1941) can be explained by the ocean warming observed in the 1930's (Fu *et al.*, 1999).

In the 1950's, a study of the *C. finmarchicus* life cycle was conducted in the nearshore Barents Sea at a longitude of 36°E. It resulted in a conclusion on the bicyclic character of *Calanus* life cycle in that region: specimens of the spring generation lived about three months and specimens of summer and fall generations lived about 9 months (Kamshylov, 1952, 1955; Nesmelova, 1966). The study performed in 1964 did not confirm that conclusion (Nesmelova 1968). In 1976-1977, the next run of experiments justified the bicyclic character of *Calanus* life cycle (Fomin, 1978, 1995). In the latter case, spring reproduction of *C. finmarchicus* was established to be more extended in time and more intensive, whereas fall reproduction was relatively short-term and not intensive (Fomin, 1978, 1995). The study resulted in the conclusion that a monocyclic *Calanus* life cycle existed during cold years, and bicyclic *Calanus* life cycle existed during warm years (Zelikman, 1982). Moreover, a conclusion was made that the changes in reproduction of Barents Sea *C. finmarchicus* had resulted from variations of the annual temperature regime (Degtereva 1971, 1973, 1979; Degtereva *et al.*, 1990). M. Kamshylov (1955) had determined fertility of *C. finmarchicus* females: potential fertility was 2,000 eggs per female, the observed was between 1,000 and 1,500 eggs.

References

The literature list of research on the zooplankton of the Barents Sea is presented in the [references](#). The papers on distribution, biology, and ecology of euphausiid crustaceans are not included, as reviews on these crustaceans are presented in the papers of Drobysheva (1994) and Timofeev (1996a).

2.3 Zoobenthos

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Brief Historical Note (Barents Sea)

The initiation of Barents Sea benthos studies date back to the second half of 18th century, when Ozeretskovsky (1804) began gathering collections of marine animals in nearshore Murman waters. The systematic study of species composition and distribution of the bottom invertebrates started in the Barents Sea with the intensification of the fisheries in the last quarter of the 19th century. The study was focused on the effect of various environmental factors on the distribution of organisms.

The results of commercial and biological endeavors headed by Knipovich served as the scientific basis for the use of bioresources of the Barents Sea and the adjacent North Atlantic regions (Knipovich, 1902, 1904). For the first time, the collected zoological data provided valuable information for biogeographical zoning and showed the increase of the Atlantic origin species in the Kola Bay in 1893-1908 (Deryugin, 1915).

By 1915, more than 3,000 benthos stations were sampled, two thirds of these during Russian expeditions (Galkin, 1979).

In the period 1920-1925, a hypothesis on the possibility of shifting zoobenthic biogeographic boundaries in the Barents Sea, as a result of marine environment temperature, was verified (Tanasiichuk, 1927; Shorygin, 1928).

Since 1924, besides quantitative sampling equipment, grabs have been used for benthic studies, the methods for quantitative accounting of the bottom fauna have been refined, which allowed for comprehensive and detailed benthic surveys of the Barents Sea in the 1920's-1930's. A result of these surveys was the identification of patterns of the distribution of some zoobenthic taxonomic groups and the zoobenthic community (Brotskaya, Zenkevich, 1939; Filatova, 1938).

From 1921-1940, benthos collections were conducted at 5,000 stations, of which 4,800 were made by Russian investigators (Galkin, 1979). Figure 1 depicts the locations of data from 2,700 benthic stations collected in the period 1920-1940.

In the second half of the 1940's, thanks to the efforts of the PINRO and the Murman Biological Station (MBS), wide-scale benthos investigations were restored. The collected material made it possible to study littoral and sublittoral zone communities of the south and southeast Barents Sea, to determine patterns in the distribution of important taxonomic groups, and to analyze zoobenthos trophic structure as a whole (Kuznetsov, Matveeva, 1948; Turpaeva, 1948; Pergament, 1957; Zatsepin, 1962; Galkin, 1964; Zatsepin, Rittikh, 1968a, 1968b; Kuznetsov, 1970).

The samples of the bottom fauna collected in the 1940's-1950's along the *Kola Meridian* transect, served as a basis for the analysis of the bottom fauna multi-year fluctuations in that region (Nesis, 1960).

Since the early 1960's the "scuba diving method" of hydrobiological studies has been developed in Russia. This method was used for investigation of the bottom ecosystems of the upper sublittoral zone in the fjords and bays of the Murman region, the Frants-Josef Land and the Nonaya Zemlya areas (Propp, 1966; Pushkin, 1968; Shelf Biocenosis, 1977; Golikov, Averintsev, 1977). During the

same years the ecosystem approach in the zoobenthos investigations was targeted at the communities of the littoral zone, which made it possible to study not only the ecosystem structure but functionality. ([Streltsov et al.](#), 1974).

In 1968-1970, during a short time period and using one standard method. PINRO conducted a total survey of the Barents Sea, which revealed a substantial decrease in zoobenthos biomass in comparison with the 1920's-1930's ([Antipova](#), 1975).

On the whole, in the period 1945-1977, data from about 4,000 benthic stations were collected in the Barents Sea ([Galkin](#) 1979), of which approximately 3,400 stations were collected by Russian investigators.

In the 1980's, underwater photographic surveys and benthos collections were widely used by Russian geological institutions for conducting landscape and ecological shelf investigations ([Gurevich, Kazakov](#), 1989). Today the total number of benthic stations conducted with these methods is about several thousand. These data have limited utility due to the lack of detailed metadata. Simultaneously with photo surveys, the gathering of collections was usually conducted at stations using the same gear for both animals and sediments. The quality of photographs was only good for recognizing megabenthos and large-scale forms of macrobenthic epifauna.

The use of traditional methods of benthos collection with the combination of advanced underwater imaging techniques made it possible for the MMBI and the Zoological Institute (St. Petersburg) to study in detail the structure and functioning of the bottom ecosystems in the fjords of the Murman waters ([Zhukov](#), 1988; [Semenov](#), 1991; [Golikov et al.](#), 1993; Hydrobiological Study, 1994).

Zoobenthos investigations were jointly carried out by MMBI and PINRO, searching for and identifying populations of commercially important invertebrates (mostly crustaceans, mollusks, and echinoderms). In the 1970's and 1980's, the results of these studies served as a basis for the rational use of northern shrimps and Icelandic scallops in the Barents Sea ([Bryazgin](#), 1981; [Denisenko](#), 1988; [Denisenko, Bliznichenko](#), 1989; [Berenboim](#), 1992).

Along with the scientific and commercial study of some species, traditional investigations of zoobenthos was continued. However it was mostly targeted at detailed information on the background state of marine biota in the regions planned for intensification of economic activity or the regions under ecological protection ([Averintsev](#), 1993; [Luppova et al.](#), 1993; [Denisenko et al.](#), 1995; [Denisenko et al.](#), 1997). These studies were mostly conducted by expeditions of the MMBI, organized in cooperation with international scientists. During recent years, some attempts were made to restore regular observations along the *Kola Meridian* transect ([Denisenko](#), 1999).

During 1978-1999, the number of benthic stations sampled, excluding underwater surveys, was 2,000. The processing of the data collected during these expeditions has not been finalized, and as a result their analysis is far from complete.

Zoobenthos as an indicator of climate change

Many investigators believe that the macrozoobenthos is a good indicator of the environmental multi-year fluctuations, as most of the bottom animals are characterized by a sedentary mode of life and a long life cycle. One can consider [Deryugin](#) (1915) as the initiator of studies on multi-year fluctuations of the Barents Sea bottom fauna. In 1908-1909, in the Kola Bay, he detected several species unusual for that fjord. He related this phenomena to the fluctuation of the water temperature ([Deryugin](#), 1924).

Based on various zoobenthic taxonomic groups, [Shorygin](#) (1928), [Tanaisiichuk](#) (1927), [Cheremisina](#) (1948) *et al.* substantiated the possibility of shifting biogeographic boundaries in the Barents Sea as a result of temperature fluctuations. [Gurianova](#) (1947) related the occurrence of some Atlantic and Arctic species in the White Sea to multi-year hydrological fluctuations in the northeast Atlantic. [Balker](#) (1957, 1965) concluded that the benthos might react to Arctic seas warming or cooling with a lag time depending on the particular species. This was also confirmed by [Nesis](#) (1960), who analyzed multi-year fluctuations of boreal and Arctic species along the *Kolsky Meridian* as a function of hydrological regime. [Galkin](#) (1964, 1984, 1998) presented multi-year variations of mollusks as a function of the temperature regime.

The monitoring of the benthic community of the Barents Sea showed that some boreal species can react to environmental changes ([Cheremisina](#) 1948; [Nesis](#), 1960). This is due to variations in the population size at the habitat boundaries, not because of changes in the sizes and shapes of the habitats. ([Galkin](#), 1998).

Besides the analysis of zoobenthos biogeographic composition for studies of climatic tendency, there are some other effective and easily standardized methods that allow for accurate determination of temperature paleoreconstructions ([Zolotarev](#), 1989). Many marine animals have massive carbonate formations, which act as a recording structure. As with tree rings and fish scales, these carbonate formations record seasonal growth patterns ([Clark](#), 1974). Analysis of the recording structure allow for descriptions of environmental conditions.

A great number of long-lived benthic animals dwell in the Arctic seas; clams such as *Arctica islandica*, *Serripes groenlandicus*; horse mussel *Modiolus modiolus*; sea urchins of the genus *Strongylocentrotus*; brittle stars (*Ophiuroidea*); barnacles of the genus *Balanus*, and other animals that can live several dozens of years. Multiple samples of these dominant species collected in the Barents Sea during the last several centuries are present in the scientific institutions of Russia and other countries. Analysis of recording structures can be used for the documentation of climatic trends.

Problems of estimation of zoobenthos fluctuations

The analysis of fluctuations in zoobenthos functional characteristics is usually based on the results of quantitative collection techniques. In faunistic and biogeographic investigations, the use of these data is often hindered because the archive lists of species are frequently less comprehensive than present ones, as a result of the limited capabilities of the older sampling equipment, the greater experience of modern taxonomists, and the progressive development of taxonomy. Comparability of qualitative lists, despite their incompleteness, is often more effective as they present mostly large sized dominant forms, easily collected with simple sampling equipment. In addition, the probability of catching rare animals with the use of these tools is greater, as a result of covering more surface area for their collection. Key attention should be focused on these specimens as they can be good indicators of both warming and cooling ([Zenkevich](#), 1963).

Some problems in the estimation of zoobenthos fluctuations result from navigational errors and poor-quality collecting, washing, sorting, and storing procedures of the benthic samples. The errors in determination of the ship location without any control via sextant, for system of satellite navigation or system of radiolights during 2-3 days could be up to 20-30 miles. Thus a 20-30 mile deviation in localization of one or another population or community can result from navigational errors.

In the analysis of possible fluctuations of the Barents Sea bottom fauna resulting from climatic or other reasons, it is necessary to take into account the elements of collection and processing of benthic samples. These elements should be formalized and included in the data description report.

References

The list of papers on the Barents Sea zoobenthos are presented in [references](#).

3. PHOTOGRAPHS OF PHYTOPLANKTON OF THE ARCTIC SEAS

Identification of the phytoplankton taxonomic composition of a sample is the most critical stage of the data processing. As a result high level specialists are usually involved in this type of work. Ultimately, the quality of plankton data depend on the accuracy of species identification.

In practice, for the identification of the various species in biological communities, systematic specialists widely use taxonomic keys containing drawings and/or photographs of organisms. The accuracy of the species identification depends on accuracy of the representation in a photograph or drawing. The majority of the modern illustrative materials do not present the detail structure of microalgae cells. This disadvantage brings up the problem of getting more realistic images of phytoplankton cells, closest to the natural appearance.

Information on the Barents Sea and the Kara Sea phytoplankton is presented as an interactive collection of photographs of 50 phytoplankton color images in JPEG format with a resolution of 75 dpi.

[Click on](#) a photo shows a zoomed picture of live cells of microalgae, a drawing from the taxonomic keys, and a classification table. The table has scientific names and synonyms. Each taxon is provided with its biomass value, its ecological and phytogeographical characteristics, as well as its corresponding ITIS (Integrated Taxonomic Information System) TSN (Taxonomic Serial Number) and NODC (National Oceanographic Data Center) code. Biomass (cell weight) was calculated through the method of geometrical shape similarity for each species (Koltsova, 1970; Kozhova *et al.*, 1978; Plinski *et al.*, 1984).

Phytoplankton filming

Algae samples were collected throughout the Barents Sea using standard methods ([Manual](#), 1980). The samples were concentrated by the usual method of reverse filtering ([Dodon and Thomas](#), 1964; [Sukhanova](#), 1983) through specialized nuclepore filters (produced in the Integrated Institute of Nuclear Research, Dubna) with a pore size of 1.0-2.0 μm . It was necessary to avoid deformation and breakage of phytoplankton cells resulting from preserving or storing live samples. The samples were preserved in a weak solution (Lougol, 1% formaldehyde) or were placed and stored in a thermos. In May-June, water samples with live materials were collected from points located in the Kola Bay. In August they were collected in the fjord Dalnezelskaya (area of biological station of the MMBI in the settlement Dalnie Zelentsy, 69°07'08"N, 36°05'08"E). Slightly preserved algological material were collected from the southern Barents Sea during July cruise of the *Viktor Kingisepp*. Only phytoplankton collected in 1998 have been used for photography.

The experiment targeted natural microalgae images, which rejected the use of color shading, outline tracing, or emphasizing any cell segment. Shading was applied only as a background in case of thick mud/severe dirt or the presence of other cells within the exposure. Due to object size, the filming was performed at magnifications from 80^x to 800^x.

4. DATA.

4.1. Data Characteristics

Inventory

This atlas contains the data from 158 cruises carried out in the Barents Sea, the Kara Sea, and the White Sea from 1913-1999. The atlas includes the White Sea in order to not separate cruises which started in the White Sea and were completed in the Barents Sea. One of the 158 cruises was conducted in the Barents Sea by the American research vessel *Tanner* in 1963 (CD-ROM, file 31tn6370.csv). Another cruise was carried out in the Barents Sea and Arctic Basin by the German research icebreaker *Polarstern* in 1996 (CD-ROM, file 06aq9670.csv), and the other cruises were carried out by Russian vessels. In addition, the atlas includes phytoplankton data collected in two bays of the Kola Peninsula during 1968-1989. In each bay, measurements were taken at the same station with a frequency of 2-10 measurements per month.

The hydrobiological database is characterized by:

Period of observations: 1913-1999

Total number of cruises: 158

Total number of stations: 4,608 ([Data distribution plot](#))

Physical and hydrochemical data: 3,096 ([Data distribution plot](#))

Temperature: 3,046 stations

Salinity: 2,947 stations

Oxygen: 1,998 stations

pH: 1,418 stations

Alkalinity: 1,141 stations

Ammonium (NH₄): 17 stations

Nitrites: 1,773 stations

Nitrates: 1,794 stations

Total Nitrogen: 152 stations

Phosphate: 1,957 stations

Total Phosphorus: 17 stations

Silicate (SiO₄): 439 stations

Chlorophyll: 386 stations ([Data distribution plot](#))

Primary Productivity: 76 stations

Phytoplankton: 1,539 stations and 4,275 samples ([Data distribution plot](#))

Zooplankton: 2,475 stations and 9,081 samples ([Data distribution plot](#))

The [inventory table](#) contains data distribution plots, information, and data for each cruise. Original data are presented on the CD-ROM in the folder DATA\PRIMARY, in a format adjusted for use of electronic tables.

Sources

The archive created by the Murmansk Marine Biological Institute (1952-1999) is a basic data source for this atlas. It includes the data collected by the investigators of the Murmansk biological station in 1920-1940. The Central Library of NOAA (Silver Spring, MD, USA), the Slavic Library (Helsinki, Finland), Dartmouth College Library (Hanover, NH, USA), and the Slavonic and Baltic Division of the New York Public Library (New York, NY, USA) are also sources of hydrobiological data collected from 1913-1964.

Format

The data format is based on a data format developed by the Ocean Climate Laboratory (National Oceanographic Data Center/ NOAA, USA). It is of a block structure, with each block clearly defined by a keyword, containing data identified by additional keywords. Let us consider the blocks and their components.

Each data file starts with the block *Cruiseinfo* which presents cruise information. This block incorporates the country name, vessel name, and a list of the investigators performing the measurements.

The *Station* block contains station coordinates, date and time. This block is obligatory for each station. Its word order is fixed.

The *Station* block is followed by the *Type* blocks, which contain information on the results of measurements of meteorological (*Type, Meteo*), hydrophysical (*Type, Hydrology*), and biological (*Type, Plankton*) parameters.

The *Header* block presents information on the methods of measurements and observational conditions. For example, the block *Type, Headers plankton, Phytoplankton* contains the information on the type of the instrument used for sampling phytoplankton.

On the CD-ROM in the section DATA\FORMAT, the enumerations of modes, keywords and tolerance limits of parameters are presented. The block organizational structure of this data format allows for the easy addition of new types of data without modifying the structure of existing files. For example, on the CD-ROM in the file DATA\PRIMARY\ 90BY9270.csv, the data of the 67th cruise of the R/V *Dalnie Zelentsy* are presented. On this cruise, benthic samples were also collected and added to the data. This demonstrates that it is possible to add benthic data to the existing data format.

4.2. Discrete Measurements

Hydrology, hydrochemistry

The measurements of physical and hydrochemical parameters of sea water have been carried out by MMBI according to present manuals and method of applications.

- Water temperature was determined by deep-water reversing thermometers (Manual, 1977).
- Salinity was measured by salinometer GM-65, which was calibrated using standard synthetic sea water (Manual, 1977; International, 1966).
- Sea water samples were collected by bathymeters BM-48 (Manual, 1977).
- Dissolved oxygen was obtained by iodometric titration, by the method of Winkler (Chernyakova, 1978).
- Active pH reaction was determined through potentiometric method using potentiometers "pH-121" and "pH-340" with a glass electrode (Bogoyavlensky, Ivanenkov, 1978).
- Phosphate (PO₄) was determined by the method of Murphy and Riley (1962) using electric colorimeter KFK-2MP (Sapozhnikov, 1978a).
- Total phosphorus was determined by the method of Murphy and Riley (1962) (Sapozhnikov, 1978b).
- Nitrite (NO₂) was determined by the method of Griss-Ilosway with spectrophotometric measurement of concentrations using electric calorimeter KFK-2MP (Konnov 1978).
- Nitrate (NO₃) was determined by the method of Wood-Richards-Armstrong (Wood et al., 1967) using a spectrophotometric cap on electrophotocalorimeter KFK-2MP (Sapozhnikov et al., 1978).
- Total nitrogen was determined by the method of a sample burning in an autoclave with a dry reagent potassium persulphate in alkaline medium with subsequent nitrate determination (Sapozhnikov, Sokolova, 1978).
- Silicates were determined by the method of Mulin-Railly modified by Strickland and Parsons from blue silicon and molybdenum complex using electrophotocolorimeter KFK-2MP with a spectrophotometric cap (Gusarova, 1978).
- Primary production was determined by the method of Steemann - Nielsen (1952). Samples were collected in 10-liter plastic bathymeters at horizons of 0, 5, 10, 20, 30, 50m. Samples from each horizon were poured into two transparent and two dark 250 ml bottles with the addition of 1 ml NaHCO₃ (isotope C¹⁴) of 2 microcurie activity. Then, the samples were suspended at depths corresponding to the depth of collection. The samples were exposed for 4 to 5 hours, and after exposure the bottle content was filtered through membrane filters (*Millipore* of NA type with a pore size of 0.45 micron). The filters were cleaned by sea water and dried in a dessicator with freshly calcinated silica gel, for 24 hours. The activity of sediments on filters was measured by equipment with a meter BFL-25.

- Chlorophyll **a, b, and c** determination was carried out using the method of [Richards and Thompson](#) (1952). Sampling was carried out using 10-liter plastic bothymeters. Water samples (of no less than 2 liter) were filtered through "Whatman" glass fiber filters under a pressure of 0.1-0.2 atmosphere. After the process of filtration, the filters were placed into a dessicator with freshly calcinated silica gel and were refrigerated for 12 hours, until completely dried. The dry filters were placed into centrifuge test tubes, with the addition of 8 ml of fresh 90% acetone solution, for 2 hours. The extract was then centrifuged for 10 minutes, at a speed of 5,000 revolutions per minute, and poured into measuring bottles. Later the extract was placed into 5 ml cells and processed using a scanning spectrophotometer SPECORD UV-VIS (Carl Zeiss, JENA). Chlorophyll concentration was calculated from the formula of [Jeffrey and Humphrey](#) (1975).

Phytoplankton

Phytoplankton sampling was carried out with plankton nets (usually by Juday plankton net) or by plastic bothymeters of different capacity (2-10 l) at standard hydrological horizons ([Manual](#), 1977; [Manual](#), 1980). Since 1960 only bothymeters have been used for phytoplankton sampling. Sample concentration utilized two methods: the settlement method ([Sukhanova](#), 1983) or the method of reverse filtering ([Dodgson, Thomas](#), 1964; [Sukhanova](#), 1983). The method of reverse filtering has been used by the MMBI since 1986.

The settlement method of sample concentration is carried out as follows: preserved 1 liter samples are motionless and allowed to settle for no less than 10 days. After sedimentation of cells is complete, the sample is slowly (drop by drop) poured off until its volume reduces to 30-50 ml. For this purpose, a glass tube-syphon is used with an extended end that is bent 2-3 cm upwards.

The method of reverse filtering is based on the use of a special filtering cell provided with nuclepore filters with a pore size of 1.0-2.0 μm ([Makarevich, Druzhkov](#), 1989). This allows for filtering of sea water up to 10 liters, depending on season and plankton abundance. When using this method, concentration of samples is caused by pressure resulting from the difference between a height at which the filtering equipment is placed and a level at which the bottle with sample is kept.

Phytoplankton processing was carried out according to the following scheme: phytoplankton samples were divided into three subsamples. A Najotte glass counting cell with a capacity of 0.05 ml and 1 cm^2 dimension ([Fedorov](#), 1979; [Manual](#), 1980) was used, with light microscope (100-400 \times), to determine the taxonomic composition and number of cells in the sample. From the results of these three experiments species content and abundance for each species for phytoplankton sample, as a whole, were determined ([Sukhanova](#), 1983).

During the last years the MMBI utilized Lougol solution as preservative. Water samples of 200 ml were preserved in Lougol's solution (concentration 1%). The samples were rapidly poured into a bottle containing a portion of preservative. After 3 days samples were concentrated until 20-30 ml of liquid remained, and were preserved by neutral formalin with a final concentration of 2 percent ([Mikheeva](#), 1989). The counting of microalgae and heterotrophic flagellates exceeding 10 μm , and their identifications were carried out in a counting chamber of original construction ([Druzhkov, Makarevich](#), 1988; [Druzhkov](#), 1989) using a light microscope with a magnification of 200 \times .

Microalgae and heterotrophic flagellates exceeding 10 µm were examined in the same chamber with a magnification of 400^x (usually 1/3 of subprobe volume). Large and less numerous phytoplankton samples were calculated full sample volume in the *Bogorov* chamber at a magnification of 32^x.

The phytoplankton abundance per unit volume (N) was calculated from the mean of cells in one sample using the following formula:

$$N = N_k \cdot V_{ck} / V_n \cdot V_k$$

in which:

N_k - is the number of phytoplankton cells in the counting chamber;

V_k - is the capacity of counting chamber;

V_{ck} - is a volume of concentrated sample;

V_n - is a sample volume.

Microalgae biomass was calculated using tables of average cell volumes and weights compiled for the Barents Sea ([Solovieva, 1976](#); [Makarevich et al., 1991, 1993](#)). In most cases measurements of the cell volume parameters were measured using a micrometer (magnification was 400^x, measurement accuracy was up to 3 µm). All cell volumes were calculated using the method of geometrical similarity of figures as average values of individual volumes ([Clarke et al., 1987](#)) using recommended approximation models for simple geometric bodies ([Koltsova, 1970](#); [Makarova, Pichkily, 1970](#); [Recommendations, 1979](#); [Kozhova et al., 1978](#); [Plinski et al., 1984](#)).

Zooplankton

Zooplankton were sampled and analyzed according to standard procedures used in Russia ([Bogorov, 1927, 1934, 1938, 1940](#)). For the sampling of zooplankton, the large model of the Juday plankton net was used at standard water depths (bottom-100, 100-75, 75-50, 50-25, 25-10 and 10-0 meters). Towing on all layers was carried out from the bottom to the surface only at some stations. The Juday net has an opening diameter 37 cm, and a mesh size of 168 µm. The sample was poured into prepared bottles and preserved with 4% neutral formalin.

Sample processing included two successive operations: first, determining the sample wet weight, and second, quantitative sample processing (identification and calculation of each species, taking into account life stage and size groups). Sample wet weight was determined using a torsion balance with an accuracy of up to 0.1 mg. The counting carried out by Hensen ([Manual, 1980](#)) calculational method using the Bogorov's counting chamber. If the number of species in the counting chamber was insufficient, all species were analyzed. In other cases, large specimens were taken out of the sample, identified, calculated, and measured separately. The sample remainder was concentrated to a volume of 50-100 ml (or higher, depending on plankton abundance). Then the sample was carefully mixed and a subsample was collected with a stamp pipette (1, 2 or 5 ml depending on the capacity of the stamp pipette) and then analyzed in the Bogorov's counting chamber using a binocular microscope. Two or three similar subsamples were collected from each sample. The difference of values between subsamples should not exceeded 30%, otherwise the number of samples was increased. The obtained results were averaged, and the sample was analyzed as a whole for identification and counting of rare species.

4.3. Continuous Measurements

In June 1993, during the 72nd cruise of the R/V *Dalnie Zelentsy*, continuous measurements of temperature, salinity, and chlorophyll-*a* were conducted in the surface layer of the region between 68°-74°N and 34°-46°E (CD-ROM, file DATA\PRIMARY\90BY936s.csv). A two-channel fluorometer (KVANT-7) was utilized for chlorophyll-*a* measurements. Instrument EPT-65 was used for sea water temperature and salinity measurements. Coordinates were determined using a GPS navigational system (RAYSTAR-900). Section DOC\SERIAL presented on the accompanying CD-ROM illustrates detailed technology for measurements and calibrating curves.

4.4. Lists of Plankton Species

For HTML version of the atlas, a searchable table of 527 taxonomic names of phytoplankton in alphabetic order was created. Also all phytoplankton were split into 8 taxonomic groups (*Bacillariophyta*, *Chlorophyta*, *Chrysophyta*, *Cryptophyta*, *Dinophyta*, *Euglenophyta*, *Haptophyta*, *Prasinophyta*) and organized as a systematic search table. The table has scientific names and synonyms. Each taxon is provided with its biomass value, its (EG)- ecological and (PG)- phytogeographical characteristics, as well as its corresponding ITIS (Integrated Taxonomic Information System) TSN (Taxonomic Serial Number) and NODC (National Oceanographic Data Center) code. A weight was computed by the method of geometrical similarity of figures (Koltsova, 1970; Kozhova et al., 1978; Plinski et al., 1984). PG - phytogeographic characteristics (A = arctoboreal species; B = boreal species; C = cosmopolitan species); EG - ecological characteristics (O = oceanic forms; N = neritic forms; P = panthalassic forms; M = microphytobenthos; F = freshwater forms). The total list of phytoplankton species in original format is on the CD-ROM, file DATA\TAXA\TAXPHYTO.XLS.

The zooplankton list in alphabetic order for the Barents and Kara Seas includes approximately 282 taxa. The searchable table is of the following structure: zooplankton are split into groups characterized by taxonomic relationships (*Coelenterata*, *Ctenophora*, *Rotatoria*, *Crustacea*, *Gastropoda*, *Chaetognatha*, *Appendicularia*, and benthic invertebrate larvae).

The total zooplankton species list is on the CD-ROM in the file DATA\TAXA\TAX_ZOO.XLS.

5. QUALITY CONTROL OF HYDROBIOLOGICAL DATA

5.1. Physical and hydrochemical data

Quality control of physical, hydrochemical, and meteorological data was conducted using the method described by Conkright, et al. (1998), Matishov et al., 1998.

In order to process data for the period 1952-1959 it was necessary to combine the biological and physical data. The primary information was presented in the form of two arrays each with a different data structure. The first array consisted of physical data grouped by cruises. The name of the research vessel and geographic coordinates for each station were present for each cruise. The second array consisted of weight characteristics for the phytoplankton samples. The number of the station and sample location was specified for each sample. Both arrays were then merged, based on table defining relationships between the station numbers and coordinates of stations.

5.2. Biological data

One of the necessary quality control stages in processing hydrobiological data consists of checking a parameter value against permissible ranges. Reference materials are available presenting the range of measurements of oceanographic characteristics for different Barents Sea regions (Matishov et al., 1998). We are not aware of papers presenting the information on permissible range of plankton data

for different regions of the Barents Sea. The present section considers some generalities of the plankton population, based on which criteria for hydrobiological data control were generated.

Phytoplankton

The papers of [Druzhkov and Makarevich \(1991\)](#), [Druzhkov et al. \(1997\)](#), [Roukhiyainen \(1967\)](#), [Ryzhov \(1985\)](#), [Druzhkov and Makarevich \(1999\)](#) discuss the generalized scheme for phytoplankton community functioning (succession scheme) in the southern the Barents Sea. The structure of succession systems of the other Barents Sea regions, in general, is similar to the structure considered in the following section. The difference consists in timing of the phytoplankton bloom and its duration.

Spring. Middle of March-Beginning of June

In the spring, phytoplankton activity is characterized by the appearance of early spring diatoms in the coastal pelagic zone in the second half of May. *Thalassiosira hyalina* (Grun.) Gran, *T. cf.gravida* Cl., *Navicula pelagica* Cl., *N. septentrionalis* (Grun.) Gran, *Nitzschia grunowii* Hasle, *Amphora hyperborea* (Grun.) are the main constituents in the composition of the early spring diatoms complex that replicates each year. At this time, cell numbers are low and can vary, depending on species composition, from tens to several hundred cells per liter. The biomass of phytoplankton reaches a maximum in the second part of April. The peak of biomass itself is a short-term phenomenon, and the biomass maximum is present only for several days. During the early blooming season, phytoplankton abundance can vary between several hundred thousands to 2 million cells/liter (from unpublished data of M. Roukhiyainen it can vary up to 12 million cells/liter), and biomass can vary between 1 and 3 mg/liter. During this period, the concentration of greatest biomass is observed within the 0-10m layer. *Thalassiosira cf.gravida* Cl., *T. nordenskioldii* Cl., *Chaetoceros socialis* Laud., *C. furcellatus* Bail., *Navicula vanhoeffenii* Gran. are species forming the first peak of the Barents Sea phytoplankton bloom. During some years, this period is characterized by an intensive development of *Phaeocystis pouchetii* (Hariot) Lagerh., which can attain great values in its abundance and biomass, and participate actively in the formation of the spring maximum (the documented peak abundance and biomass were 8 million cells/liter and 1.7 mg/liter, respectively; [Druzhkov and Makarevich, 1989](#)).

Summer. End of June-End of August

The significant changes in the phytoplankton community occurred during the summer season. The number of diatoms sharply decrease. At the same time a sporadic increase of dinoflagellates is observed though their presence in the pelagic zone. Pronounced replacement of the Arctic boreal forms by cosmopolitan ones, and neritic forms by panthalassic and oceanic ones, are observed. During this season, the dominant group is basically comprised of the diatoms *Skeletonema costatum* (Grev.) Cl., *Leptocylindrus danicus* Cl., *L. minimus* Gran, *Chaetoceros decipiens* Cl., *C. lacinosus* Schutt, and dinoflagellate algae of the genus *Protoperidinium*. The maximum abundance of the pelagic algae cells does not exceed 20,000 per liter.

Fall. Middle of September-End of November

The maximum microalgae cell concentration is in the 0-25 m depth layer. The dominant components of the microalgae community are: diatoms of the genus *Chaetoceros* and dinoflagellates of the genus *Ceratium*, *Dinophysis*, *Protoperidinium*. During this period, cell abundance usually does not exceed 2,000 per liter. By early December, the abundance of cells is less than 1,000 per liter, and

biomass is less than 5 µkg/liter. In the pelagic zone dinoflagellates are dominant, and nanoplanktonic flagellates remain as the only active group of photosynthesizing organisms.

Winter. Beginning of November-End of March

Throughout the entire winter, the phytoplanktonic community is in a resting stage, *i.e.* its vital functions are almost inactive. In the pelagic zone, phytoplankton are represented by large oceanic dinoflagellates of cosmopolitan and Arctic boreal origin. The dominant component consist of *Ceratium longipes* (Bail.) Gran, *C. tripos* (O.Müll.) Nizsch, *Dinophysis norvegica* Clap. Et. Lachm., *Protoperidinium depressum* (Bail.,) Balech.

The table below presents quantitative characteristics of the annual development cycle of Barents Sea phytoplankton. This table determines the range of permissible values for the dominant phytoplankton species for the southern Barents Sea.

Barents Sea: quantitative characteristics of the phytoplankton annual cycle

Region: 74°N - Kola Peninsula

PG - phytogeographic characteristics (A = arctoboreal species; B = boreal species; C = cosmopolitan species);

EG - ecological characteristics (O = oceanic forms; N = neritic forms; P = panthalassic forms; M = microphytobenthos; F = freshwater forms).

Time	Depth of the habitat (m)	Ecological structure	Dominant taxa	Total count (cells/liter)
Spring				
Middle of March - Beginning of June	0-70	N > O+P+M+F A > B+C	<i>Phaeocystis pouchetii</i> <i>Thalassiosira grvida</i> <i>T. nordenskioldii</i> <i>Navicula</i> <i>Nitzschia grunowii</i> <i>Chaetoceros socialis</i>	100,000 - 12,000,000
Summer				

End of June - End of August	0-50	C \diamond A+B N \diamond P+O	<i>Leptocylindrus danicus</i> <i>L. minimus</i> <i>Chaetoceros decipiens</i> <i>C. laciniosus</i> <i>Protoperidinium Skeletonema costatum</i>	>100,000
Fall				
Middle of September - End of November	0-25	C > A; C > B O \diamond P; O \diamond N	<i>Chaetoceros</i> <i>Ceratium</i> <i>Dinophysis</i> <i>Protoperidinium</i>	> 2,000
Winter				
Beginning of November - End of March	0-bottom	O > N O > P; C+A > B	<i>Ceratium</i> <i>Protoperidinium</i>	10 - 500

Zooplankton

Determining a permissible range of variation is an important element of the quality control of hydrobiological data. The availability of 9,000 zooplankton samples in the database makes it possible to consider the relationship between abundance and number of species.

The figure below presents a graph illustrating the relationship between zooplankton number of species per m³ and their abundances per m³ for the Barents Sea and the Kara Sea (holoplankton only). The observed relationship is in good agreement with the theoretical curves widely used in ecology ([Magurran, 1988](#)).

Number of species (#/m³)	1	2-3	4-5	6-10	11-15	16-20	>20
Minimum abundance (#/m ³)	0.1	1	3	10	12	14	>15
Average abundance (#/m ³)	1-75	76-200	201-260	261-350	351-400	401-450	>450

Maximum abundance (#/m3)	150	350	1500	2500	2550	2600	>2600
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6. DATA VISUALIZATION

This chapter corresponds to the [Marine Environment](#) section of Web version of the Atlas.

6.1. Physical Characteristics

The processes of ice melting, water mass vertical structure, and thermal characteristics of the marine environment determine the dynamics of the Kara Sea and the Barents Sea plankton development. The present section provides the information on ice edge climatology, water vertical structure, and temperature and salinity fields.

Ice

the web version of the Atlas contains [maps](#) characterizing the mean ice edge position for the middle of each month ([Eastern-Western Arctic Sea Ice Climatology, 1984](#)).

Temperature and Salinity

The objective data analysis procedure used for this work generally corresponds to the scheme suggested by Barnes (1973) and the methods for calculating the data spatial distribution and map plotting used by [Levitus and Boyer](#) (1994). Additions to the algorithm have been made to account for the anisotropic structure of oceanographic fields in the Barents and Kara Seas

For the calculation of temperature distribution fields at the surface of the Barents and Kara Seas, in the summer a correlation radius of 250 km is used and in the winter this radius was reduced to 180 km. At a depth of 100 m the radius is 35-40% less than at the surface. The values of temperature and salinity are calculated for the grid of 20 x 20 km for three time intervals: 1920-1940, 1950-1960, and 1980-1990. The choice of these periods is determined by the availability of plankton data, water temperature, and salinity data for these years. For each time interval the following [searchable maps](#) were constructed:

Barents Sea - temperature and salinity, surface and depth 100 m, winter and summer;

Kara Sea - temperature and salinity, surface and depth 100 m, summer.

Winter = {January, February, March, April}.

Summer = {July, August, September}.

The oceanographic data used for mapping of temperature and salinity were obtained from the database of the WDC (Silver Spring, MD, USA) and MMBI.

Vertical Structure of the Barents Sea

A great number of papers are concerned with the problems of the vertical structure of the Barents Sea. It is established that, in winter, the water temperature **T**(°C) and density **d** (kg/m³) vary insignificantly with depth. In summer, in the layer of 30-80 m, sharp **T** and **d** gradients are observed

as a result of the temperature rise in the surface water layer. The availability of temperature and salinity monthly climatic fields for the Barents Sea ([Matishov et al., 1998](#)) makes it possible to document the annual cycle of **T** and **d** variations in the vertical plane. The algorithm of computation of the vertical gradients **T** and **d** is comprised of several stages.

a) The climatic density fields were calculated for January, February, ..., December, based on the monthly climatic temperature and salinity fields on a 10' x 30' grid.

b) The fields characterizing the difference in the values of temperature (ΔT) and density (Δd) at the horizons of 0 and 100 meters were calculated for each month:

$$\Delta T = T_{0m} - T_{100m} ; \quad \Delta d = d_{0m} - d_{100m}$$

c) The method of the objective analysis was used for mapping the ΔT , and Δd values.

Using the HTML information system, the CD-ROM presents [graphs and maps](#) characterizing the annual cycle of variation of ΔT and Δd values. The obtained results distinguish two time periods with the stable temperature and density structures: the winter and summer regimes. The duration of the winter regime is from January until April. During this period the values of ΔT and Δd reach an annual minimum. The duration of the summer regime is from July until September. During this period, the values of ΔT and Δd reach an annual maximum.

6.2. Biological Characteristics

The distribution fields (searchable maps) of abundance, biomass, and number of [phyto](#) and [zooplankton](#) species are used to describe the state of the planktonic communities. Coefficients of biodiversity, calculated based up on the above mentioned characteristics, are used in hydrobiological studies. These coefficients characterize the level of diversity in the plankton community. The rise in the biodiversity level is induced by additional energy in the ecosystem ([Legendre and Demers, 1985](#)), the source of which is determined by the regional features of the investigated ocean region. For example, in the Kara Sea it can be the flux of the Atlantic waters coming from north or the discharge of the Ob or Yenisey rivers. In the Barents Sea it can also be the flux of Atlantic waters coming from the Norwegian Sea or an influx of fresh water resulting from ice melting ([Timofeev 1988](#)). Thus, the fields of distribution of the plankton characteristics can be used not only as an indicator of the state of the plankton community, but also as a tool of study for water masses of the Barents and Kara Seas.

The Glisson coefficient is used as biodiversity coefficient (**Kgl**):

$$Kgl = (Nt-1) / \log(Ni)$$

in which:

Ni - number of individuals,

Nt - number of species in the sample.

The CD-ROM database contains information on zooplankton collected from the vessel *Nerpa* in 1936 and from the R/V *Dalnie Zelentsy* in 1981. In 1981, zooplankton abundance was determined in ind./m³. For comparison of the data obtained during these cruises, we use the same units as zooplankton abundance of 1936 using the following scales ([Drobysheva et al., 1986](#)):

Rare = 1-10 ind./m³

Common = 11-100 ind./m³

Abundant = 101-1,000 ind./m³

Very abundant > 1,000 ind./m³

The Marine Environment section presents fields of distributions of plankton characteristics in the vertical and horizontal planes.

Searchable maps demonstrate winter variation of phytoplankton characteristics, along the route of nuclear icebreakers from the Barents Sea to the Kara Sea and on their way home. These graphs exhibit the phytoplankton state in regions previously inaccessible for hydrobiological studies during winter.

7. CHANGES OF THE PLANKTON COMMUNITY

This Section is targeted at illustrating the database's capability to document changes in the plankton communities of the Barents and Kara Seas. Two data groups have been selected: (i) data collected during the period of sharp Arctic warming of 1920-1930 (Fu et al., 1999); (ii) data collected since 1950, during the period of more severe climatic conditions (Fu et al., 1999). Searchable figures available from " Plankton Community Changes" section.

Phytoplankton. Barents Sea. Section *Kola Meridian*: 1921 vs. 1997

Data: a) cruise of R/V *Sokolitsa*, May 1921, 5 stations, 16 samples along the section *Kola Meridian*;
b) cruise of R/V *Pomor*, May 1997, 7 stations, 35 samples along the section *Kola Meridian*.

Characteristics: Phytoplankton abundance, biodiversity coefficient (the Glisson coefficient), percent of Arctic and oceanic species. The graphs display substantial differences in the phytoplankton structure between 1921 and 1997.

Conclusion: Each of the analyzed characteristics shows that the conditions for phytoplankton development were more favorable in May 1921 than in May 1997.

Phytoplankton. Barents Sea: 1921-1957-1985-1997

Data: Data processing covers the data collected during the April - May of 1921, 1957, 1985, and 1997 within the region with a 15-mile radius and a central point with coordinates 71°N, 33°30'E. 37 samples from 8 stations were collected.

Characteristics: Spring season mean values of biodiversity coefficient (the Glisson coefficient) and phytoplankton cell abundance are calculated in m² for the years 1921, 1957, 1985, and 1997. This figure shows that values were greater in 1921 than in the years 1957, 1985, and 1997.

Conclusion: The conditions for phytoplankton growth in spring of 1921 were more favorable than in similar periods of 1957, 1985, and 1997.

Zooplankton. Kara Sea: 1936 vs. 1981

Data: a) cruise of the R/V *Nerpa*, August 1936, 38 stations, 143 samples in the Kara Sea; b) cruise of the R/V *Dalnie Zelentsy*, August 1981, 24 stations, 109 samples in the Kara Sea.

Characteristics: Occurrence (the number of species in percent from the total amount) of zooplankton species as indicators of the Arctic Waters has been calculated. It was substantially higher in 1981 than in 1936.

Conclusion: The climatic conditions in the Kara Sea were more severe in 1981 than in 1936.

Zooplankton. Southern Barents Sea: 1952-1959

Data: The materials of 84 cruises carried out during the period 1952-1959. 7137 samples from 1630 stations were collected.

Characteristics: The graphs characterizing variation of biomass, abundance, biodiversity index (the Glisson coefficient), and temperature anomaly during the period 1952-1959 are plotted. The tendency toward decrease in the values of 1952-1959 parameters is demonstrated.

Conclusion: The period from 1953-1955 had more favorable conditions for zooplankton development in comparison to the period from 1956-1958. One of the possible explanations for this phenomenon comes from the observed positive temperature anomalies in the period from 1953-1955.

CONCLUSION

The listed examples have demonstrated that more favorable conditions for plankton development in the investigated Arctic region existed in the period during 1920-1930 than during 1960-1980. This conclusion complies with existing observations of Arctic warming during the period 1920-1930 (Fu et al., 1999).

8. CD-ROM CONTENT

The accompanying CD-ROM contains original data, read-me file, auxiliary tables, interactive figures and text of the Atlas in MS doc and HTML formats. The WEB version of the Atlas consists of the following sections:

Documentation: this Section contains the full text of *The Biological Atlas of the Arctic Seas-2000: Plankton of the Barents and Kara Seas*, references in Russian and English.

History: the searchable list of publications of the Barents Sea phytoplankton and zooplankton is presented. The maps specifying locations of benthos stations in the Barents Sea are attached.

Plankton taxa: phytoplankton and zooplankton species of the Arctic seas are listed in alphabetical order. The geographic and ecological characteristics are given for each species. Search capability by taxonomic group is provided.

Photo Gallery: includes photographs and drawings of 50 dominant phytoplankton species of the Arctic Seas and photographs of plankton sampling during the expedition of the Murmansk Marine Biological Institute on the nuclear icebreaker *Soviet Union* in the Barents and Kara Seas. March-April, 1998

Database: data distribution maps are exhibited. The technique for review of the data obtained during each cruise is provided. Section DATA\PRIMARY presented on the CD-ROM displays the data of 158 cruises for the period 1913-1999.

Marine environment: this section incorporates searchable maps and graphs describing the distribution of various characteristics of the plankton, and maps of the temperature and salinity, monthly mean ice edge positions, and vertical structure of the Barents Sea water.

Plankton community changes: comparisons between the structure of the plankton in the 1930's, 1950's, and 1990's are presented. Observed changes are related to the variability of the Arctic climate.

Authors: names of the authors, their addresses, telephones, and e-mail addresses are listed.

9. CONCLUSION AND FUTURE WORK

The zoobenthos example showed that the suggested data description format can be used for wide variety hydrobiological parameters.

The comparison results have demonstrated that the 1920's and the 1930's were more favorable for plankton development compared with the period 1950-1980.

The data collected in the nearshore Kola Peninsula region in the period 1952-1959 demonstrated that intra-year variation in zooplankton characteristics is in phase with the temperature anomaly fluctuations.

The database development and documentation of fluctuations in hydrobiological characteristics of the Arctic Seas are of priority for our future work. We plan to develop the database through improvement of the quality control procedures for hydrobiological characteristics and detailed descriptions of the methods and gears.

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