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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 Internet in accordance with the principles of the World Data Center system of the International Council of Scientific Unions and the UNESCO Intergovermental Oceanographic Commission.

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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 WDC, Silver Spring, J. Antonov, T. Boyer, M. Conkright, C. Forgy, S. Fillips, R. Gelfeld, D. Johnson, C. Sazama, C. Stephens, and G.Trammell, who have contributed significantly to the database development. 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. Drobusheva, Ph.D., Polar Institute of Fisheries and Oceanography (Murmansk, Russia), Anthony R. Picciolo, Ph.D., and P. Murphy, Ph.D., (NOAA, Silver Spring, USA) for editing this publication.

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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 ice-breakers 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. Comparisons of the structure of the plankton community in the 1930's, 1950's, and 1990's are presented. 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 oceanographical, 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 data set.

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 of the plankton community 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 Appendix A.

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 conclusions (Kiselev, 1928; Usachev, 1935). These papers resulted in a list of species of Arctic phytoplankton giving details of its taxonomic composition. 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 *et al.*) 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, 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 *et al.*, 1997).

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 Oceanography (PINRO), Murmansk, the Institute of Oceanology, Moscow, the Botanical Institute, St. Petersburg, and the Murmansk Hydrometeorological Service.

From the 1980's untill 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'nezelenskaya Bay multi-year complex ecological monitoring was carried out (Druzhkov *at el.*, 1990).

The list of publications of the Barents Sea phytoplankton has been presented in Appendix A1. The stages of phytoplankton study of the Barents Sea by Russian scientists are presented in Table 1.

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 examination 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 ice-breakers 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.

Table 1. Chronology of the phytoplankton study of the Barents Sea by Russian scientists

Period	Author	Content	Regions of the Barents Sea
1898-1913	Palibin I.V. Linko A.K. Derjugin K.M.	• Taxonomical composition • Seasonal dynamic of dominant species	North and south
1920-1940	Kiselev I.A. Kireeva M.S. Schapova T.F. Mosentsova T.N. Manteifel B.P.	• Taxonomical composition • Seasonal dynamics of dominant species	South-west and south-east, coastal waters of the Kola Peninsula
1950-1960	Roukhiyainen M.I. Kashkin N.I. Mileikovsky S.A.	• Taxonomical composition • Abundance and biomass dynamic • Spatial distribution • Biology and ecology of dominant species • Chlorophyll • Primary production	South and central
1970-1983	Sokolova S.A. Solovieva A.A. Ryzhov V.M. Syuzeva N.G. Salahutdinov A.N. Vasyutina N.P. Makarova I.V. Bobrov Yu.A. Khromov V.M. Savinov V.M. Vedernikov V.I.	• Taxonomical composition • Abundance and biomass dynamics (seasonal and • multi-year) • Spatial distribution • Chlorophyll • Primary production	South and central
1984-1990	Makarevich P.R. Larionov V.V. Druzhkov N.V. Ryzhov V.M. Kuznetsov L.L. Bobrov Yu.A. Savinov V.M.	• Taxonomical composition • Abundance and biomass dynamics (seasonal and • multi-year) • Spatial distribution • Chlorophyll • Primary production	South and central
1991-2000	Makarevich P.R. Larionov V.V. Druzhkov N.V. Druzhkova E.I. Vedernikov V.I. Gagarin V.I. Titov O.V. Shavikin A.A.	• Taxonomical composition • Abundance and biomass dynamics (seasonal and multi-year) • Spatial distribution • Chlorophyll • Primary production	The whole sea

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 Deryugina (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 whales 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 (Tereshchcenko *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, 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, 1979; Zalessky, 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, Shirokobolova, 1993; Druzhinina, 1997; Timofeev, 1997a, 1998). 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 by investigators in maps, figures and tables:

- Distribution of abundance of euphausiid crustaceans during 1953-1996 (Drobysheva, 1988; Drobysheva, Nesterova, 1996);
- Multi-year dynamics of abundance of euphausiid crustaceans in the South Barents Sea during 1953-1996 (Drobysheva, 1988; Drobysheva, Nesterova, 1996);
- Distribution of mesozooplankton biomass in Southwest Barents Sea during 1959-1990 (Nesterova, 1990);
- Multi-year dynamics of mesozooplankton biomass along the *Kola Meridian* transect during 1959-1990 (Nesterova, 1990);
- Multi-year dynamics of mesozooplankton biomass in the Murmansk coastal zone during 1953-1959 (Kamshylov *et al*., 1958; Zelikman, Kamshylov, 1960; Zelikman, 1977);
- Multi-year and seasonal dynamics of mesozooplankton biomass in the Kola Bay (Glukhov *et al*., 1992);
- Distribution mesozooplankton biomass in the central Barents Sea during 1982-1993 (Tereshchenko *et al*., 1994);
- Multi-year dynamics of abundance of dominant mesozooplankton species (*Calanus finmarchicus, Oithona similis, Appendicularia*) along the *Kola Meridian* transect during 1959-1983 (Degtereva, 1979; Degtereva, Nesterova, 1985);
- Multi-year dynamics of abundance of pelagic hyperiids during 1980-1988 (Drobysheva, Nesterova, 1992);
- Multi-year dynamics of abundance of eggs and larvae of dominant Barents Sea commercial fishes during 1959-1990 (Mukhina, 1992).

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 the abundance of 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 and 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, 1936a,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.*, 1994a, 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 Breitfus), and presented them in a monograph (Linko, 1907). Linko established that *C. finmarchicus,* a dominant species in the Barents Sea zooplankton, 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 morphologic 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 occurrance 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 southwestern Barents Sea consists of *Calanus*. The average biomass of *C. finmarchicus* comprised 24 ton/km^2; with a minimum biomass value (8.5 ton/km^2) in March and April, and a maximum in August. V. Yashnov estimated the annual production of *C. finmarchicus* to be 65 ton/km^2, and from the data of the PINRO (1950-1970) the crustacean production comprised 77.5 ton/km^2 (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/m^3 (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 carried out 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:

$$\mathbf{Y} = 774.6\mathbf{X} - 2035.2,$$

in which: **Y** is nauplii abundance in the Murman drift in the layer of 0-50 m (individuals/m^3);
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, 1939), 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* descend 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 it 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 list of papers on the Barents Sea zooplankton are presented in Appendix A2. 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 biological resources 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 carried out at 5,000 stations, of which 4,800 stations 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.

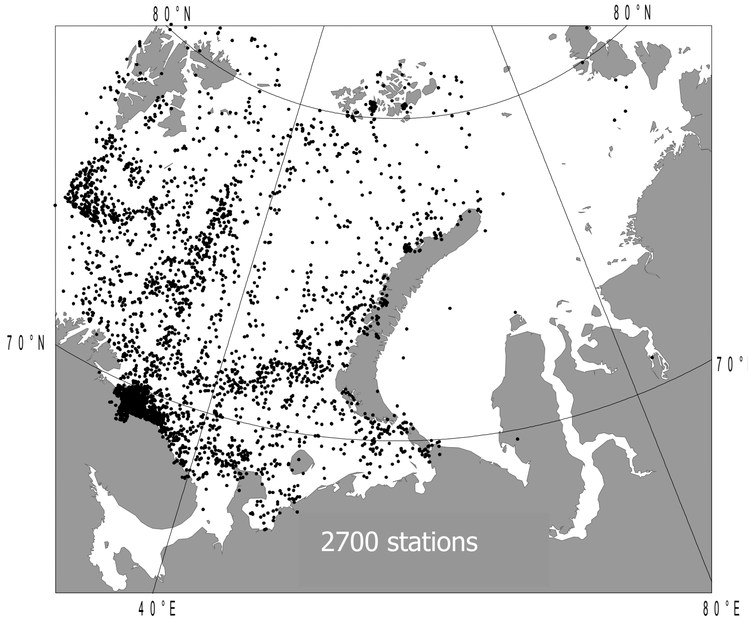

Fig. 1. Distribution of benthic stations for the period 1920-1940

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 and 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 and 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 the ecosystem structure and it functionality (Streltsov *et al*., 1974).

In 1968-1970, using one standard method PINRO conducted a total survey of the Barents Sea (Figure 2), which revealed a substantial decrease in zoobenthos biomass in comparison with the 1920's-1930's (Antipova, 1975).

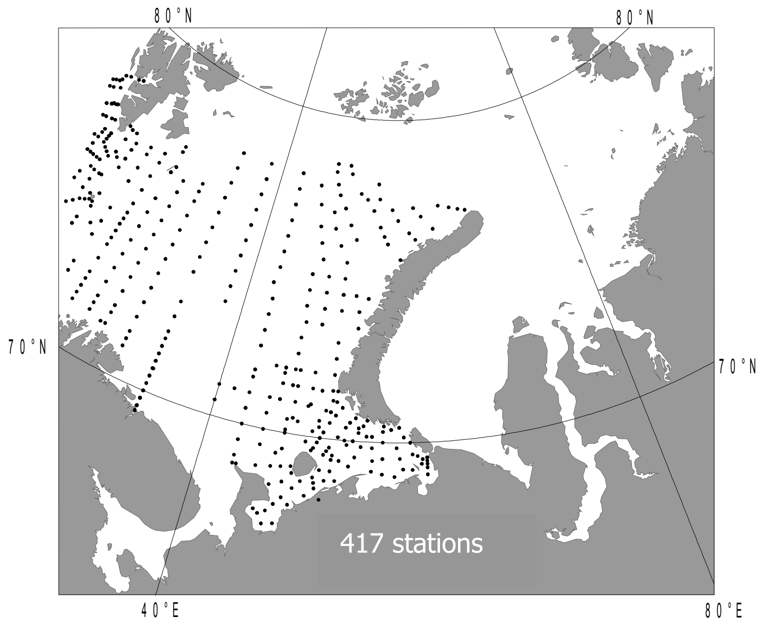

Fig. 2. Distribution of benthic stations for the period 1968-1970

On the whole, in the period 1945-1977, data from 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, under-water photographic surveys and benthos collections were widely used by Russian geological institutions for performing landscape and ecological shelf investigations (Gurevich, Kazakov, 1989). Today the total number of benthic stations carried out 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 K. Nesis (1960), who analyzed multi-year fluctuations of boreal and Arctic species along the *Kolsky Meridian* section 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,* and *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. Analys of recording structures may allow 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 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-scale 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.

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 figures and/or photographs of organisms. The accuracy of the species identification depends on the accuracy of the representation of details in a photograph or drowing. The majority of modern illustrative materials do not present the detail structure of micro-algae cells. That substantially hinders their use for the taxonomic identification of the organisms. This disadvantage brings up the problem of getting more realistic images of phytoplankton cells, closest to the natural appearance. Figure 3 illustrates a black and white overview photograph of 40 phyto-plankton species. Color photographs of the same species are presented on the CD-ROM accompanying this atlas. Figure 4 shows images of two phytoplankton species in detail.

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 solution, 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 Dalnezelenskaya (area of biological station of the MMBI in the settlement Dalnie Zelentsy, 69°07′08″N, 36°05′08″E). Slightly preserved algological material collected in July cruise was collected from the South Barents Sea on board 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.

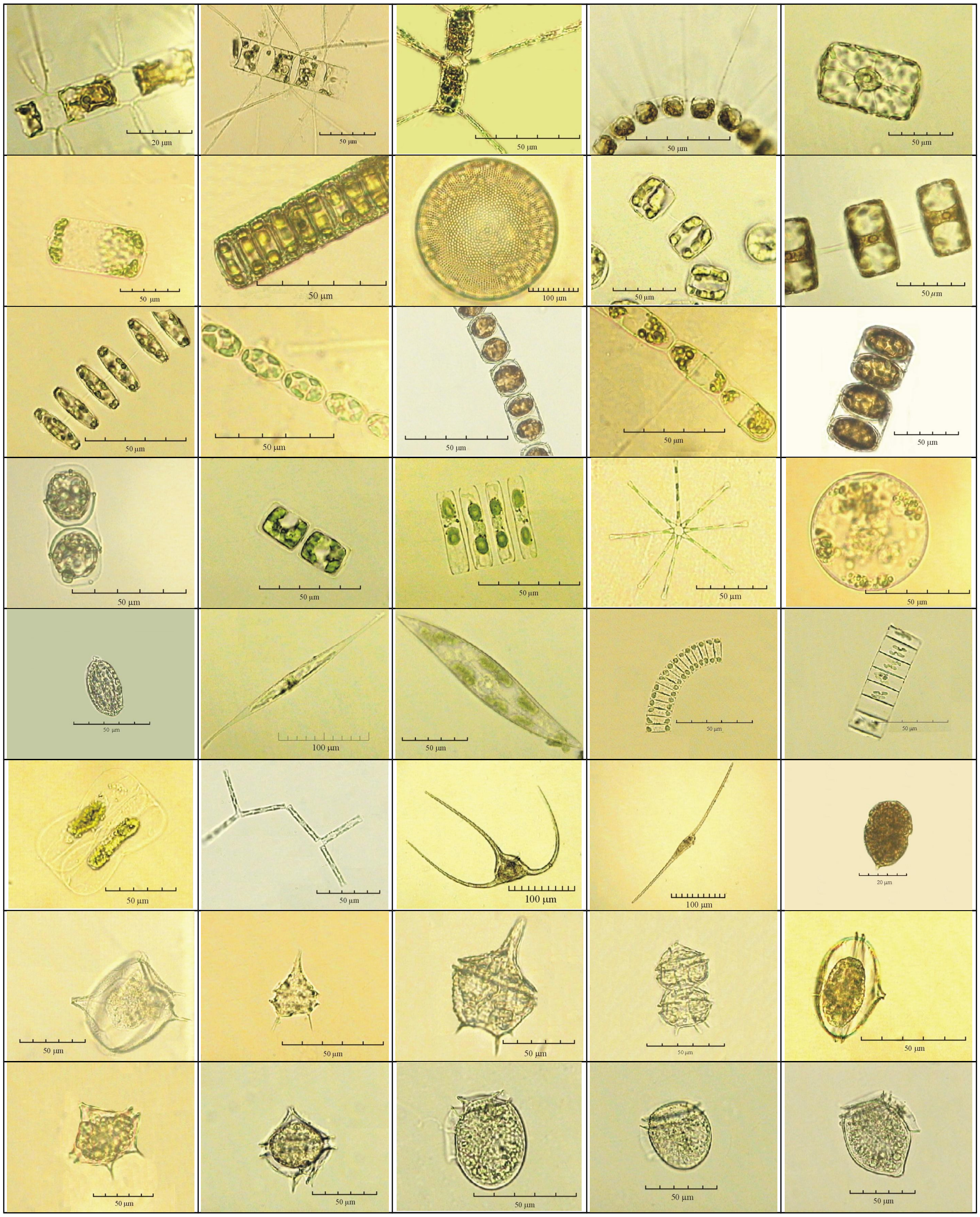

Fig. 3. Images of dominant phytoplankton taxa of the Barents and Kara Seas

Dinophysis acuminata Clap. Et Lachm.

Thalassiosira bioculata (Grun.) Ostf.

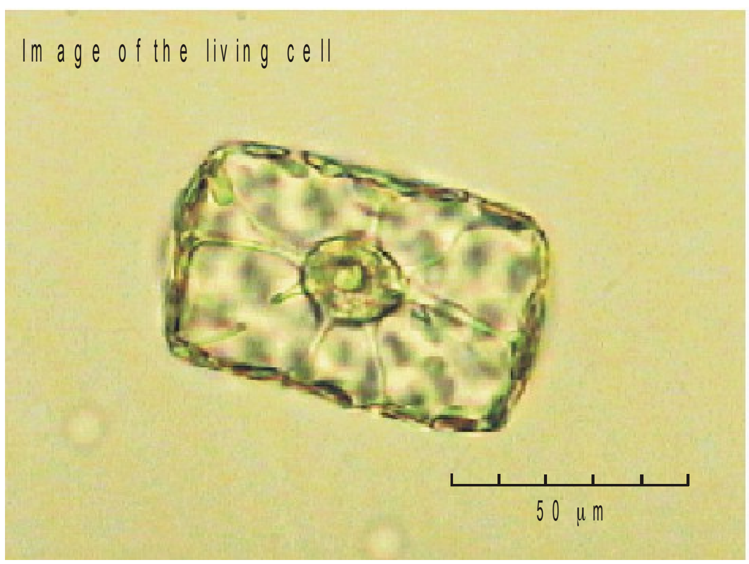

Fig.4. Examples of images of phytoplankton living cells

Photo album

Information on the Barents Sea and the Kara Sea phytoplankton is presented as a photoalbum, which is present on the accompanying CD-ROM in HTML format and contains two sections. a) A list of phytoplankton species. b) Photographs of 50 phytoplankton color images in JPG format with a resolution of 75 dpi.

The table of phytoplankton species lists the taxa and their synonyms according to present botanical nomenclature. Cell weight, calculated through the method of geometrical shape similarity, is given for each species (Koltsova, 1970; Kozhova *et al.*, 1978; Plinski *et al.*, 1984). Taxonomic composition, ecological, and phytogeographic characteristics of phytoplankton are presented (Chapter 4.4). Taxons are also provided with identification numbers from international codes (Integration Taxonomic Information System (ITIS) and NODC Taxonomic Code). Appendix B1 contains a part of a table of phytoplankton species. The CD-ROM presents the same table in its entirety. The table lists information on 307 phytoplankton species of the Barents and Kara Seas.

4. DATA

4.1. Data Characteristics

Inventory

This atlas contains the data from 158 cruises carried out in the Barents, Kara, and White Seas from 1913-1999. The atlas includes the White Sea in order to not separate cruises that 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 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 carried out 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; 158 cruises; 4,608 stations (Appendix C1)
- Total number of stations with physical and hydrochemical data: 3,096 (Appendix C2)
  - Temperature: 3,046 stations
  - Salinity: 2,947 stations
  - Oxygen: 1,998 stations
- Chlorophyll: 385 stations (Appendix C3)
- Phytoplankton: 1,539 stations and 4,275 samples (Appendix E1)
- Zooplankton: 2,475 stations and 9,081 samples (Appendix F1)

Appendix C4 contains the maps of the data distribution 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), the Slavonic and Baltic Division of the New York Public Library (New York, NY, USA), and

Dartmouth College Library (Hanover, NH, 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 seawater 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 seawater (Manual, 1977; International, 1966).
- Seawater samples were collected by bathometers BM-48 (Manual, 1977).
- Dissolved oxygen was obtained by iodometric titration, through the method of Winkler (Chernyakova, 1987).
- Active pH reaction was determined by potentiometric method using potentiometers "pH-121" and "pH-340" with a glass electrode (Bogoyavlensky, Ivanenkov, 1978).
- Phosphate (PO_4) 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) (see, Sapozhnikov, 1978b).
- Nitrite (NO_2) was determined by the method of Griss-Ilosway with spectrophotometric measurement of concentrations using electric calorimeter KFK-2MP (Konnov 1978).
- Nitrate (NO_3) was determined by the method of Wood-Richards-Armstrong (Wood *et al.*, 1967) using a spectrophometric 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).
- Silicate was determined by the method of Mulin-Railly modified by Strickland and Parsons from blue silicon and molybdenum complex using electrophotocolori-meter KFK-2MP with a spectrophotometric cap (Gusarova, 1978).
- Primary production was determined by the method of Steemann - Nielsen (1952). Samples were collected by 10-liter plastic bathometers 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 are carried out using the method of Richards and Thompson (1952). Sampling was carried out using 10-liter plastic bathometers. 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 bathometers of different capacity (2-10 l) at standard hydrological horizons (Manual, 1977; Manual, 1980). Since 1960 only bathometers have been used for phytoplankton sampling. Sample concentration utilized two methods: the settlement method (Sukhanova, 1983) and 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 performed 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-siphon 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 counting chamber 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 dimention was used, with light microscope ($100\text{-}400^x$), to determine the taxonomic composition and number of cells in the sample (Fedorov, 1979; Manual, 1980). From the results of these three observations species composition and abundance for each species for phytoplankton sample, as a whole, were determined (Sukhanova, 1983).

During the last years, along with above mentioned methods of preserving and processing of phytoplankton samples, the MMBI utilized a method using Lougol's solution. Water samples of 200 ml were preserved in Lougol's solution (of final 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^x. Microalgae and heterotrophic flagellates exceeding 10 μm were examined in the same counting chamber with a magnification of 400^x (usually 1/3 of sub-probe volume). Large and less numerous phytoplankton samples were calculated in full sample volume in the *Bogrov* counting 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:

$$\mathbf{N} = \mathbf{N}_к \cdot \mathbf{V}_{ск} / \mathbf{V}_п \cdot \mathbf{V}_к,$$

in which: $\mathbf{N}_к$ is the number of phytoplankton cells in the counting chamber;

$\mathbf{V}_к$ is the capacity of counting chamber;

$\mathbf{V}_{ск}$ is a volume of concentrated sample;

$\mathbf{V}_п$ 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 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 a diameter opening of 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. Quantitative processing of the samples was performed through the calculational method of Hensen (Manual, 1980). Counting of organisms was carried out in 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 sub-sample 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. Device 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 this atlas, a table was created which contains the taxonomic names of 527 species of phytoplankton, including the synonymy according to the requirements of the modern botanical nomenclature. All phytoplankton were separated into 8 taxonomical groups (Bacillariophyta, Chlorophycota, Chrysophyta, Cryptophycophyta, Pyrrophycophyta, Euglenophycota, Haptophyta, Prasinophyta). For each entry, a weight is provided, computed by the method of geometrical similarity of figures (Koltsova, 1970; Kozhova *et al.*, 1978; Plinski *et al.,* 1984). Ecological and phytogeographical characteristics of species are also presented (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 = microphyto-benthos; F = freshwater forms). Taxons are provided with the ITIS and NODC Taxonomic Code. The example of a phytoplankton species table is given in the Appendix B1. The total list of phytoplankton species is on the CD-ROM, file DATA\TAXA\TAXPHYTO.XLS.

The zooplankton list (Appendix B2) for the Barents and Kara Seas includes approximately 282 taxanomic names. The table is of the following structure: zooplankton are split into groups characterized by taxonomic relationships. A large group of unicellular zooplankton is separated. Whereas multicellular zooplankton are presented by both holoplankton (Coelenterata, Ctenophora, Rotatoria, Crustacea, Gastropoda, Chaetognatha, Appendicularia) and meroplankton (pelagic larvae of benthic animals).

The example of a zooplankton species table is given in Appendix B2. The total zooplankton species table 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 development and generates quality control criteria for biological data.

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 of 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 forms 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 content 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 highest biomass is observed within the 0-10m layer. *Thalassiosira cf.gravida* Cl., *T. nordenskioeldii* 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. laciniosus* Schutt, and dinoflagellates 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 phytosynthesyzing organisms.

Winter. Beginning of November-End of March

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

Table 2 presents characteristics of the phytoplankton annual development cyclea. This table determines the range of values for the dominant phytoplankton species for the southern Barents Sea.

Table 2. Characteristics of the phytoplankton annual development cycle of the Barents Sea
Region: 74°N - Kola Peninsula

Time period	**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	*Phaeocystis pouchetii* *Thalassiosira gravida* *T. nordenskioeldii* *Nitzschia grunowii* *Chaetoceros socialis* *Navicula*	100,000 - 12 millions
Summer				
End of June – End of August	0-50	C ! A+B N ! P+O	*Leptocylindrus danicus* *L. minimus* *Chaetoceros decipiens* *C. laciniosus* *Protoperidinium* *Skeletonema costatum*	>100,000
Fall				
Middle of September - End of November	0-25	C > A; C > B O ! P; O ! N	*Chaetoceros* *Ceratium* *Dinophysis* *Protoperidinium*	> 2,000
Winter				
Beginning of November - End of March	0–bottom	O > N O > P; C+A > B	*Ceratium* *Protoperidinium.*	10 - 500

Zooplankton

The availability of 9,000 zooplankton samples in the database makes it possible to consider the relationship between abundance and number of species in m^3.

Figure 5 presents a graph illustrating the relationship between zooplankton species number in m^3 and abundance in m^3 for the Barents Sea and the Kara Sea (holoplankton only). The obtained dependence is in good agreement with the theoretical curves widely used in ecology (Magurran, 1988).

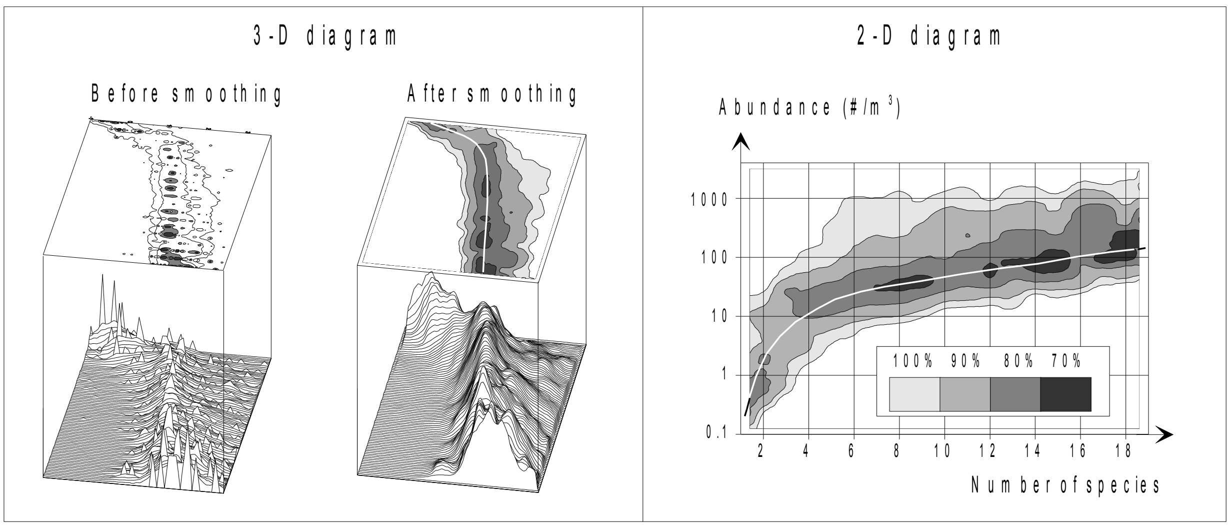

Fig. 5. Zooplankton of the Barents and Kara Seas: abundance *vs*. number of species

The graph given in the figure can be tabulated for simplification of the algorithmic procedure for data quality control.

Number of species (#/m3)	**1**	**2-3**	**4-5**	**6-10**	**11-15**	**16-20**	**>20**
Minimum abundance (ind/m3)	0.1	1	3	10	12	14	>15
Average abundance (ind/m3)	1-75	76-200	201-260	261-350	351-400	401-450	>450
Maximum abundance (ind/m3)	150	350	1500	2500	2550	2600	>2600

6. DATA VISUALIZATION

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 chapter provides the information on ice edge climatology, water vertical structure and temperature and salinity fields.

Ice

The CD-ROM contains maps (WWW\MAP\ICE) 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, 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 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}.

These maps are attached in the Appendix D and displayed on CD-ROM in HTML format

The oceanographic data used for mapping of temperature and salinity were obtained from the database of the WDC Silver Spring, 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 (**σ** (kg/m^3)) vary insignificantly with depth. In summer, in the layer of 30-80 m, sharp **T** and **σ** 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 **σ** variations in the vertical plane. The algorithm of computation of the vertical gradients **T** and **σ** 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 (**Δσ**) at the horizons of 0 and 100 meters were calculated for each month:

$$\Delta T = T_{0м} - T_{100м};\ \Delta\sigma = \sigma_{0м} - \sigma_{100м}.$$

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

Using the HTML information system, the CD-ROM presents graphs and maps characterizing the annual cycle of variation of **ΔT** and **Δσ** 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 till April. During this period the values of **ΔT** and **Δσ** reach an annual minimum. The duration of the summer regime is from July untill September. During this period, the values of **ΔT** and **Δσ** reach an annual maximum.

6.2. Biological Characteristics

The distribution fields (maps) of abundance, biomass, and number of plankton 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, 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 ($\mathbf{K_{gl}}$):

$$\mathbf{K_{gl}=(N_t-1)/log(N_i)}$$

in which: $\mathbf{N_i}$ - number of individuals,

$\mathbf{N_t}$ - 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./m^3. 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./m^3
Common = 11-100 ind./m^3
Abundant = 101-1,000 ind./m^3
Very abundant > 1,000 ind./m^3

Appendixes E and F present fields of distributions of plankton characteristics in the vertical and horizontal planes. Appendix E4 demonstrates graphs of winter variation of phytoplankton characteristics, along the route of nuclear icebreakers from the Barents Sea to the Kara Sea and on their way homeward. These graphs exhibit the phytoplankton state in regions previously inaccessible for hydrobiological studies during winter. This graphic material is also presented on the CD-ROM using the HTML information system.

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). All figures from this chapter have been listed in Appendix G.

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 (figures G1, G5) display substantial difference 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 collected during 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: April-May mean values of biodiversity coefficient (the Glisson coefficient) and phytoplankton cells abundance are calculated under m^2 for the years 1921, 1957, 1985, and 1997 (Fig. G2). This figure shows that values were greater in 1921 than in the years 1957, 1985, and 1997.

Conclusion: Conditions for phytoplankton growth in April-May 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: Relative occurrence (the number of species in percent from the total amount) of zooplankton species as indicators of the Arctic waters has been calculated (Figure G3). It is 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: Data of 84 cruises carried out during the period 1952-1959 (1630 stations, 7137 samples).
Characteristics: The graphs characterizing variation of biomass, abundance, biodiversity index (the Glisson coefficient), and temperature anomaly during the period 1952-1959 (Figure G6) 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 (Figure G4).

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, auxiliary tables, figures and text of the Atlas in MS doc and HTML formats. The HTML version of the Atlas consists of the following sections:

Documentation. This Section contains the text of *The Biological Atlas of the Arctic seas-2000: The Barents Sea and the Kara Sea Plankton* in Russian and English.

History. The list of publications of the Barents Sea phytoplankton and zooplanktion is presented. The maps specifying locations of benthos stations carried out 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 MMBI 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 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 the formalization of a 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 1950-1990.

The data collected in the 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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11. APPENDIXES

A. History of hydrobiological studies: lists of publications
B. Lists of plankton taxa
C. Database
D. Temperature and salinity
E. Phytoplankton
F. Zooplankton
G. Documentation of changes of the plankton community

Appendix A. History of hydrobiological studies: lists of publications

Appendix A1. Phytoplankton

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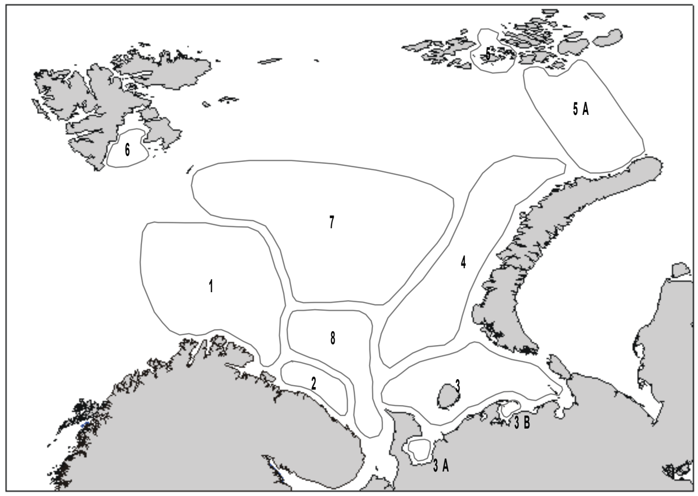
Zooplankton: review of publications by regions



Region 1. The western Barents Sea

Period	Brief overvie	Source
1903-1904	List of species, seasonal dynamics of species content	Linko, 1907
1921	List and biogeographic characteristics of the dominant species	Virketis, 1928
1926-1931	Biomass, production	Jaschnov, 1940
1929-1930	Biomass, production, abundance of the dominant species	Jaschnov, 1939b
1930	Chemical composition of *Calanus finmarchicus*	Vinogradov, 1938
1930	Populational structure of *Calanus finmarchicus*	Jaschnov, 1939a
1930	Size and age structure of populations of Chaetognatha and Euphausiacea	Bogorov, 1940b
1930	Size and age structure of hyperiid population	Bogorov, 1940c
1931-1939	Biomass, seasonal development, vertical distribution	Manteifel, 1941
1933-1938	Ecology of euphausiids, hyperiids, and chaetognaths	Boldovsky, 1941
1934-1935	Seasonal development of zooplankton	Manteifel, 1938
1934-1970	Biomass	Antipova *et al*., 1974
1937	Seasonal development of zooplankton	Mosentsova, 1939
1957-1959	Occurrence and morphology of polychaete larvae (Polychaeta)	Mileikovsky, 1960a
1957-1960	Morphology of polychaete larvae (Polychaeta)	Mileikovsky, 1967
1958	Distribution, abundance, morphology of polychaete larvae	Mileikovsky, 1959
1958-1959	Distribution of mollusc larvae (Gastropoda)	Mileikovsky, 1960b
1958-1959	Occurrence of polychaete (Poluchaeta) in plankton	Mileikovsky, 1961a
1958-1959	Biomass, structure of *Calanus finmarchicus* polulation	Degtereva, 1960
1958-1960	Occurrence of pelagic polychaetes (Polychaeta)	Mileikovsky, 1962a
1958-1960	Occurrence of starfish larvae (Echinodermata)	Mileikovsky, 1968
1958-1962	Occurrence, morphology of brittle star larvae (Echinodermata)	Semenova *et al*., 1964
1959	Occurrence of polychaete larvae (Polychaeta)	Mileikovsky, 1961b
1959	Biomass, structure of *Calanus finmarchicus* population	Mileikovsky, 1962b
1959-1961	Biomass, structure of *Calanus finmarchicus* population	Degtereva, 1964
1959-1969	Biomass, abundance of *Calanus finmarchicus*	Degtereva, 1973
1959-1977	Biomass, abundance of the dominant species	Degtereva, 1979
1959-1983	Biomass, abundance of the dominant species	Degtereva, Nestareova, 1985
1959-1990	Biomass	Nesterova, 1990
1962-1963	Biomass, structure of *Calanus finmarchicus* population	Degtereva, 1971
1965-1968	Biomass, structure of *Calanus finmarchicus* population	Degtereva, 1972
1970	Biomass, abundance of dominant species, structure of *Calanus* population	Nesterova, 1974
1972	Abundance, vertical distribution of macroplankton	Kashkin, 1976
1980-1988	Abundance of hyperiids (*Themisto sp.*)	Drobysheva, Nesterova, 1992
1982	Seasonal dynamics of biomass	Timofeev, 1989b
	Morphology, distribution of gastropod mollusc larvae	Mileikovsky, 1960c

Region 2. The coastal zone of the Kola Peninsula

Period	Brief overviw	Source
1899-1909	Kola Bay: list of species, seasonal dynamics of species content	Deryugin, 1915
1903-1904	List of species, seasonal dynamics of species content	Linko, 1907
1920-1930	List of species of zooplankton in the Motovsky Bay	Virketis, 1931
1930-1931	Chemical composition of *Calanus finmarchicus*	Vinogradov, 1938
1932	Seasonal biomass dynamics of zooplankton in the Motovsky Bay	Manteifel, 1941
1949-1951	Seasonal dynamics of populational structure of *Pseudocalanus elongates*	Kamshylov, 1961a
1949-1951	Seasonal dynamics of populational structure of *Calanus finmarchicus*	Kamshylov, 1955
1949-1952	Distribution and dynamics of barnacle larvae abundance	Kamshylov, 1958b
1950-1951	Seasonal dynamics of populational structure of *Calanus finmarchicus*	Kamshylov, 1952
1951	Body length and weight of *Calanus finmarchicus*	Kamshylov, 1951
1952-1956	Seasonal biomass dynamics including *Calanus*	Kamshylov *et al.*, 1958
1952-1956	Abundance, distribution, feeding, growth of ctenophore (Ctenophora)	Kamshylov, 1961b
1950-s	Distribution and dynamics of barnacle larvae abundance	Rzhepishevsky, 1958a
1953-1959	Seasonal dynamics of abundance of *Calanus finmarchicus*	Golovkin, Zelikman, 1965
1953-1959	Abundance of jelly-fish	Zelikman, 1970
1954-1955	List of species, reference table and seasonal dynamics of polychaeta larvae	Petrovskaya, 1960
1954-1957	List of species, seasonal dynamics of taxonomic composition of zooplankton in the Motovsky Bay	Lobanov *et al.*, 1983; Mikhailovsky, 1986,1988
1954-1959	Seasonal biomass dynamics	Timofeev, 1997b
1955-1959	Populational structure of *Calanus*	Nesmelova, 1966
1956-1959	Biomass distribution, seasonal biomass dynamics including *Calanus*, intra-year biomass variability	Zelikman, Kamshylov, 1960
1956	Distribution and abundance of *Pseudocalanus elongatus*	Zelikman, 1961c
1958-1959	Occurrence of polychaete (Polychaeta) in plankton	Mileikovsky, 1961a
1958-1960	Occurrence of starfish (Echinodermata) larvae	Mileikovsky, 1968
1964	Biomass seasonal dynamics including *Calanus finmarchicus*	Nesmelova, 1968
1972	List of species, abundance and vertical distribution in the layer of 0-45 cm	Tupitsky, 1976
1976	Abundance, vertical distribution of the dominant species in spring and winter	Fomin, 1977
1976-1977	List of species, seasonal dynamics of biomass and abundance of the dominant species	Fomin, 1978
1976-1977	Body length and weight of *Calanus finmarchicus*	Fomin, 1982
1976-1977	Biological seasons, seasonal vertical migrations of *Calanus*	Fomin, 1985
1976-1977	Seasonal dynamics of species content	Fomin, 1989a
1976-1984	Seasonal dynamics of abundance of dominant species including *Calanus*	Fomin, 1991
1976-1985	Distribution, abundance and biology of larvaceans	Zubova, Fomin, 1989
1976-1984	Populational biology of *Calanus finmarchicus*	Fomin, 1995
1979-1984	Seasonal and multi-year dynamics of zooplankton biomass in the Kola Bay	Glukhov *et al.*, 1992
1982-1984	Structure of hyperiid population (*Themisto abyssorum)*	Koszteyn *et al.*, 1995
1983-1984	Seasonal dynamics of abundance including *Calanus finmarchicus*	Fomin, Chirkova, 1988
1983-1984	Seasonal dynamics of species content	Druzhkov, Fomin, 1991
1986-1990	Zooplankton biomass in the Kola Bay	Kireeva *et al.*, 1991
1987	Species content, biographical and ecological characteristics, characteristics of dominant species biology	Тимофеев, 1994a
1987-1988	Size structure of copepod communities	Timofeev, 1992b
1990	Species content, abundance, vertical distribution, trophic structure of zooplankton in the Kislaya Bay (Motovsky Bay)	Timofeev, Shirokolobova, 1993
1990	Species content, abundance, vertical distribution, trophic structure of zooplankton in the Kislaya Bay (Motovsky Bay)	Shirokolobova, 1996
1991	Zooplankton species content, abundance in the Belokamenka Bay	Iliin *et al.*, 1992
1995	Abundance, populational structure of euphausiid, hyperiid and decapod larvae in the Kola Bay	Timofeev, 1997a
1996	Species content, abundance of zooplankton in the Motovsky Bay	Druzhinina, 1997
1996	Abundance and size structure of decapod larvae in the Kola and Motovsky Bays	Timofeev, 1999
	List of species	Kamshylov, Zelikman, 1958
	Structural and functional community arrangement	Timofeev, 1990b,1996b

Region 3. The Pechora Sea

Period	Brief overview	Source
1924	Diurnal vertical distribution of crustaceans	Bogorov, 1932,1938b
1924	Body length and weight of *Calanus finmarchicus*	Bogorov, 1933
1958	List of species, biomass, abundance of the dominant species	Zelikman, 1961a
1958	List of zooplankton species detected in the stomach of Arctic cod (*Boreogadus saida*)	Belova, Tarverdieva, 1964
1959	Biomass, abundance of the dominant species	Zelikman, 1966
1978	Biomass, abundance of the dominant species	Koptev, Nesterova, 1983
1983-1984	Distribution and abundance of nauplii and capepodite stages of copepods	Borkin, Nesterova, 1990
1992	Volume (мм^3/м^3) of zooplankton samples	Timofeev, 1992a
	List of species, biomass	Timofeev, 1995
1992-1996	Biomass	Troshkov, Gnetneva, 1998
	List of species, biomass	Timofeev, Shirokolobova, 1996

Region 3A. The Cheshskaya Bay

Period	Brief overview	Source
1925-1926	List of species	Virketis, Kiselev, 1933
1958	Biomass, distribution of the dominant species	Zelikman, 1961a
1959	Biomass, distribution of the dominant species	Zelikman, 1966
1964	Biomass	Zelikman, 1968
1992-1996	Biomass	Troshkov, Gnetneva, 1998
1994	List of species, biomass, abundance of the dominant species, relationships between holo- and meroplanktonic forms	Makarevich, Druzhinina, 1997

Region 3B. The Pechora Bay

Period	Brief overview	Source
1958	List of species of pelagic crustaceans	Myaemets, Veldre, 1964
1961-1983	Biomass for years of various thermal regime	Zalesskikh, 1986
1963	List of species, abundance of the dominant species	Nadezhdin, 1964
1964-1966	List of species, biomass	Chuksina, 1970
1967-1968	Biomass, abundance of dominant species	Chuksina, 1971
1972-1978	Biomass for years of various thermal regime	Zalesskikh, 1990
1992-1995	Biomass	Troshkov, 1998
1992-1996	Biomass	Troshkov, Gnetneva, 1998
1994	Biomass, abundance	Stogov, Antsulevich, 1995
1994-1995	Biomass, abundance	Stogov, Antsulevich, 1996

Region 4. The eastern Barents Sea

Period	Brief overview	Source
1967	List of species, biomass, abundance and distribution of the dominant species	Zelikman, Golovkin, 1972
1978	Biomass, abundance and distribution of the dominant species	Koptev, Nesterova, 1983
1983-1984	Biomass, abundance and distribution of the dominant species	Borkin, Nesterova, 1990
	List of species, biomass	Timofeev, 1995

Region 5. The Franz Josef Land

Period	Brief overview	Source
1929	List of species	Bernshtein, 1932
1929	New species of marine rotifers (Rotatoria)	Smirnov, 1932
1970	List of species, biomass, abundance of the dominant species in the layer of 0-45 cm	Shuvalov, Pavshtiks, 1977
1970	Biomass, abundance, age and morphology of *Calanus glacialis* and *Calanus finmarchicus*	Pavshtiks, Vyshkvartseva, 1977
	List of species, biomass	Timofeev, Shirokolobova, 1993

Region 5A. The northeastern Barents Sea

Period	Brief overview	Source
1929	List of species	Bernshtein, 1932
1930	List of species	Bernshtein, 1934

Region 6. The Storfjord

Period	Brief overview	Source
1991	Size structure of the copepod community	Timofeev, 1992c
1991	Meroplankton	Timofeev, Shaban, 1992
1991	Age and size structure of the population of *Parasagitta elegans*	Timofeev, 1994b
1991	Meroplankton	Timofeev, 1998b

Region 7. The southern Barents Sea

Period	Brief overview	Source
1959	Biomass, abundance and distribution of the dominant species	Zelikman, 1966
1982	Diurnal vertical distribution	Rossov *et al.*, 1984
1982-1993	Biomass	Tereshchenko *et al.*, 1994
1993	Distribution, abundance of the dominant species	Shirokolobova, 1994

Region 8. The central Barents Sea

Period	Brief overview	Source
1959	Biomass, abundance and distribution of the dominant species	Zelikman, 1966
1993	Distribution, abundance of the dominant species	Shirokolobova, 1994

Appendix A3. Zoobenthos

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Appendix B. Lists of plankton taxa

Appendix **B** contains examples of lists of phytoplankton and zooplankton taxa names. Full lists of phytoplankton and zooplankton taxa of the Barents and Kara seas are available on the CD-ROM.

Appendix B1. Phytoplankton

Tables contain scientific names and synonyms according to modern botanical taxonomy. Each taxon provided with its biomass value, its ecological and phytogeographycal characteristics, as well as its corresponding ITIS (Integrated Taxonomic Information System):

http://www.itis.usda.gov/plantproj/itis/index.html,

NODC (National Oceanographic Data Center) code (CD-ROM: NODC Taxonomic Code, Ver. 8.0, 1996) and Taxonomic Serial Numbers (TSN). On CD-ROM contains taxonomic list in alphabetic order and systematic classification table. This Example made for the Chlorophycota systematic group.

Taxonomic Name	Author	Mass (ug)	PG	EG	NODC Code	TSN
Chlorophycota					8	5413
Ankistrodesmus convolutus	Corda	0.000098		F	803050703	5887
Chlamydomonas	Ehrenberg	0.000607		F	8020204	5448
Dunaliella tertiolecta	Butcher	0.00216	A	N	802010203	189433
Hexasterias problematica	Cleve	0.00088	B	O	1003010101	9576
Pandorina morum	Bory	0.0077	A	N	802030202	5580
Volvox morum (syn)	O. F. Mueller	0.0077	A	N	802030202	5581
Scenedesmus quadricauda	(Turpin) Brebisson	0.00012		F	803090203	6110

PG - phytogeographical groups:

- A - arcto-boreal;
- B - boreal;
- C - cosmopolitan species.

EG - ecological groups:

- O - oceanic;
- P - panthalassic;
- N - neritic;
- M - typical microphytobenthic;
- F - freshwater species.

syn - synonym a previous name for a currently recognized taxon. A single taxon may have more than one common name.

Appendix B2. Zooplankton

Taxonomic search organized as a collection of tables composed by systematic groups (SG). Each taxon provided with its corresponding ITIS (Integrated Taxonomic Information System):

http://www.itis.usda.gov/plantproj/itis/index.html),

NODC (National Oceanographic Data Center) code (CD-ROM: NODC Taxonomic Code, Ver. 8.0, 1996) and Taxonomic Serial Numbers (TSN). On CD-ROM contains taxonomic list in alphabetic order and systematic classification table. This example made for the fragment of alphabetic order table.

Taxonomic Name	Author	NODC Code	TSN	SG
Meganyctiphanes norvegica	(M. Sars, 1857)	6174020201	95534	Crustacea
Melicertum octocostatum	(M. Sars, 1835)	3704100402	50547	Coelenterata
Mertensia ovum	(Fabricius, 1780)	3802020101	53881	Ctenophora
Mesochra lilljeborgi	Boeck, 1865	6119290301	88183	Crustacea
Metacylis annulata				Protozoa
Metacylis vitreoides				Protozoa
Metridia longa	(Lubbock, 1854)	6118160212	85746	Crustacea
Metridia lucens	Boeck, 1864	6118160207	85741	Crustacea
Microcalanus pusillus	(Sars, 1903)	6118050401	85367	Crustacea
Microcalanus pygmaeus	(G.O.Sars, 1900)	6118050402	85368	Crustacea
Microsetella norvegica	(Boeck, 1864)	6119090101	86209	Crustacea
Mitraria				Benthic larvae
Mitrocomella cruciata	(A. Agassiz, 1865)	3704080602	50454	Coelenterata
Mitrocomella polydiademata	(Romanes, 1876)	3704080605	50459	Coelenterata
Monstrilla longicornis	I. C. Thompson, 1890	6122020106	88998	Crustacea
Monstrillopsis dubia	Scott,1899			Crustacea
Mormonilla polaris	Sars, 1900			Crustacea
Mysis oculata	(Fabricius, 1780)	6153011403	90044	Crustacea

Appendix C. Data distributions

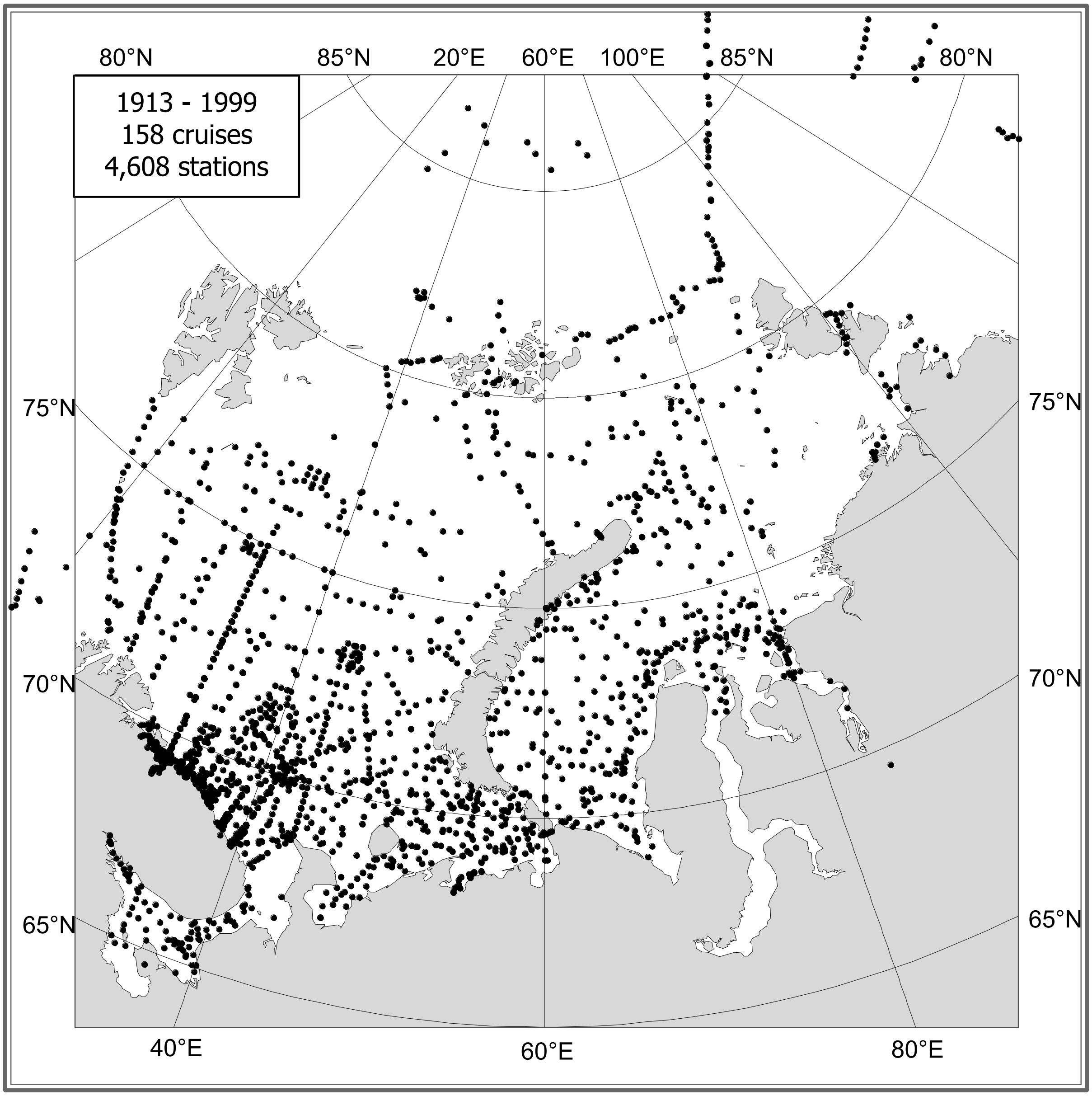


Fig. C1. Distribution of all stations

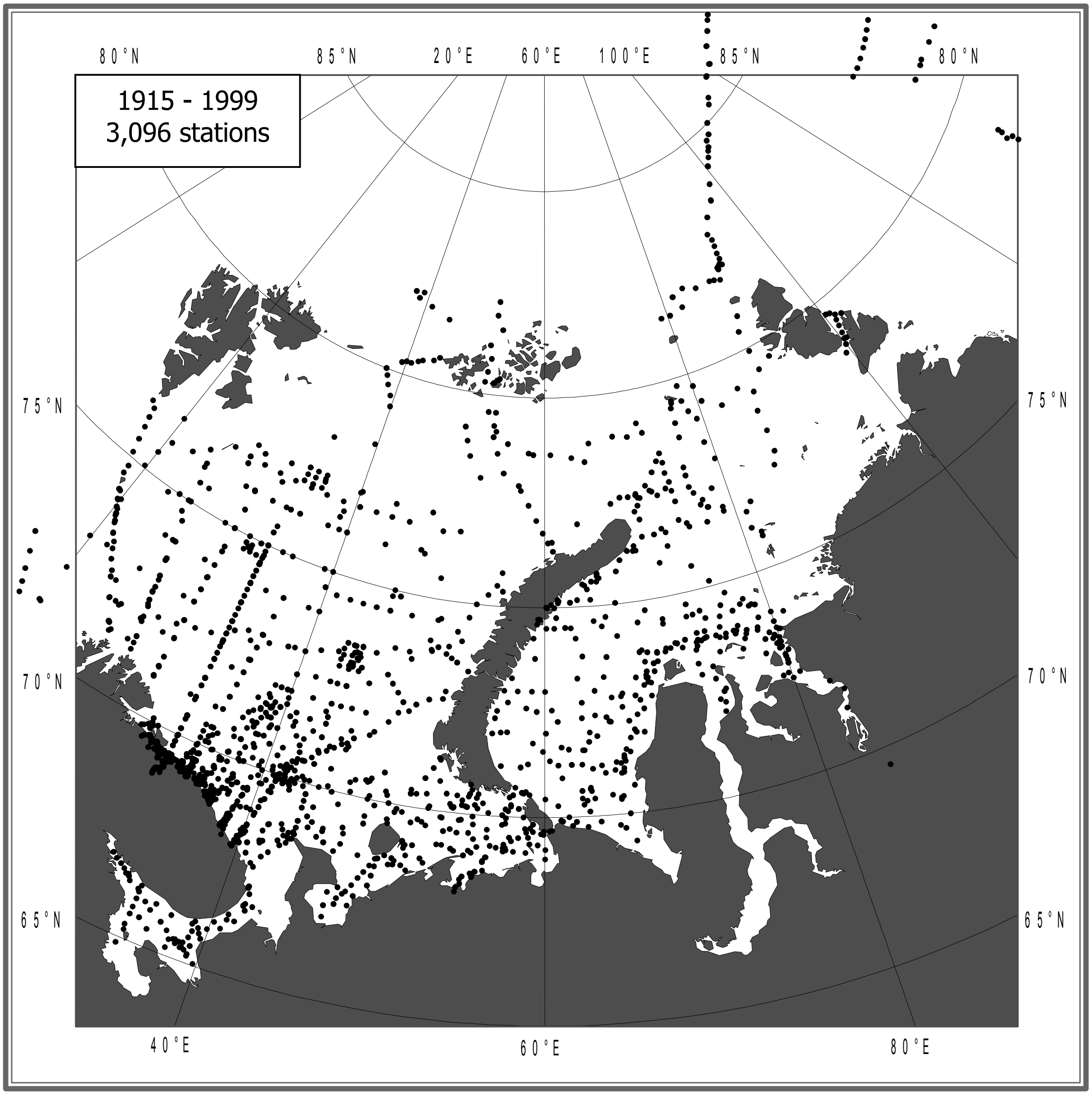


Fig. C2. Distribution of physical and hydrochemical data

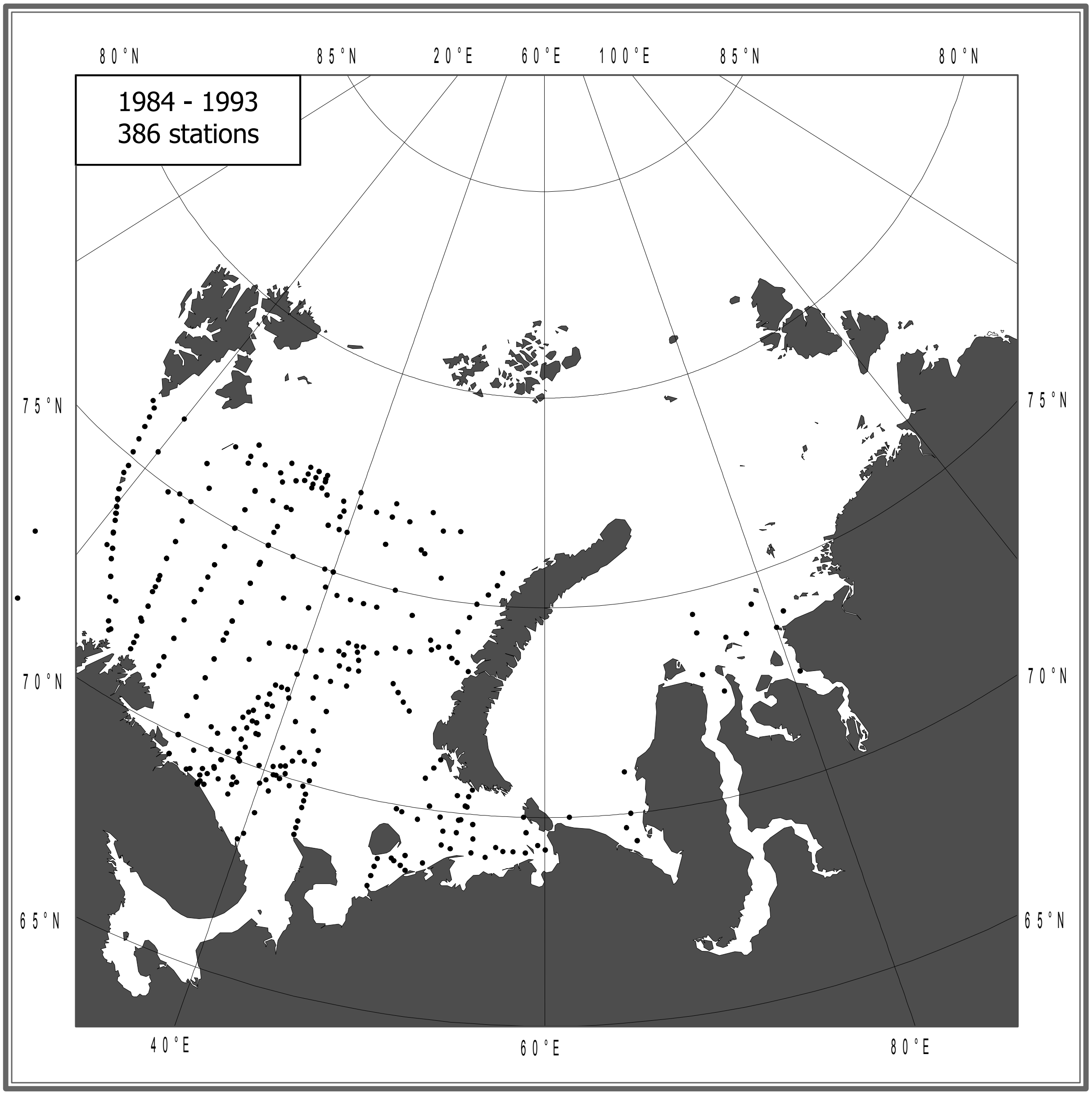


Fig. C3. Distribution of chlorophyll data

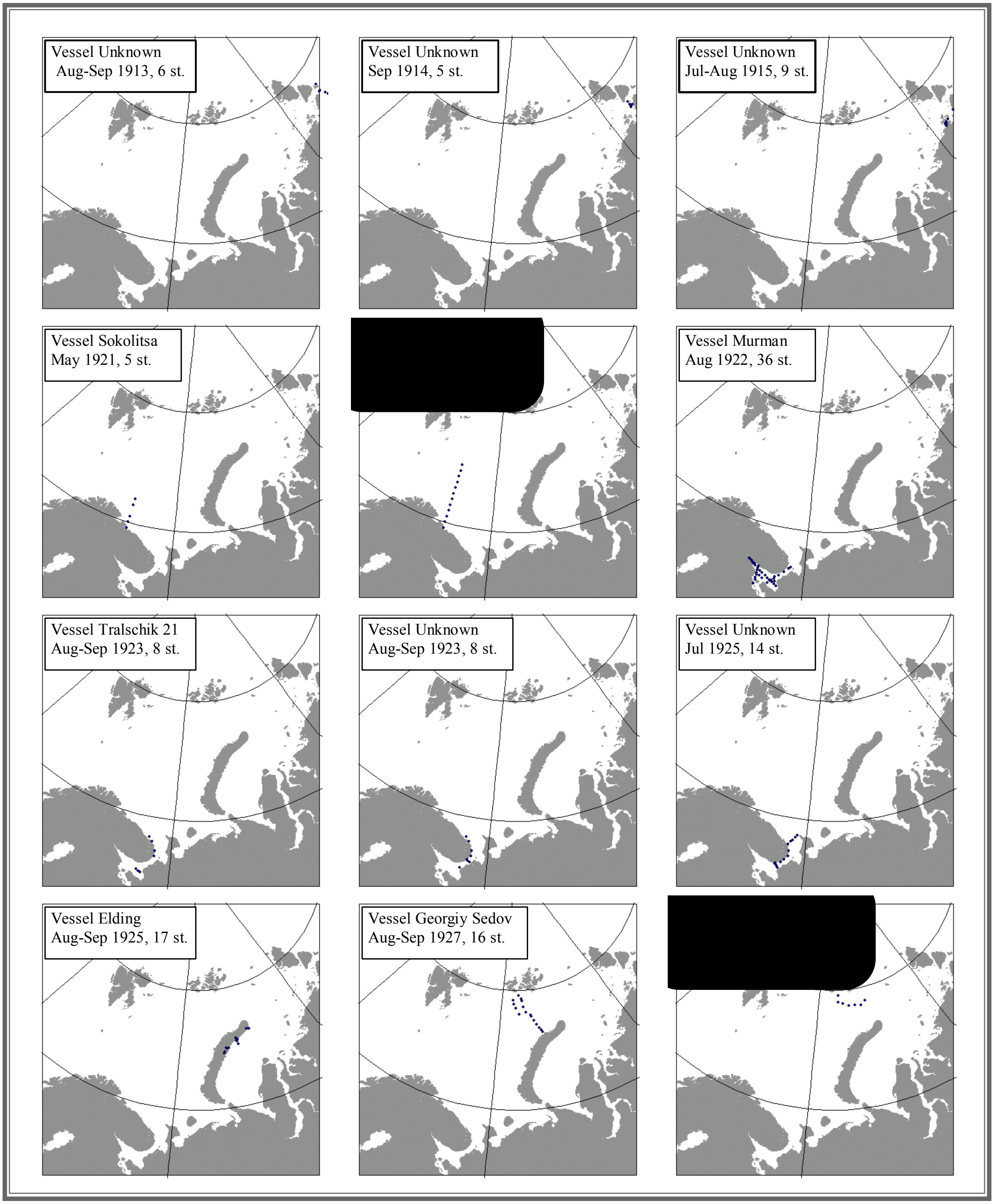


Fig. C4.1. 1913-1929

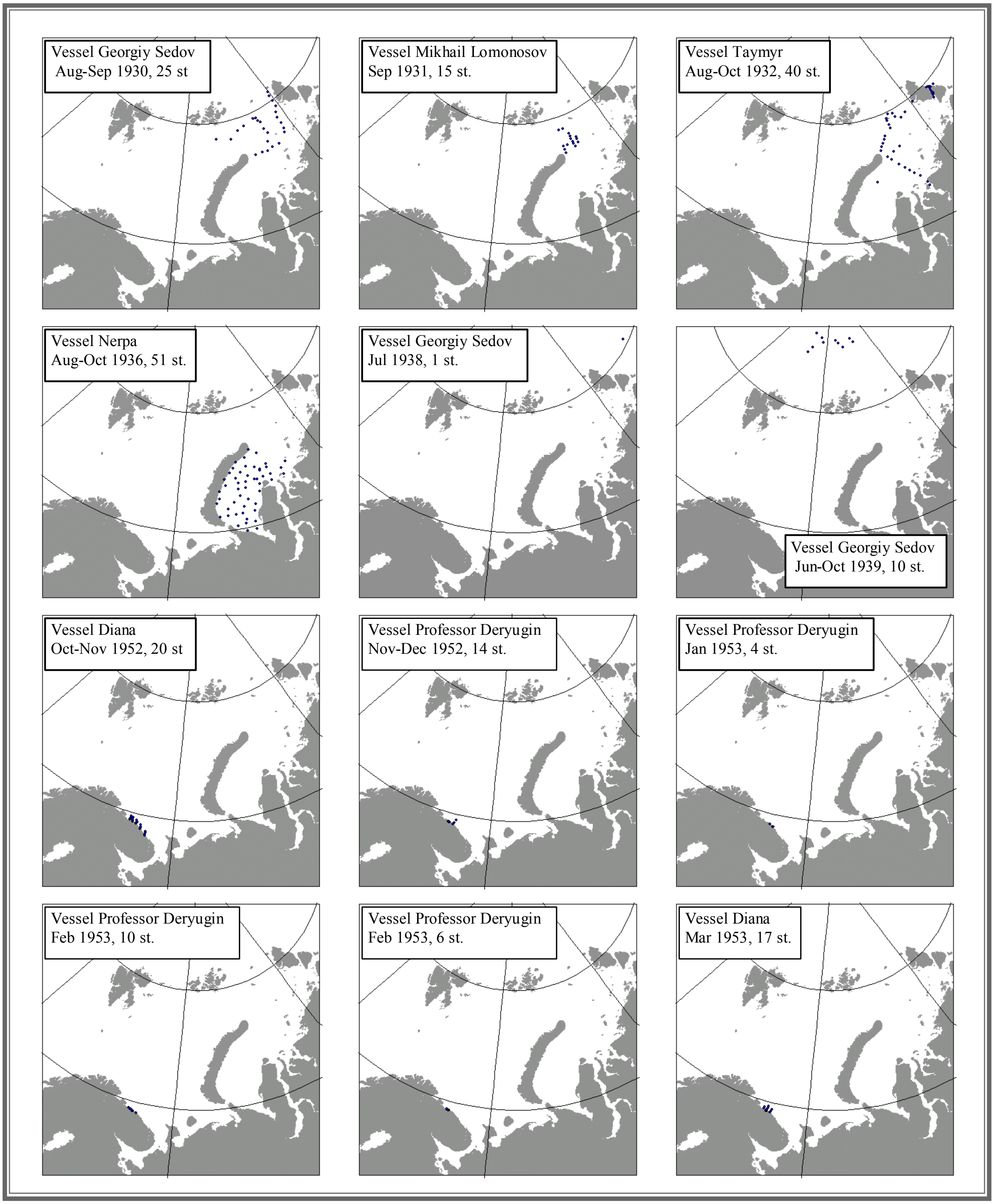


Fig. C4.2. 1930-1953

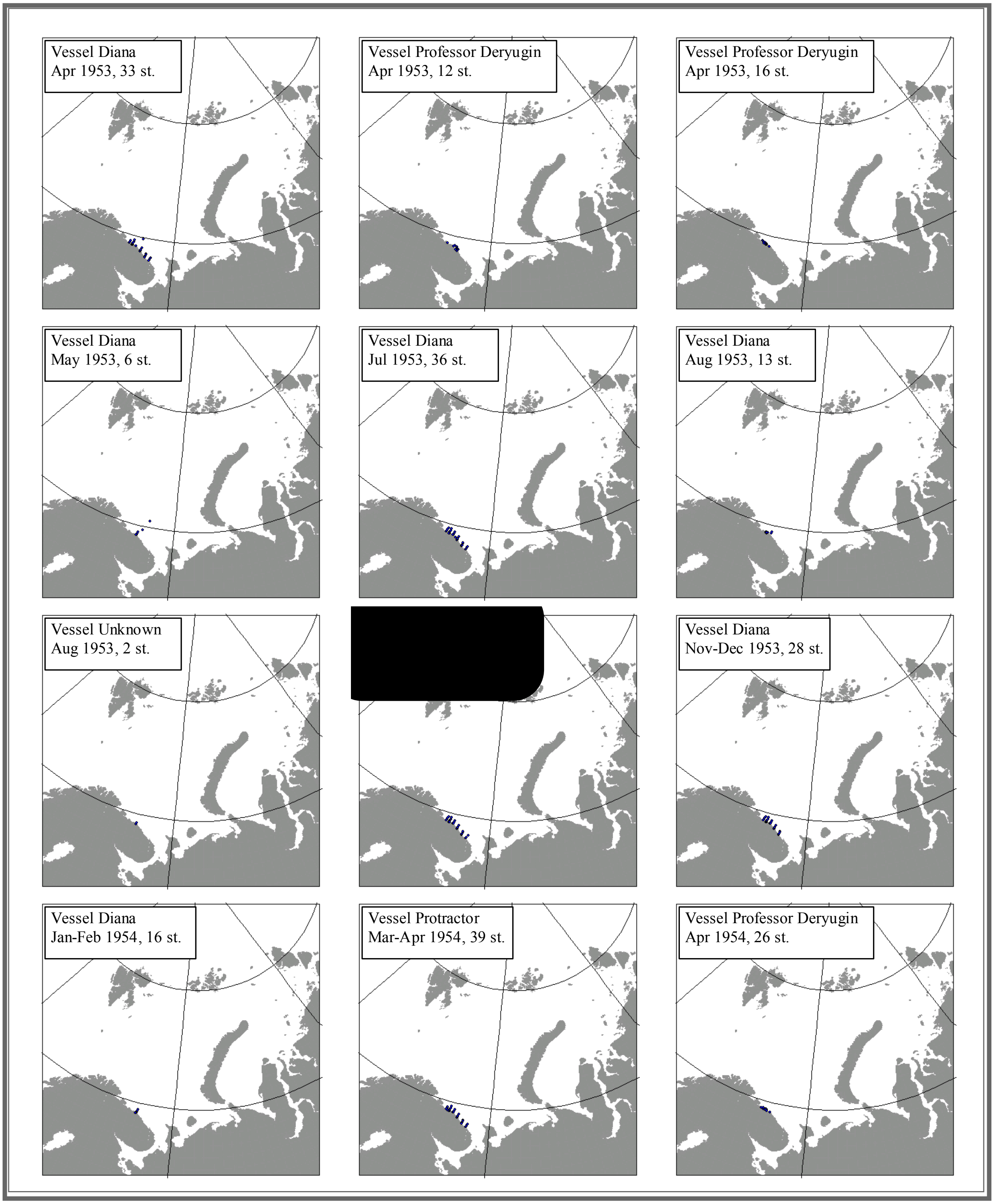


Fig. C4.3. 1953-1954

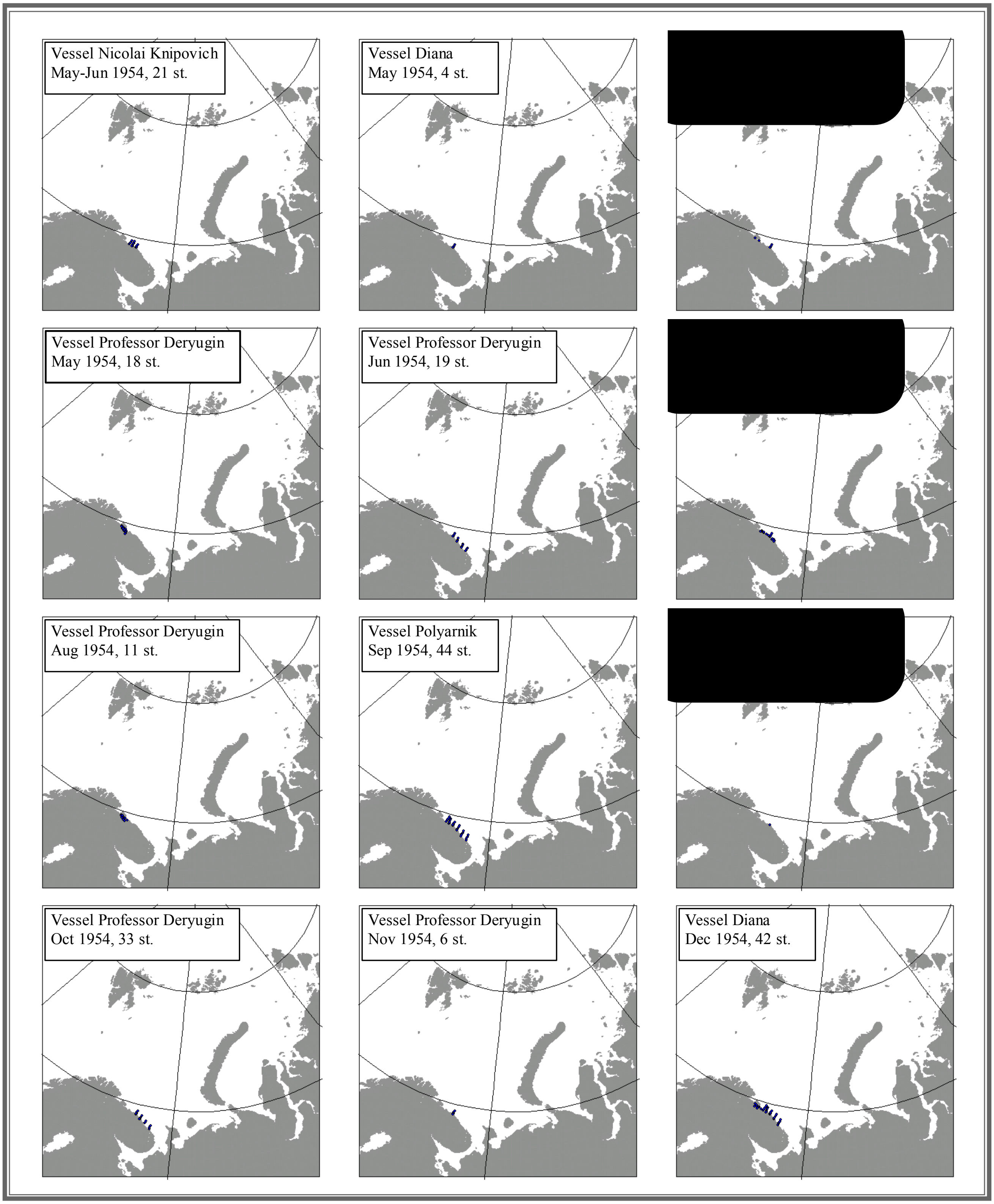

Vessel Nicolai Knipovich
May-Jun 1954, 21 st.
Vessel Diana
May 1954, 4 st.
[redacted]
Vessel Professor Deryugin
May 1954, 18 st.
Vessel Professor Deryugin
Jun 1954, 19 st.
[redacted]
Vessel Professor Deryugin
Aug 1954, 11 st.
Vessel Polyarnik
Sep 1954, 44 st.
[redacted]
Vessel Professor Deryugin
Oct 1954, 33 st.
Vessel Professor Deryugin
Nov 1954, 6 st.
Vessel Diana
Dec 1954, 42 st.

Fig. C4.4. 1954

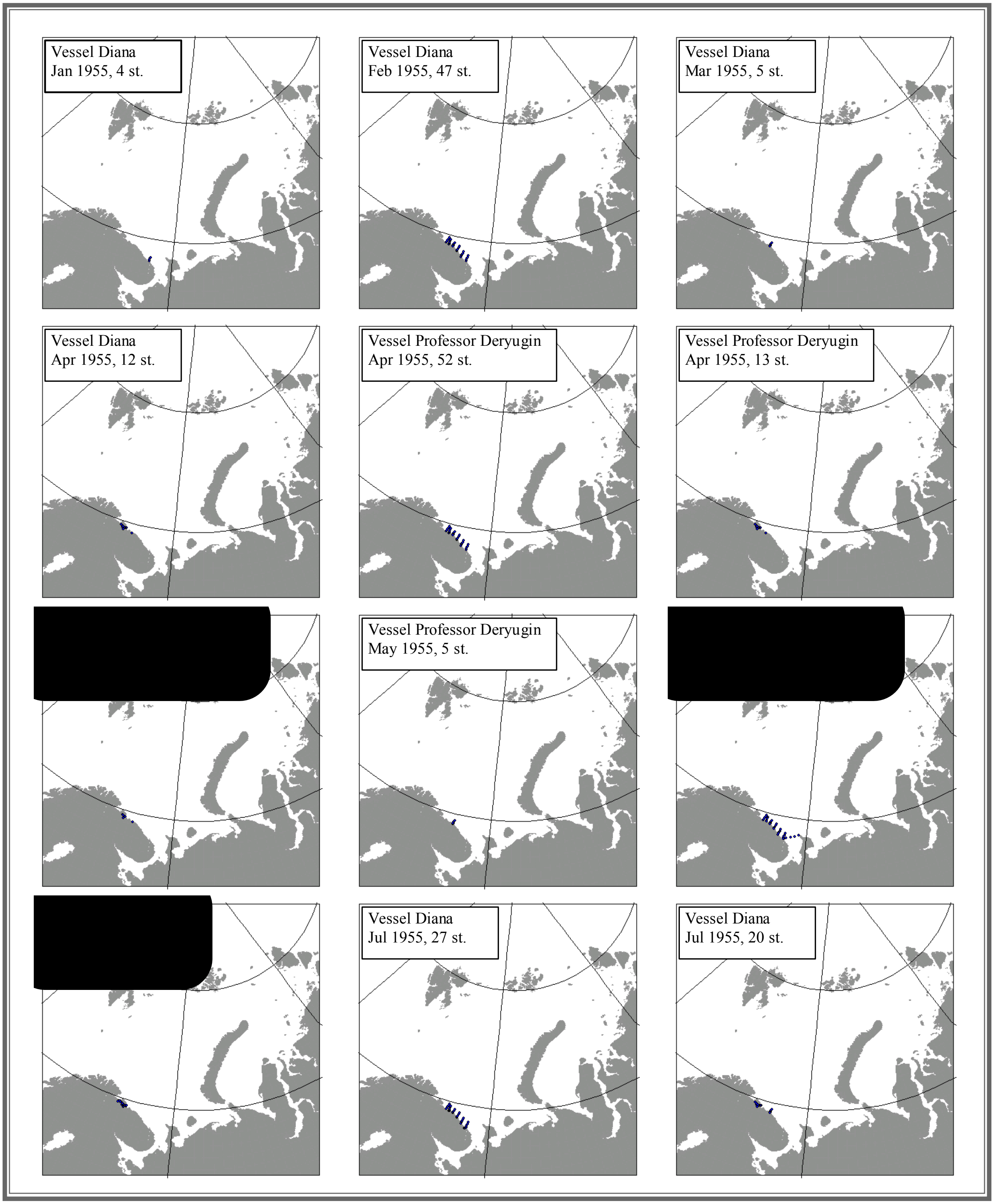

Vessel Diana
Jan 1955, 4 st.
Vessel Diana
Feb 1955, 47 st.
Vessel Diana
Mar 1955, 5 st.
Vessel Diana
Apr 1955, 12 st.
Vessel Professor Deryugin
Apr 1955, 52 st.
Vessel Professor Deryugin
Apr 1955, 13 st.
[redacted]
Vessel Professor Deryugin
May 1955, 5 st.
[redacted]
[redacted]
Vessel Diana
Jul 1955, 27 st.
Vessel Diana
Jul 1955, 20 st.

Fig. C4.5. 1955

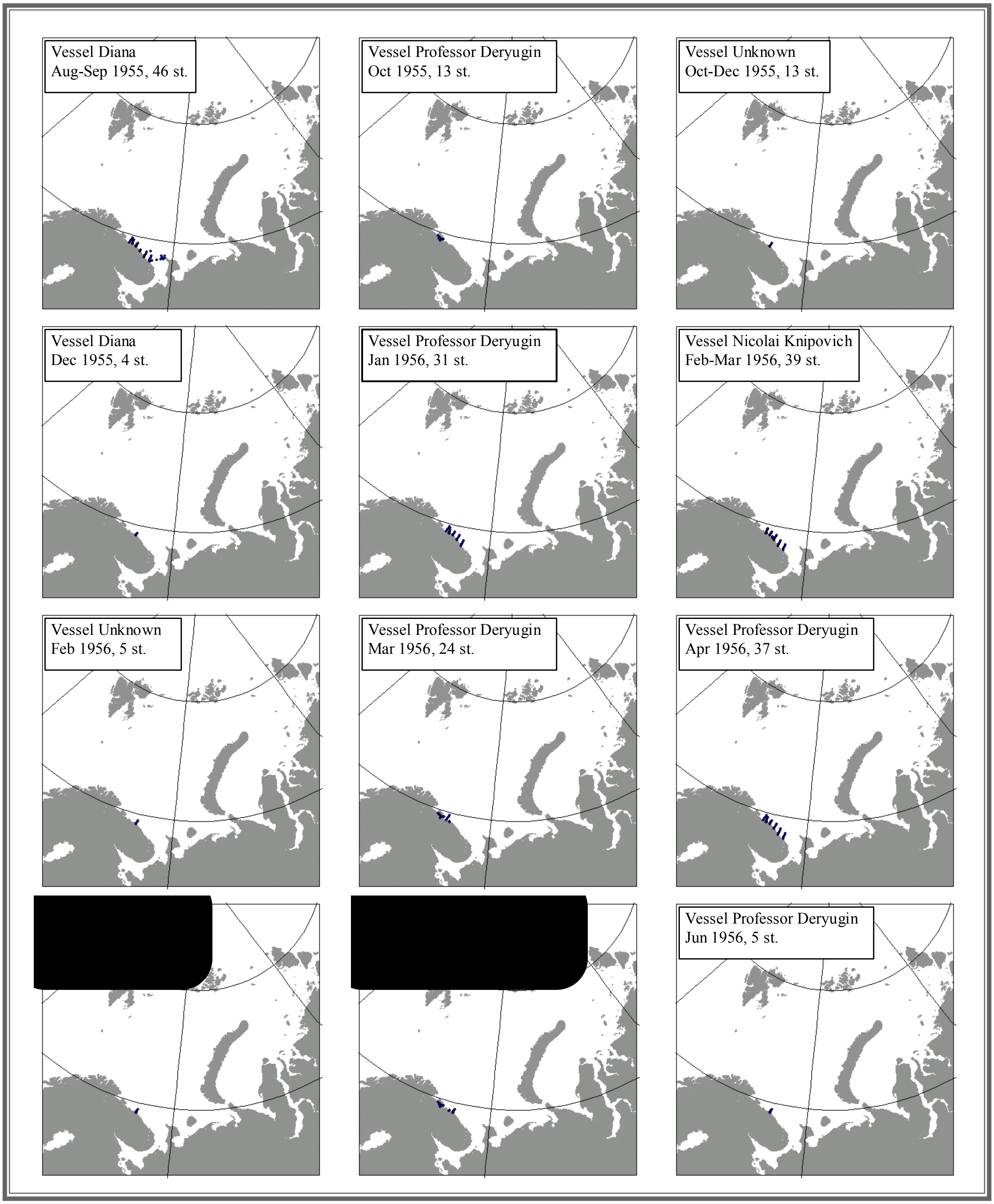


Fig. C4.6. 1955-1956

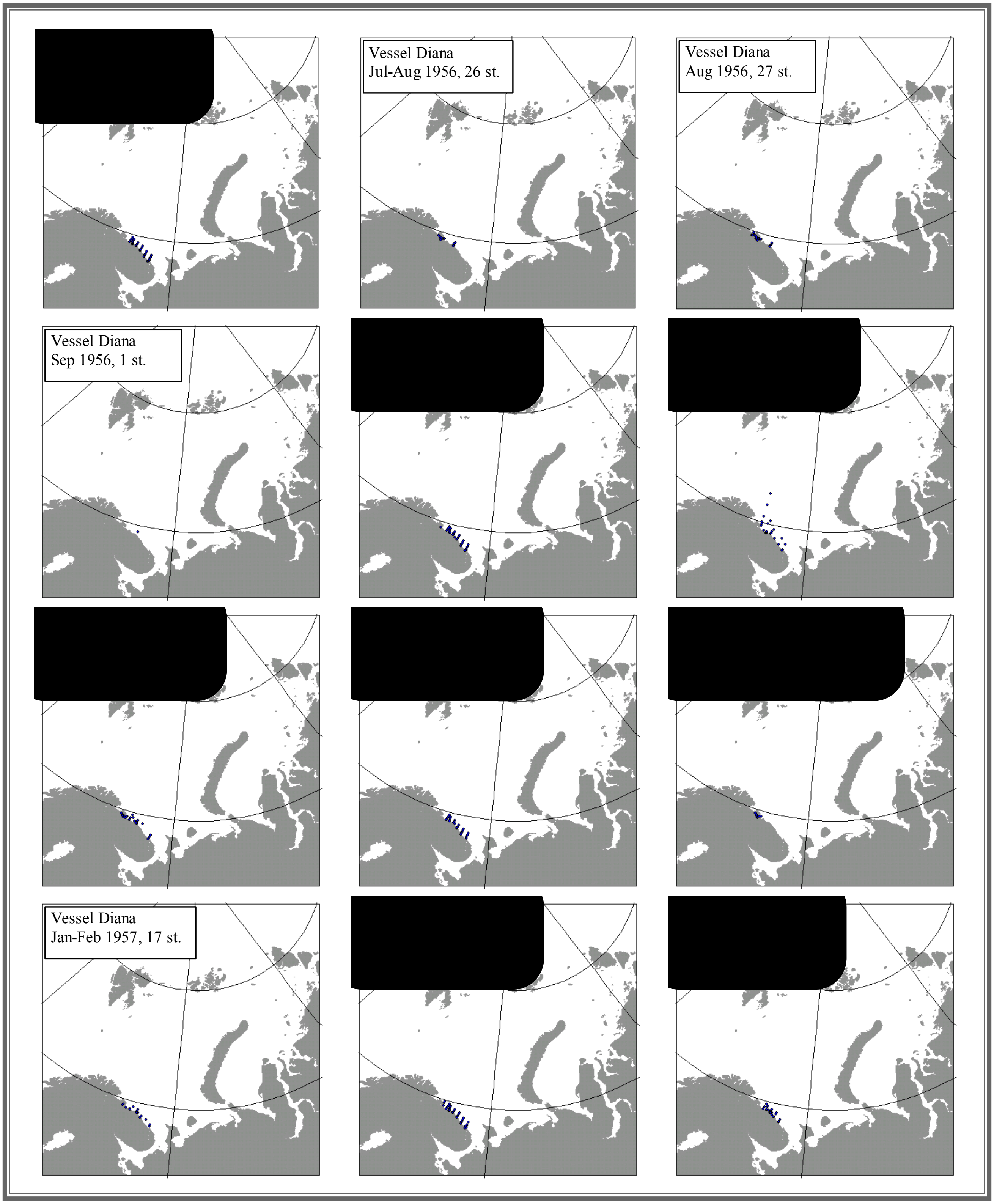


Fig. C4.7. 1956-1957

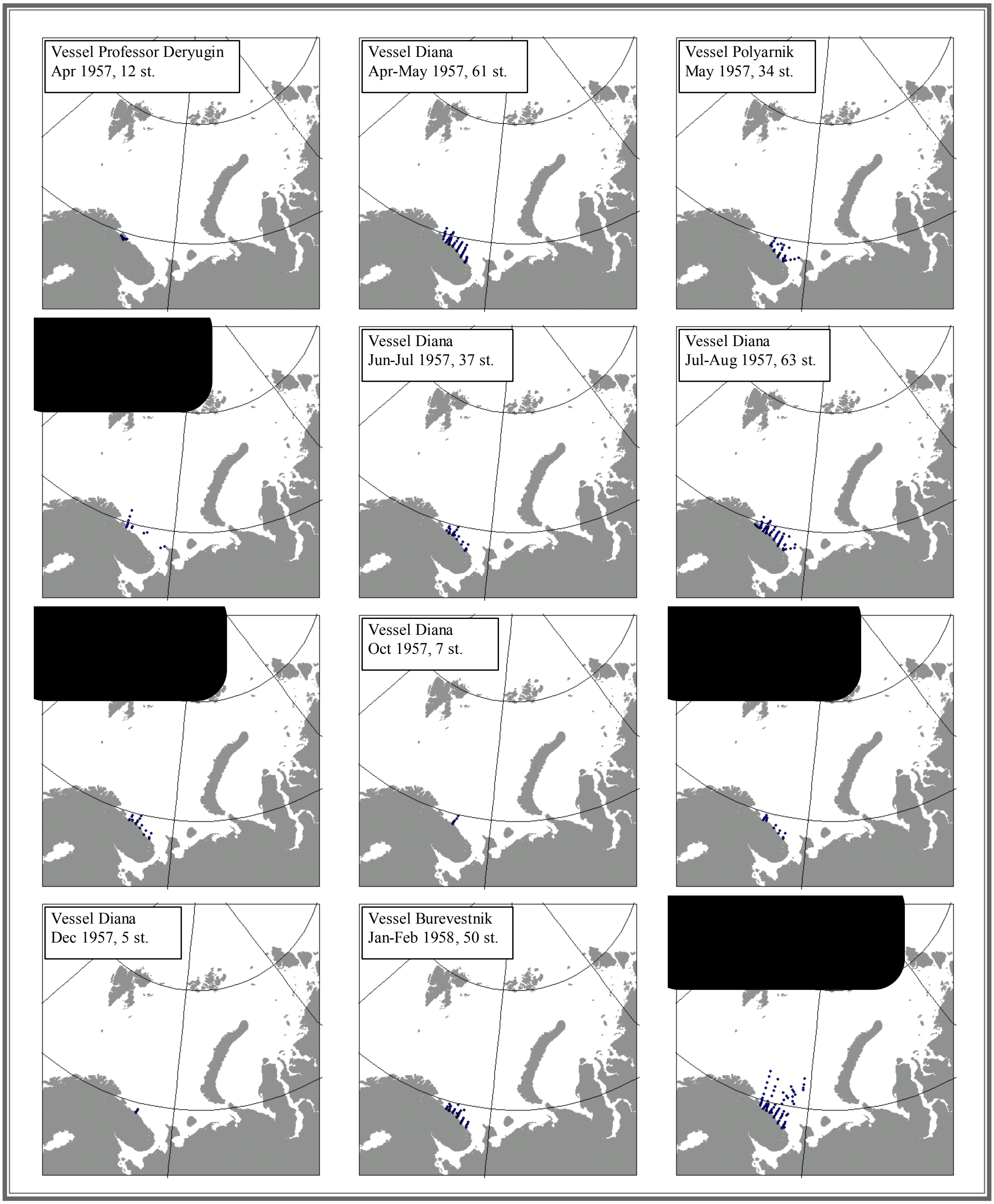


Fig. C4.8. 1957-1958

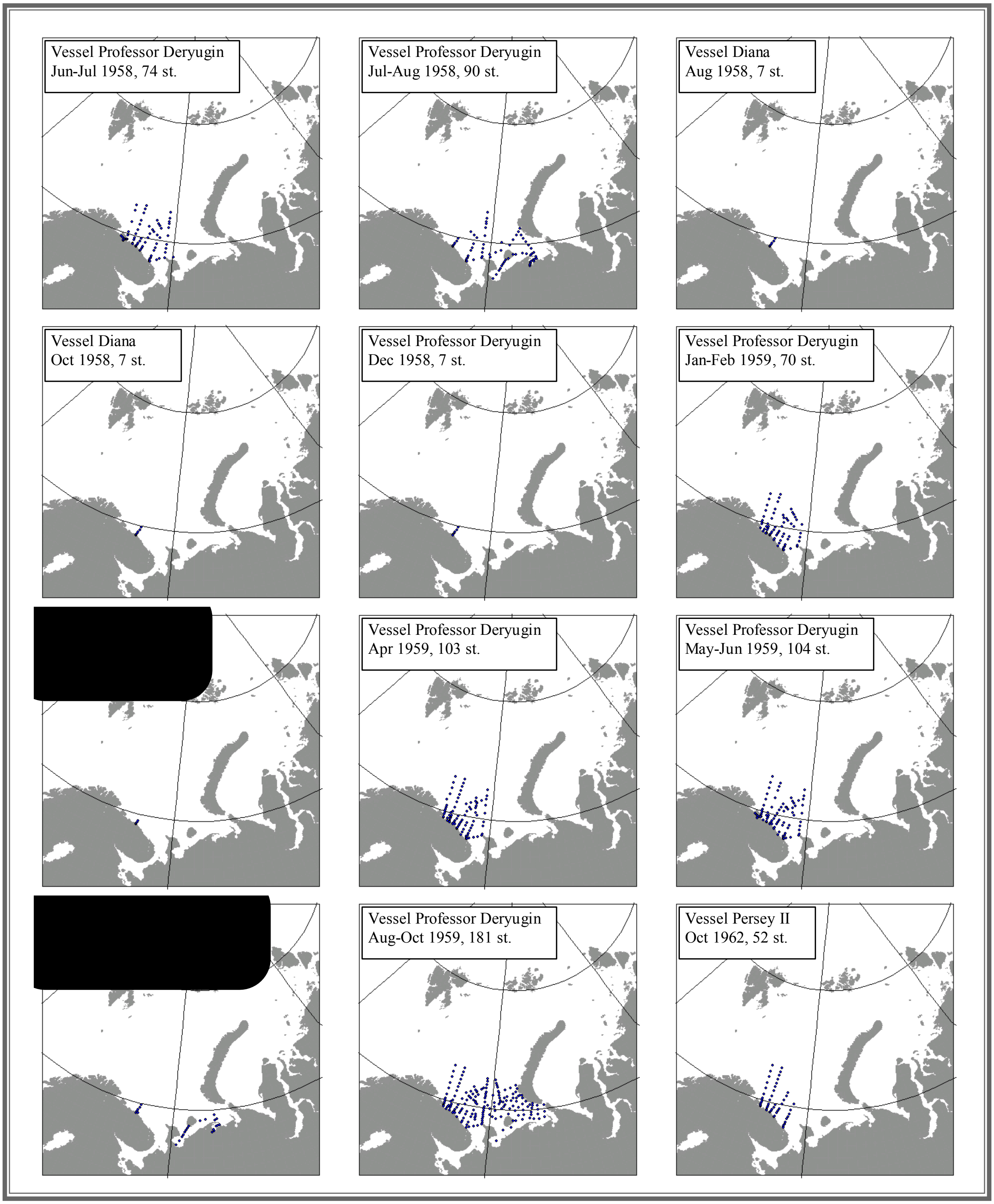


Fig. C4.9. 1958-1962

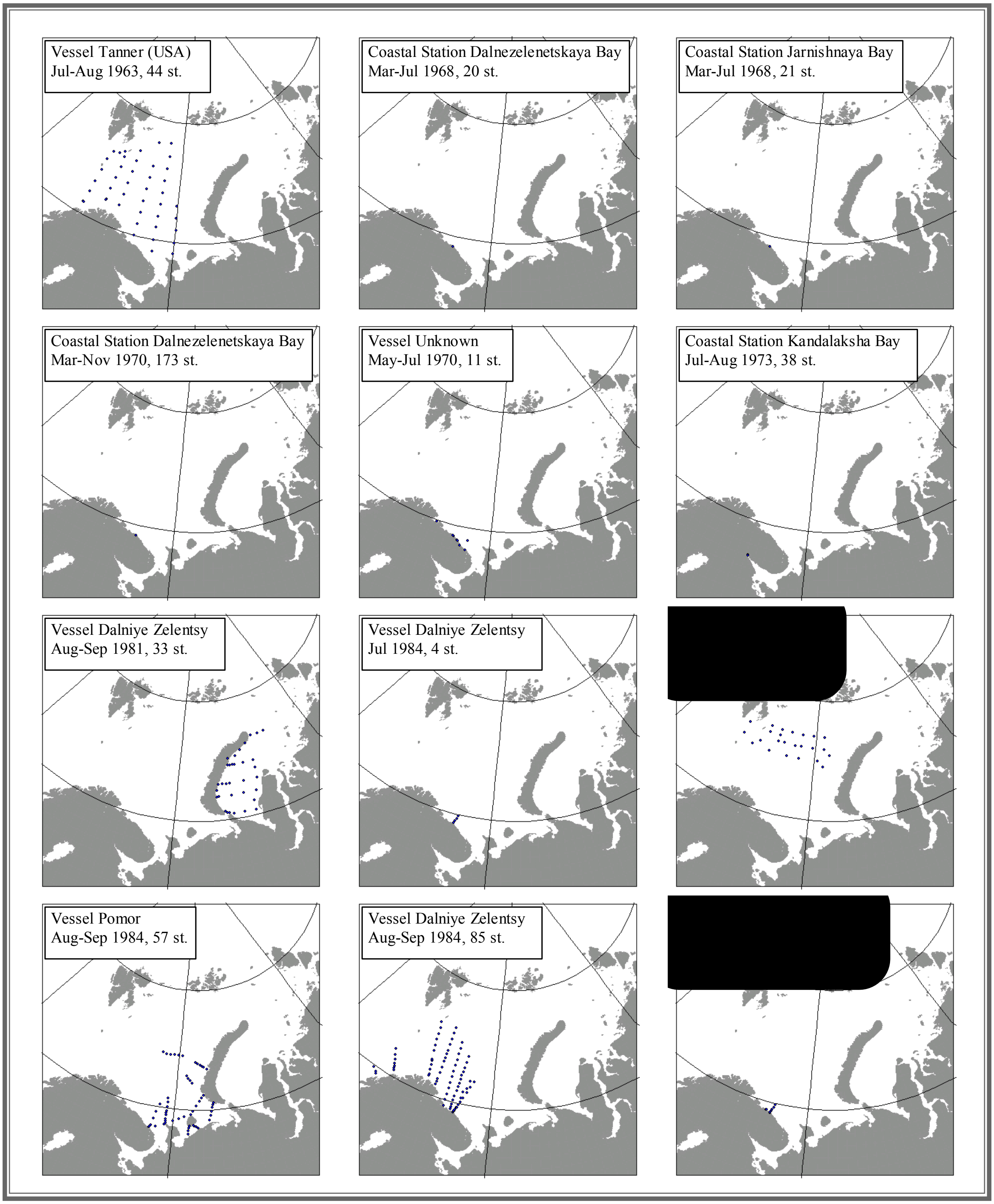


Fig. C4.10. 1963-1984

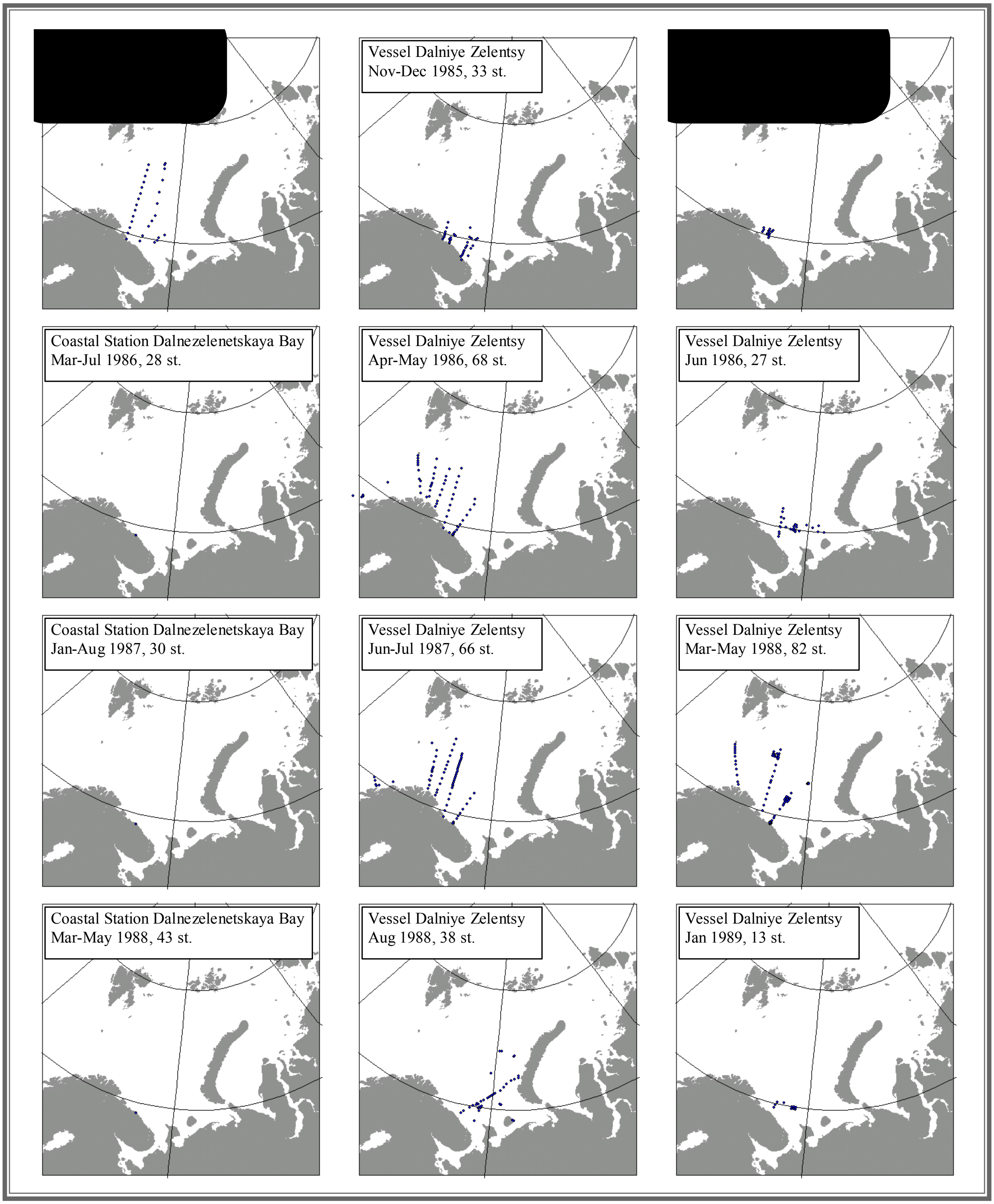


Fig. C4.11. 1985-1989

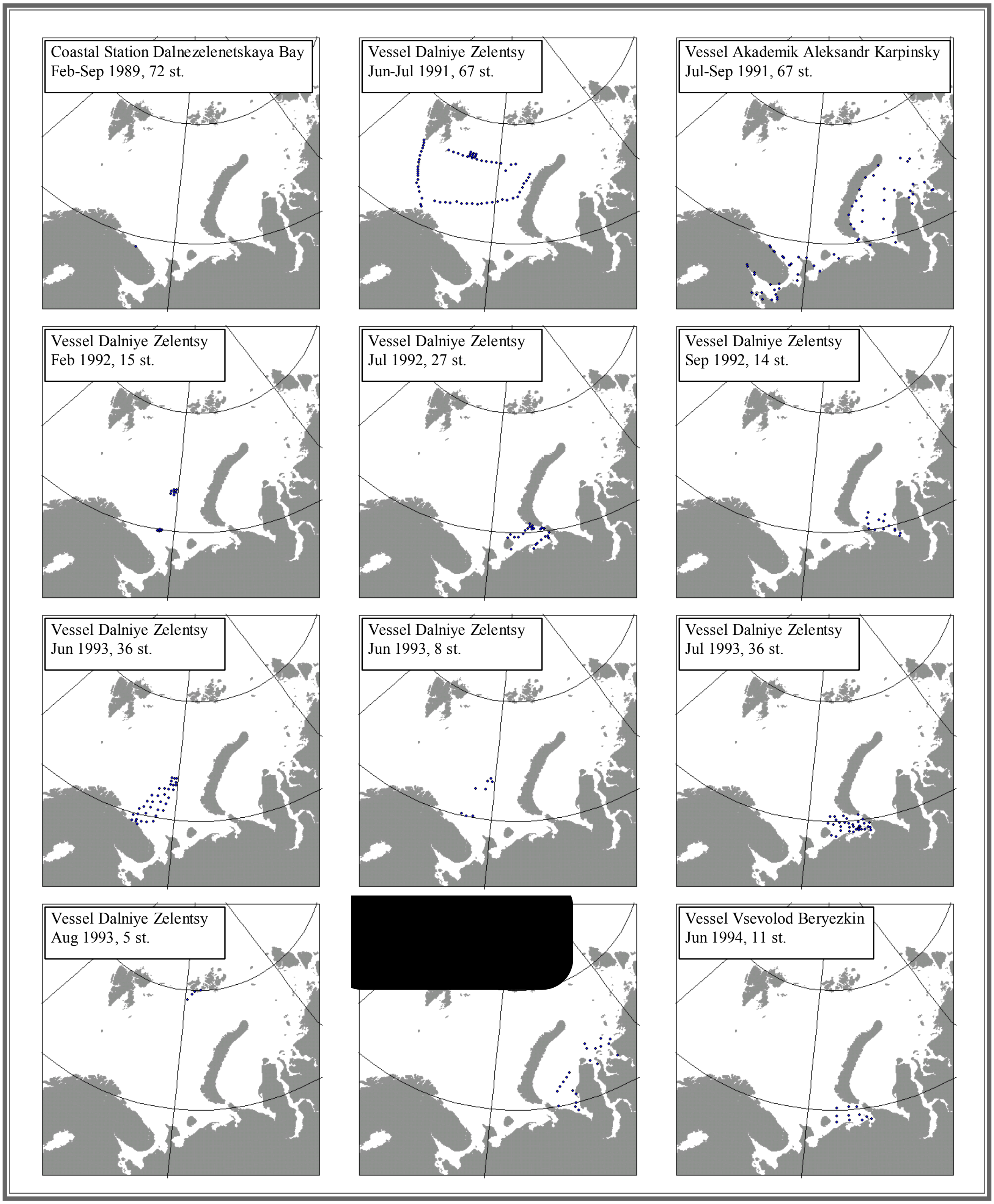


Fig. C4.12. 1989-1994

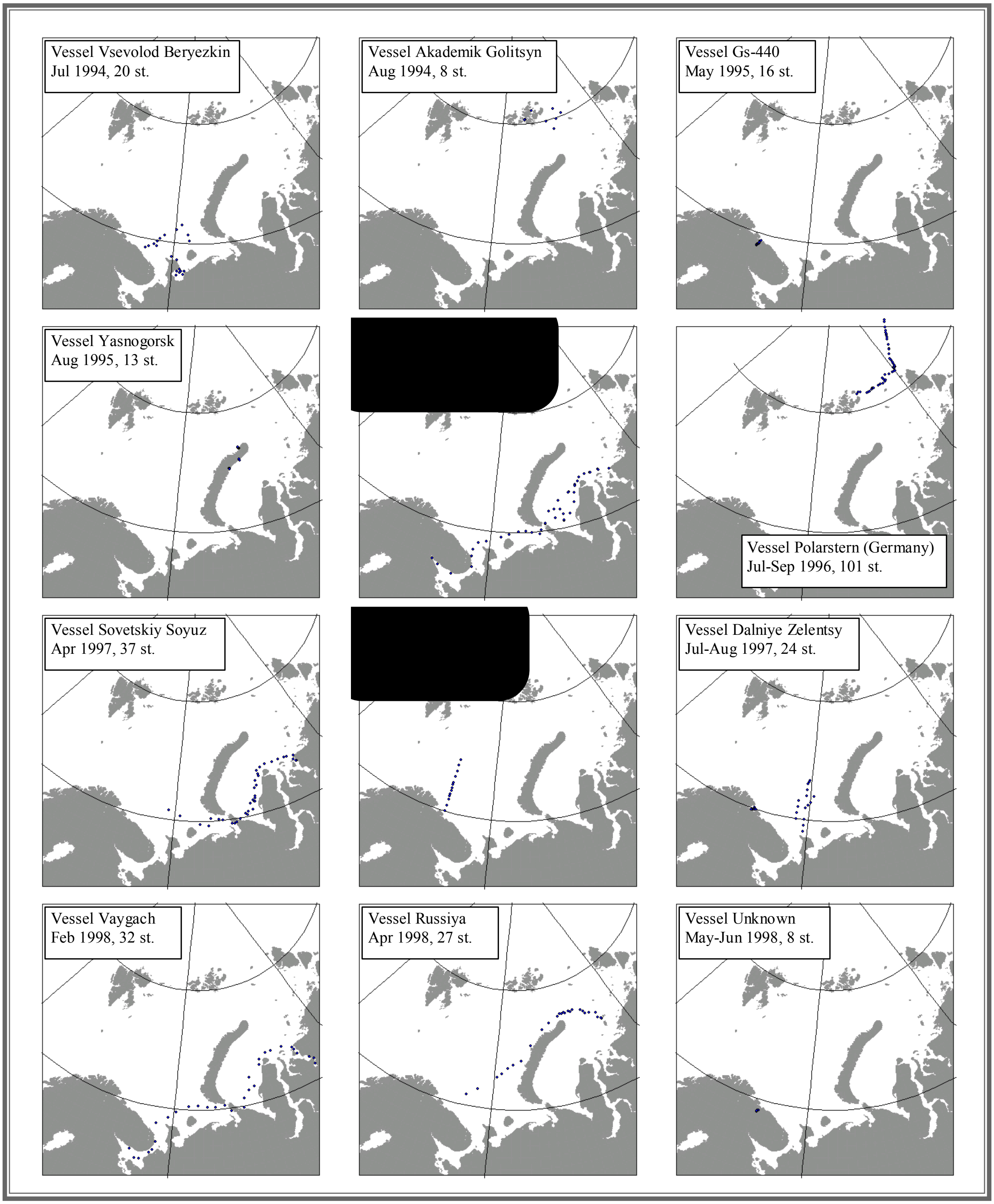


Fig. C4.13. 1994-1998

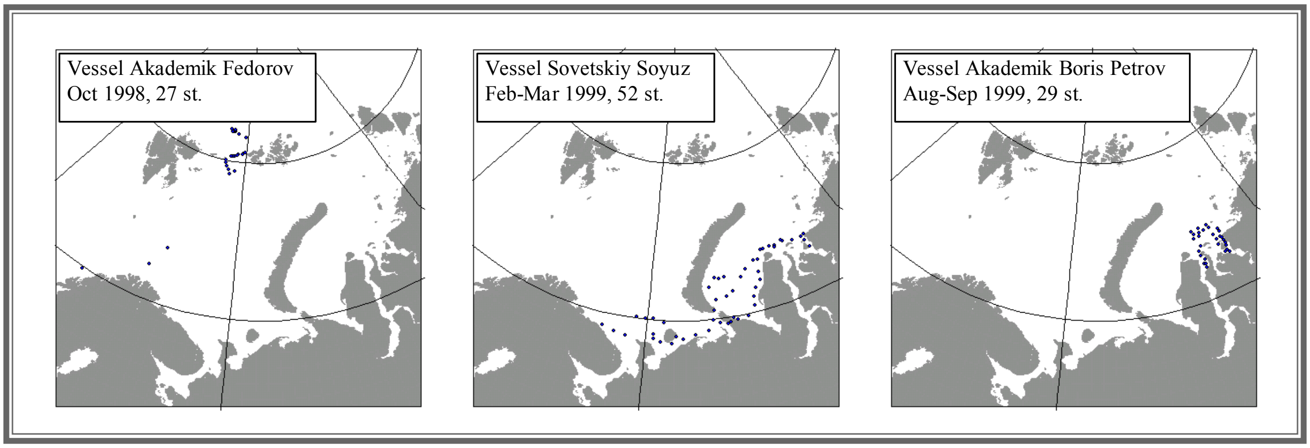


Fig. C4.14. 1998-1999

Appendix D. Temperature and salinity analyses

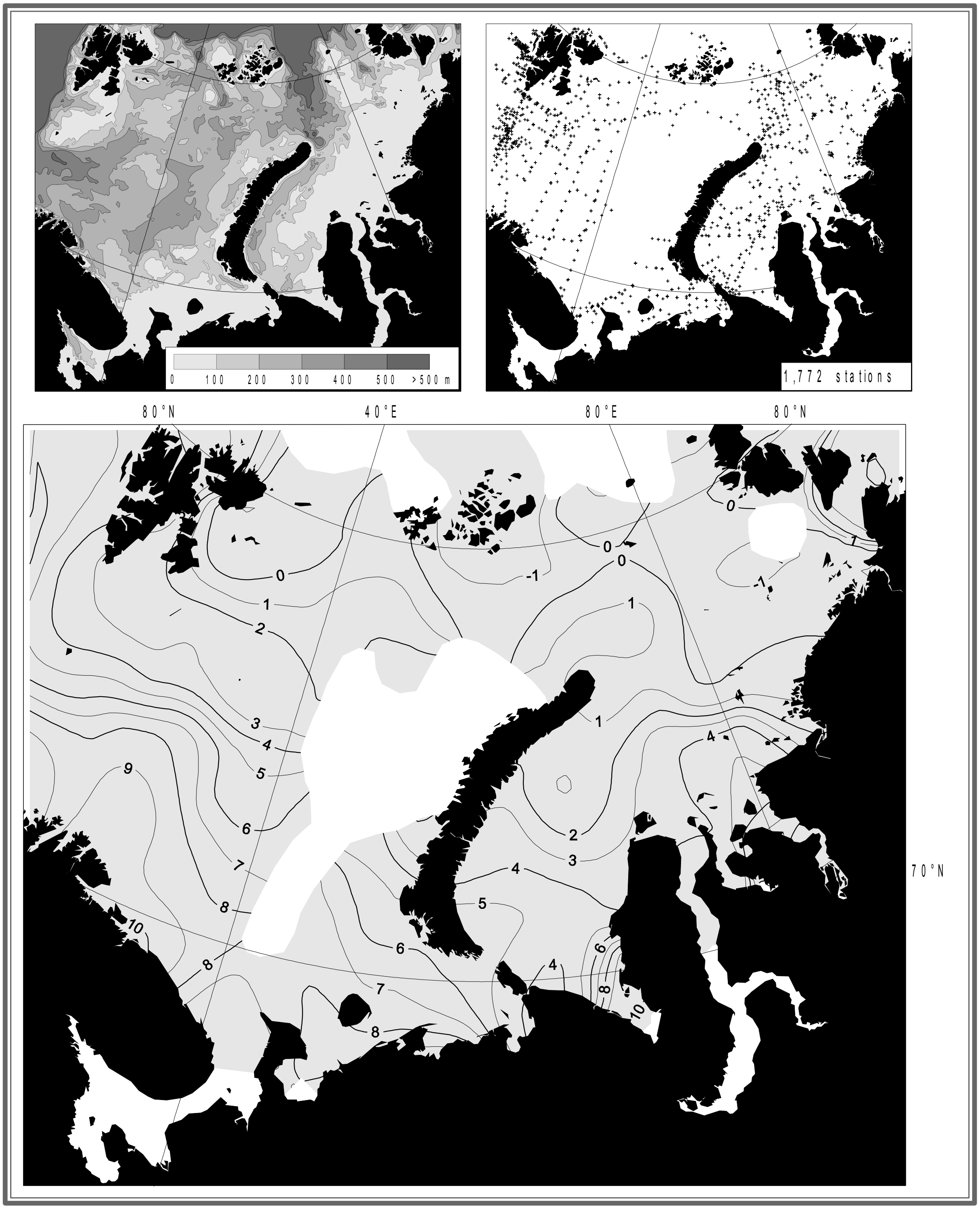


Fig. D1. Temperature (°C). August–September, 1920–1940. Depth 0 m

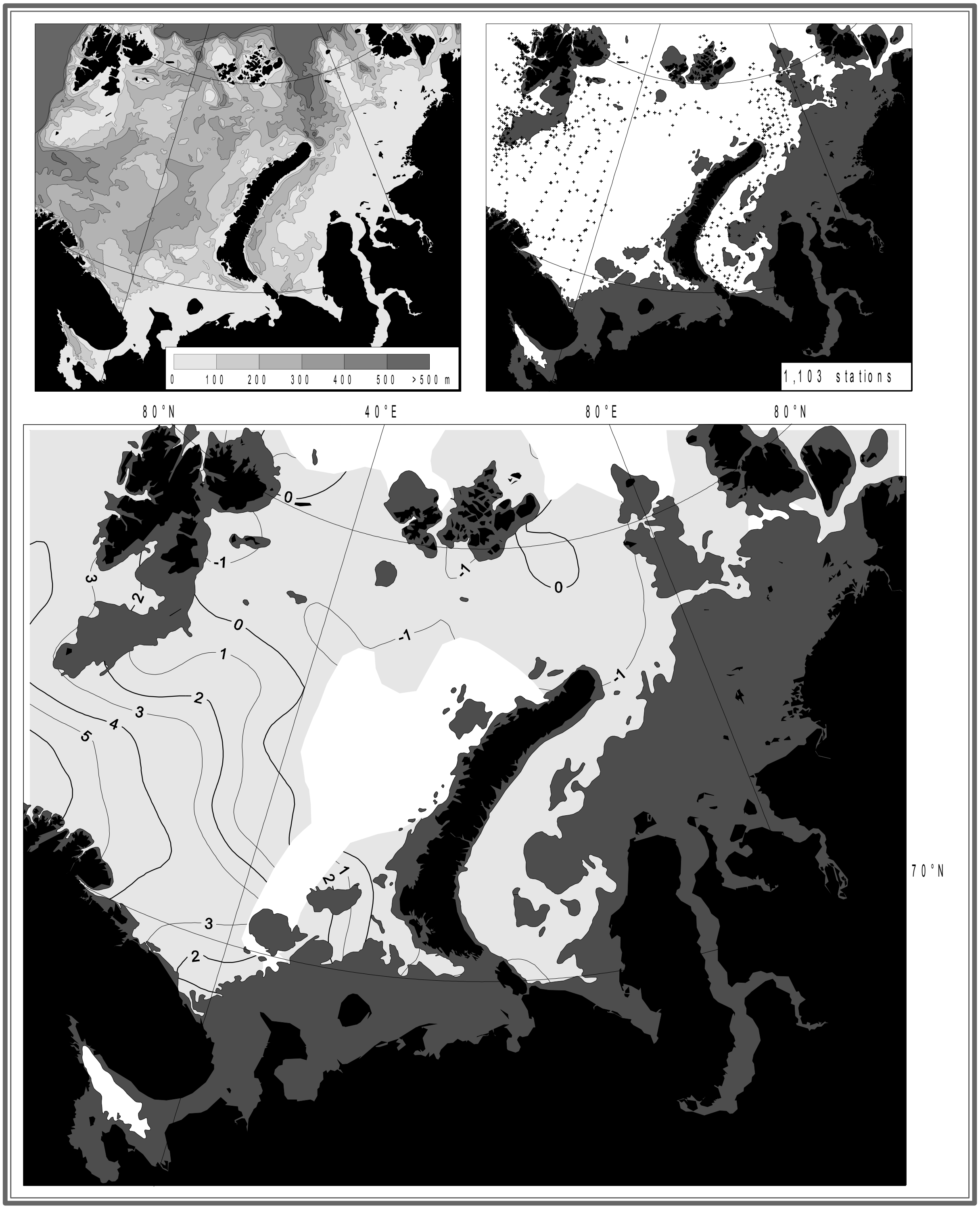


Fig. D2. Temperature (°C). August–September, 1920–1940. Depth 100 m

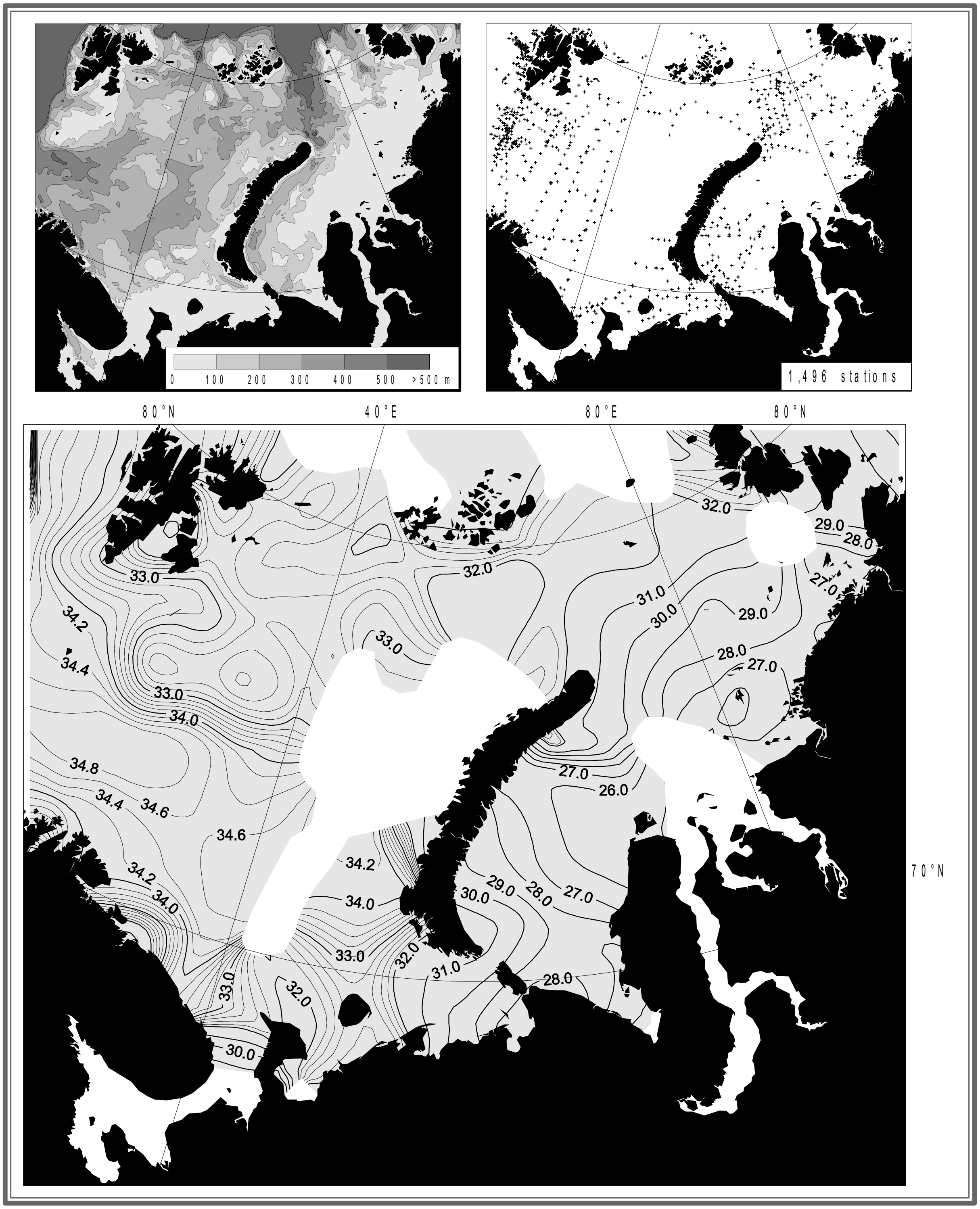


Fig. D3. Salinity (pss). August–September, 1920–1940. Depth 0 m

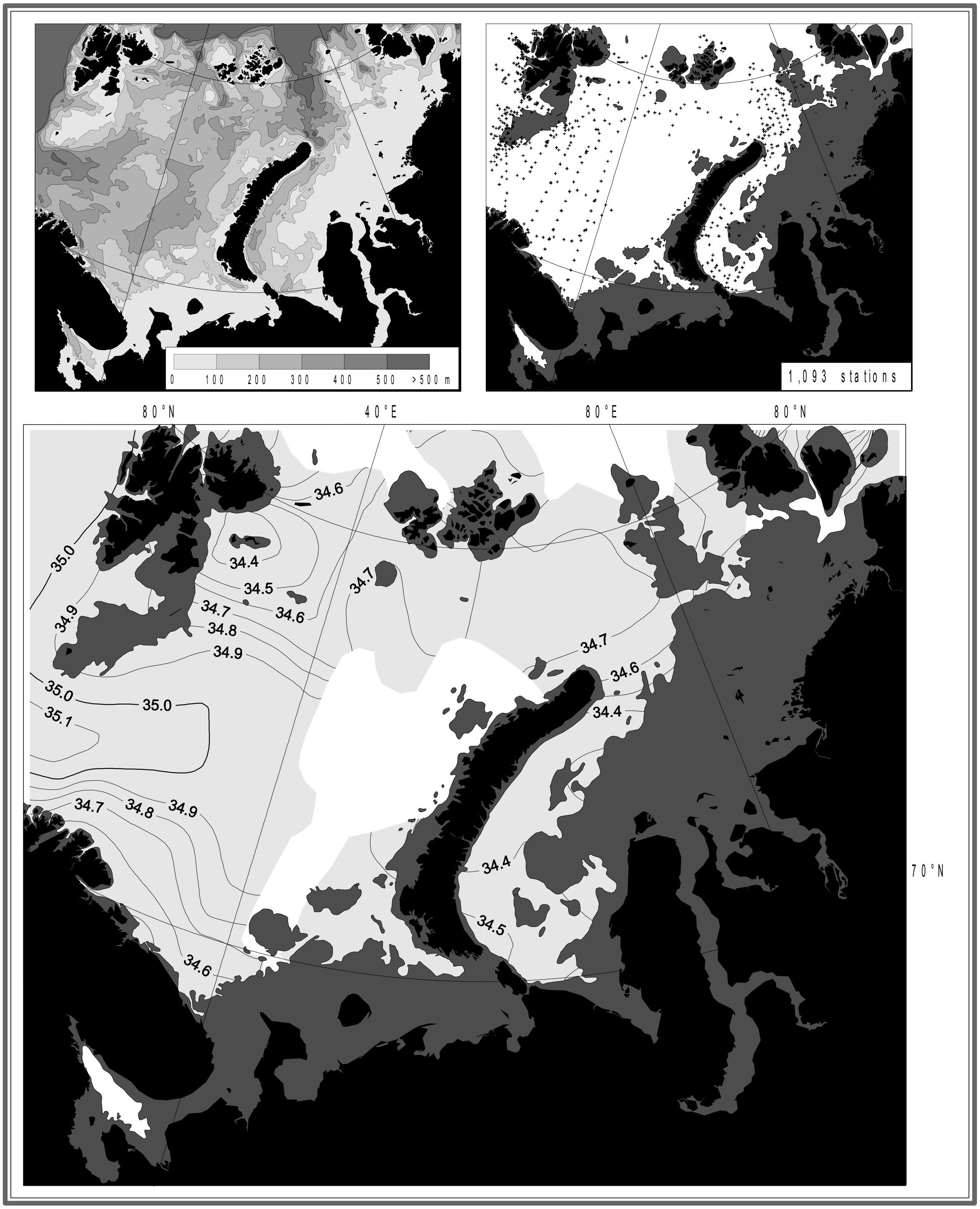


Fig. D4. Salinity (pss). August–September, 1920–1940. Depth 100 m

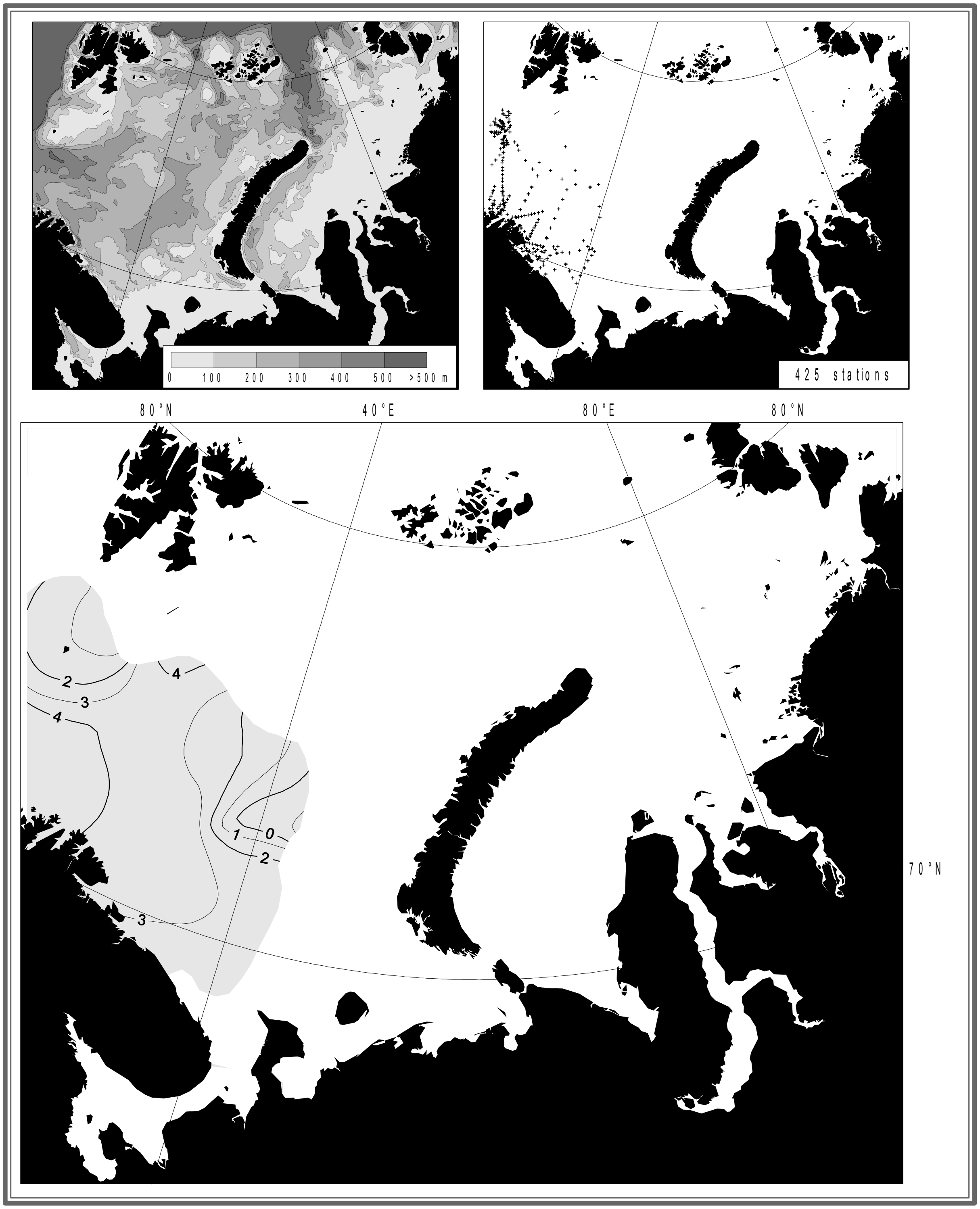


Fig. D5. Temperature (°C). February–April, 1920–1940. Depth 0 m

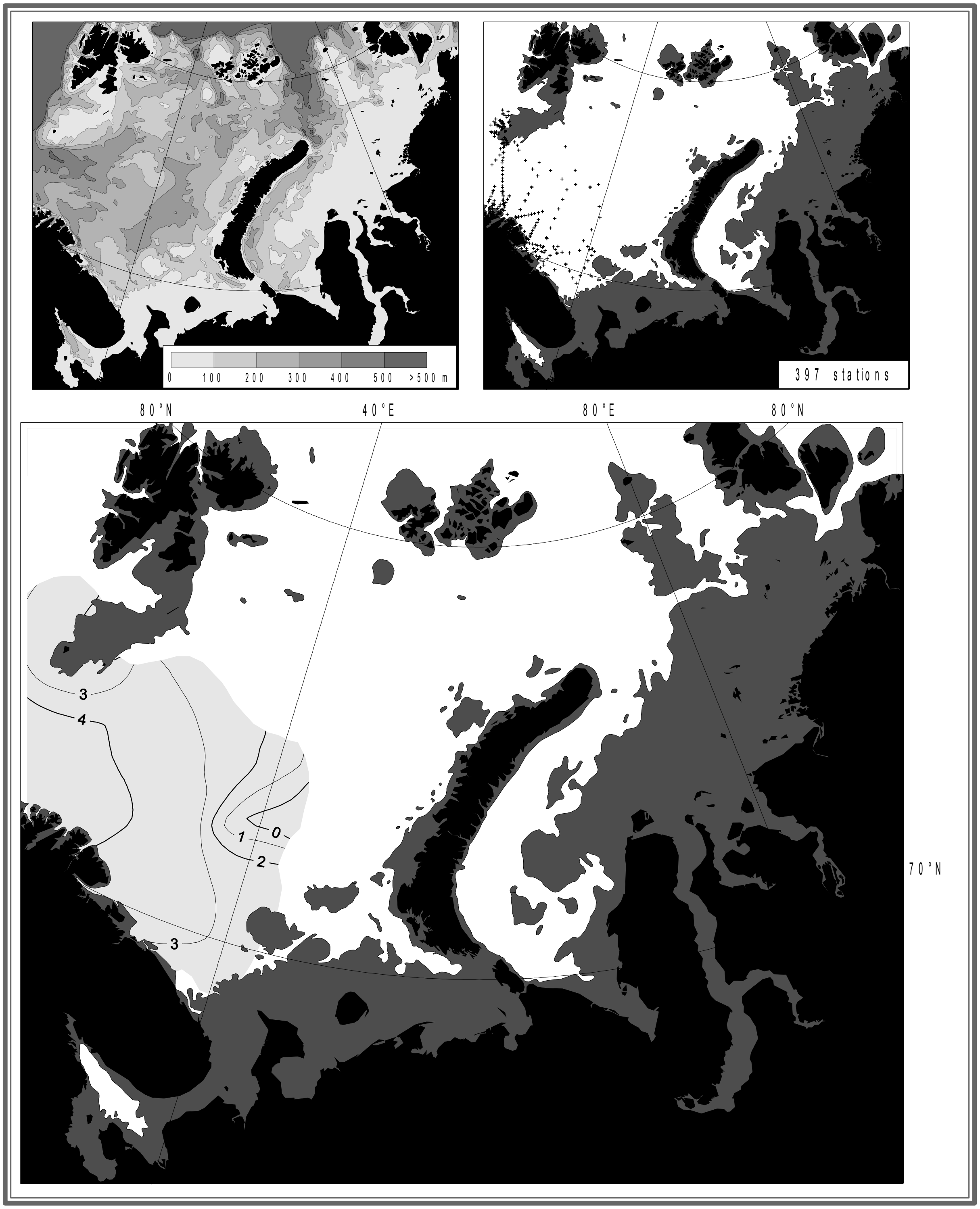


Fig. D6. Temperature (°C). February–April, 1920–1940. Depth 100 m

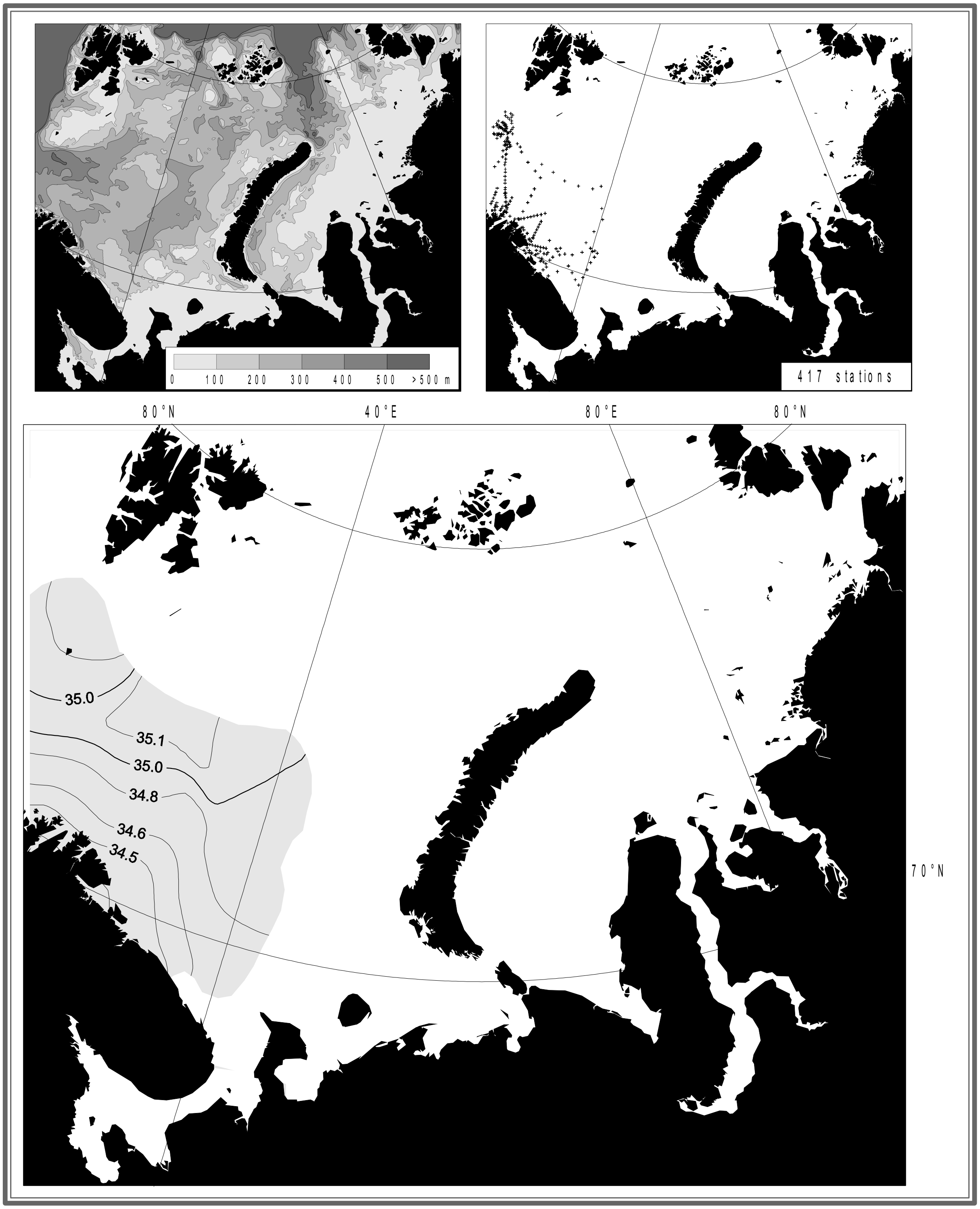


Fig. D7. Salinity (pss). February-April, 1920–1940. Depth 0 m

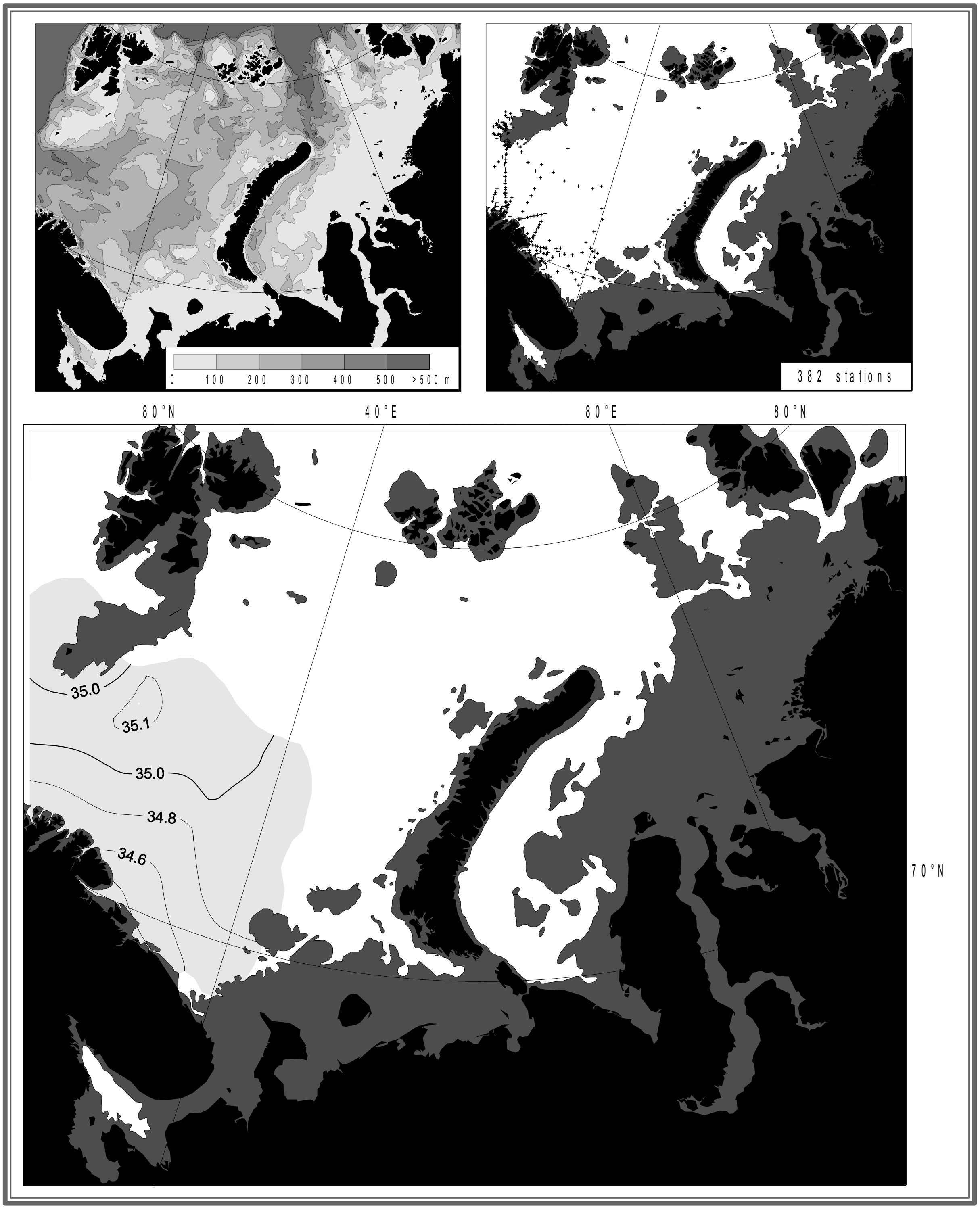


Fig. D8. Salinity (pss). February-April, 1920–1940. Depth 100 m

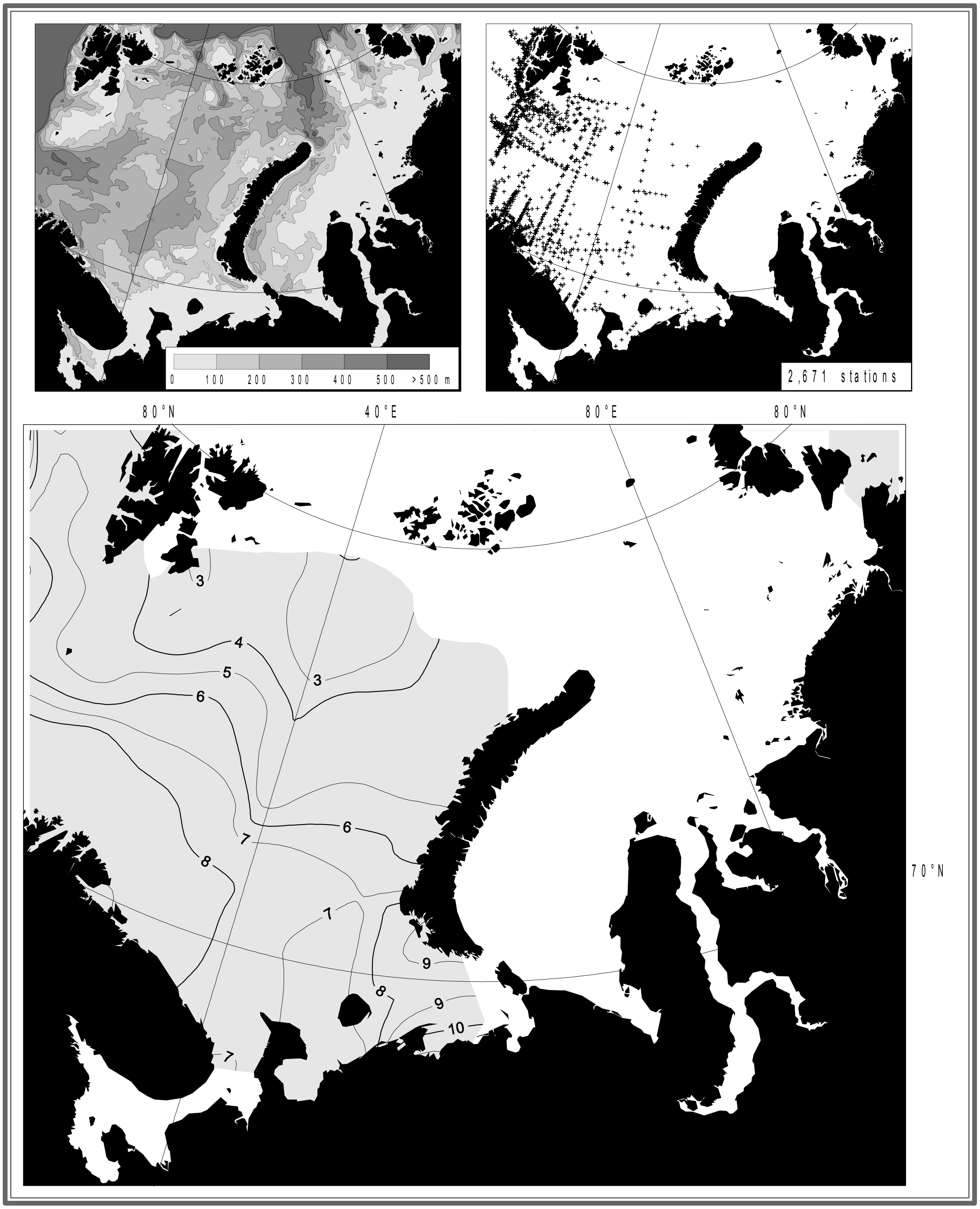


Fig. D9. Temperature (°C). August–September, 1950–1960. Depth 0 m

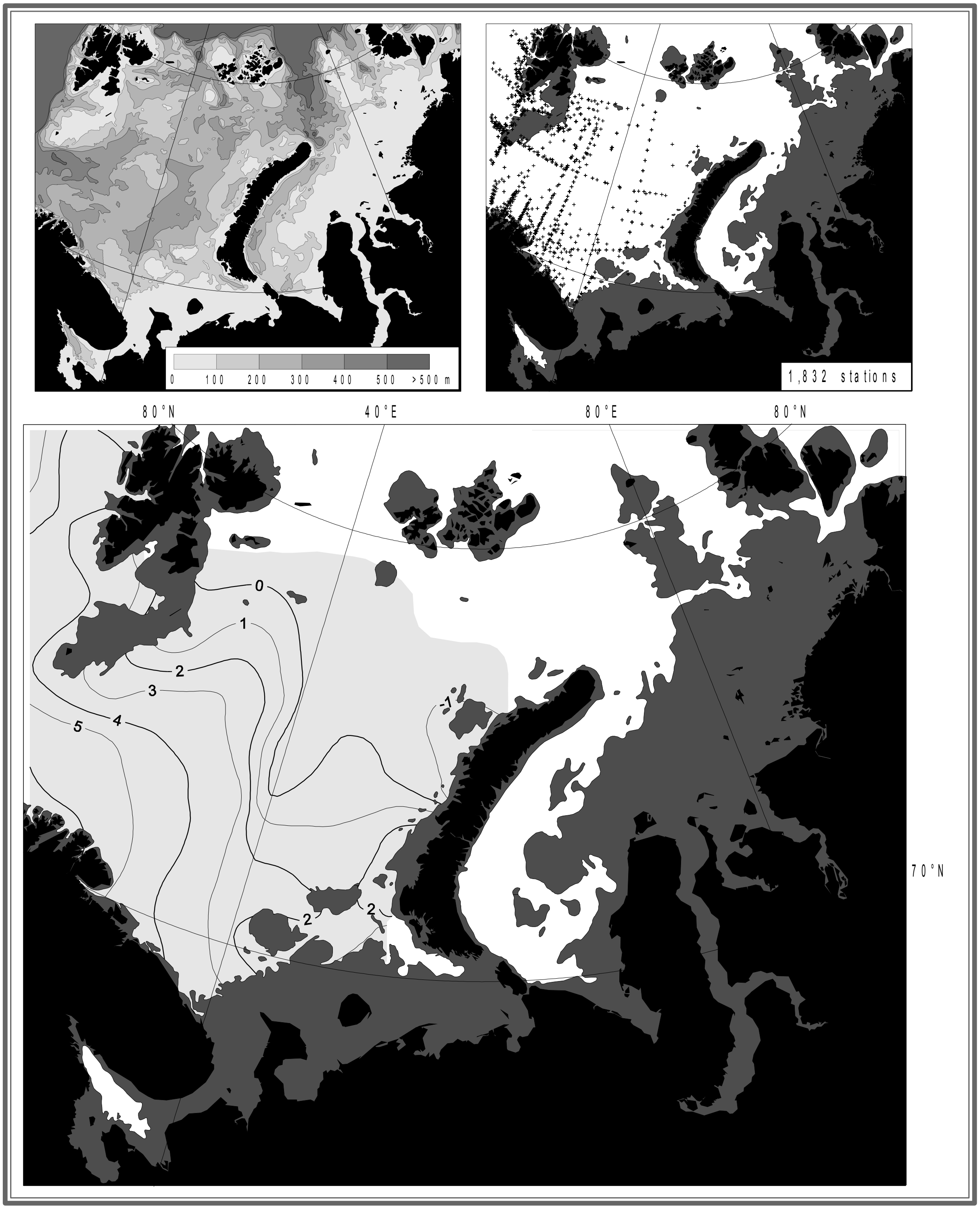


Fig. D10. Temperature (°C). August–September, 1950–1960. Depth 100 m

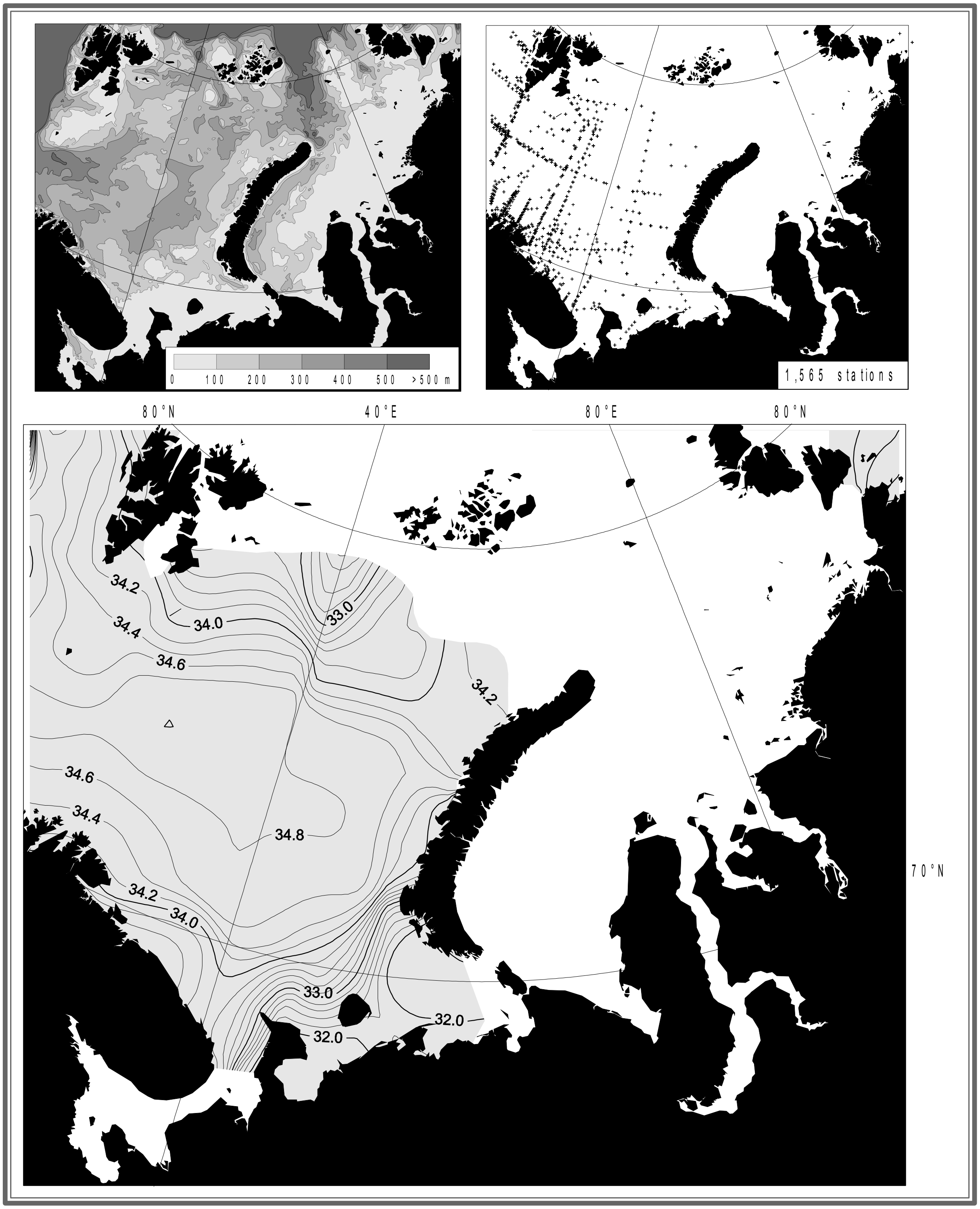


Fig. D11. Salinity (pss). August-September, 1950–1960. Depth 0 m

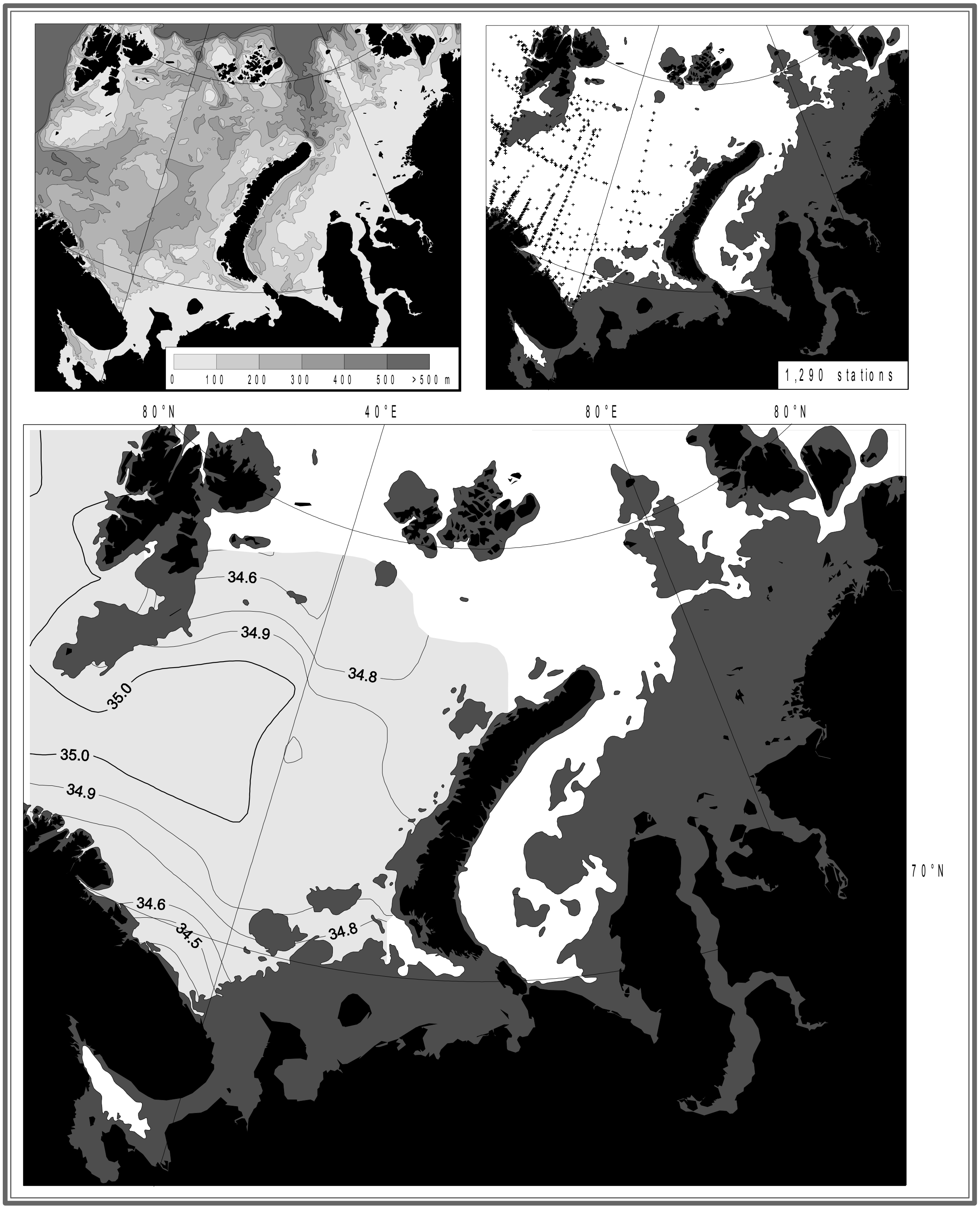


Fig. D12 Salinity (pss). August-September, 1950–1960. Depth 100 m

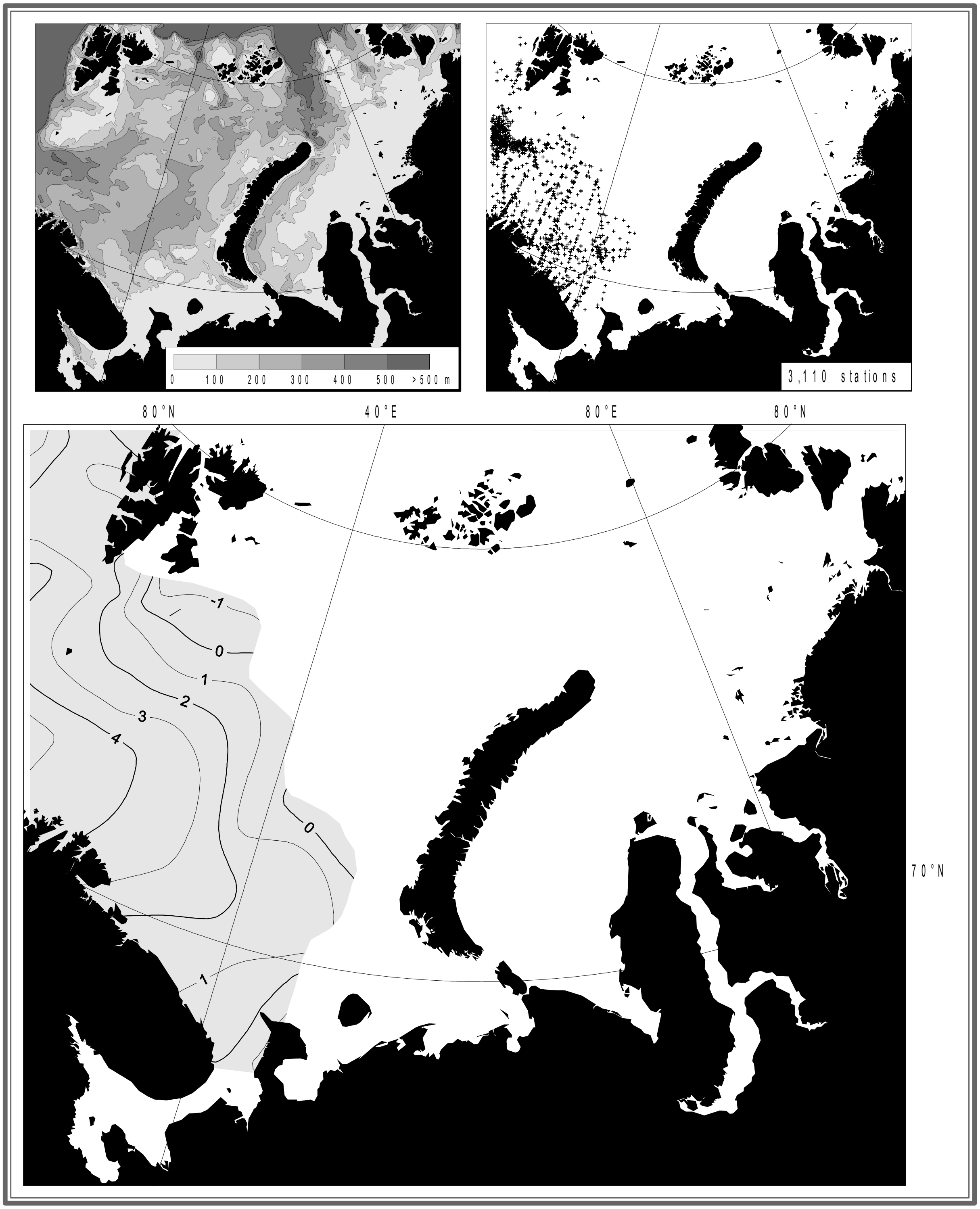


Fig. D13. Temperature (°C). February–April, 1950–1960. Depth 0 m

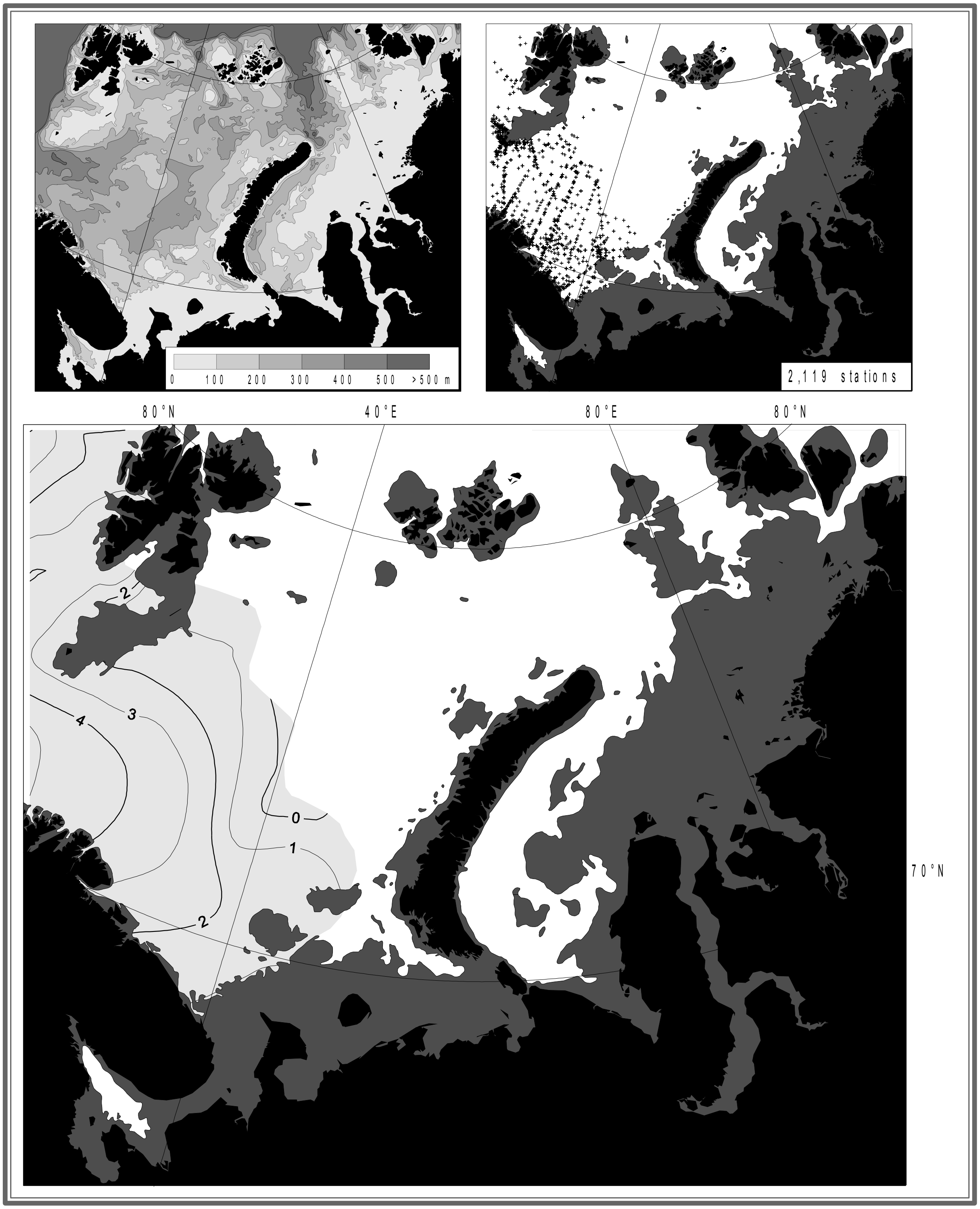


Fig. D14. Temperature (°C). February–April, 1950–1960. Depth 100 m

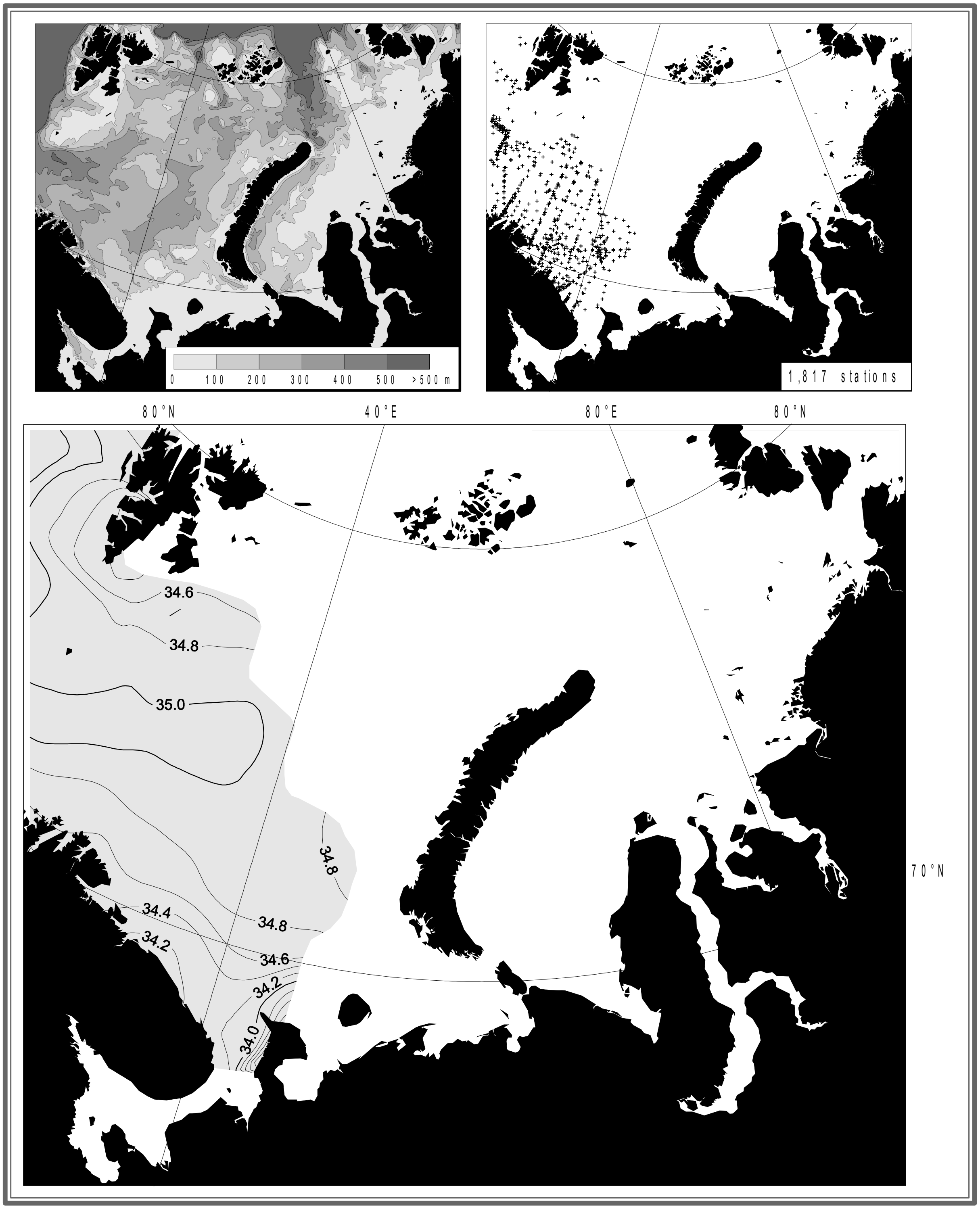


Fig. D15. Salinity (pss). February-April, 1950–1960. Depth 0 m

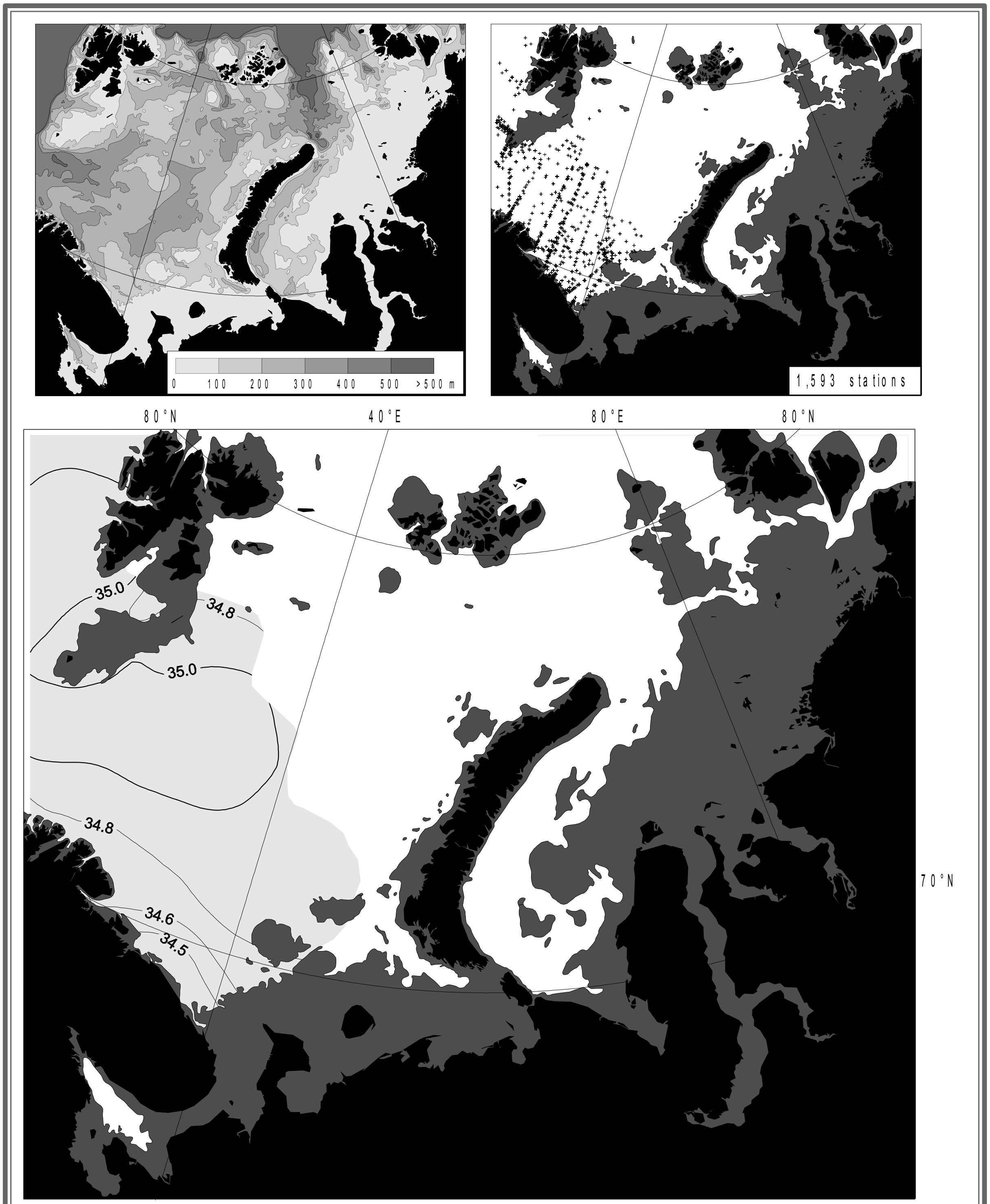


Fig. D16. Salinity (pss). February-April, 1950–1960. Depth 100 m

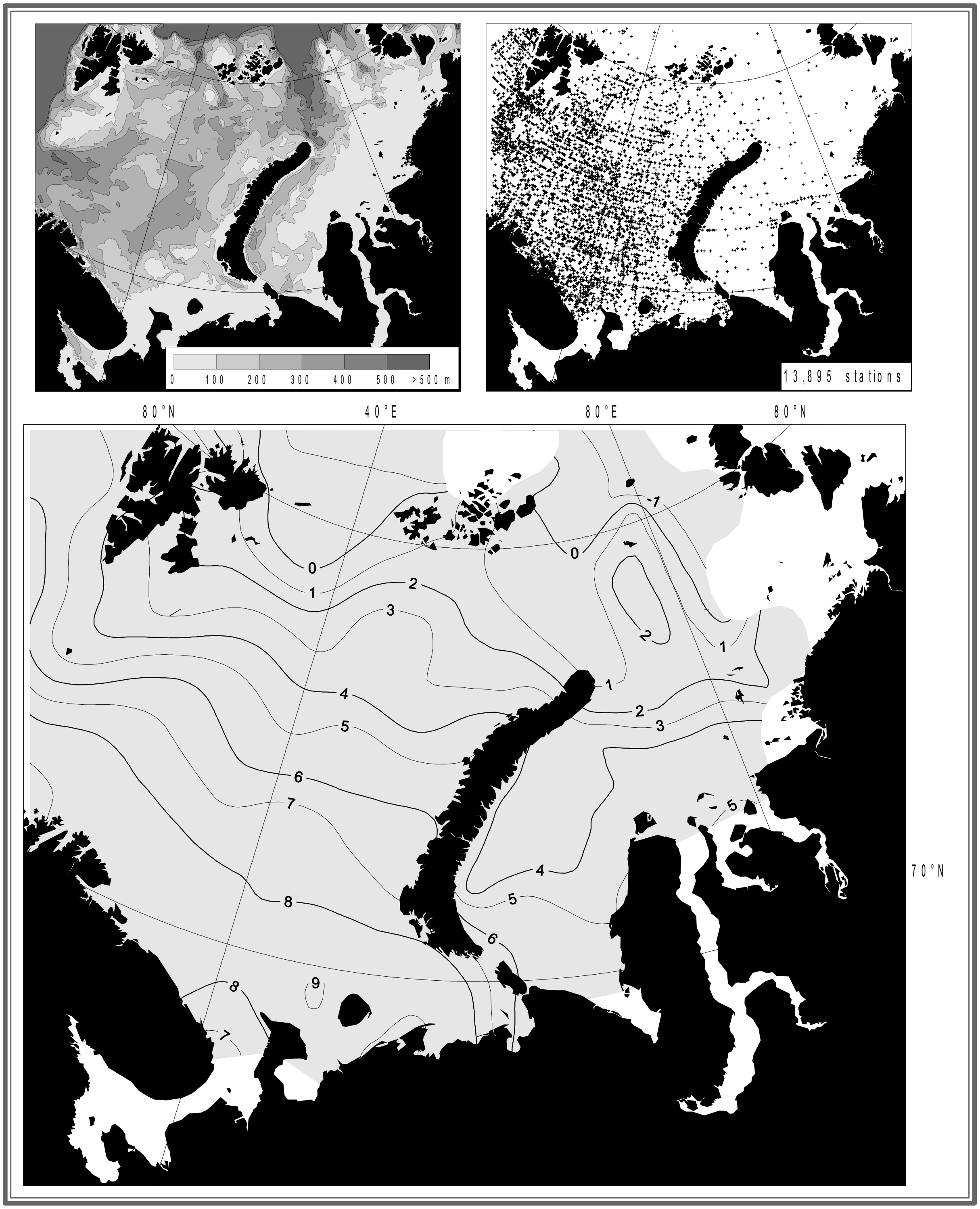


Fig. D17. Temperature (°C). August–September, 1980–1990. Depth 0 m

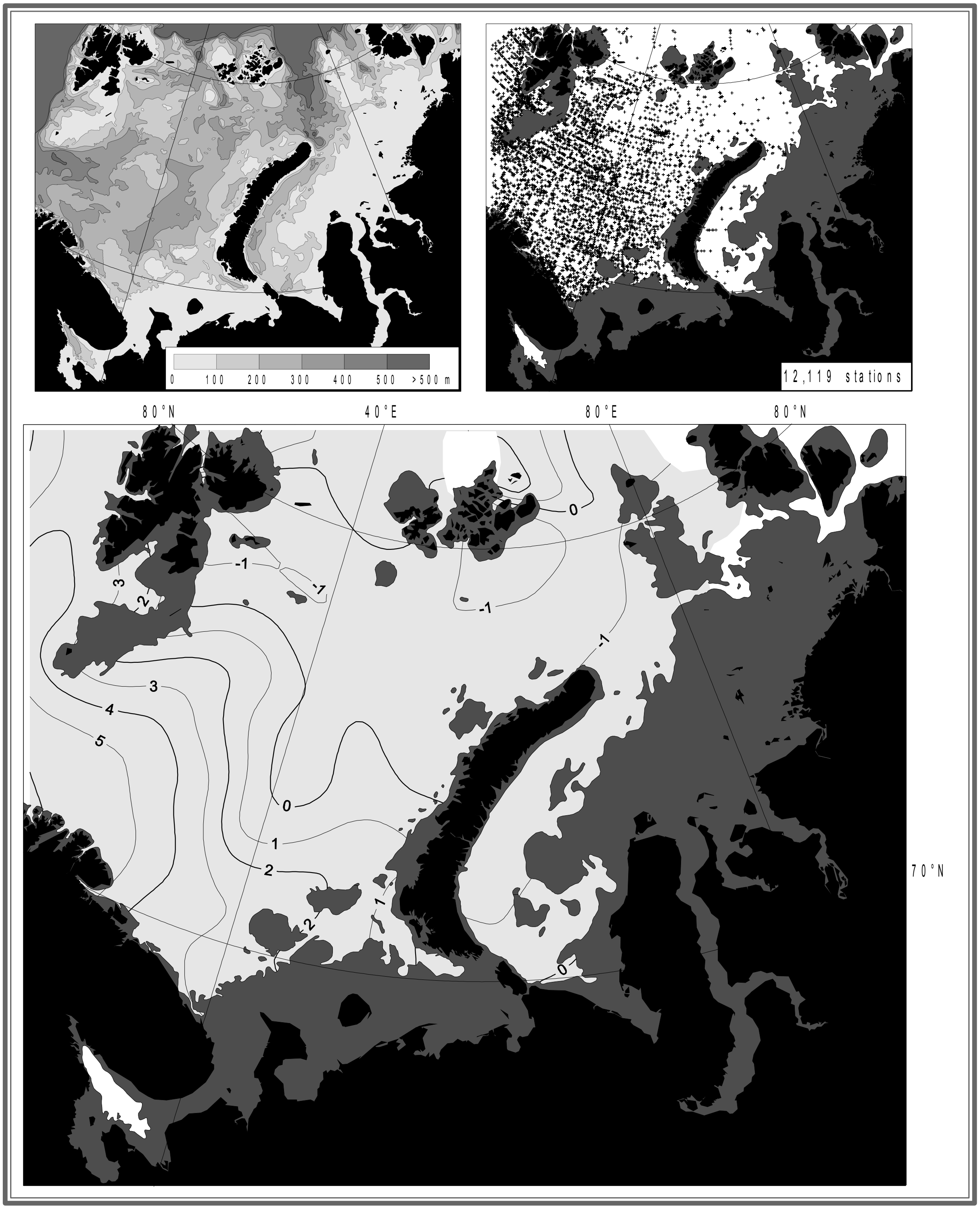


Fig. D18. Temperature (°C). August–September, 1980–1990. Depth 100 m

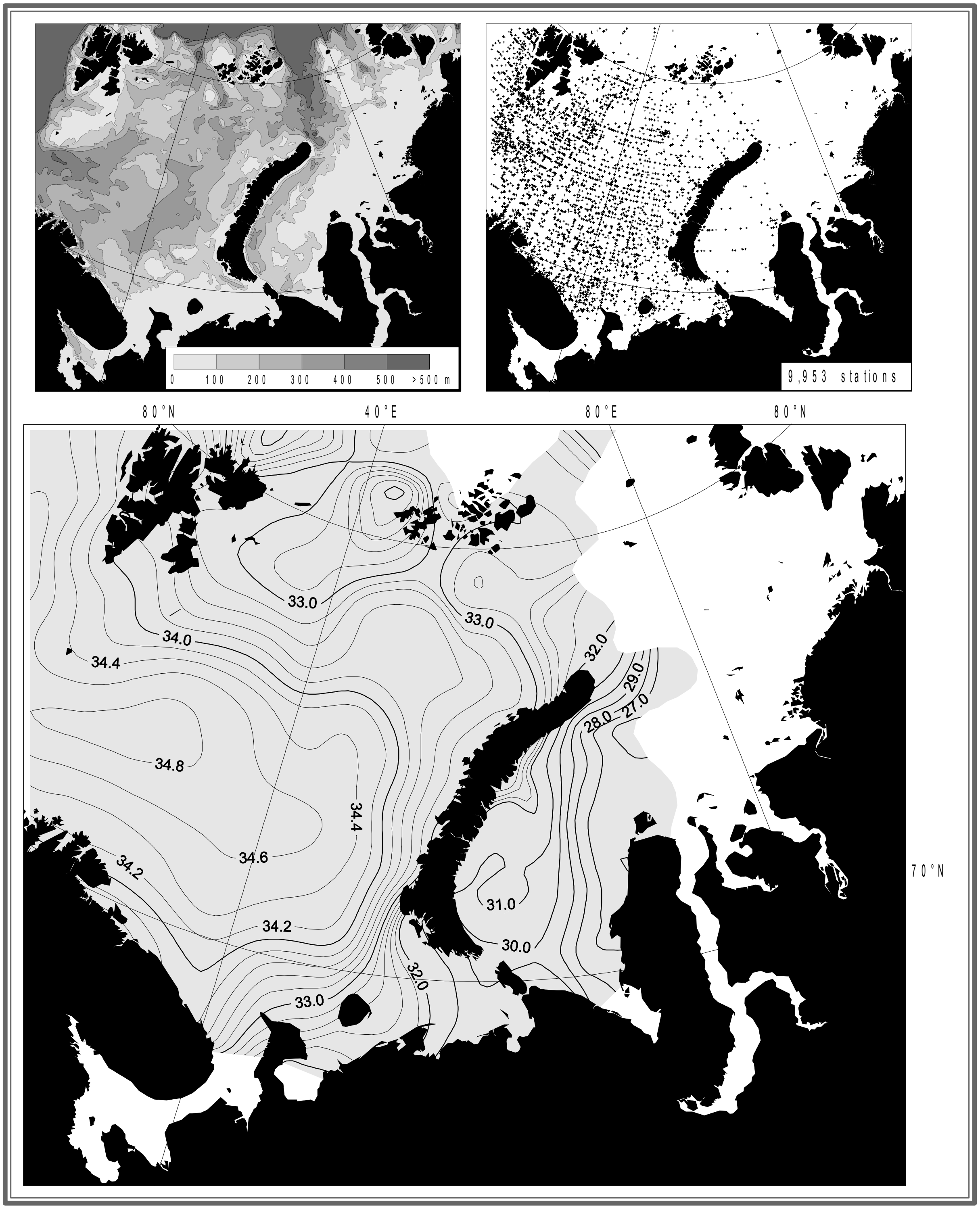


Fig. D19. Salinity (pss). August–September, 1980–1990. Depth 0 m

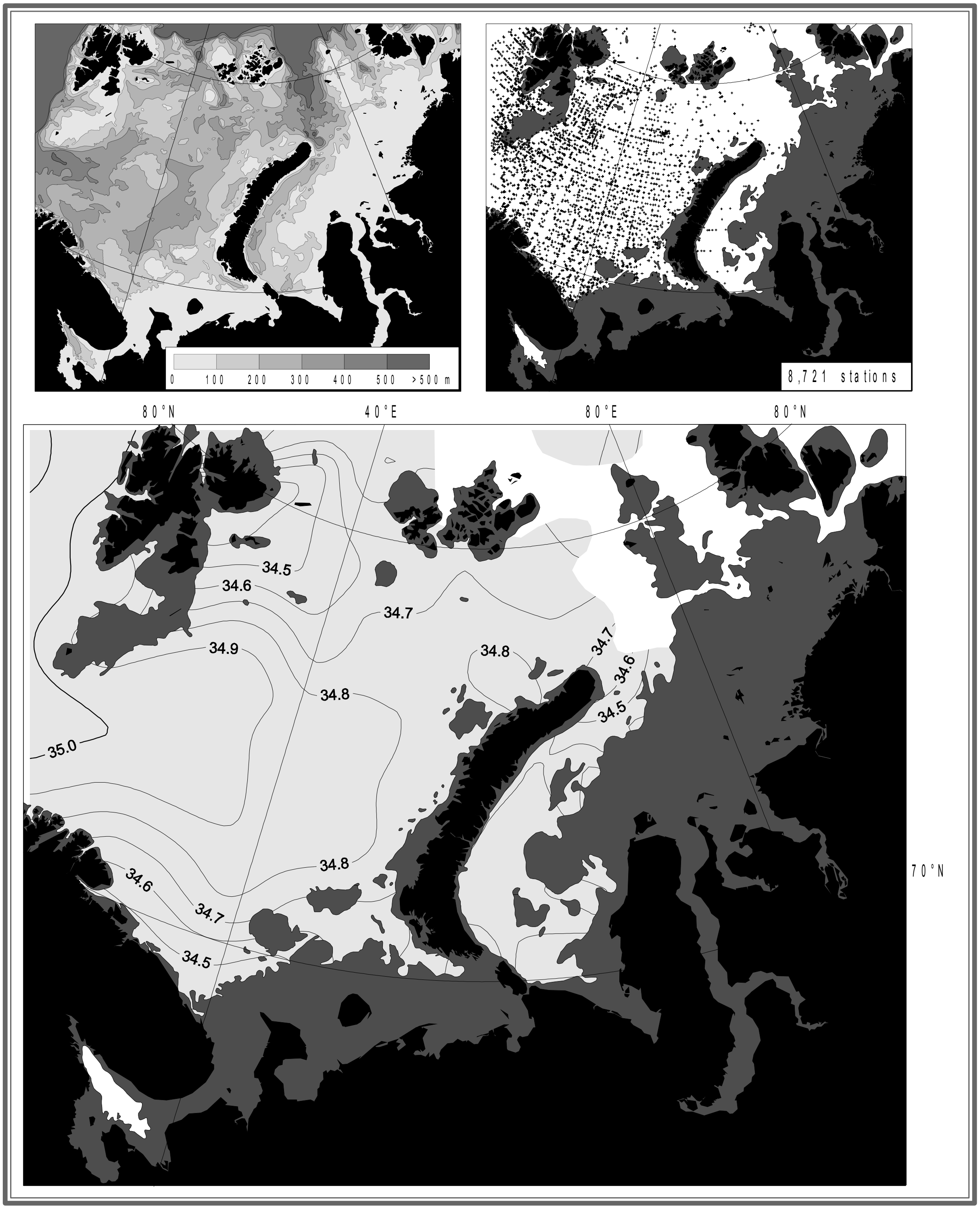


Fig. D20. Salinity (pss). August–September, 1980–1990. Depth 100 m

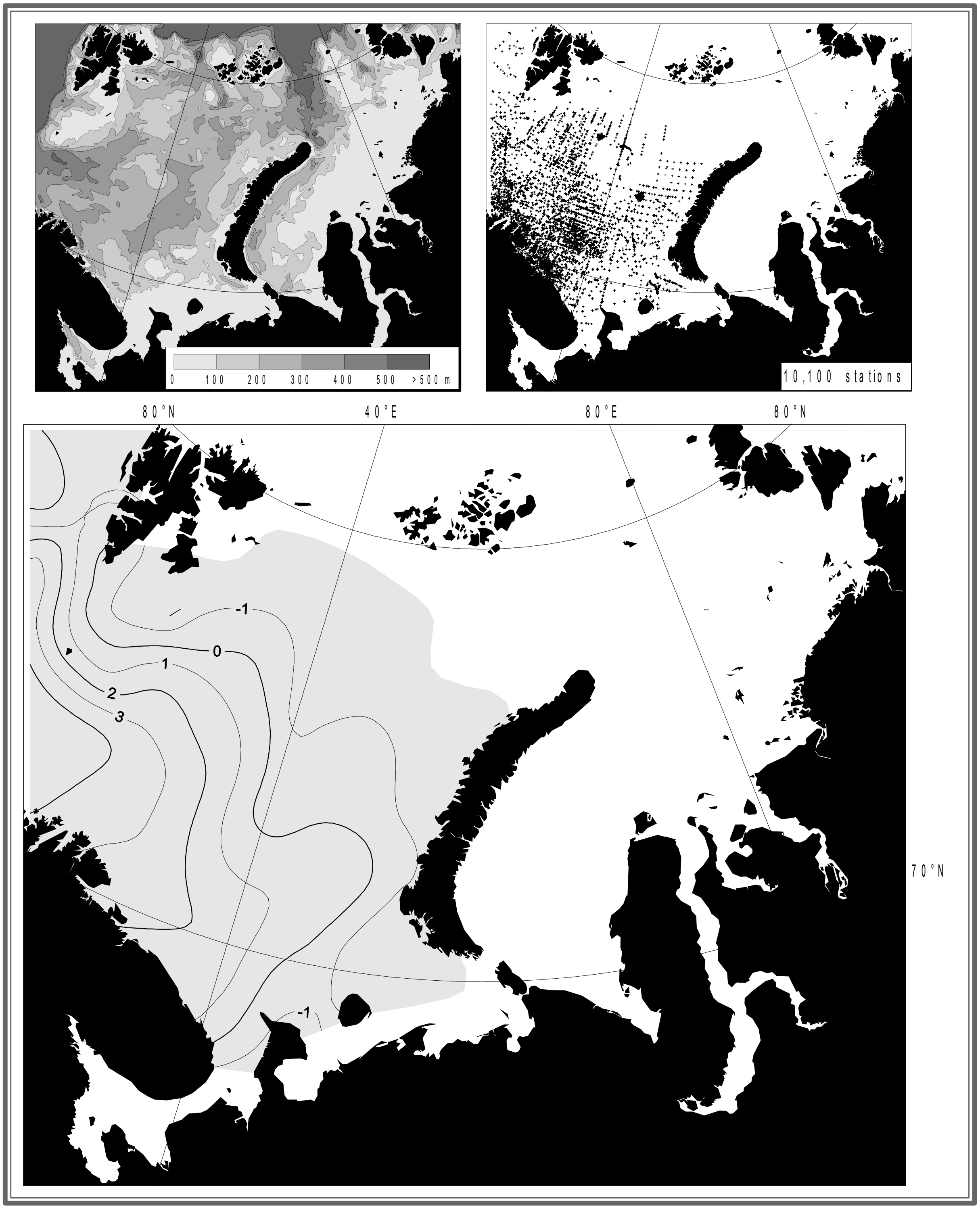


Fig. D21. Temperature (°C). February-April, 1980–1990. Depth 0 m

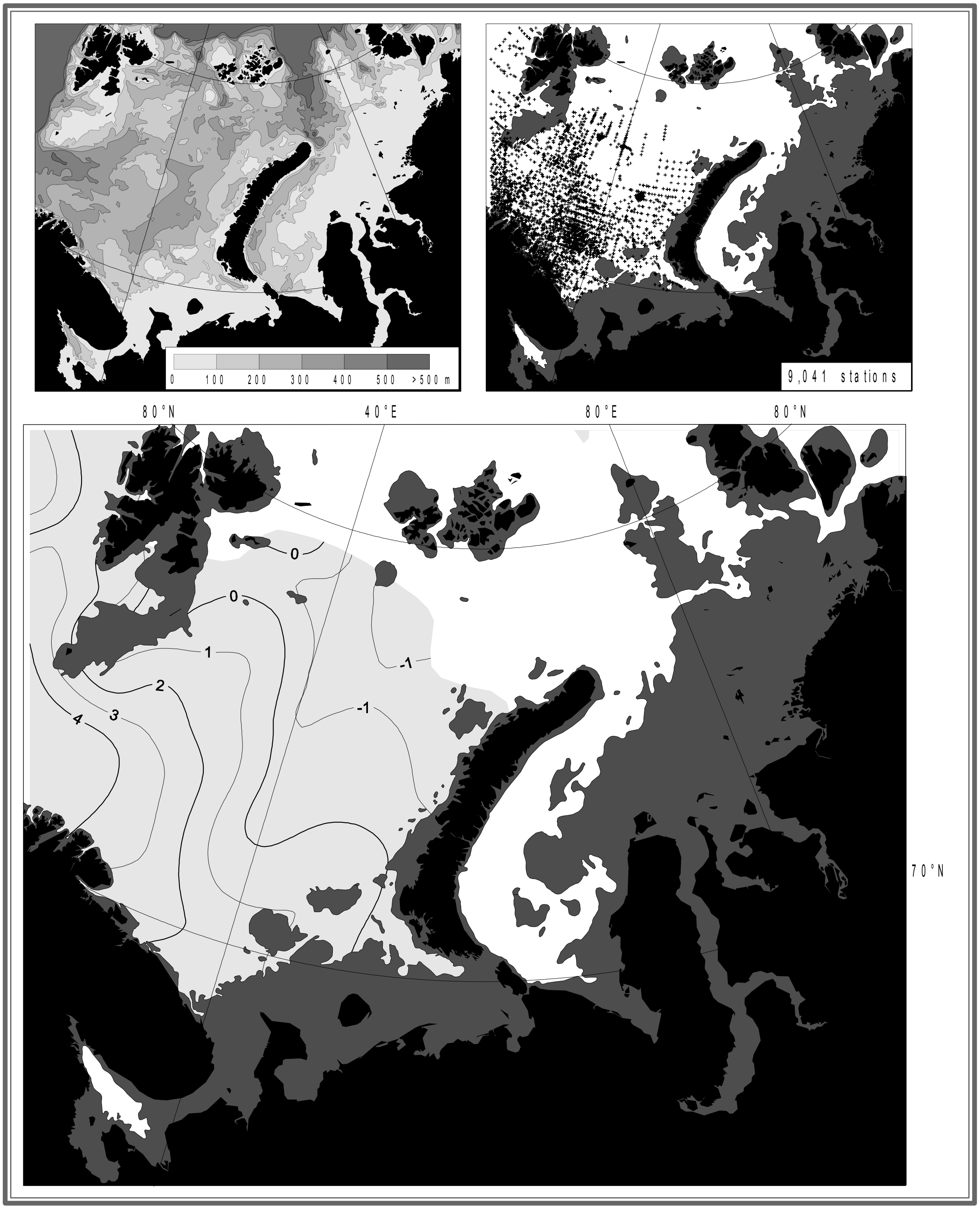


Fig. D22. Temperature (°C). February-April, 1980–1990. Depth 100 m

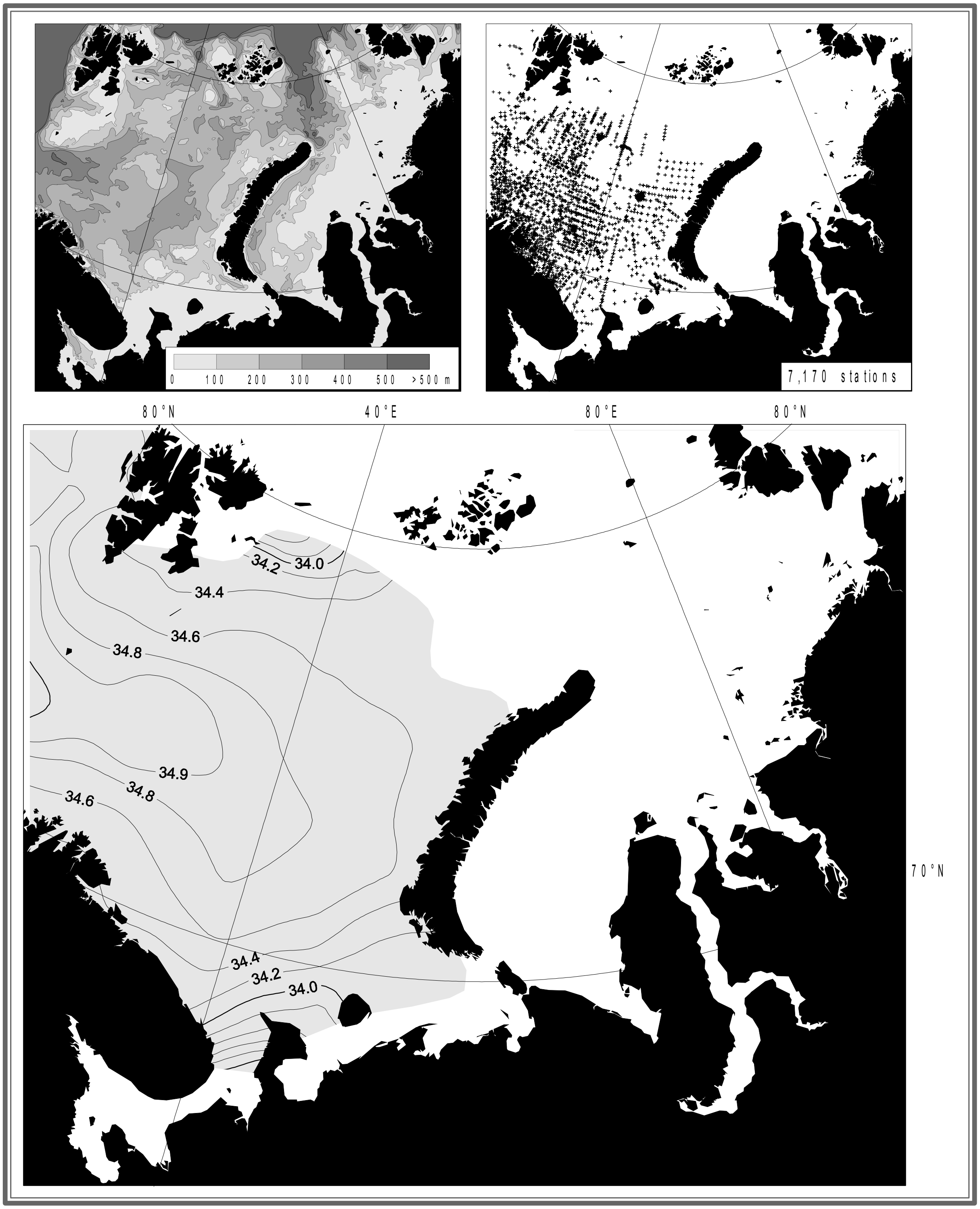


Fig. D23. Salinity (pss). February-April, 1980–1990. Depth 0 m

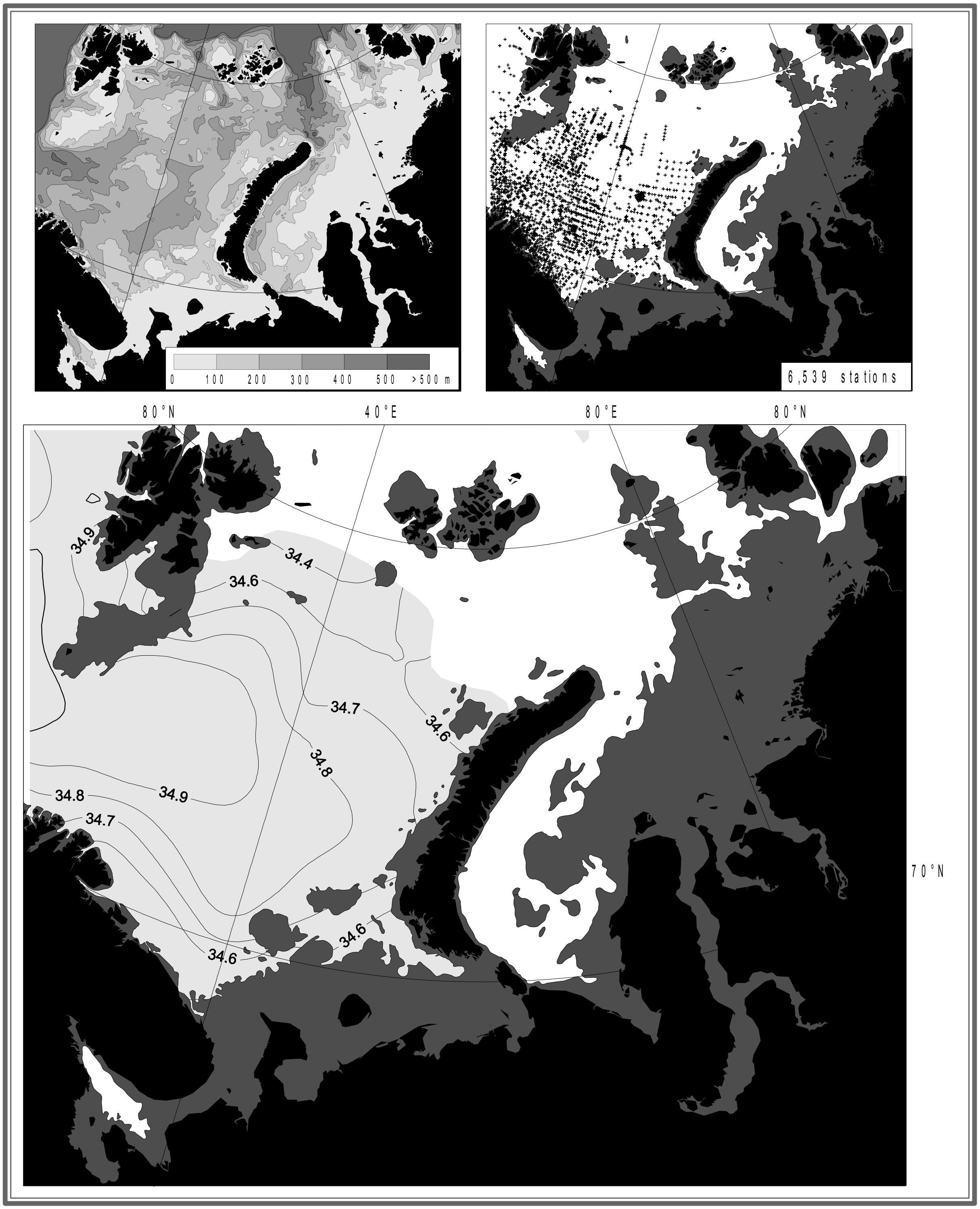


Fig. D24. Salinity (pss). February-April, 1980–1990. Depth 100 m

Appendix E. Phytoplankton

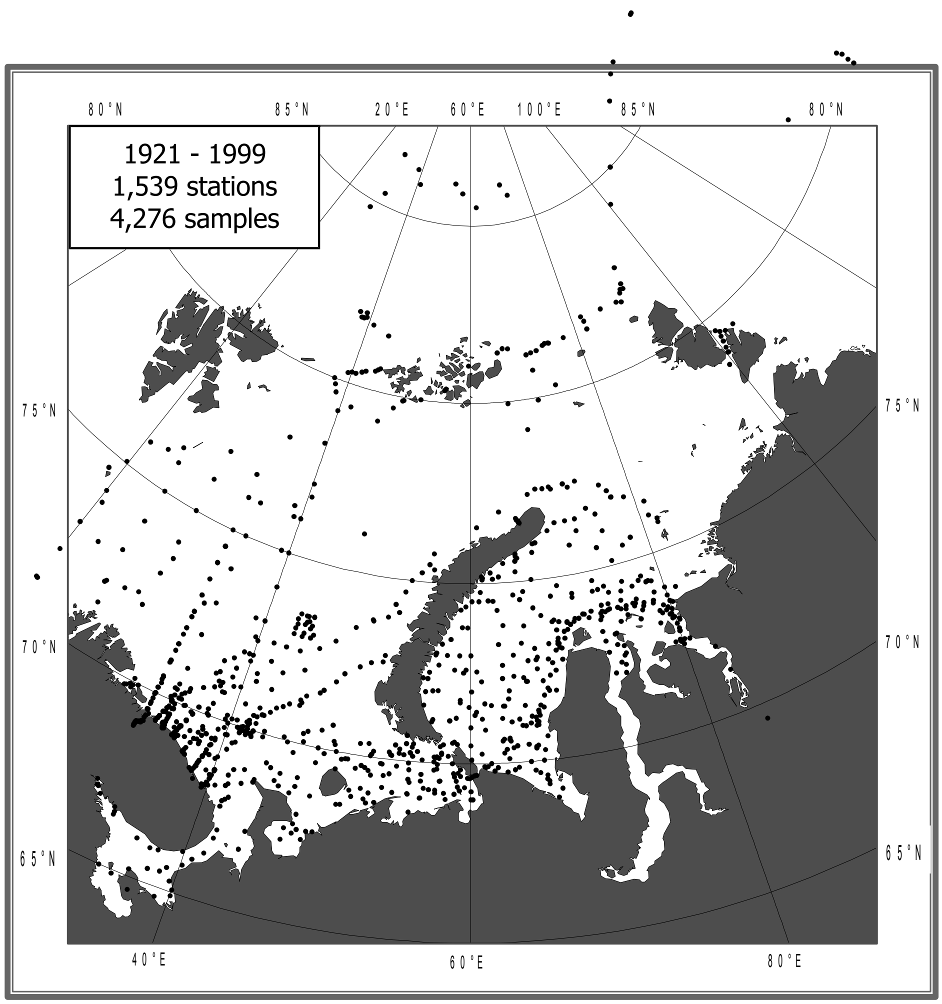


Fig. E1. Distribution of phytoplankton data

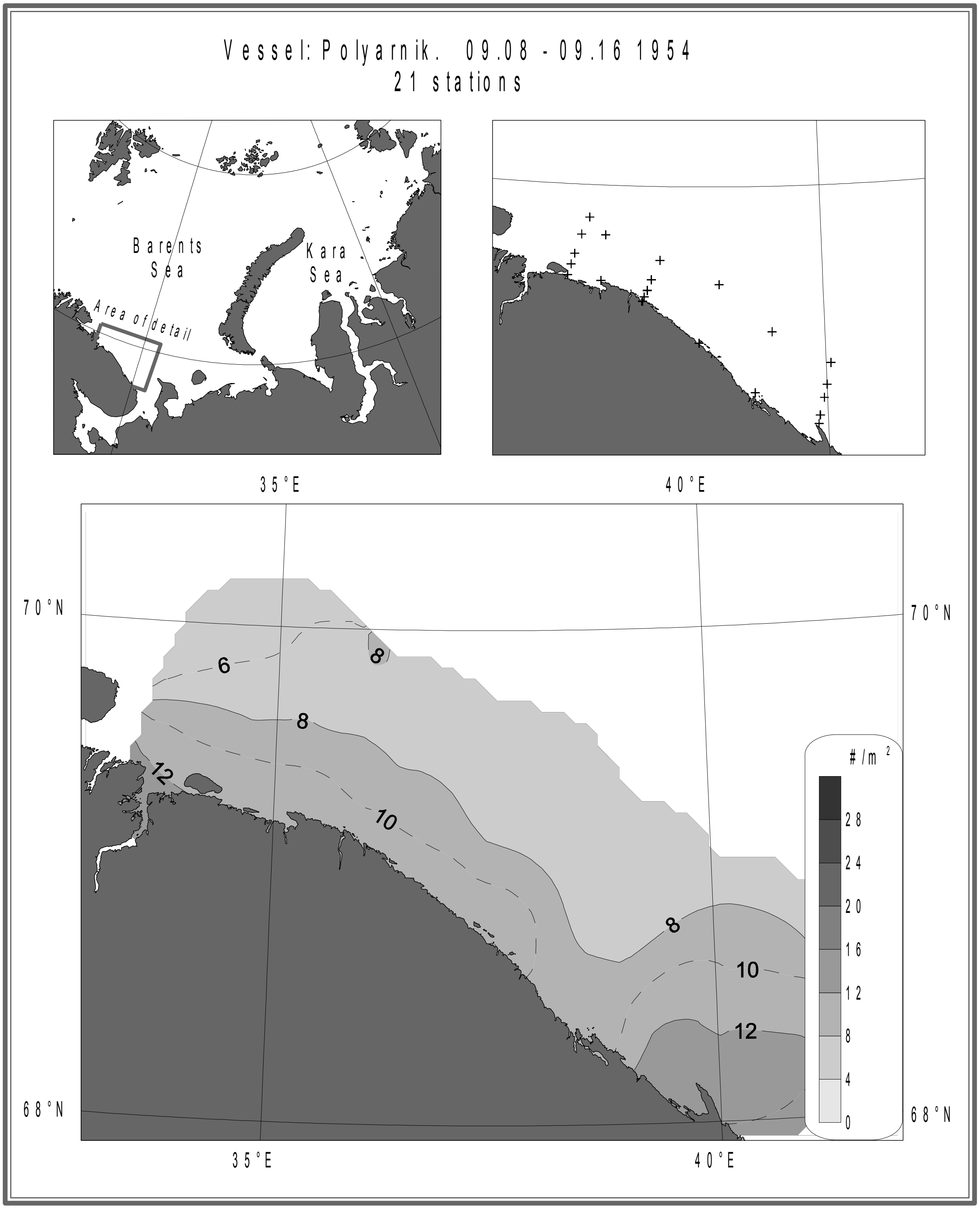


Fig. E2.1. Phytoplankton. Surface-bottom. Number of species. September, 1954

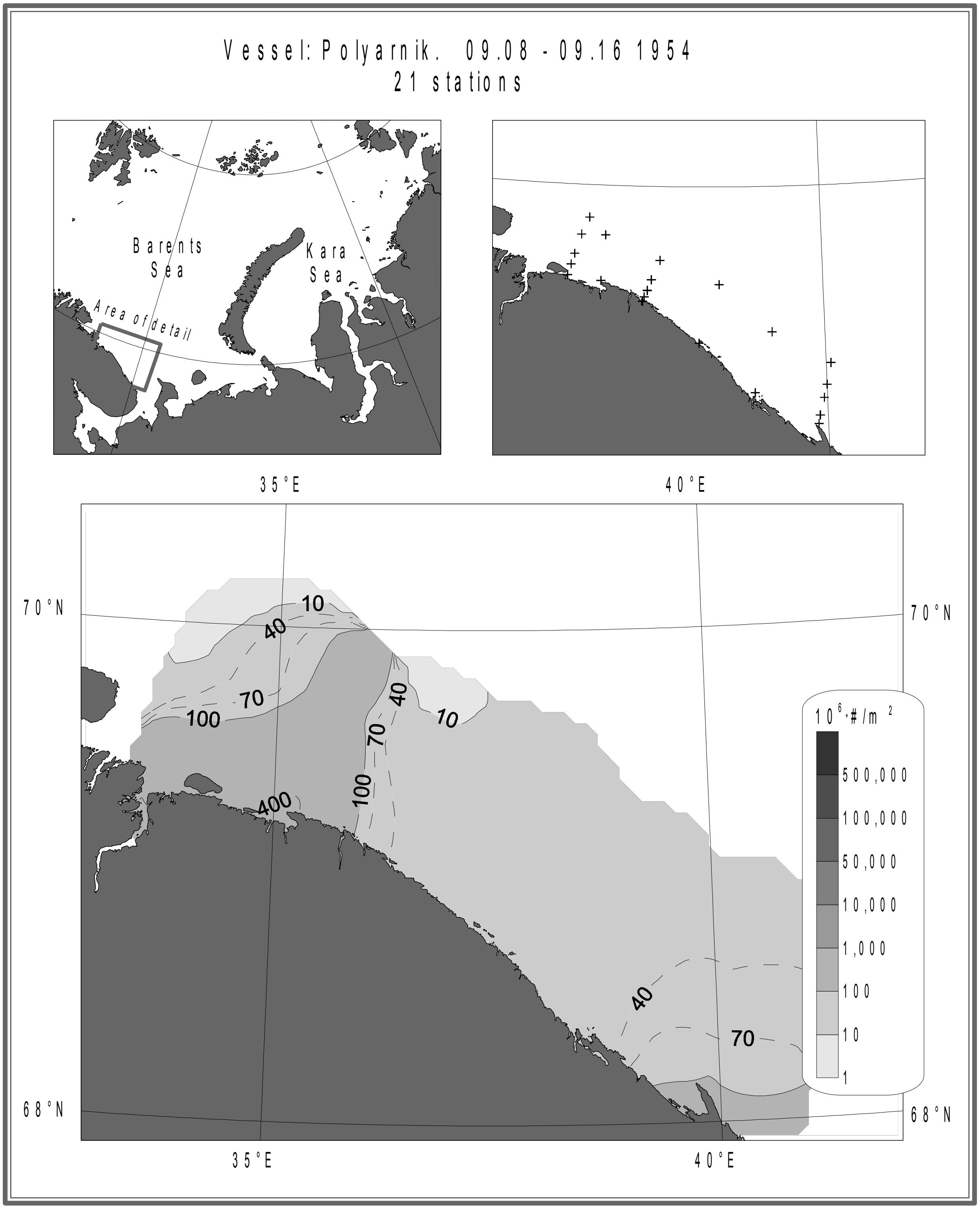


Fig. E2.2. Phytoplankton. Surface-bottom. Number of cells. September, 1954

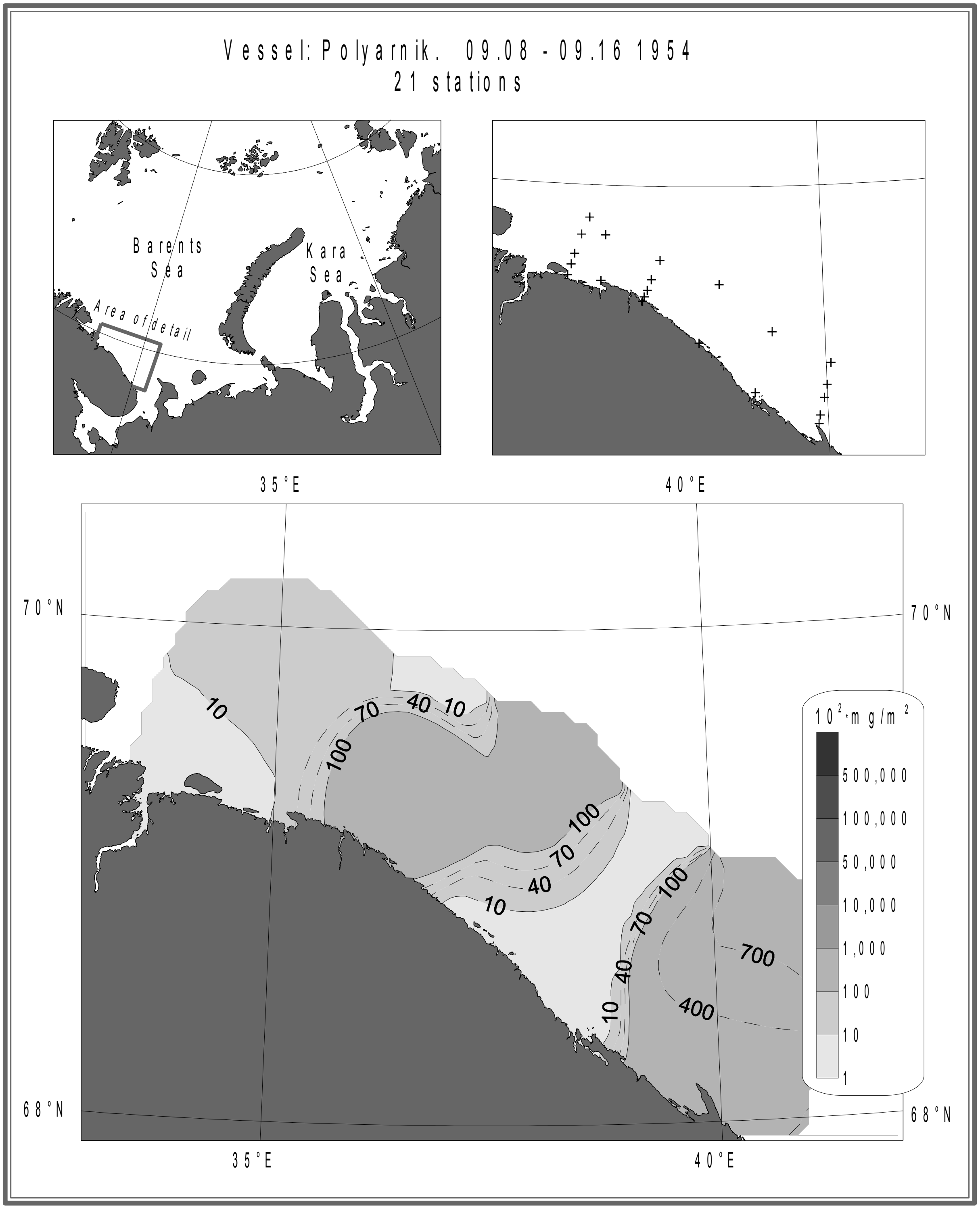


Fig. E2.3. Phytoplankton. Surface-bottom. Biomass. September, 1954

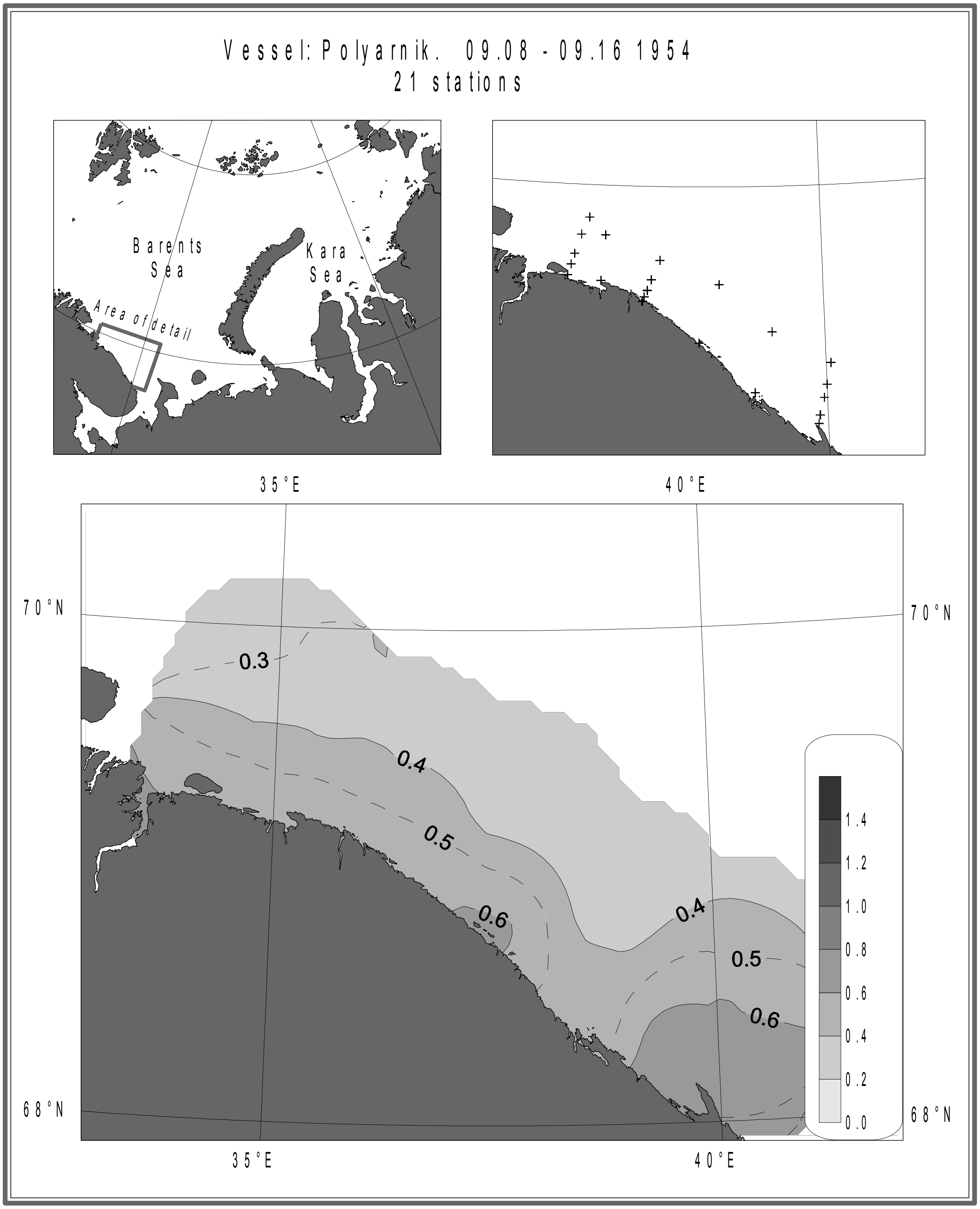


Fig. E2.4. Phytoplankton. Surface-bottom. Biodiversity. September, 1954

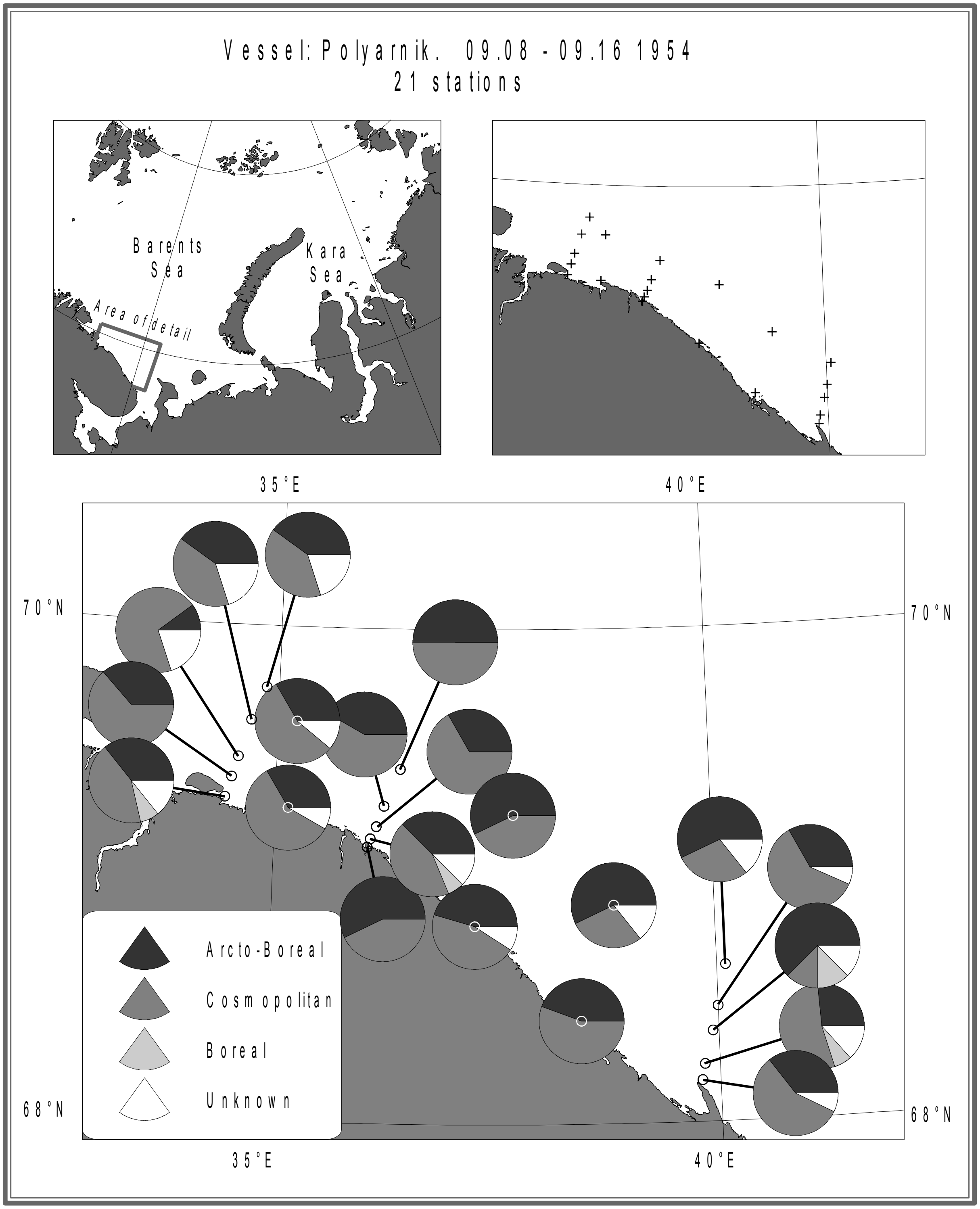


Fig. E2.5. Phytoplankton. Surface-bottom. Geographical characteristics. September, 1954

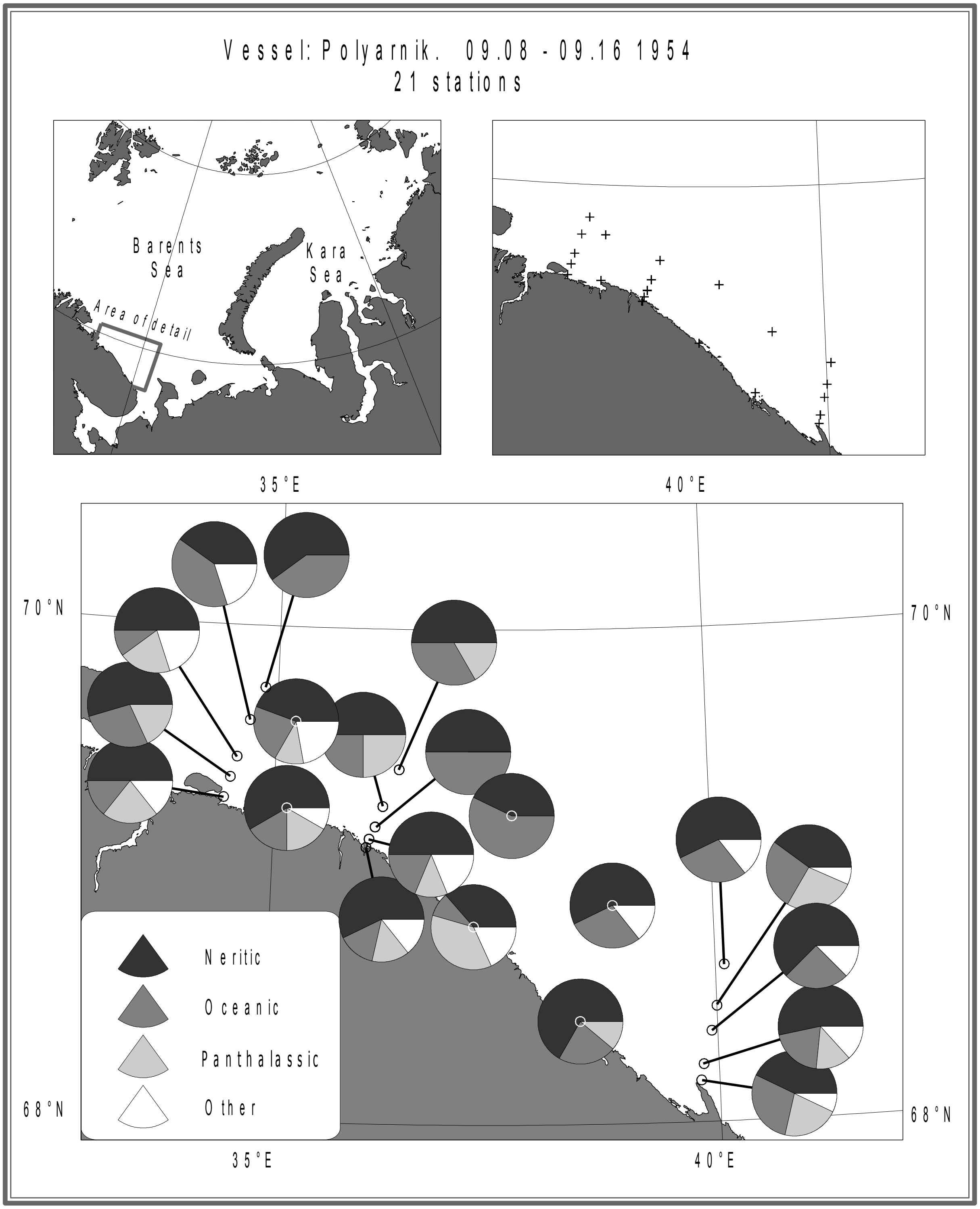


Fig. E2.6. Phytoplankton. Surface-bottom. Ecological characteristics. September, 1954

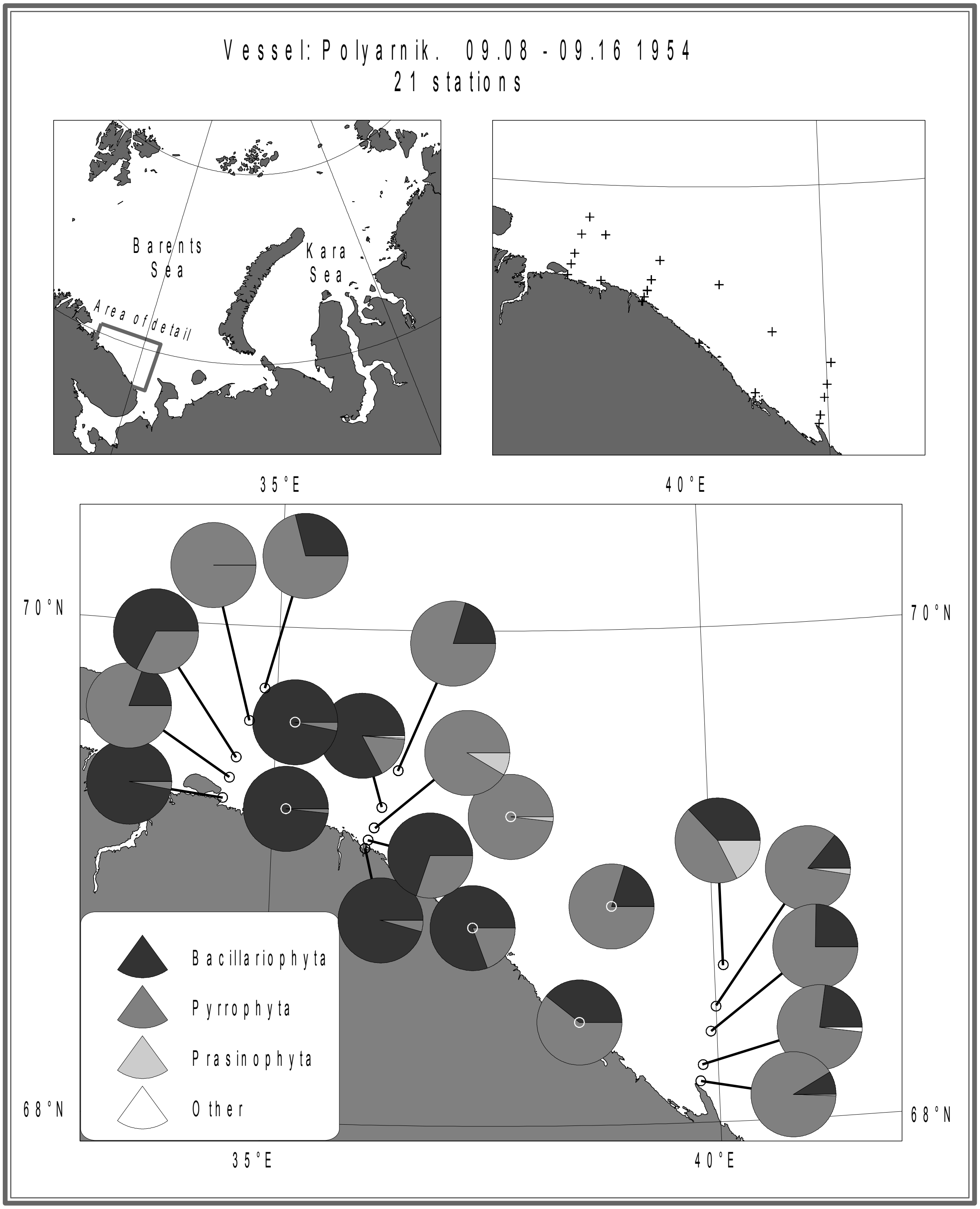


Fig. E2.7. Phytoplankton. Surface-bottom. Taxonomic composition. September, 1954

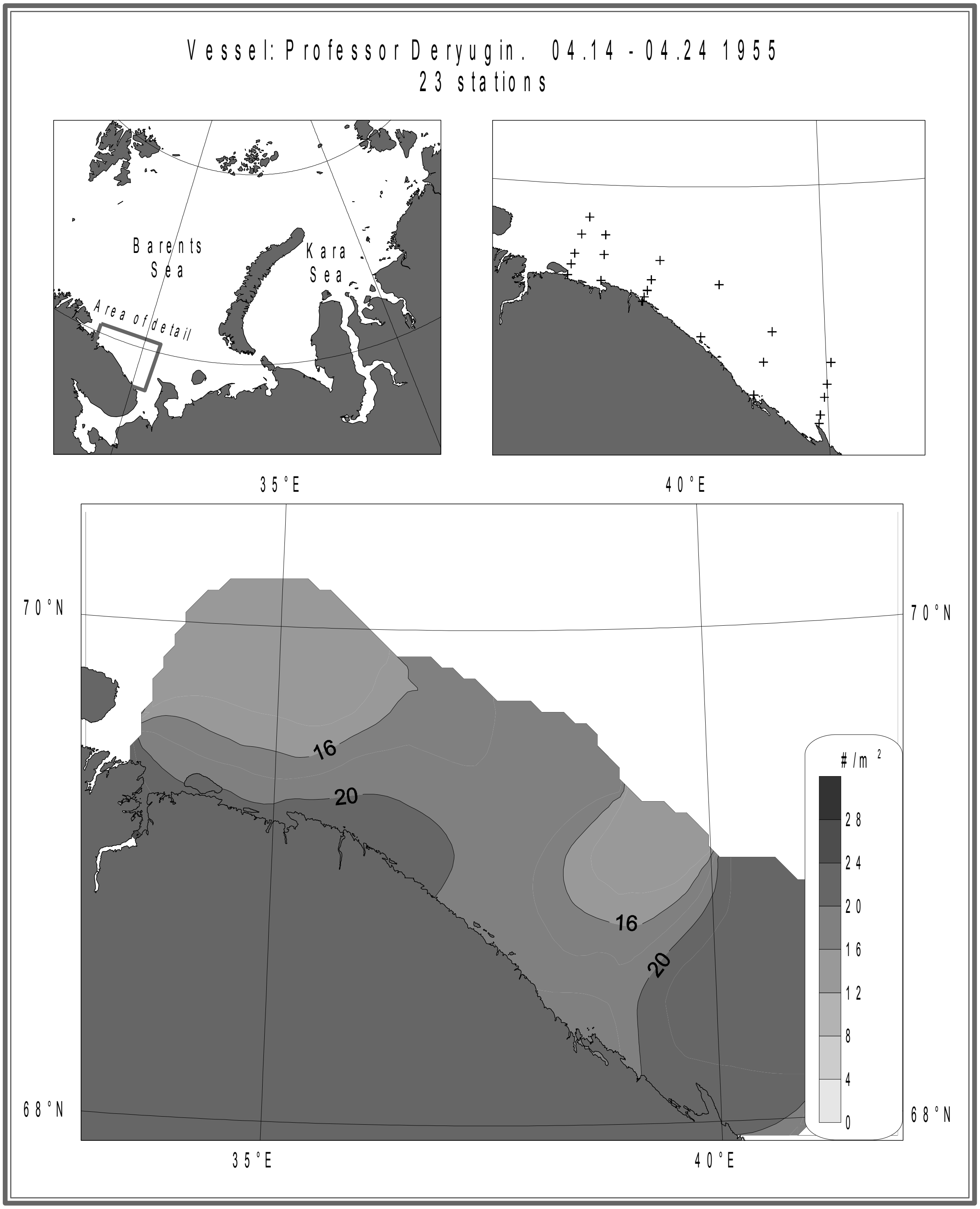


Fig. E2.8. Phytoplankton. Surface-bottom. Number of species. April, 1955

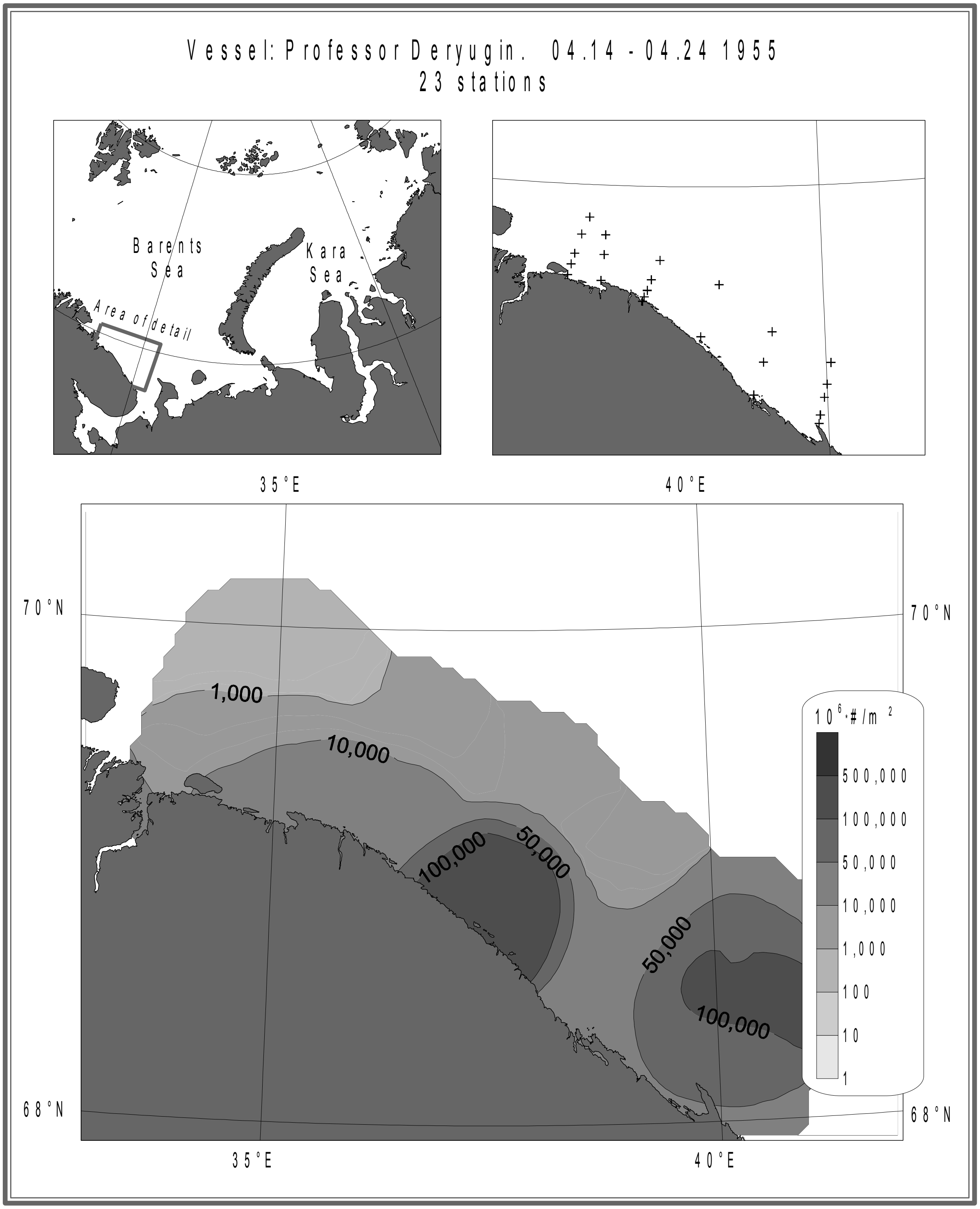


Fig. E2.9. Phytoplankton. Surface-bottom. Number of cells. April, 1955

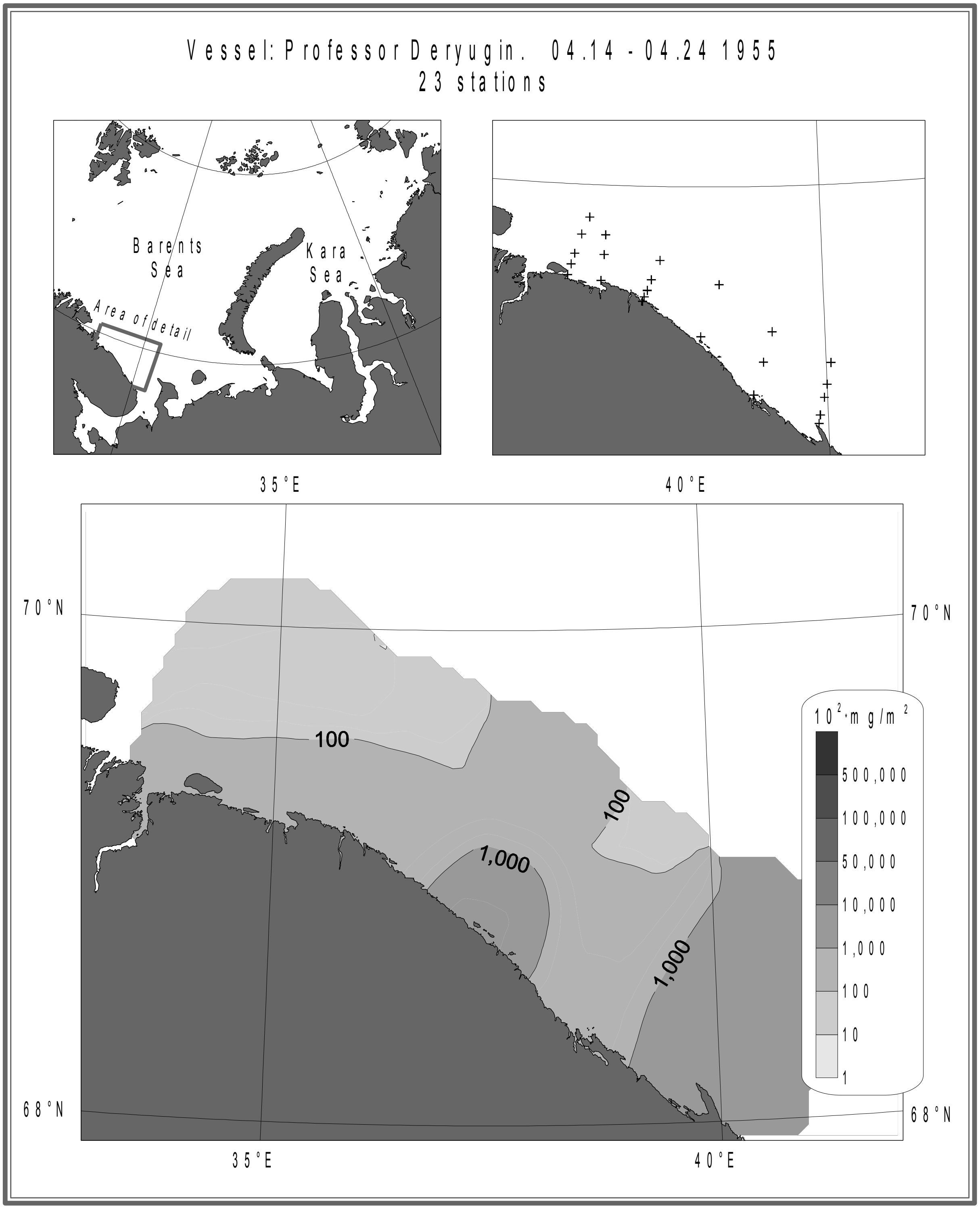


Fig. E2.10. Phytoplankton. Surface-bottom. Biomass. April, 1955

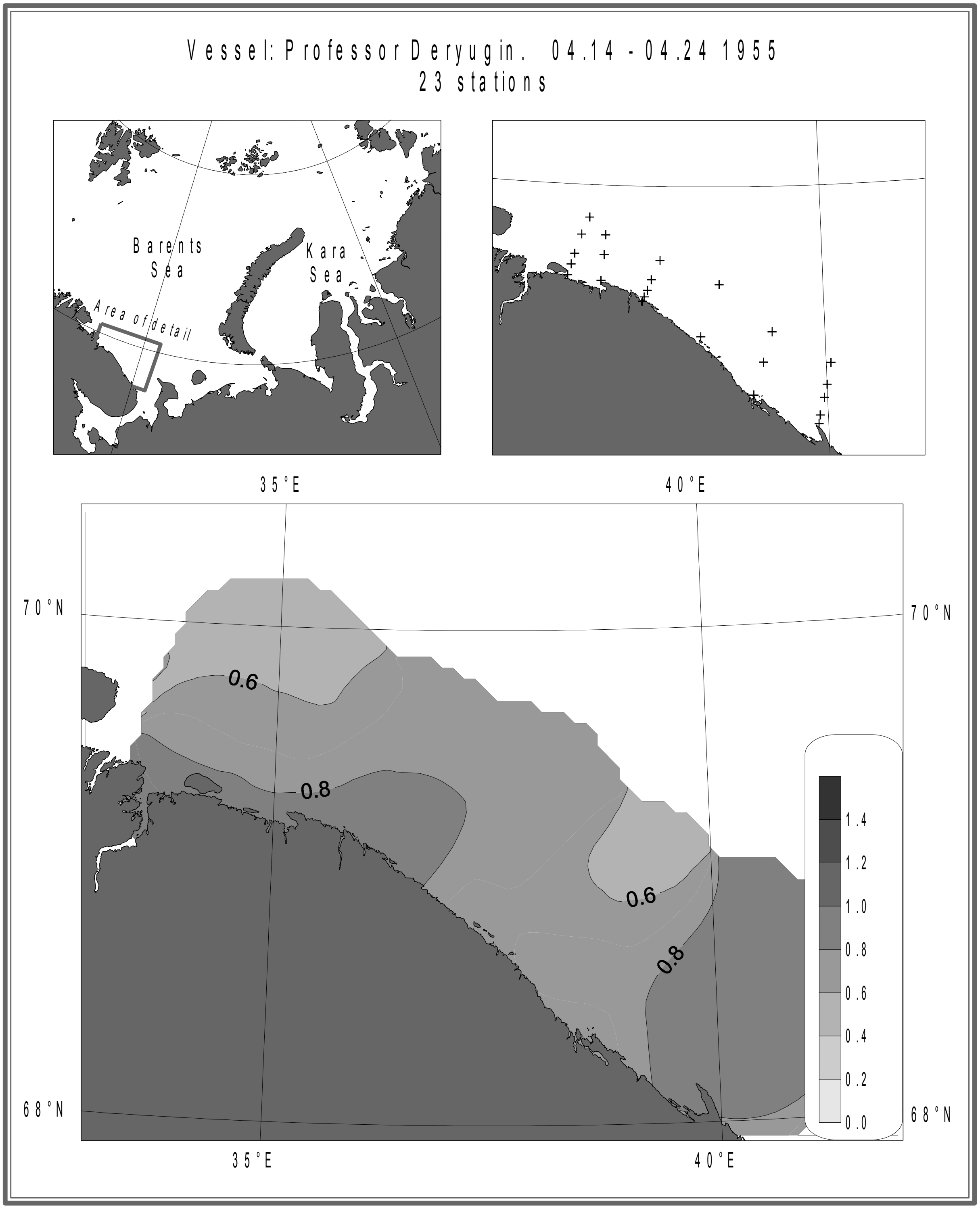


Fig. E2.11. Phytoplankton. Surface-bottom. Biodiversity. April, 1955

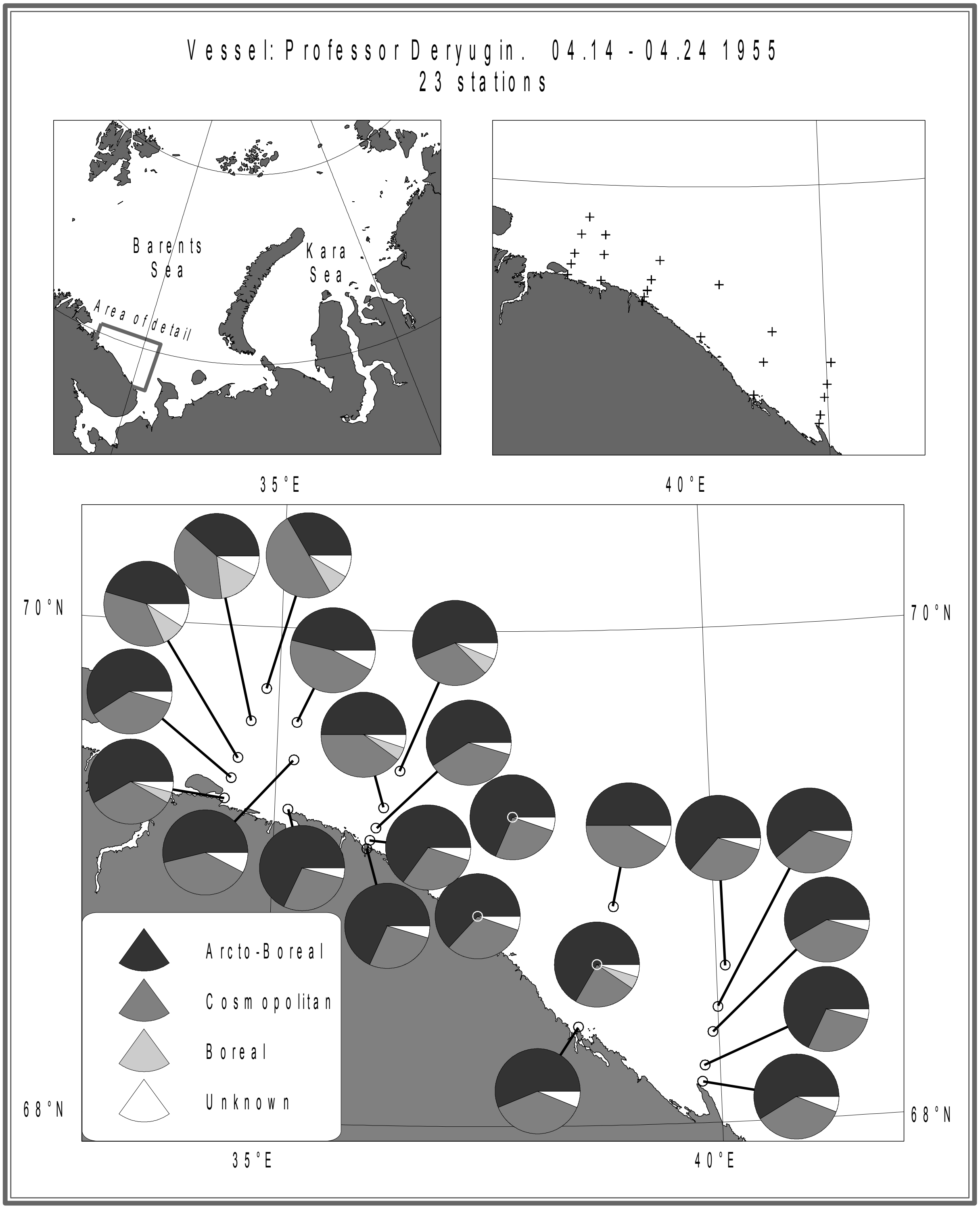


Fig. E2.12. Phytoplankton. Surface-bottom. Geographical haracteristics. April, 1955

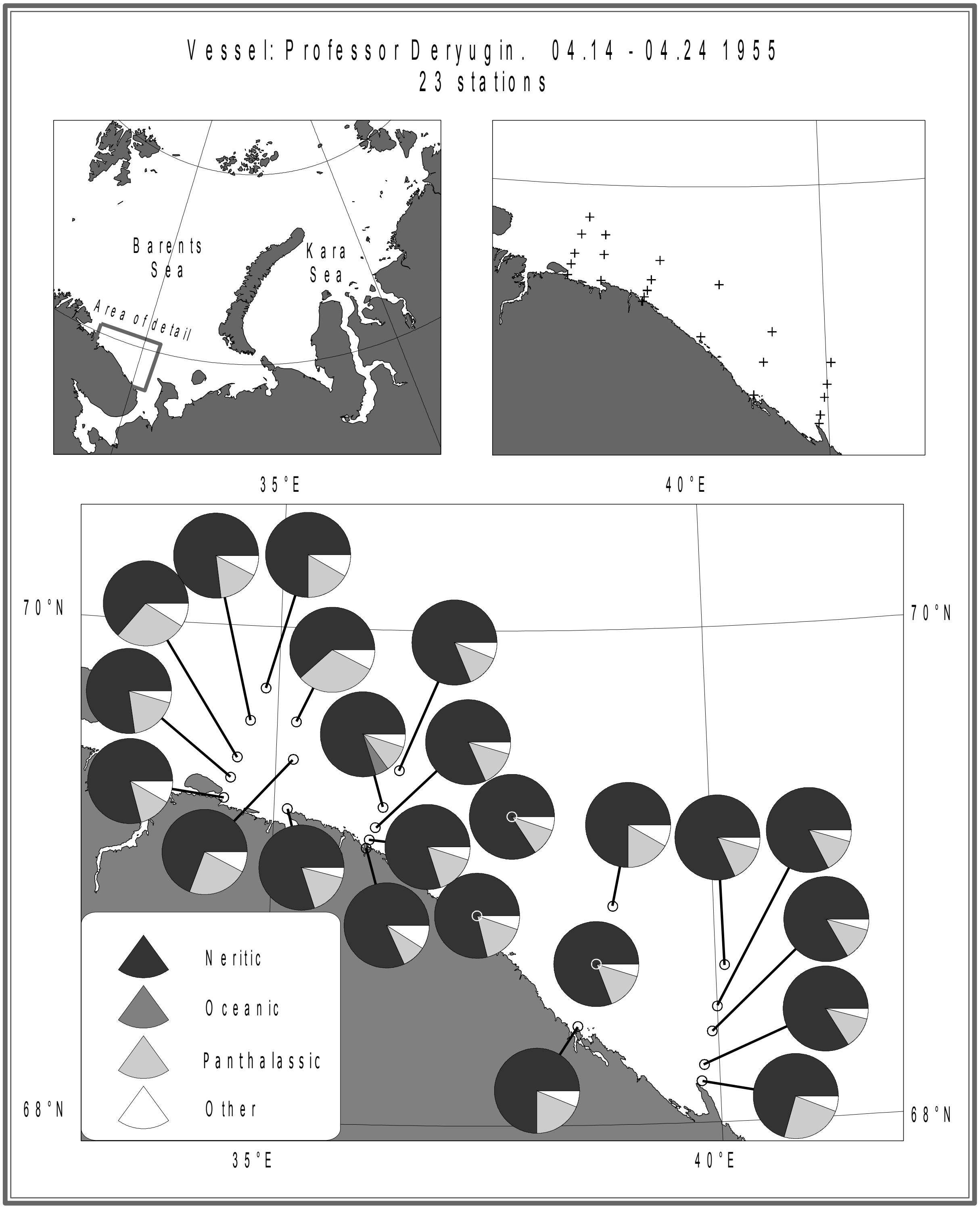


Fig. E2.13. Phytoplankton. Surface-bottom. Ecological characteristics. April, 1955

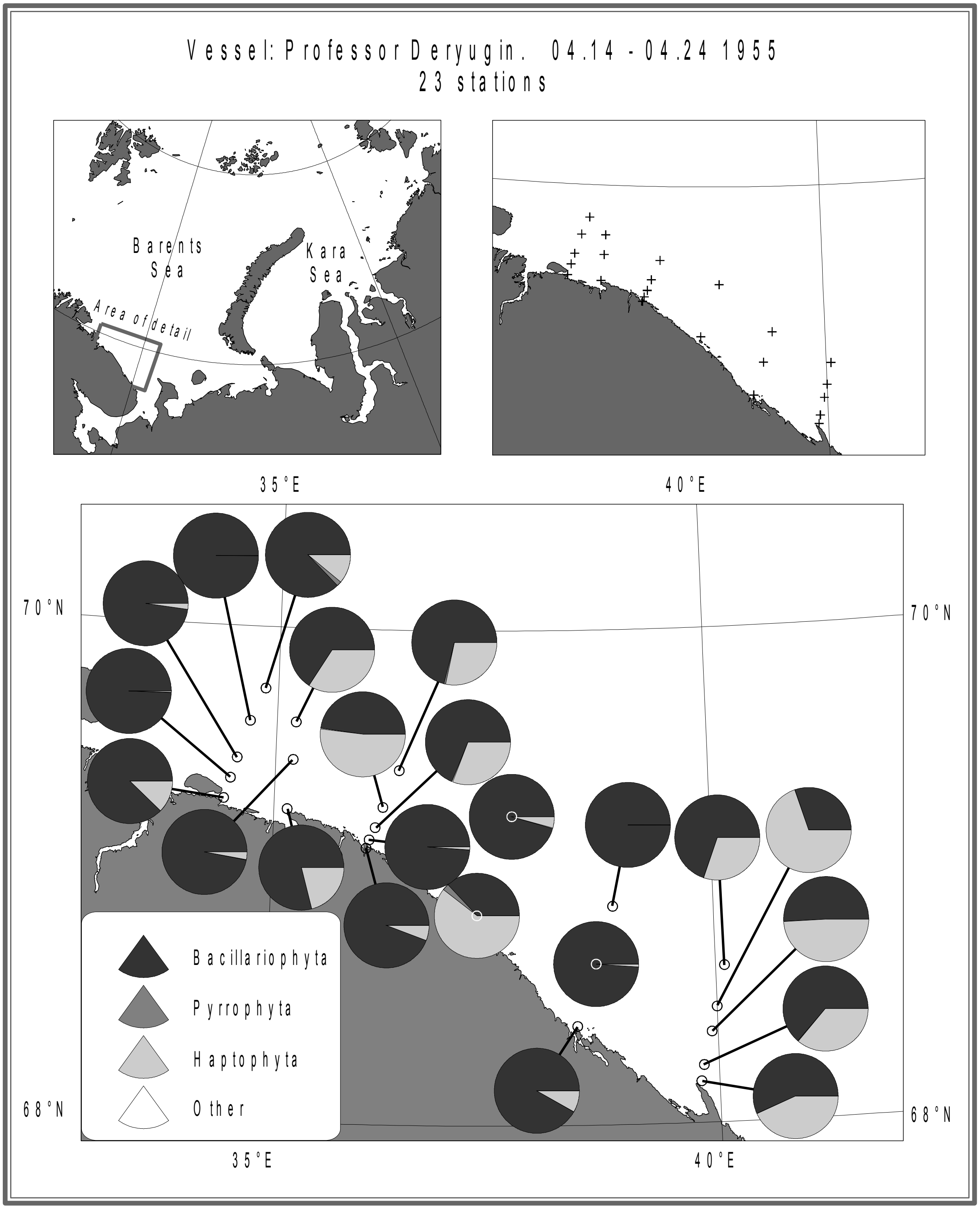


Fig. E2.14. Phytoplankton. Surface-bottom. Taxonomic composition. April, 1955

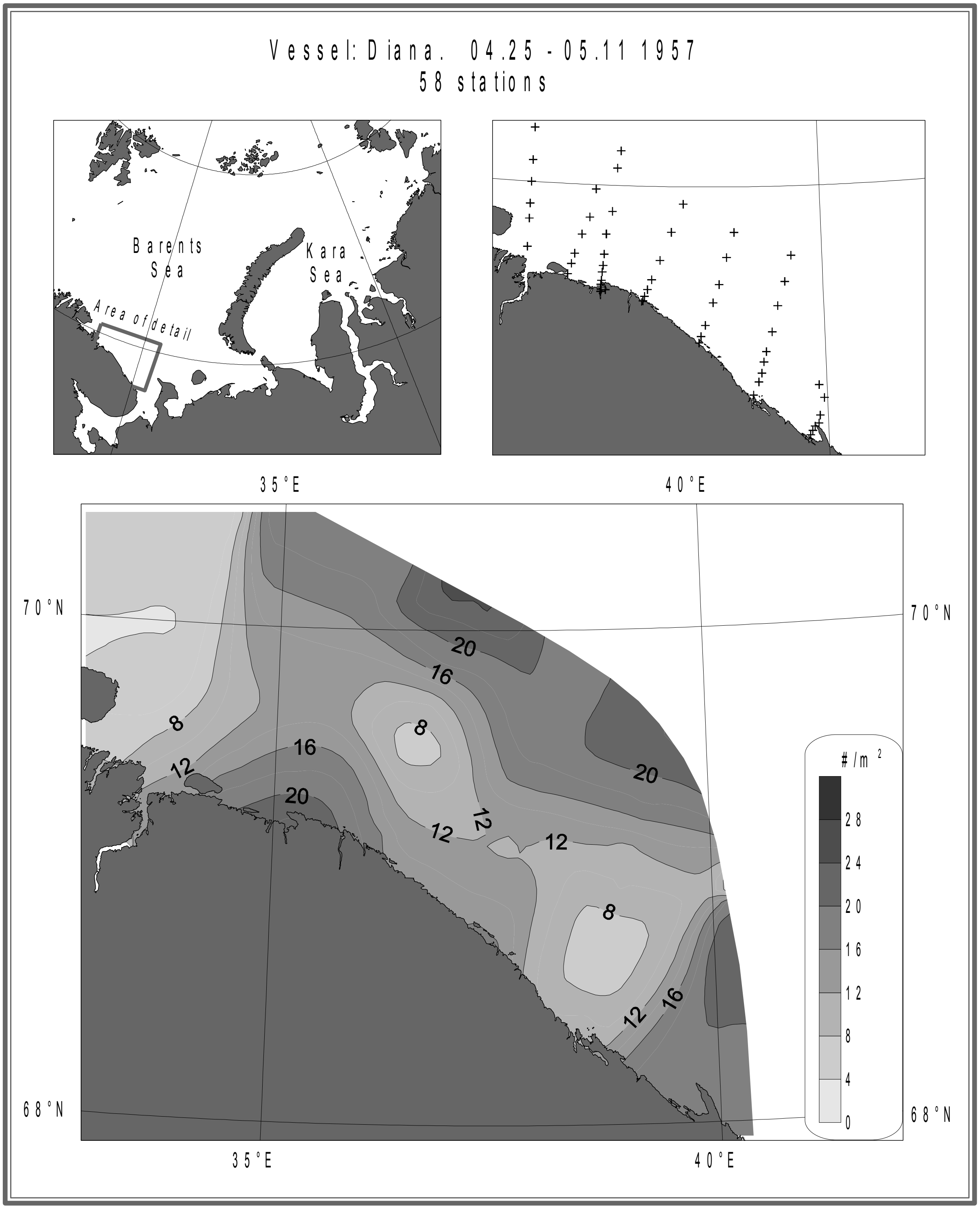


Fig. E2.15. Phytoplankton. Surface-bottom. Number of species. April-May, 1957

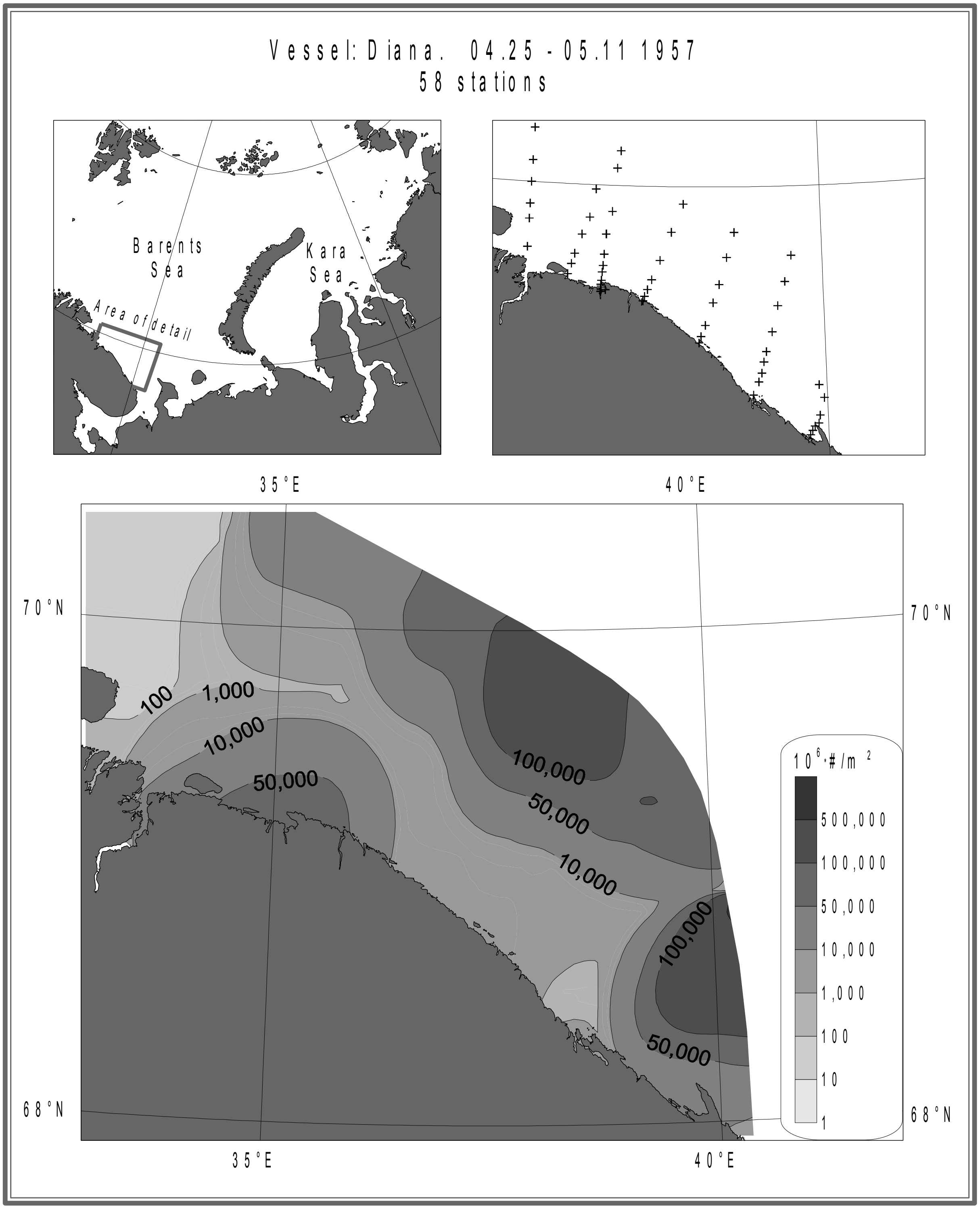


Fig. E2.16. Phytoplankton. Surface-bottom. Number of cells. April-May, 1957

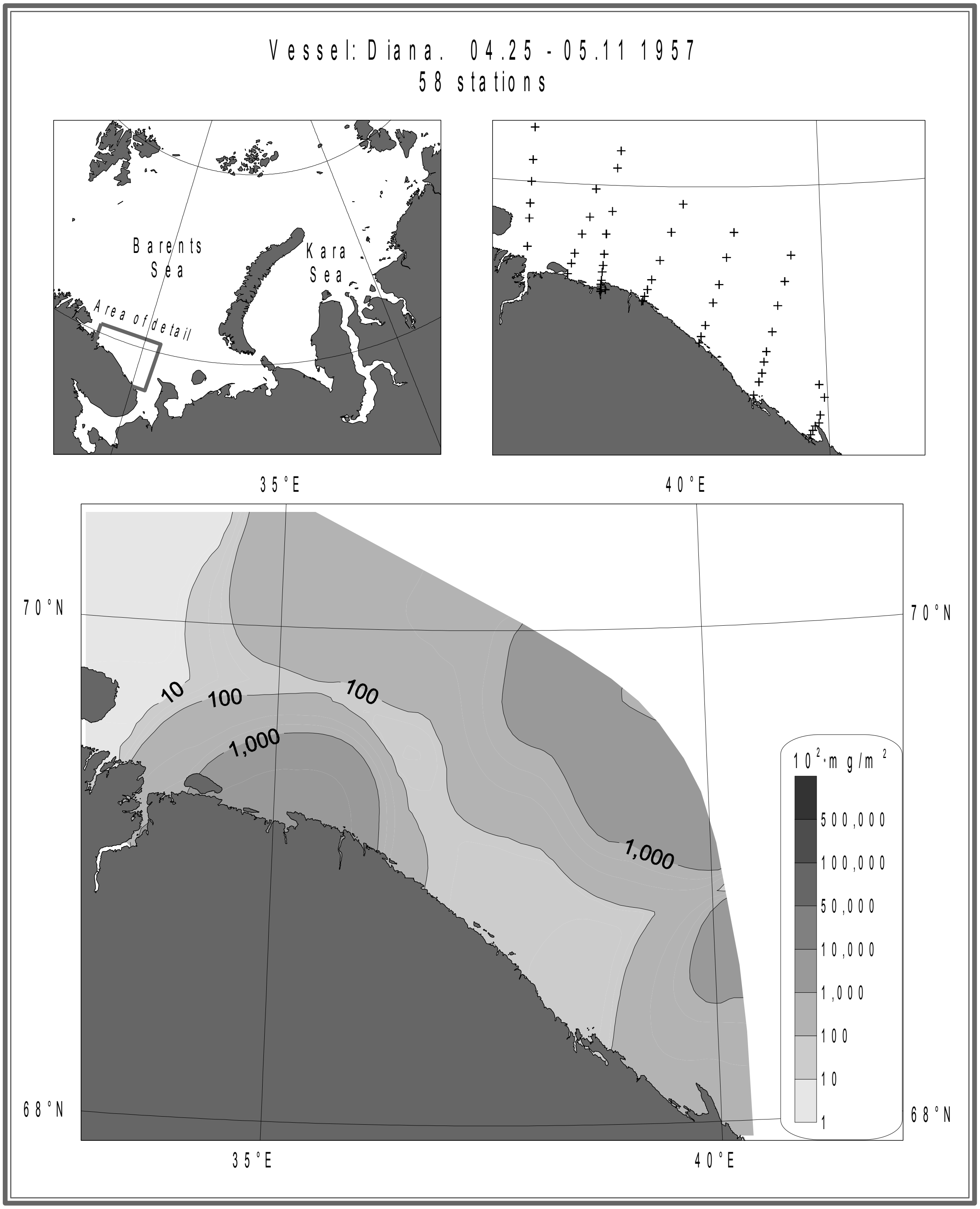


Fig. E2.17. Phytoplankton. Surface-bottom. Biomass. April-May, 1957

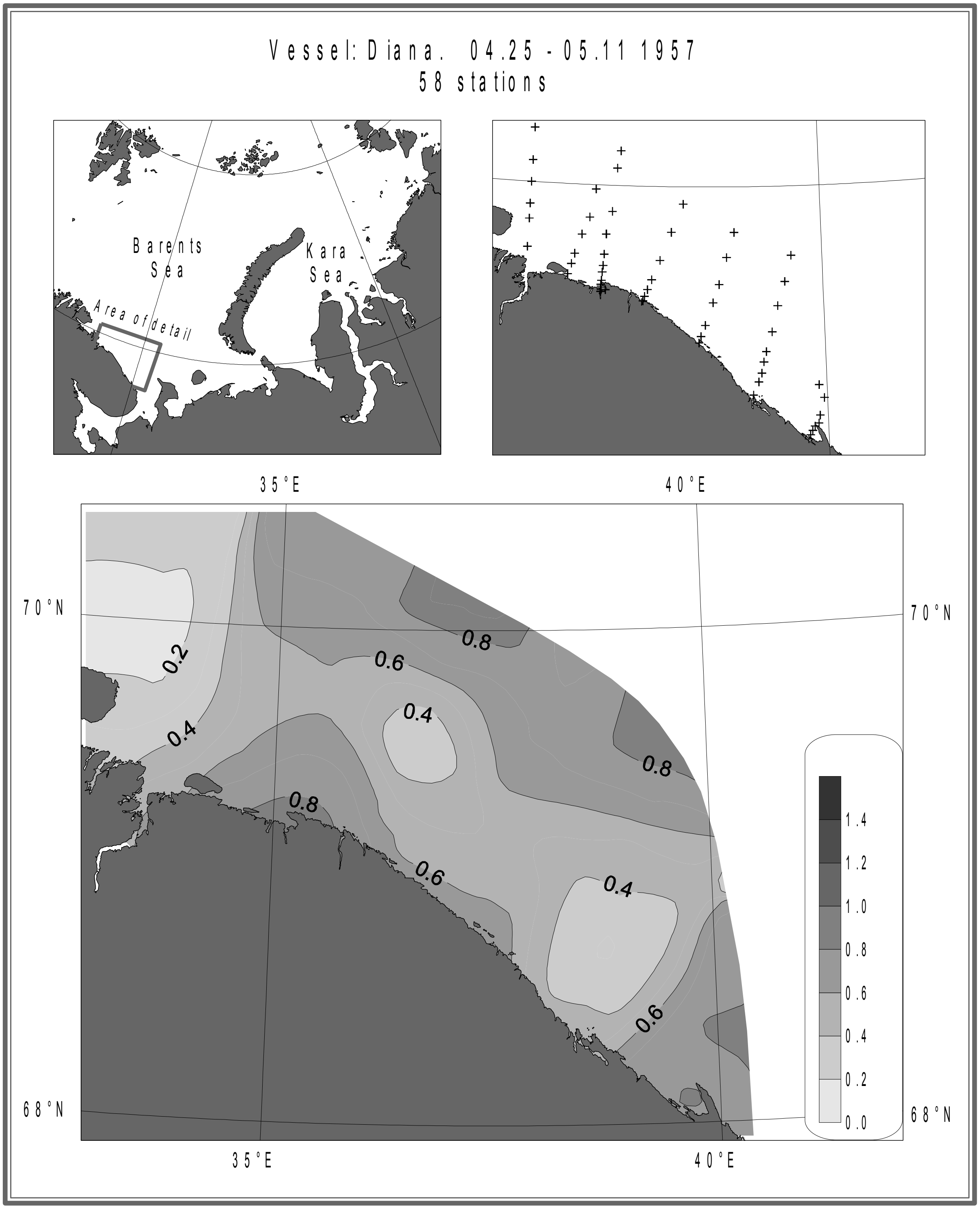


Fig. E2.18. Phytoplankton. Surface-bottom. Biodiversity. April-May, 1957

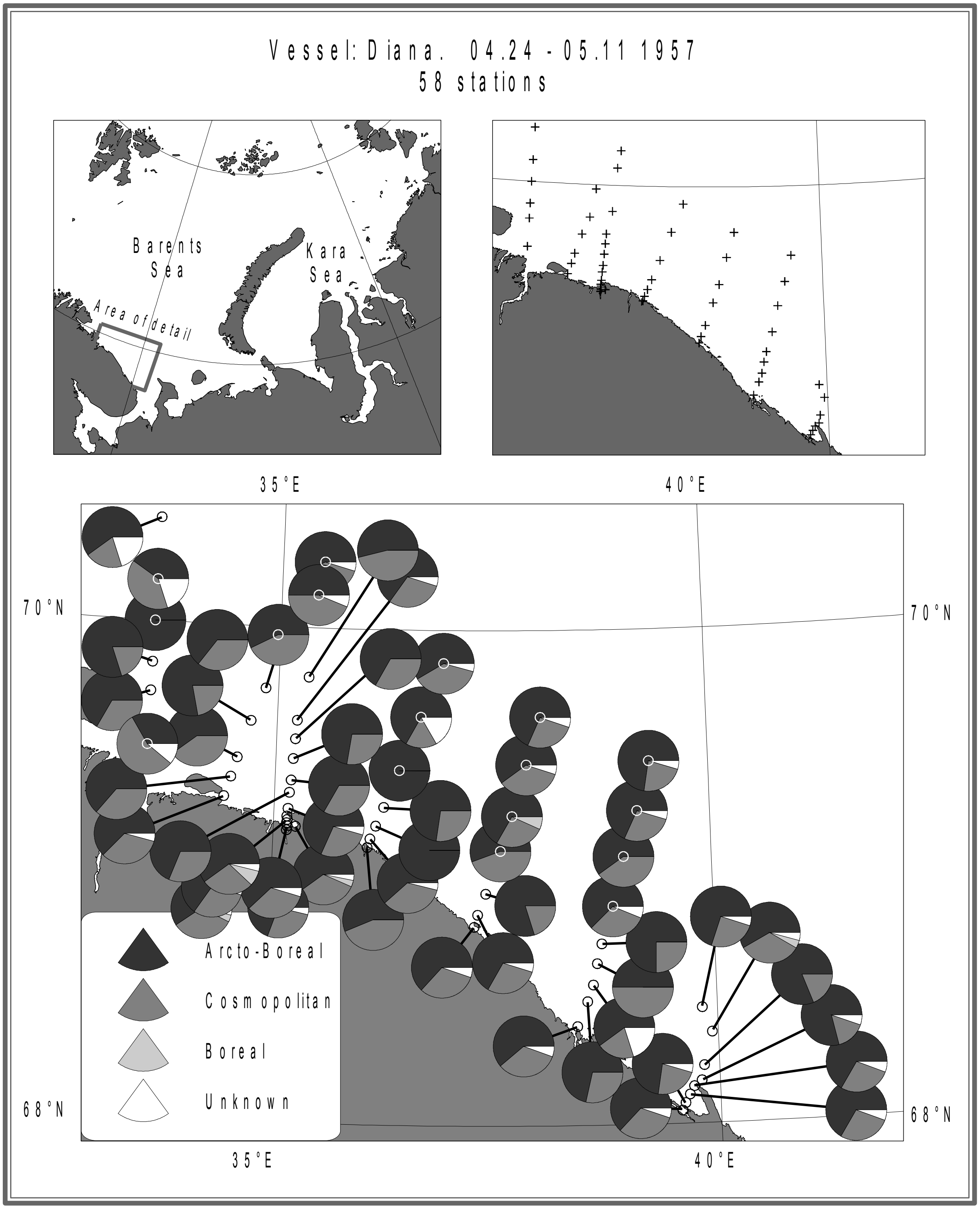


Fig. E2.19. Phytoplankton. Surface-bottom. Geographical characteristics. April-May, 1957

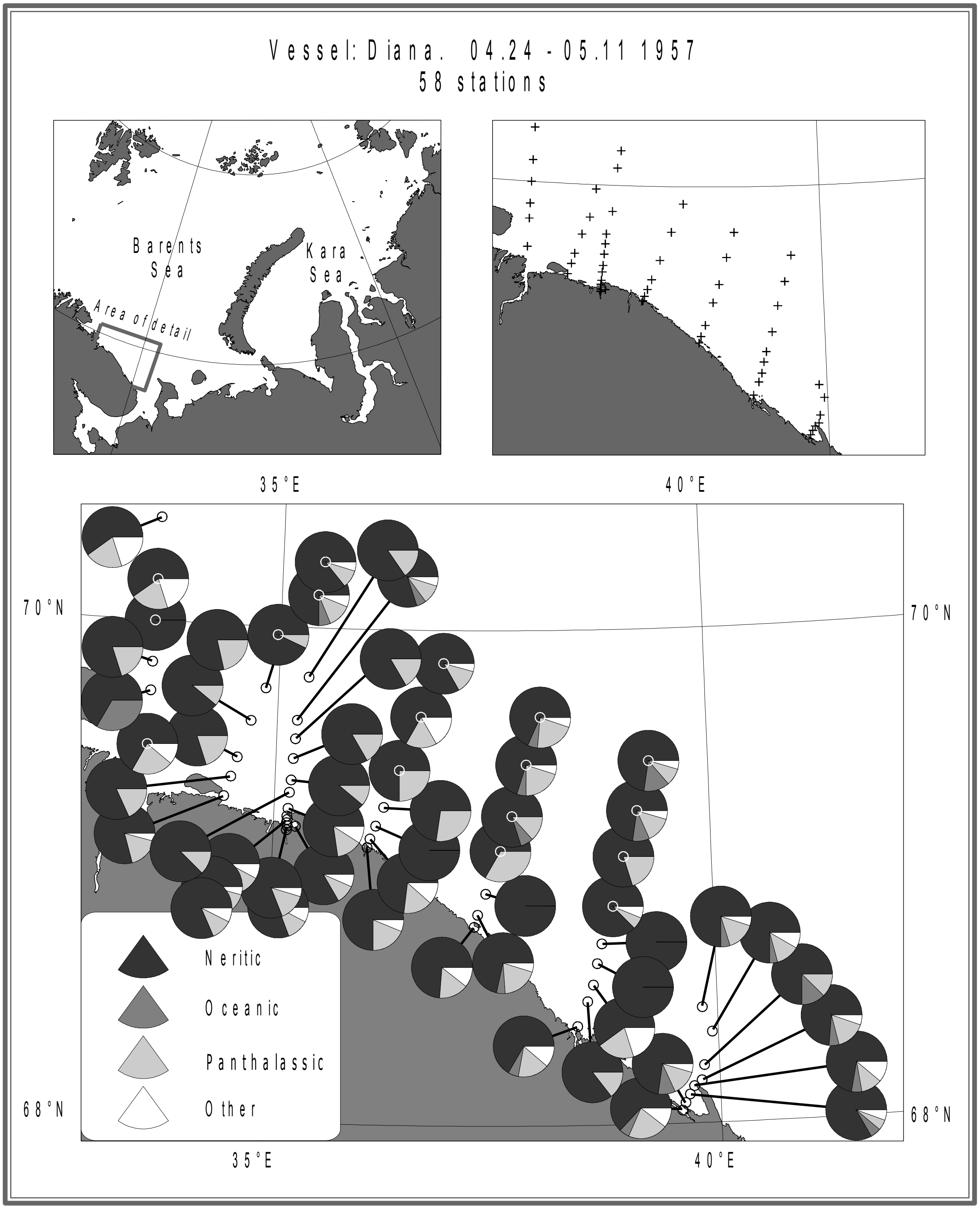


Fig. E2.20. Phytoplankton. Surface-bottom. Ecological characteristics. April-May, 1957

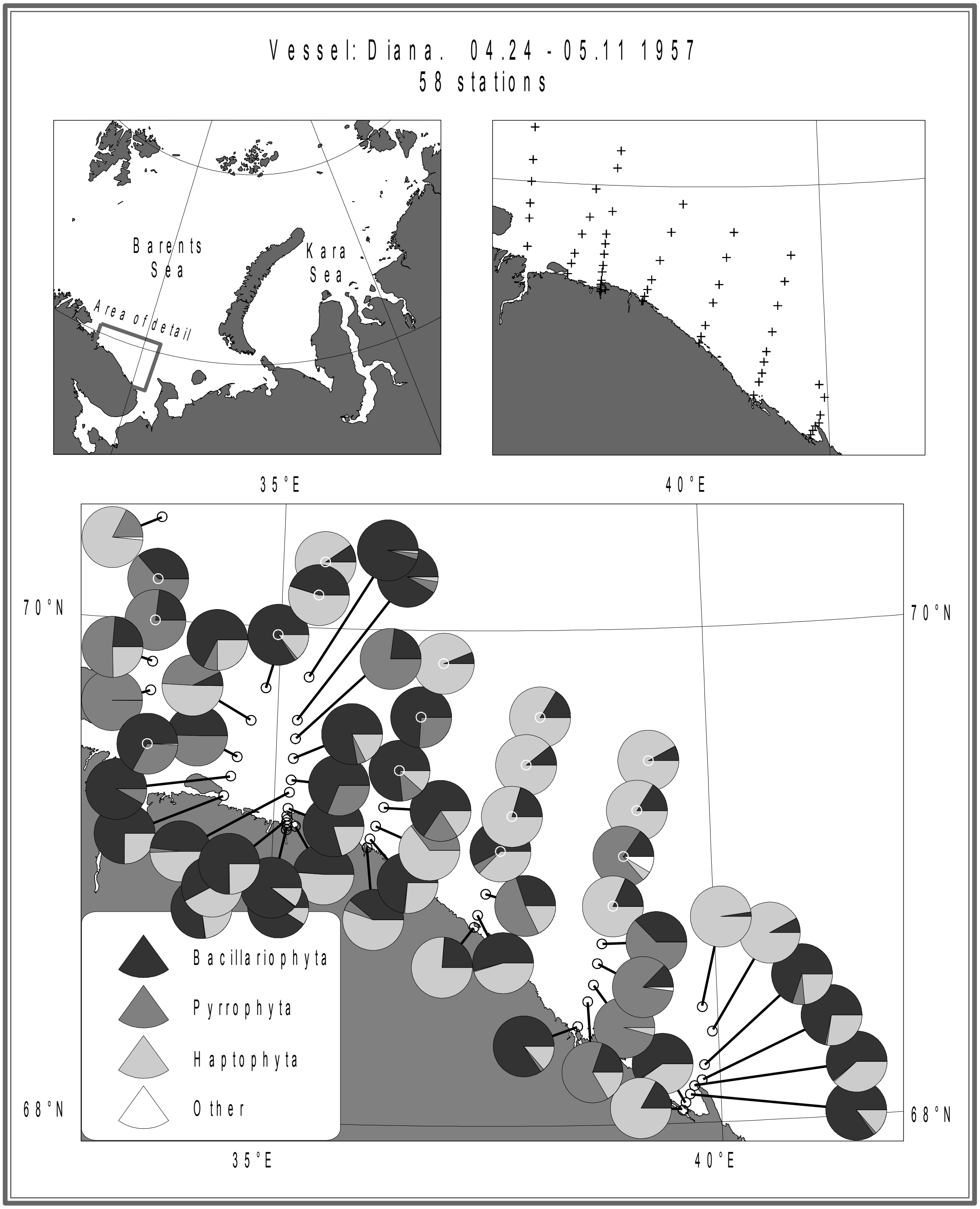


Fig. E2.21. Phytoplankton. Surface-bottom. Taxonomic composition. April-May, 1957

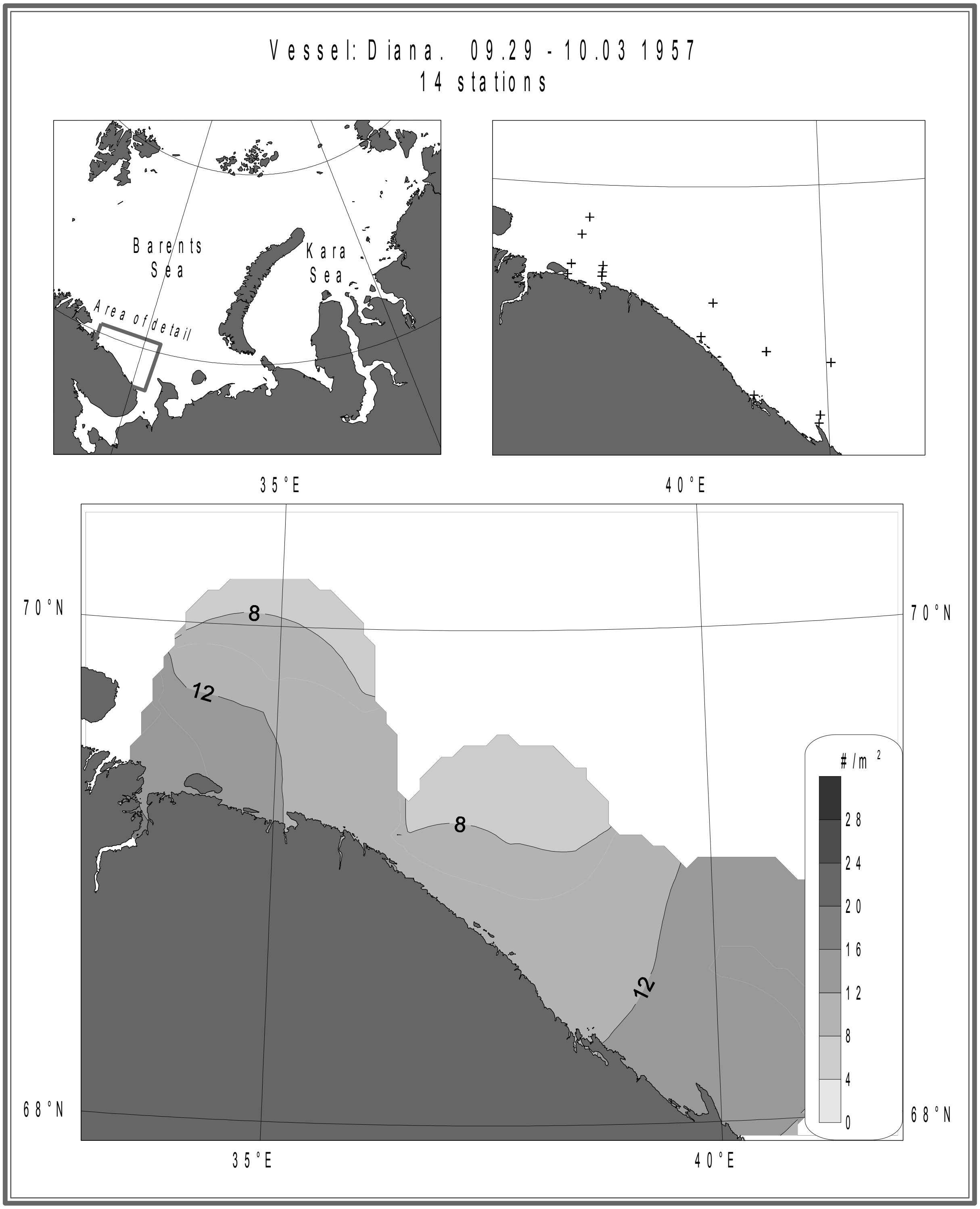


Fig. E2.22. Phytoplankton. Surface-bottom. Number of species. September-October, 1957

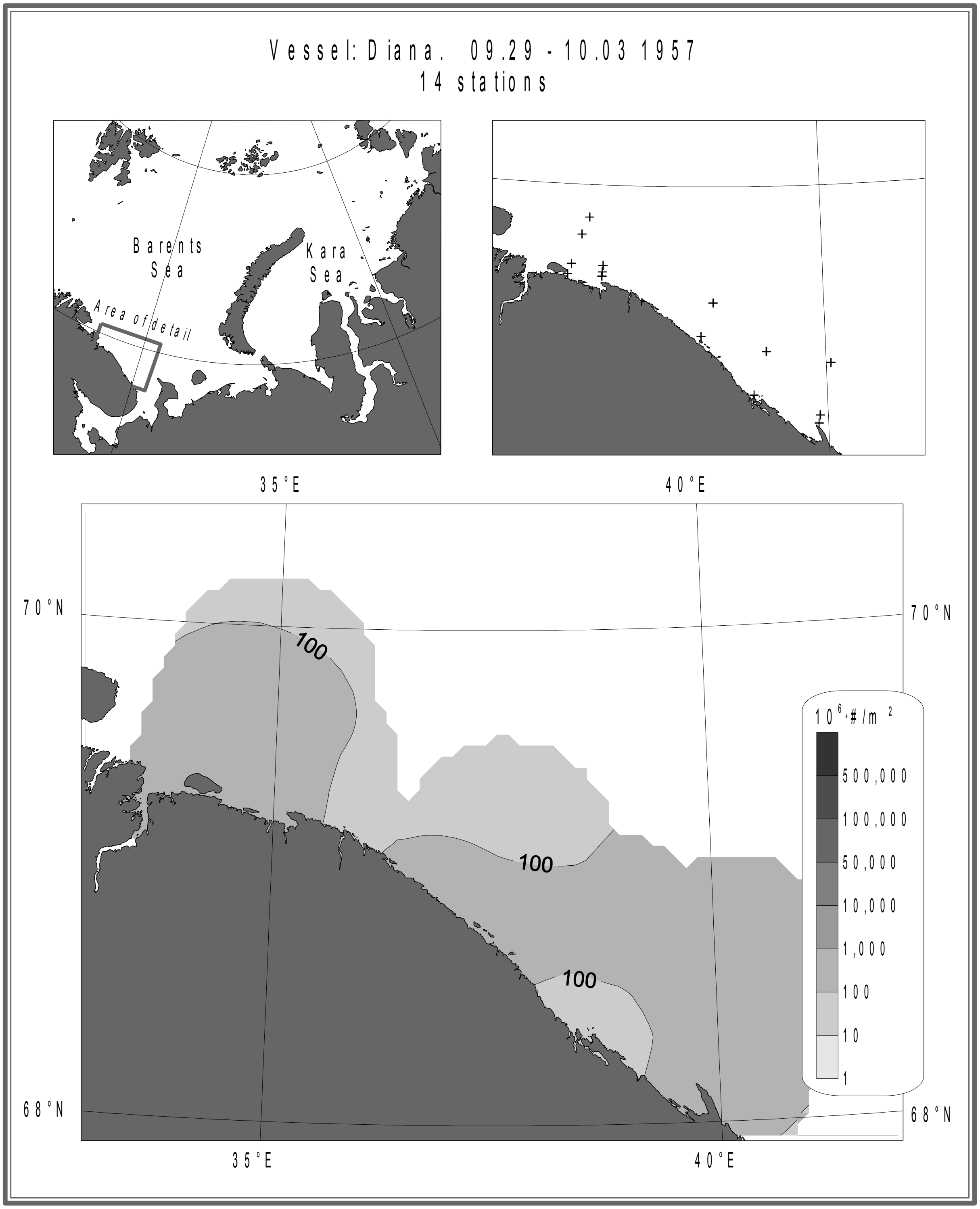


Fig. E2.23. Phytoplankton. Surface-bottom. Number of cells. September-October, 1957

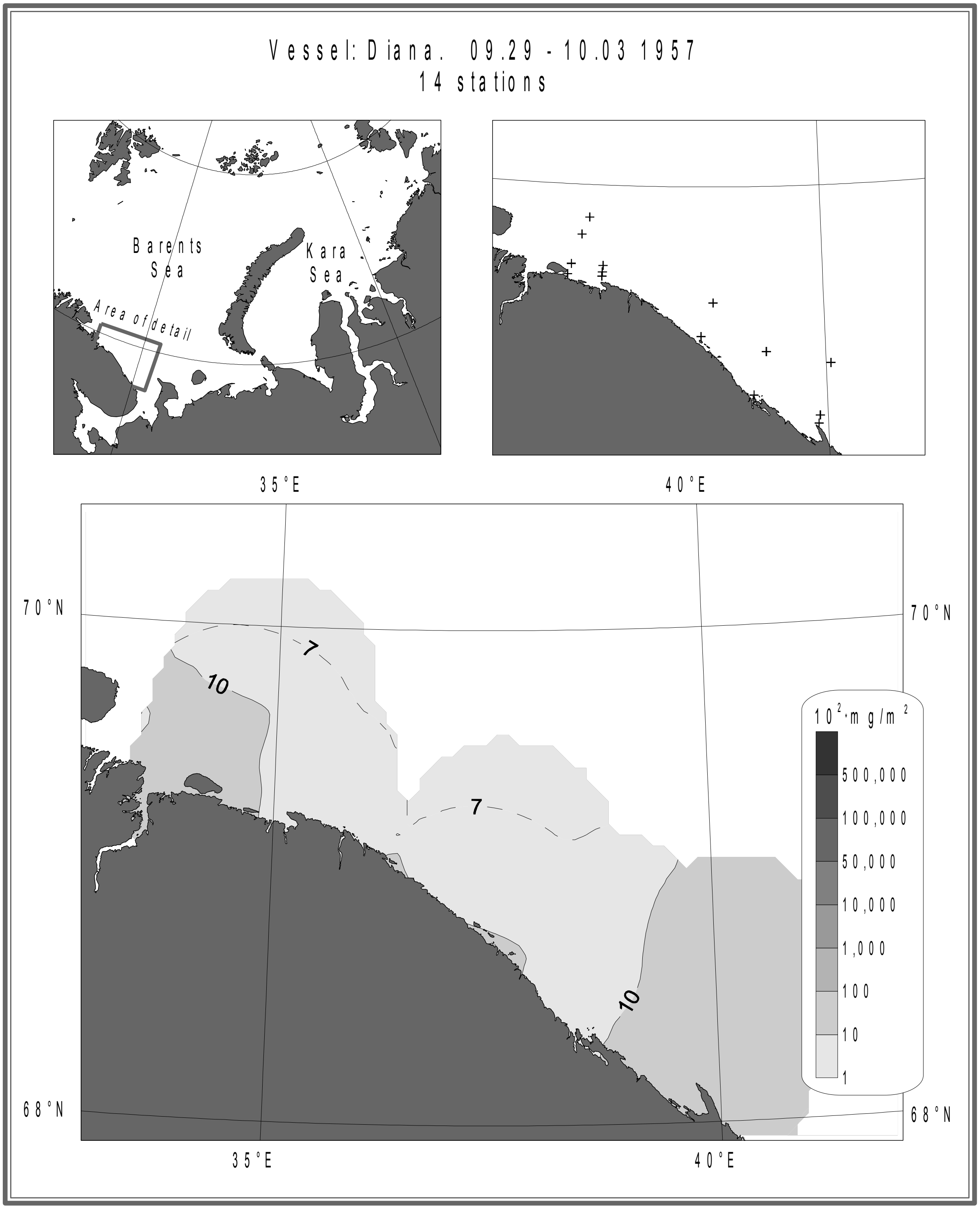


Fig. E2.24. Phytoplankton. Surface-bottom. Biomass. September-October, 1957

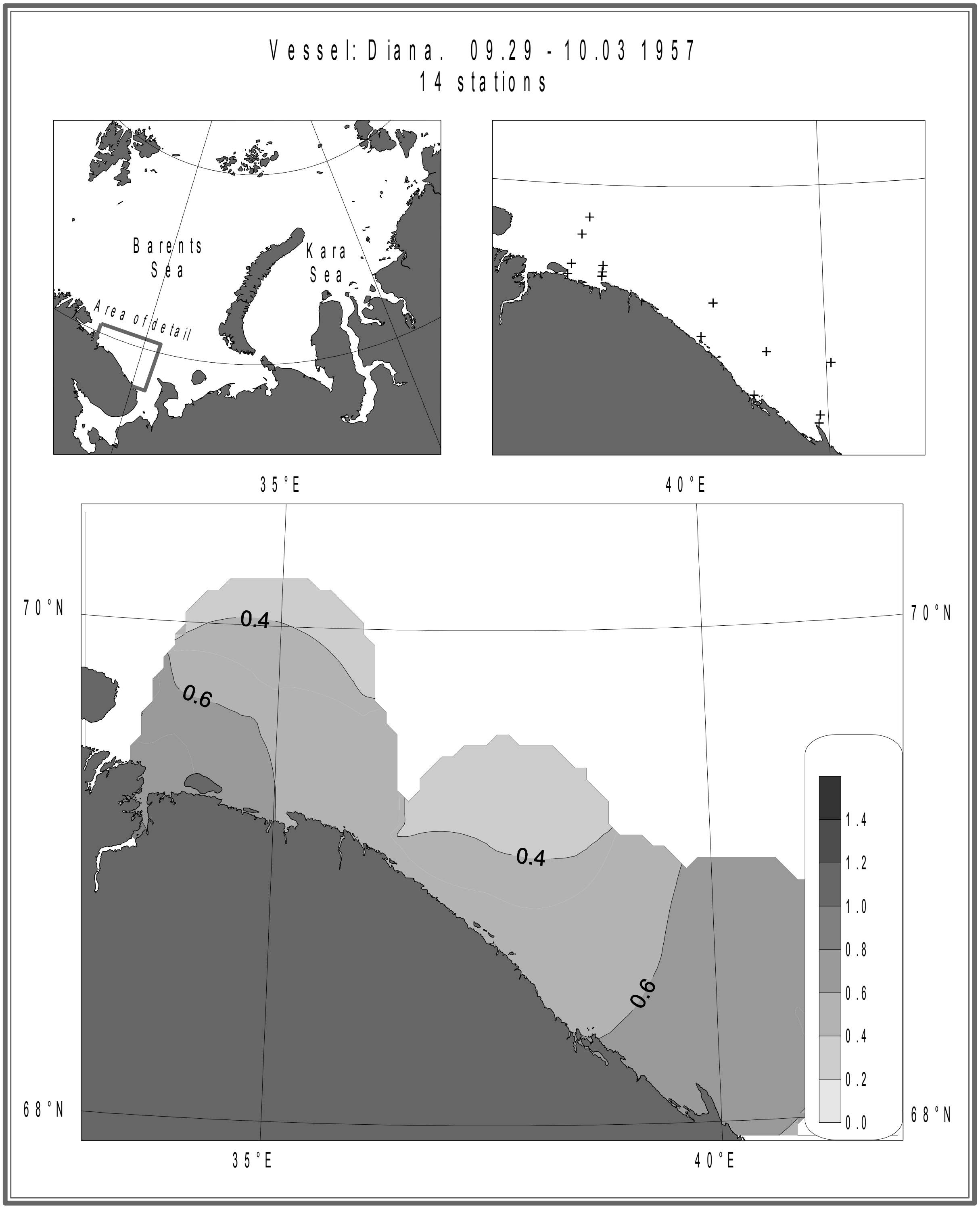


Fig. E2.25. Phytoplankton. Surface-bottom. Biodiversity. September-October, 1957

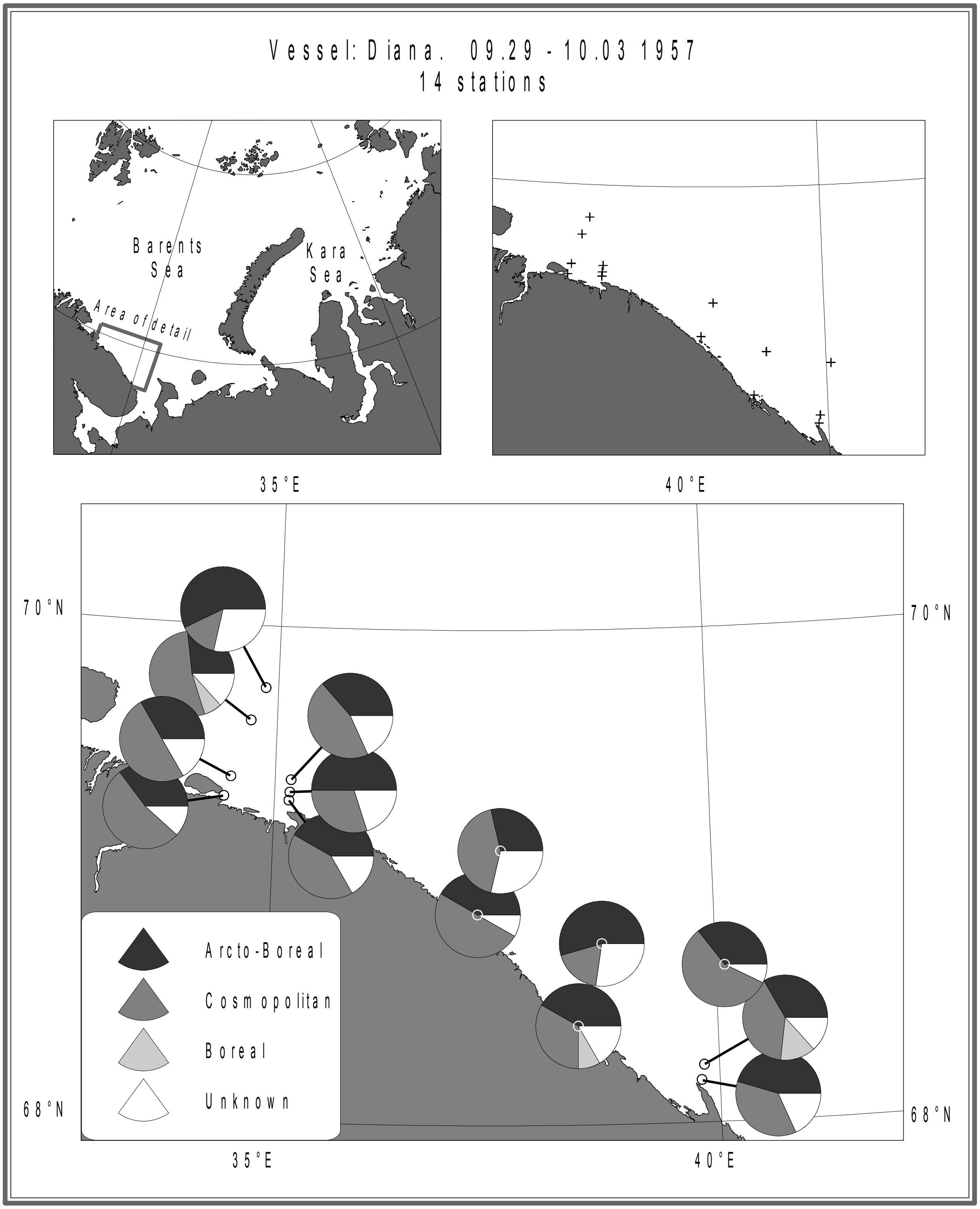


Fig. E2.26. Phytoplankton. Surface-bottom. Geographical characteristics. September-October, 1957

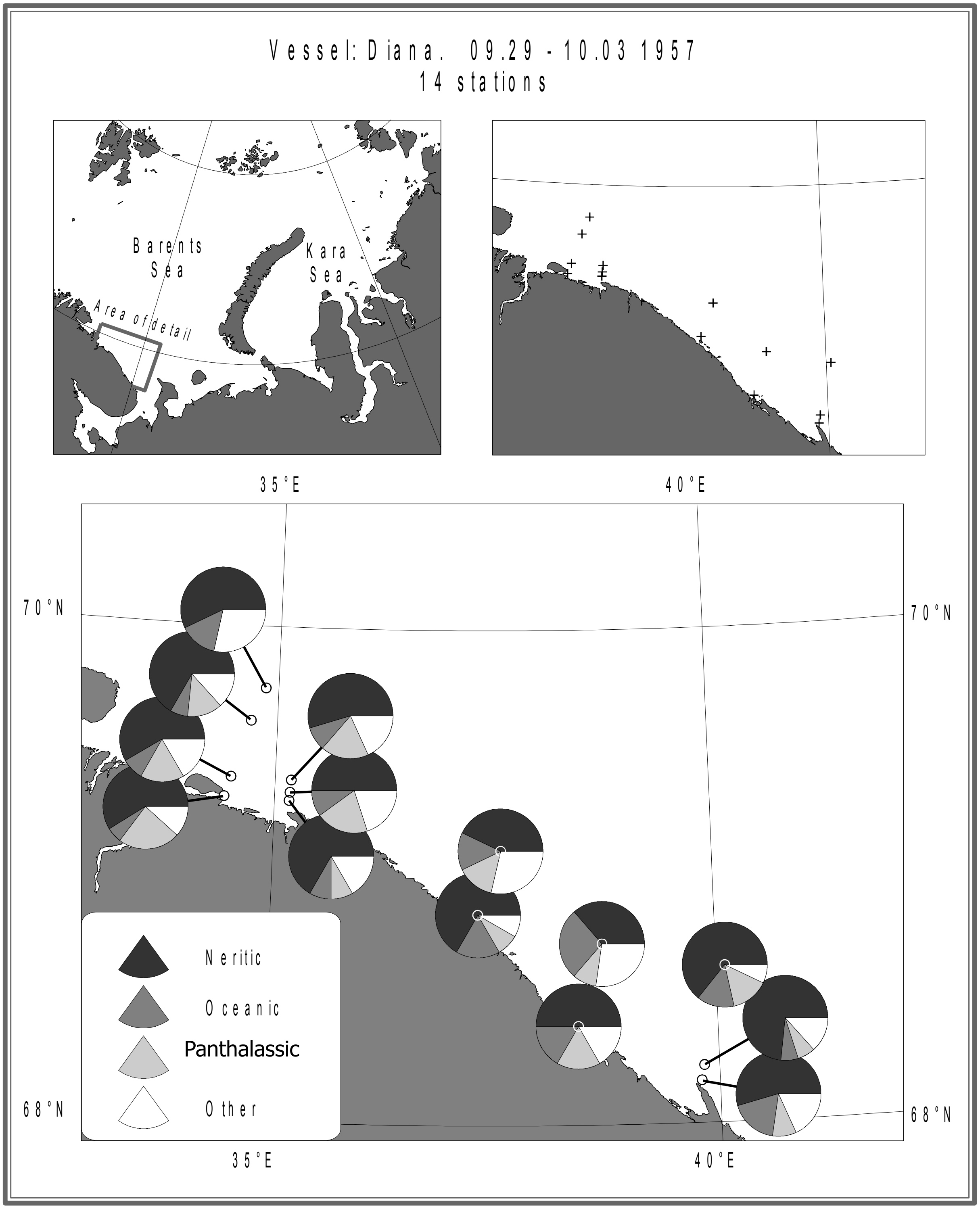


Fig. E2.27. Phytoplankton. Surface-bottom. Ecological characteristics. September-October, 1957

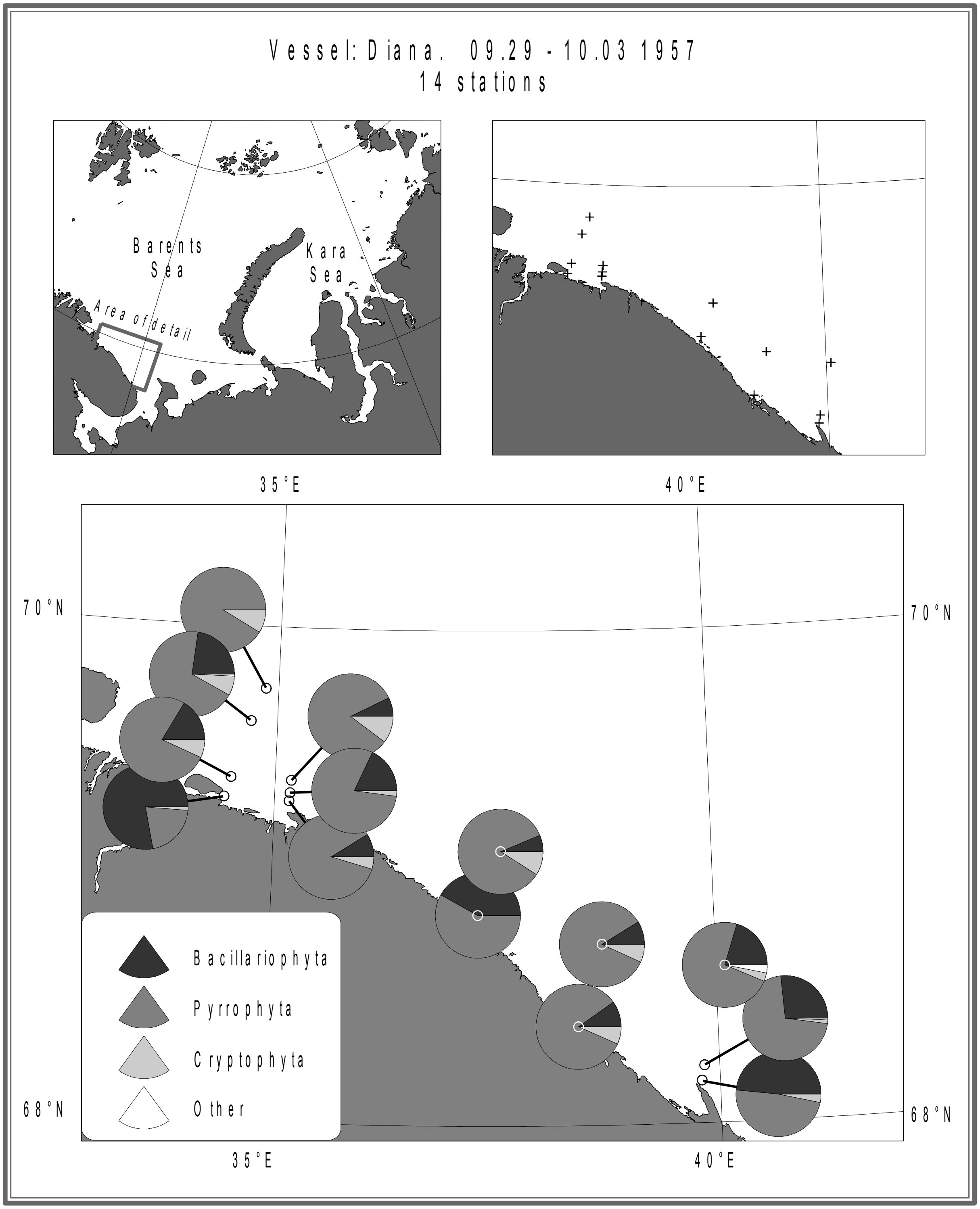


Fig. E2.28. Phytoplankton. Surface-bottom. Taxonomic composition. September-October, 1957

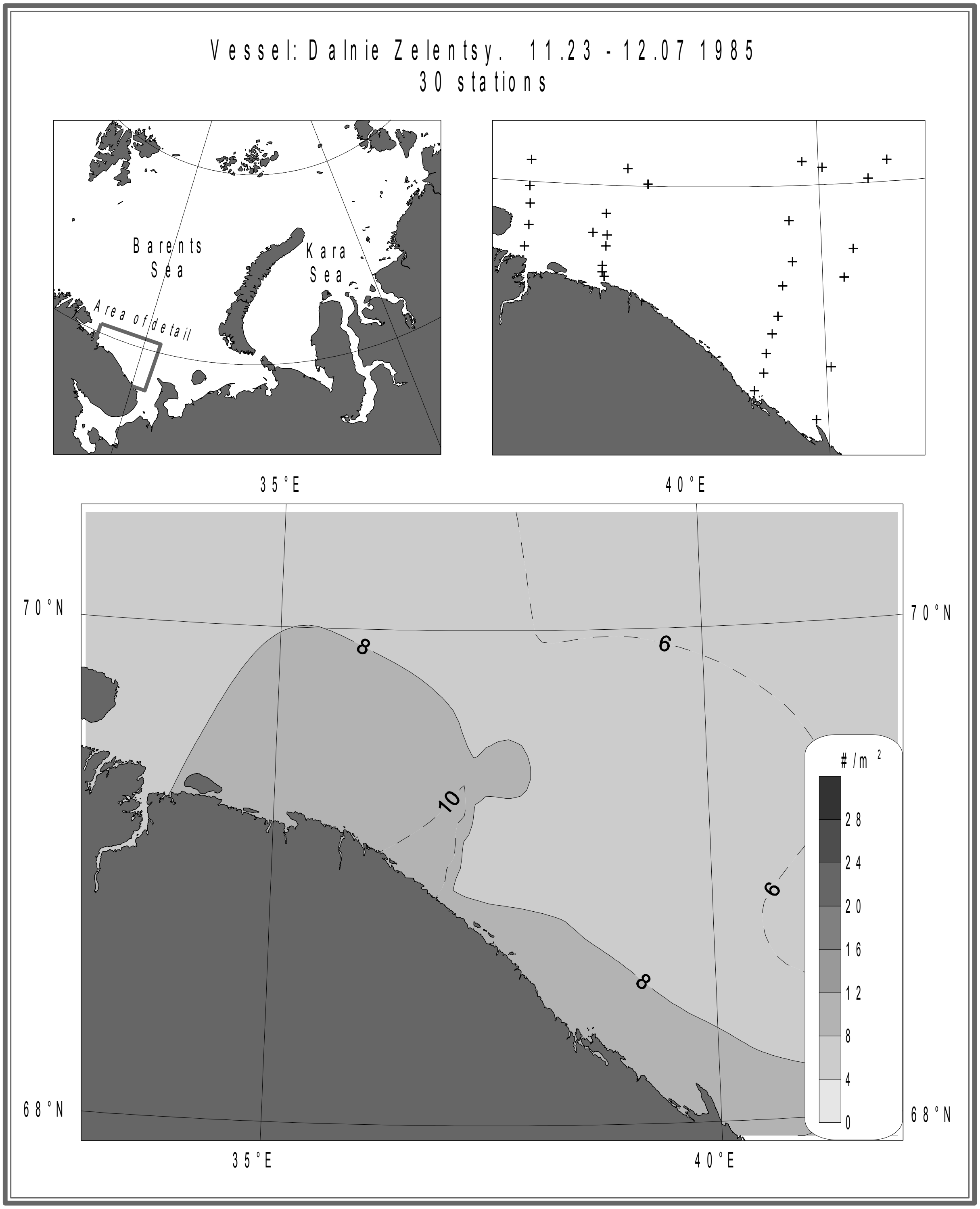


Fig. E2.29. Phytoplankton. Surface-bottom. Number of species. November-December, 1985

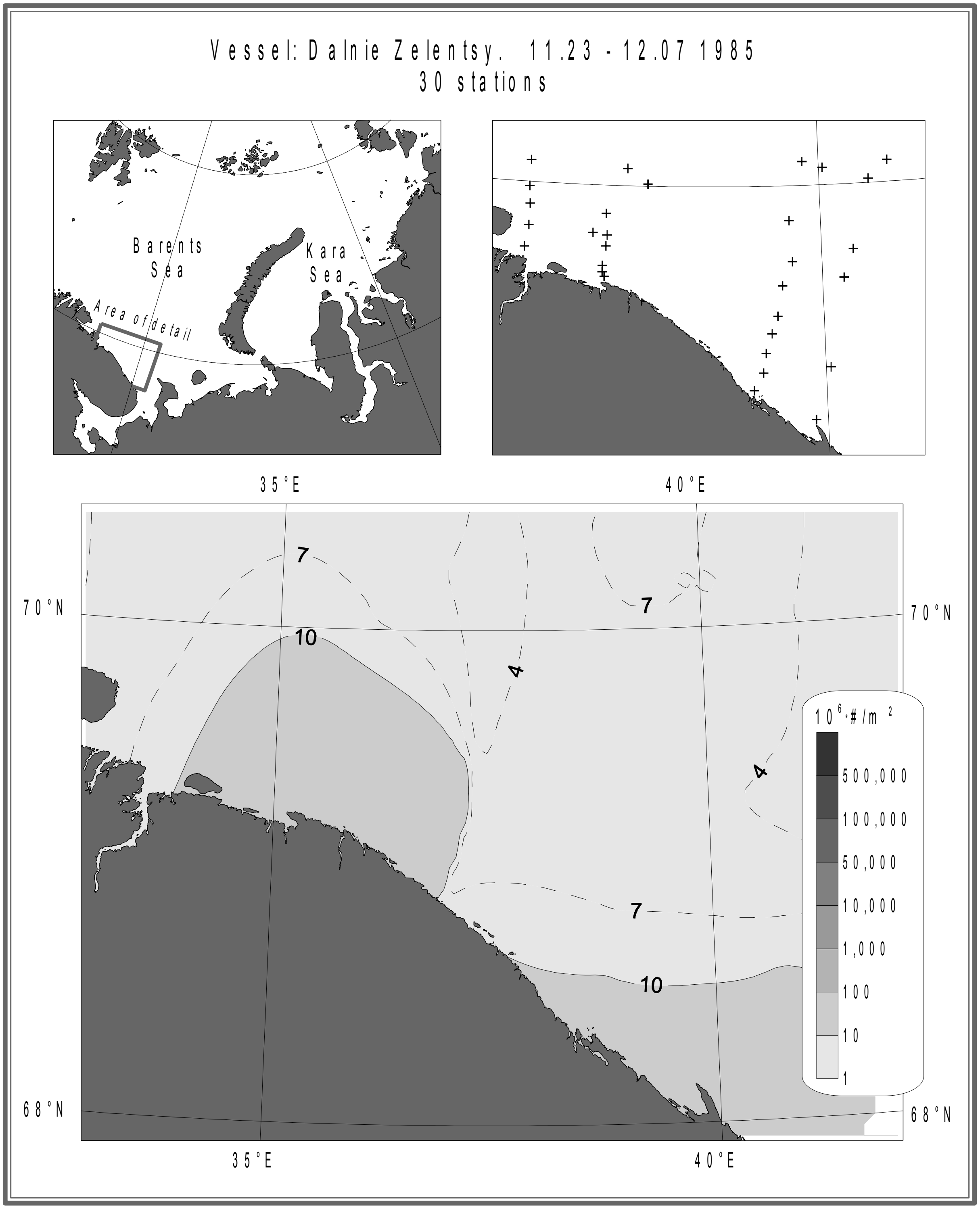


Fig. E2.30. Phytoplankton. Surface-bottom. Number of cells. November-December, 1985

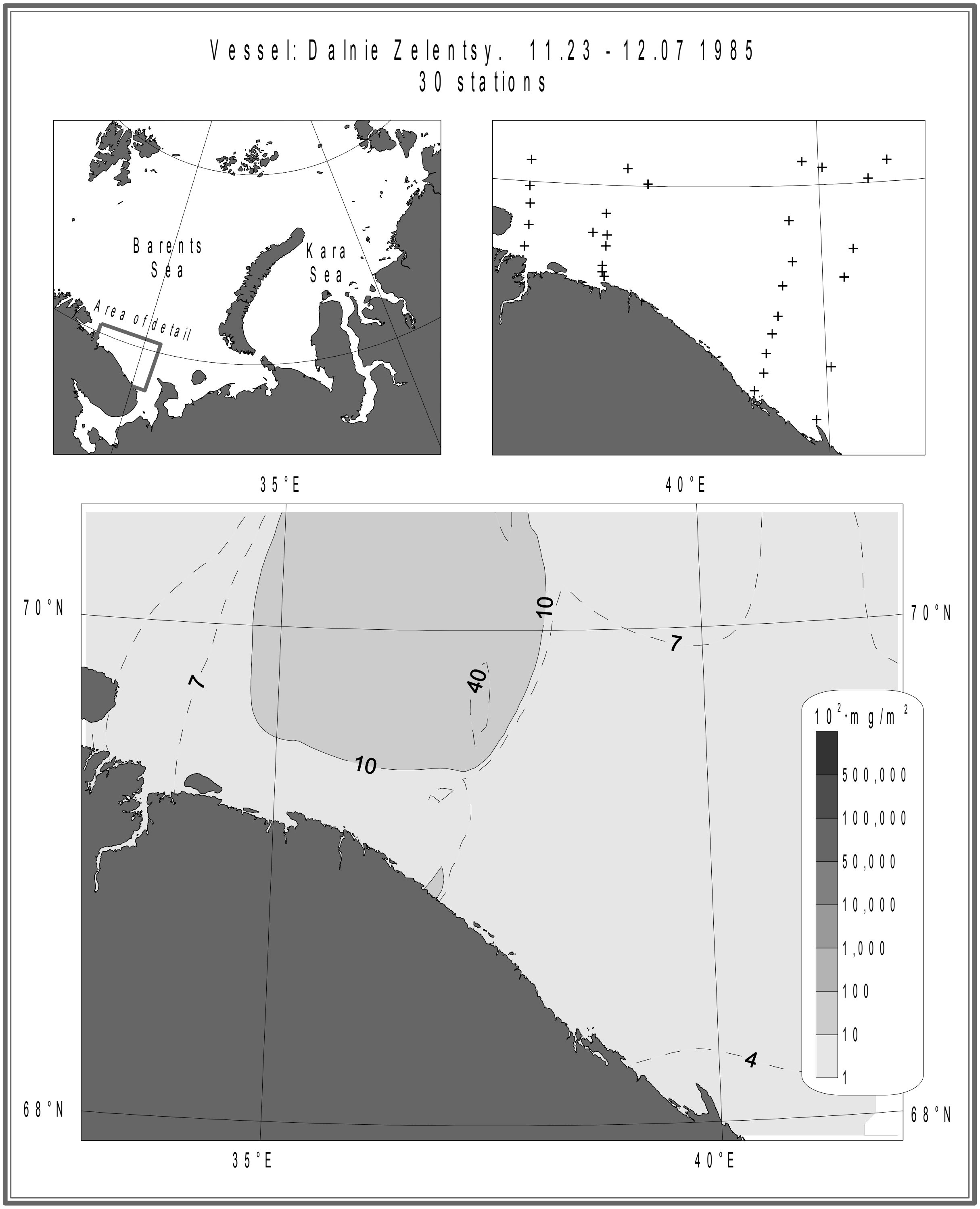


Fig. E2.31. Phytoplankton. Surface-bottom. Biomass. November-December, 1985

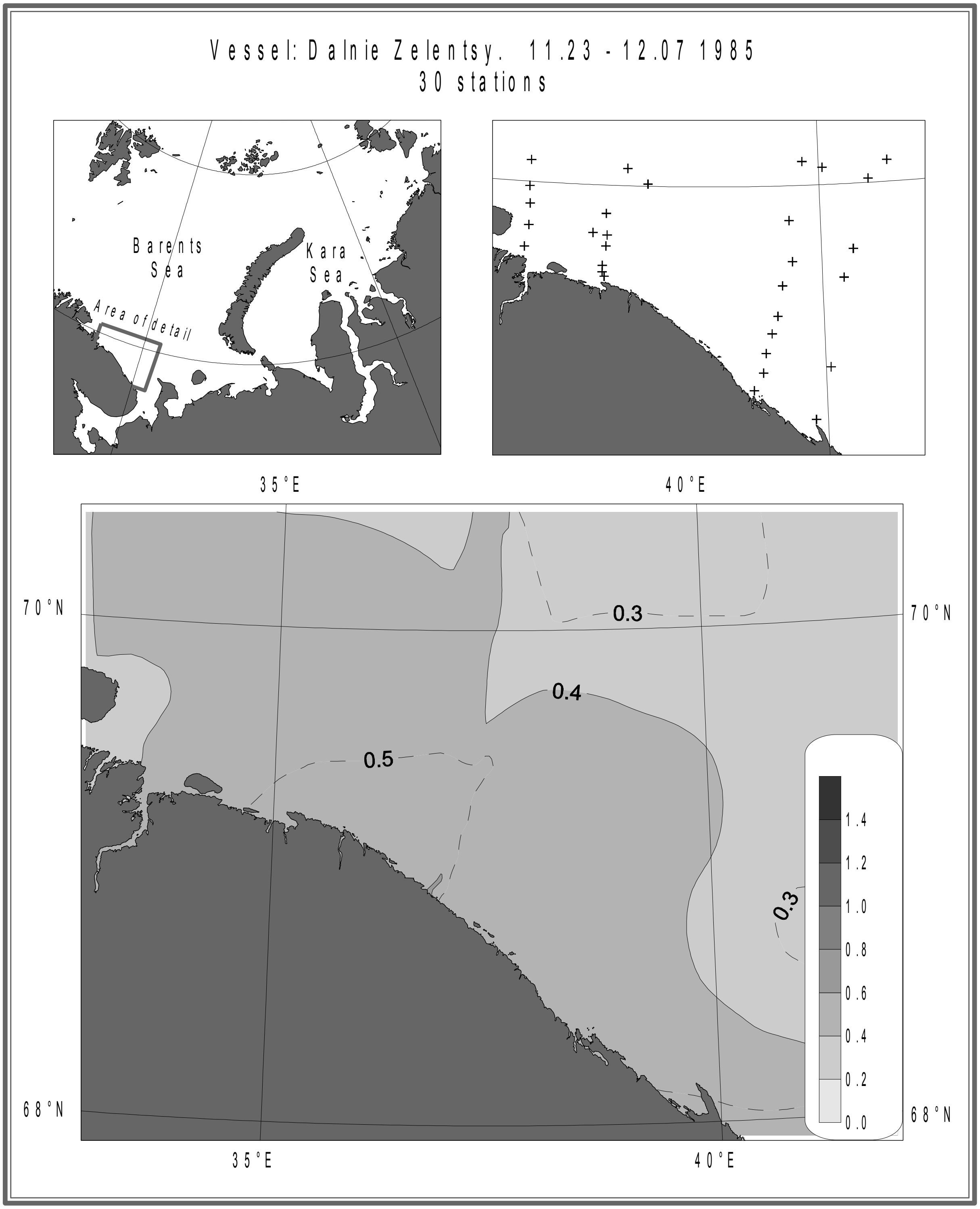


Fig. E2.32. Phytoplankton. Surface-bottom. Biodiversity. November-December, 1985

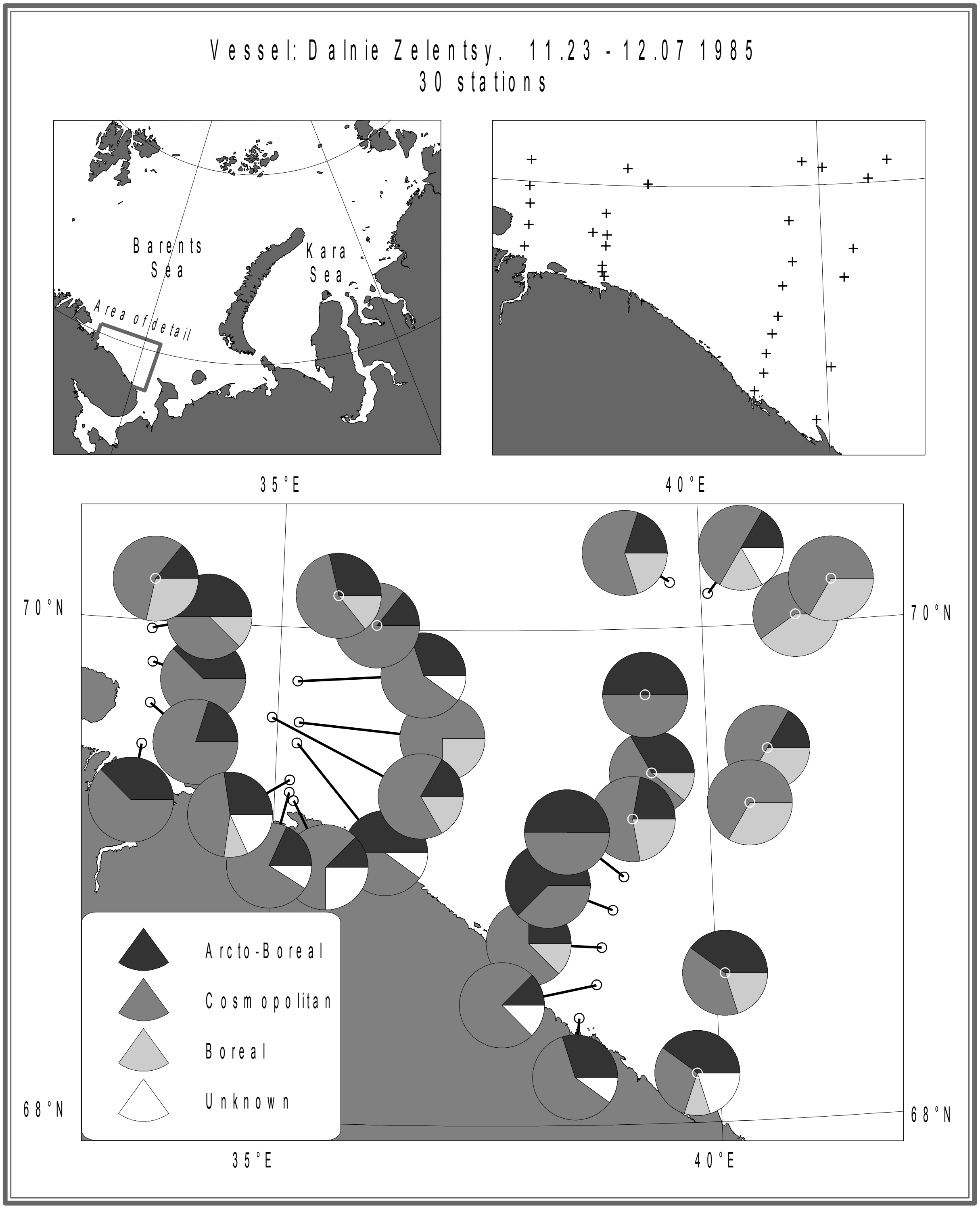


Fig. E2.33. Phytoplankton. Surface-bottom. Geographical characteristics. November-December, 1985

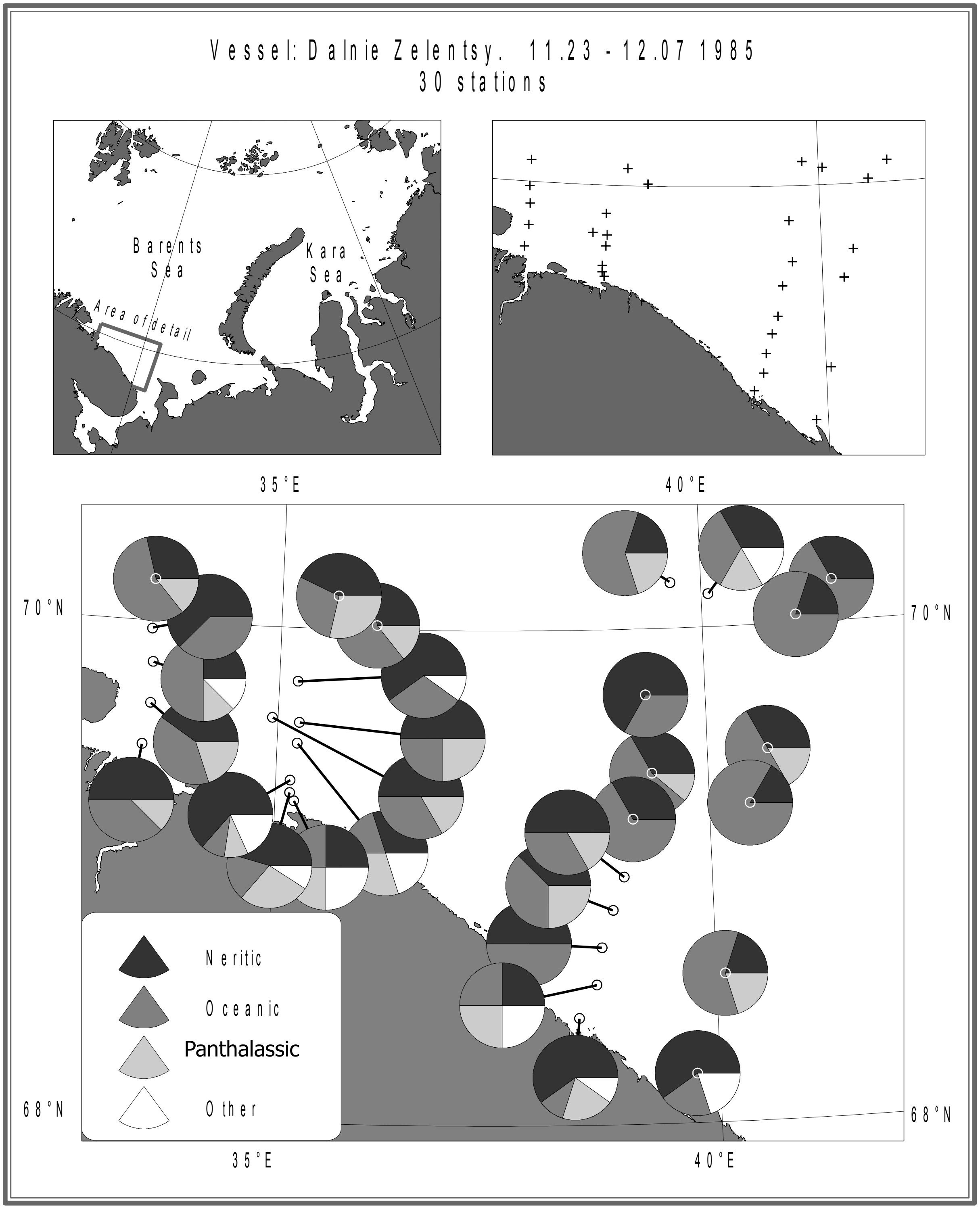


Fig. E2.34. Phytoplankton. Surface-bottom. Ecological characteristics. November-December, 1985

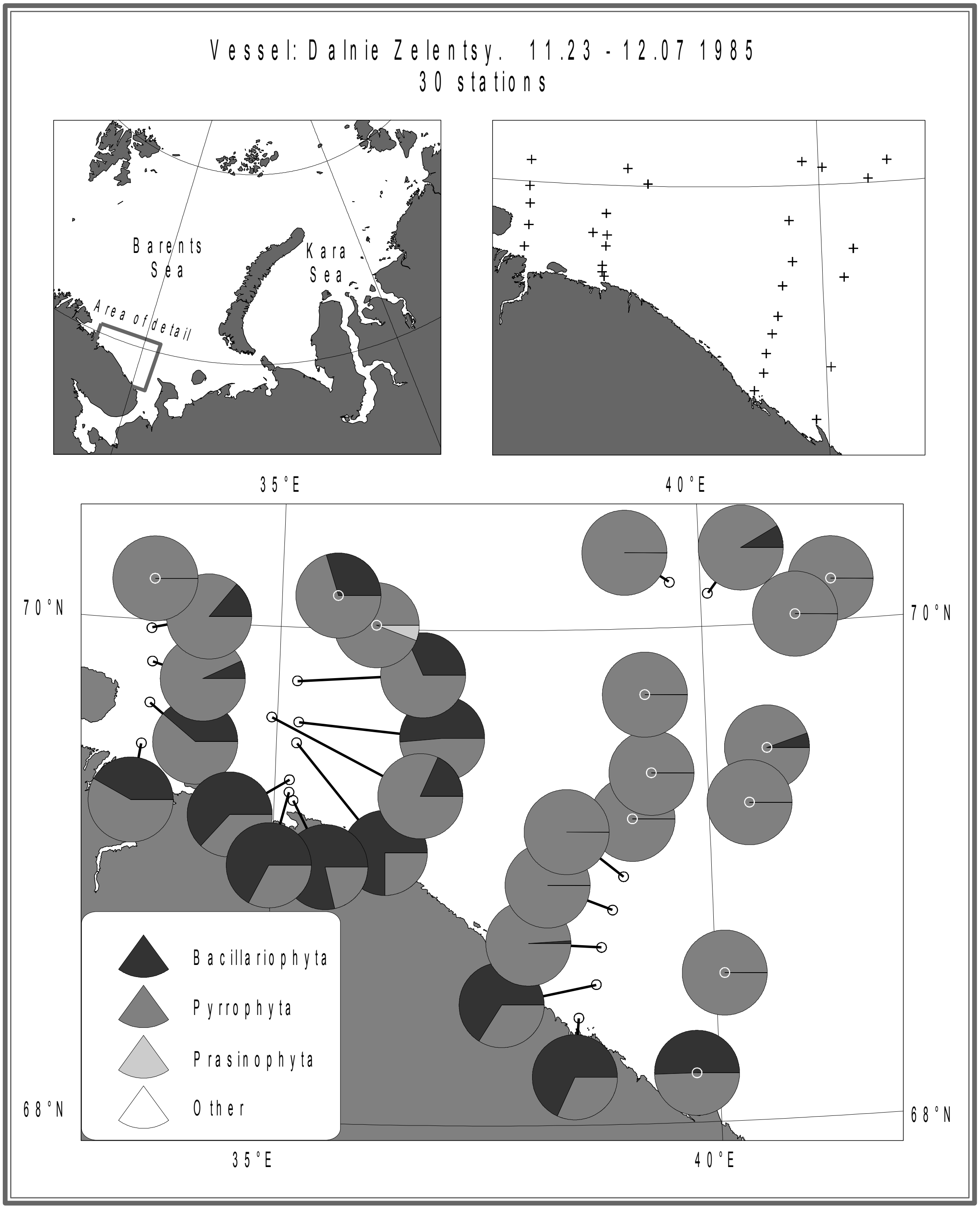


Fig. E2.35. Phytoplankton. Surface-bottom. Taxonomic composition. November-December, 1985

Fig. E2.36. Annual observations in the coastal zone. Position of stations

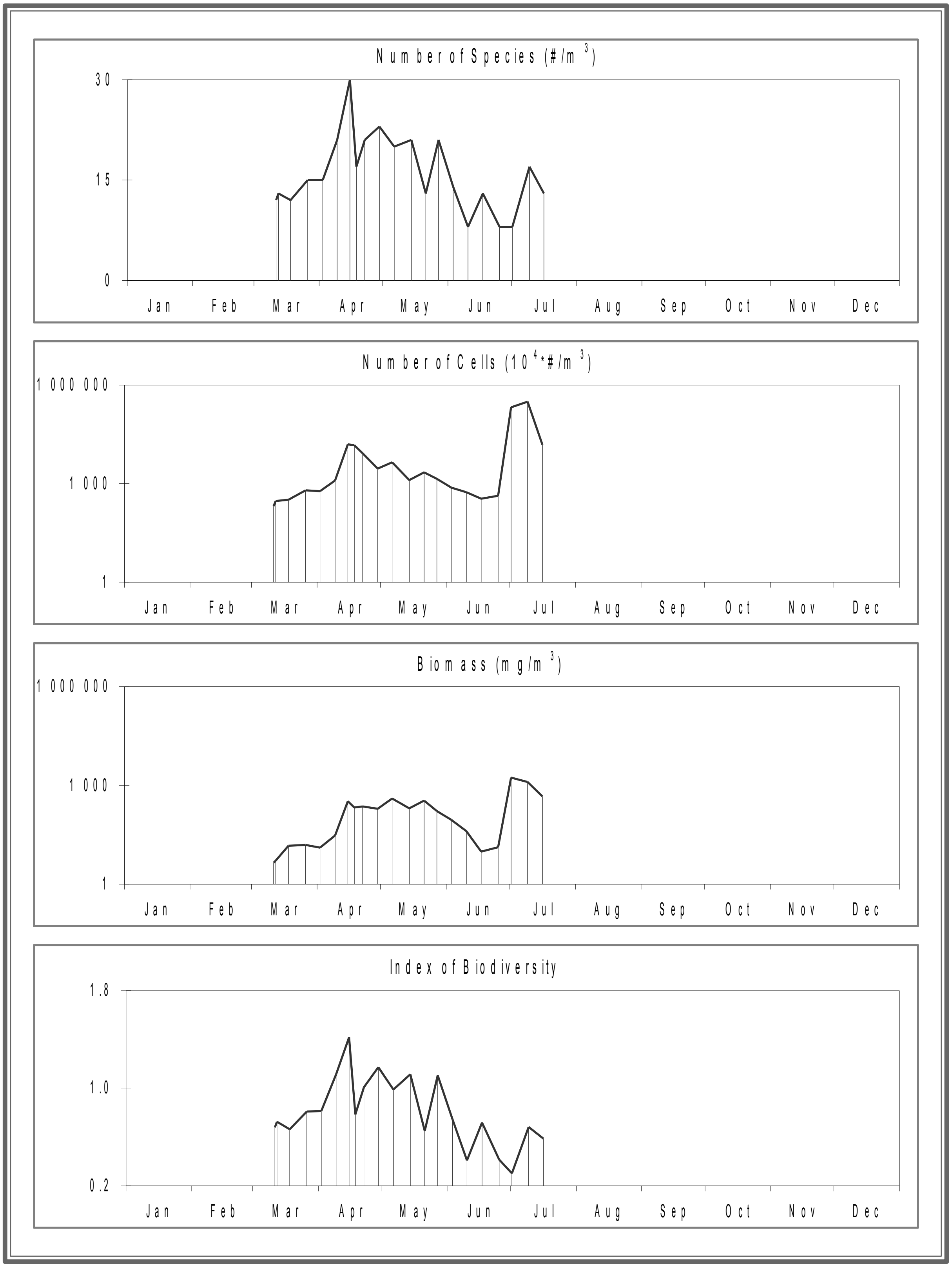


Fig. E2.37. Phytoplankton. Quantitative variables. Jarnishnaya Bay. 1968

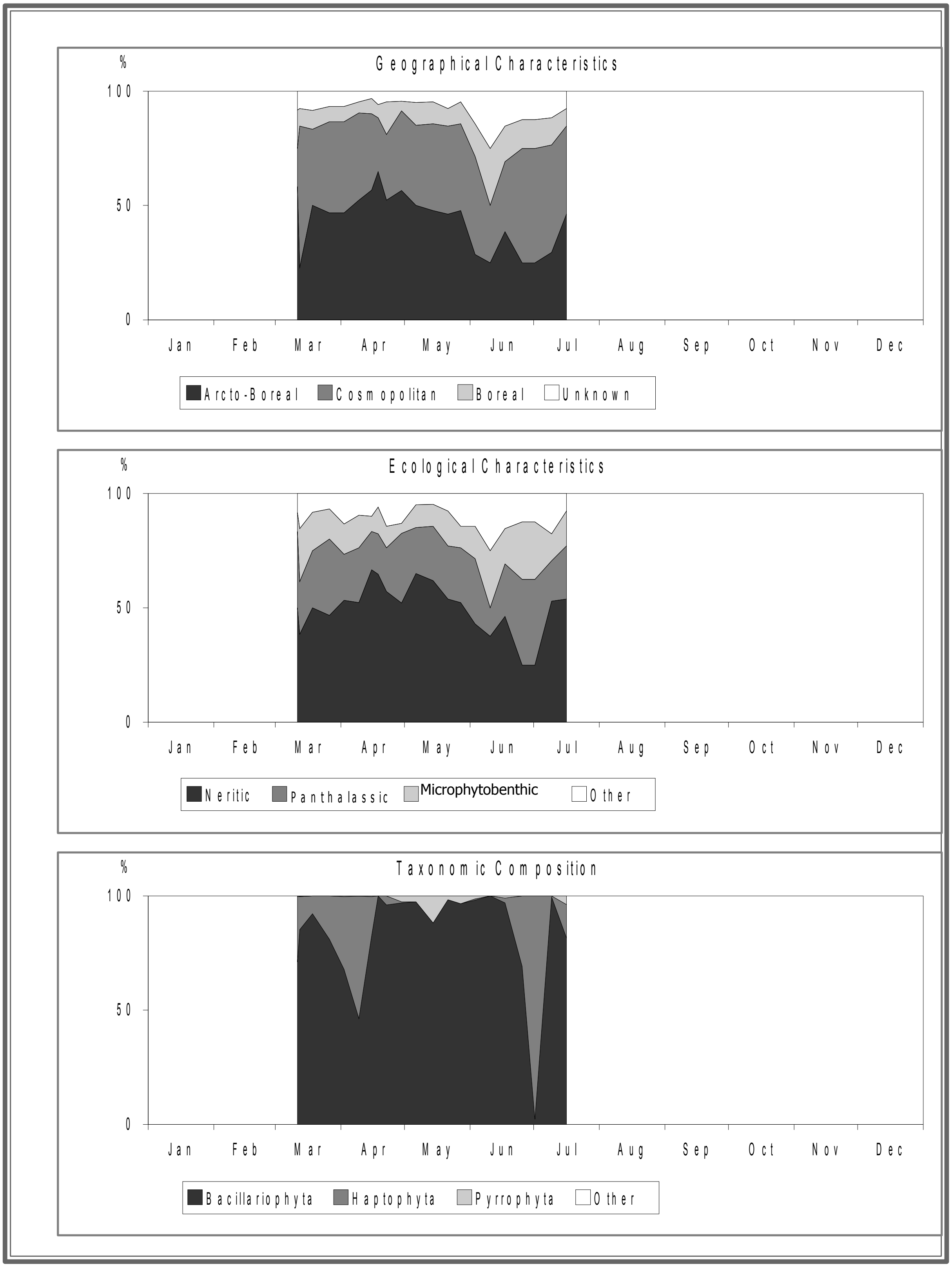


Fig. E2.38. Phytoplankton. Structural variables. Jarnishnaya Bay. 1968

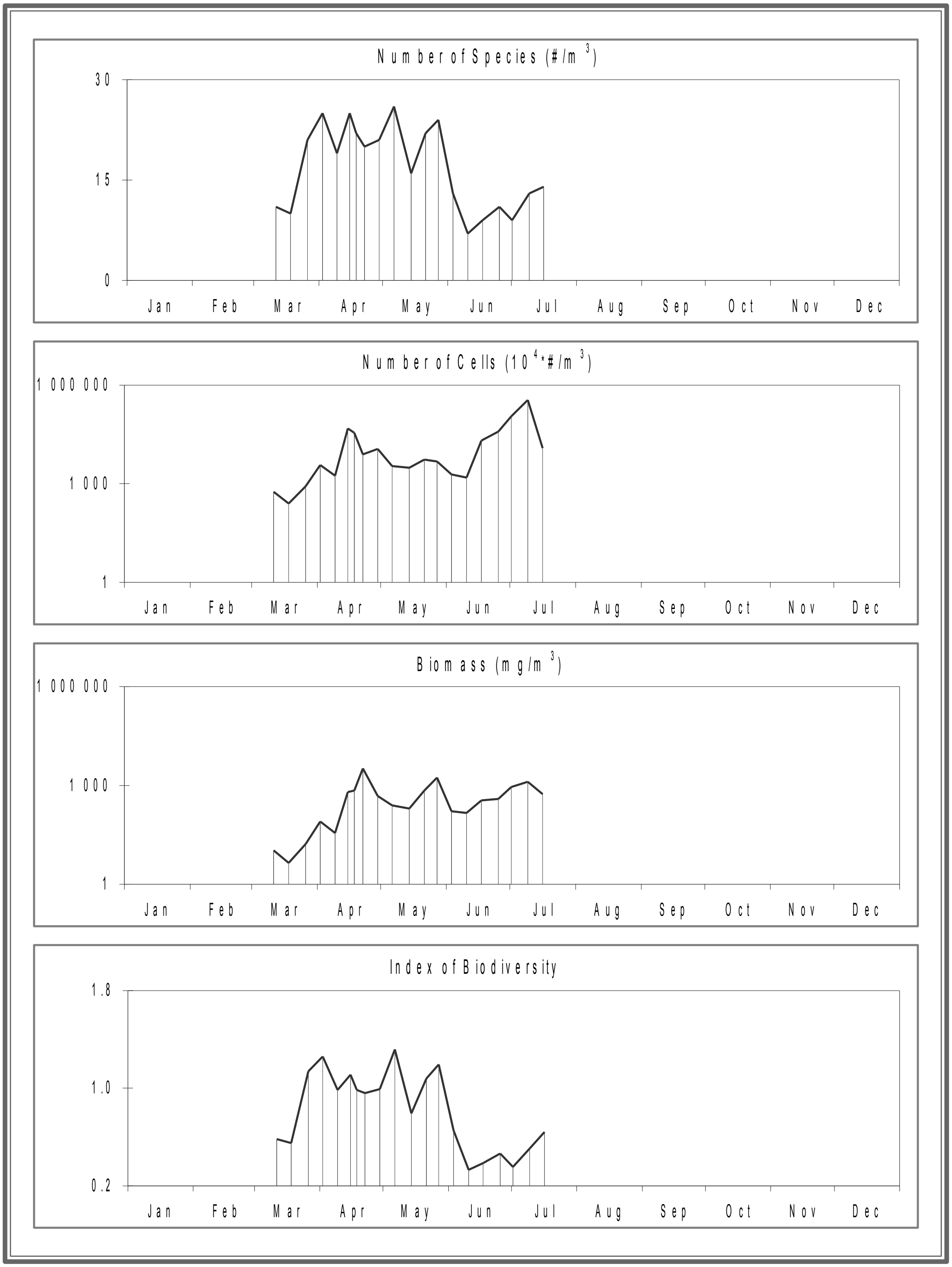


Fig. E2.39. Phytoplankton. Quantitative variables. Dalnezelenetskaya Bay. 1968

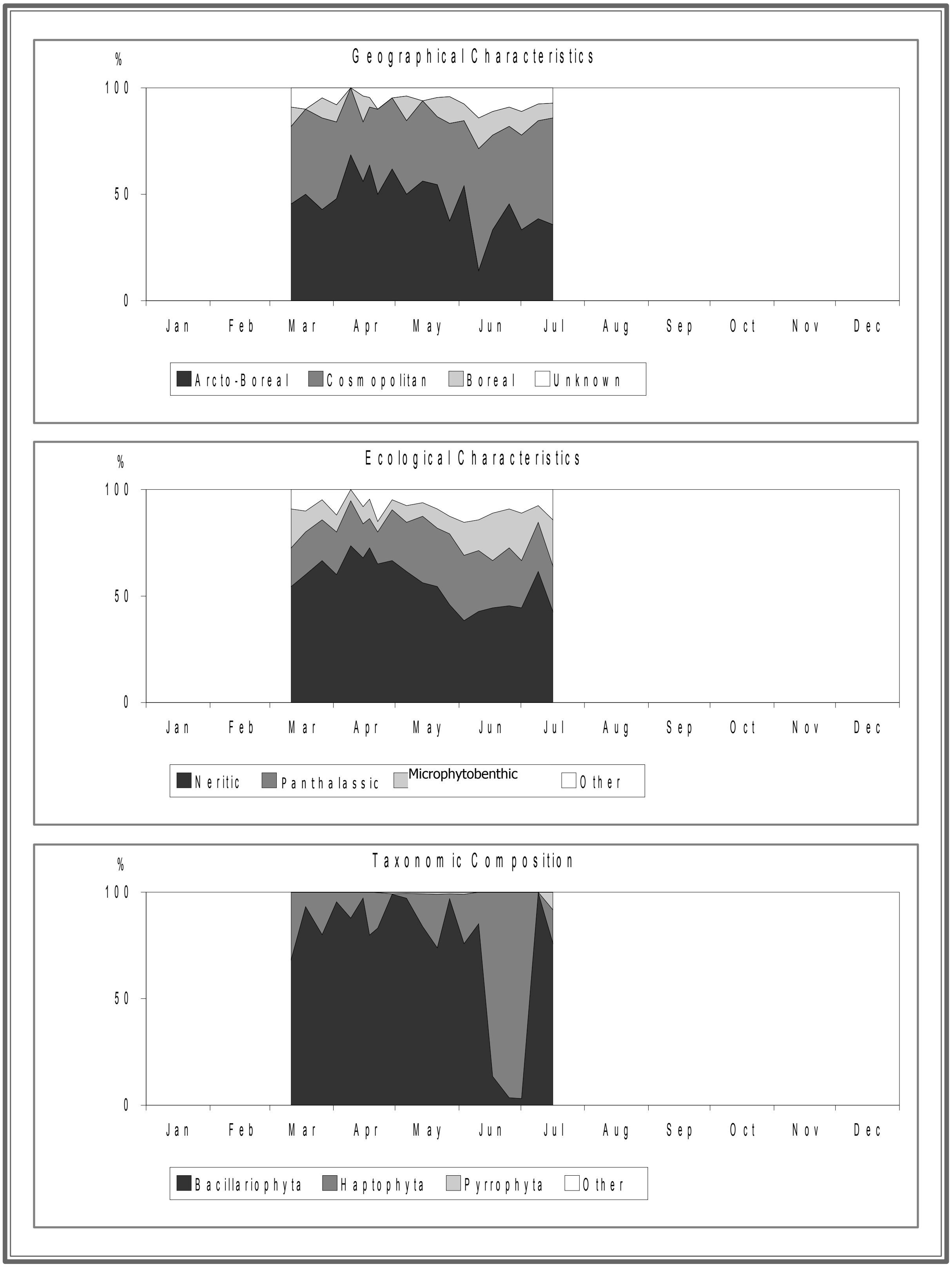


Fig. E2.40. Phytoplankton. Structural variables. Dalnezelenetskaya Bay. 1968

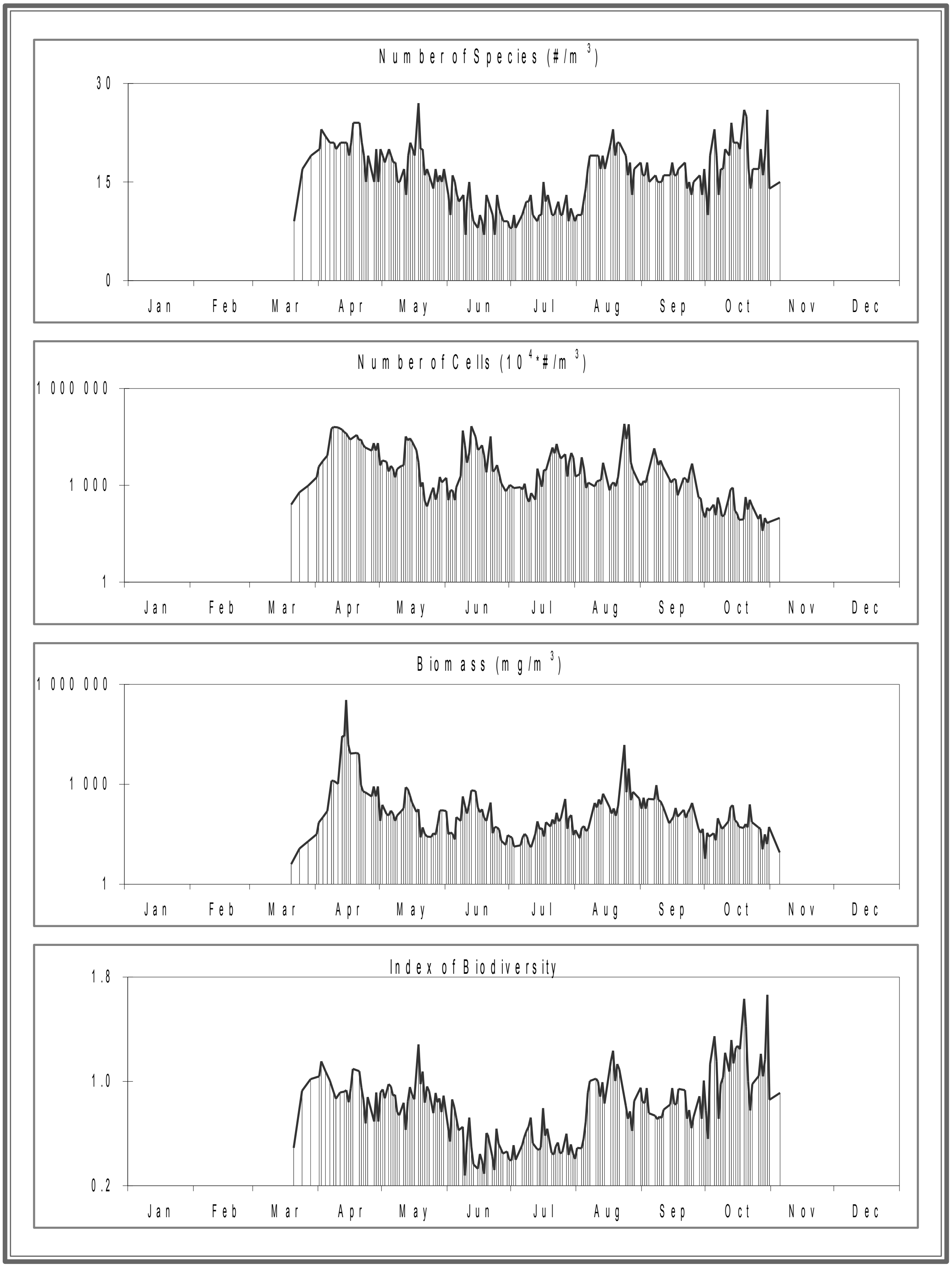


Fig. E2.41. Phytoplankton. Quantitative variables. Dalnezelenetskaya Bay. 1970

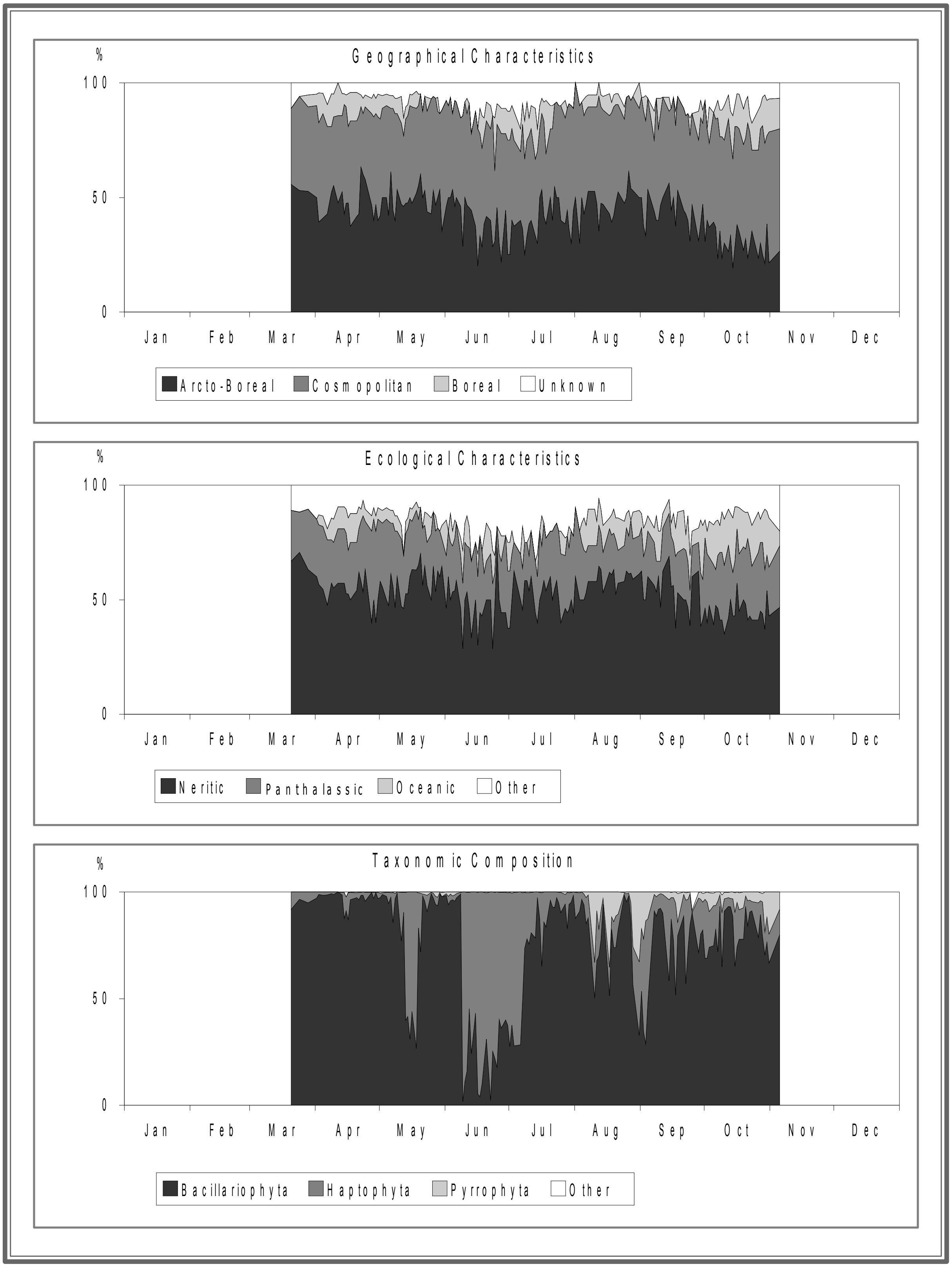


Fig. E2.42. Phytoplankton. Structural variables. Dalnezelenetskaya Bay. 1970

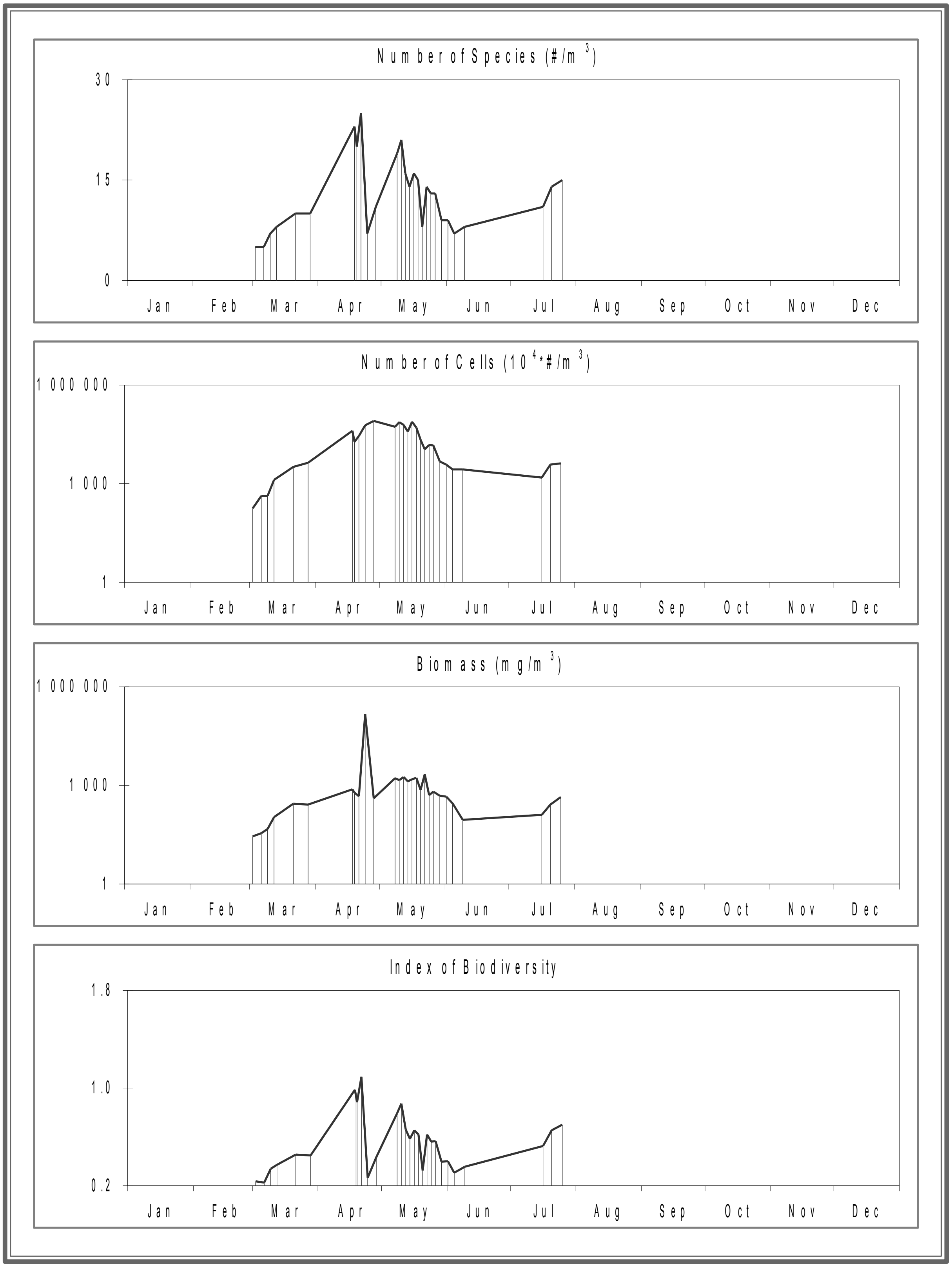


Fig. E2.43. Phytoplankton. Quantitative variables. Dalnezelenetskaya Bay. 1986

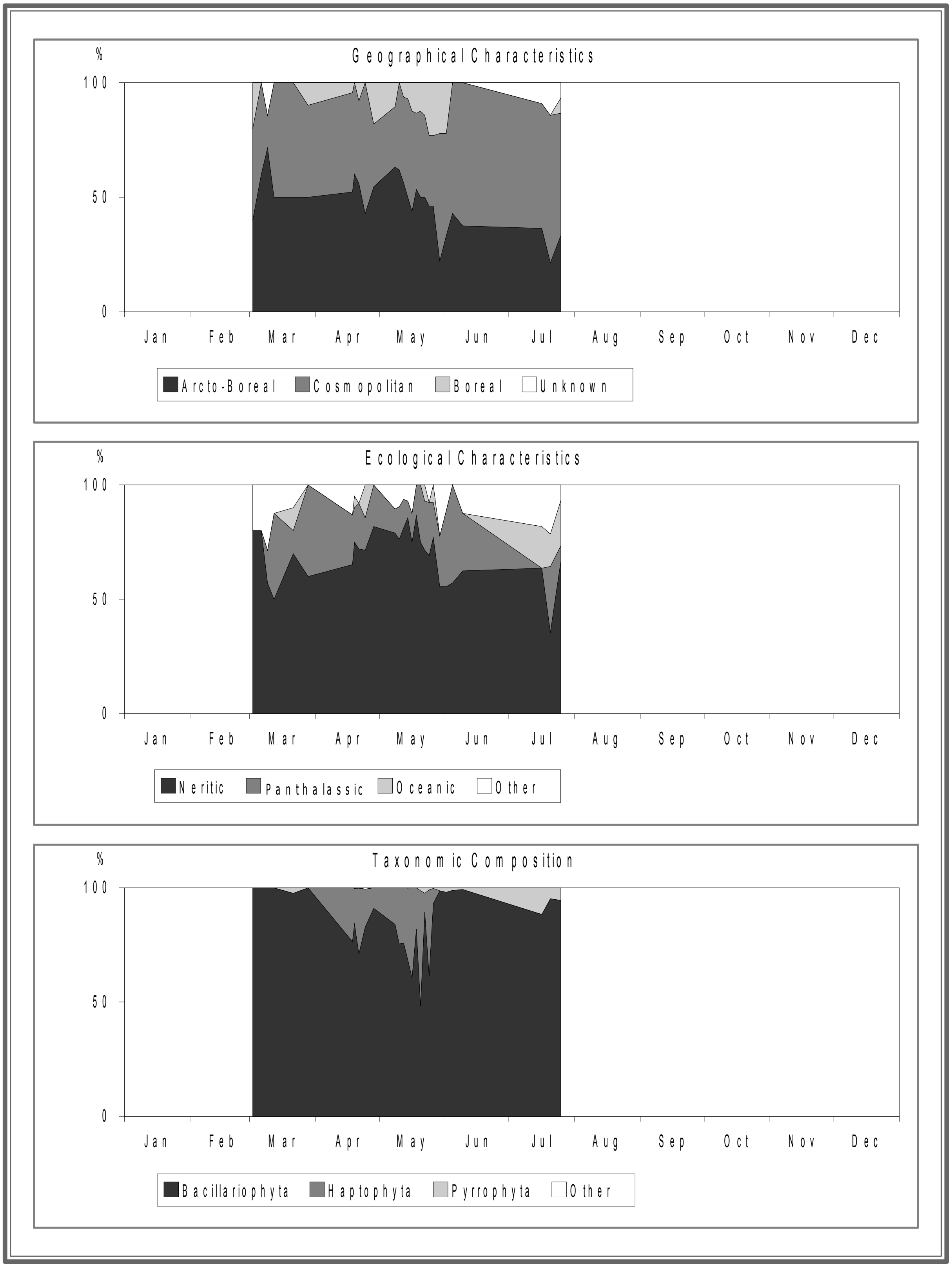


Fig. E2.44. Phytoplankton. Structural variables. Dalnezelenetskaya Bay. 1986

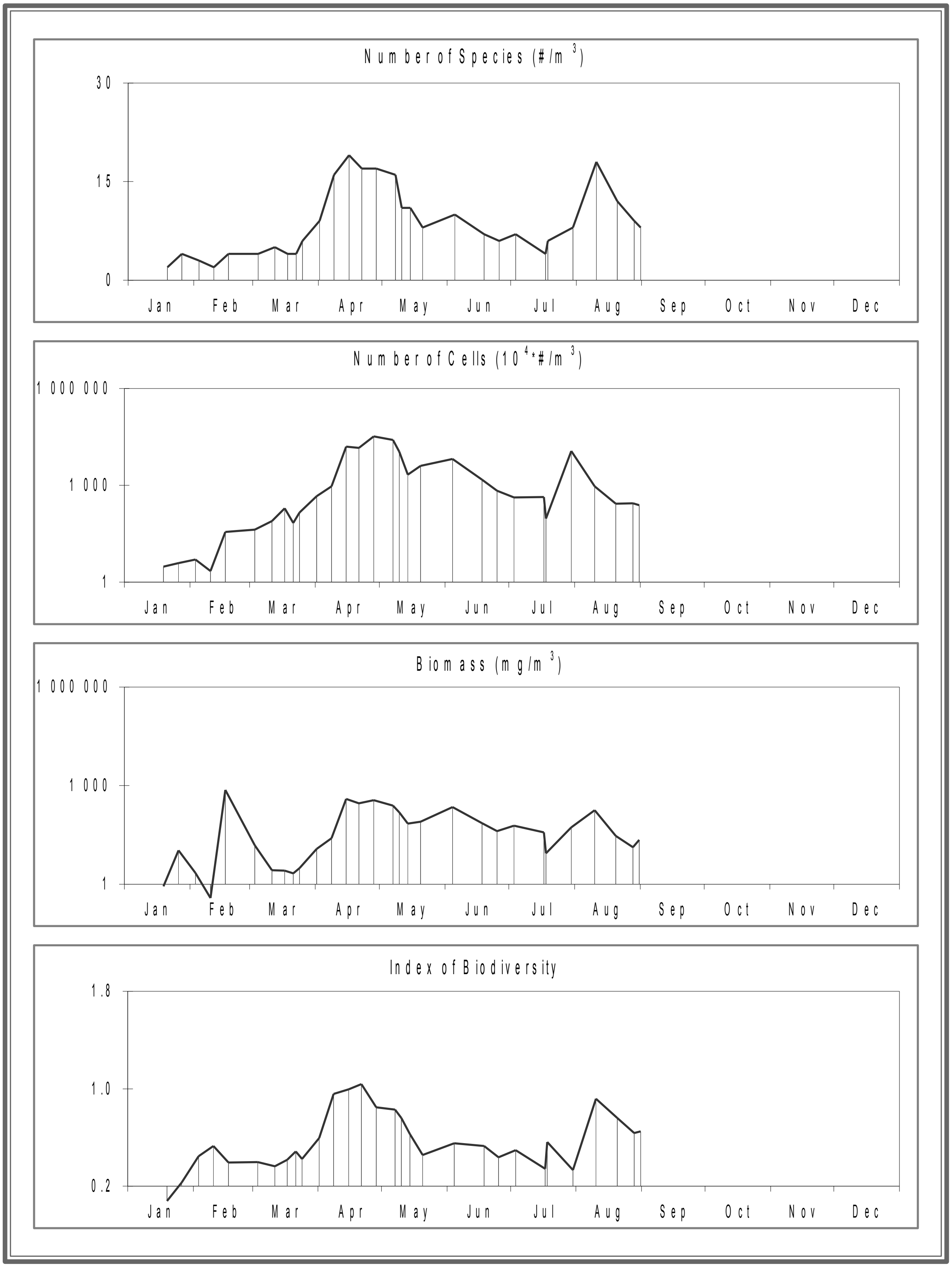


Fig. E2.45. Phytoplankton. Quantitative variables. Dalnezelenetskaya Bay. 1987

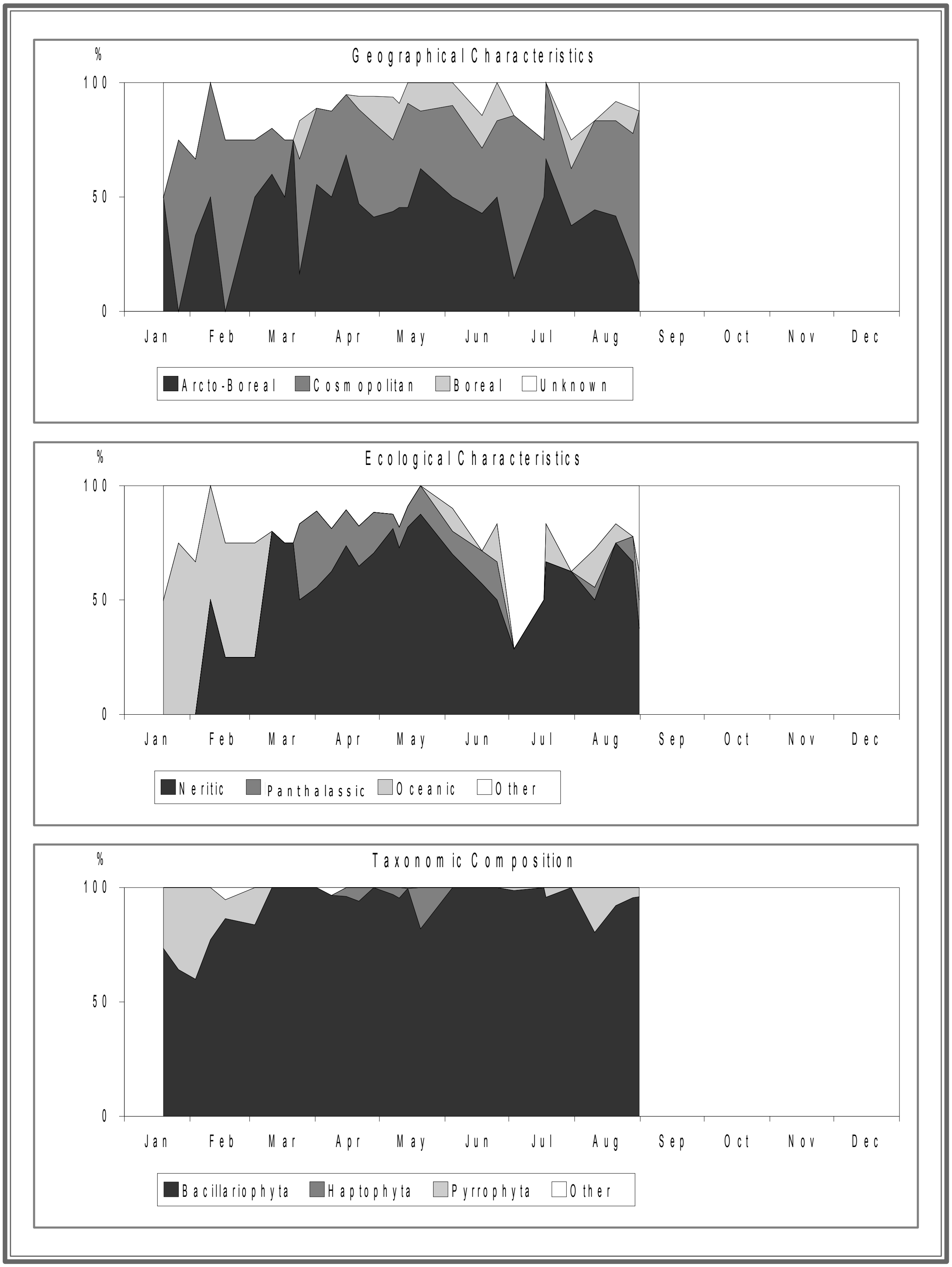


Fig. E2.46. Phytoplankton. Structural variables. Dalnezelenetskaya Bay. 1987

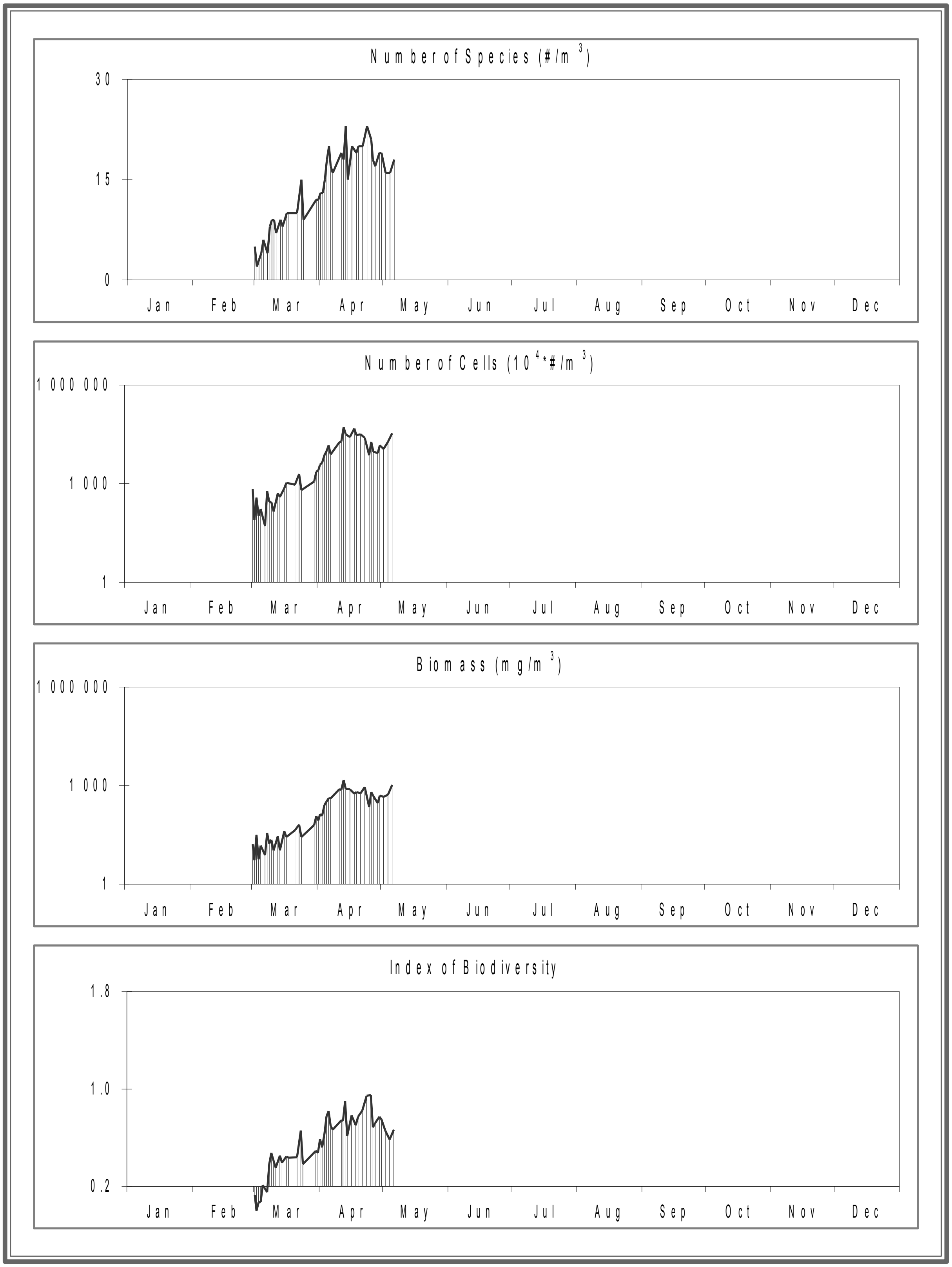


Fig. E2.47. Phytoplankton. Quantitative variables. Dalnezelenetskaya Bay. 1988

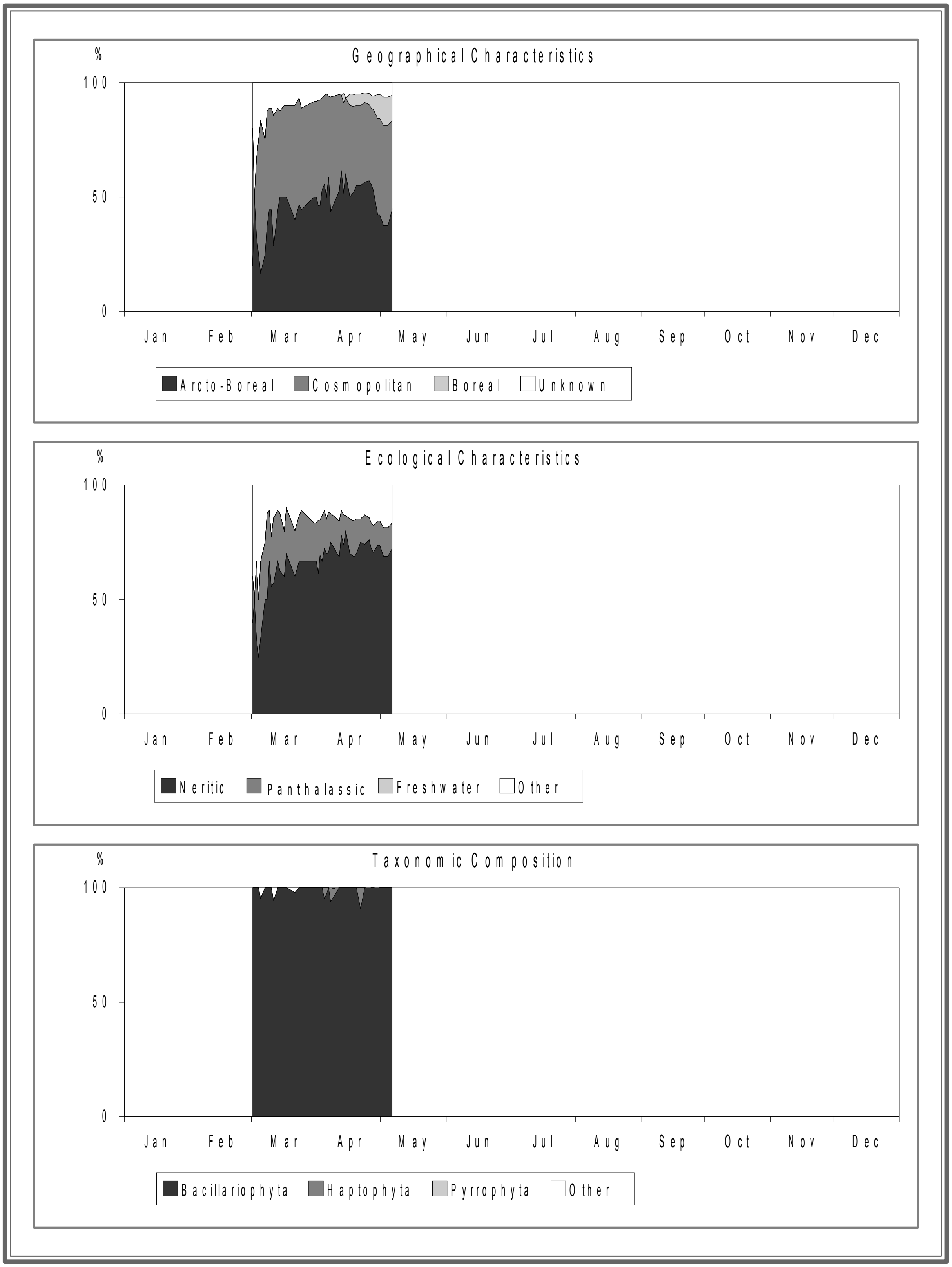


Fig. E2.48. Phytoplankton. Structural variables. Dalnezelenetskaya Bay. 1988

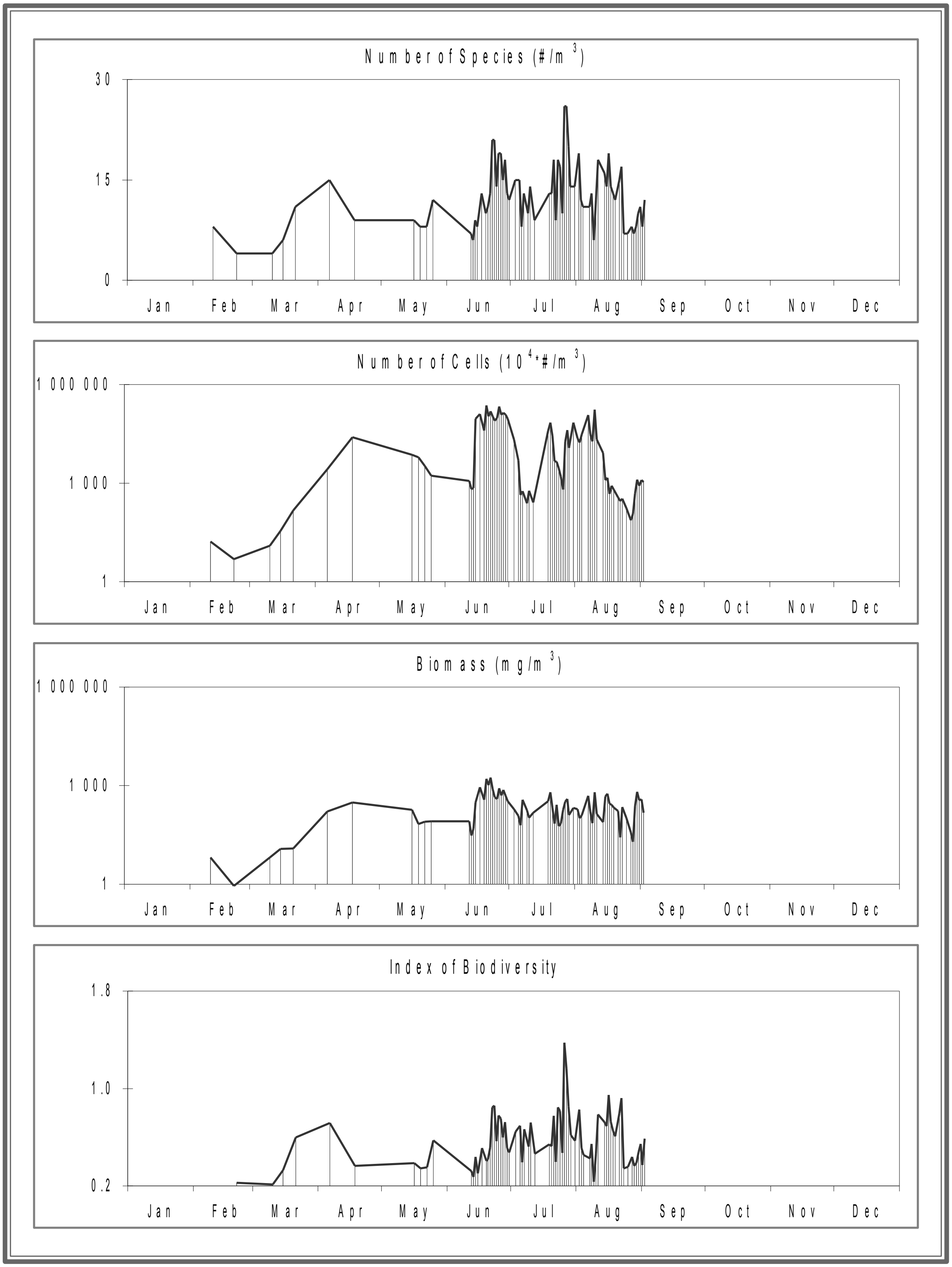


Fig. E2.49. Phytoplankton. Quantitative variables. Dalnezelenetskaya Bay. 1989

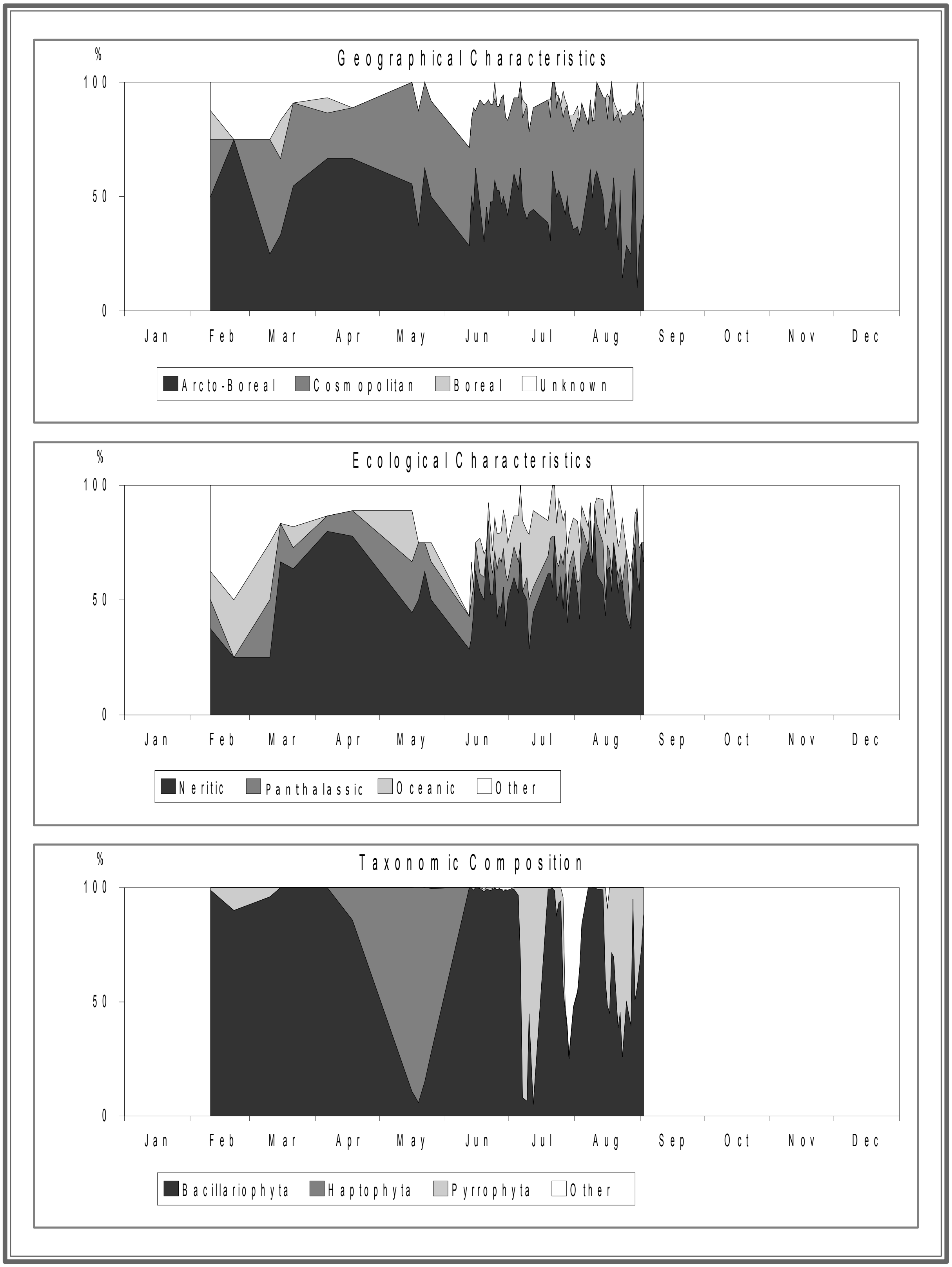


Fig. E2.50. Phytoplankton. Structural variables. Dalnezelenetskaya Bay. 1989

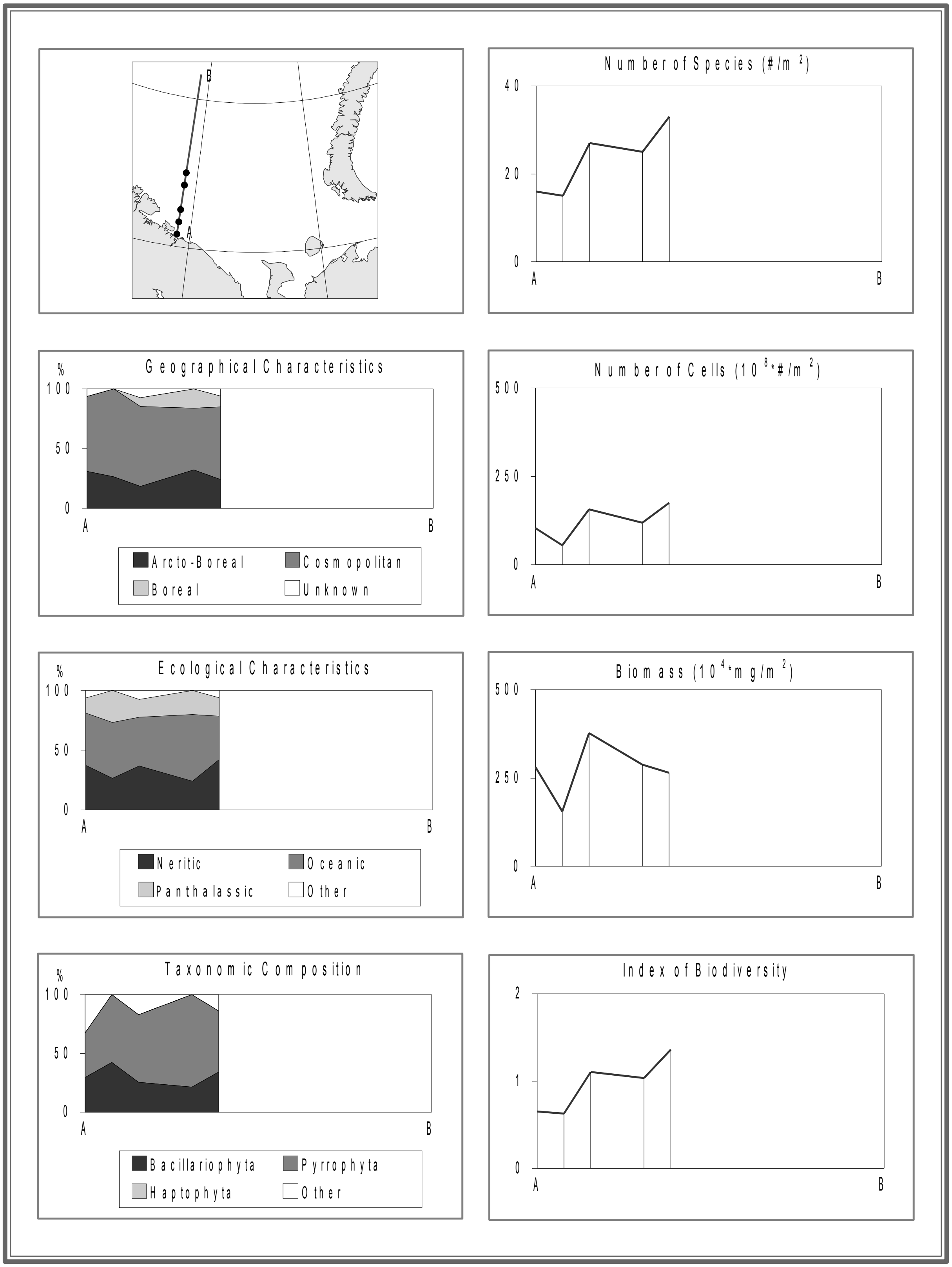


Fig. E2.51. Phytoplankton. Surface-bottom. Vessel *Sokolitsa*. May, 1921

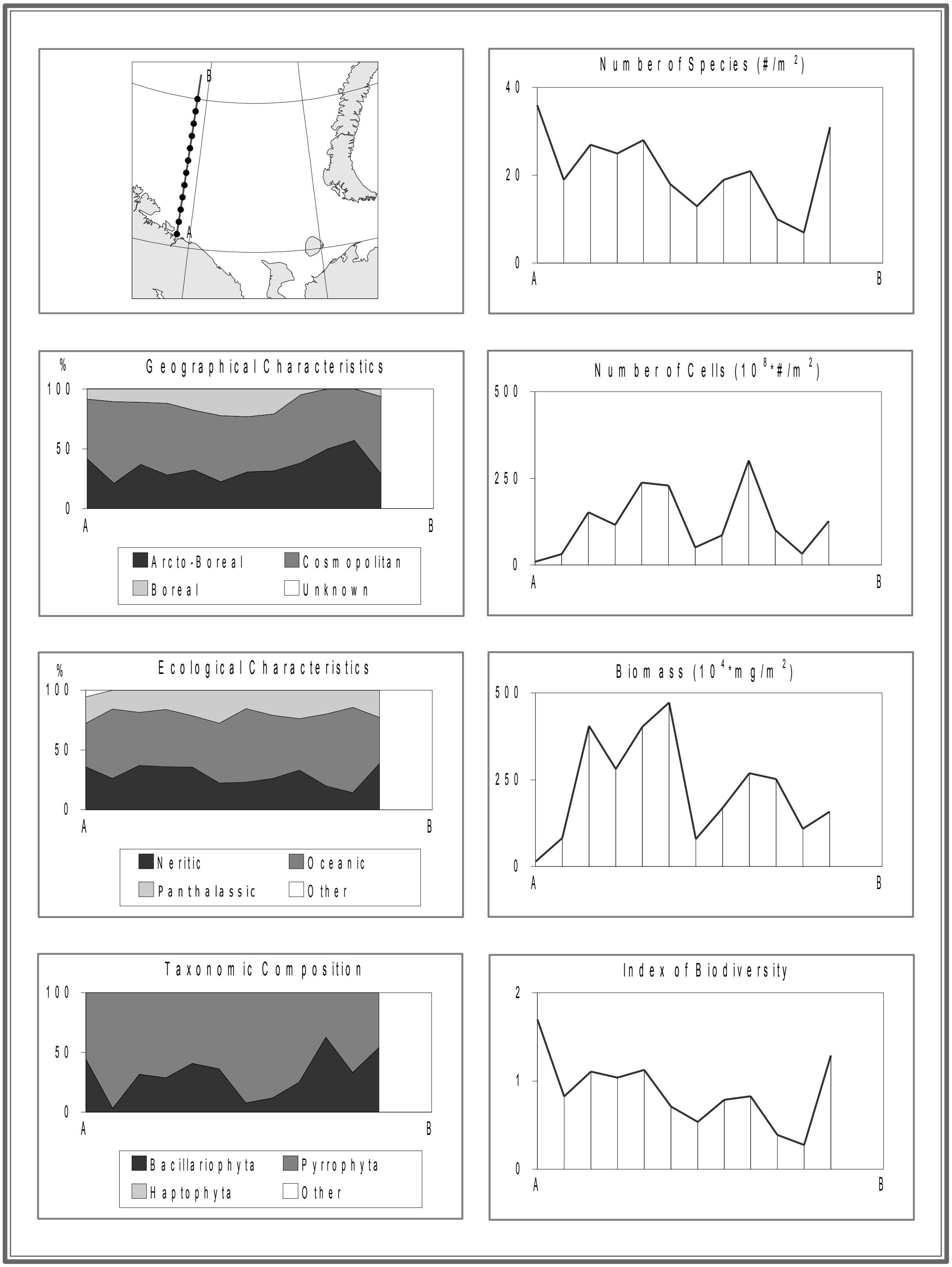


Fig. E2.52. Phytoplankton. Surface-bottom. Vessel *Sokolitsa*. August, 1921

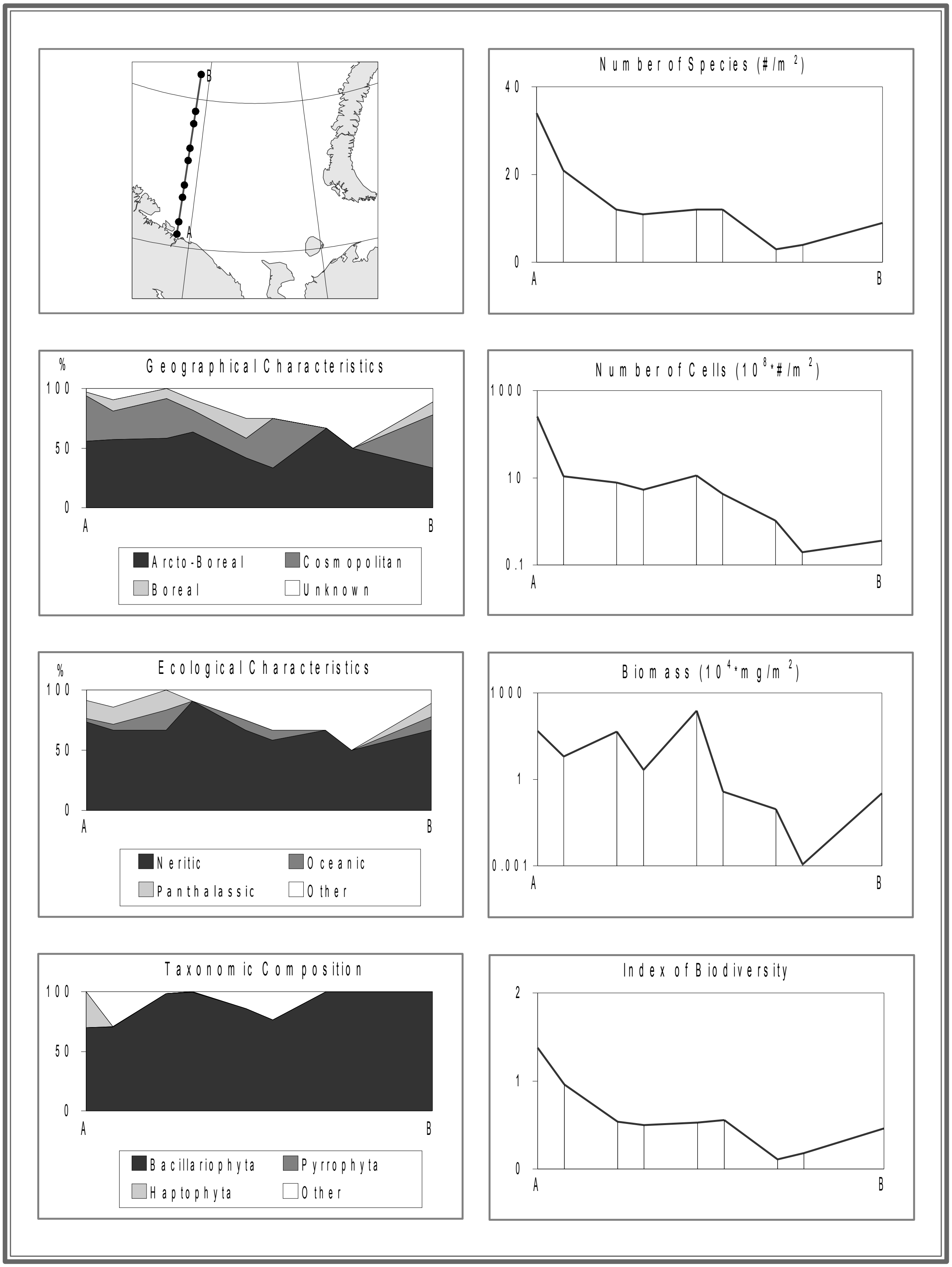


Fig. E2.53. Phytoplankton. Surface-bottom. Vessel *Pomor*. April, 1985

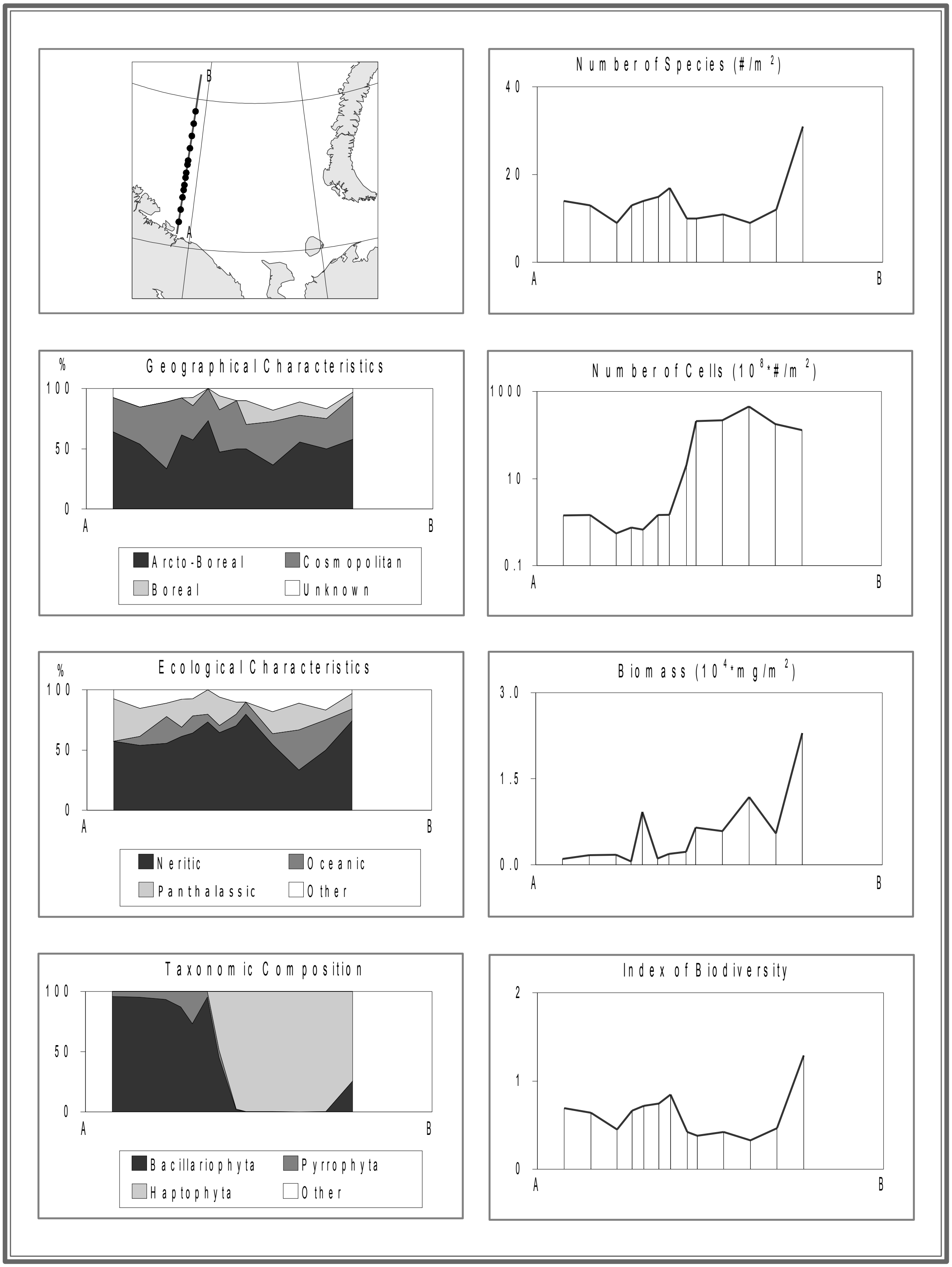


Fig. E2.54. Phytoplankton. Surface-bottom. Vessel *Pomor*. May, 1997

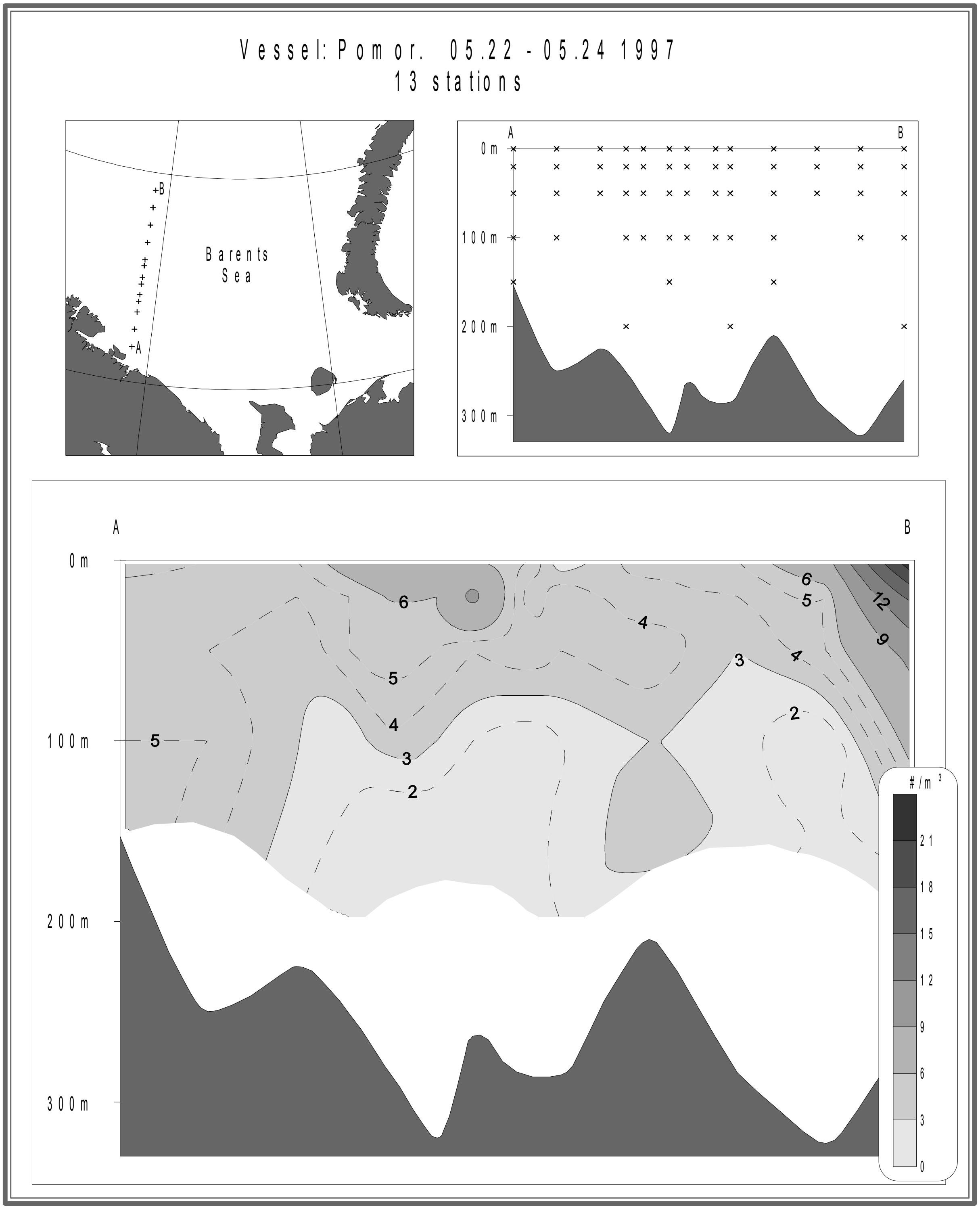


Fig. E2.55. Phytoplankton. Number of species. May, 1997

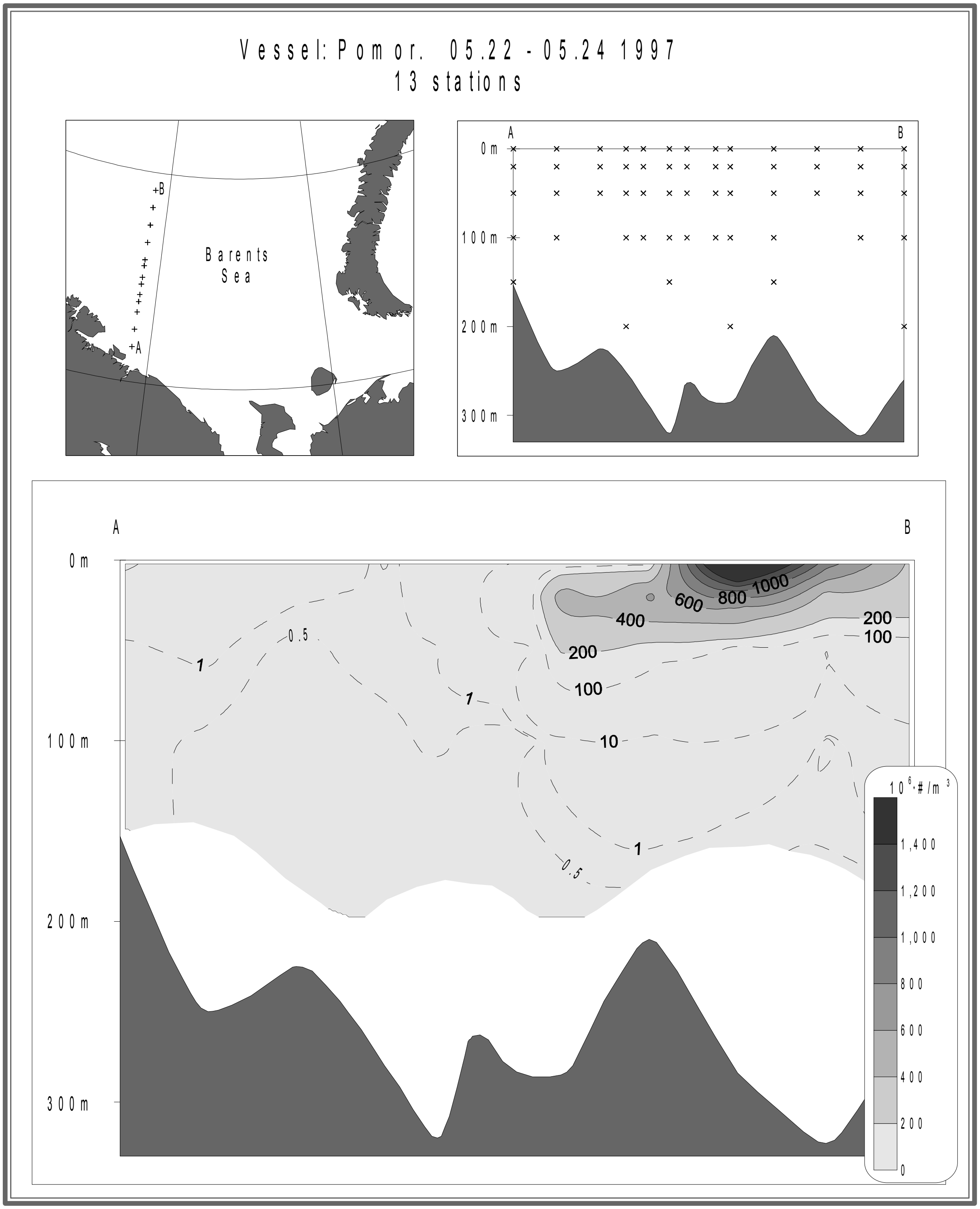


Fig. E2.56. Phytoplankton. Number of cells. May, 1997

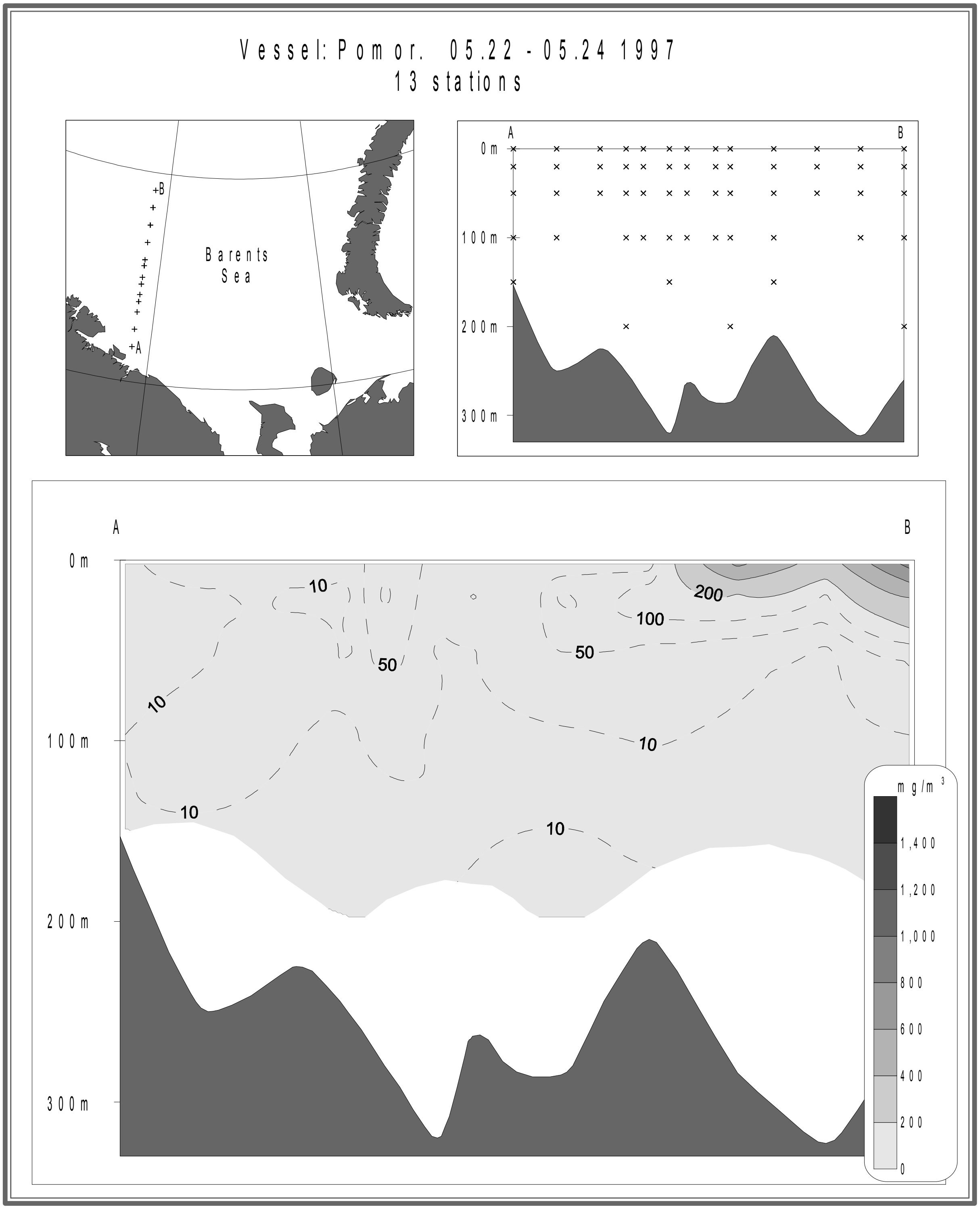


Fig. E2.57. Phytoplankton. Biomass. May, 1997

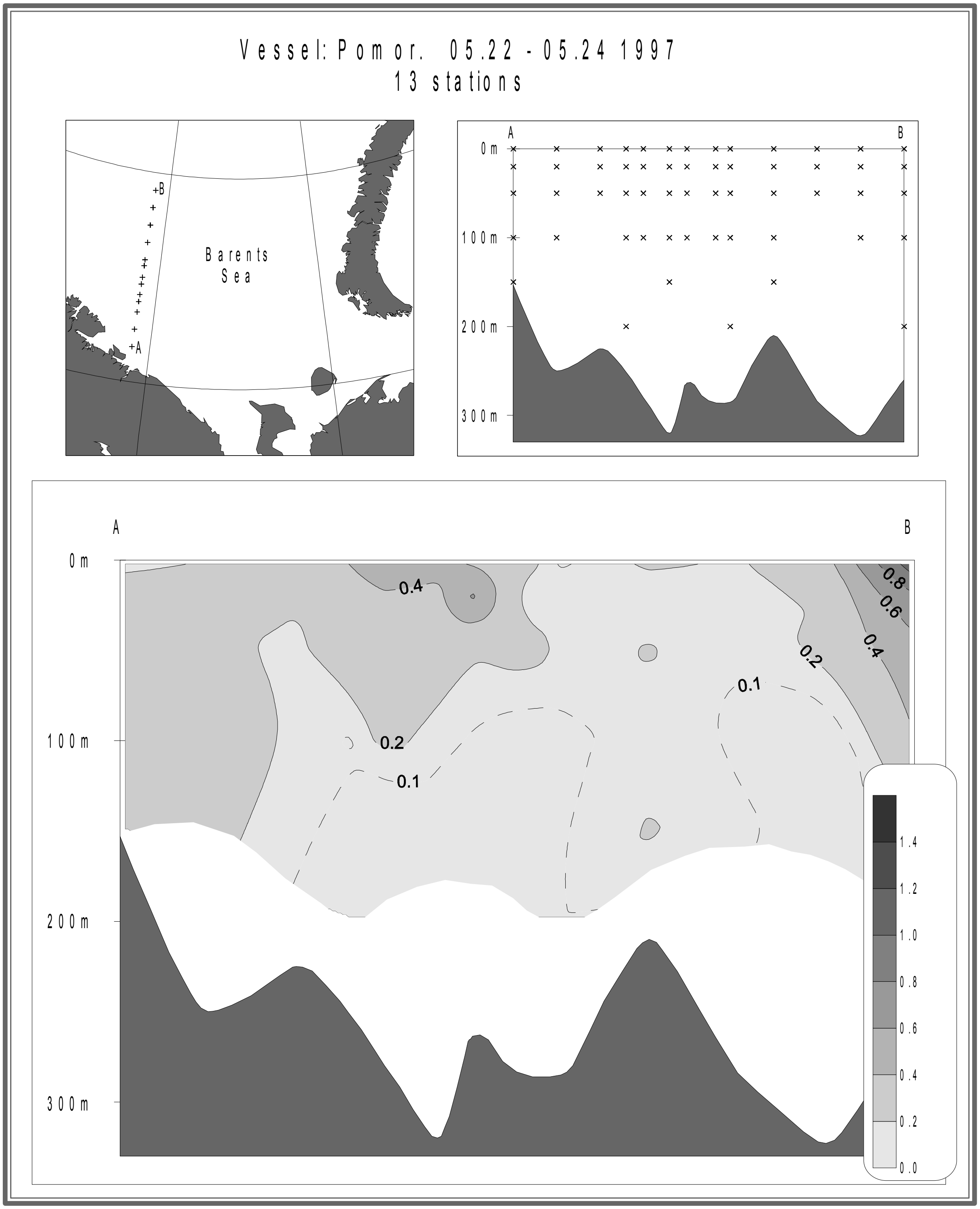


Fig. E2.58. Phytoplankton. Biodiversity. May, 1997

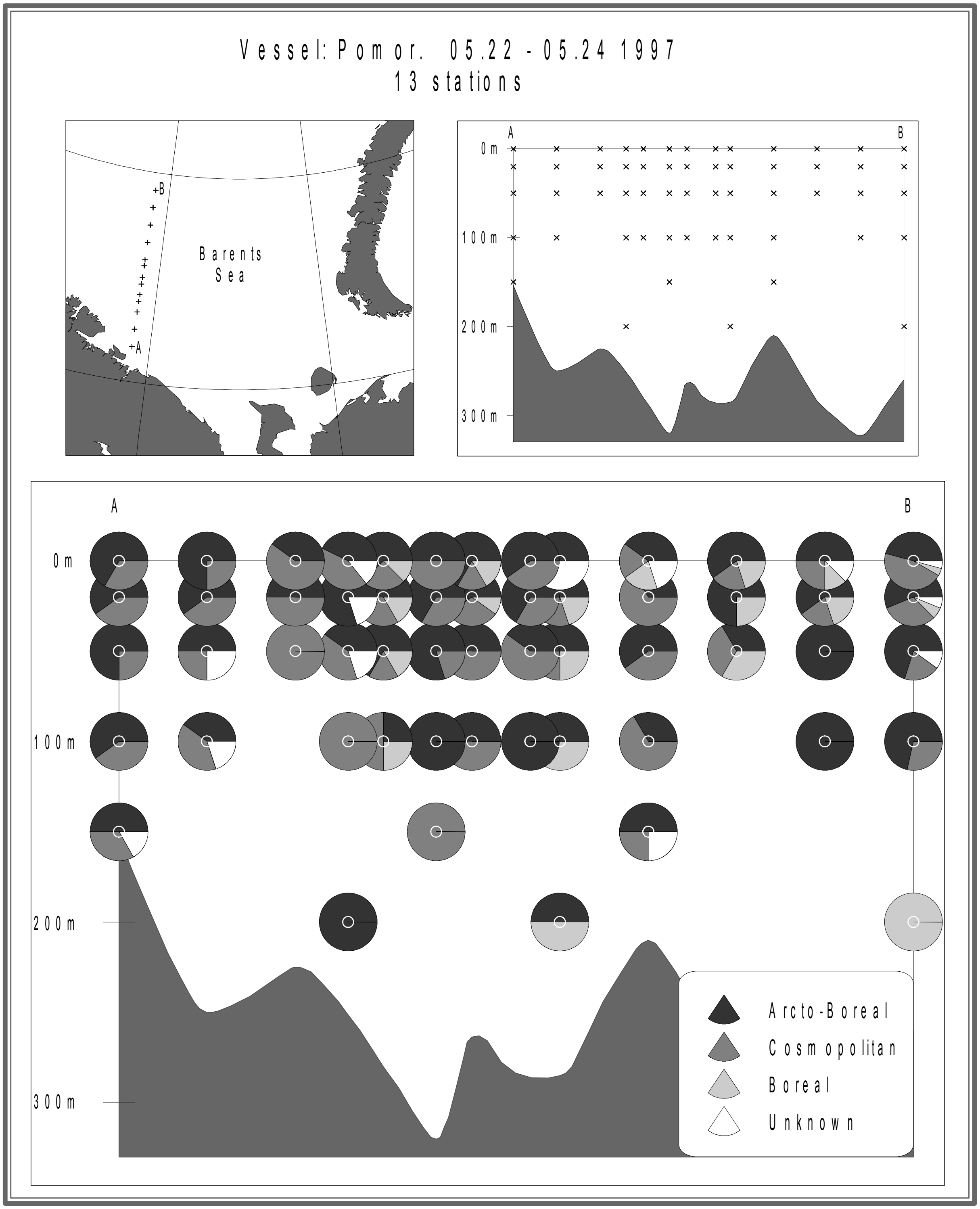


Fig. E2.59. Phytoplankton. Geographical characteristics. May, 1997

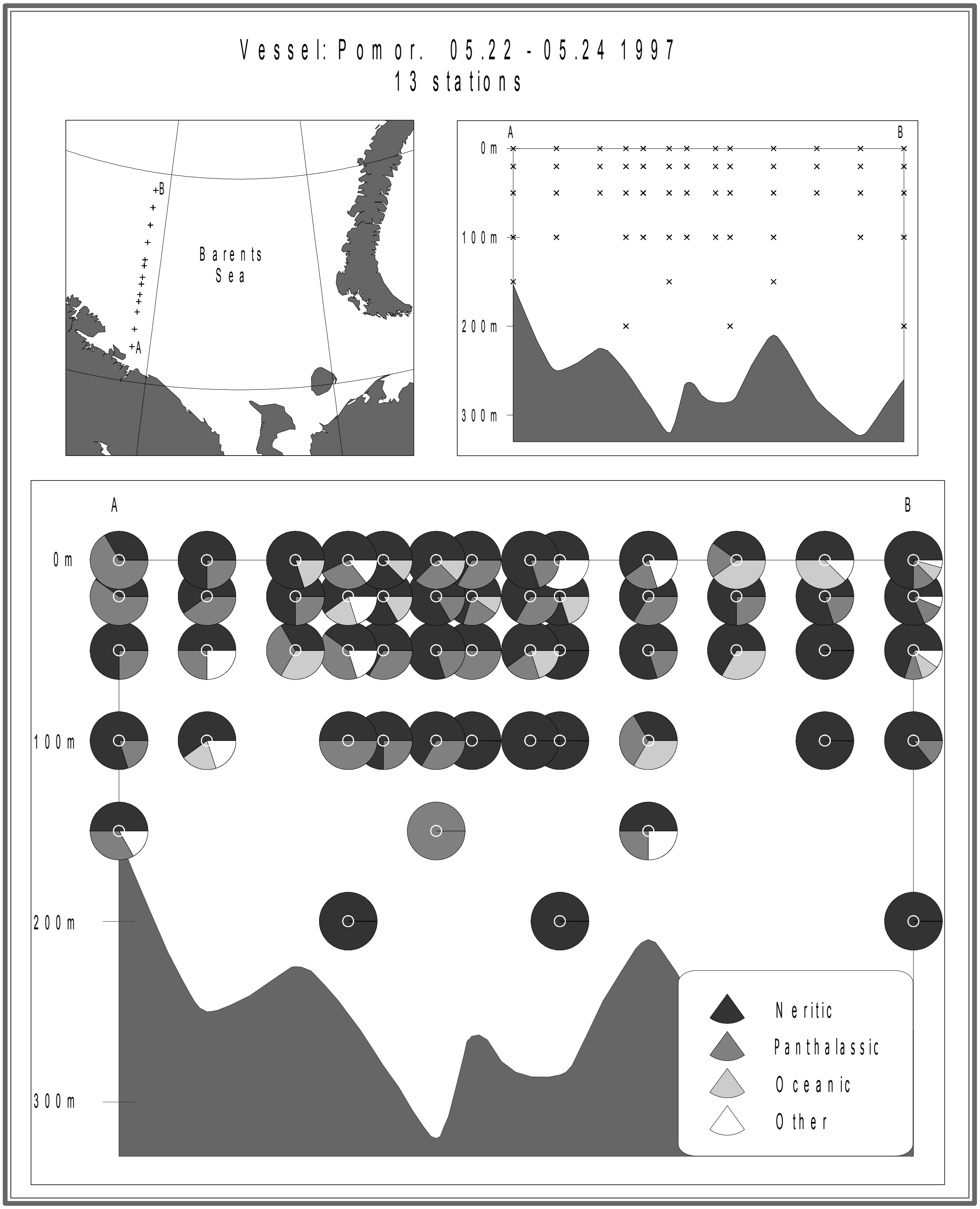


Fig. E2.60. Phytoplankton. Ecological characteristics. May, 1997

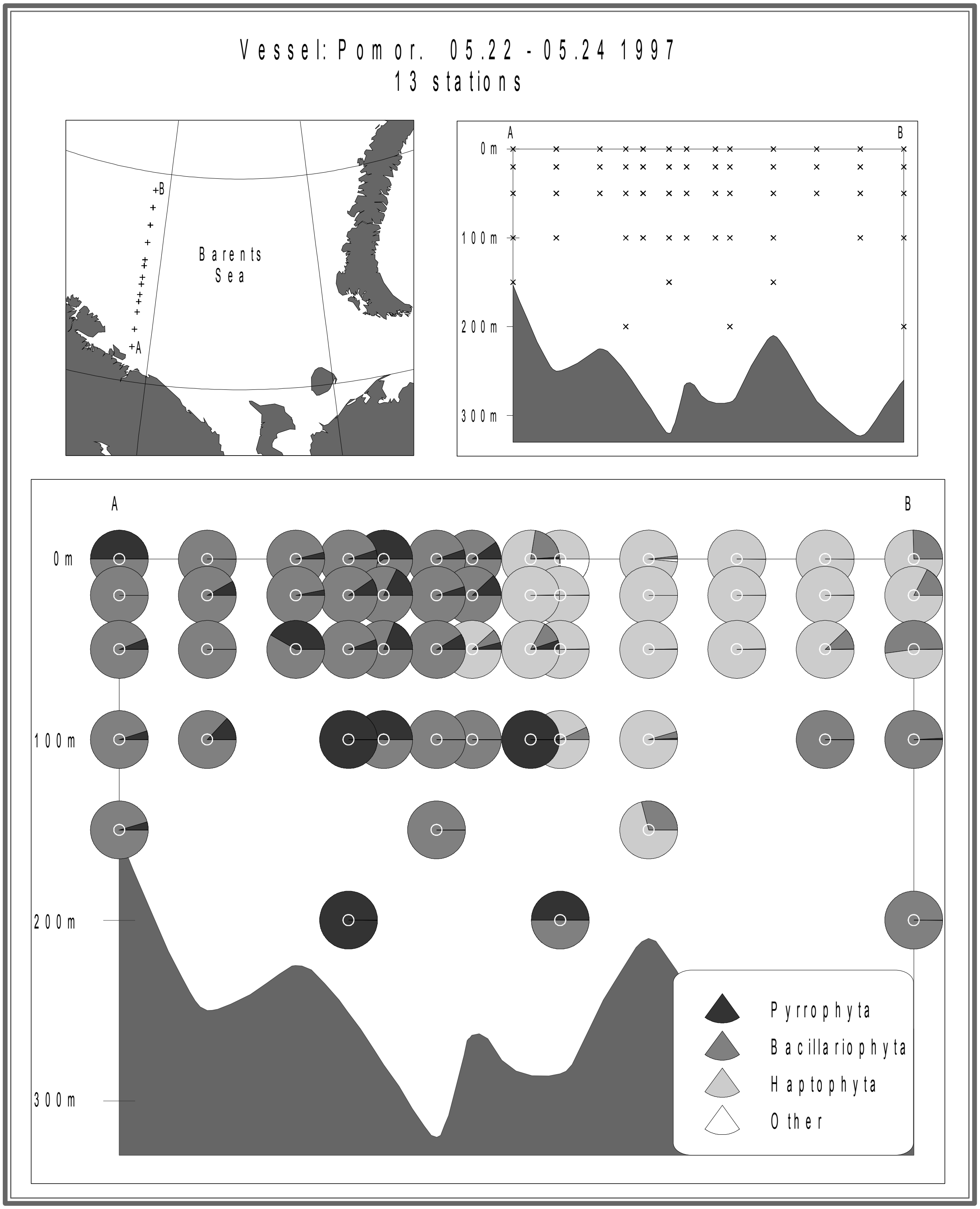


Fig. E2.61. Phytoplankton. Taxonomic composition. May, 1997

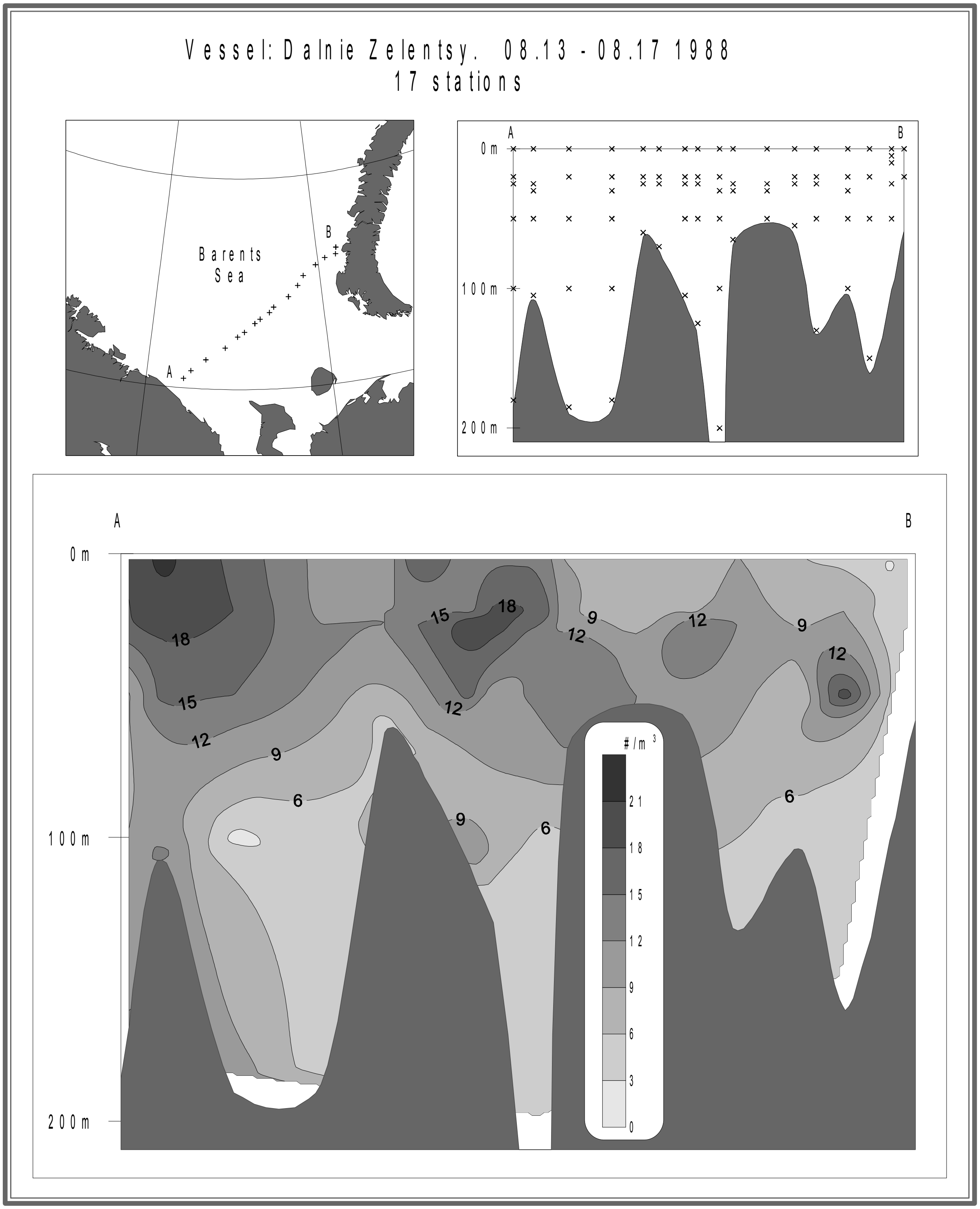


Fig. E2.62. Phytoplankton. Number of species. August, 1988

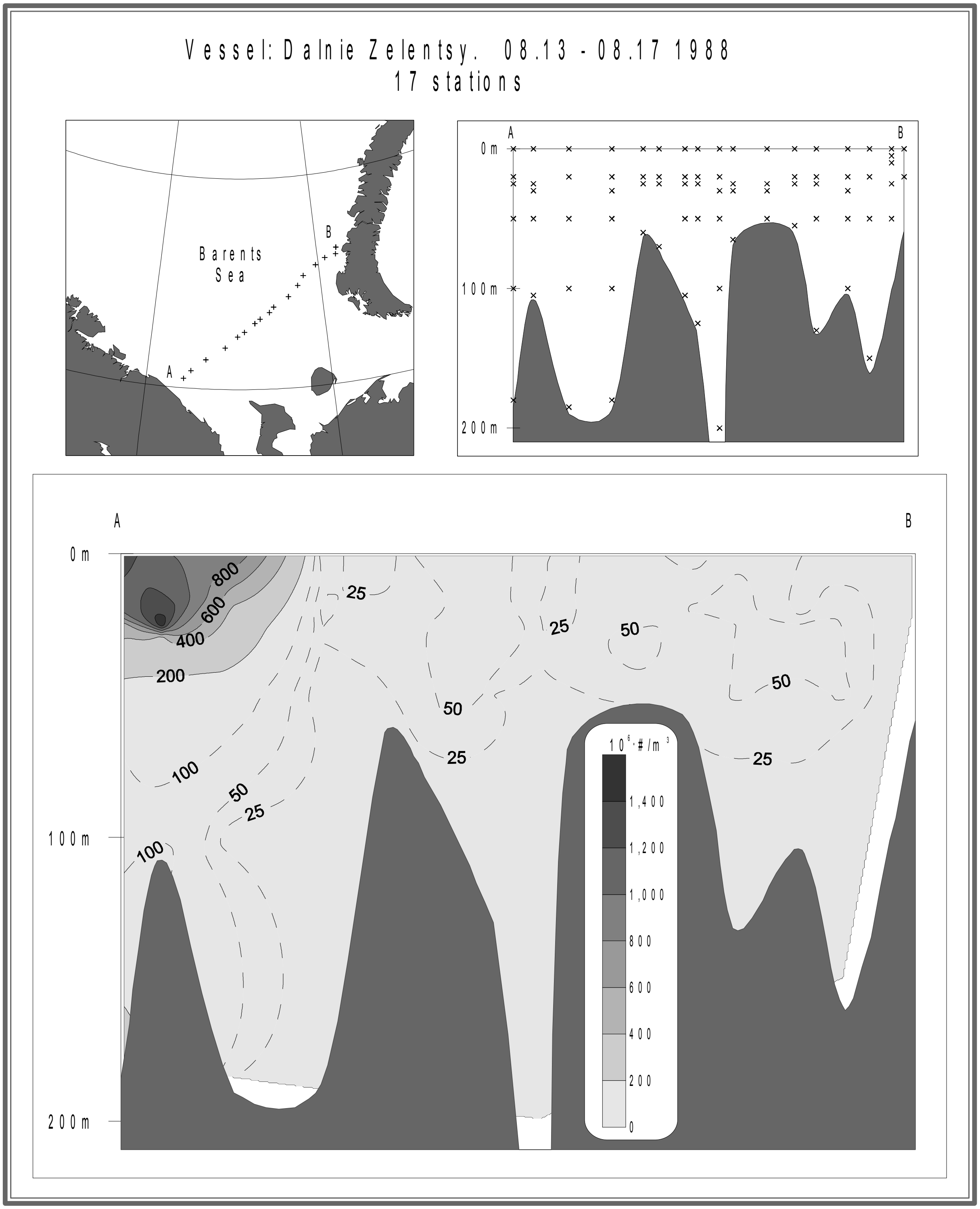


Fig. E2.63. Phytoplankton. Number of cells. August, 1988

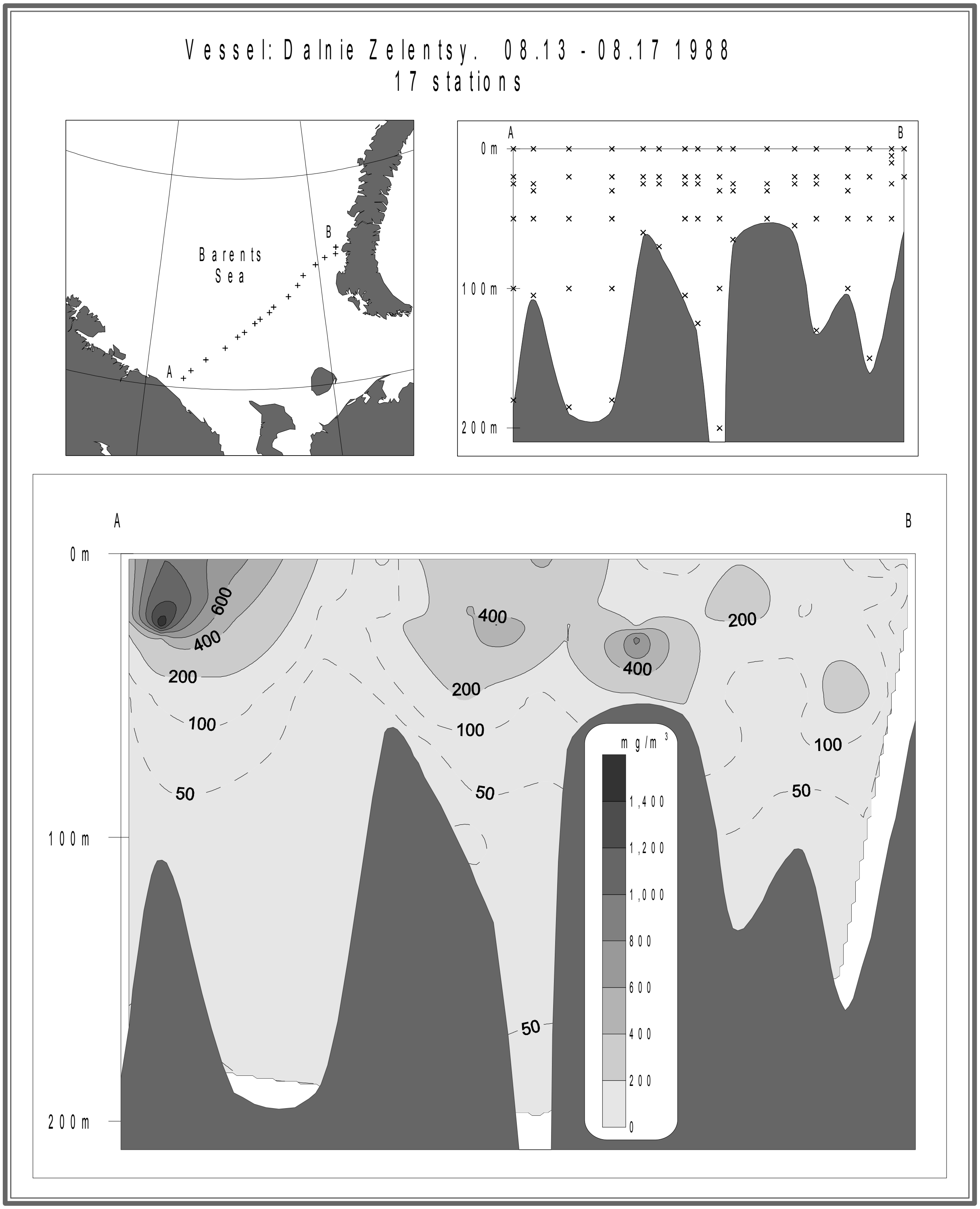


Fig. E2.64. Phytoplankton. Biomass. August, 1988

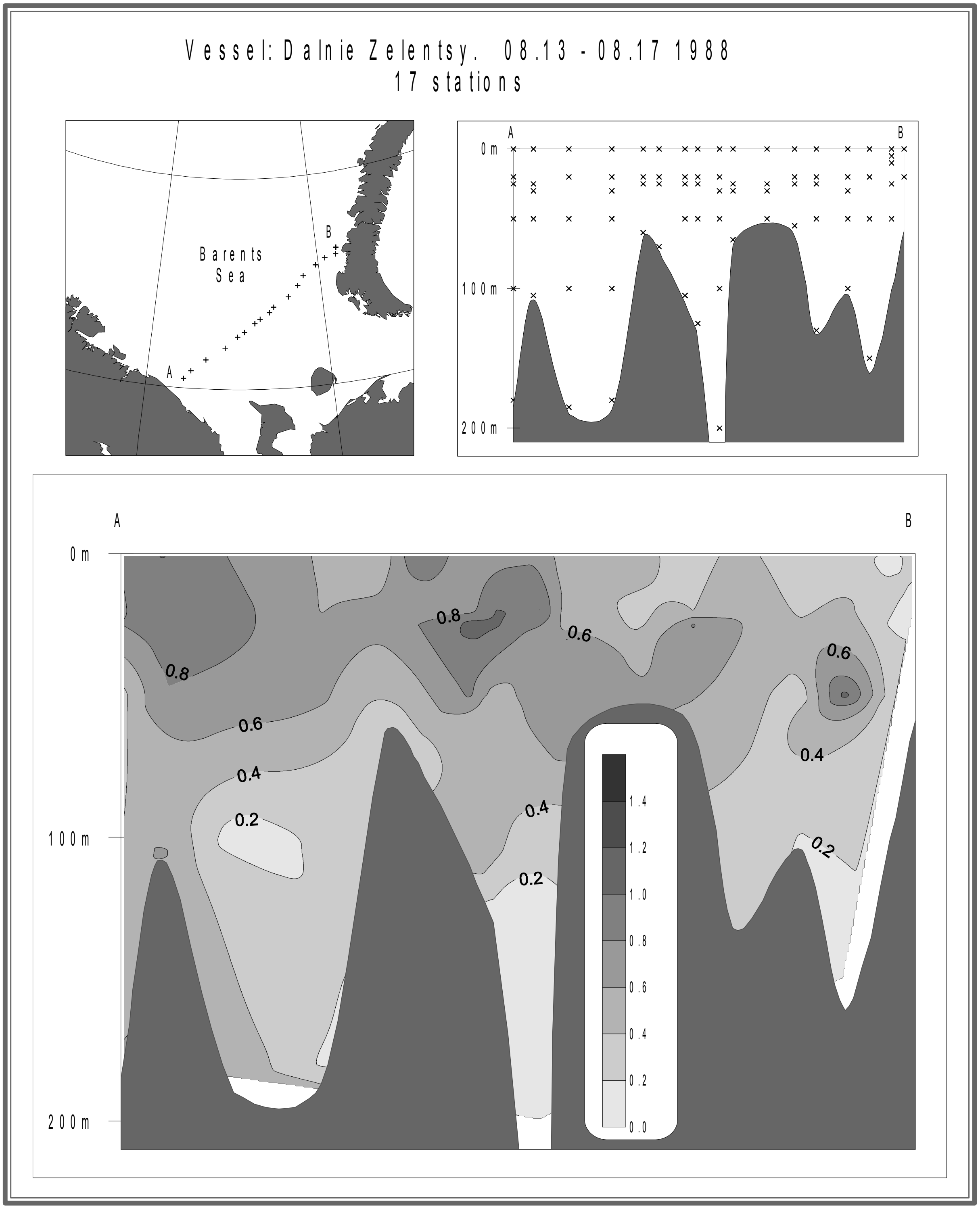


Fig. E2.65. Phytoplankton. Biodiversity. August, 1988

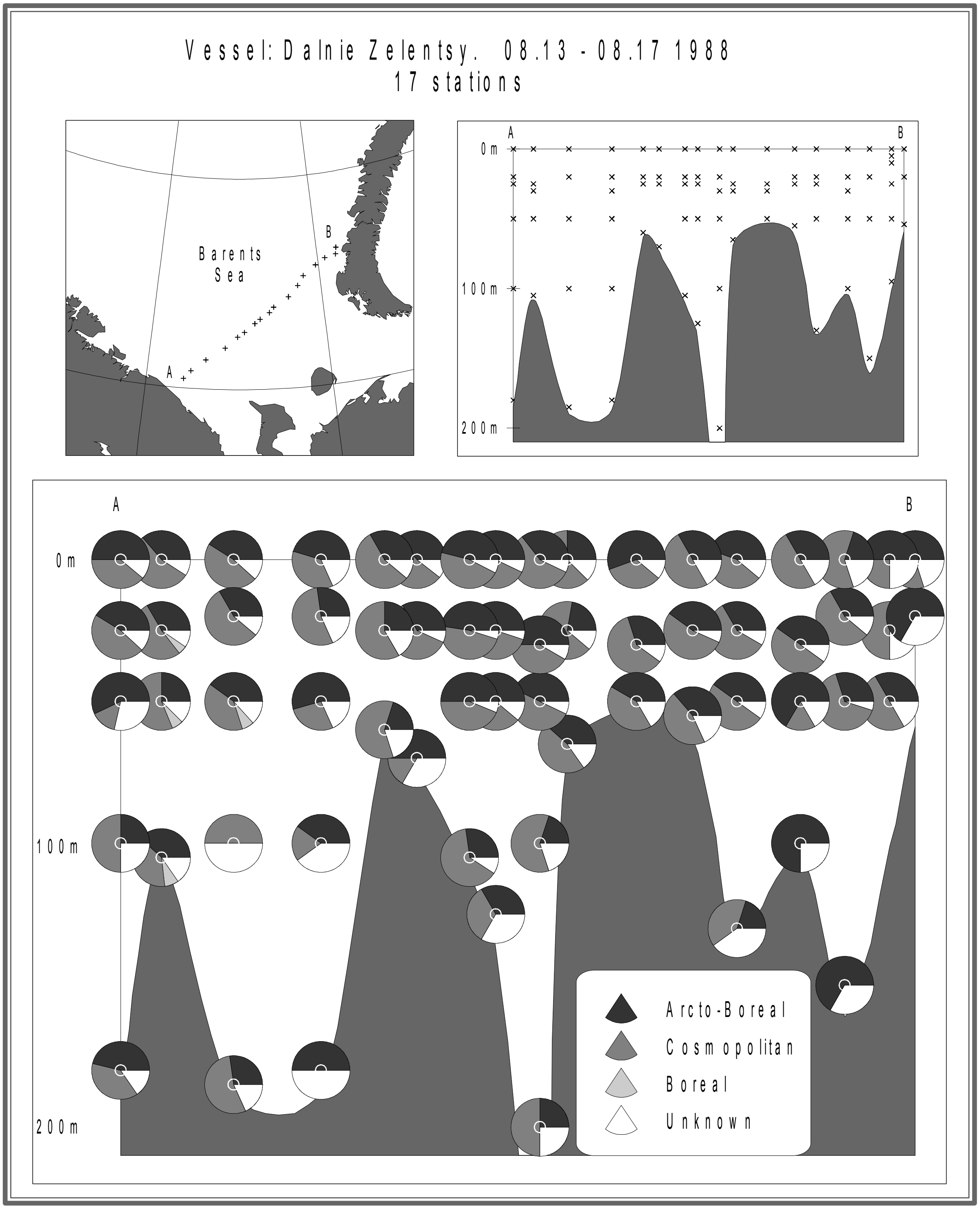


Fig. E2.66. Phytoplankton. Geographical characteristics. August, 1988

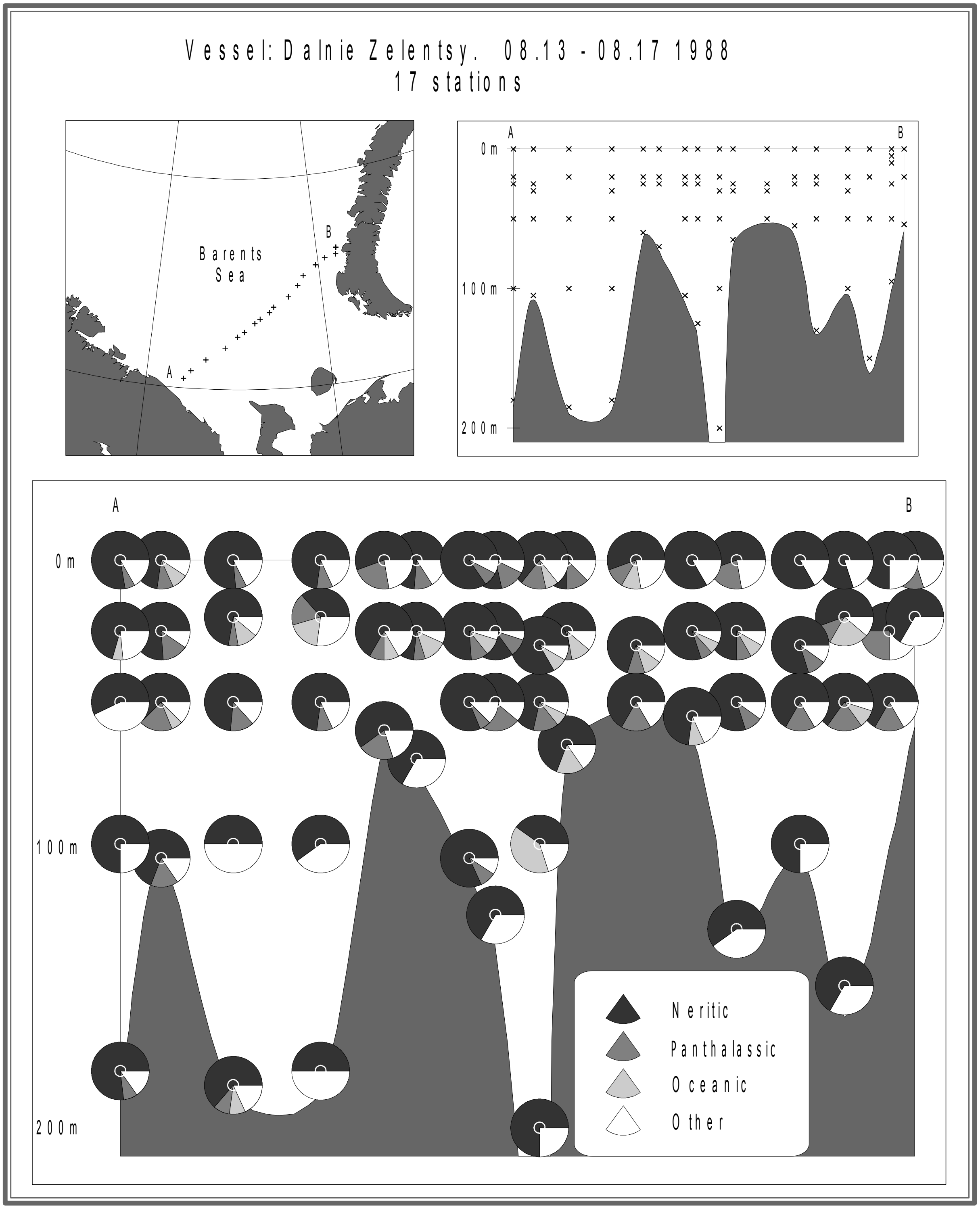


Fig. E2.67. Phytoplankton. Ecological characteristics. August, 1988

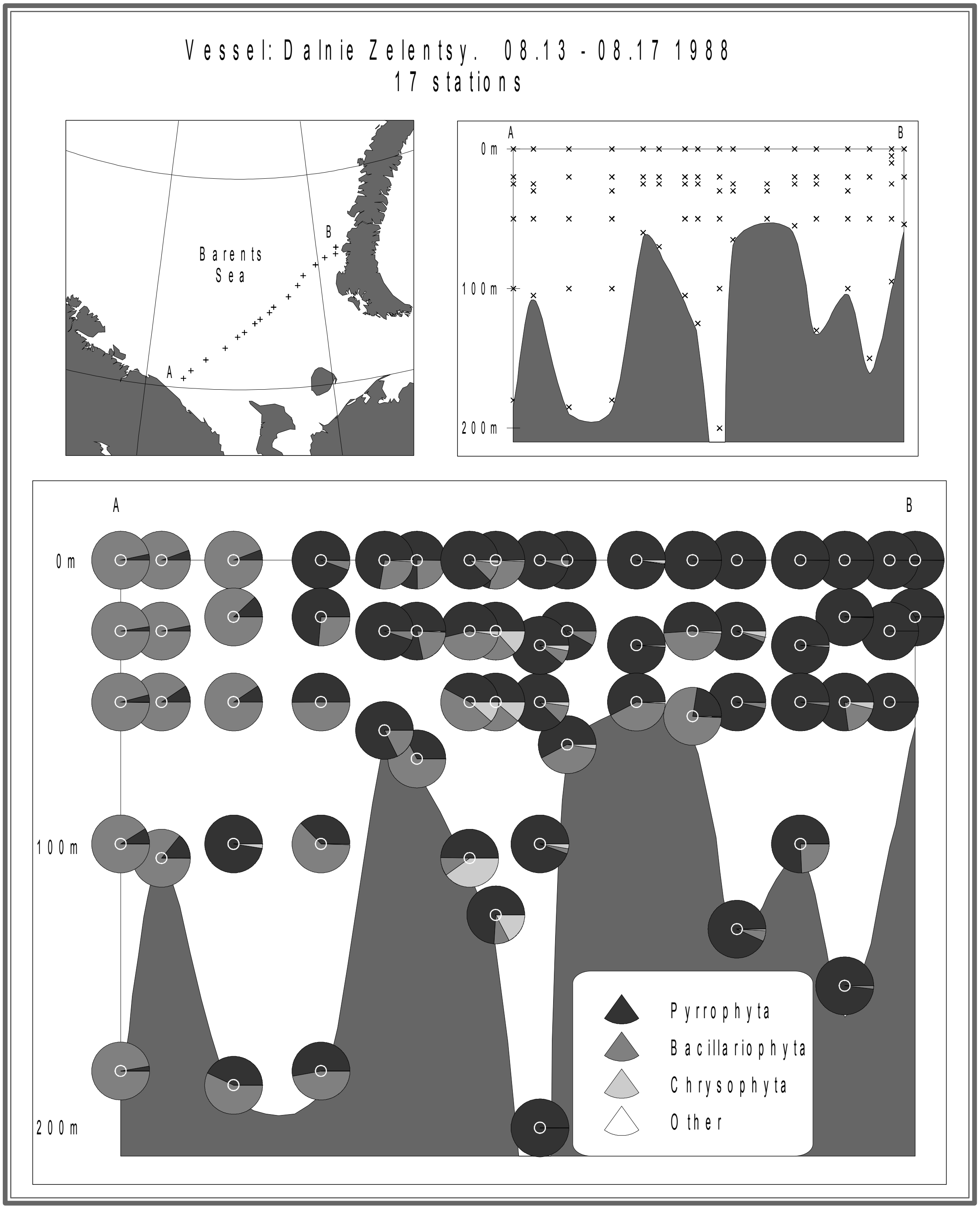


Fig. E2.68. Phytoplankton. Taxonomic composition. August, 1988

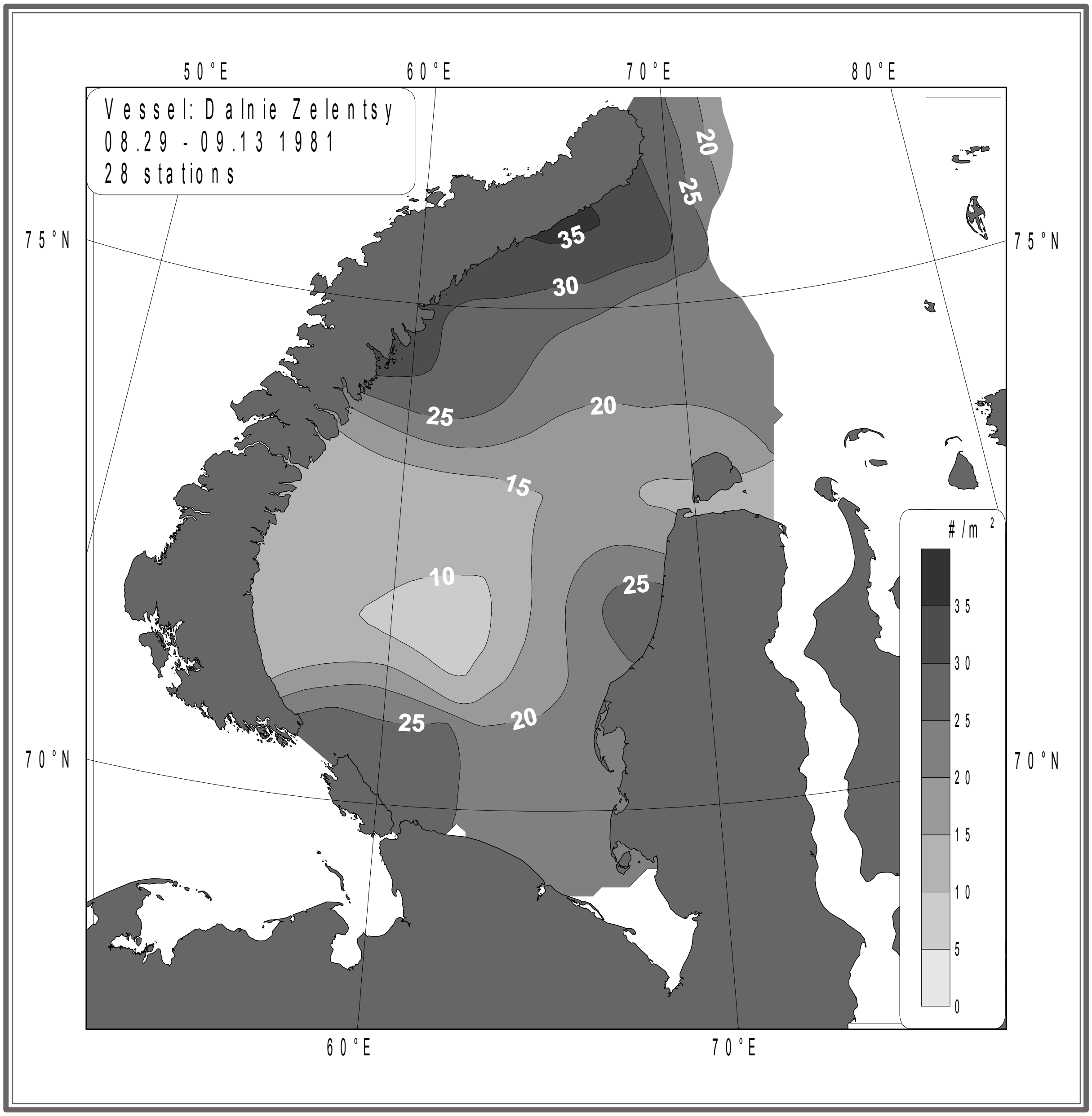


Fig. E3.1. Phytoplankton. Surface-bottom. Number of species. August-September, 1981

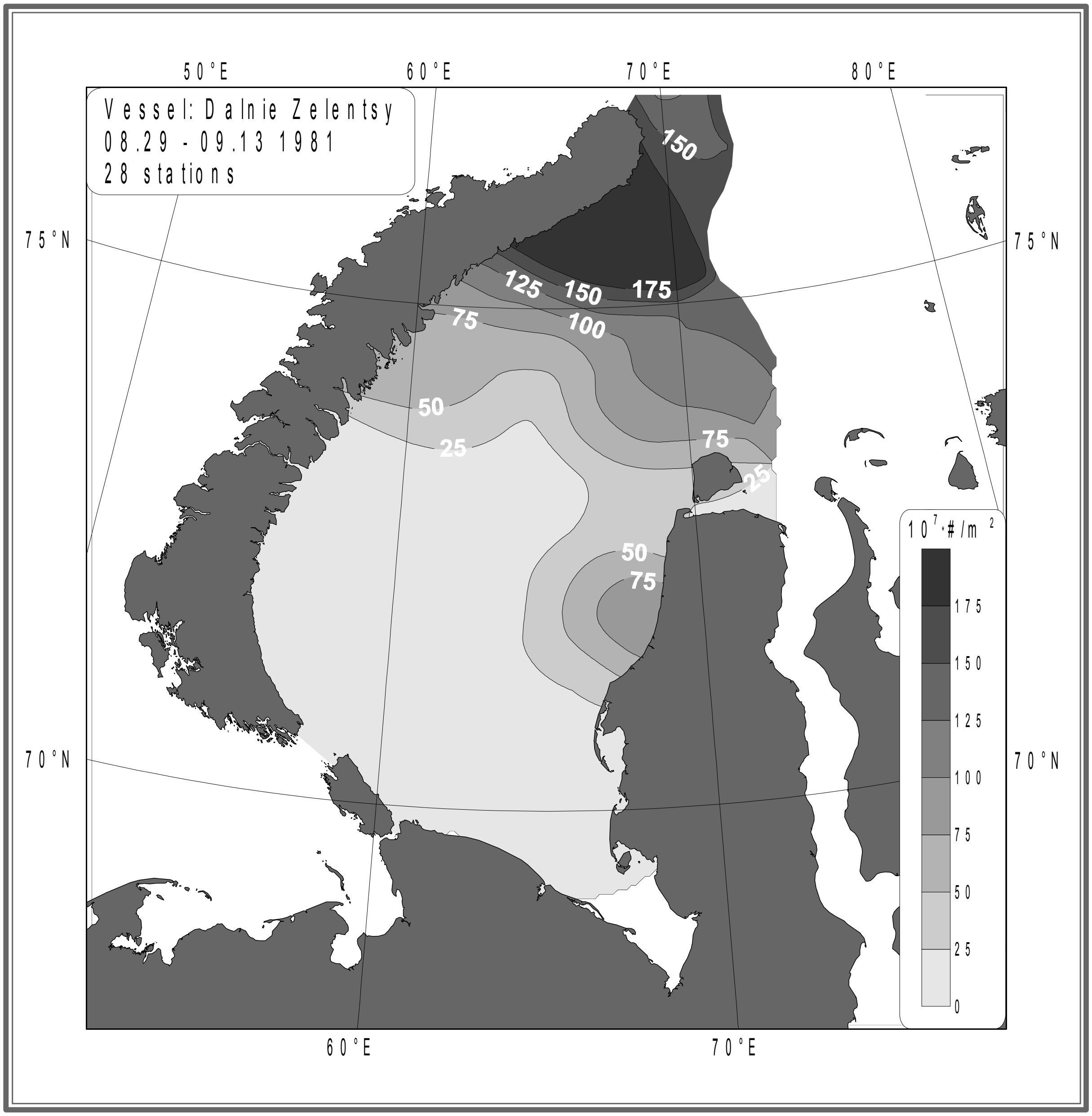


Fig. E3.2. Phytoplankton. Surface-bottom. Number of cells. August-September, 1981

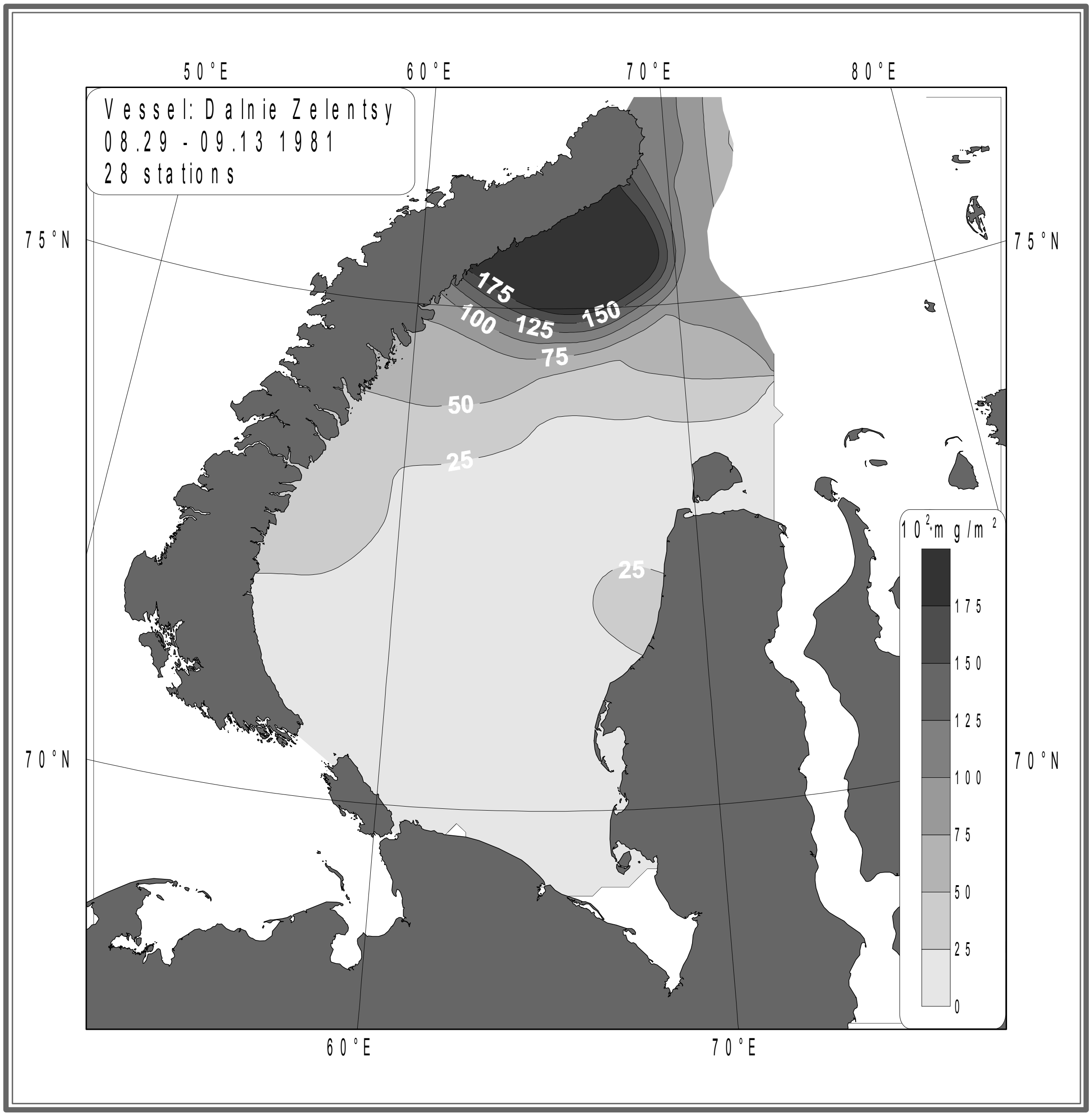


Fig. E3.3. Phytoplankton. Surface-bottom. Biomass. August-September, 1981

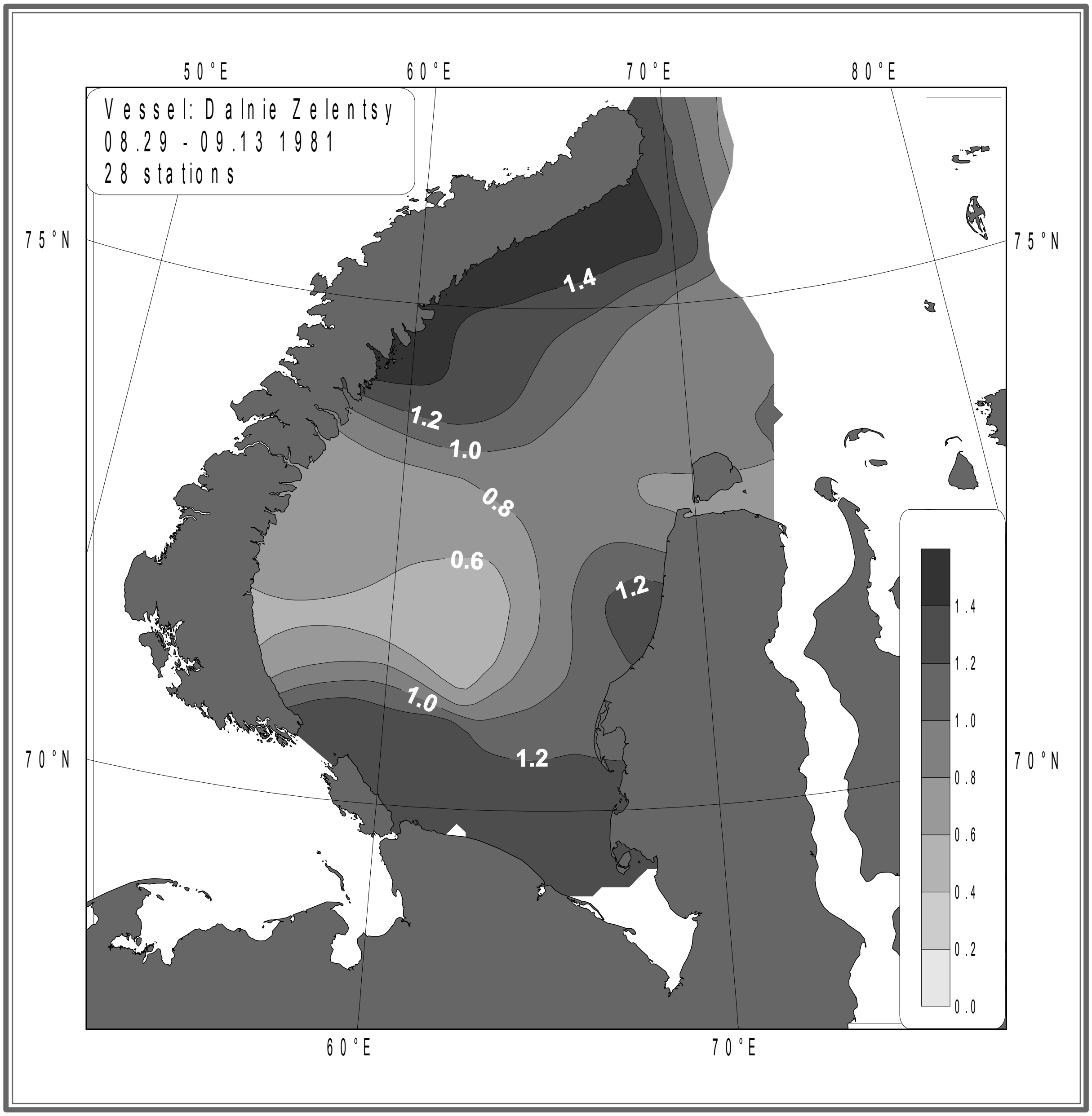


Fig. E3.4. Phytoplankton. Surface-bottom. Biodiversity. August-September, 1981

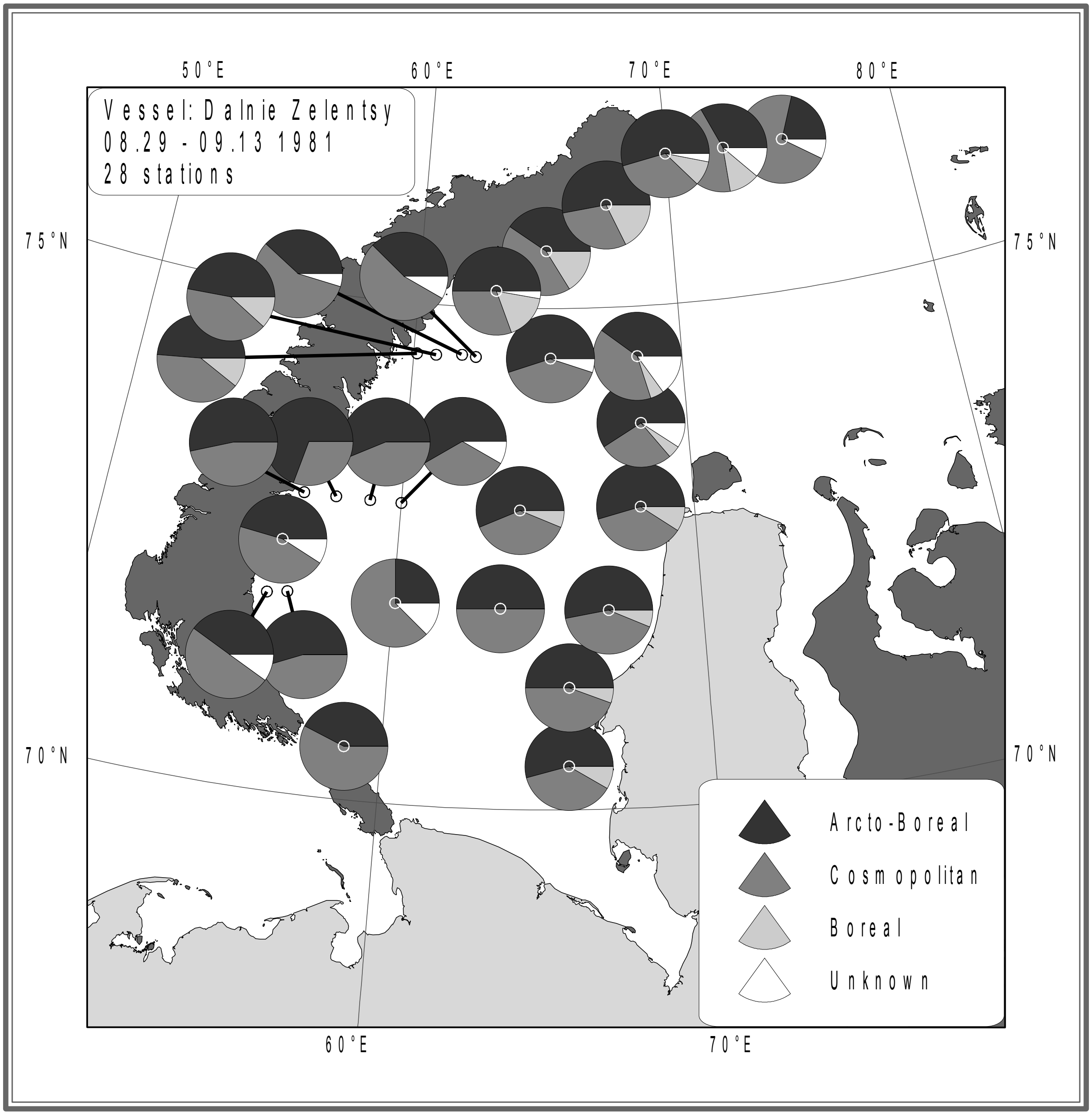


Fig. E3.5. Phytoplankton. Surface-bottom. Geographical characteristics. August-September, 1981

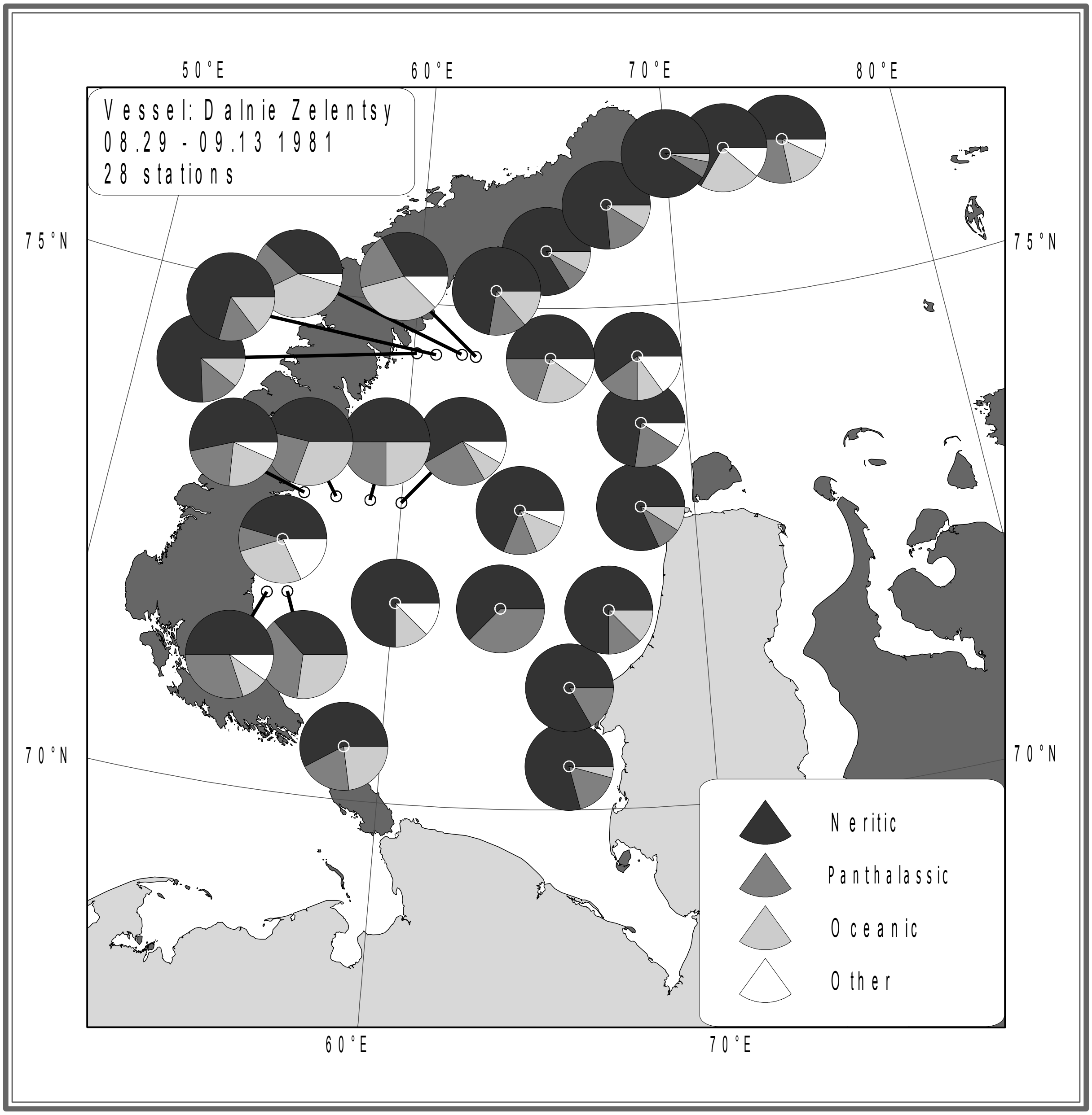


Fig. E3.6. Phytoplankton. Surface-bottom. Ecological characteristics. August-September, 1981

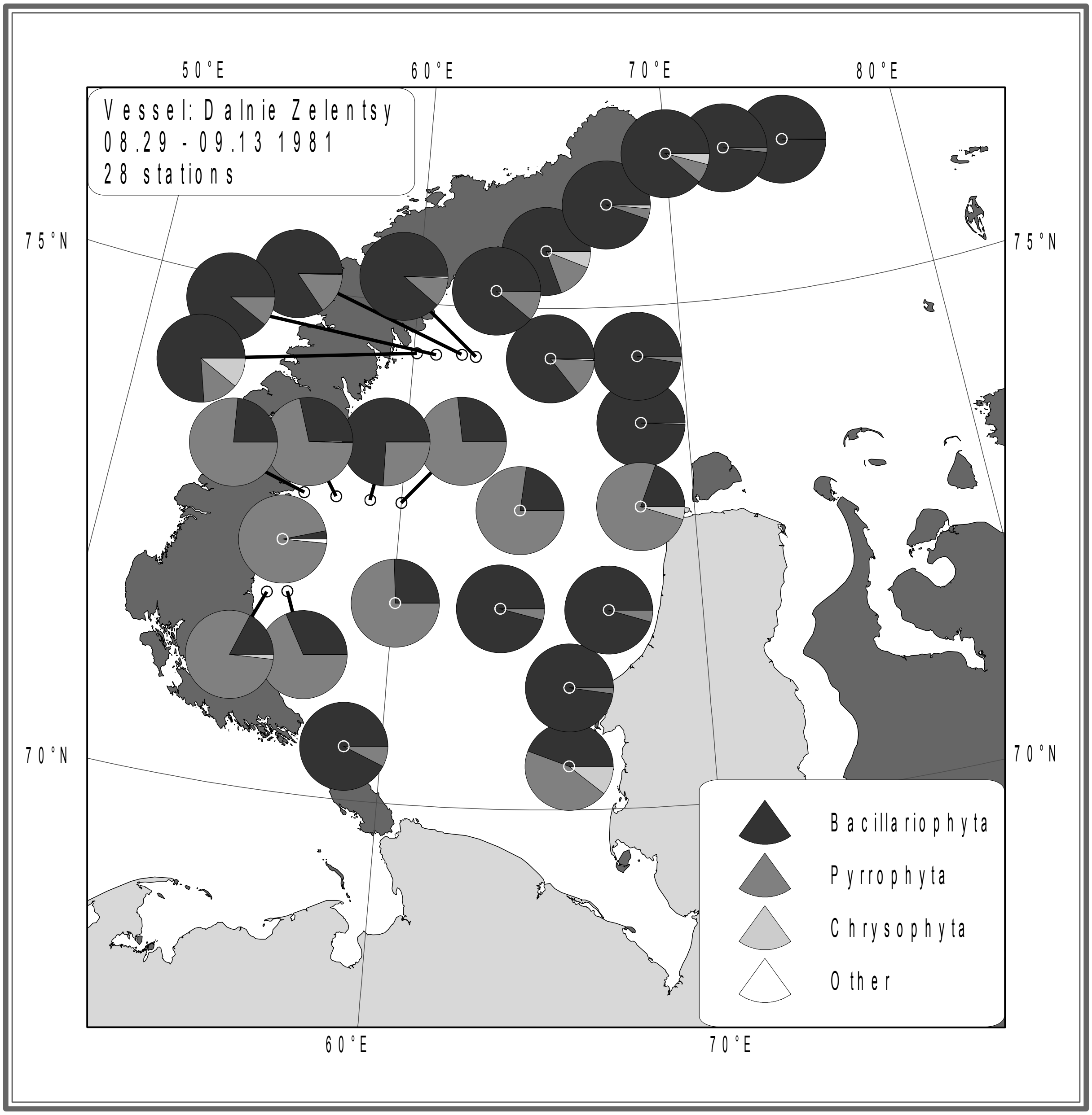


Fig. E3.7. Phytoplankton. Surface-bottom. Taxonomic composition. August-September, 1981

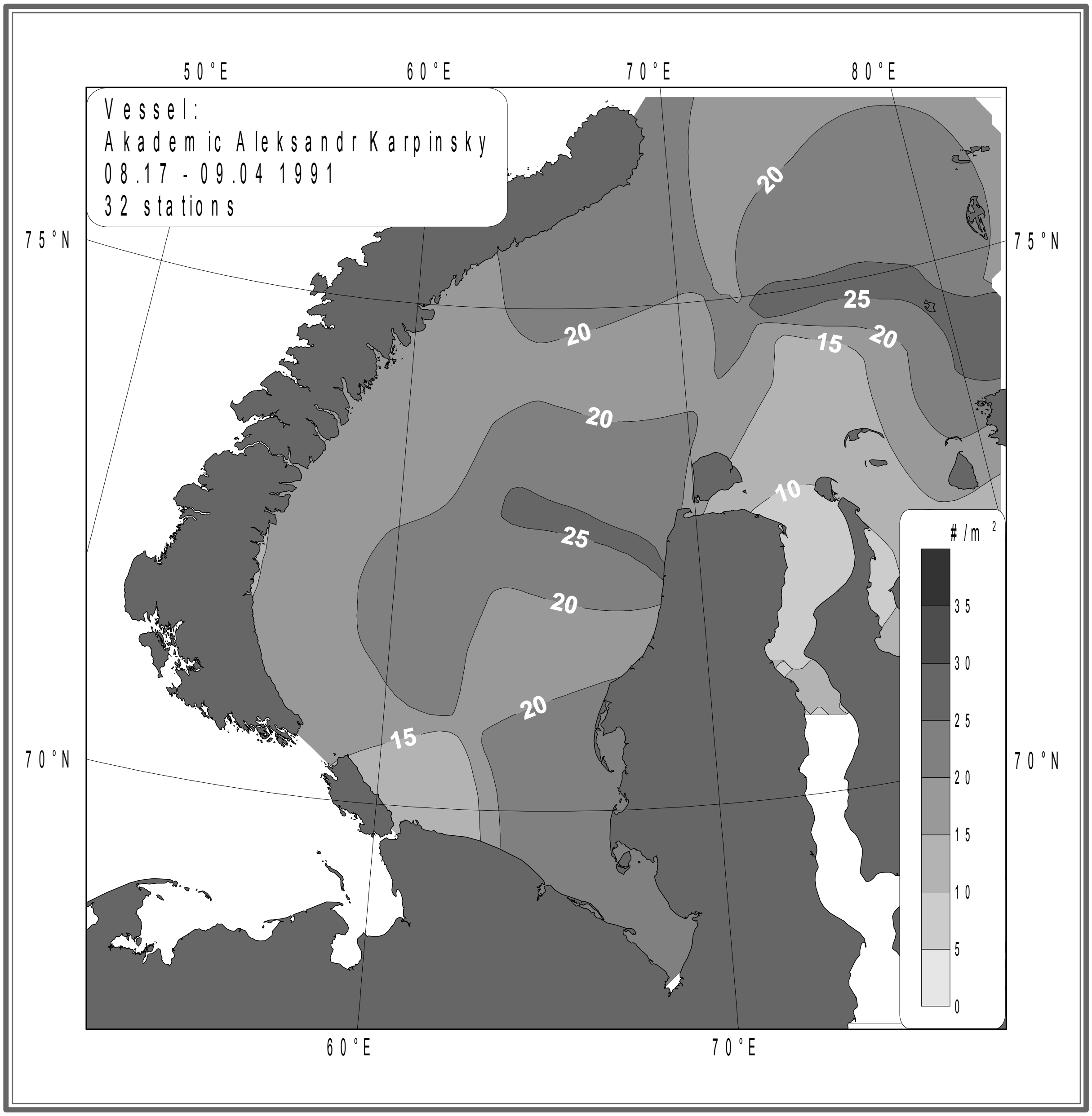


Fig. E3.8. Phytoplankton. Surface-bottom. Number of species. August-September, 1991

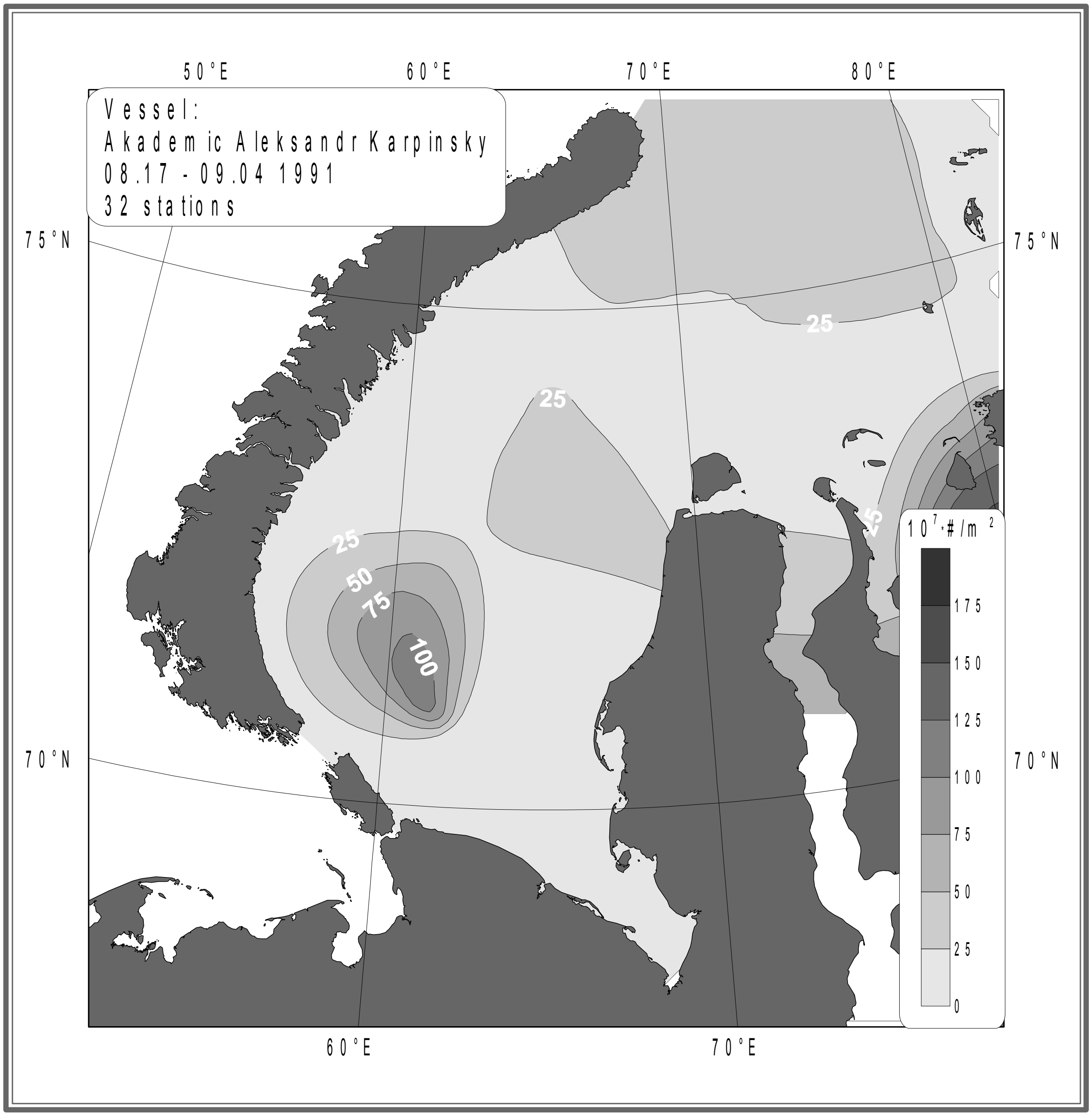


Fig. E3.9. Phytoplankton. Surface-bottom. Number of cells. August-September, 1991

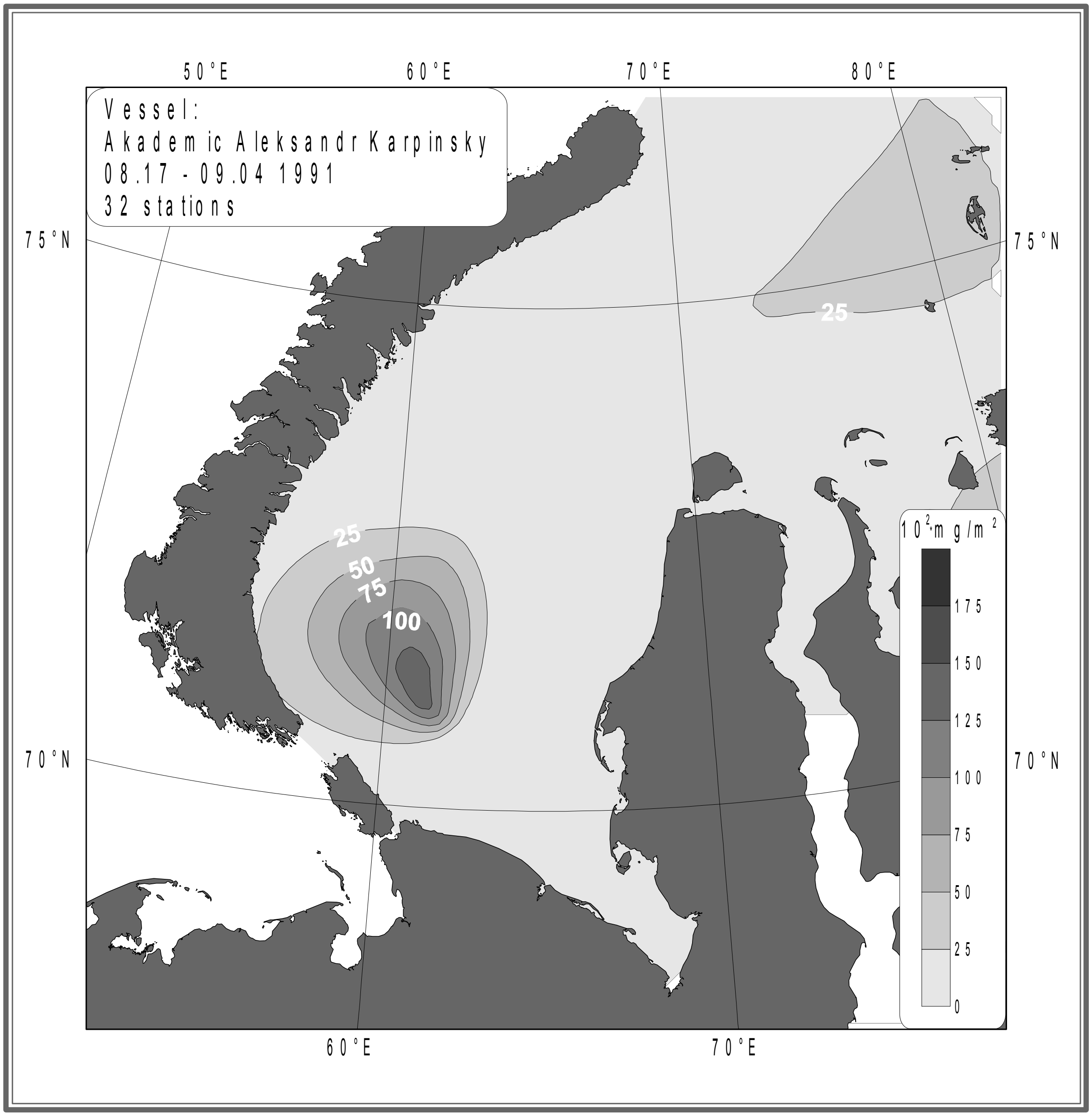


Fig. E3.10. Phytoplankton. Surface-bottom. Biomass. August-September, 1991

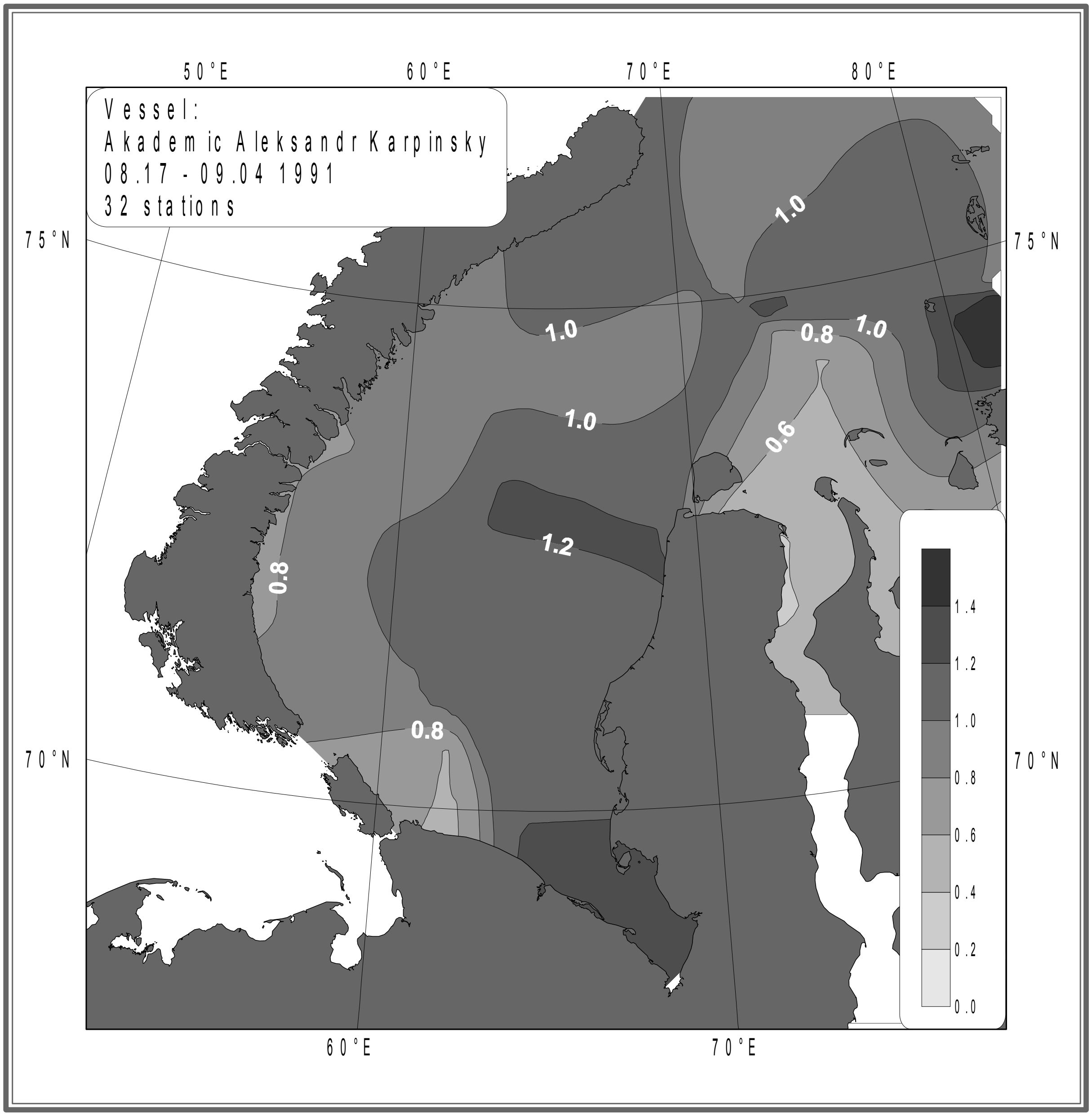


Fig. E3.11. Phytoplankton. Surface-bottom. Biodiversity. August-September, 1991

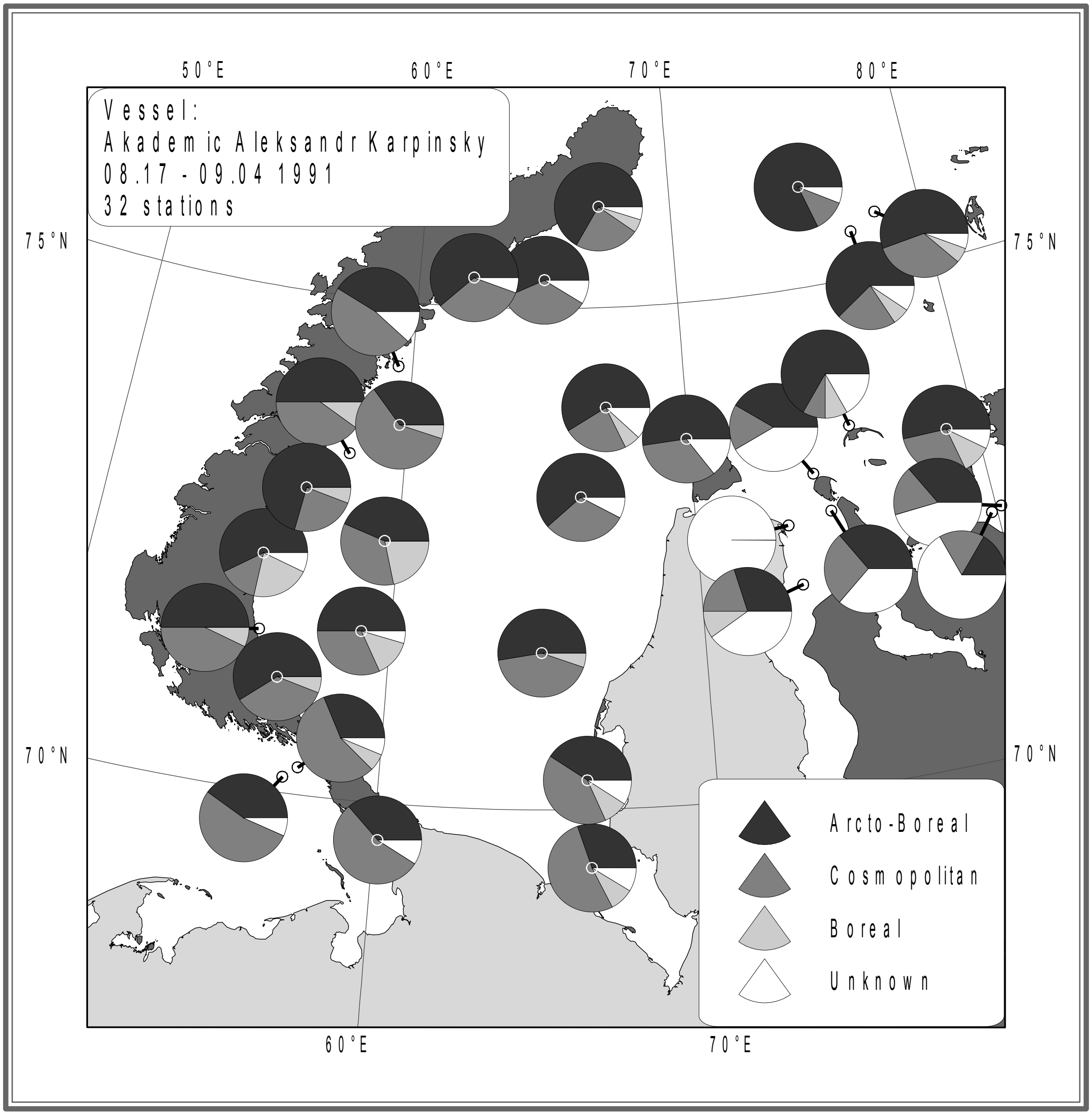


Fig. E3.12. Phytoplankton. Surface-bottom. Geographical characteristics. August-September, 1991

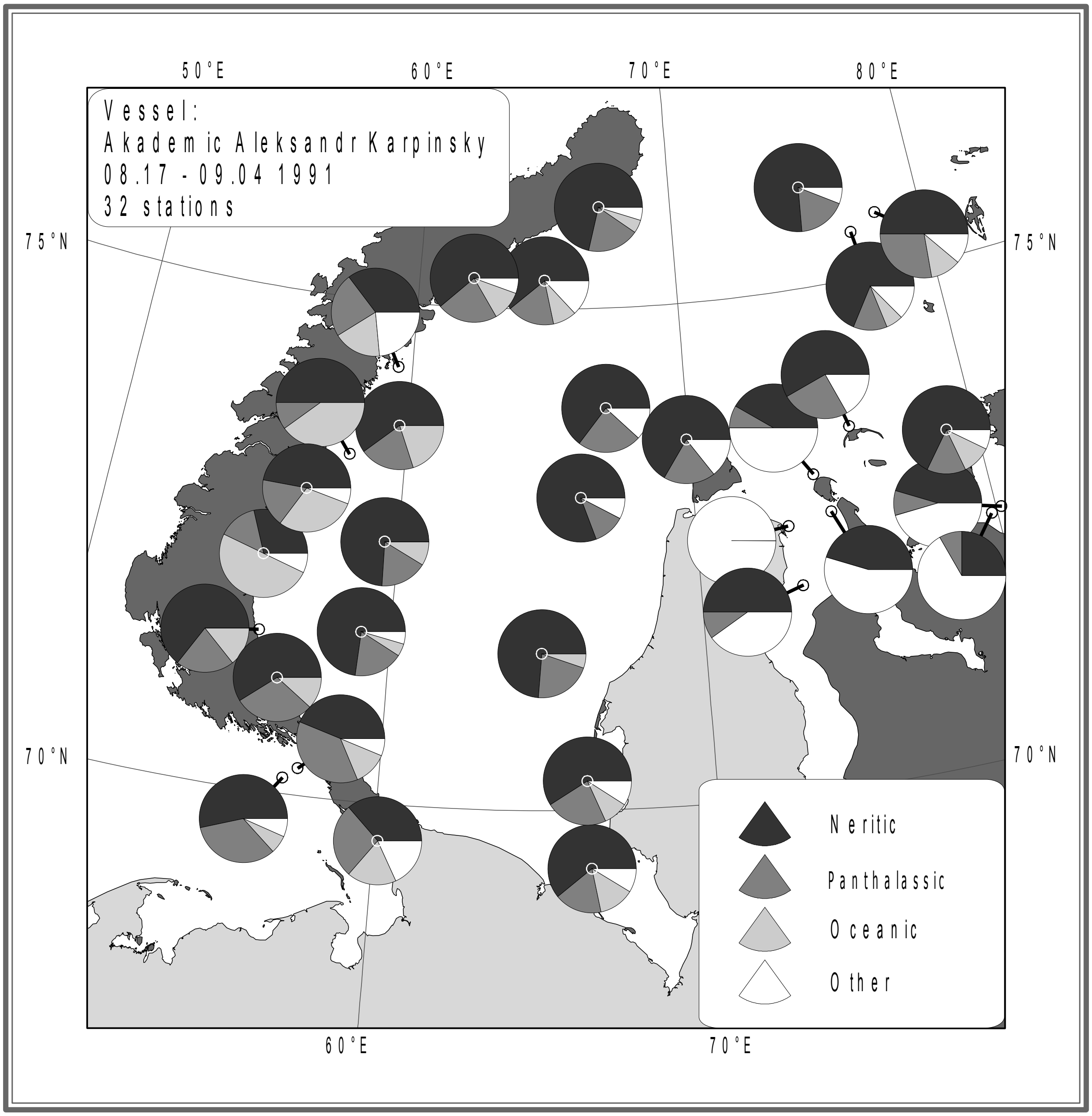


Fig. E3.13. Phytoplankton. Surface-bottom. Ecological characteristics. August-September, 1991

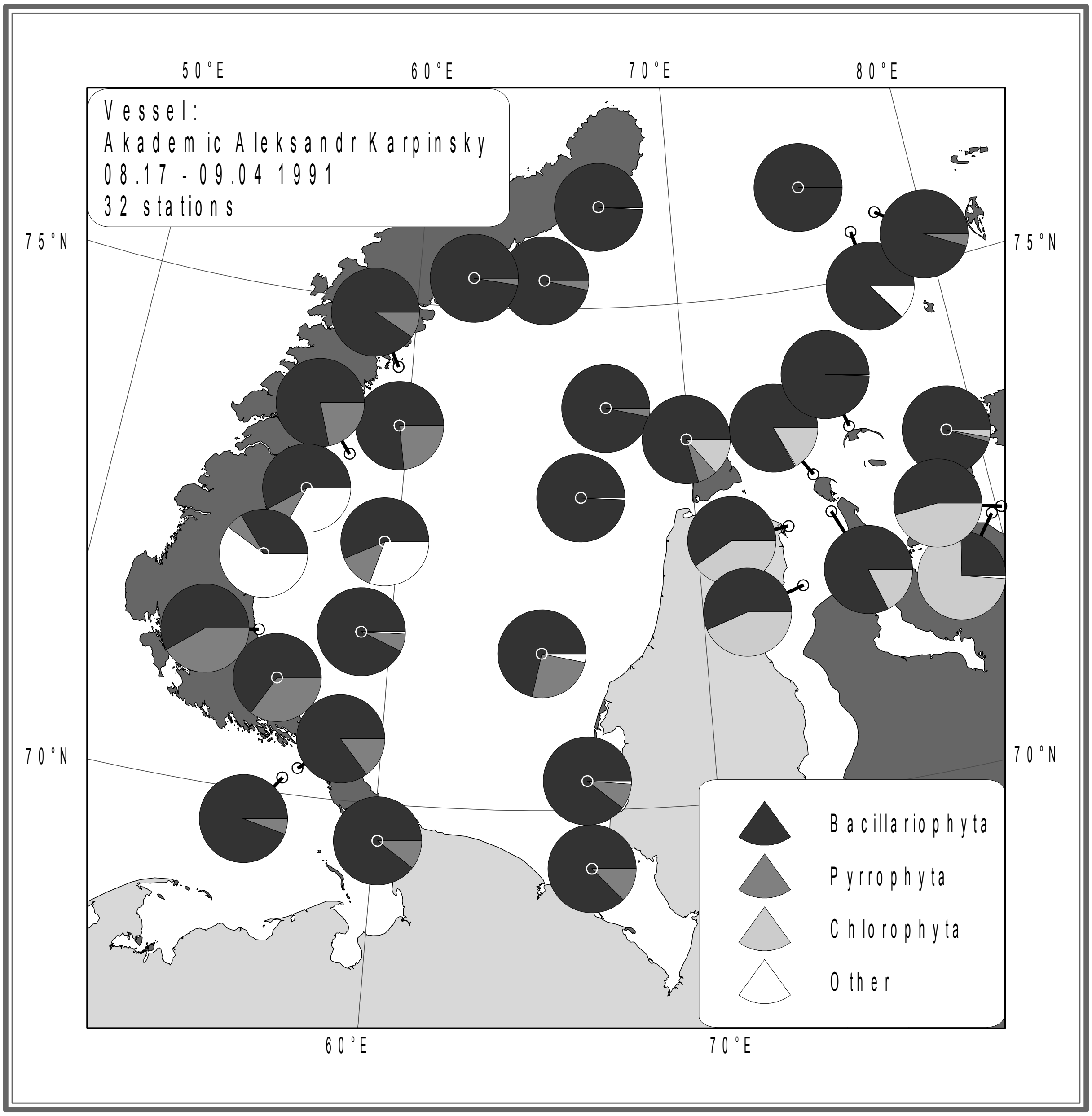


Fig. E3.14. Phytoplankton. Surface-bottom. Taxonomic composition. August-September, 1991

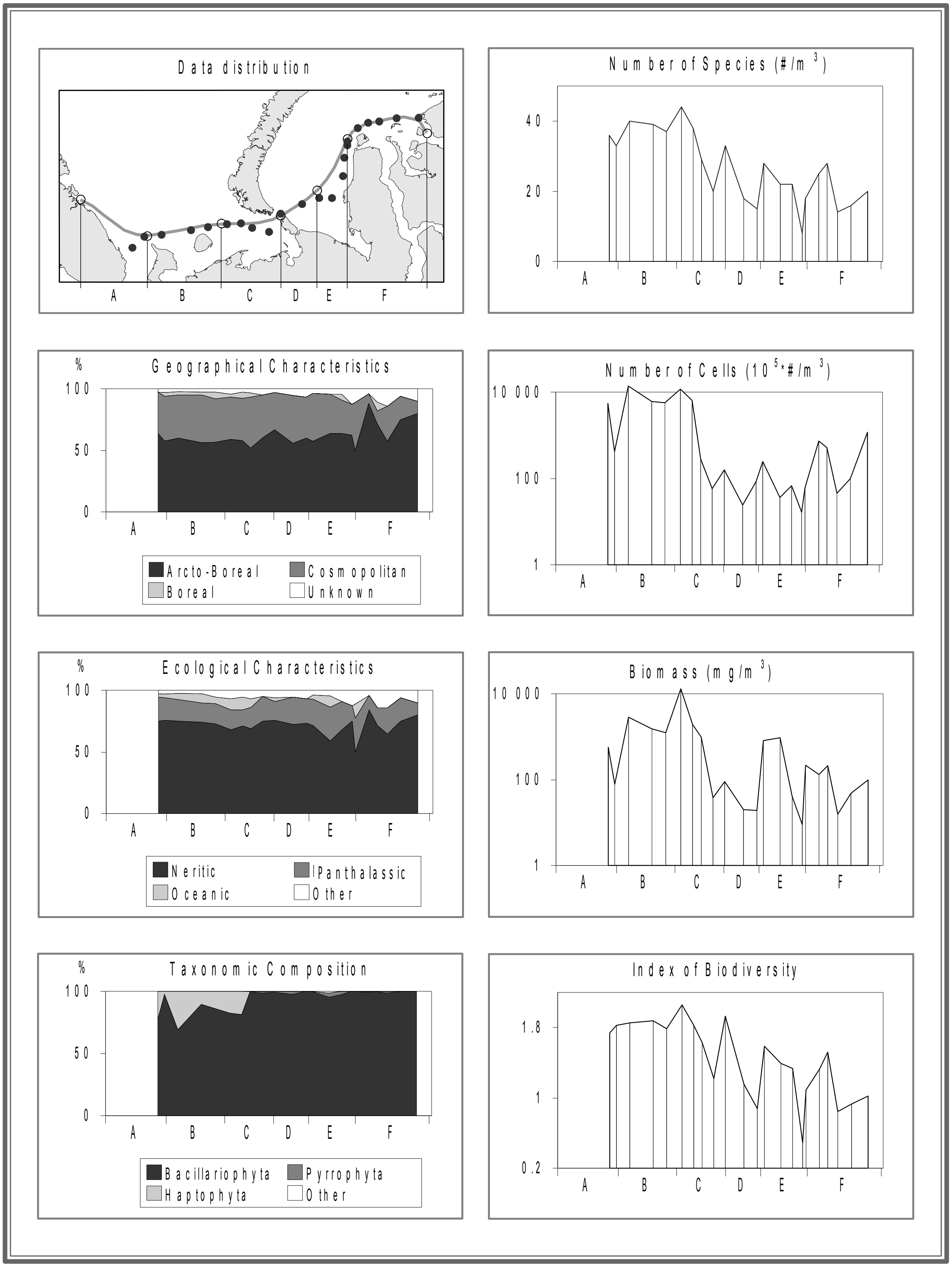


Fig. E4.1. Phytoplankton. Surface. Icebreaker *Arktika*. April-May, 1996

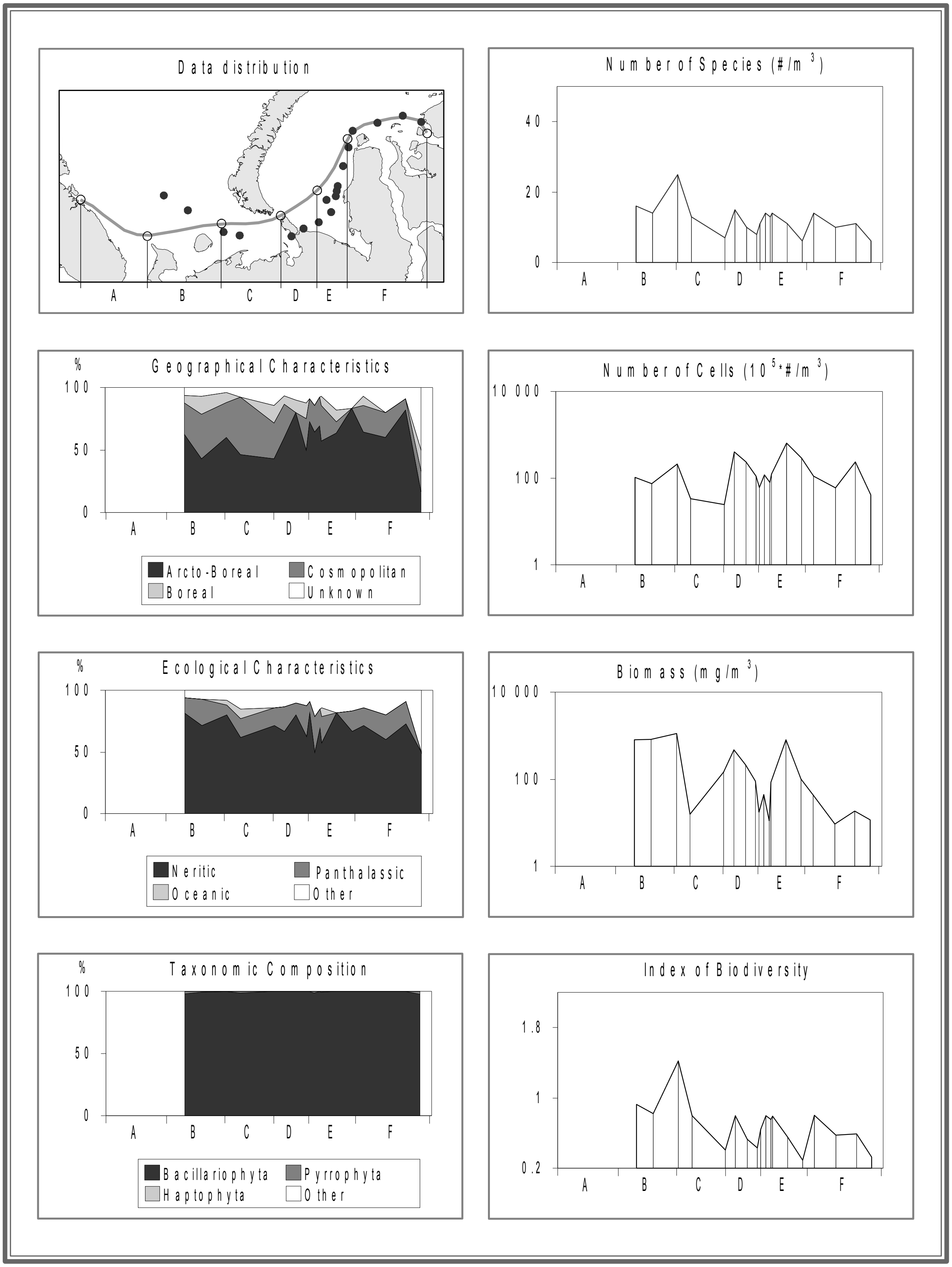


Fig. E4.2. Phytoplankton. Surface. Icebreaker *Sovetskiy Soyuz*. April 1-9, 1997

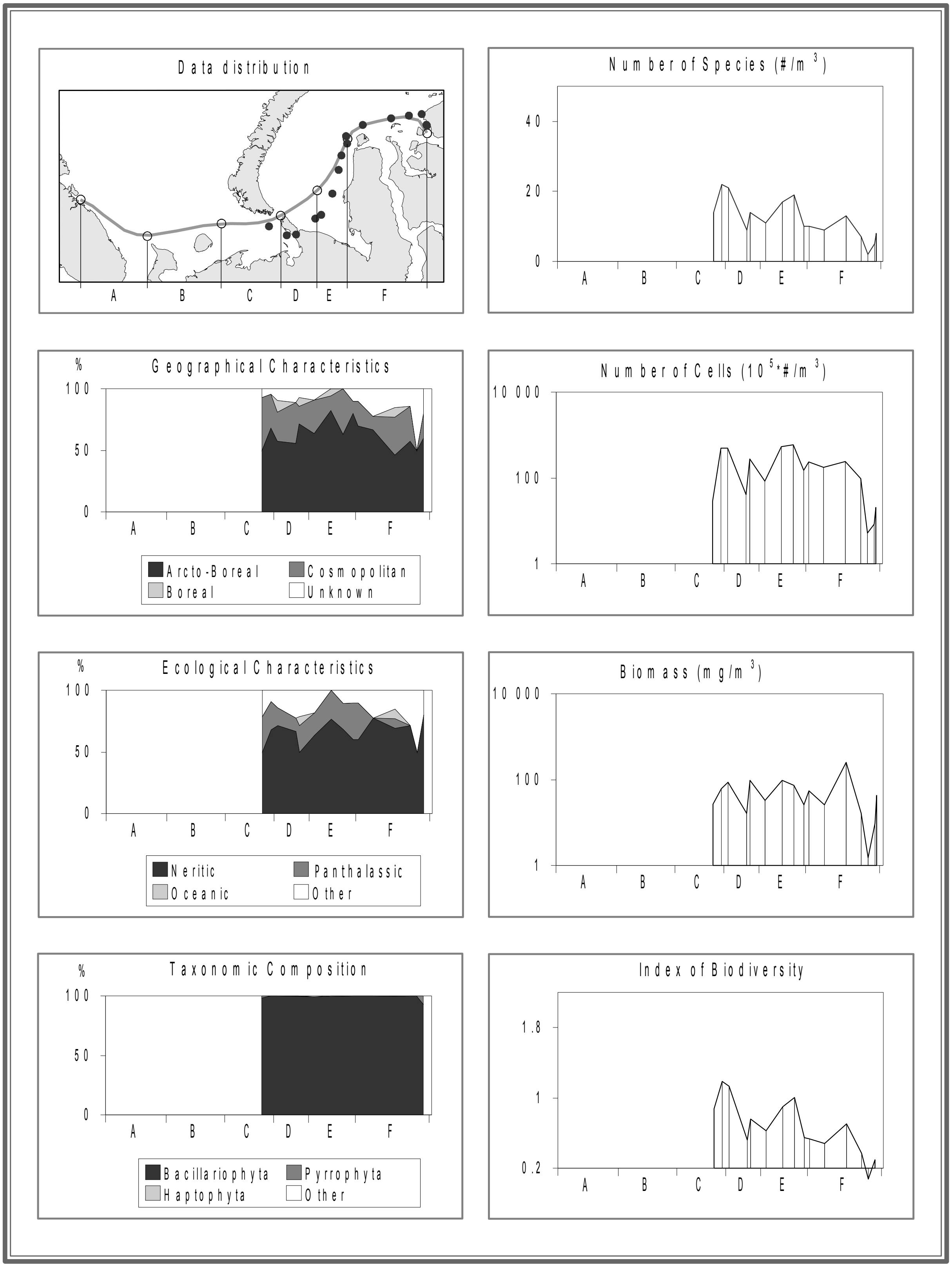


Fig. E4.3. Phytoplankton. Surface. Icebreaker *Sovetskiy Soyuz*. April 17–22, 1997

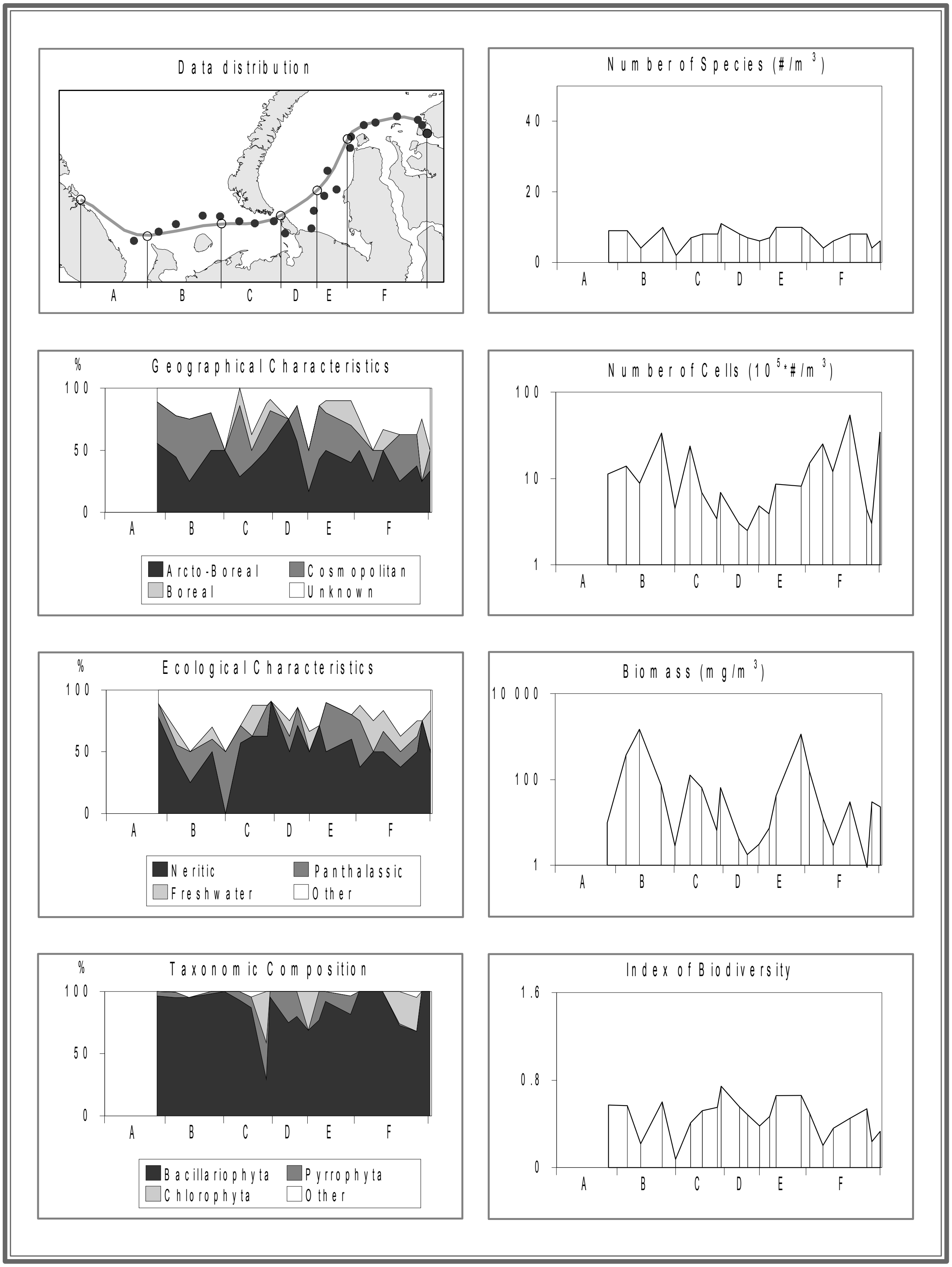


Fig. E4.4. Phytoplankton. Surface. Icebreaker *Vaygach*. February, 1998

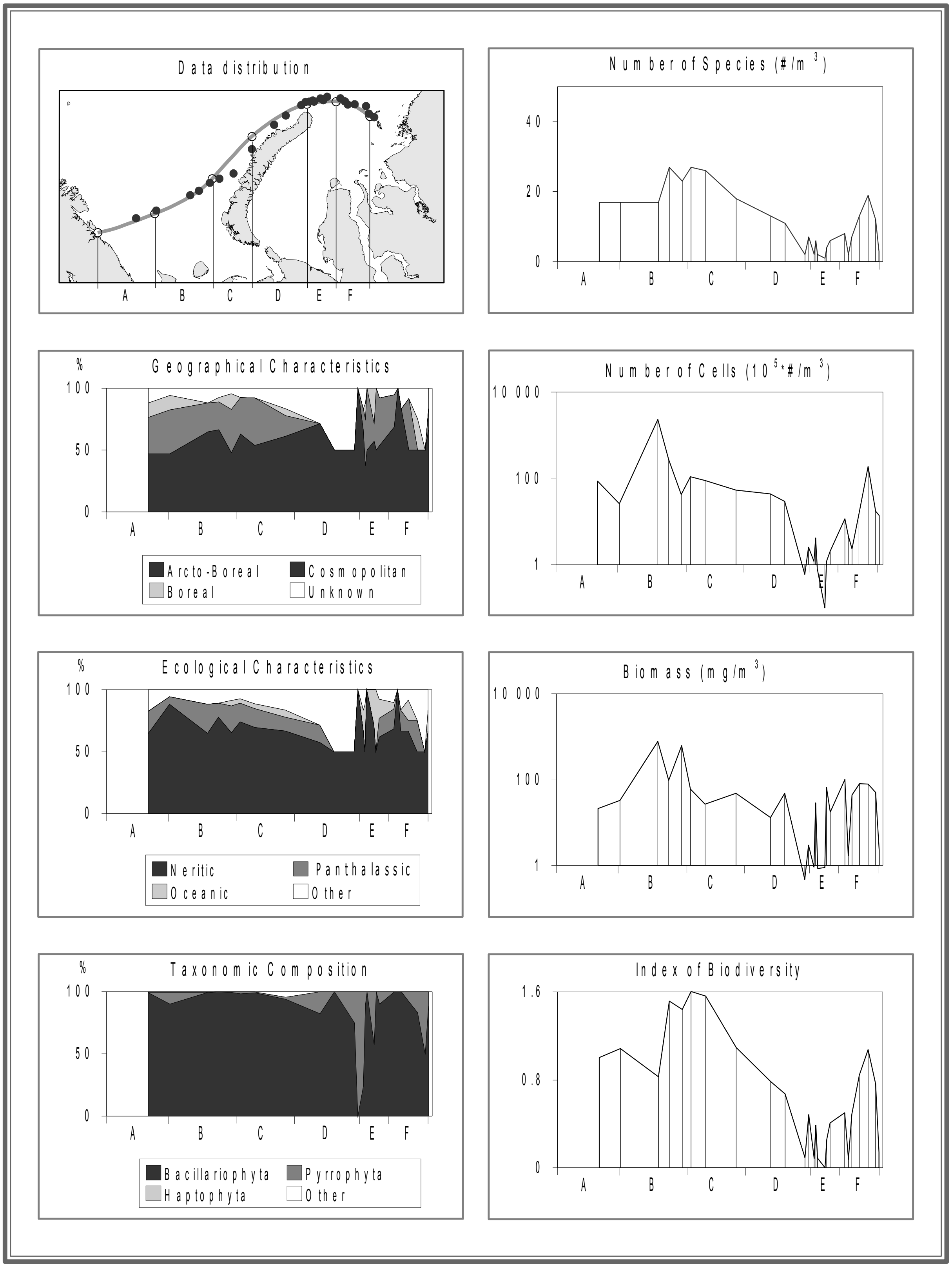


Fig. E4.5. Phytoplankton. Surface. Icebreaker *Russiya*. April, 1998

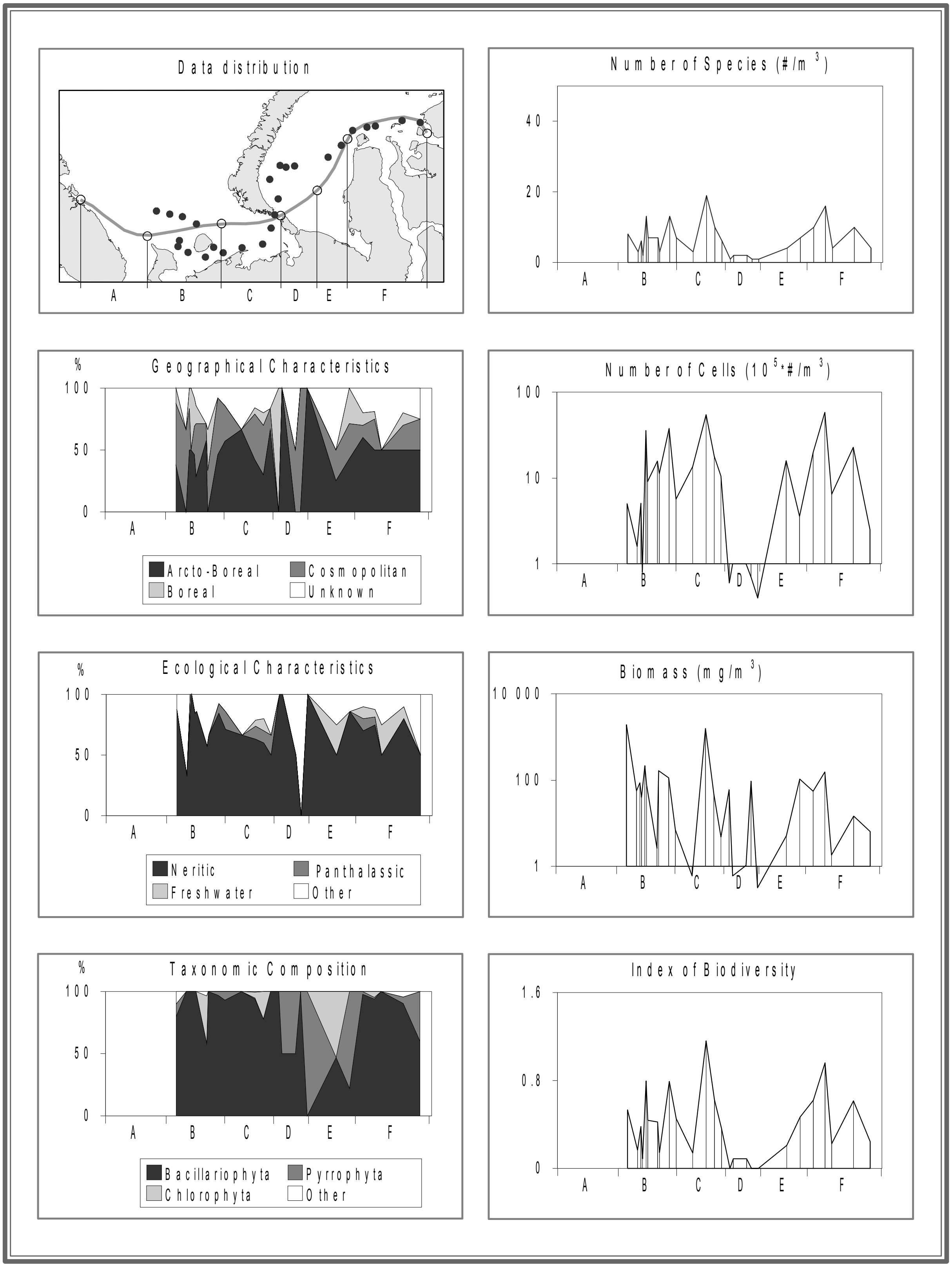


Fig. E4.6. Phytoplankton. Surface. Icebreaker *Sovetskiy Soyuz*. February-March, 1999

Fig. E4.6. Phytoplankton. Surface. Icebreaker *Sovetskiy Soyuz*. February-March, 1999

Appendix F. Zooplankton

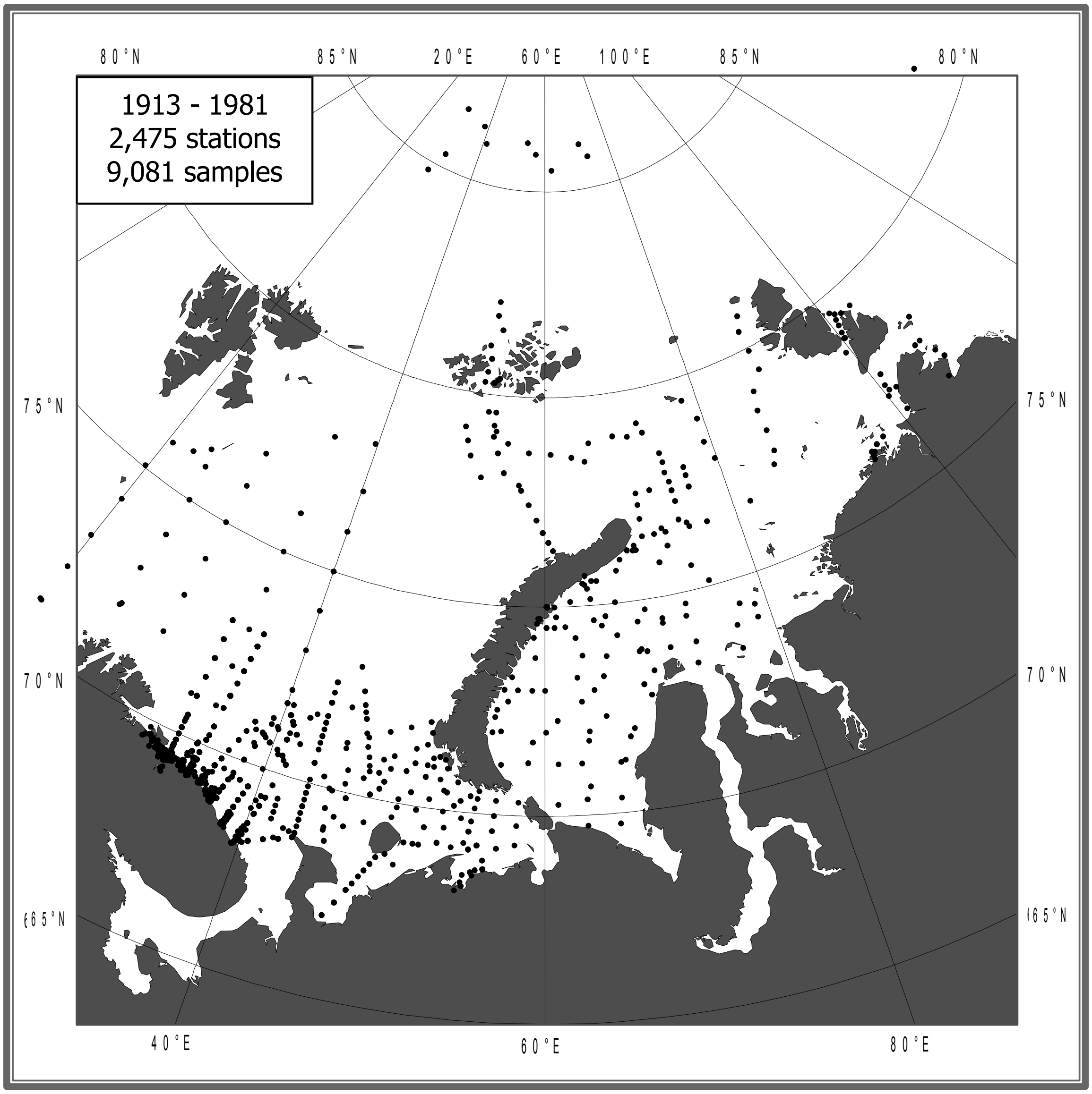


Fig. F1. Distribution of zooplankton data

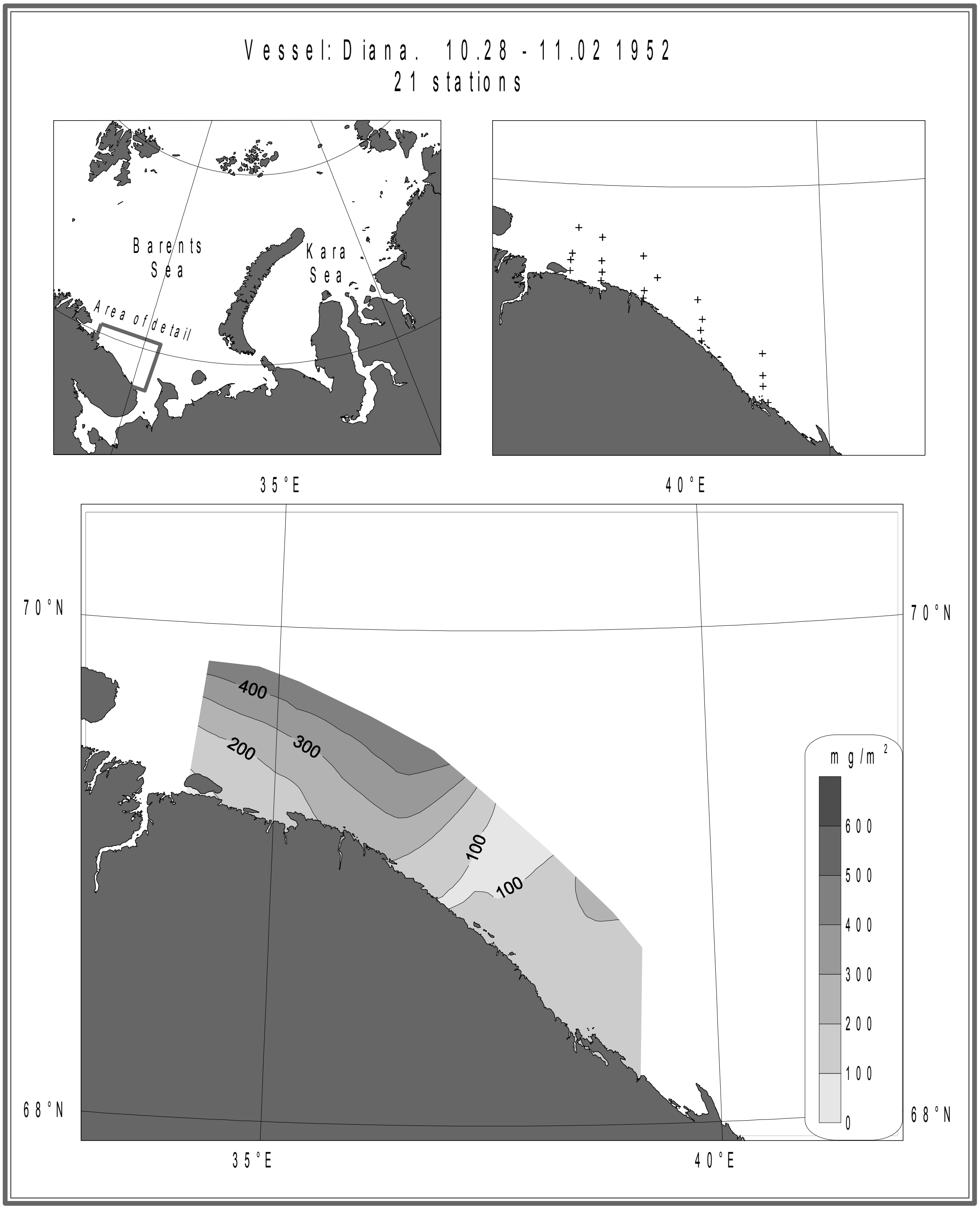


Fig. F2.1. Zooplankton. Surface-bottom. Biomass. October-November, 1952

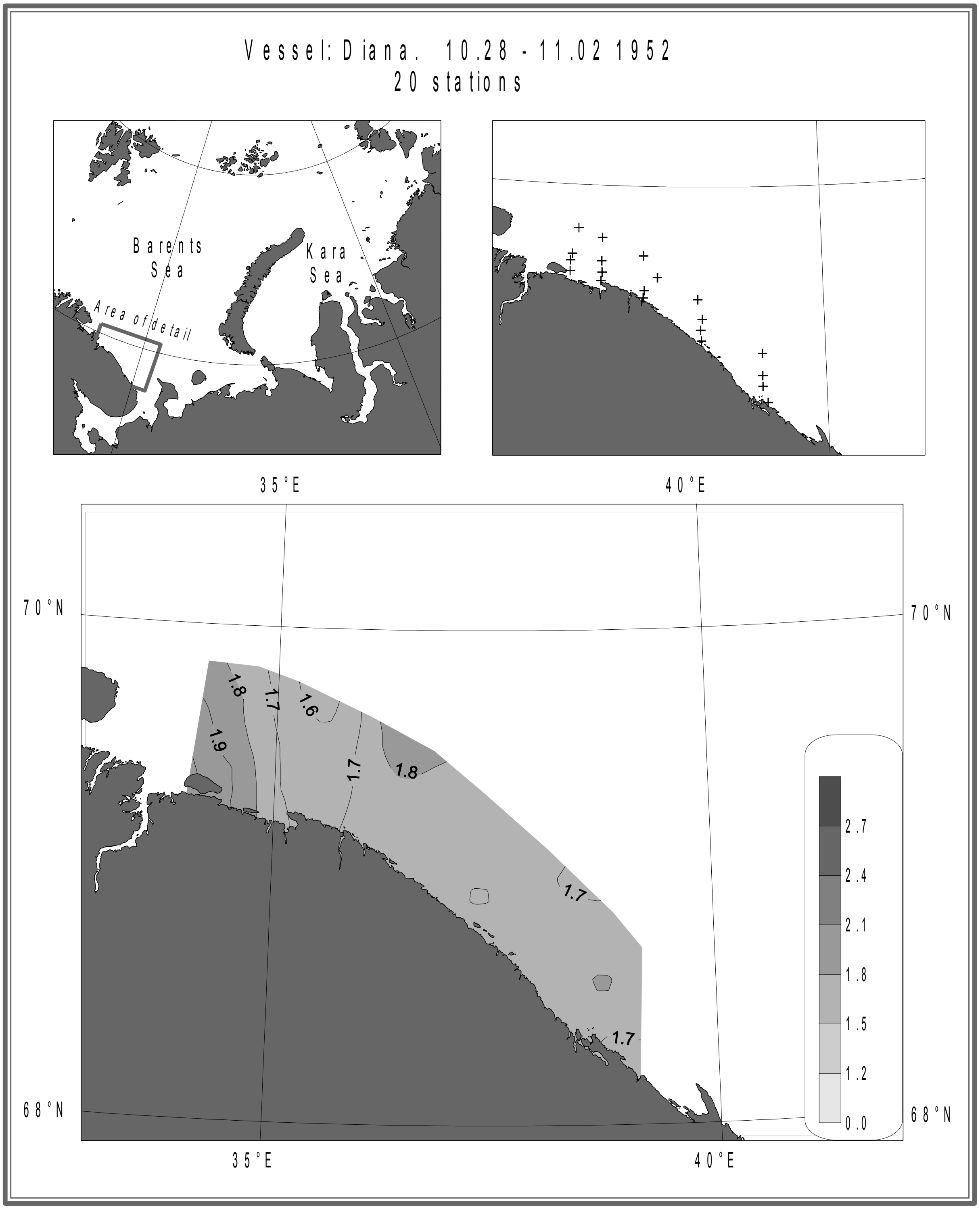


Fig. F2.2. Zooplankton. Surface-bottom. Biodiversity. October-November, 1952

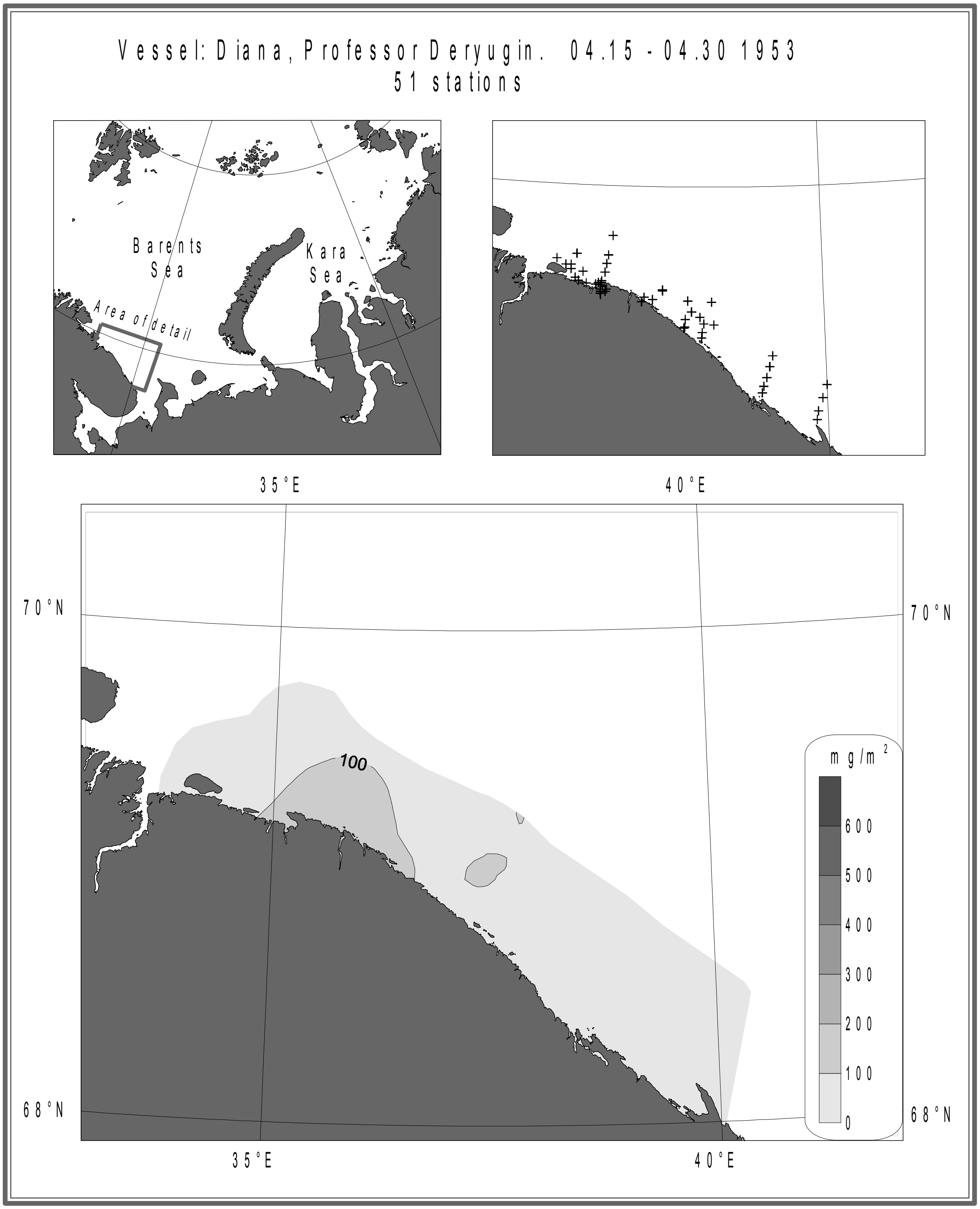


Fig. F2.3. Zooplankton. Surface-bottom. Biomass. April, 1953

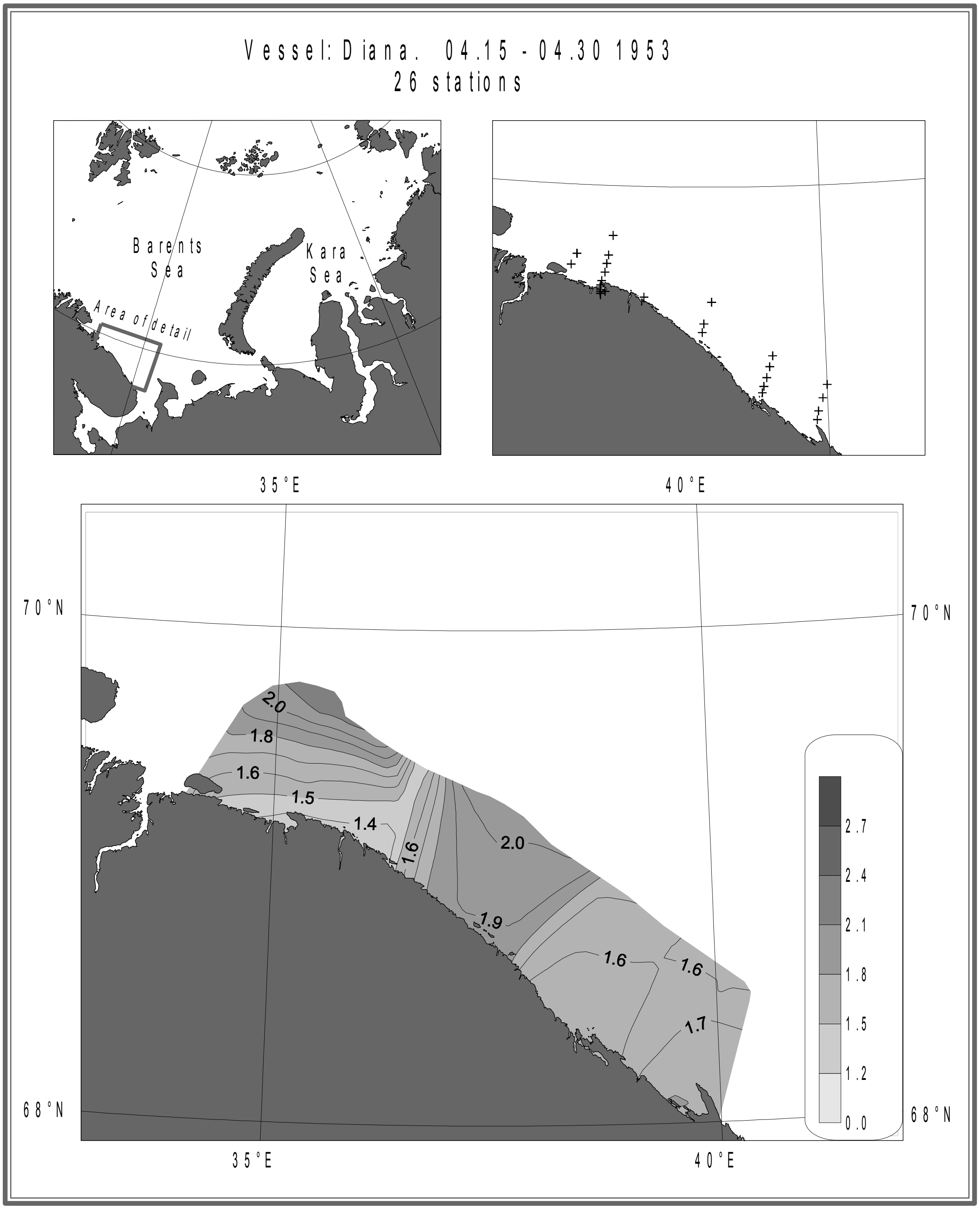


Fig. F2.4. Zooplankton. Surface-bottom. Biodiversity. April, 1953

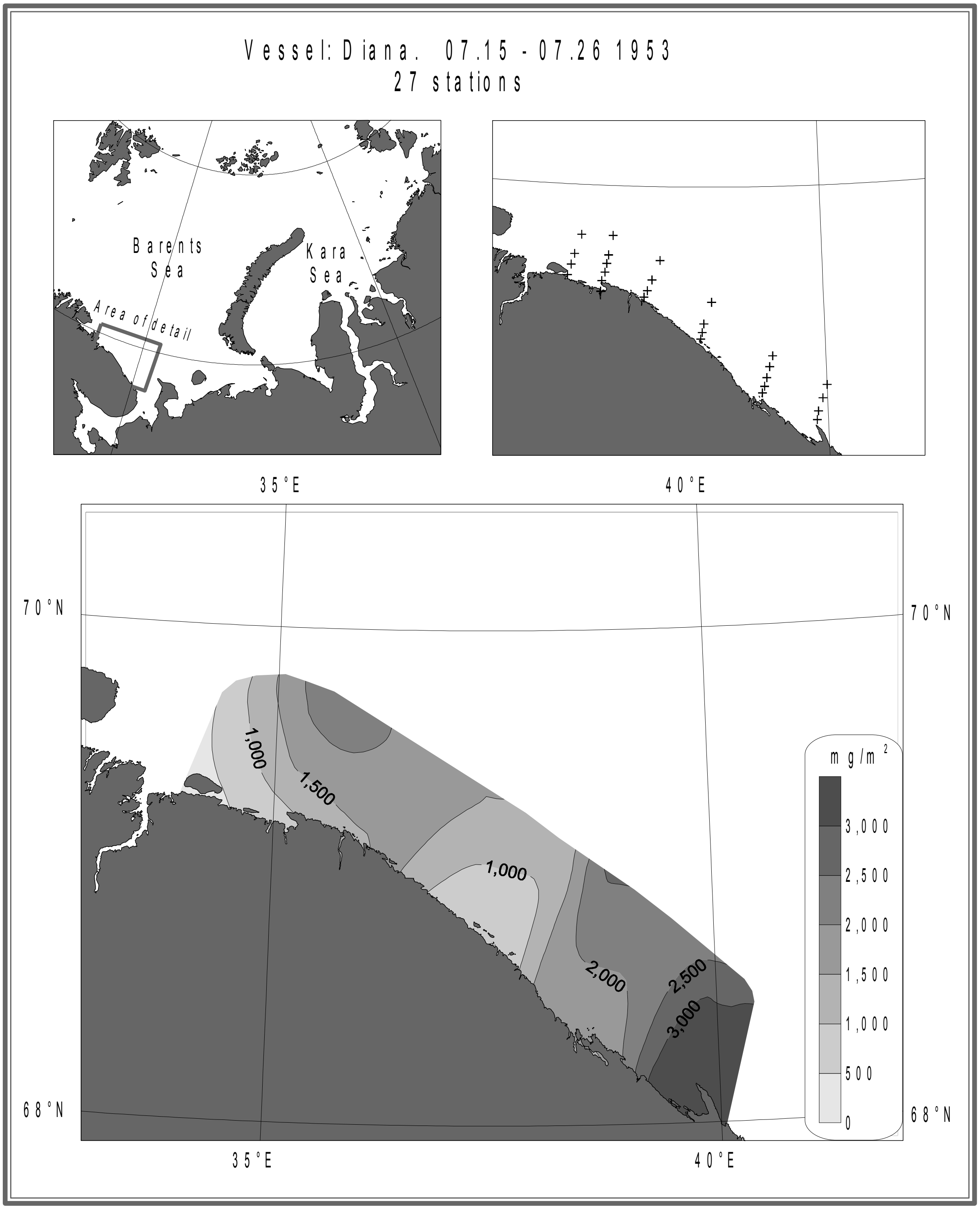


Fig. F2.5. Zooplankton. Surface-bottom. Biomass. July, 1953

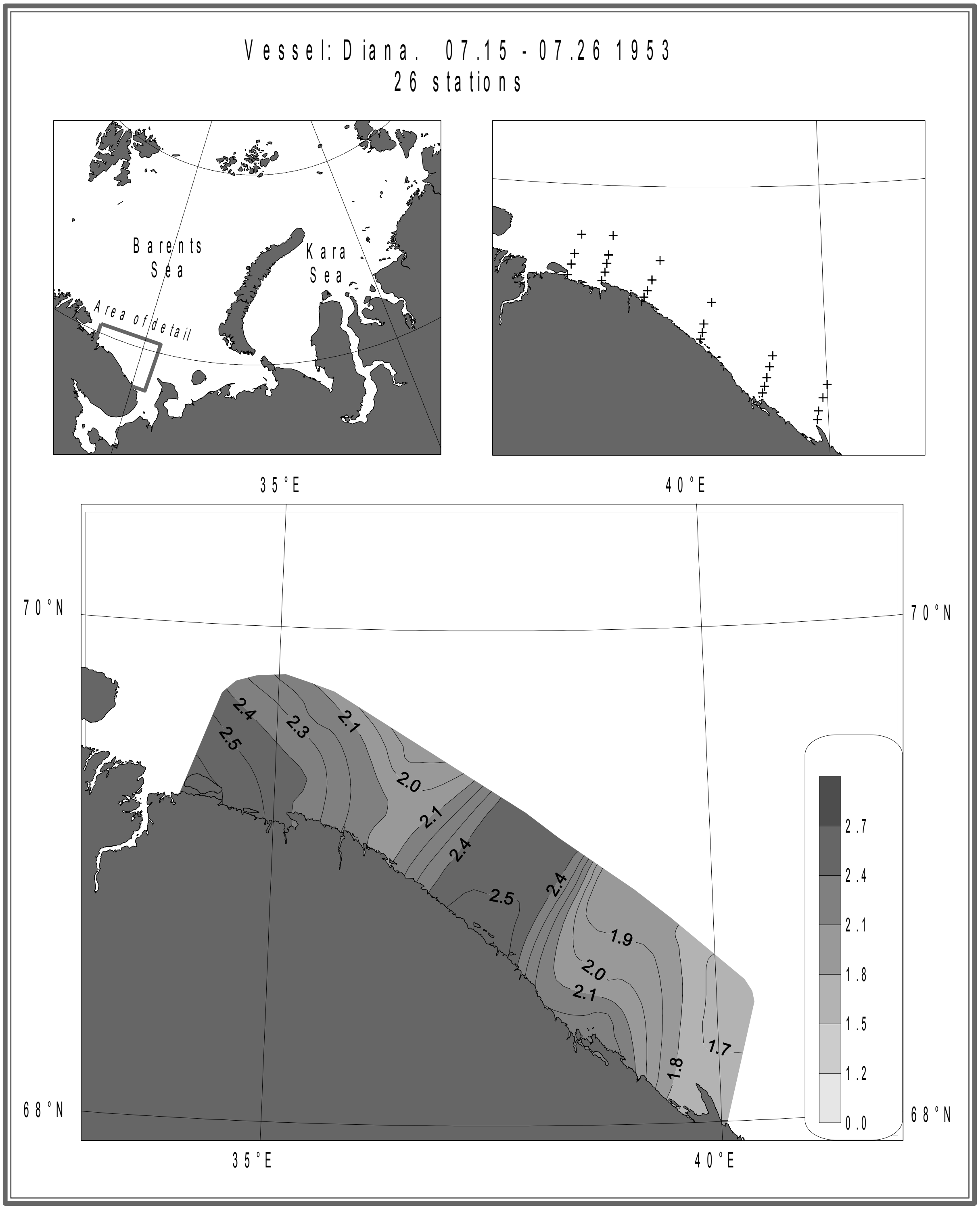


Fig. F2.6. Zooplankton. Surface-bottom. Biodiversity. July, 1953

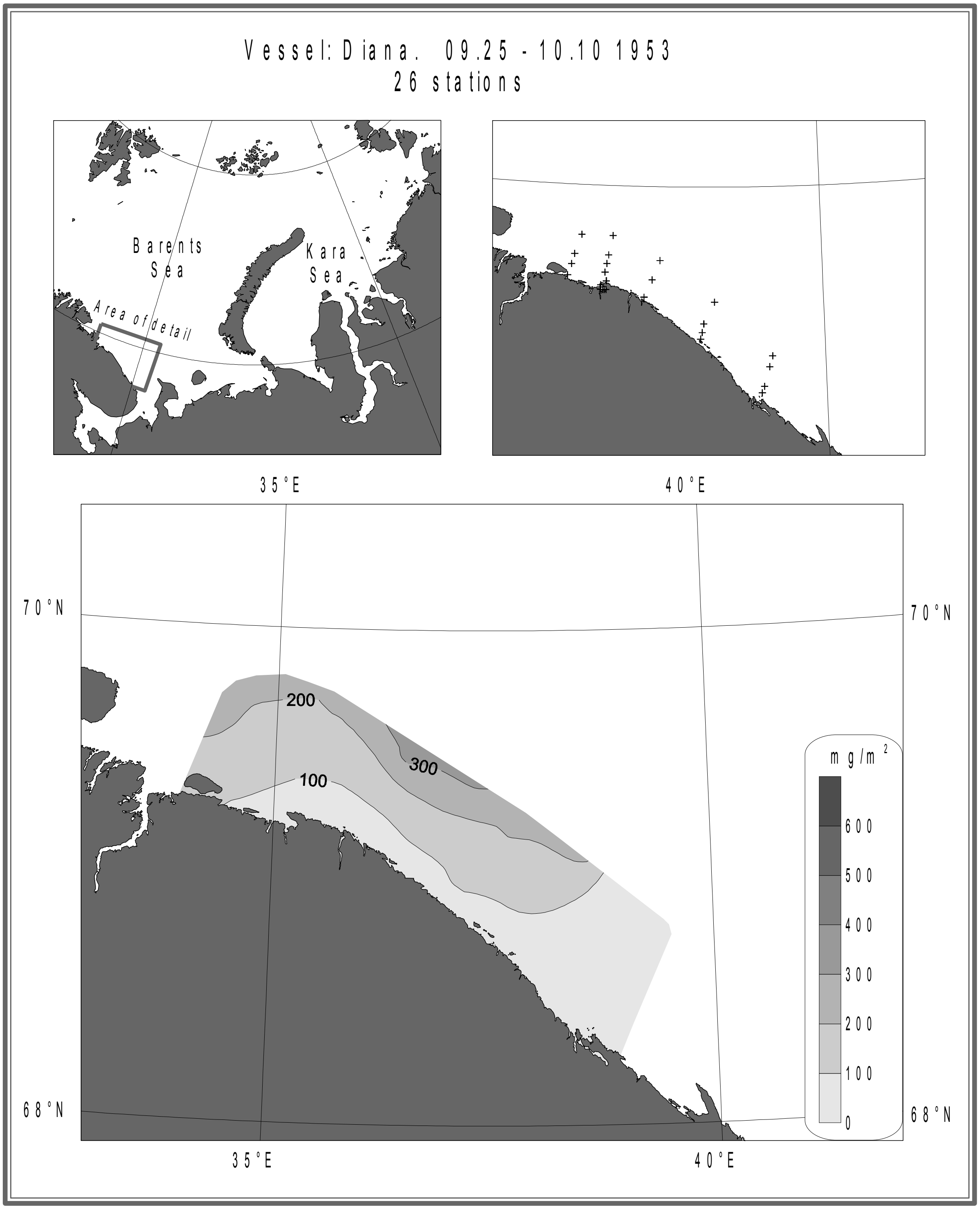


Fig. F2.7. Zooplankton. Surface-bottom. Biomass. September-October, 1953

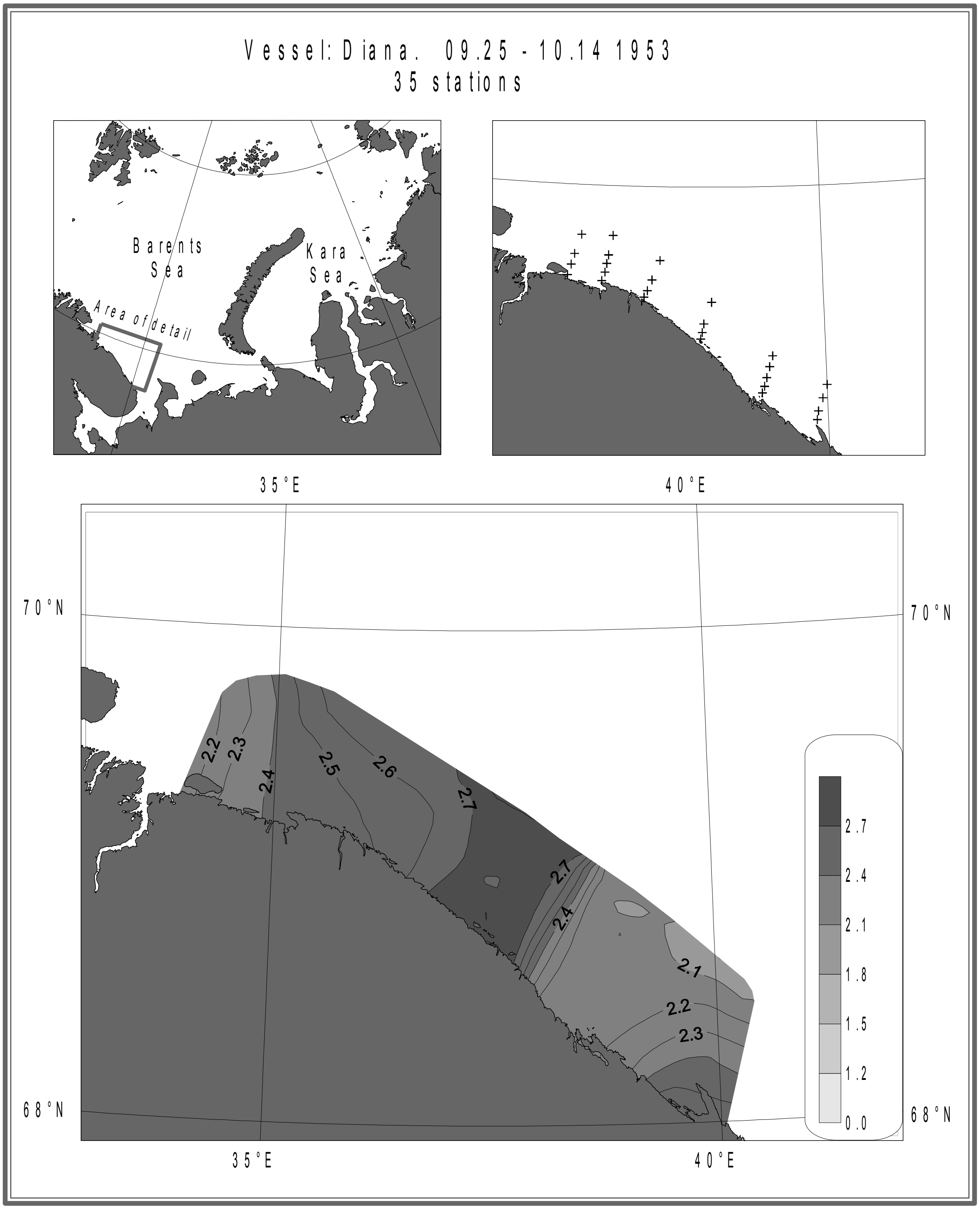


Fig. F2.8. Zooplankton. Surface-bottom. Biodiversity. September-October, 1953

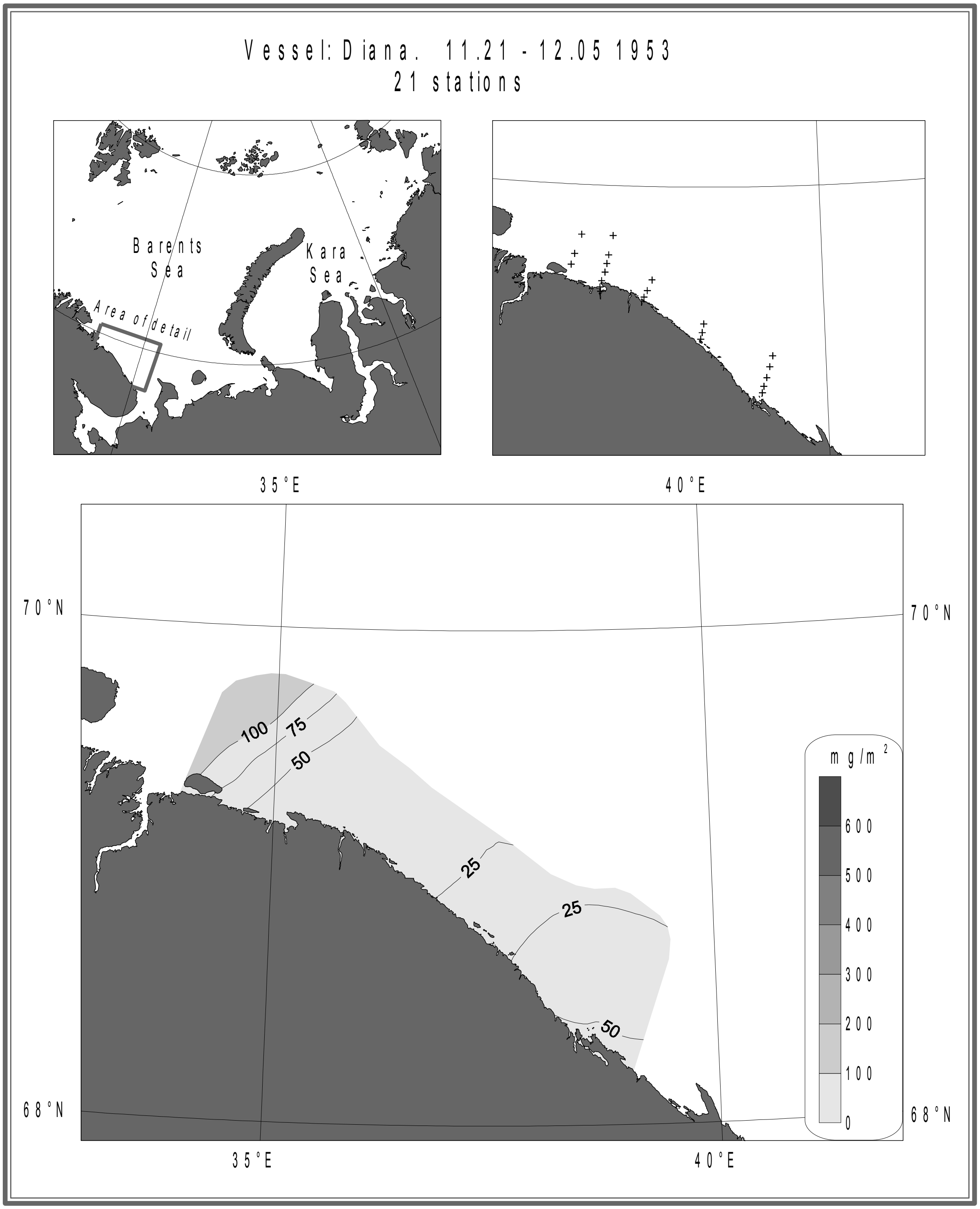


Fig. F2.9. Zooplankton. Surface-bottom. Biomass. November-December, 1953

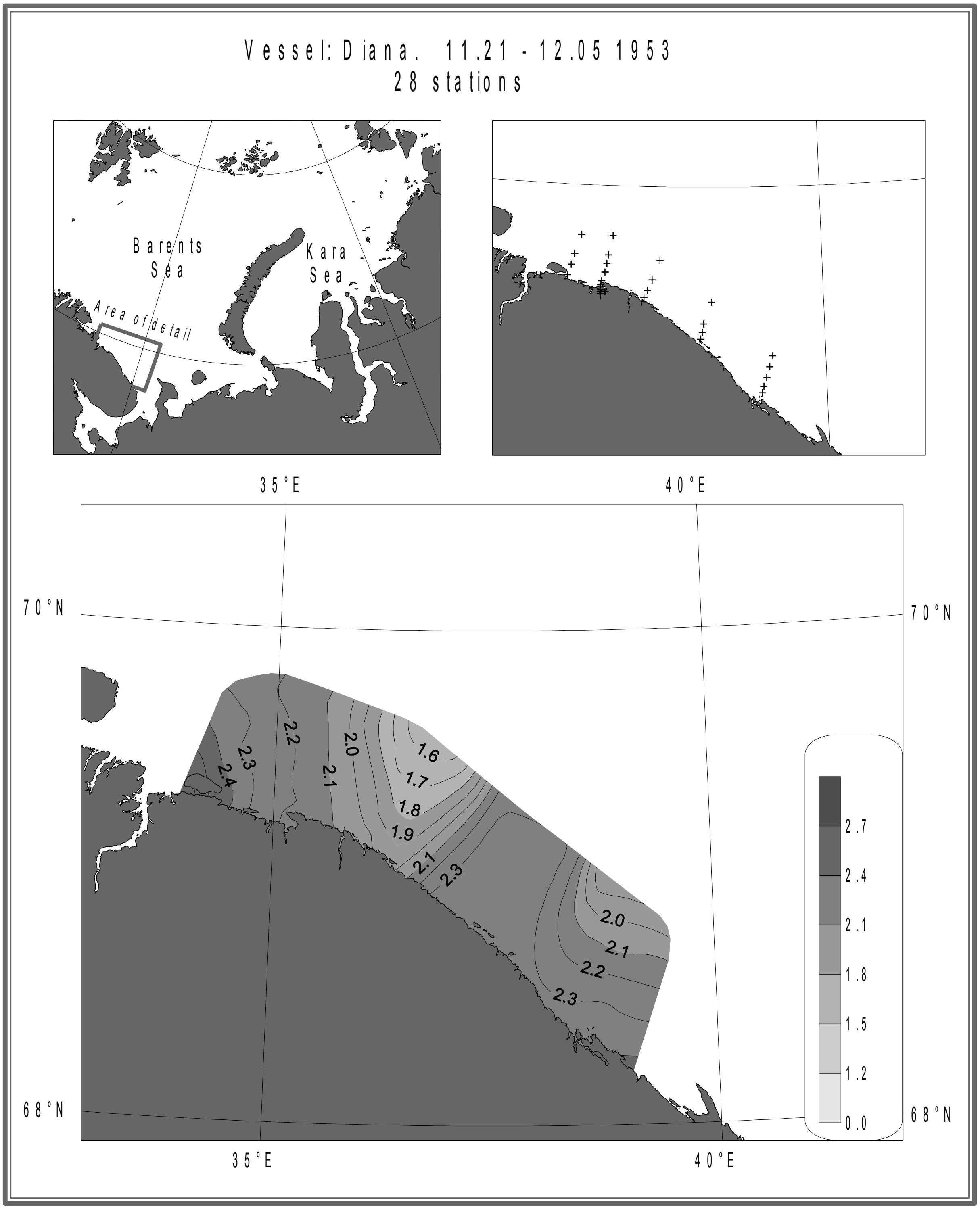


Fig. F2.10. Zooplankton. Surface-bottom. Biodiversity. November-December, 1953

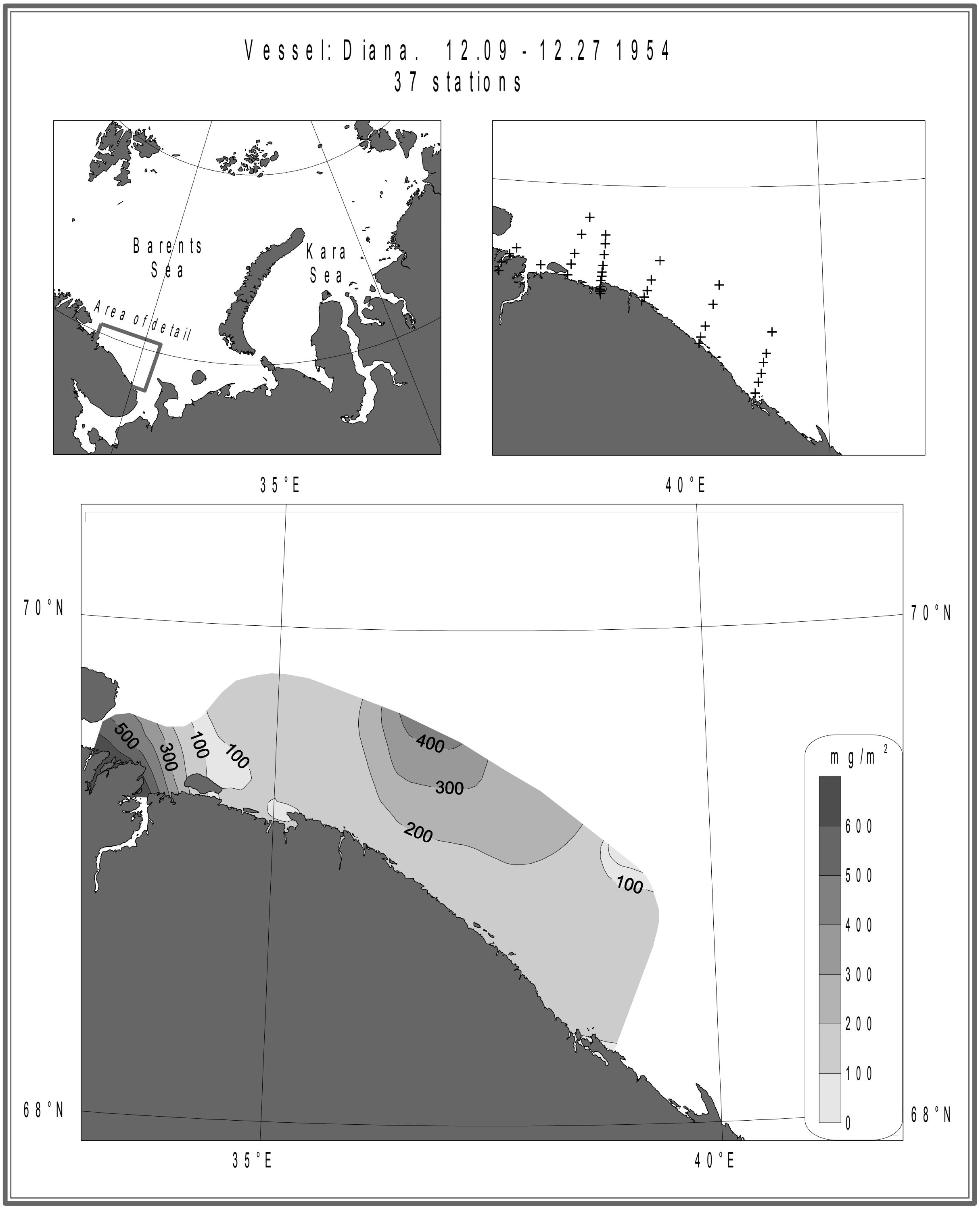


Fig. F2.11. Zooplankton. Surface-bottom. Biomass. December, 1954

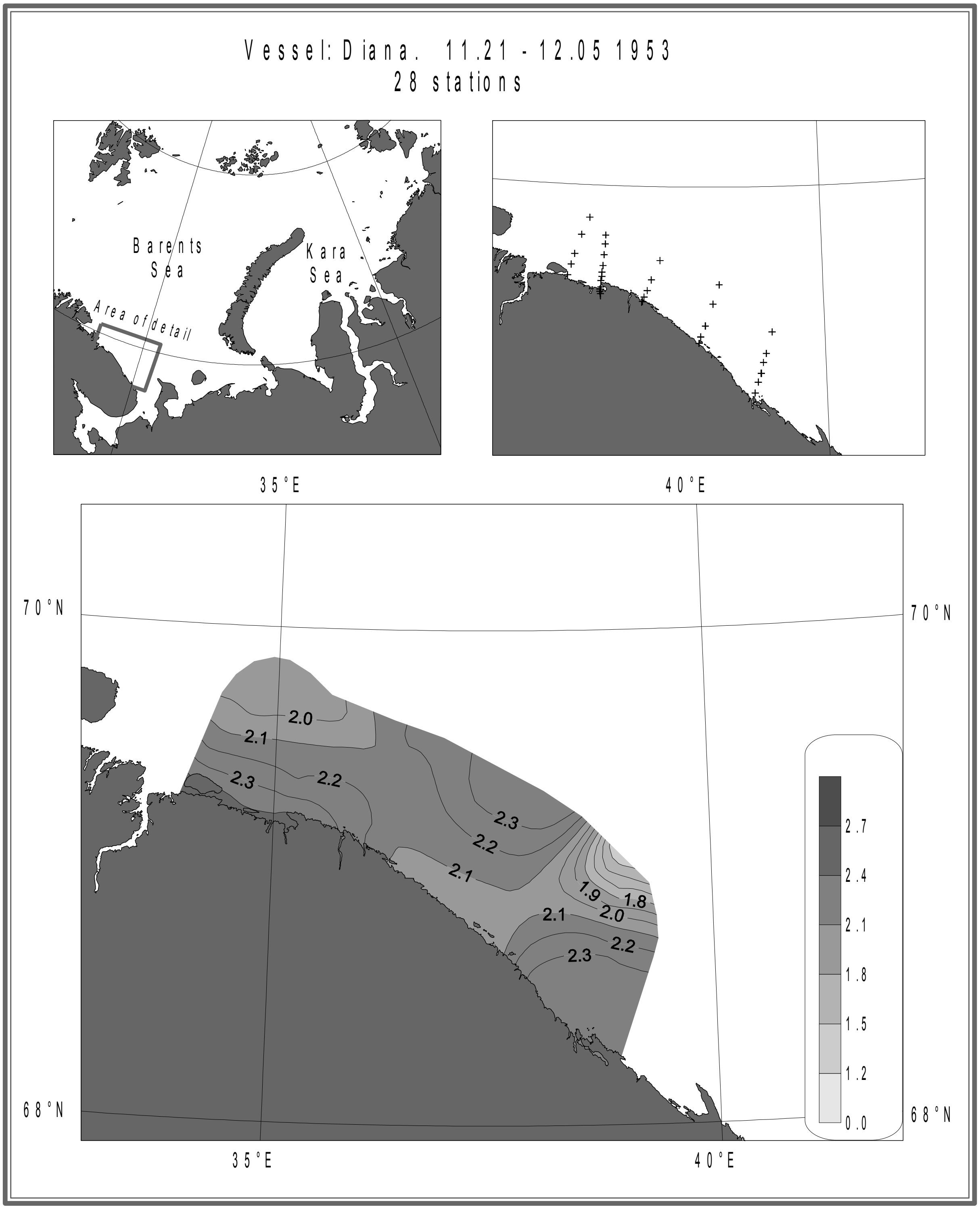


Fig. F2.12. Zooplankton. Surface-bottom. Biodiversity. December, 1954

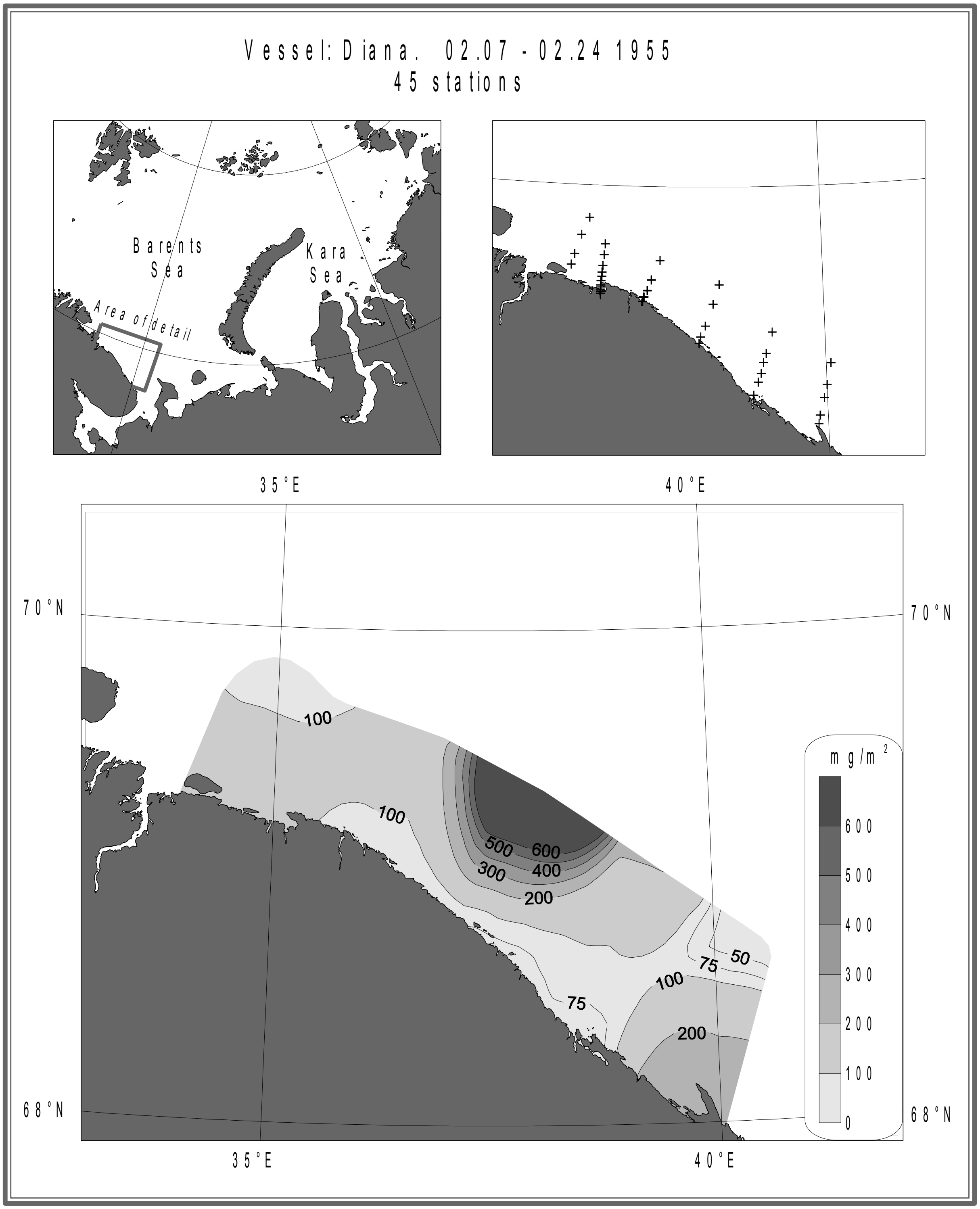


Fig. F2.13. Zooplankton. Surface-bottom. Biomass. February, 1955

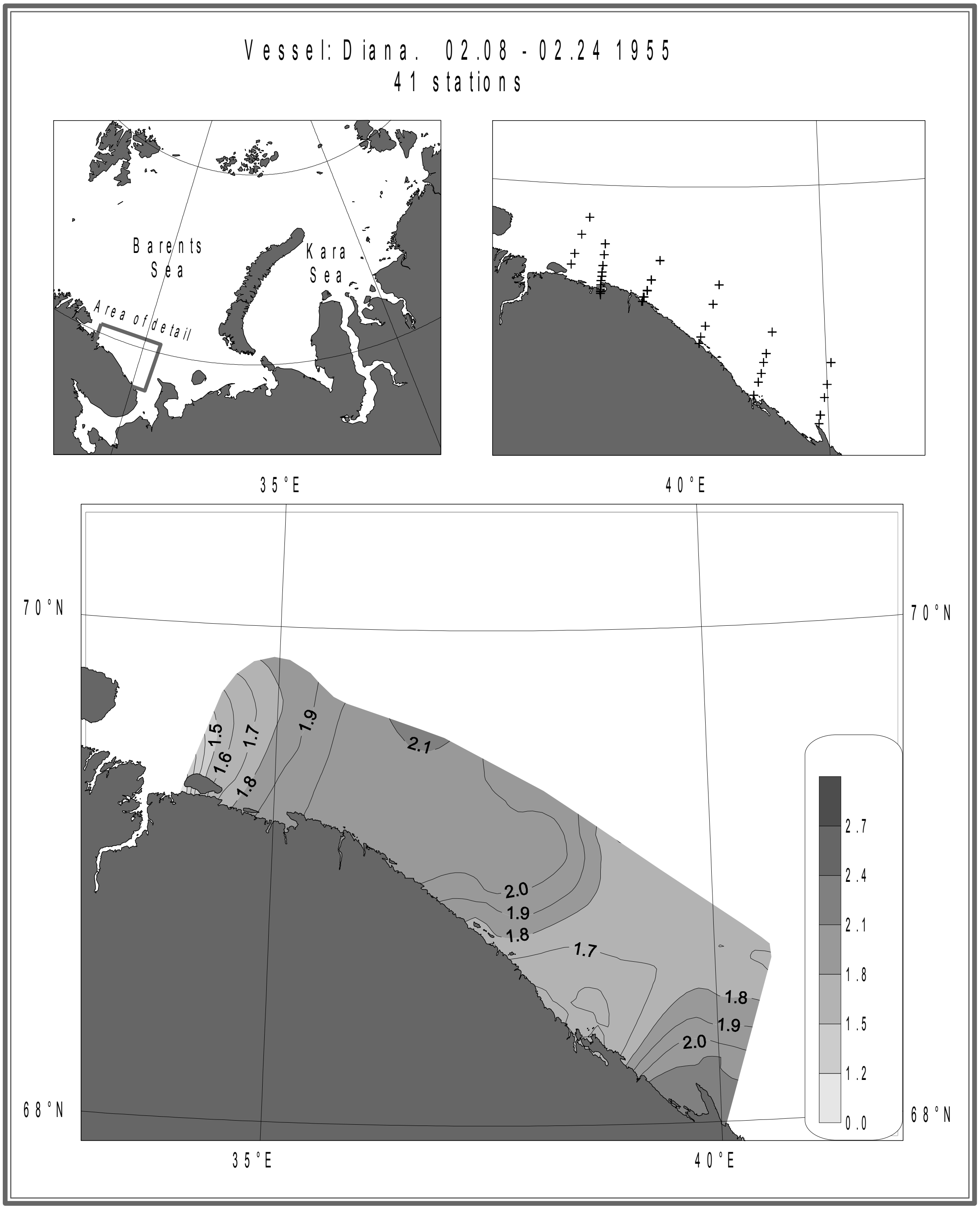


Fig. F2.14. Zooplankton. Surface-bottom. Biodiversity. February, 1954

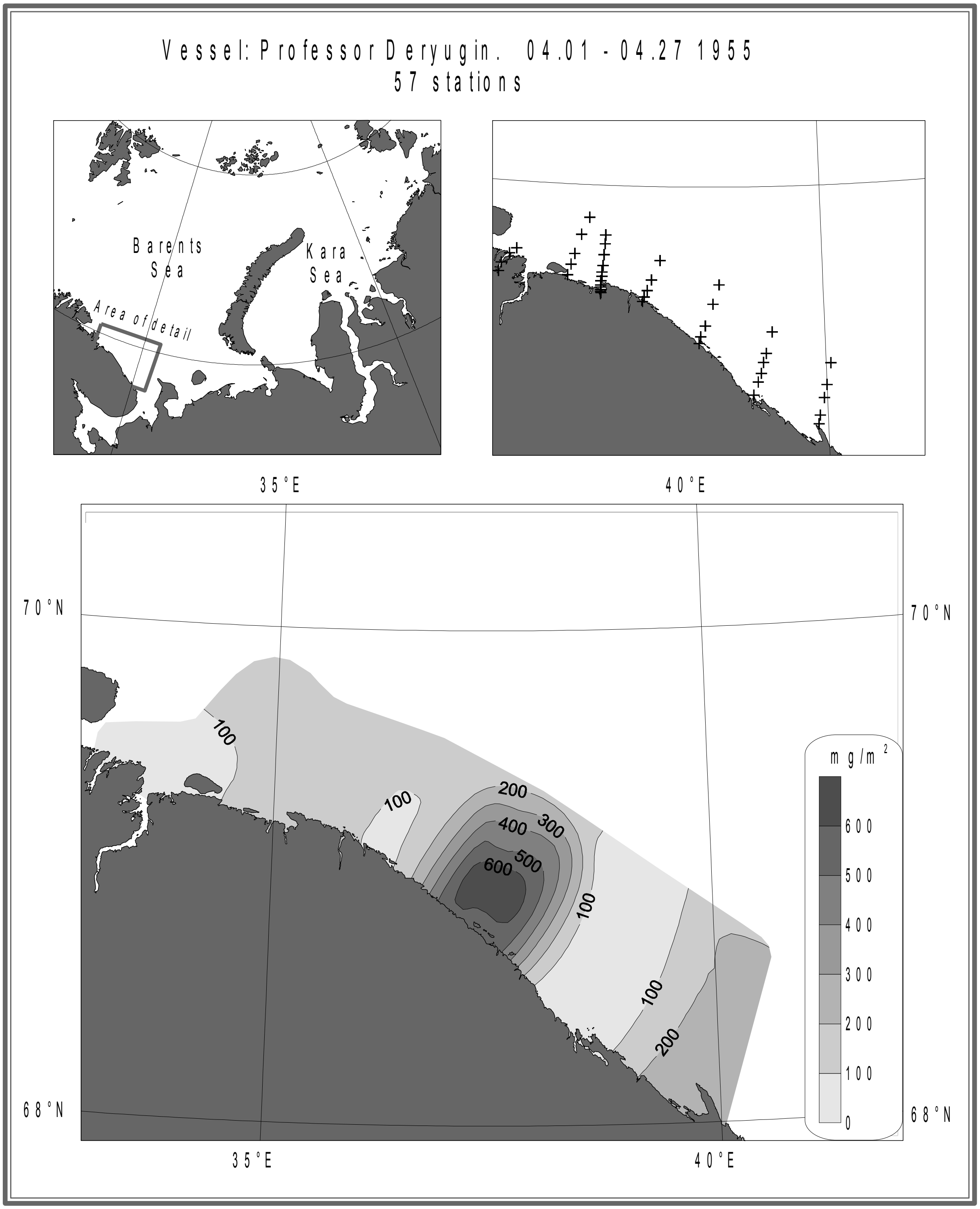


Fig. F2.15. Zooplankton. Surface-bottom. Biomass. April, 1955

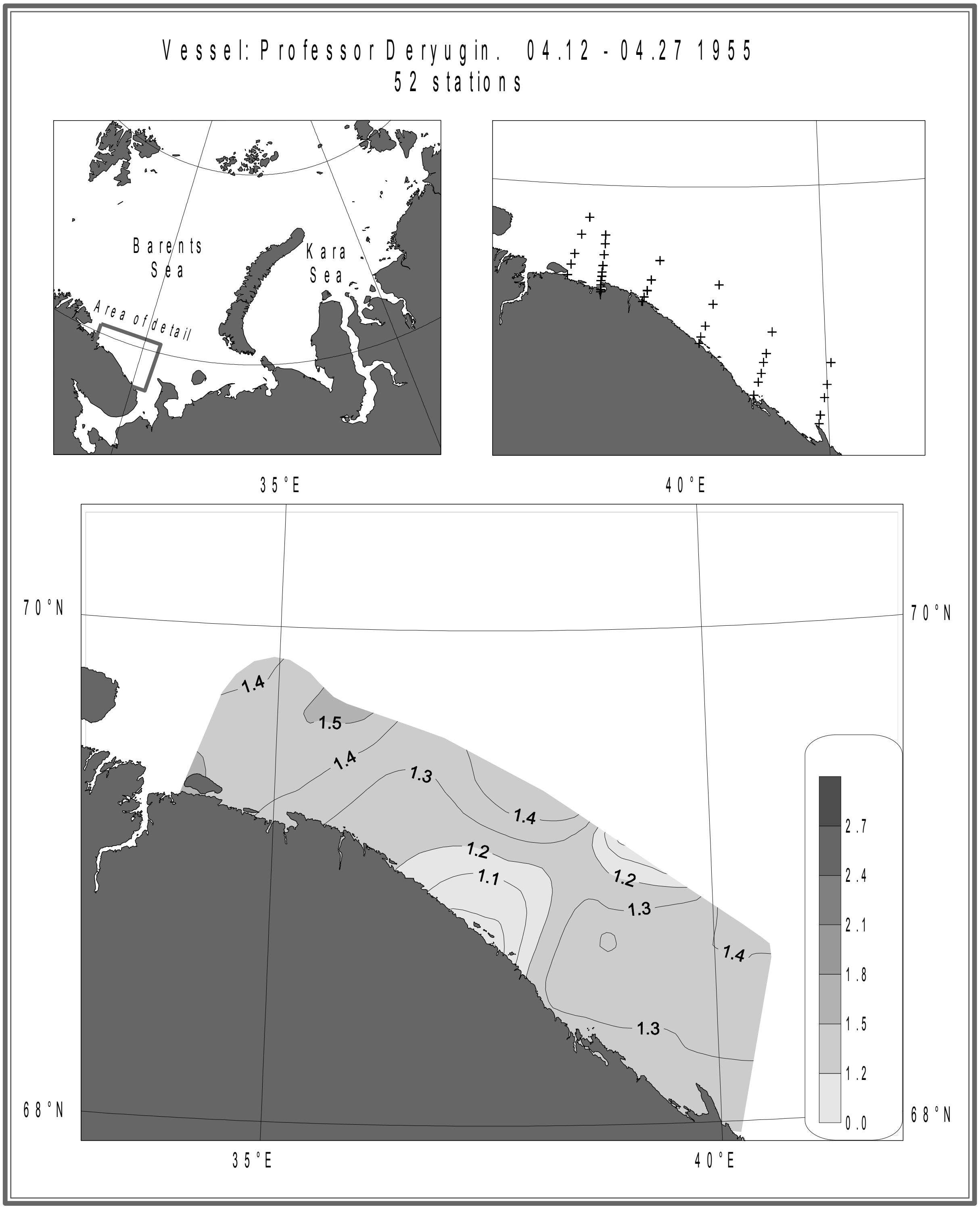


Fig. F2.16. Zooplankton. Surface-bottom. Biodiversity. April, 1955

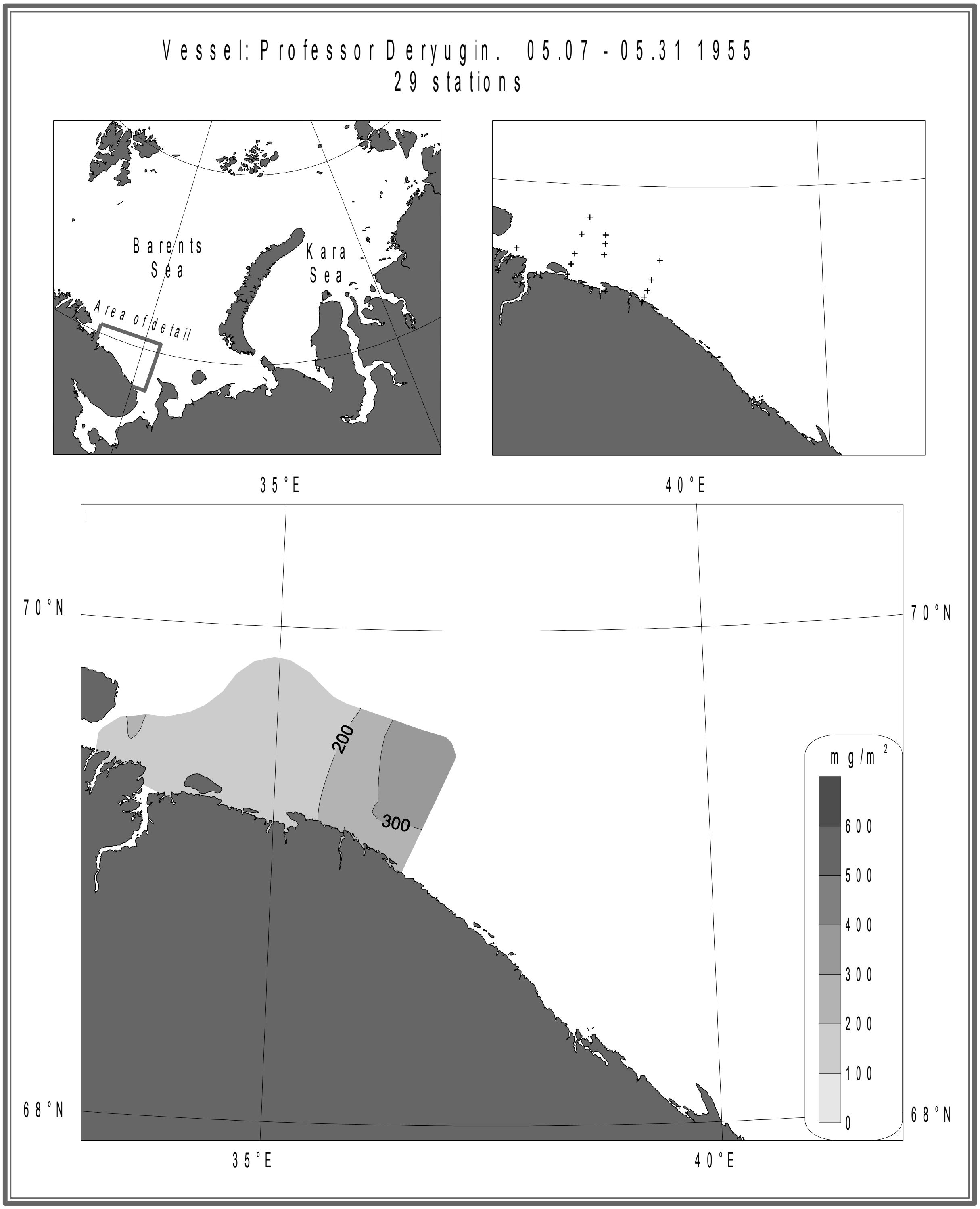


Fig. F2.17. Zooplankton. Surface-bottom. Biomass. May, 1955

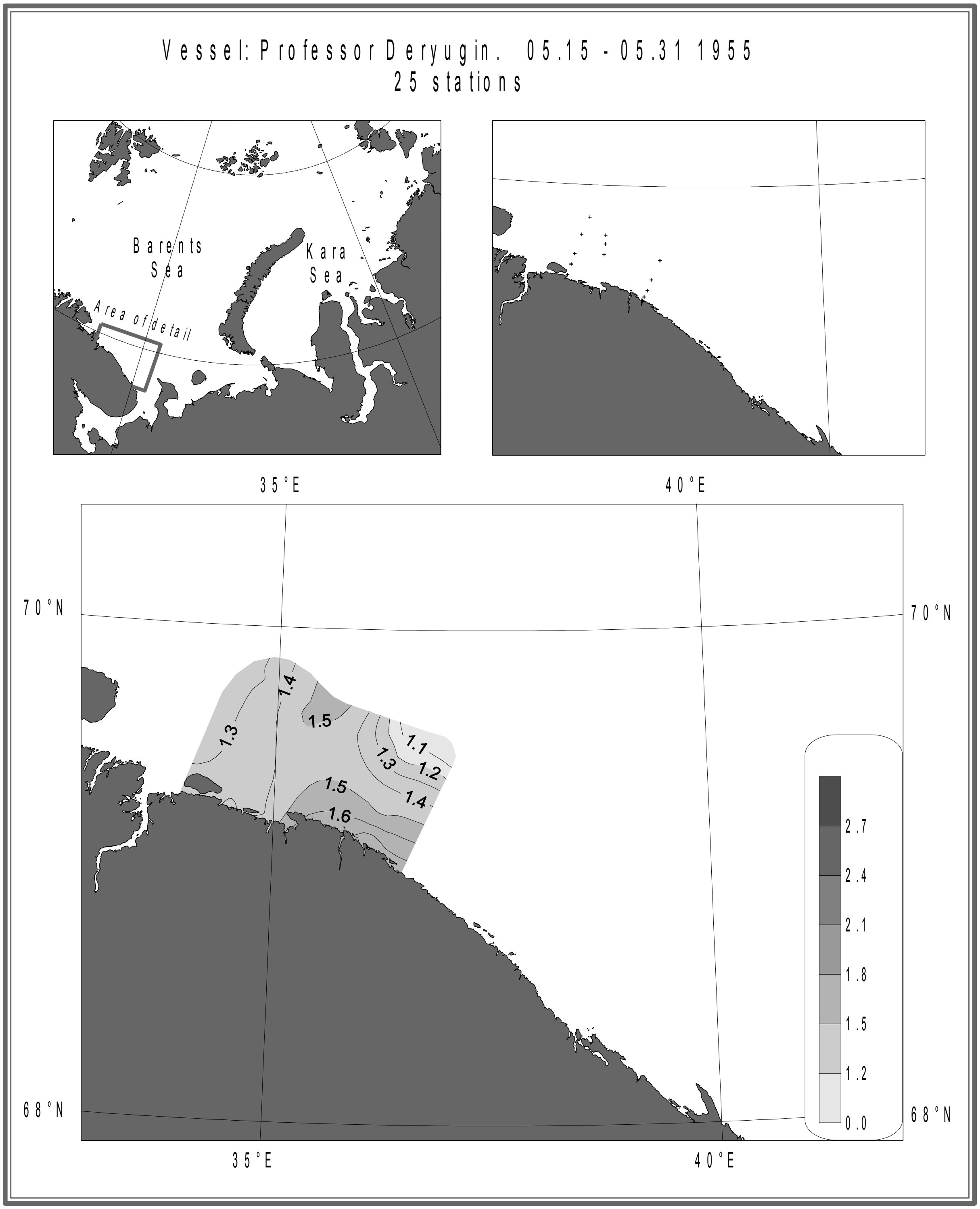


Fig. F2.18. Zooplankton. Surface-bottom. Biodiversity. May, 1955

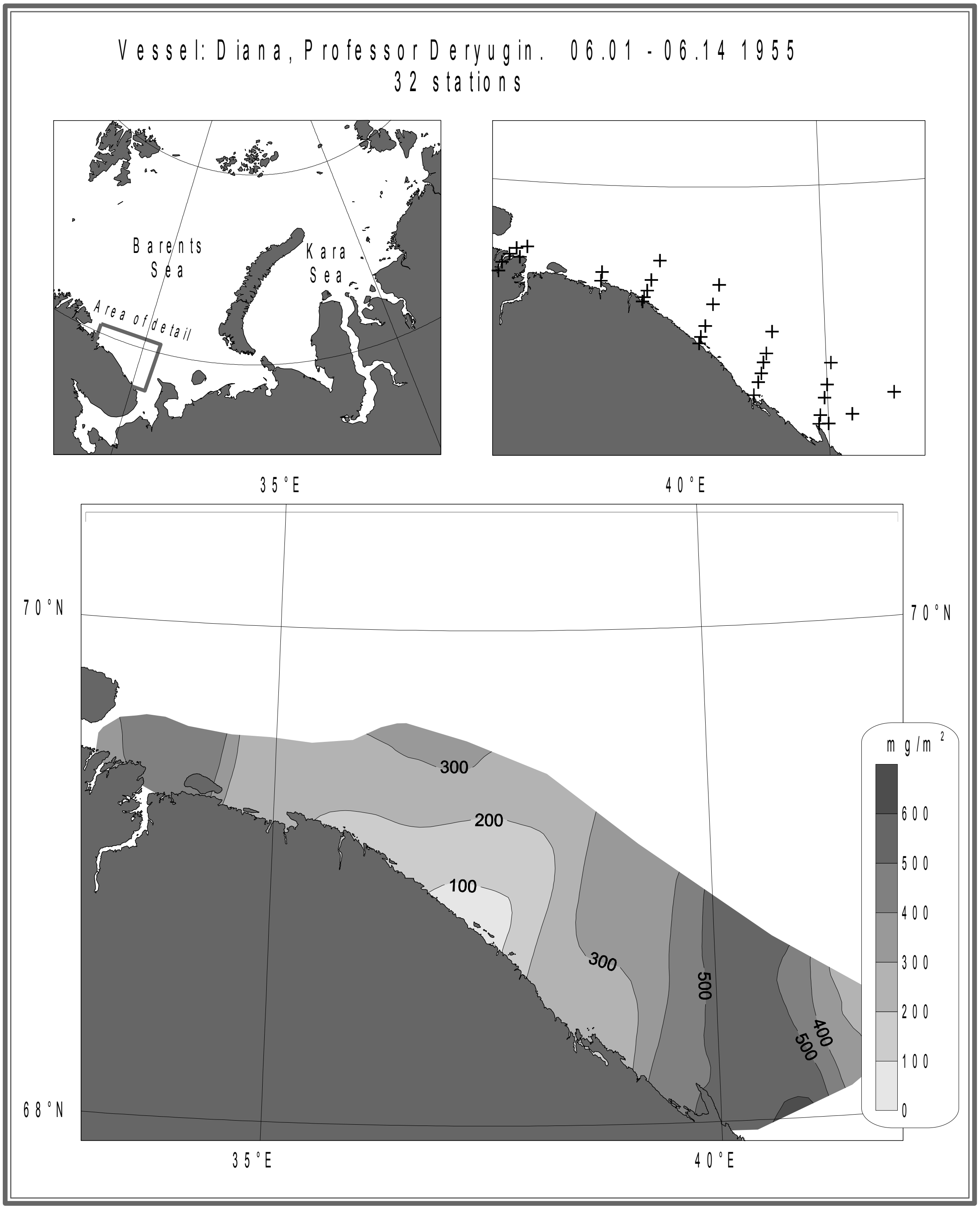


Fig. F2.19. Zooplankton. Surface-bottom. Biomass. June, 1955

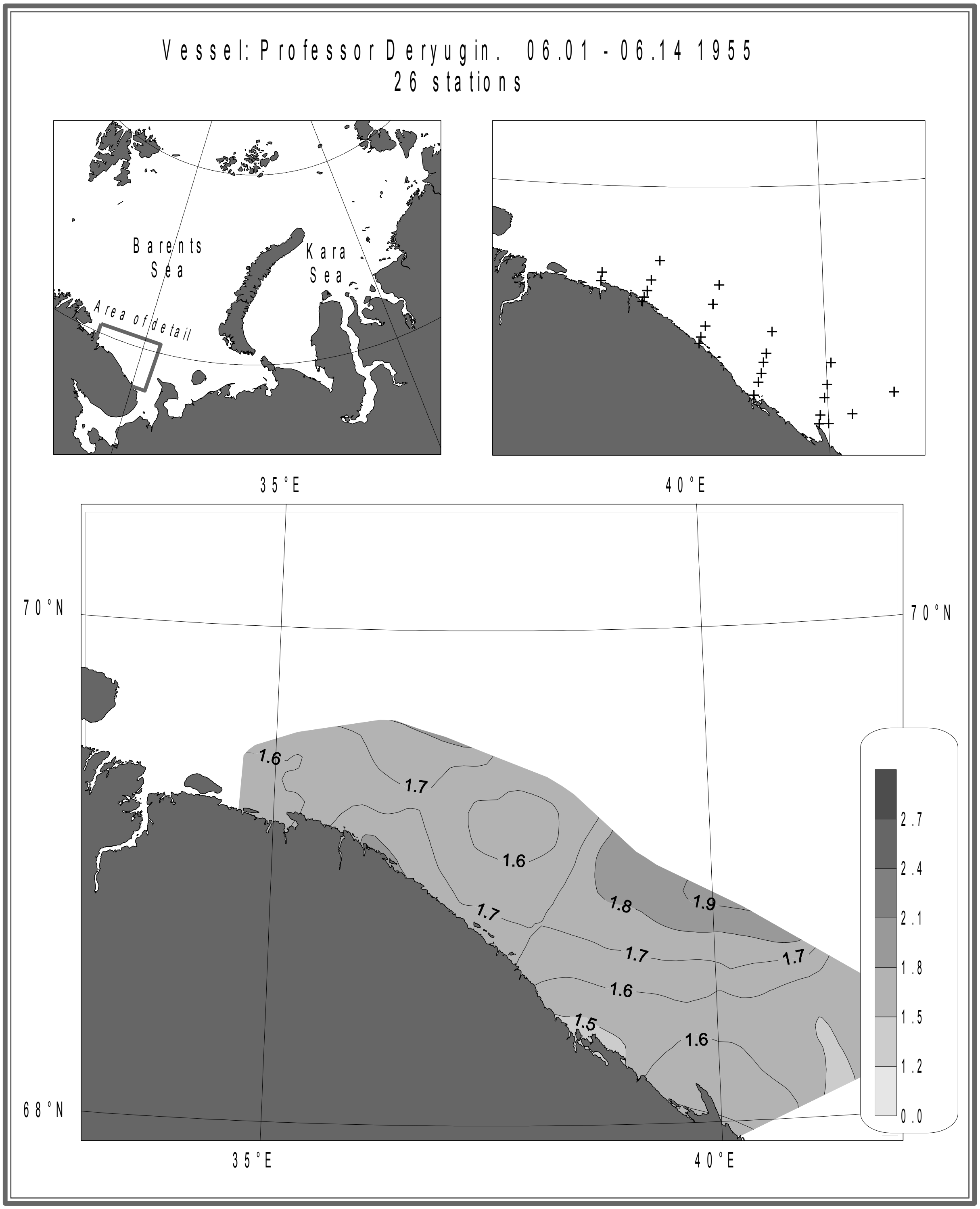


Fig. F2.20. Zooplankton. Surface-bottom. Biodiversity. June, 1955

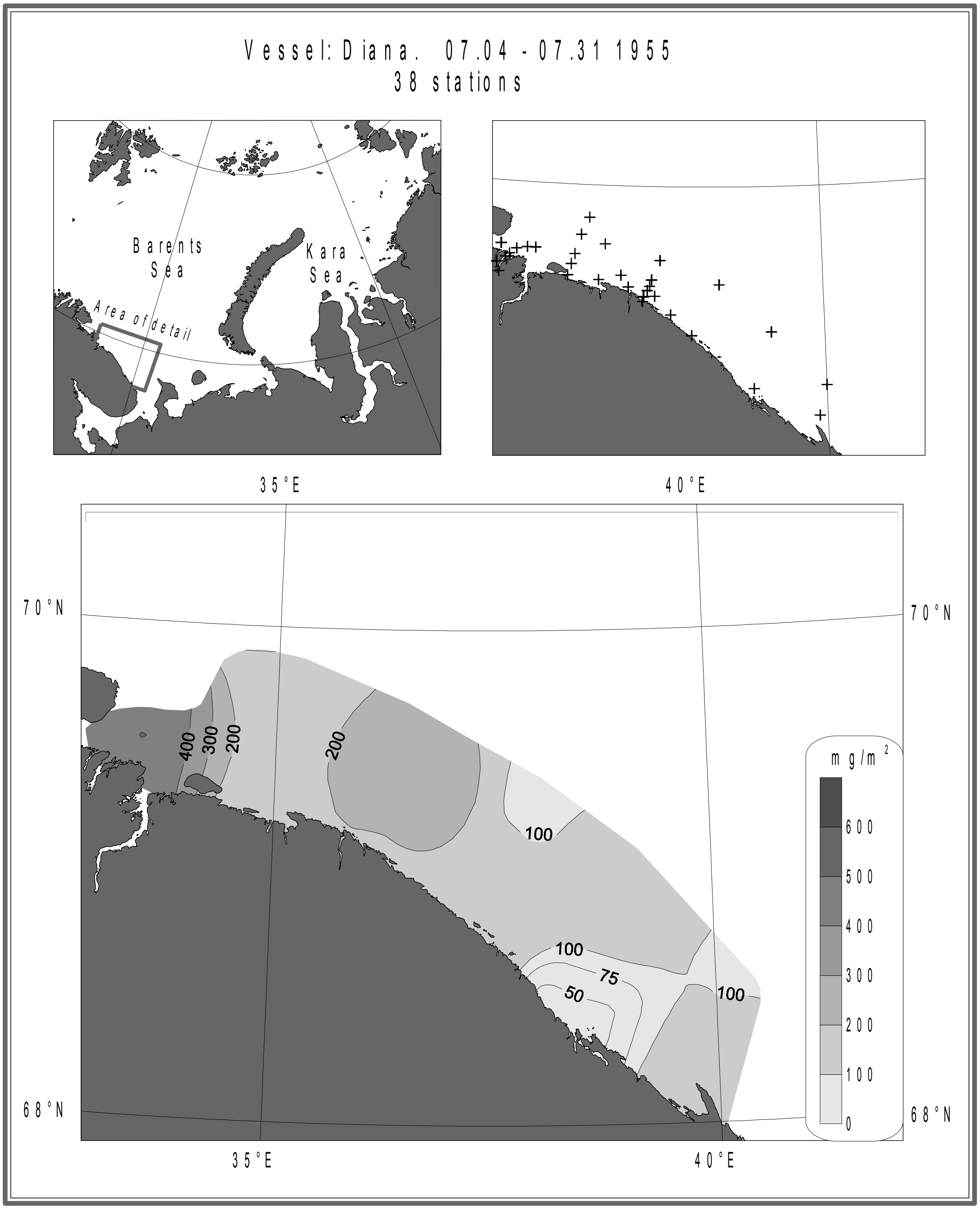


Fig. F2.21. Zooplankton. Surface-bottom. Biomass. July, 1955

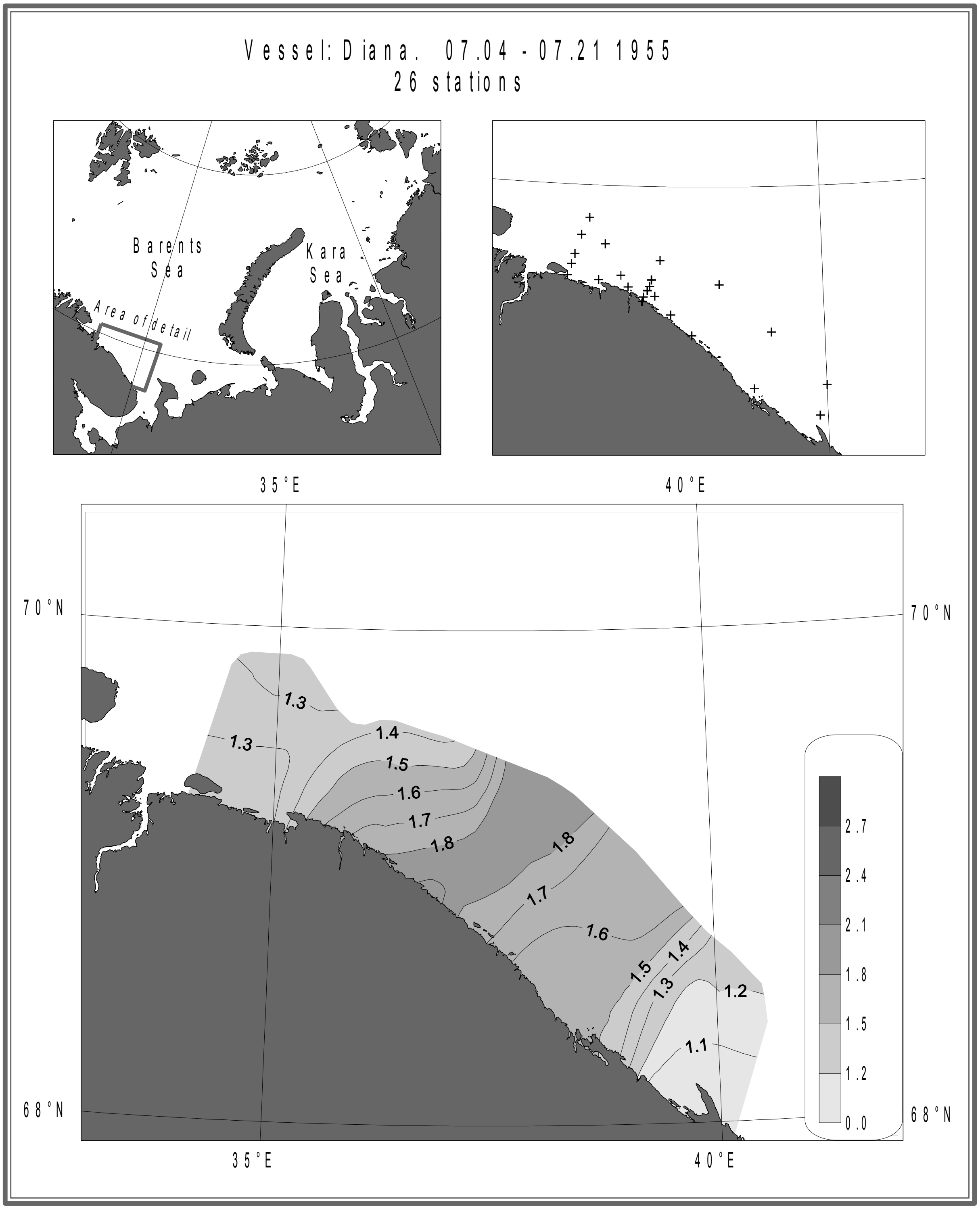


Fig. F2.22. Zooplankton. Surface-bottom. Biodiversity. July, 1955

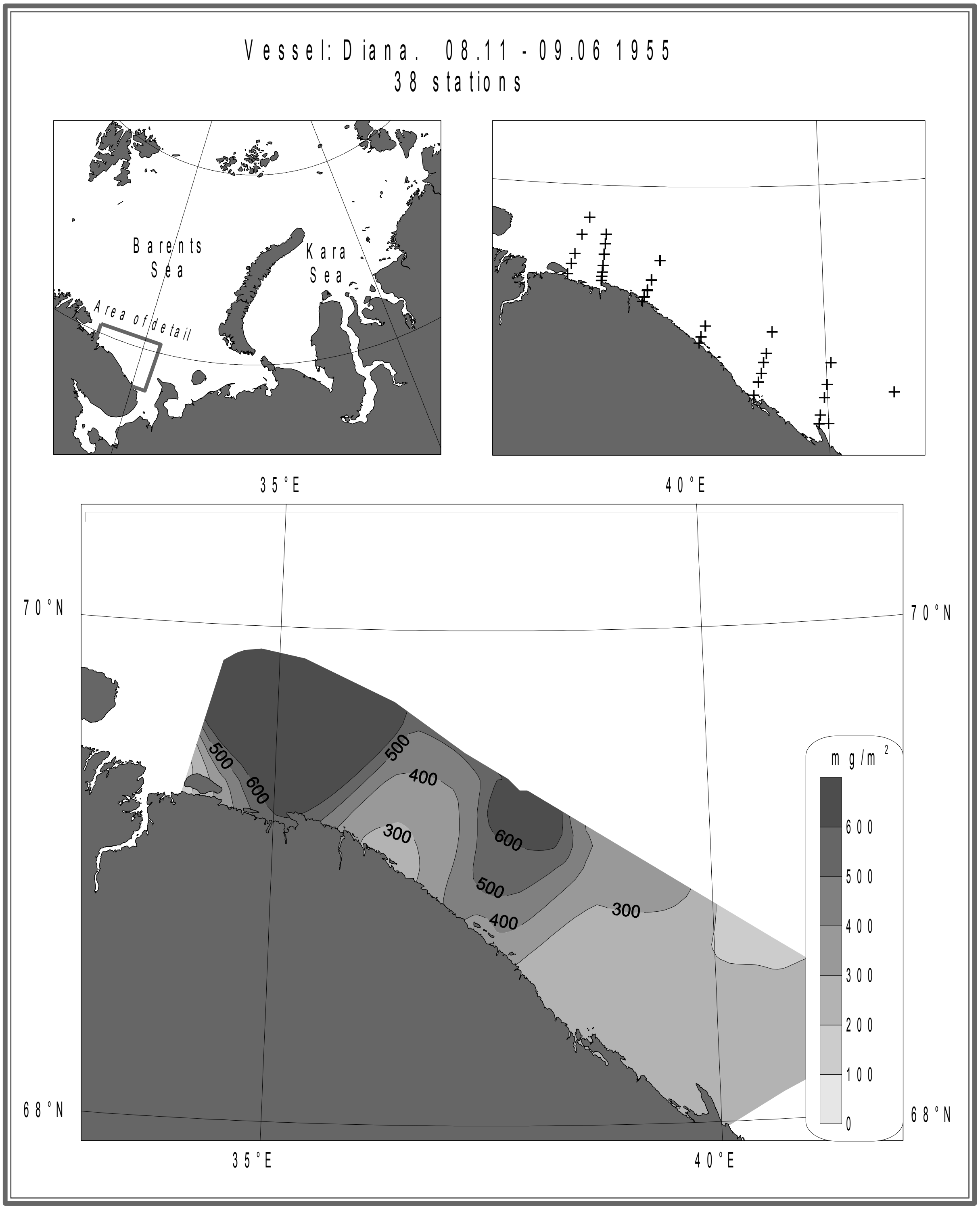


Fig. F2.23. Zooplankton. Surface-bottom. Biomass. August-September, 1955

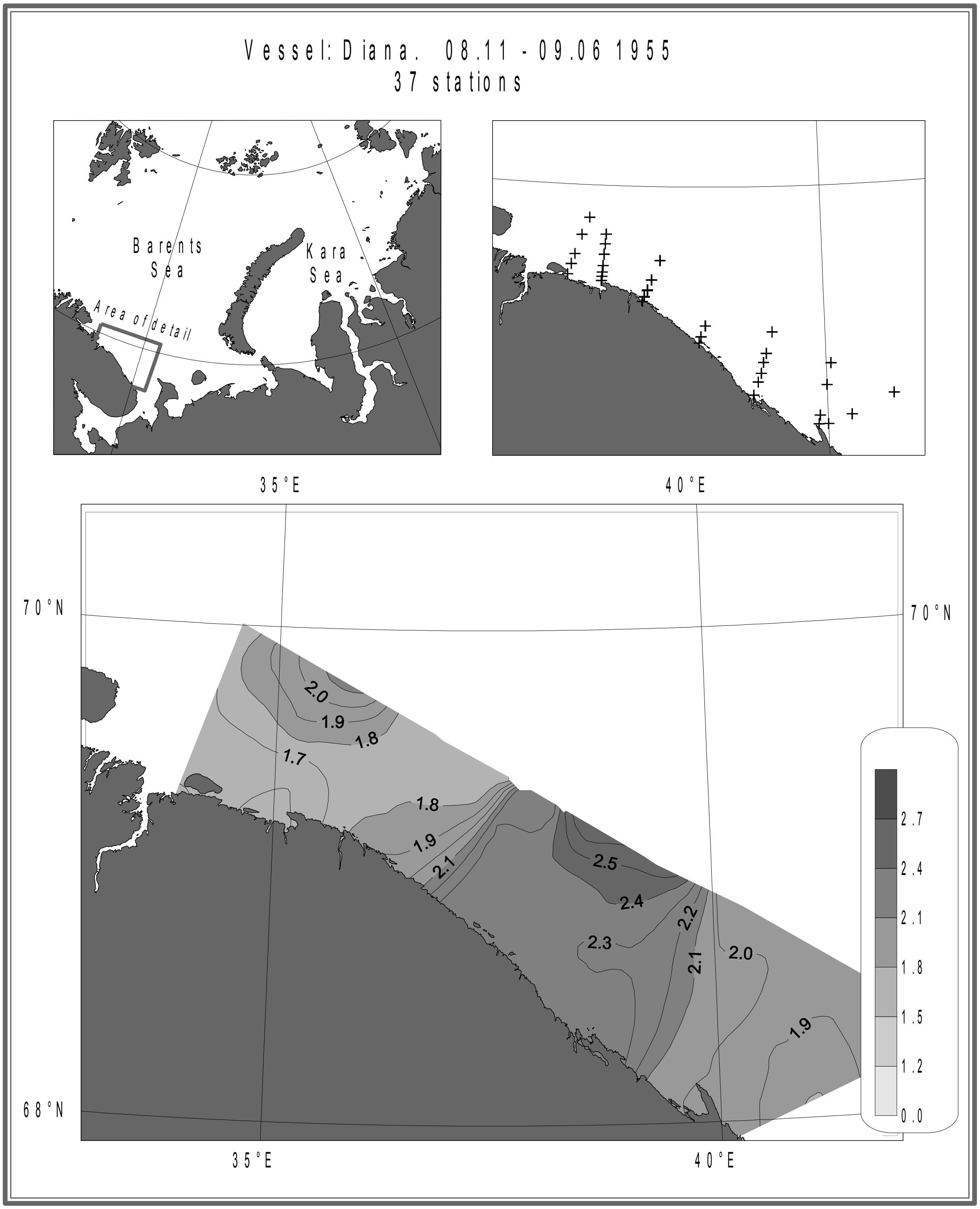


Fig. F2.24. Zooplankton. Surface-bottom. Biodiversity. August-September, 1955

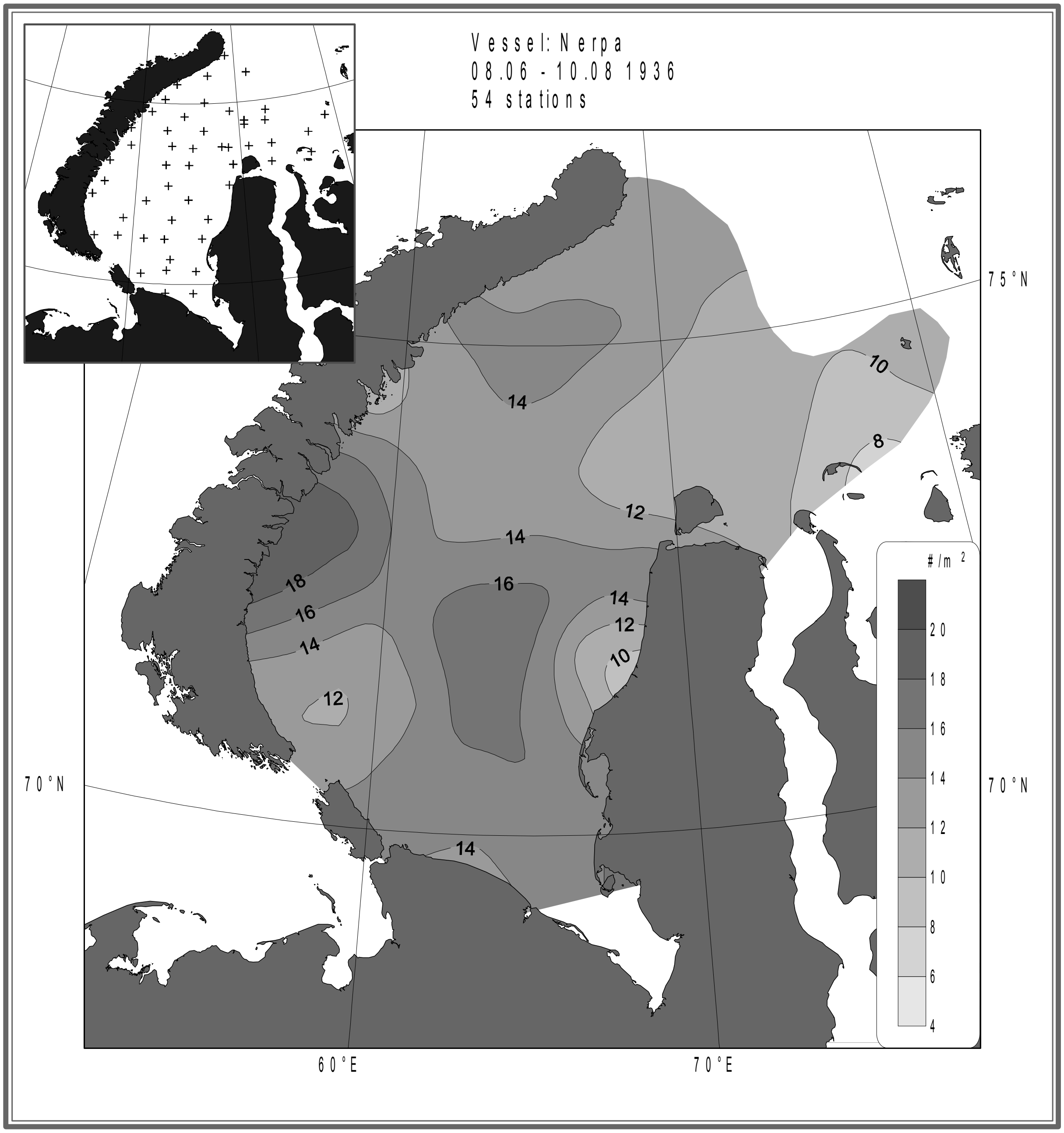


Fig. F3.1. Zooplankton. Surface-bottom. Number of species. August-October, 1936

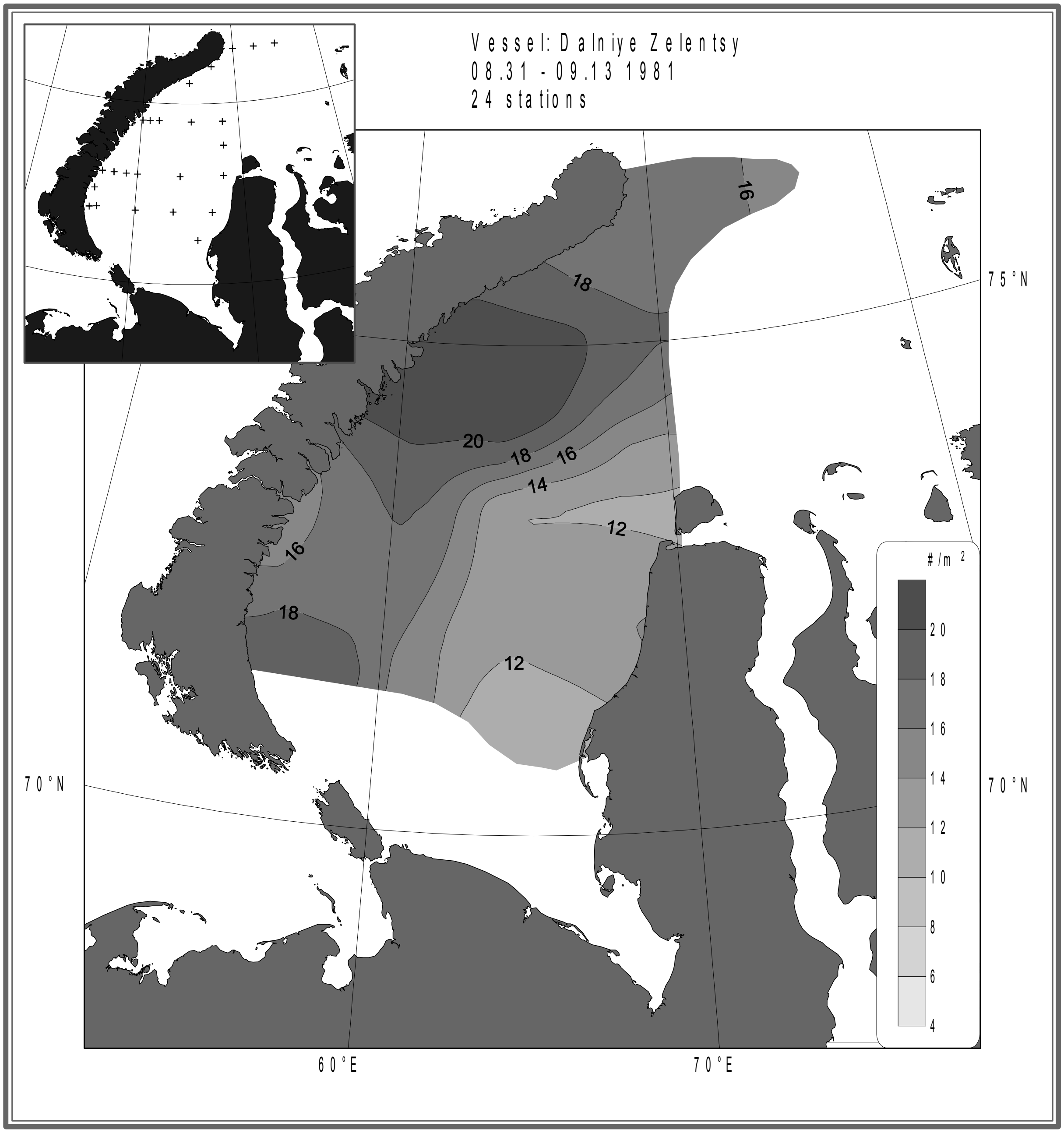


Fig. F3.2. Zooplankton. Surface-bottom. Number of species. August-September, 1981

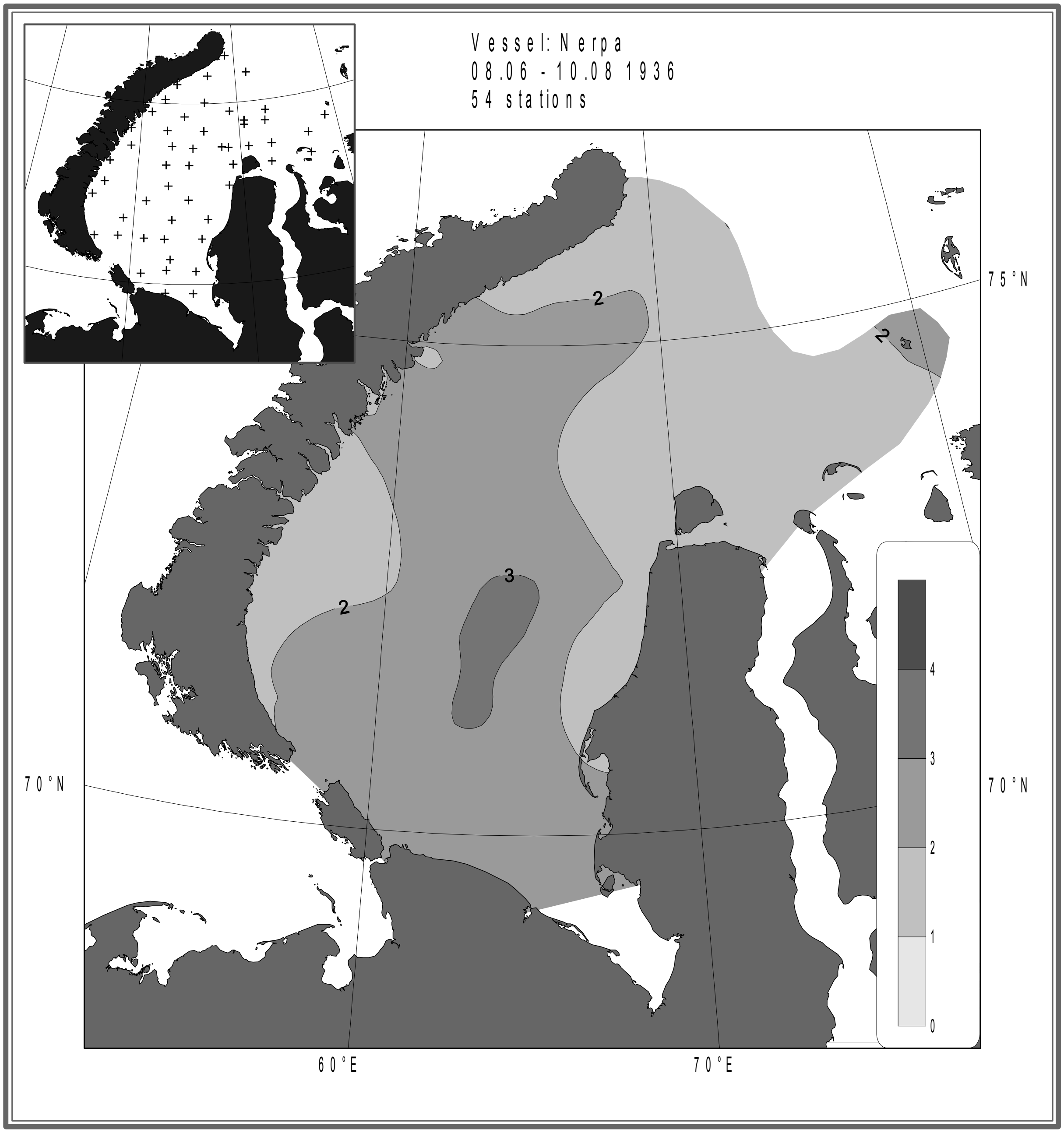


Fig. F3.3. Zooplankton. Surface-bottom. Relative abundance. August-October, 1936
(1–rare; 2–common; 3–abundant; 4–very abundant)

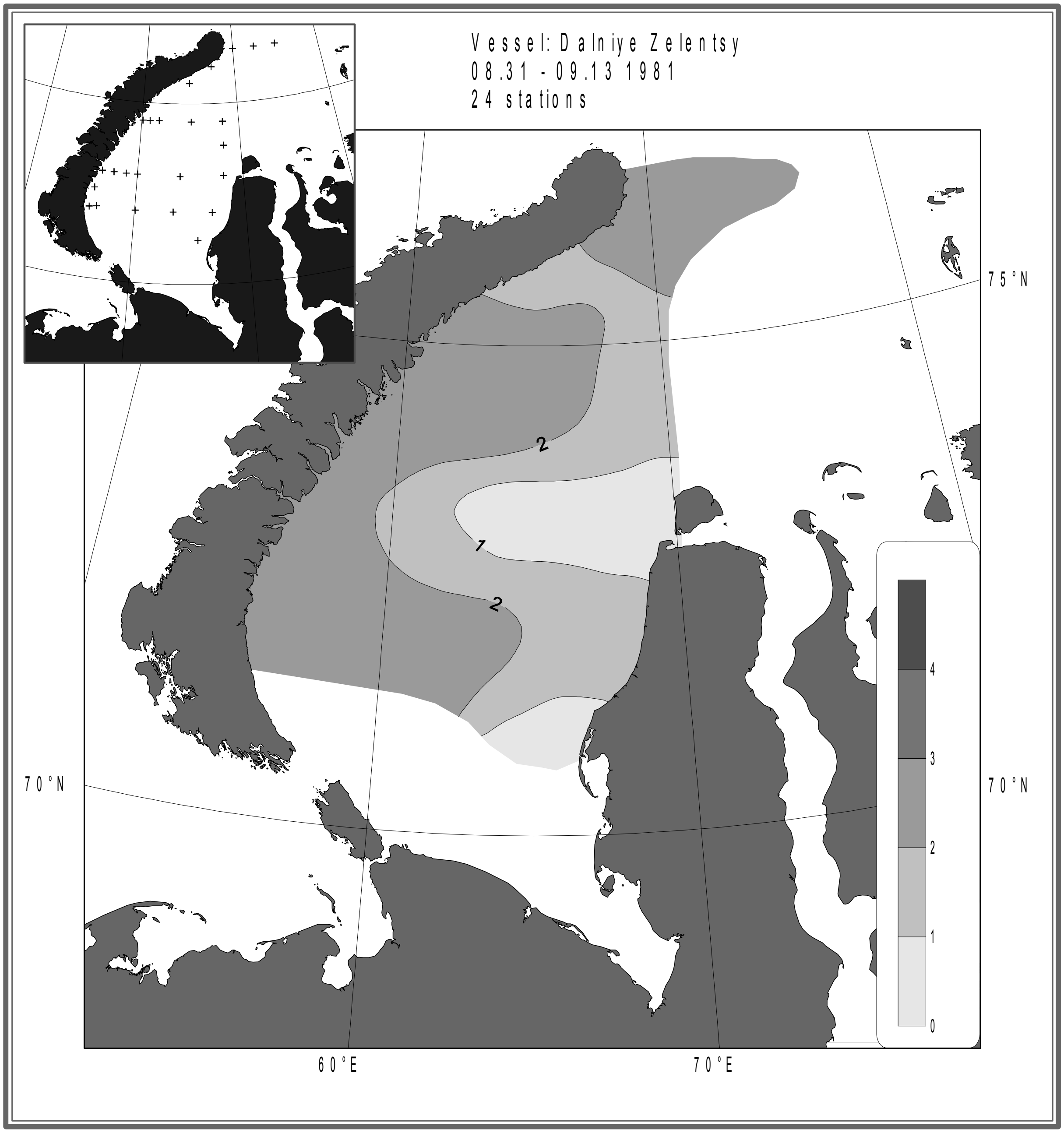


Fig. F3.4. Zooplankton. Surface-bottom. Relative abundance. August-September, 1981
(1–rare; 2–common; 3–abundant; 4–very abundant)

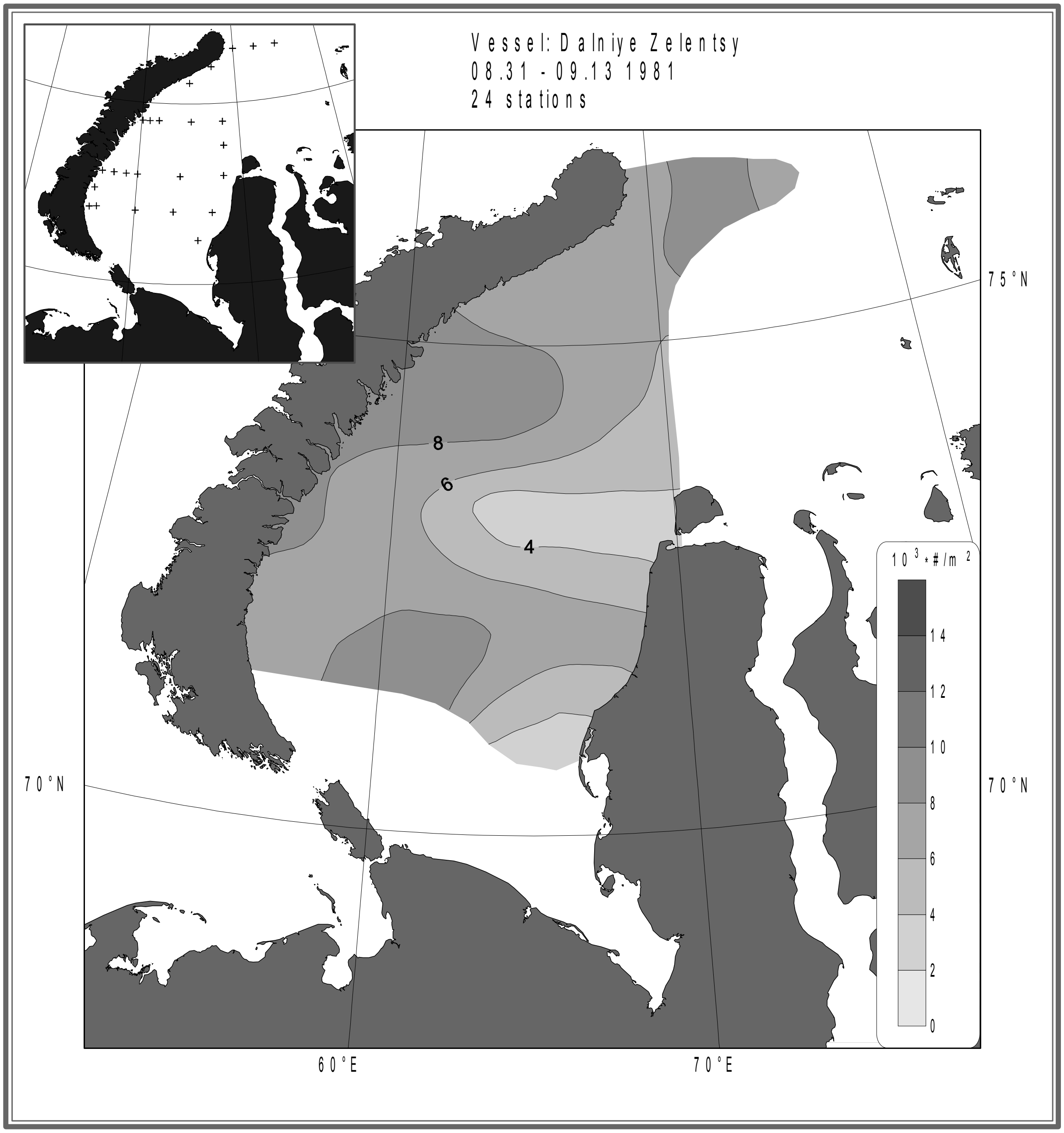


Fig. F3.5. Zooplankton. Surface-bottom. Abundance. August-September, 1981

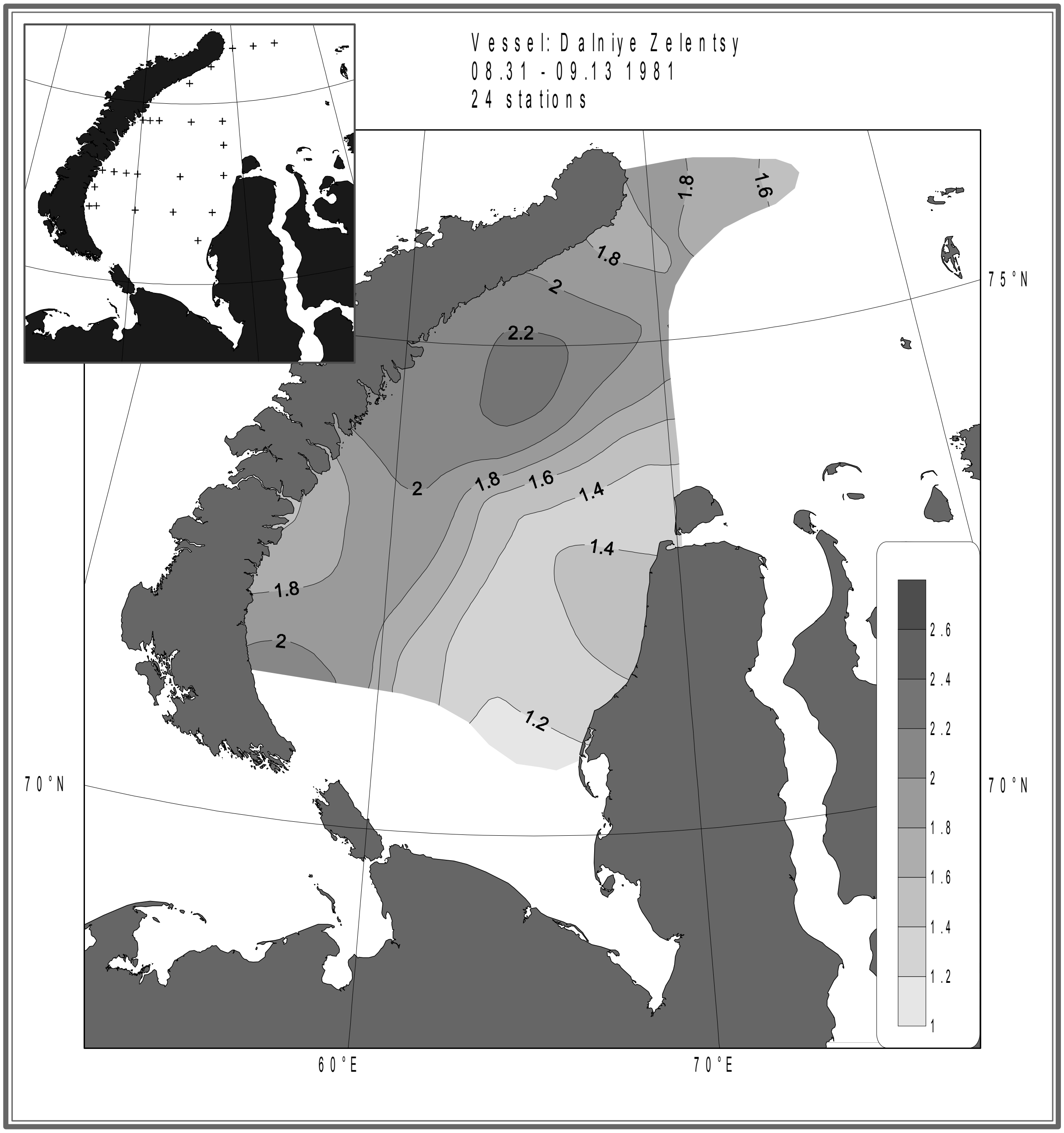


Fig. F3.6. Zooplankton. Surface-bottom. Biodiversity. August-September, 1981

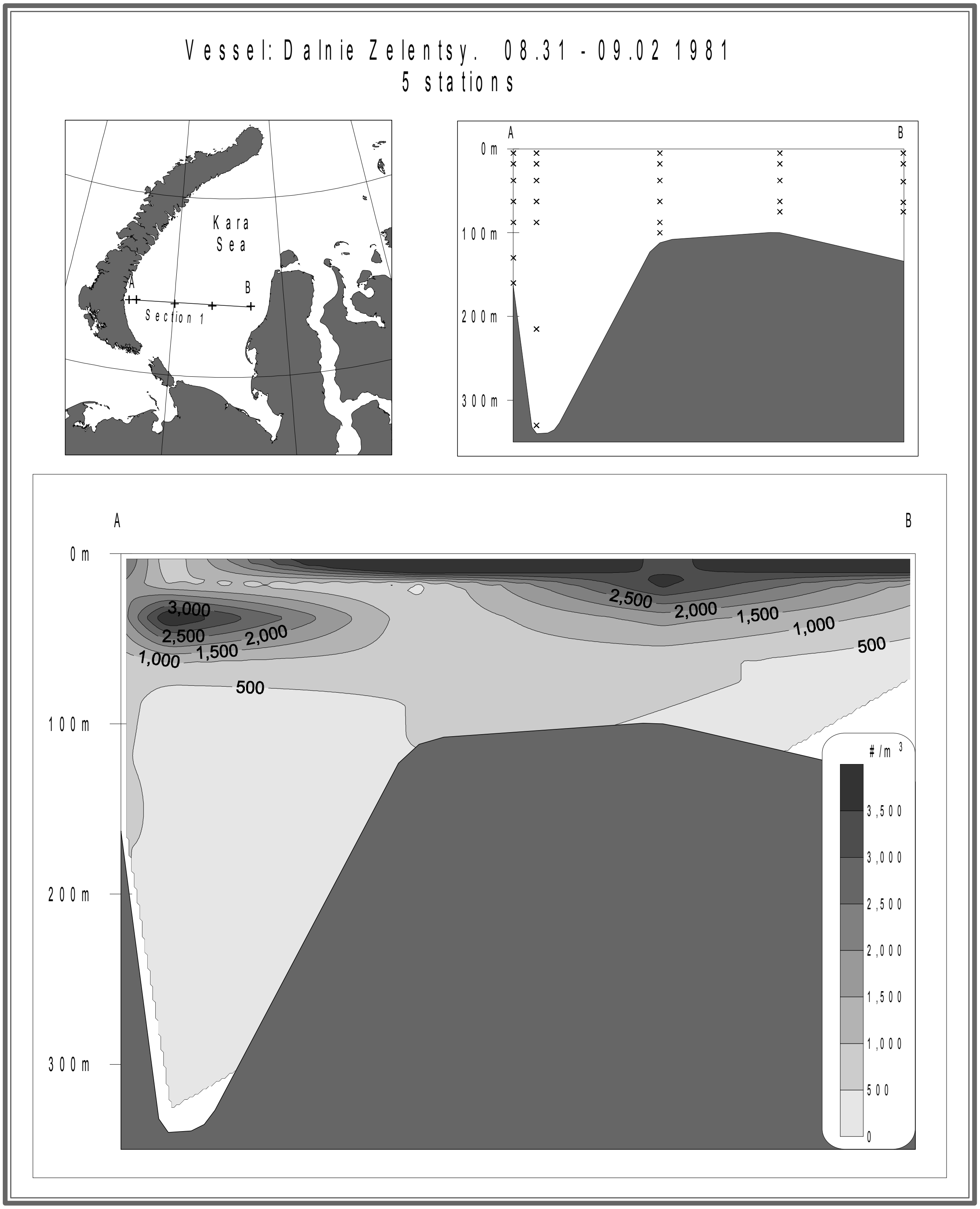


Fig. F3.7. Zooplankton. Section 1. Abundance. August-September, 1981

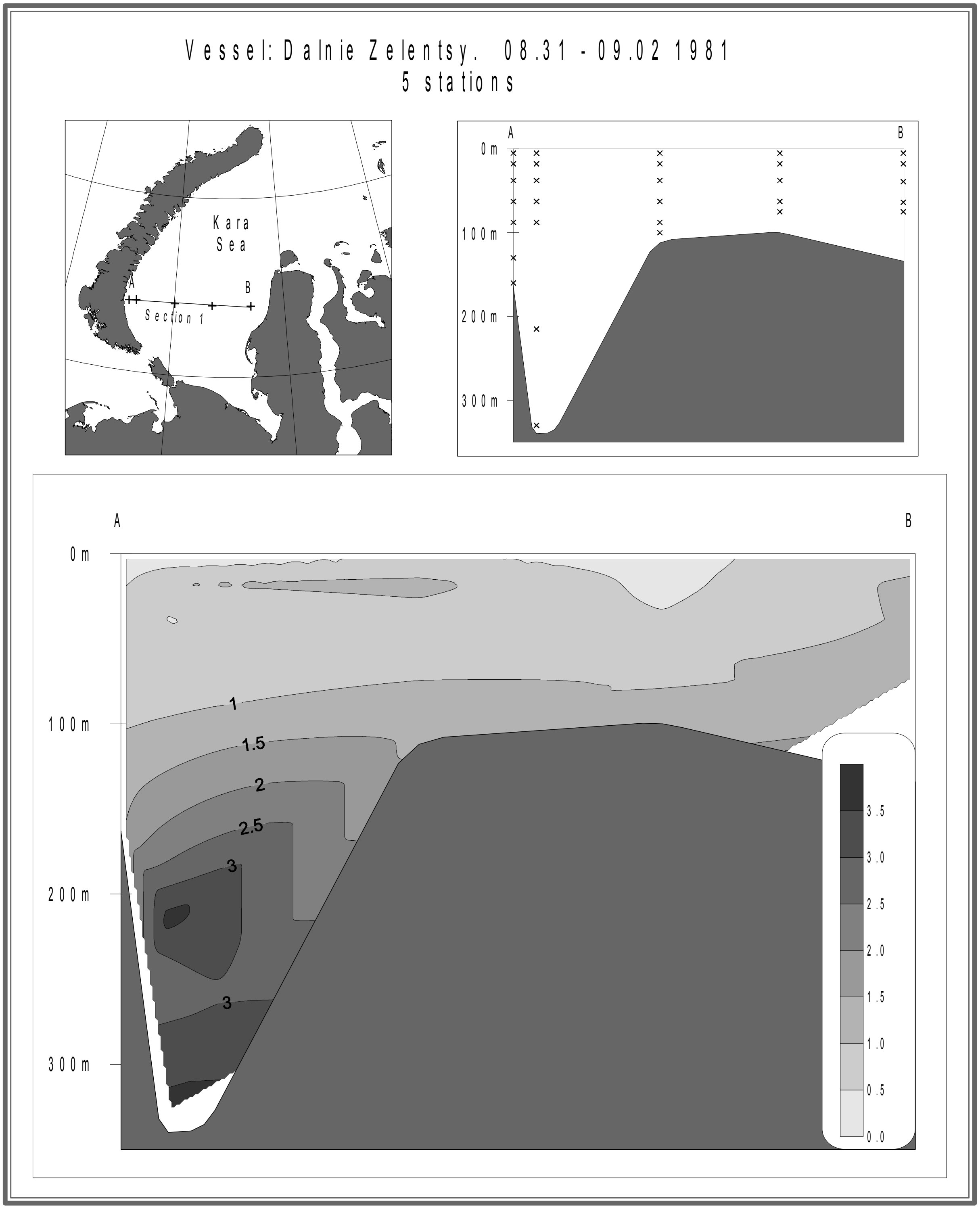


Fig. F3.8. Zooplankton. Section 1. Biodiversity. August-September, 1981

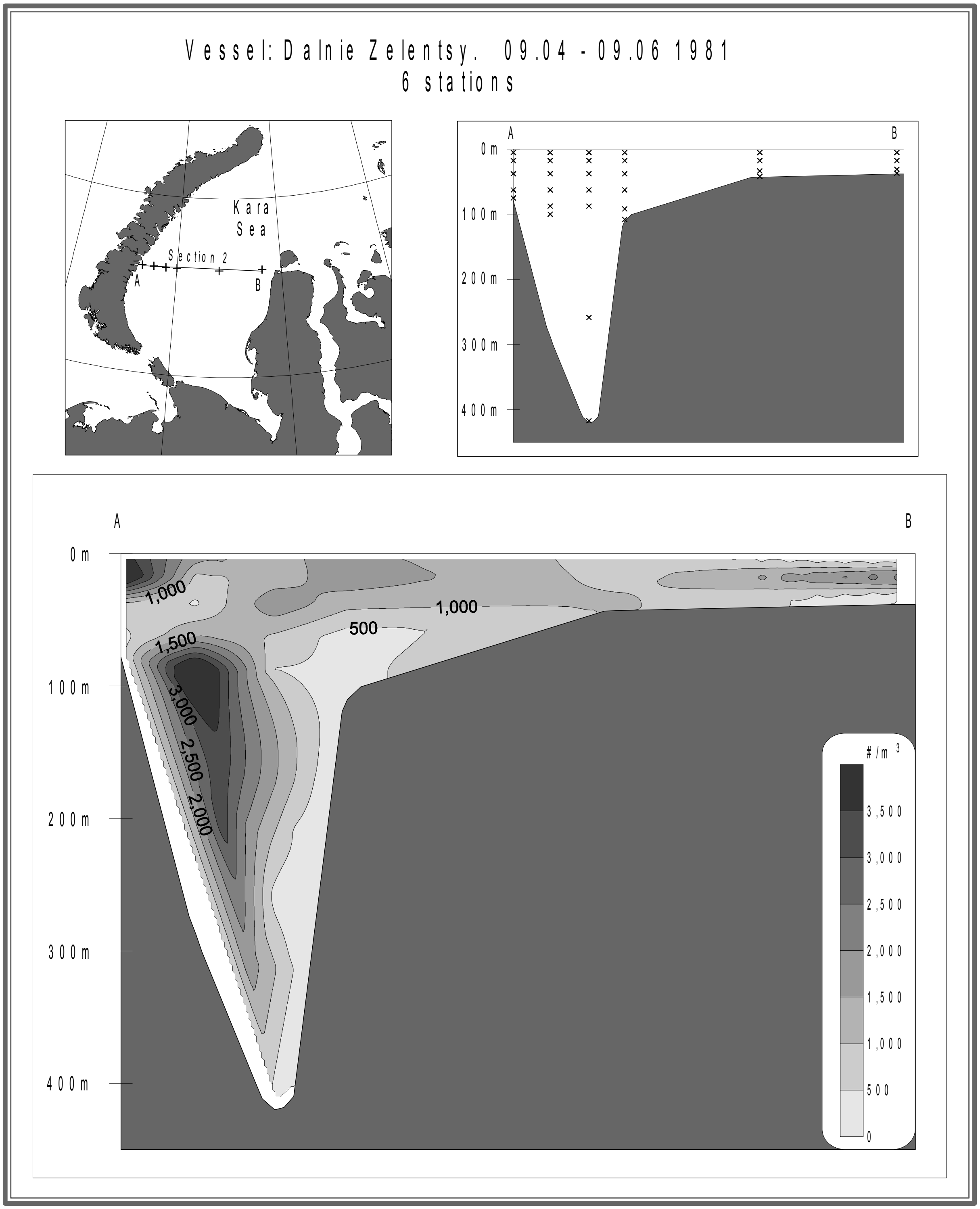


Fig. F3.9. Zooplankton. Section 2. Abundance. September, 1981

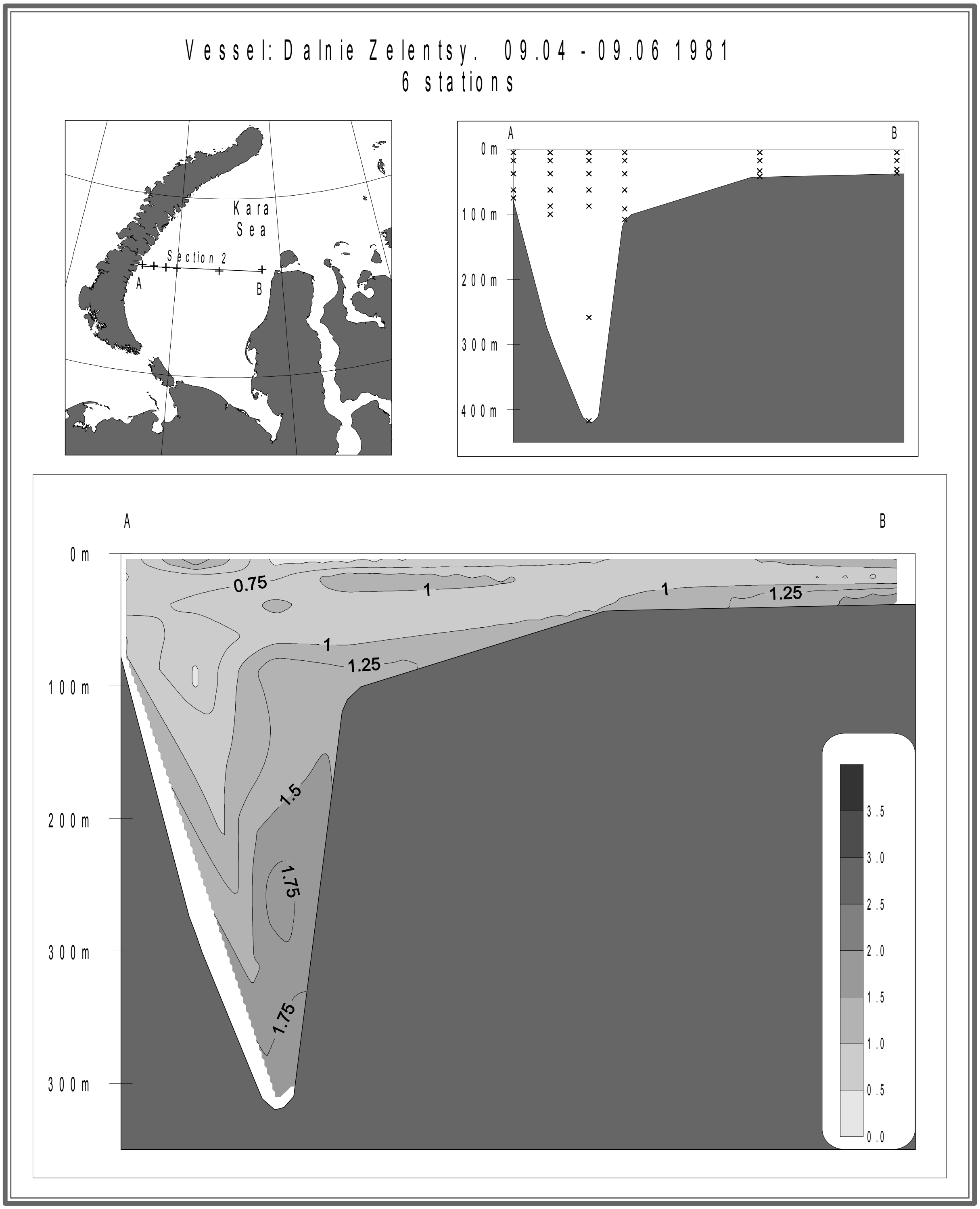


Fig. F3.10. Zooplankton. Section 2. Biodiversity. September, 1981

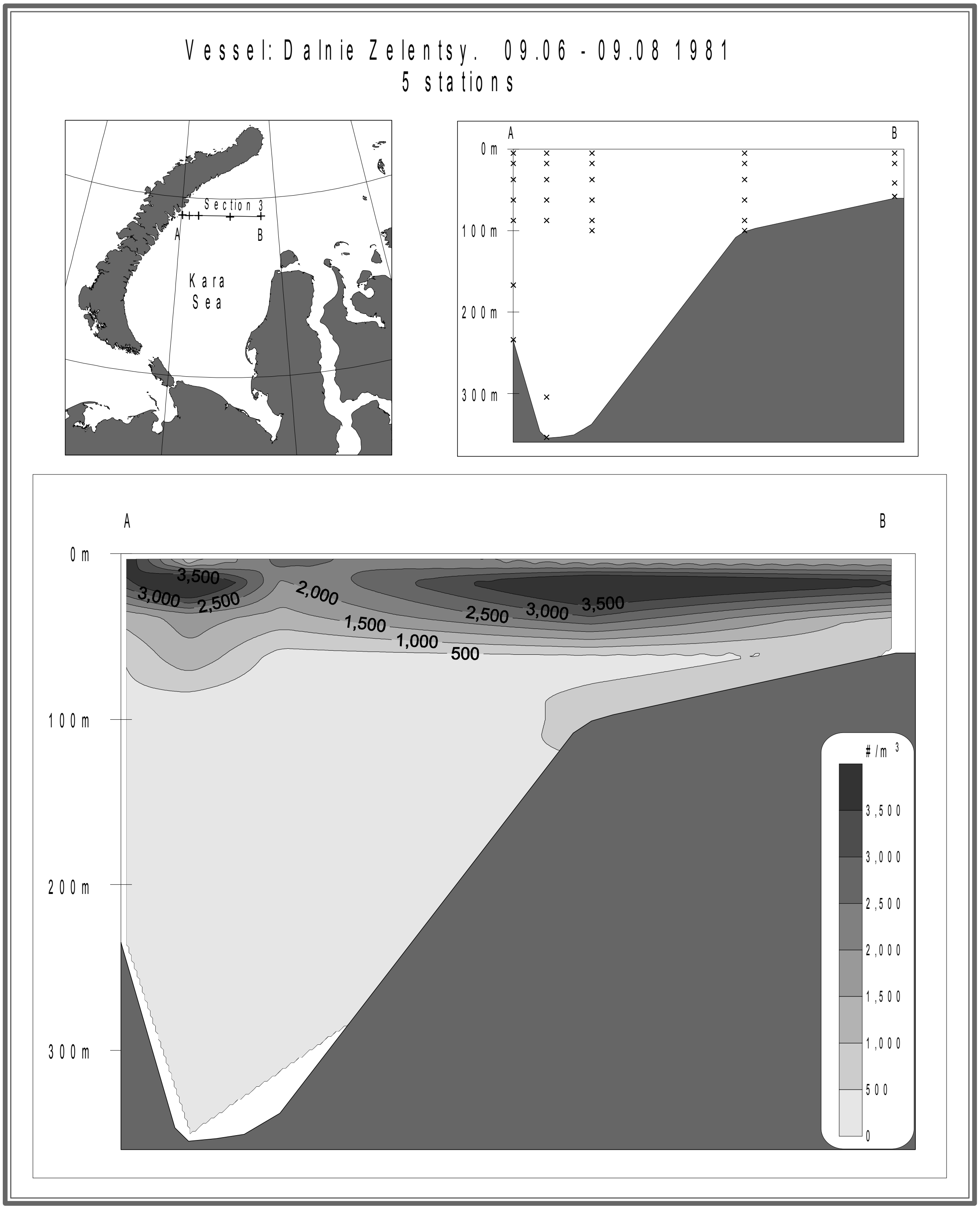


Fig. F3.11. Zooplankton. Section 3. Abundance. September, 1981

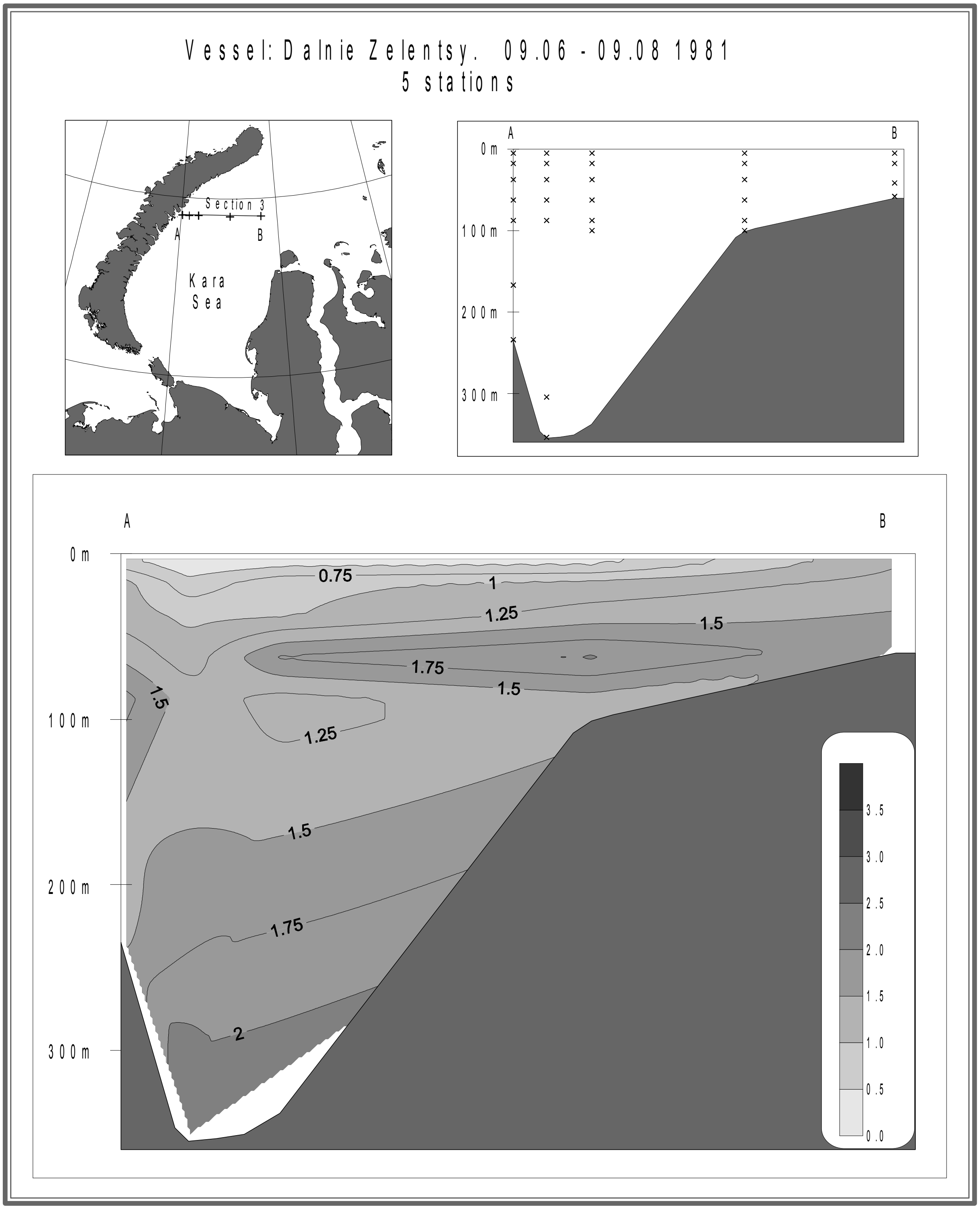
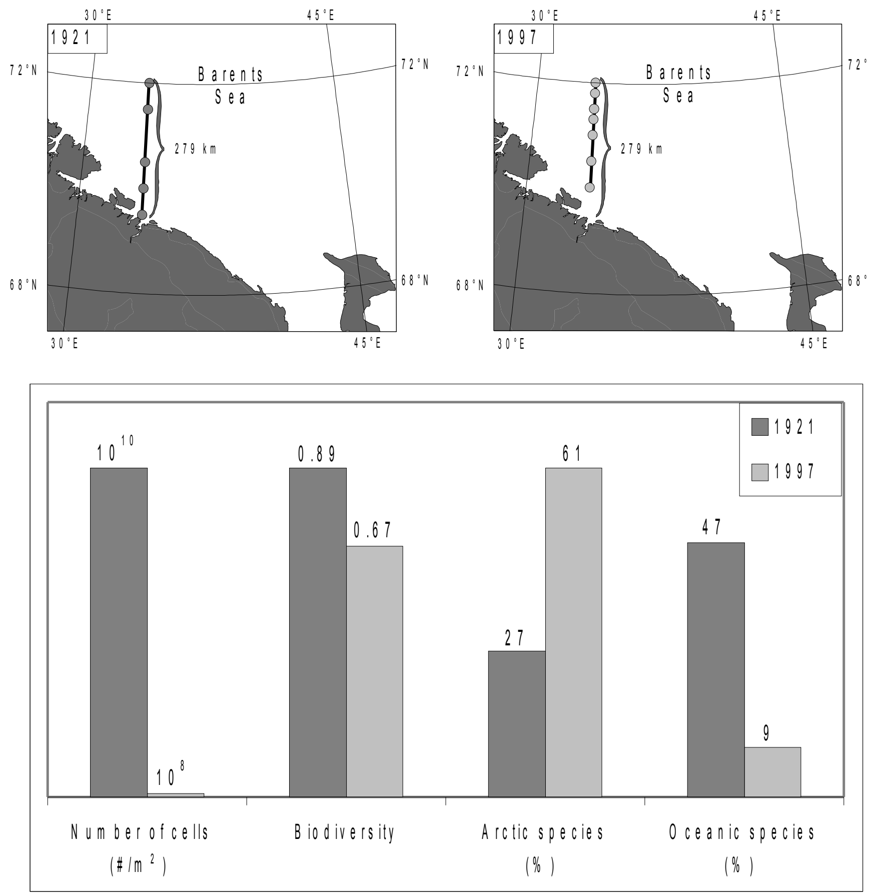


Fig. F3.12. Zooplankton. Section 3. Biodiversity. September, 1981

APPENDIX G. DOCUMENTATION OF CHANGES OF THE PLANKTON COMMUNITY



Data

Vessel	Date	Stations/samples
Sokolitsa	May, 1921	5/16
Dalnie Zelentsi	May, 1997	7/35

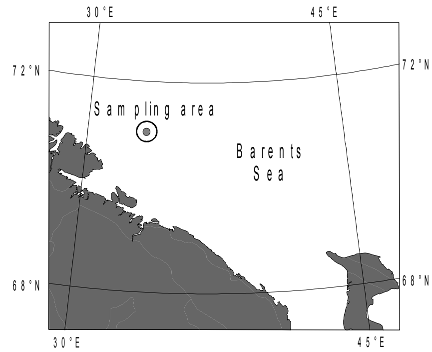
Characteristics

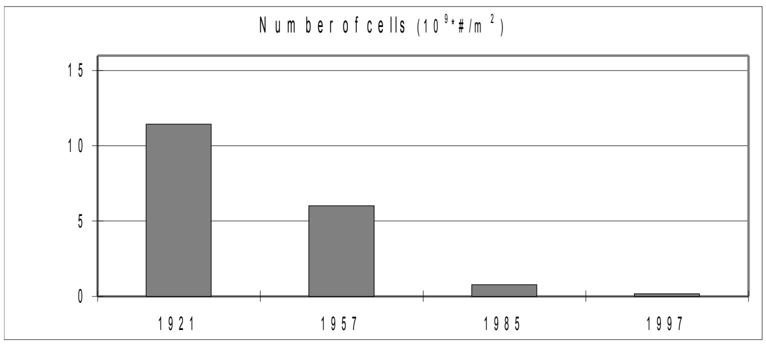
Phytoplankton abundance, biodiversity coefficient (the Glisson coefficient), percent of Arctic and oceanic species.

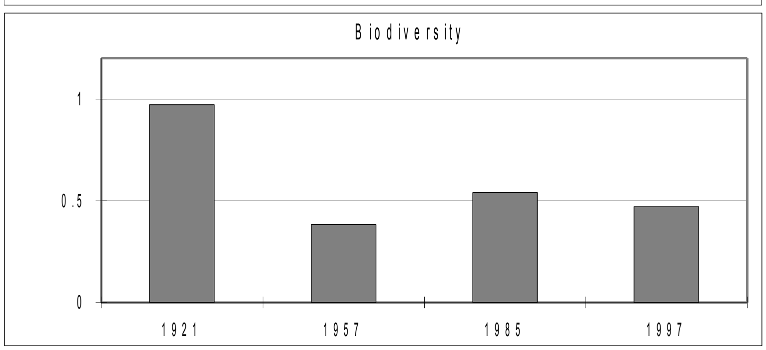
Conclusion

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

Fig. G1. Phytoplankton. Barents Sea. 69-72°N, 33°30' E. 1921 *vs*. 1997







Data

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

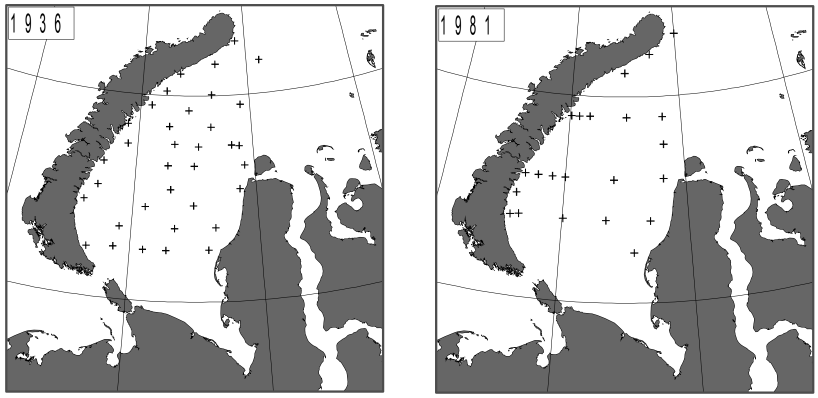
Characteristics

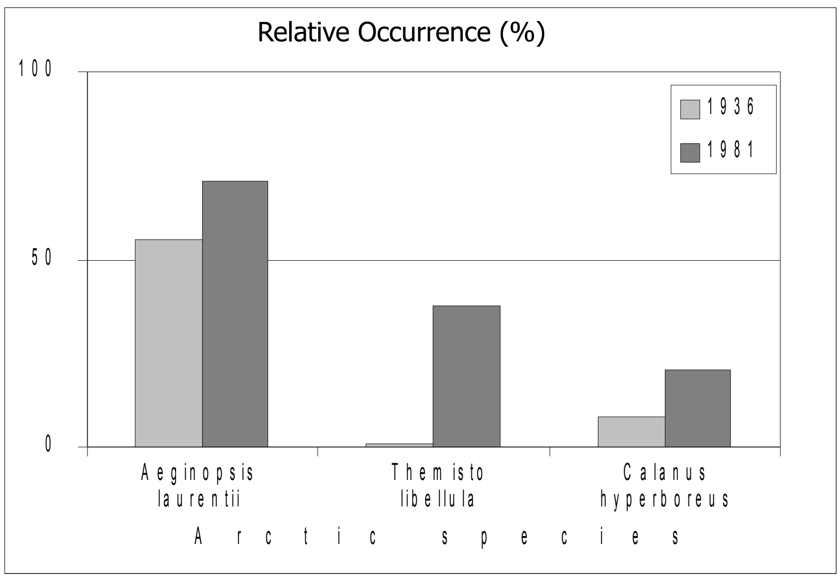
Summer average values of biodiversity and number of cells are calculated under m^2.

Conclusion

The conditions for phytoplankton growth in April-May of 1921 were more favorable than in the similar period of 1957, 1985, and 1997.

Fig. G2. Phytoplankton. Barents Sea. 71°N, 33°30'E. 1921-1957-1985-1997





Data

Vessel	Date	Stations/samples
Nerpa	August, 1936	38/143
Dalnie Zelentsi	August, 1981	24/109

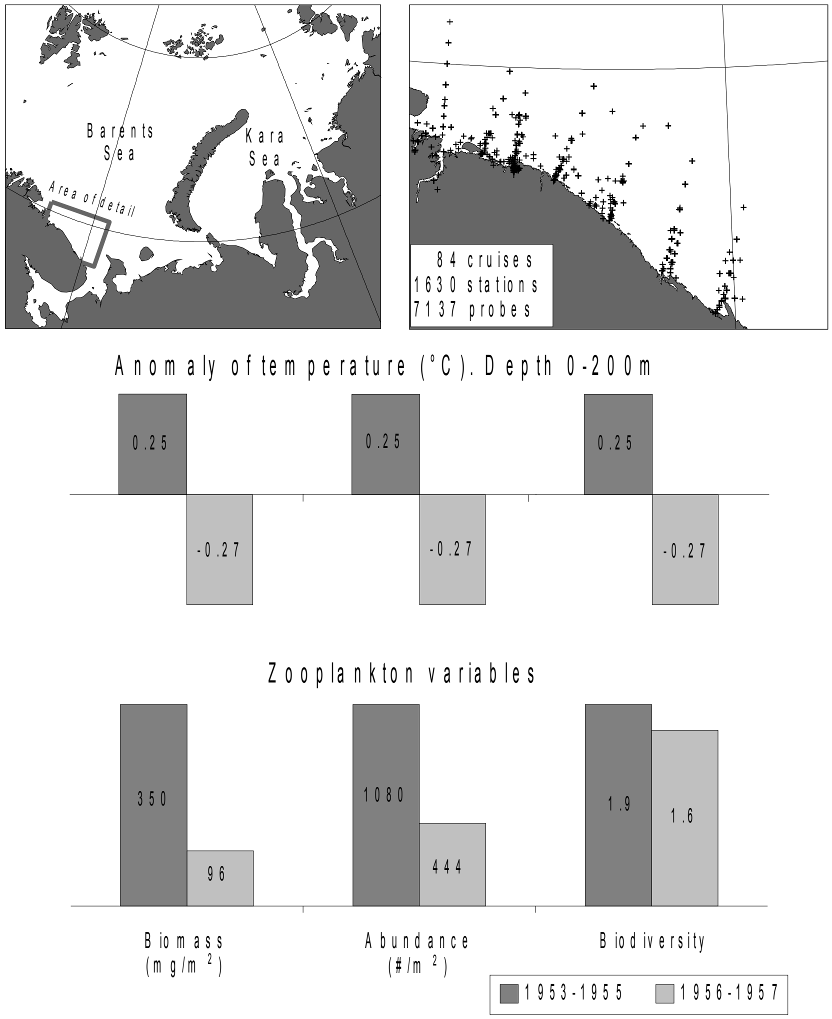
Characteristics

Relative occurrence (the number of species in percent from the total amount) of zooplankton species as indicator of the Arctic waters has been calculated.

Conclusion

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

Fig. G3. Zooplankton. Kara Sea. 1936 *vs*. 1981



Data

Zooplankton of 84 cruises carried out during the period 1953-1958. 1630 stations, 7137 samples.

Characteristics

Temperature anomaly, biomass, abundance, biodiversity coefficient.

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 reasons for this phenomenon comes from the observed positive temperature anomalies in the period 1953-1955.

Fig. G4. Zooplankton. Barents Sea. 1953-1955 *vs*. 1956-1957

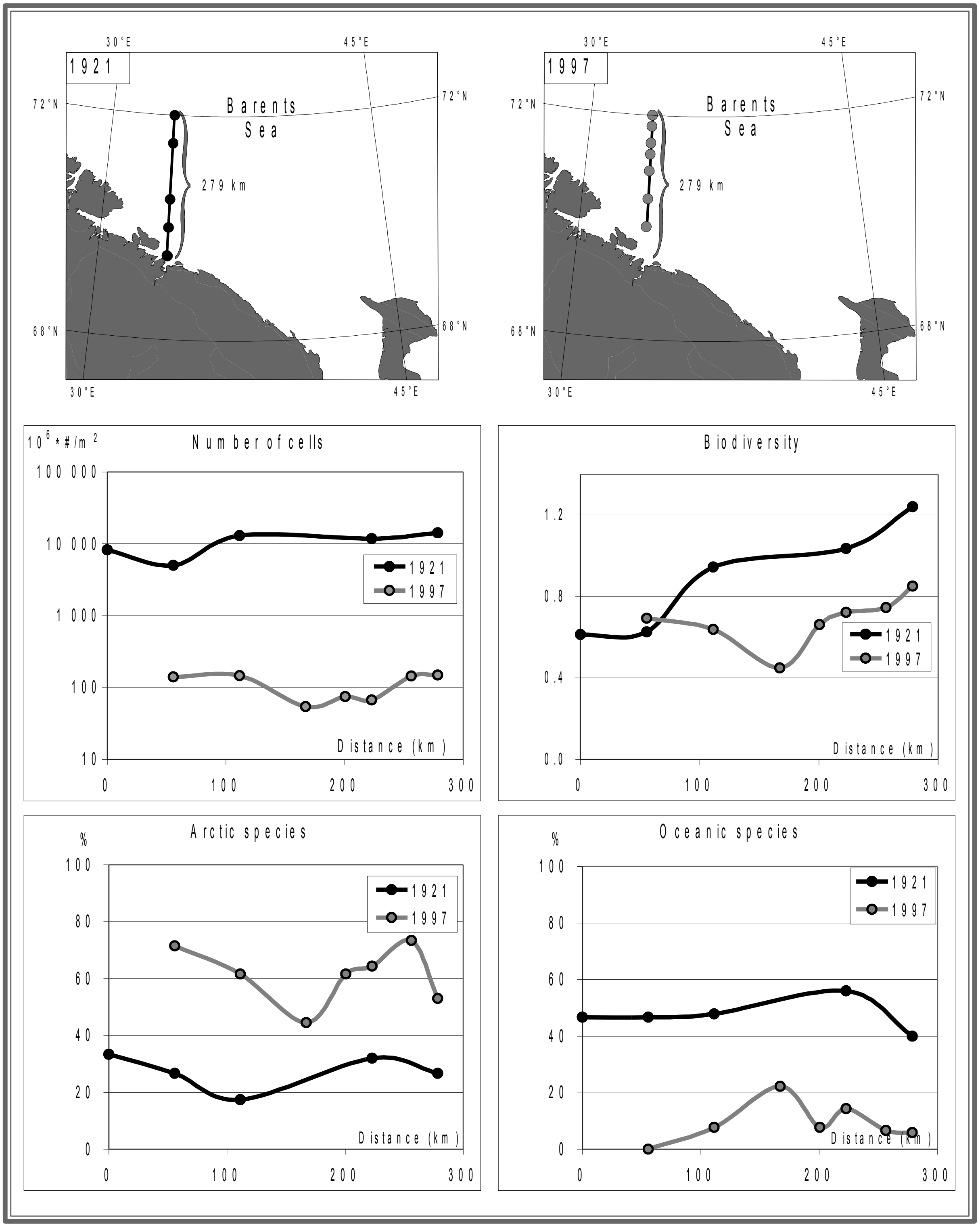


Fig. G5. Phytoplankton. Barents Sea. Kola Section. 1921 *vs*. 1997

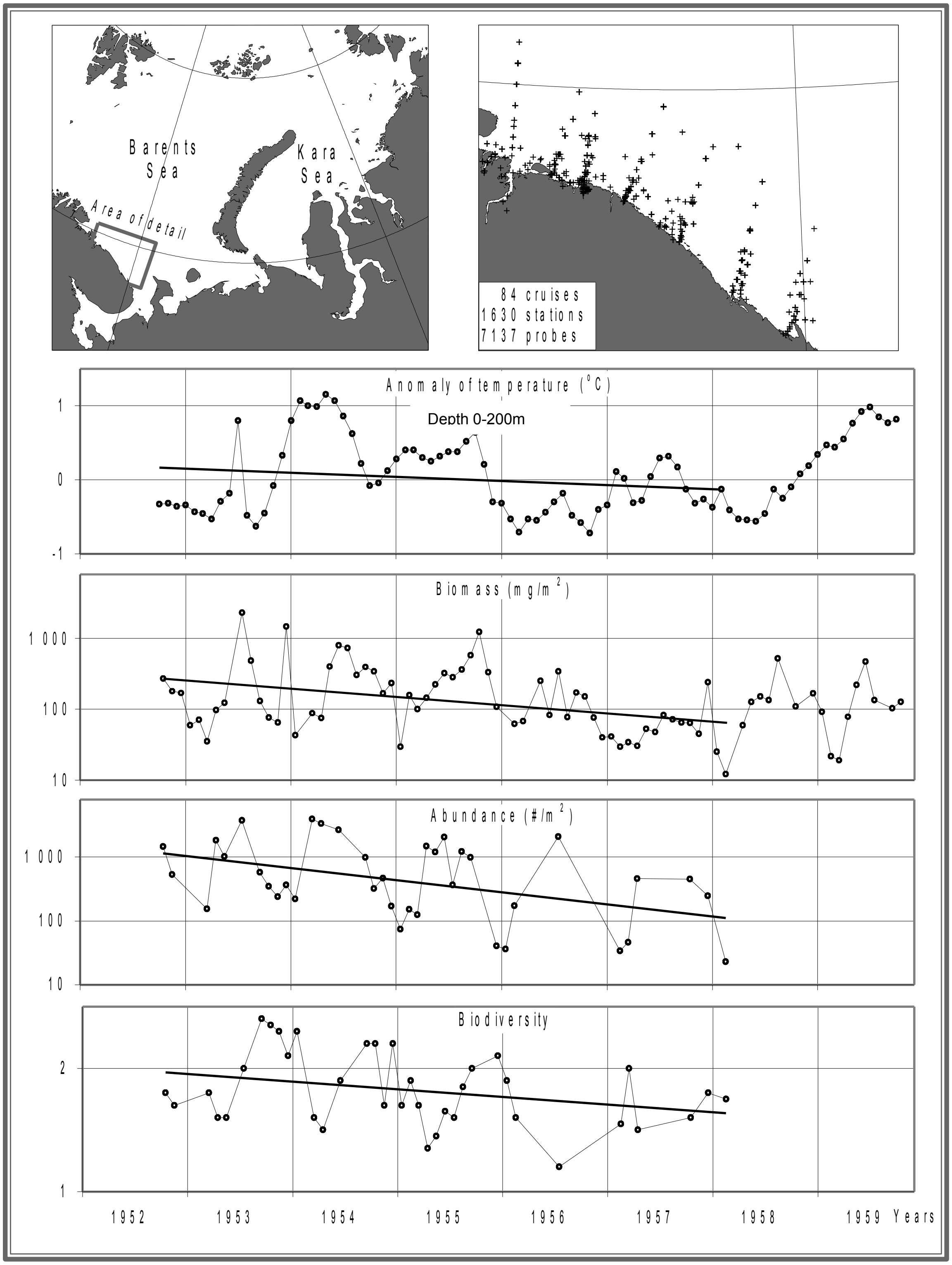


Fig. G6. Zooplankton. Barents Sea. Trends. 1952-1959