Preface

Natural and anthropogenic processes can cause temporal and spatial changes in ecological systems. Therefore, analyses of the structure and functioning of various ecosystems should be based on long-term, rather than single or even seasonal, observations. Conclusions are more accurate when based on long-term data series that allow us to differentiate background (or natural) variations in the dynamics of an ecosystem from an anthropogenic component. Such long-term studies have been carried out extensively in meteorology but not in biological oceanography.

A scientific team headed by Prof. V.V. Kuznetzov established a research biological station on the White Sea in 1957. Since that time, during the past 40 years and for every 10 days, scientists from the Zoological Institute, Russian Academy of Sciences (ZIN RAS), have collected samples at a fixed point using standard equipment and techniques. Using a research vessel in summer and from the ice cover in winter, they obtained samples of zooplankton and measured oceanographic variables at different depths. This work represents an excellent example of a long-term study of marine ecosystems. Unfortunately, this data has been accessible only to a limited number of scientists who could read Russian. Other scientists knew little about the results of these studies, which were published in Russian journals.

However, the publication of this book and the original data contained on the CD-ROM is now made publicly available to the broader scientific community. The effort to compile a digital database and process all the information has been accomplished in a joint collaborative effort between researchers of the Zoological Institute, Russian Academy of Sciences, and the U.S. National Oceanic and Atmospheric Administration (NOAA). We hope this example of fruitful collaboration of Russian and American scientists will serve to further development of international science.

Director of the Zoological Institute, Russian
Academy of Sciences

Academician A. F. Alimov

Vice-President of Russian Academy of
Sciences, Nobel Prize laureate

Academician G. I. Alferov.

Acknowledgement

This product is a result of dedicated individuals who carried out hydrological and zooplankton studies at the White Sea Biological Station since 1961. Several generations of zoologists and hydrologists took part in this effort including R.V. Prygunkova, who carried out zooplankton sampling and data analysis; R.V. Pyaskowsky, who carried out hydrological observations; planktologists R.V. Prygunkova, S.S. Burlakova, S.S. Ivanova, I.P. Kutcheva, N.V. Usov, and D.M. Martynova; hydrologists Yu.M. Savoskin, A.I. Babkov, V.Yu. Buryakov, M.E. Sorokin; and I.M. Primakov, who continued this study. V.Yu. Buryakov was the first to create a digital database and use computers for data analysis. We are indebted to all of these scientists for their diligent efforts.

We also express our gratitude to the crews and captains of the research vessels: "Professor Mesyatsev," "Onega," "Ladoga," "Kartesh," "Professor Vladimir Kuznetsov," and "Belomor," all of which belong to the Zoological Institute, Russian Academy of Sciences. We are also grateful to the personnel of the White Sea Biological Station, in particular, K.V. Sunnari and P.I. Velichko for their assistance during summer and winter sampling periods.

Special thanks are due the staff of the NOAA central library and the Zoological Institute Library; the staff of the NOAA/NODC/Ocean Climate Laboratory; M. Chepurin for preparing the interface in a Visual Basic environment for the CD-ROM; I. Minin for preparing the Internet version; O. Baranova for web design and V. Yanuta, who provided the English translation.

Abstract

The present study is based on marine physical and biological observations since 1961. The data on zooplankton has been collected since 1963 in the vicinity of the White Sea Biological Station of the Zoological Institute, RAS, (Chupa Inlet of Kandalaksha Bay, Cape Kartesh). Temperature and salinity measurements have been carried out since 1961. The study describes the seasonal and long-term dynamics of oceanographic parameters and plankton abundance, giving special consideration to long-term trends. The effects on plankton due to extreme oceanographic conditions are estimated, and the anomalies of plankton seasonal dynamics during cold and warm, high- and low-salinity years are shown. The influence of long-term salinity and temperature variations on the plankton community is examined. The temperature optima of dominant plankton species are determined according to the long-term dynamics of their abundance.

1. Introduction

The hydrobiological data on the world ocean collected up to the present, along with new technological advances for data analysis and storage, has provided the basis for solving a wide variety of problems in studying the ocean climate and its bioresources. The raw data collected by scientists at the White Sea Biological Station since 1961 had been archived but not in an electronic format. The implication was that, in the future, existing data would be inaccessible to the international scientific community or even to the scientists of the Zoological Institute. Hence, it was necessary to digitize all the available information. Once this task was completed, the data was integrated into the World Ocean Database, which will greatly enhance further study of the White Sea as well as its interaction with the entire Arctic basin.

This document presents an analysis of zooplankton data from the White Sea Biological Station for the period 1963-1998. In addition, temperature and salinity observations at different depths for the period 1961-1999 are presented. The objectives of this effort are:

- to compile a database from the observations of temperature, salinity, and zooplankton at a fixed point of the White Sea, which were obtained since 1961;
- to quantitatively describe the environmental effects on zooplankton development.

In Chapters 2 and 3, a brief description of the atmospheric and marine geochemical characteristics of the White Sea is provided as well as information about the history of the White Sea Biological Station, respectively. Chapter 4 describes the data used for this study and includes an inventory of temperature, salinity, and zooplankton stations as well as a list of taxa. The methodology and results are presented in Chapter 5. In Chapter 6, a description of the contents of the CD-ROM is provided, followed by concluding remarks and a list of references in Chapters 7 and 8, respectively.

The raw data used in the present study are being disseminated internationally without restriction via CD-ROM and the Internet in conjunction with the principles of the World Data Center system of the International Council of Scientific Unions (ICSU) and the UNESCO Intergovernmental Oceanographic Commission (IOC).

2. Atmospheric and Marine Geochemical Characteristics of the White Sea

In-depth descriptions of the atmospheric and marine geochemical characteristics of the White Sea can be found in the work by Berger et al. (2001). The following information is only a brief introduction.

The White Sea is an almost landlocked extension of the Arctic Ocean indenting the shores of northwestern European Russia. The northern boundary of the sea runs along a line joining Cape Svyatoy Nos and Cape Kanin Nos (Figure 1). The area of the White Sea is 89,600 km^2; the volume is 5,400 km^3; the average depth is 60 m; and the maximum depth is 343 m (Babkov, Golikov, 1984).

The White Sea is traditionally divided into seven parts, as shown in Figure 1. The northern part of the White Sea, the Voronka, provides an opening to the Barents Sea and forms an external part of the White Sea. Within the Voronka is the Mezen Bay. Three other bays represent the interior part of the White Sea: Kandalaksha Bay, Onega Bay, and Dvina Bay. Into these bays empty the Mezen, the Northern Dvina, and the Onega Rivers. The White Sea is connected to the more northerly Barents Sea by a long, narrow, and shallow strait named Gorlo (throat). The Basin is where most of the deep water is found. The coastline is heterogeneous and complex. The shores of Kandalaksha Bay are heavily dissected with numerous inlets and fjords. Most islands of the White Sea are located in Kandalaksha Bay and Onega Bay. The western coast is hilly while the eastern coast is primarily lowland. The western shores of the Sea are formed by exposed ledge rock, while clayish and sandy beaches predominate on the eastern coast.

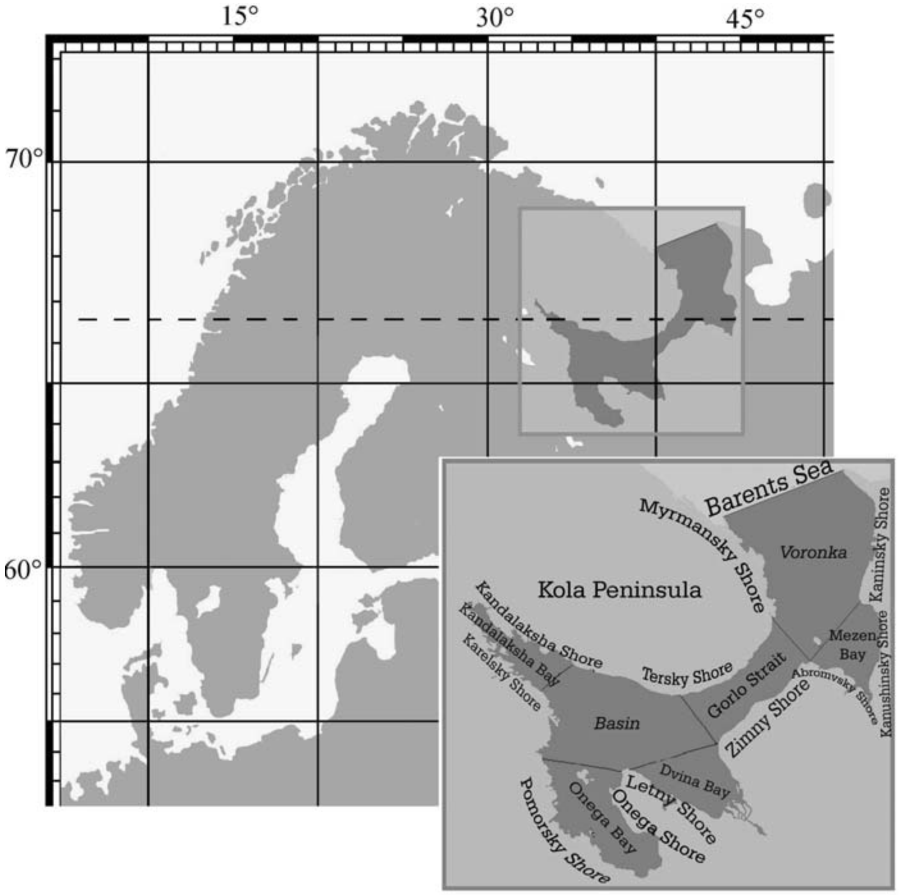

Figure 1. Map of the White Sea and its regions (Berger et al., 2001).

2.1 Meteorology

Characteristics of atmospheric pressure patterns over the North Atlantic and the Arctic Ocean basins determine the monsoon character of alternating winds dominating the White Sea. This causes northeast winds to prevail in the summer and southwest winds in winter. In summer, when the anticyclone over the Barents Sea interacts with the cyclone in the south of the White Sea, winds arise in the northeast quarter of the horizon accompanied by low cloudiness and rain. In the winter, low-and high-pressure areas are reversed: the anticyclone moves to the south of the White Sea, whereas the cyclone shifts to the Barents Sea. This meteorological pattern results in winds from the southwest. The sky becomes clear, and air temperatures decrease. In winter, the Atlantic cyclone often shifts south passing over the White Sea and southwest winds arise, cloudiness increases, temperatures rise, and snow falls. In winter, northeast winds coming from the Kara Sea and northwestern Siberia result in clear skies but temperatures dipping as low as -20 to -30^{o} C. In the summer, temperatures can reach +30° C; however, temperatures average about 15-20° C. In the northern part of the White Sea, the temperature is usually lower than that found in the southern part.

2.2 Geology

The topography of the White Sea floor is diverse with a variety of depths (Figure 2). In the Voronka maximum depths are 60-70 m with multiple-oriented northwest underwater ridges of heights from 8-12 m to 35-45 m, on average. A fairly deep trough approaches the Tersky Shore and connects the Voronka to the Gorlo Strait. A shallow zone lies along the Kanin Peninsula Shore and gradually converts into a gentle slope. In the Gorlo Strait, troughs and ridges stretch parallel to the Tersky and Zimny shores alternating with separate rises and local troughs averaging 40 m in depth, and individual troughs extending down to 100 m below the surface. The topography of Dvina Bay floor is relatively homogenous. A number of banks stretch along the southern and southeastern parts of the bay. Maximum depths over 100 m are found in the northern part of the Sea, such as in Cape Tury, which has a depth of 343 m.

The deepest, central part of the White Sea is referred to as the Basin. The floor topography of the Central Trough has local rises, mostly on its periphery. Due to its floor topography, Kandalaksha Bay is closely related to the Basin. In the northwest direction, depth sharply decreases to 50-100 m; the highest underwater ridge is in the head of the Bay. Onega Bay is a large depression elongated in the northwest direction. The central, deepest part of the Bay (50-60 m) is separated from the shallow, northwestern part (15-20 m) by a gently sloping ledge. In the southeast, an elevated region with a depth of 30-40 m adjoins the deepest part of the Bay. The head of the Bay is 10-20 m below the surface. White Sea tides are regular and semidiurnal in the Gorlo Strait and near the Tersky Shore, but they are shallow and semidiurnal in other parts of the Sea. A tidal wave originating in the Barents Sea and approaching the Voronka and the Gorlo Strait can produce 8- to 9-m high tides in Mezen Bay. In the other bays and in the Basin, the tidal amplitude is normally about 2 m, and the tidal current speed is rather high: 5 knots in the Gorlo Strait and 2 knots in Onega Bay.

The sediments on the floor of the White Sea differ in mechanical composition. A high content of sandy fractions (about 70%) is characteristic of the northern shoal of the Sea and the

Gorlo Strait. Near Cape Kanin Nos, sandy fractions decrease by 10-30% due to sediment enrichment with aleurite components. Certain regions of the Voronka, Mezen Bay, and Gorlo Strait contain 30-50% pebble and gravel components. Near the Tersky Shore, sand contains large amounts of bivalve and barnacle shells. In the White Sea Basin area, a narrow strip of sediments containing about 70% sand fraction runs along the coast; local sandstone cliffs occur. As the water depth increases, sediments contain more fine-grained material. In the deepest parts of the Basin and Dvina Bay, floor sediments consist of 70-90% pelitic components. Due to intensive water flow, sand occurs in shallow areas. In Kandalaksha Bay, pelitic sediments lie at the deepest levels. At depths to 100 meters, sand and aleurite predominate. In Onega Bay, sand and sand aleurite cover large floor areas.

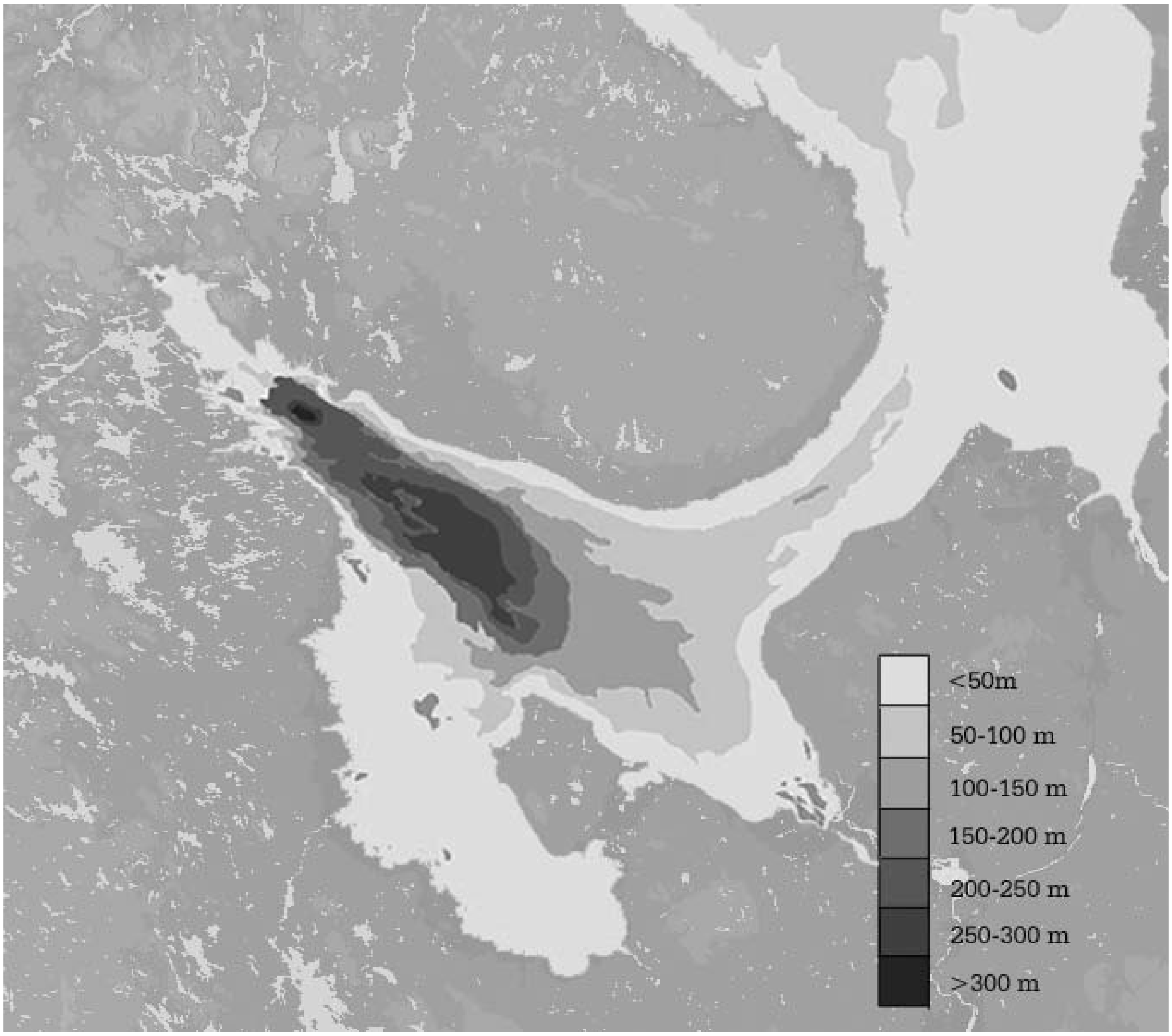

Figure 2. Map showing the bathymetry of the White Sea (modified from Berger et al., 2001).

2.3 Physical Oceanography

According to Berger et al. (2001), the White Sea exhibits interesting oceanographic characteristics. In the northern part of the Sea, summer water temperatures are low, about 6-8°C on average. In some areas, tidal currents cause an intense turbulence, which results in a well-mixed water column so that the water temperatures at the surface and on the floor are virtually the same. For example, vertical temperature homogeneity is typical of the Gorlo Strait region. A similar situation takes place in Onega Bay. Average summer water temperatures are higher, ranging from 9-12° C but can be as high as 14-16° C. In the Basin and internal bays, water surface temperatures are usually 13-15° C increasing to 20-24° C in the heads of the bays and in the shoal. In the inlets and creeks, in summer, water surface temperatures are generally higher than near open shores. Due to the intensive water circulation, summer heating reaches down to a depth of 15 m. Below this level, the water temperature sharply decreases, falling below zero at about 50-60 meters below the surface. The lowest constant summer temperatures of about -1.4° C to -1.5° C are registered in deep-water hollows of the White Sea. In winter, the water surface temperatures are close to the freezing point. These temperatures range from -1.2° C to -1.7° C in the Basin, Gorlo Strait, and Voronka, but vary from -0.5° C to -1.4°C in the bays. By the end of spring, usually in May, water starts warming. In autumn, water temperatures in the open sea vary but only minimally. In October, the temperatures of coastal waters rapidly decrease to low values as compared to the open sea.

In the White Sea, due to a large river discharge of fresh water and limited water exchange with the Barents Sea, salinity values are considerably lower than in the Arctic Ocean. Surface water salinity varies from 24-27‰ in the Basin and open parts of the bays and reaches about 29.5-30‰ in deep-water regions. At the heads of the bays, the average annual water salinity is 13-17‰. In the estuaries of large rivers, salinity decreases to less than 5-8‰. In the Gorlo Strait, salinity reaches 29‰ near the Tersky Shore and 24‰ at the Zimny Shore. Northward, near the Barents Sea boundary, salinity increases up to 32‰. In the White Sea, the dynamics of freshwater inflow causes sharp, seasonal variations in surface water salinity. In winter, when ice covers the surface of the White Sea, salinity increases (see CD-ROM, Environment/Salinity/Annual Cycle). In April-May, due to snow and ice melt, salinity drastically decreases to a depth of 2 or 3 m. Occasionally, in a surface layer of about 0.5 m thickness, the water becomes almost fresh in this period.

River discharge brings fresh water to the White Sea, which accounts for 95% of its water budget. Seasonal variations in water exchange between the Barents and White Seas depend on river discharge. About half the annual fresh water flows into the White Sea in the spring, intensifying water exchange between the Seas. The annual river water outflow from the White Sea is about 240 km^3. The annual river discharge into the White Sea is equivalent to a 2.6-m thick layer of water; precipitation and evaporation are equal to a 37-cm and 24-cm layer; respectively. At the same time, the seasonal sea-level variations are within several centimeters.

2.4 Hydrochemistry

In the White Sea, high oxygen concentrations of 6.06 to 8.59 ml L^{-1} are observed. Surface waters are most aerated in Onega Bay and the Gorlo Strait. Even in the deepest water layers of Kandalaksha Bay, Dvina Bay, and in the Basin, oxygen concentrations of 6.6 to 7.8 ml L^{-1} are rather common. Waters from the Barents Sea that are released into the White Sea (approximately 21.3 x 10^6 metric tons) contain a larger annual oxygen amount. However, during a year the White Sea gives back to the Barents Sea (approximately 21 - 22 x 10^6 metric tons), an equal oxygen amount is exchanged. Therefore, the oxygen balance of the White Sea depends on the processes occurring within the entire water layer. The total oxygen is obtained from the oxygen content of river waters and from photosynthesis. However, the available data is insufficient to calculate the oxygen balance of the White Sea. The seasonal dynamics of oxygen shows that, in surface waters, the concentration is highest in spring. During the summer-autumn period, oxygen concentration decreases due to a reduction in photosynthetic activity and an increase in remineralization of organic matter.

Inorganic nitrogen exists mostly in a maximally oxidized form, i.e., nitrates make up about 80% of all nitrogen-containing inorganic substances. In the White Sea, an average concentration of nitrate varies from 52 mg m^{-3} in surface waters up to 70 mg m^{-3} on the floor. In spring, the highest concentration of nitrates, 60 mg m^{-3}, is found in the euphotic layer of Onega Bay, while the lowest concentrations are found in Kandalaksha Bay and in the Basin – 30 mg m^{-3} and 20 mg m^{-3}, respectively. In autumn, when total nitrate increases to 40-50 mg m^{-3}, the discrepancies among the regions grow. In Dvina Bay, nitrate is at a maximum – 50 mg m^{-3} – while in the euphotic layer of Kandalaksha Bay, Onega Bay, and the Gorlo Strait, the concentration of nitrate is only 35-40 mg m^{-3}. In the White Sea, nitrite makes up not more than 10% of the total inorganic nitrogen reservoir, so its contribution is insignificant to the nitrogen supply for phytoplankton. In the euphotic layer, the nitrite content is about 1.7 mg m^{-3}, increasing to 3.3 mg m^{-3} in autumn, with the maximum concentration observed in Mezen and Onega Bays. Ammonia reaches a maximum concentration of 20 mg m^{-3} in autumn after oxidation is completed, then in winter, its content falls to half or one-fourth of this value.

In the White Sea, phosphates are mostly presented as inorganic forms of phosphorus-containing compounds with an average of 20 mg m^{-3} and not more than 15 mg m^{-3} of phosphorus in the euphotic layer. In August, phosphorus content drops to 10 mg m^{-3} in the neritic zone and below the detection limit in the euphotic layer of the pelagic area. In October, these values are equal to 11-16 and 9 mg m^{-3}, respectively. Phosphates vary considerably in certain regions of the Sea. In summer, due to intensive turbulence the concentration of phosphates is much higher (11-14 mg m^{-3}) in Onega Bay than in surface waters of the Basin. In Onega Bay, the content of phosphates is actually the same at all depths as compared to other regions where it varies with depth reaching maximum values in the deepest parts of the Sea. Compared to the Basin and Kandalaksha Bay, where phosphates are usually low, in shallow freshened regions of Dvina, Onega, and Mezen Bays, during the period of active vegetation, phosphates average 5 mg m^{-3}, and phytoplankton, consequently, gets more nutrition.

In the White Sea, the content of silicate varies considerably from season to season. When there are extensive blooms of phytoplankton, silicate in the euphotic layer never falls below the detection limit. According to long-term observation data in Mezen and Dvina Bays, the content of silicic acid is never less than 500 and 400 mg m^{-3}, respectively. The maximum silicate content of 2000 mg m^{-3} and above was registered in Dvina Bay. In deeper waters, the silicate concentration is more or less consistent (450 mg m^{-3}) for the entire water basin. In spring and summer, silicic acid decreases due to dissolution in surface waters; then in autumn and winter, it increases. However, no major trends are revealed in annual variations of this hydrochemical characteristic.

2.5 Zooplankton

According to recent reports about the White Sea, zooplankton is divided into 142 taxa with the most diverse taxa being tintinnids and copepods (Pertzova and Prygunkova, 1995; Berger et al., 2001). In addition, in a water column, pelagic larvae and eggs of mollusks, echinoderms, polychaetes, and crustaceans occur temporarily.

Compared to the Barents Sea, White Sea plankton fauna is less diverse. Several zooplankton taxa typical of the Barents Sea, *Radiolaria*, planktonic *Foraminifera*, *Siphonophora,* and *Ostracoda*, do not inhabit the White Sea. Other taxa like *Copepoda* are represented by a significantly lower abundance of species. Several factors like strong tidal currents, intensive water mixing in the Gorlo Strait, and very low salinity make the composition of species in the White Sea comparatively poor. Neritic species comprise a major portion of White Sea zooplankton, Arctic species - 42%, arcto-boreal species - 41%, and boreal species - 17%.

In earlier studies, the White Sea was considered to have low organism abundance and zooplankton productivity (Zenkevich, 1947; Epstein, 1963). However, in the many regions of the White Sea, except for the Gorlo Strait (Troshkov, 1998) and Mezen Bay, zooplankton biomass has been found to be 200 mg m^{-3} on average, sometimes as high as 760 mg m^{-3} (Bondarenko, 1994) to 2,470 mg m^{-3} (Pertzova and Prygunkova, 1995), which compares well with the neighboring Barents Sea.

Based on the averaged data from different regions of the White Sea, we can roughly estimate the total wet weight of its zooplankton biomass at 0.65×10^6 tons (Berger et al., 1995). The volume of the White Sea is 5.4×10^3 km^3, which is 0.0004% of the world ocean's volume of $1{,}370 \times 10^6$ km^3 (Moiseyev, 1969). White Sea zooplankton biomass is 0.0032% of the total world ocean zooplankton biomass of $20\text{-}21.5 \times 10^9$ tons (Vinogradov, 1955; Bogorov et al., 1968). As seen, the average zooplankton biomass of the White Sea is more than eightfold of that of the world ocean.

3. White Sea Biological Station

The White Sea Biological Station (WSBS) of the Zoological Institute, Russian Academy of Sciences, was established in 1949 as a separate scientific unit under the Karelian-Finnish Branch of the USSR Academy of Sciences. The station lacked a permanent base during the first eight years, and studies were performed only in the summer from the research vessels (R/Vs) "Professor Mesyatsev" and "Ispytatel." The material collected during the summer periods was then processed during the winter in Petrozavodsk and Belomorsk.

In 1957, the WSBS moved to Cape Kartesh, located in the Chupa Inlet of Kandalaksha Bay (Figure 3). Professor V.V. Kuznetsov, the first Director of the station, outlined the critical scientific objectives to be studied: seasonal, annual, and long-term variations in living conditions and features of organisms inhabiting the White Sea. These objectives matched the goals declared by the Presidium of the Academy of Sciences in 1960:

> "Studying seasonal, annual, and long-term variations and changes in main biological objects, in particular, the population dynamics of key fauna and flora species of the White Sea; studying seasonal, annual, and long-term variations and changes in living conditions for different biological groups inhabiting the White Sea."

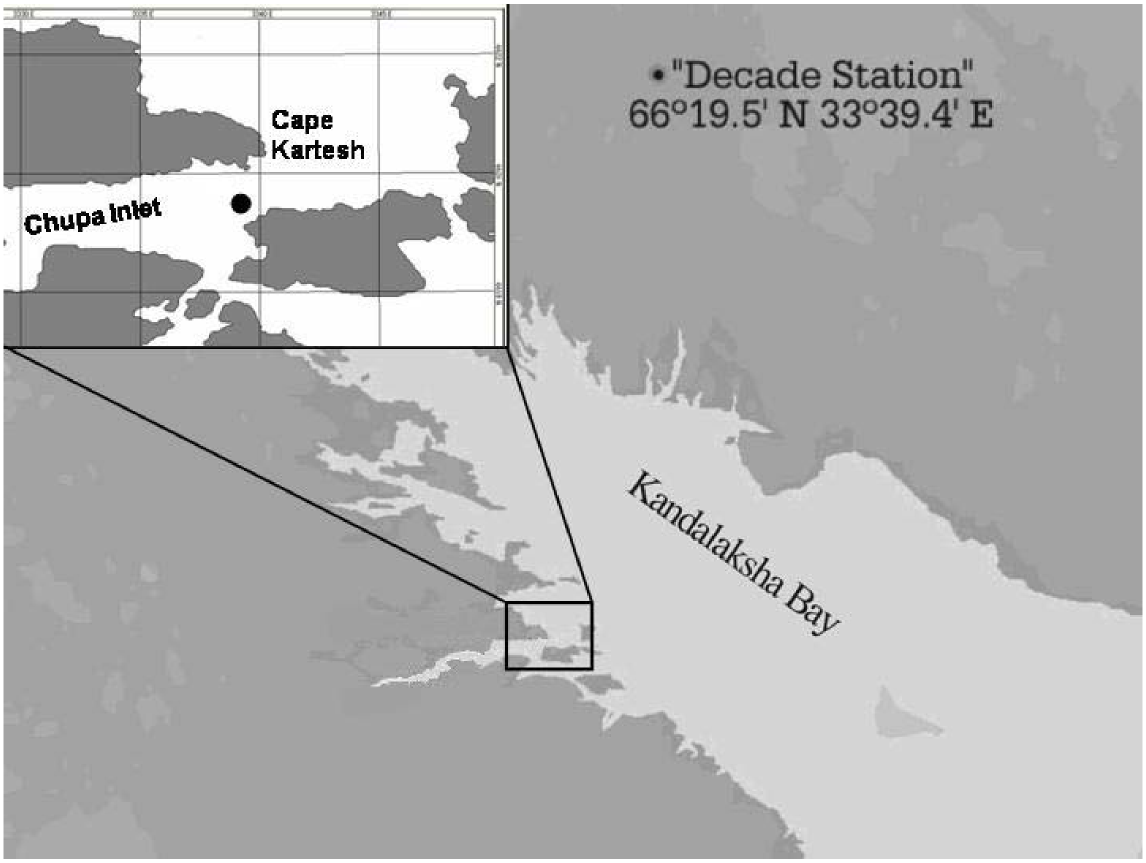

Figure 3. Map showing the current location of the White Sea Biological Station.

Soon after the WSBS moved to Cape Kartesh on 19 July 1957, regular hydrological and plankton observation commenced. These observations were carried out at a standard depth of 66 m at a point in the mouth of the Chupa Inlet. This location was named Decade Station D1 because data was collected there from research vessels every ten days from the spring to autumn (in the Russian language, *decade* means a period of ten days). In the winter, when ice cover was present, data was collected once a month.

In December 1957, R.V. Pyaskowsky initiated regular hydrological observations of water temperature and salinity at different depths. Over a short period of time (until the late 1960s), P.G. Lobza carried out various hydrochemical observations, and in 1966-1967, T.V. Klebovitch performed short-term phytoplankton studies.

The hydrological observations have been carried out from 1949 until the present time with only short interruptions. Until 1961, the lead for these observations was R.V. Pyaskowsky; during 1961-1971, Yu. M. Savoskin took over; and from 1971-1995, A.I. Babkov took charge. Since 1995, V.Yu. Buryakov, M.E. Sorokin, and I. M. Primakov have led these efforts.

Studies on zooplankton were started in summer 1957 and performed irregularly during the first three years. From 1961 until the present time, regular observations have been carried out with short intermissions. Standard techniques have been used to collect water samples and process the data (refer to the section on Methodology). Those involved with the collection of water samples and processing of the data obtained at Decade Station D1 were R.V. Prygunkova, S.S. Burlakova, S.S. Ivanova, I.P. Kutcheva, N.V. Usov, M.A. Zubaha, and D.M. Martinova.

V.Yu. Buryakov and M.A. Zubaha were the first to compile an electronic plankton and hydrological database in Microsoft Excel format along with a set of built-in retrieval procedures using Visual Basic.

Since 1961 and for every ten days throughout the year, scientists have measured temperature and salinity at 0, 5, 10, 15, 25, 50, and 65 m and obtained zooplankton samples from 0-10, 10-25, and 25-65-meter depths. As a result, scientists have collected abundant data to study the development cycles for different plankton species and the environmental effects on zooplankton abundance and structure. The results of these studies have been presented in numerous reports and several monographs, which are listed on the CD-ROM under References.

4. Data

The current study is based on the long-term data series obtained at one point in Kadalaksha Bay, located in Chupa Inlet of the White Sea (66° 19.5' N, 33° 39.4' E), and which has a depth of 65 m (see Figure 3). Regular hydrological observations were performed every 10 days throughout 1961-2000. In 1963, in addition to hydrological observations, plankton sampling commenced. Depending on the weather conditions, the sampling dates varied. The present study covers analyses of 938 oceanographic profiles and 812 stations where plankton was sampled at three levels, for a total of 2,514 plankton samples (see Tables 1 and 2). A list of all zooplankton taxa as documented by the White Sea Biological Station is presented on Table 3.

Temperature and salinity were measured at depths of 0, 5, 10, 15, 25, and 50 m, and in the bottom layer at 65 m below the surface. The temperature was measured with a deep-water turning-over TG-type thermometer with a resolution of 0.1^{o} C or a bathythermograph with the same resolution. Water was sampled with a Nansen water sampler BH-48. Salinity was determined by titration or with an electric salt gauge GM-65M.

Plankton were caught with a standard large Judey net with locker. The diameter of the mouth opening was 0.1 m^2, mesh size – 0.168 mm. Samples were taken from three standard depth levels at 10-0, 25-10, and 65-25 meters. After the net was lifted, plankton was fixed with a 10% formaldehyde solution. A Bogorov counting dish (kamera Bogorova) was used to count the organisms. A sample was reduced by the concentration method to 200 ml. Of this amount, two aliquots of 1 ml each were taken. In each aliquot, the abundance of zooplankton was determined. Then the total abundance of rarer species was determined for the entire sample. All abundance data were presented by the number of animals in one cubic meter - # m^{-3}.

Table 1. Inventory of temperature and salinity measurements

Years	Jan			Feb			Mar			Apr			May			Jun			Jul			Aug			Sep			Oct			Nov			Dec			Total
1961	**1**	**1**		**1**	**1**						**1**				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			25
1962			**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**		1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1		1	1	1	1	**1**	31
1963	**1**	**1**	**2**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**		1	1	1		1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	**1**	34
1964	**1**	**1**	**1**	**1**		**1**	**1**	**1**	**1**	**1**	**1**	**1**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1			32
1965	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			**1**	**1**	34
1966	**1**	**1**		**1**	**1**	**1**	**1**			**1**	**1**	**1**	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			32
1967		**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	**1**	33
1968			**1**	**1**	**1**	**1**	**1**	**1**	**2**	**1**	**1**	**1**	**1**	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	2	1	1	1	**1**			36
1969			**1**	**1**	**1**		**1**	**1**	**1**	**1**	**1**	**1**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1		31
1970		**1**			**1**			**1**	**1**	**1**	**1**	**1**		1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1			1		1		27
1971		**1**		**1**					**1**	**1**	**1**	**1**	1	1	1	1	1	1	1	1	1	1	1	1	1		1										20
1972																				1	1	1	1	1	1	1	1	1	1								10
1973													1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1					19
1974		**1**			**1**					**1**				1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1			1		21
1975		**1**			**1**				**1**		**1**			1		1	1	1	1	1	2	1	1	1	1	1		1	1	1	1	1			1		23
1976		**1**			**1**			**1**			**1**			1		1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1				24
1977					**1**			**1**			**1**					1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			23
1978			**1**		**1**			**1**			**1**		1		1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	**1**		25
1979		**1**			**1**			**1**			**1**		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		**1**		26
1980				**1**	**1**		**1**	**1**		**1**	**1**	**1**		1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1		1		27
1981					**1**		**1**	**1**						1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		24
1982	**1**		**1**		**1**			**1**	**1**	**1**	**1**	**1**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			30
1983					**1**			**1**	**1**		**1**	**1**		1	1	1	1	1	1	1	1	1	1		1	1	1	2	1	1	1	1					24
1984		**1**						**1**	**1**	**1**	**1**	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1			1		26
1985					**1**			**1**	**1**	**1**	**1**	**1**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1					25
1986		**1**			**1**			**1**	**1**		**1**	**1**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1			1		26
1987		**1**			**1**			**1**	**1**	**1**	**1**	**1**		1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1							23
1988		**1**			**1**			**1**		**1**					1	2	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1					22
1989			**1**		**1**			**1**			**1**		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1							22
1990		**1**				**1**		**1**		**1**	**1**			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1					23
1991		**1**			**1**	**1**		**1**		**1**				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1				**1**	24
1992					**1**					**1**						1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1						18
1993											**1**		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1					20
1994							**1**	**1**			**1**					1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1					19
1995																1	1	1	1	1	1	1		1	1	1	1	1	1	1		1		1			16
1996	**1**					**1**			**1**			**1**				1	1	1	1	1	2	1	1	1	1	1	1	1	1								19
1997															1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1						17
1998				**1**				**1**			**1**					1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1					19
1999			**1**	**1**				**1**		**1**					1	1	1	1																			8

Total number of profiles 938

1 = number of measurements carried out from the vessel

1 = number of measurements carried out on the ice

▨ = unknown ice conditions

Table 2. Inventory of zooplankton stations

Years	Jan			Feb			Mar			Apr			May			Jun			Jul			Aug			Sep			Oct			Nov			Dec			Total
1963																									1		1	1	1		1		1	1			7
1964		**1**	**1**	**1**	**1**		**1**	**1**	**1**	**1**	**1**	**1**	1	1	1		1		1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	**1**		30
1965			**1**		**1**		**1**	**1**	**1**	**1**	**1**	▨1	1	1	1	1	1	1	1	1	1	1	1	1			1	1	1	1	1	1	1			**1**	28
1966					**1**	**1**	**1**	**1**	**1**	**1**	**2**	**1**	1	1	1	1	1		1	1	1	1	1	1	1	1	1			1	1	1	1	1			28
1967		**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	**1**	33
1968			**1**	**1**	**1**	**1**	**1**	**1**	**1**		**1**	**1**		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1		**1**			28
1969			**1**				**1**	**1**	**1**	**1**	**1**	**1**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			1			27
1970		**1**			**1**			**1**	**1**	**1**	**1**	**1**		1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1			1		1		27
1971		**1**		**1**					**1**	**1**	**1**	**1**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1										21
1972																				1	1	1	1	1	1	1	1	1	1								10
1973													1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1					19
1974		**1**			**1**					**1**				1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1			1		21
1975		**1**			**1**				**1**		**1**			1		1	1	1	2	1	1	1	1	1	1	1		1	2	1		1			1		23
1976		**1**			**1**			**1**			**1**			1		1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1				24
1977					**1**			**1**			**1**	**1**				1	2	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1			25
1978			**1**		**1**			**1**			**1**		1		1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	**1**		25
1979		**1**			**1**			**1**			**1**		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		**1**		26
1980				**1**	**1**		**1**	**1**		**1**	**1**	**1**		1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1		1					24
1981					**1**		**1**							1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1		22
1982								**1**			**1**	**1**		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1				22
1983					**1**		**1**				**1**	**1**		1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1						21
1984		**1**						**1**	**1**	**1**	**1**	**1**	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1			▨1		26
1985				**1**	**1**			**1**	**1**	**1**	**1**	**1**	▨1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1					26
1986		**1**			**1**			**1**	**1**		**1**	**1**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1			▨1		26
1987		**1**			**1**			**1**	**1**	**1**	**1**	**1**		1		1	1	1	1	1	1	1	1	1	2	1	1	1	2	1		1					26
1988		**1**			**1**			**1**		**1**					1	1	2	1	1	1	1	1	1		1	1	1	1	1	1	1	1					22
1989			**1**		**1**			**1**			**1**		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1					23
1990		**1**				**1**		**1**		**1**	**1**			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1					23
1991		**1**			**1**	**1**		**1**		**1**				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1					23
1992					**1**					**1**						1	1	1	1	1	1	1	1	1	1		1	1	1	2	1						18
1993														1	1		1	1	2	1	1	1	1	1	1	1	1	1	1		1	1					18
1994																1	1	1	1	1	1	1	1	1	1	1	1	1	1		1						15
1995																1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1		▨1			17
1996						**1**			**1**			**1**				1	1	1	2	1	1	1	1	1	1	1	1	1	1	1		1				**1**	21
1997					**1**											1	2	1	1	1	1	1	1	1	1	1	1	1	1	1		1					18
1998				**1**				**1**			**1**					1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1					19

Total stations 812

1 = number of measurements carried out from the vessel

1 = number of measurements carried out on the ice

▨ = unknown ice conditions

Table 3. List of taxa.

Group	Species	Ontogenetic stages
Protista	*Parafavella denticulata*	Adult
Hydrozoa	*Aglantha digitale*	
Copepoda	*Calanus glacialis*	Female VI
Copepoda	*Calanus glacialis*	Male VI
Copepoda	*Calanus glacialis*	Cop V
Copepoda	*Calanus glacialis*	Cop IV
Copepoda	*Calanus glacialis*	Cop III
Copepoda	*Calanus glacialis*	Cop II
Copepoda	*Calanus glacialis*	Cop I
Copepoda	*Calanus glacialisi*	Nauplii
Copepoda	*Metridia longa*	Female VI
Copepoda	*Metridia longa*	Male VI
Copepoda	*Metridia longa*	Cop V
Copepoda	*Metridia longa*	Cop IV
Copepoda	*Metridia longa*	Cop III
Copepoda	*Metridia longa*	Cop II
Copepoda	*Metridia longa*	Cop I
Copepoda	*Metridia longa*	Nauplii
Copepoda	*Pseudocalanus minutus*	Female VI
Copepoda	*Pseudocalanus minutus*	Male VI
Copepoda	*Pseudocalanus minutus*	Cop V
Copepoda	*Pseudocalanus minutus*	Cop IV
Copepoda	*Pseudocalanus minutus*	Cop III
Copepoda	*Pseudocalanus minutus*	Cop II
Copepoda	*Pseudocalanus minutus*	Cop I
Copepoda	*Pseudocalanus minutus*	Nauplii
Copepoda	*Acartia longiremis*	Female VI
Copepoda	*Acartia longiremis*	Male VI
Copepoda	*Acartia longiremis*	Cop.
Copepoda	*Acartia longiremis*	Juv.
Copepoda	*Acartia longiremis*	Nauplii
Copepoda	*Centropages hamatus*	Female VI
Copepoda	*Centropages hamatus*	Male VI
Copepoda	*Centropages hamatus*	Cop.
Copepoda	*Centropages hamatus*	Juv.
Copepoda	*Centropages hamatus*	Nauplii
Copepoda	*Oithona similis*	Female VI
Copepoda	*Oithona similis*	Male VI
Copepoda	*Oithona similis*	Cop.
Copepoda	*Oithona similis*	Juv.
Copepoda	*Oithona similisi*	Nauplii
Copepoda	*Temora longicornis*	Female VI
Copepoda	*Temora longicornis*	Male VI
Copepoda	*Temora longicornis*	Cop.
Copepoda	*Temora longicornis*	Juv.
Copepoda	*Temora longicornis*	Nauplii
Copepoda	*Microsetella norvegica*	Adult
Copepoda	*Microsetella norvegica*	Cop.
Copepoda	*Microsetella norvegica*	Juv.
Copepoda	*Microsetella norvegica*	Nauplii
Copepoda	*Oncaea borealis*	Female VI
Copepoda	*Oncaea borealis*	Male VI
Copepoda	*Oncaea borealis*	Cop.
Cladocera	*Podon leuckarti*	Adult
Cladocera	*Evadne nordmanni*	Adult
Cirripedia	*Cirripedia*	Nauplii
Chaetognata	*Sagitta elegans*	Adult
Polychaeta	*Polychaeta*	Larvae
Bivalvia	*Bivalvia*	Larvae
Gastropoda	*Gastropoda*	Larvae
Echinodermata	*Echinodermata*	Larvae
Bryozoa	*Bryozoa*	Larvae
Appendicularia	*Fritillaria borealis*	Adult
Appendicularia	*Oicopleura vanhoffenis*	Adult
Ascidia	*Ascidia*	Larvae

5. Methodology and Results

5.1 Temperature and Salinity Dynamics: 1961-1999

The raw data on the CD-ROM was used to construct a time series of temperature and salinity variations from 1961 to 1999 (Figures 4 and 5, respectively). Figure 4 presents the annual anomalies of temperature for the depths 0-65 m, 0-15 m, and 50-65 m. Figure 5 shows the annual anomalies for salinity for the depths 10-65 m, 10-15 m, and 50-65 m. These depths were chosen because they describe, in sufficient detail, temperature and salinity variations along the vertical. When describing salinity variations, no consideration has been given to the surface layer due to strong effects by river discharge and ice melt. The diagram of salinity anomaly variations shows two distinct time spans: 1961-1975, where the salinity anomaly is positive; and 1976-1997, where the salinity anomaly is negative.

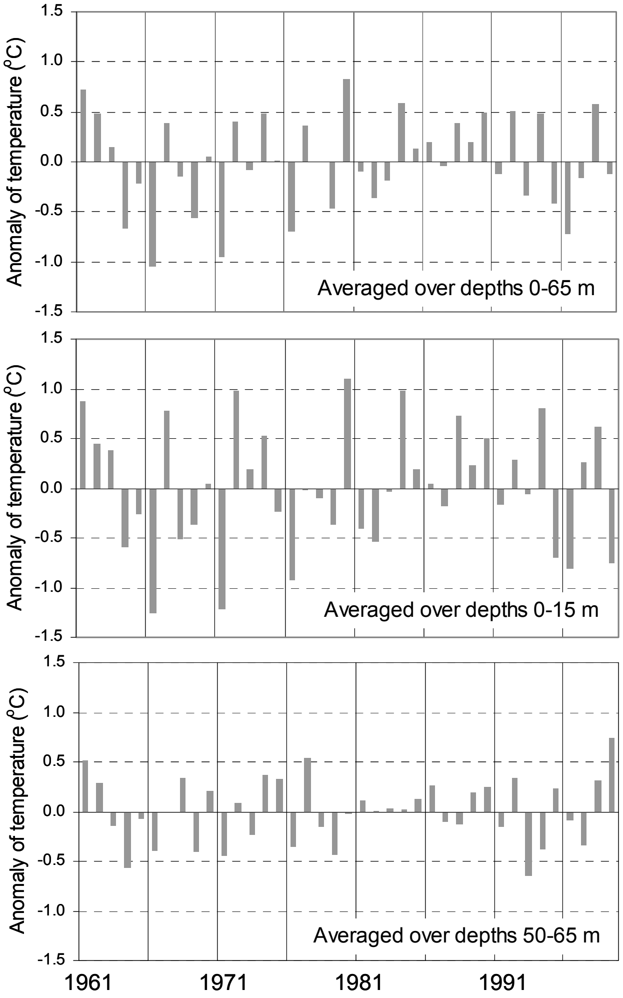

Figure 4. Time series of annual temperature anomalies for 1961-1999.

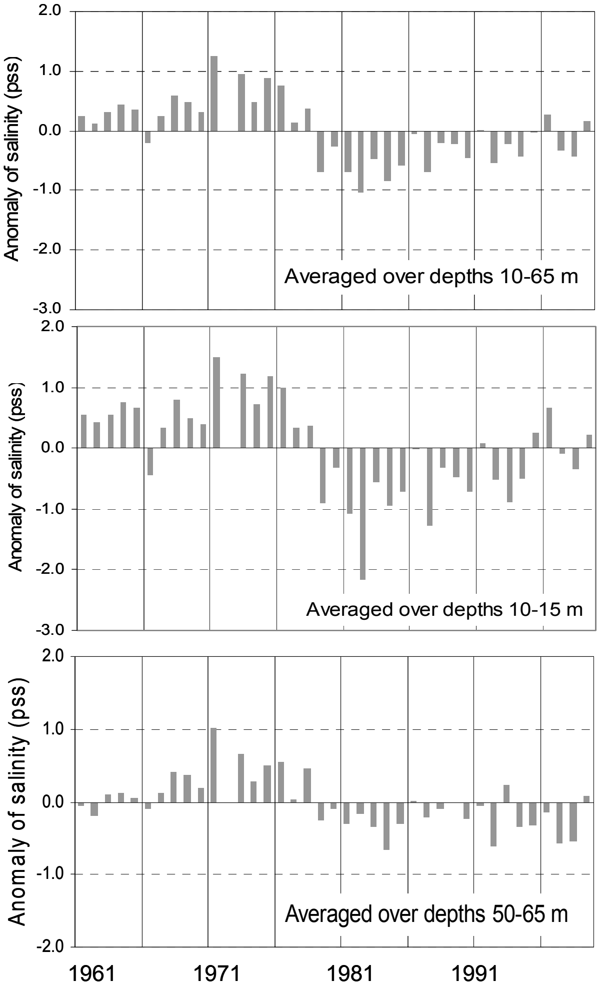

Figure 5. Time series of annual salinity anomalies for 1961 – 1999.

The algorithm used to construct the time series (Figures 4 and 5) was the following:

- Long-term temperature, $T_{j,k}$, and salinity, $S_{j,k}$, means (climatic normal) are calculated by month (*j)* and level (*k*). Table 4 presents these values for 12 months and for levels 0 m, 5 m, 10 m, 15 m, 25 m, 50 m, and 65 m.
- Monthly mean deviations of temperature, $T_k(N)$, and salinity, $S_k(N)$, are computed for the given year (*N*) and level (*k)*.
- T(*N*) and S(*N*) means are calculated for multiple layers.

Table 4. Climatological means for each month and each level for temperature and salinity.

(a) Temperature

Depth (m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	-0.98	-0.80	-0.55	-0.65	3.41	10.98	14.78	13.77	9.31	5.02	1.96	-0.05
5	-0.92	-0.68	-0.68	-0.76	2.03	7.60	13.19	13.51	9.32	5.09	2.01	0.05
10	-0.86	-0.65	-0.66	-0.76	1.06	5.51	11.26	12.04	8.93	5.13	2.22	0.18
15	-0.76	-0.48	-0.44	-0.63	0.34	3.43	8.62	9.75	8.26	4.83	2.37	0.58
25	-0.50	0.15	-0.23	-0.48	-0.33	0.96	4.02	4.81	5.31	4.18	2.61	0.95
50	0.02	0.25	-0.23	-0.58	-0.64	-0.17	0.53	1.35	1.97	1.87	2.51	1.60
65	0.08	0.18	-0.27	-0.60	-0.66	-0.24	0.39	1.17	1.72	1.65	2.29	1.33

(b) Salinity

Depth (m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	20.51	19.62	17.64	14.99	18.50	22.21	23.34	24.32	24.98	25.60	26.08	25.84
5	26.17	26.27	25.67	25.63	24.49	24.05	24.38	24.79	25.39	25.93	26.54	26.74
10	26.65	26.60	26.00	26.20	25.47	24.87	24.96	25.21	25.64	26.06	26.63	26.74
15	27.11	27.42	27.38	27.40	26.84	26.08	25.84	25.89	26.09	26.38	26.75	27.02
25	27.37	27.61	27.80	27.91	27.68	27.12	26.88	26.76	26.79	26.90	27.03	27.21
50	27.82	28.05	28.41	28.48	28.46	28.08	27.93	27.75	27.68	27.76	27.78	27.78
65	28.02	28.32	28.63	28.67	28.54	28.31	28.05	27.93	27.88	27.87	27.79	27.97

5.2 Temperature Optima for Zooplankton Species

The temperature optimum for zooplankton species, *x*, is the temperature range within which the abundance of *x* reaches its maximum value. Let T(*x*) be the temperature optimum for zooplankton species, *x*. The current study considers T(*x*)-values for two reasons: (1) because the quantitative description of the relationship between environmental conditions and zooplankton abundance forms a basis for providing control criteria for data quality and control; (2) T(*x*)-values allow us to formulate hypotheses for which a confirmation or refutation will provide a better understanding of the mechanism of environmental effects on the annual dynamics of zooplankton development and will serve as criteria for quality control of hydrobiological data. These hypotheses will be considered in the next section.

A T(x)-value is calculated based on multiple samples, any of which is characterized by information about its species composition, abundance, and temperature and salinity at different depths. Let the number of these samples be n. The computing algorithm for T(x) is as follows:

1. For layer, h, within which zooplankton sample, i, is taken, the value of $T_h(x)$ is calculated as:

$$T_h(x) = \frac{\sum_{i=1}^{n} T_{h,i} \bullet A_{h,i}(x)}{\sum_{i=1}^{n} A_{h,i}(x)}$$

where:

$T_h(x)$ is the temperature optimum for zooplankton species, x, in layer, h;
$T_{h,i}$ is the mean temperature of layer, h, and sample, i;
$A_{h,i}(x)$ is the abundance of zooplankton species, x, in layer, h, and sample, i; and
n is the total number of samples.

1. A $T_h(x)$-value is calculated for three layers: $h_1 = 0\text{-}10$ m, $h_2 = 10\text{-}25$ m, and $h_3 = 25\text{-}65$ m. The temperature optimum for layer, h_o (surface-bottom), has been calculated based on $T_{h1}(x)$, $T_{h2}(x)$, and $T_{h3}(x)$ values:

$$T_{ho}(x) = \frac{[T_{h1}(x) + T_{h2}(x) + T_{h3}(x)]}{3}$$

2. The temperature optima of zooplankton species, T(x), as listed in Table 3, are calculated by averaging the temperature optima for all its ontogenetic stages. In accordance with the $T_{ho}(x)$-values, the entire set of species is divided into the two categories, K_1 and K_2. The temperature optimum for the species set, K_1, lies in the range of 1.5° to 4.1° C, and K_2 - in the range of 8.1° to 12.8° C (Figure 6). The difference of the temperature optimum between these two categories is about 4° C. Therefore, zooplankton species of the first category, K_1, are considered to be cold-water species and of the second category, K_2, – warm-water species. *Polychaeta* are the only intermediate group, probably, due to the diversity of species in this group.

During the year the ratio between the abundances of cold-water and warm-water species does not remain constant. In winter, the abundances are very similar; in spring, the cold-water species predominate; in summer and especially autumn, the warm-water species compose the major part of the total population abundance.

Based on multiple samples collected during the period 1963-1998 of continuous observations, Figure 6 shows the correspondence between zooplankton condition and water temperature on a climatic time scale. We plan to use these features to verify methods for the quality control of biological data for the White Sea. The results of this study and experience gained will make it possible to improve the technique of data quality control for other Arctic regions as well.

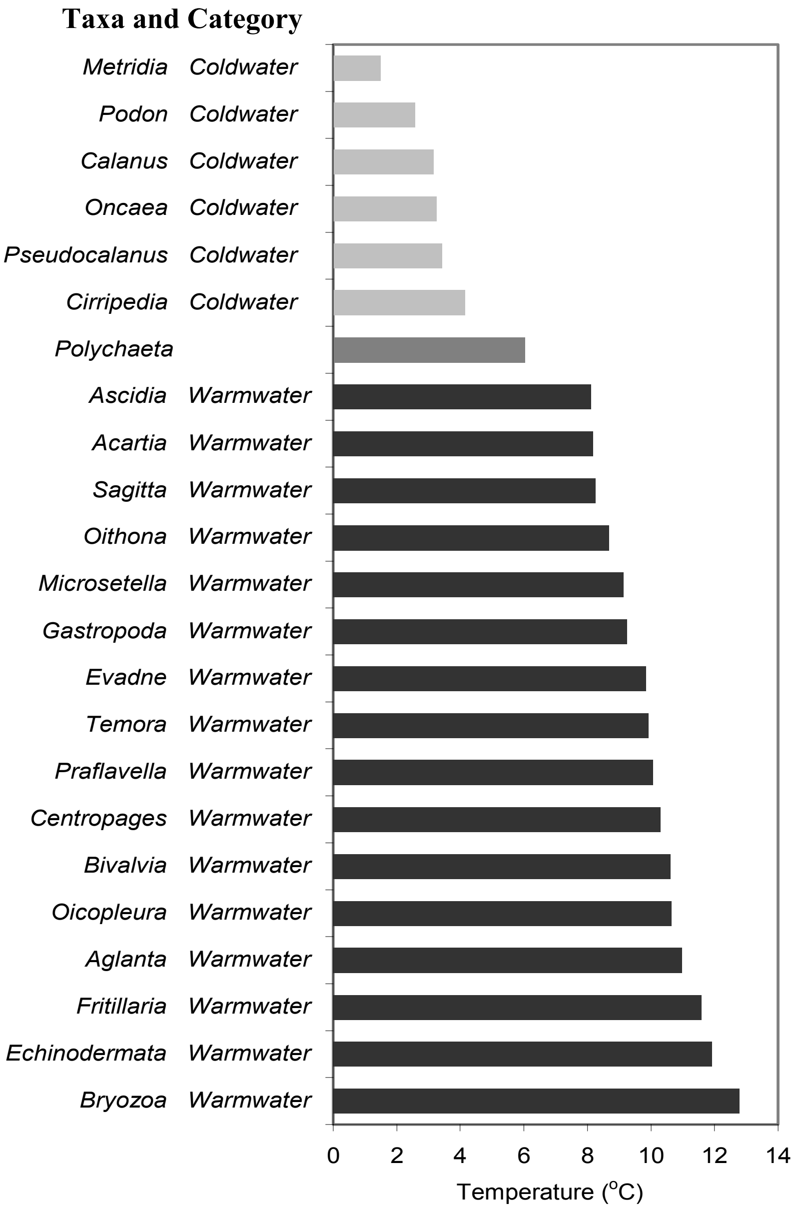

Figure 6. Correspondence between peak of zooplankton abundance and water temperature, T*(x)*.

5.3 Main Concept and Problem Statements

One of the goals of this study is the quantitative description of environmental effects on zooplankton development. Let us consider the possibility of using T(x)-values to solve this problem. Parameter T(x) determines the temperature value favorable for zooplankton reproduction (Marshall, Orr, 1955; Waterman, 1960). This allows us to formulate the following two statements:

Statement 1: In the years with negative temperature anomaly, the duration of the period favorable for reproduction of cold-water zooplankton species of category, K_1, is extended and for warm-water zooplankton species of category, K_2, it is shortened (warm-water species are inhibited). The years with positive temperature anomalies tend to reverse this effect.

Statement 2: Inhibition of warm-water species of category, K_2, can cause a reduction in the average abundance or change the duration of the intensive reproduction period or species concentration in warm upper layers. Inhibition of cold-water species can cause a reduction in abundance and concentration in deeper water layers.

Statements 1 and 2 form a basis for the formulation and solution of problems to estimate water temperature effects on zooplankton development. This study defines the problems as follows:

Problem 1: To isolate zooplankton species most sensitive to variations in water temperature.

The definition of this problem may be extended to include the case of salinity to describe the environmental conditions:

Problem 2: To isolate zooplankton species most sensitive to variations in water salinity.

5.4 Algorithm and Results

Let us consider the algorithm for solving Problem 1. It is as follows:

- The long-term (climatic) annual mean cycle of changes in the abundance of zooplankton species, x - C_x(Climatic) - is calculated for the entire observation period based on multiple samples for every zooplankton species, x.

- In accordance with the value of annual temperature anomalies (Figure 4), a set of years is divided into years with a positive temperature anomaly, (A_{T+}), and the years with a negative temperature anomaly, (A_{T-}).
  (A_{T+}) = {1970, 1974, 1984, 1985, 1986, 1990, and 1998}
  (A_{T-}) = {1964, 1966, 1969, 1971, 1976, 1979, and 1996}
  The remaining years are those with a temperature anomaly around zero. Figure 7 shows the cycle of annual temperature variations for the sets of years A_{T+} and A_{T-} and the entire set of years.

- Annual cycles of abundance variations in zooplankton species from the database have been calculated for the set of years A_{T+} and A_{T-}. Let us designate these cycles for the zooplankton species, x, as $C_x(A_{T+})$ and $C_x(A_{T-})$, respectively.

- For every zooplankton species, the long-term mean cycle - C_x(Climatic) - has been compared with $C_x(A_{T+})$ and $C_x(A_{T-})$, respectively. According to Statement 2 the operation of comparison between these cycles consists of performing the comparison among the following characteristics of the annual cycle of zooplankton development:
  - A) Annual average population abundance;
  - B) Duration of the period of intensive reproduction;
  - C) Structure of vertical zooplankton distribution.

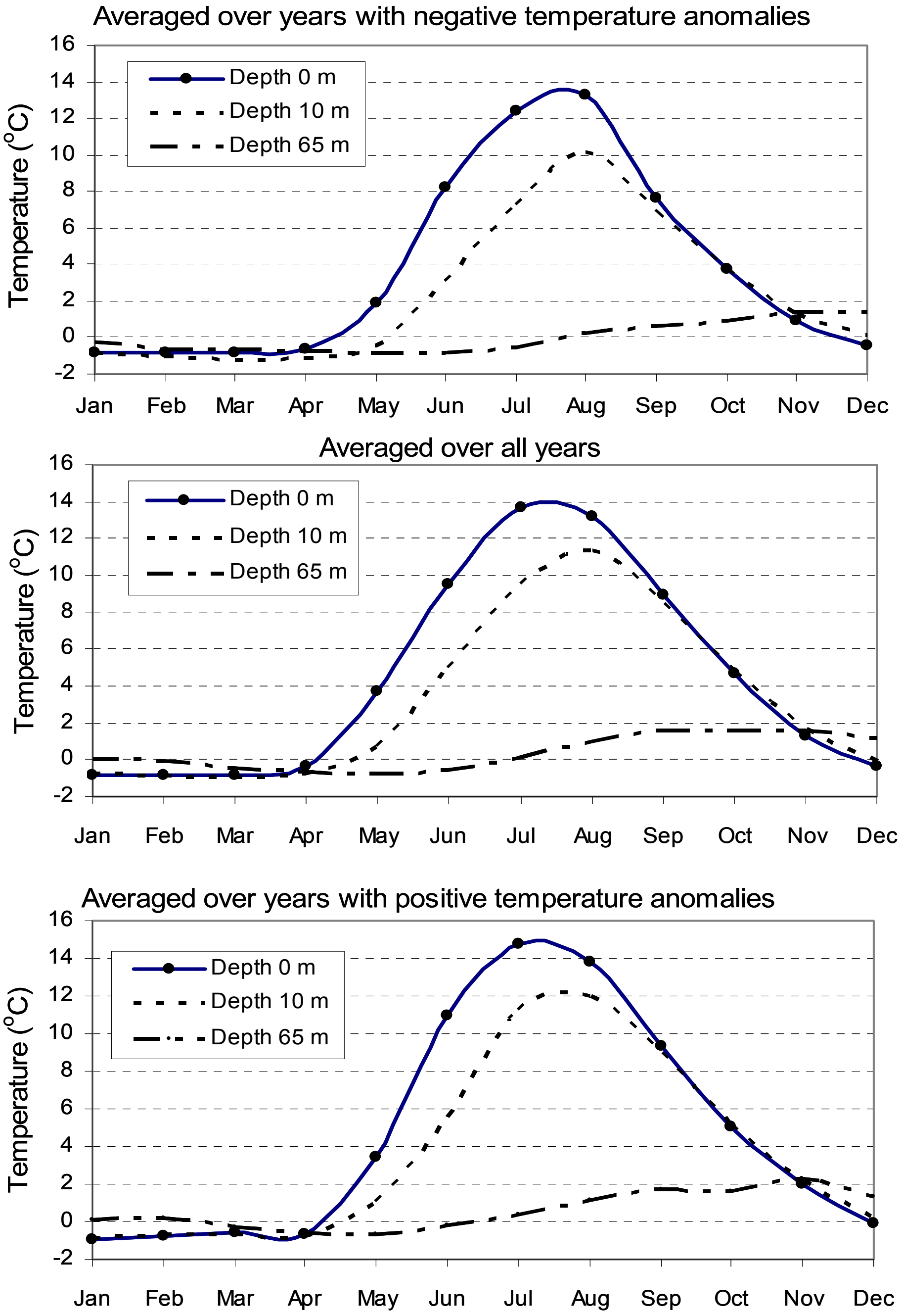

Figure 7. Climatological annual cycles of temperature.

- The zooplankton species most sensitive to water temperature variations is considered to be the one displaying maximum discrepancy among one or more of the above characteristics A, or B, or C; between both C_x(Climatic) and $C_x(A_{T+})$; and between C_x(Climatic) and $C_x(A_{T-})$. To reveal these discrepancies, it is necessary to estimate the characteristics A, B, C. It is no problem to do this for A by using the available database, but more information is required to estimate B and C for the White Sea region in particular. Therefore, we limit this study to treat only the characteristic A. In this case, the designations given above mean the following:

- C_x(Climatic) is the mean annual zooplankton abundance for species, x, calculated for all years;
- $C_x(A_{T+})$ is the mean annual zooplankton species abundance, x, calculated for those years with a positive temperature anomaly;
- $C_x(A_{T-})$ is the mean annual zooplankton species abundance, x, calculated for those years with a negative temperature anomaly.

To solve Problem 2, we may use the algorithm for Problem1 but with the introduction of slight modifications. These modifications are as follows:

- The sets of years A_{T+} and A_{T-} are substituted with A_{S+} and A_{S-}, where A_{S+} and A_{S-} are the sets of years with positive and negative annual salinity anomalies (Figure 5):
  A_{S+} = {1963, 1964, 1965, 1967, 1968, 1969, 1970, 1971, 1973, 1974, 1975, 1976, 1978}
  A_{S-} = {1979, 1981, 1982, 1983, 1984, 1985, 1987, 1990, 1992, 1994, 1998}
  The remaining years are those with a salinity anomaly around zero. Figure 8 shows the cycle of annual salinity variations for the sets of years, A_{S+} and A_{S-}, and the total set of years.

- The mechanisms of salinity effects on plankton reproduction are studied but not in as great a detail as compared to those of water-temperature effects. It makes no sense to introduce *Salinity optimum of zooplankton species* by analogy with *Temperature optimum of zooplankton species* because the biological meaning of this concept is unknown. As a result, we cannot formulate Statement 1 and Statement 2 as has been done for Problem 1. However, it is still possible to identify zooplankton species most sensitive to salinity variations. In biological terms, Problem 1 differs considerably from Problem 2.

  Problem 1 is aimed at checking the hypotheses formulated as Statement 1 and Statement 2.

  Problem 2 is aimed at deriving information that may be useful when it is necessary to formulate hypotheses about salinity on the annual cycle of zooplankton development.

- The following zooplankton characteristics are calculated:
  - $C_x(A_{S+})$ is the mean annual abundance of zooplankton species, x, calculated for those years with a positive salinity anomaly;
  - $C_x(A_{S-})$ is the mean annual abundance of zooplankton species, x, calculated for those years with a negative salinity anomaly.

- The zooplankton species most sensitive to changes in water salinity is considered to be the one showing a maximum discrepancy between C_x(Climatic) and $C_x(A_{S+})$ and between C_x(Climatic) and $C_x(A_{S-})$.

The values of characteristics C_x(Climatic), $C_x(A_{T+})$, $C_x(A_{T-})$, and C_x(Climatic) and $C_x(A_{S+})$, $C_x(A_{S-})$ are presented in Table 5 and Table 6, respectively. For convenience of comparison of changes in mean annual abundances for different zooplankton species the characteristics $C_x(A_{T+})$, $C_x(A_{T-})$, $C_x(A_{S+})$, $C_x(A_{S-})$ are calculated in percentage of C_x(Climatic). These values are shown in Table 7 and Table 8, respectively. As seen in Table 7, a temperature

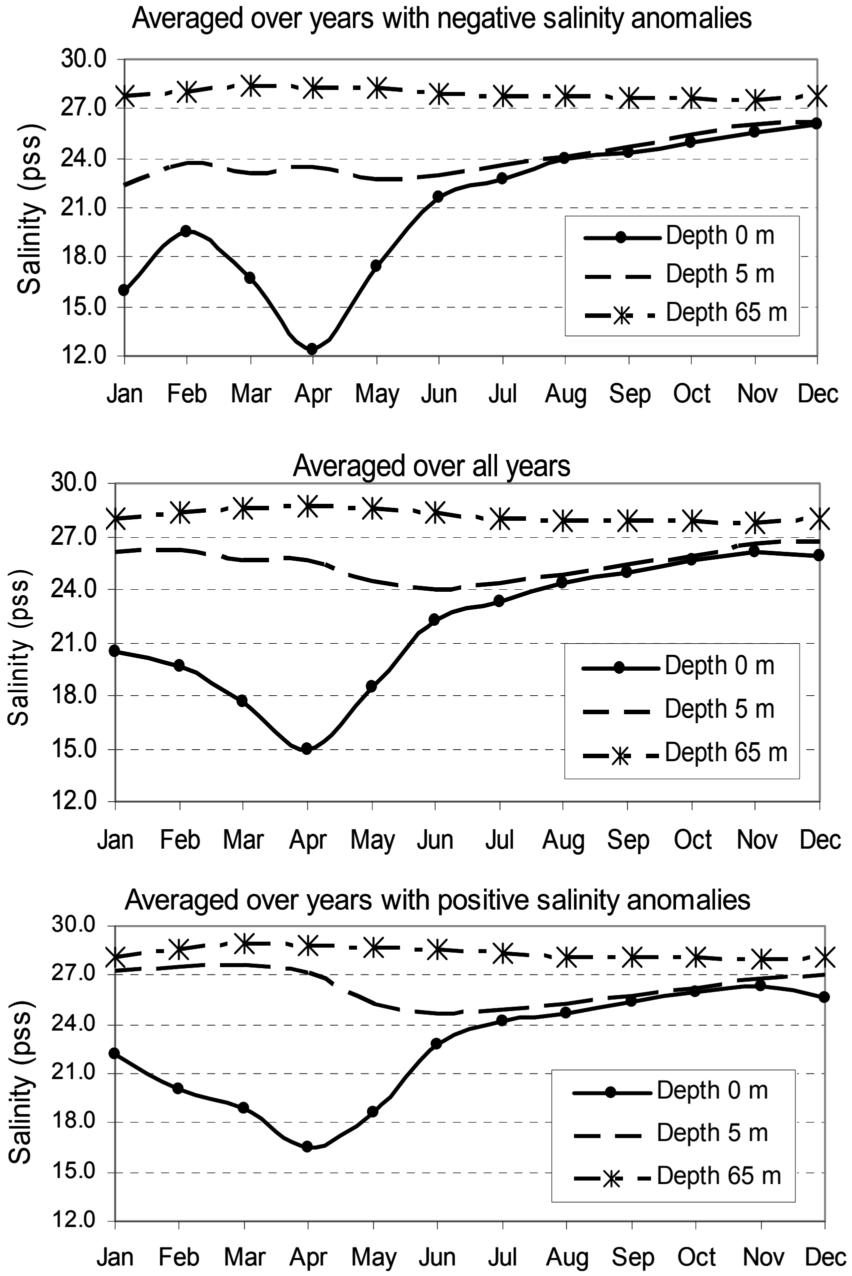

Figure 8. Climatological annual cycles of salinity.

anomaly of any sign causes a reduction in zooplankton abundance. This statement is valid for all zooplankton species from the database. During anomalous years, the total abundance of all zooplankton species is 15% relative to C_x(Climatic). For the zooplankton species most sensitive to temperature variations, the abundance decreases to 7-10% (Figure 9). This result refutes Statement 1 and Statement 2 and makes it necessary to continue studies both in terms of collecting data and developing the methods for data analysis.

Zooplankton response to changing salinity is very diverse as compared to zooplankton response to temperature variations. These diversities are divided into four categories, as can be seen in Table 8:

1. Category A includes the zooplankton species that increase their mean annual abundance as compared to C_x(Climatic) in the years with positive salinity anomaly and decrease it in the years with negative salinity anomaly.

2. Category B includes the zooplankton species that decrease their mean annual abundance as compared to C_x(Climatic) in the years with positive salinity anomaly and increase it in the years with negative salinity anomaly.

3. Category C includes the zooplankton species that increase their abundance with salinity anomaly deviation either to positive or negative values.

4. Category D includes the zooplankton species that, in practice, retain their abundance with salinity anomaly deviations from the long-term mean to positive or negative values.

Table 5. Annual abundance (#/m^3) with respect to temperature anomalies

		Annual abundance, #/m^3		
Zooplankton taxa	**Category**	Averaged over all years, C_x	Averaged over years with positive temperature anomalies, C_x(T+)	Averaged over years with negative temperature anomalies, C_x(T–)
ACARTIA LONGIREMIS Cop	Warmwater	4644	379	748
ACARTIA LONGIREMIS FemaleCop 6	Warmwater	2060	283	311
ACARTIA LONGIREMIS Juv	Warmwater	3318	283	550
ACARTIA LONGIREMIS MaleCop 6	Warmwater	1034	163	150
ACARTIA LONGIREMIS Naup	Warmwater	380	39	101
AGLANTHA DIGITALE	Warmwater	2243	190	215
ASCIDIA Larvae	Warmwater	30	18	0
BIVALVIA Larvae	Warmwater	4621	988	678
BRYOZOA Larvae	Warmwater	802	131	142
CALANUS GLACIALIS Cop 1	Coldwater	729	138	72
CALANUS GLACIALIS Cop 2	Coldwater	631	135	43
CALANUS GLACIALIS Cop 3	Coldwater	841	131	105
CALANUS GLACIALIS Cop 4	Coldwater	1196	151	206
CALANUS GLACIALIS Cop 5	Coldwater	239	24	34
CALANUS GLACIALIS MaleCop 6	Coldwater	10	0	1
CALANUS GLACIALIS FemaleCop 6	Coldwater	126	14	12
CALANUS GLACIALIS Naup	Coldwater	3993	440	286
CENTROPAGES HAMATUS Cop	Warmwater	2712	547	225
CENTROPAGES HAMATUS FemaleCop 6	Warmwater	774	143	88
CENTROPAGES HAMATUS Juv	Warmwater	2092	551	312
CENTROPAGES HAMATUS MaleCop 6	Warmwater	1249	234	138
CENTROPAGES HAMATUS Naup	Warmwater	269	74	44
CIRRIPEDIA Naup	Coldwater	1835	340	244
ECHINODERMATA Larvae	Warmwater	1876	306	288
EVADNE NORDMANNI	Warmwater	6910	1348	1153
FRITILLARIA BOREALIS	Warmwater	8877	1563	924
GASTROPODA Larvae	Warmwater	5319	717	913
METRIDIA LONGA Cop 1	Coldwater	640	35	45
METRIDIA LONGA Cop 2	Coldwater	732	26	70
METRIDIA LONGA Cop 3	Coldwater	792	54	108
METRIDIA LONGA Cop 4	Coldwater	418	33	80
METRIDIA LONGA Cop 5	Coldwater	233	29	44
METRIDIA LONGA FemaleCop 6	Coldwater	187	30	22
METRIDIA LONGA MaleCop 6	Coldwater	225	26	24
METRIDIA LONGA Naup	Coldwater	1063	138	111
MICROSETELLA NORVEGICA	Warmwater	827	159	142
MICROSETELLA NORVEGICA Cop	Warmwater	4340	583	1315
MICROSETELLA NORVEGICA Juv	Warmwater	246	32	59
MICROSETELLA NORVEGICA Naup	Warmwater	362	21	90
OICOPLEURA VANHOFFENIS.csv	Coldwater	211	12	7
OITHONA SIMILIS Cop	Warmwater	144309	21518	22068
OITHONA SIMILIS FemaleCop 6	Warmwater	57647	9486	8242
OITHONA SIMILIS Juv	Warmwater	6685	735	1423
OITHONA SIMILIS MaleCop 6	Warmwater	11546	1673	1646
OITHONA SIMILIS Naup	Warmwater	1789	173	548
ONCAEA BOREALIS Cop	Coldwater	5159	346	1726
ONCAEA BOREALIS FemaleCop 6	Coldwater	14169	1335	2201
ONCAEA BOREALIS MaleCop 6	Coldwater	3725	112	1169
PARAFAVELLA DENTICULATA	Warmwater	2540	427	292
PODON LEUCKARTI	Warmwater	2126	389	272
POLYCHAETA Larvae		2779	496	368
PSEUDOCALANUS MINUTUS Cop 1	Coldwater	16520	2367	2263
PSEUDOCALANUS MINUTUS Cop 2	Coldwater	20428	3345	2690
PSEUDOCALANUS MINUTUS Cop 3	Coldwater	44648	7959	6276
PSEUDOCALANUS MINUTUS Cop 4	Coldwater	29144	4250	4108
PSEUDOCALANUS MINUTUS Cop 5	Coldwater	26420	3055	3170
PSEUDOCALANUS MINUTUS FemaleCop 6	Coldwater	7672	966	1258
PSEUDOCALANUS MINUTUS MaleCop 6	Coldwater	1500	88	346
PSEUDOCALANUS MINUTUS Naup	Coldwater	19759	2326	3997
SAGITTA ELEGANS	Warmwater	1402	239	119
TEMORA LONGICORNIS Cop	Warmwater	9576	3233	485
TEMORA LONGICORNIS FemaleCop 6	Warmwater	5161	1488	419
TEMORA LONGICORNIS Juv	Warmwater	6229	2063	492
TEMORA LONGICORNIS MaleCop 6	Warmwater	5475	1425	467
TEMORA LONGICORNIS Naup	Warmwater	1166	223	216

Table 6. Annual abundance (#/m^3) with respect to salinity anomalies

Zooplankton taxa	**Annual abundance, #/m^3**		
	Averaged over all years, C_x	Averaged over years with positive salinity anomalies, $C_x(S+)$	Averaged over years with negative salinity anomalies, $C_x(S–)$
ACARTIA LONGIREMIS Cop	4644	7796	3611
ACARTIA LONGIREMIS FemaleCop 6	2060	2646	2426
ACARTIA LONGIREMIS Juv	3318	7129	2777
ACARTIA LONGIREMIS MaleCop 6	1034	1651	1393
ACARTIA LONGIREMIS Naup	380	1221	435
AGLANTHA DIGITALE	2243	7897	1111
ASCIDIA Larvae	30	26	210
BIVALVIA Larvae	4621	5812	4824
BRYOZOA Larvae	802	1636	1161
CALANUS GLACIALIS Cop 1	729	532	3118
CALANUS GLACIALIS Cop 2	631	607	1741
CALANUS GLACIALIS Cop 3	841	910	1496
CALANUS GLACIALIS Cop 4	1196	983	1871
CALANUS GLACIALIS Cop 5	239	161	411
CALANUS GLACIALIS MaleCop 6	10	32	19
CALANUS GLACIALIS FemaleCop 6	126	143	207
CALANUS GLACIALIS Naup	3993	2795	9949
CENTROPAGES HAMATUS Cop	2712	2243	3650
CENTROPAGES HAMATUS FemaleCop 6	774	601	1096
CENTROPAGES HAMATUS Juv	2092	2657	2557
CENTROPAGES HAMATUS MaleCop 6	1249	1298	1732
CENTROPAGES HAMATUS Naup	269	538	426
CIRRIPEDIA Naup	1835	2026	2467
ECHINODERMATA Larvae	1876	4856	814
EVADNE NORDMANNI	6910	5940	6435
FRITILLARIA BOREALIS	8877	8264	12045
GASTROPODA Larvae	5319	5255	4720
METRIDIA LONGA Cop 1	640	998	569
METRIDIA LONGA Cop 2	732	714	731
METRIDIA LONGA Cop 3	792	840	904
METRIDIA LONGA Cop 4	418	604	495
METRIDIA LONGA Cop 5	233	300	316
METRIDIA LONGA FemaleCop 6	187	210	270
METRIDIA LONGA MaleCop 6	225	235	326
METRIDIA LONGA Naup	1063	2268	1886
MICROSETELLA NORVEGICA	827	877	1968
MICROSETELLA NORVEGICA Cop	4340	7455	3735
MICROSETELLA NORVEGICA Juv	246	492	1137
MICROSETELLA NORVEGICA Naup	362	983	1031
OICOPLEURA VANHOFFENIS.csv	211	397	263
OITHONA SIMILIS Cop	144309	153596	149145
OITHONA SIMILIS FemaleCop 6	57647	51694	66332
OITHONA SIMILIS Juv	6685	12655	9898
OITHONA SIMILIS MaleCop 6	11546	10239	14906
OITHONA SIMILIS Naup	1789	4496	1603
ONCAEA BOREALIS Cop	5159	9974	4089
ONCAEA BOREALIS FemaleCop 6	14169	17111	11758
ONCAEA BOREALIS MaleCop 6	3725	8609	2934
PARAFAVELLA DENTICULATA	2540	3624	6351
PODON LEUCKARTI	2126	2487	2734
POLYCHAETA Larvae	2779	2940	4390
PSEUDOCALANUS MINUTUS Cop 1	16520	17014	30251
PSEUDOCALANUS MINUTUS Cop 2	20428	19309	31886
PSEUDOCALANUS MINUTUS Cop 3	44648	33467	62923
PSEUDOCALANUS MINUTUS Cop 4	29144	25372	33506
PSEUDOCALANUS MINUTUS Cop 5	26420	21099	26363
PSEUDOCALANUS MINUTUS FemaleCop 6	7672	7266	8736
PSEUDOCALANUS MINUTUS MaleCop 6	1500	2182	2128
PSEUDOCALANUS MINUTUS Naup	19759	28491	19417
SAGITTA ELEGANS	1402	1330	1884
TEMORA LONGICORNIS Cop	9576	10200	13507
TEMORA LONGICORNIS FemaleCop 6	5161	4415	7258
TEMORA LONGICORNIS Juv	6229	9212	5767
TEMORA LONGICORNIS MaleCop 6	5475	5776	6501
TEMORA LONGICORNIS Naup	1166	2343	990

Table 7. Annual abundance (%) with respect to temperature anomalies

		Annual abundance, %	**Annual abundance, % (relative to all years)**	
Zooplankton taxa	**Category**	Averaged over all years, C_x	Averaged over years with positive temperature anomalies, $C_x(T+)$	Averaged over years with negative temperature anomalies, $C_x(T-)$
ACARTIA LONGIREMIS Cop	Warmwater	100	8	16
ACARTIA LONGIREMIS FemaleCop 6	Warmwater	100	14	15
ACARTIA LONGIREMIS Juv	Warmwater	100	9	17
ACARTIA LONGIREMIS MaleCop 6	Warmwater	100	16	15
ACARTIA LONGIREMIS Naup	Warmwater	100	10	27
AGLANTHA DIGITALE	Warmwater	100	8	10
ASCIDIA Larvae	Warmwater	100	59	1
BIVALVIA Larvae	Warmwater	100	21	15
BRYOZOA Larvae	Warmwater	100	16	18
CALANUS GLACIALIS Cop 1	Coldwater	100	19	10
CALANUS GLACIALIS Cop 2	Coldwater	100	21	7
CALANUS GLACIALIS Cop 3	Coldwater	100	16	12
CALANUS GLACIALIS Cop 4	Coldwater	100	13	17
CALANUS GLACIALIS Cop 5	Coldwater	100	10	14
CALANUS GLACIALIS MaleCop 6	Coldwater	100	5	12
CALANUS GLACIALIS FemaleCop 6	Coldwater	100	11	10
CALANUS GLACIALIS Naup	Coldwater	100	11	7
CENTROPAGES HAMATUS Cop	Warmwater	100	20	8
CENTROPAGES HAMATUS FemaleCop 6	Warmwater	100	18	11
CENTROPAGES HAMATUS Juv	Warmwater	100	26	15
CENTROPAGES HAMATUS MaleCop 6	Warmwater	100	19	11
CENTROPAGES HAMATUS Naup	Warmwater	100	27	16
CIRRIPEDIA Naup	Coldwater	100	19	13
ECHINODERMATA Larvae	Warmwater	100	16	15
EVADNE NORDMANNI	Warmwater	100	20	17
FRITILLARIA BOREALIS	Warmwater	100	18	10
GASTROPODA Larvae	Warmwater	100	13	17
METRIDIA LONGA Cop 1	Coldwater	100	6	7
METRIDIA LONGA Cop 2	Coldwater	100	4	10
METRIDIA LONGA Cop 3	Coldwater	100	7	14
METRIDIA LONGA Cop 4	Coldwater	100	8	19
METRIDIA LONGA Cop 5	Coldwater	100	13	19
METRIDIA LONGA FemaleCop 6	Coldwater	100	16	12
METRIDIA LONGA MaleCop 6	Coldwater	100	12	11
METRIDIA LONGA Naup	Coldwater	100	13	10
MICROSETELLA NORVEGICA	Warmwater	100	19	17
MICROSETELLA NORVEGICA Cop	Warmwater	100	13	30
MICROSETELLA NORVEGICA Juv	Warmwater	100	13	24
MICROSETELLA NORVEGICA Naup	Warmwater	100	6	25
OICOPLEURA VANHOFFENIS.csv	Coldwater	100	6	3
OITHONA SIMILIS Cop	Warmwater	100	15	15
OITHONA SIMILIS FemaleCop 6	Warmwater	100	16	14
OITHONA SIMILIS Juv	Warmwater	100	11	21
OITHONA SIMILIS MaleCop 6	Warmwater	100	14	14
OITHONA SIMILIS Naup	Warmwater	100	10	31
ONCAEA BOREALIS Cop	Coldwater	100	7	33
ONCAEA BOREALIS FemaleCop 6	Coldwater	100	9	16
ONCAEA BOREALIS MaleCop 6	Coldwater	100	3	31
PARAFAVELLA DENTICULATA	Warmwater	100	17	11
PODON LEUCKARTI	Warmwater	100	18	13
POLYCHAETA Larvae		100	18	13
PSEUDOCALANUS MINUTUS Cop 1	Coldwater	100	14	14
PSEUDOCALANUS MINUTUS Cop 2	Coldwater	100	16	13
PSEUDOCALANUS MINUTUS Cop 3	Coldwater	100	18	14
PSEUDOCALANUS MINUTUS Cop 4	Coldwater	100	15	14
PSEUDOCALANUS MINUTUS Cop 5	Coldwater	100	12	12
PSEUDOCALANUS MINUTUS FemaleCop 6	Coldwater	100	13	16
PSEUDOCALANUS MINUTUS MaleCop 6	Coldwater	100	6	23
PSEUDOCALANUS MINUTUS Naup	Coldwater	100	12	20
SAGITTA ELEGANS	Warmwater	100	17	9
TEMORA LONGICORNIS Cop	Warmwater	100	34	5
TEMORA LONGICORNIS FemaleCop 6	Warmwater	100	29	8
TEMORA LONGICORNIS Juv	Warmwater	100	33	8
TEMORA LONGICORNIS MaleCop 6	Warmwater	100	26	9
TEMORA LONGICORNIS Naup	Warmwater	100	19	19

Table 8. Annual abundance (%) with respect to salinity anomalies

Zooplankton taxa	Annual Abundance, %	Annual Abundance, % (relative to all years)		Category
	Averaged over all years, C_x	Averaged over years with positive salinity anomalies, $C_x(S+)$	Averaged over years with negative salinity anomalies, $C_x(S-)$	
ACARTIA LONGIREMIS Cop	100	168	78	A
ACARTIA LONGIREMIS FemaleCop 6	100	128	118	C
ACARTIA LONGIREMIS Juv	100	215	84	A
ACARTIA LONGIREMIS MaleCop 6	100	160	135	C
ACARTIA LONGIREMIS Naup	100	321	114	C
AGLANTHA DIGITALE	100	352	50	A
ASCIDIA Larvae	100	85	700	B
BIVALVIA Larvae	100	126	104	C
BRYOZOA Larvae	100	204	145	C
CALANUS GLACIALIS Cop 1	100	73	427	B
CALANUS GLACIALIS Cop 2	100	96	276	
CALANUS GLACIALIS Cop 3	100	108	178	C
CALANUS GLACIALIS Cop 4	100	82	156	B
CALANUS GLACIALIS Cop 5	100	67	172	B
CALANUS GLACIALIS MaleCop 6	100	302	182	C
CALANUS GLACIALIS FemaleCop 6	100	113	164	C
CALANUS GLACIALIS Naup	100	70	249	B
CENTROPAGES HAMATUS Cop	100	83	135	B
CENTROPAGES HAMATUS FemaleCop 6	100	78	142	B
CENTROPAGES HAMATUS Juv	100	127	122	C
CENTROPAGES HAMATUS MaleCop 6	100	104	139	C
CENTROPAGES HAMATUS Naup	100	200	158	C
CIRRIPEDIA Naup	100	110	134	C
ECHINODERMATA Larvae	100	259	43	A
EVADNE NORDMANNI	100	86	93	
FRITILLARIA BOREALIS	100	93	136	
GASTROPODA Larvae	100	99	89	D
METRIDIA LONGA Cop 1	100	156	89	A
METRIDIA LONGA Cop 2	100	98	100	D
METRIDIA LONGA Cop 3	100	106	114	C
METRIDIA LONGA Cop 4	100	145	118	C
METRIDIA LONGA Cop 5	100	128	135	C
METRIDIA LONGA FemaleCop 6	100	112	144	C
METRIDIA LONGA MaleCop 6	100	104	145	C
METRIDIA LONGA Naup	100	213	177	C
MICROSETELLA NORVEGICA	100	106	238	C
MICROSETELLA NORVEGICA Cop	100	172	86	A
MICROSETELLA NORVEGICA Juv	100	200	462	C
MICROSETELLA NORVEGICA Naup	100	272	285	C
OICOPLEURA VANHOFFENIS.csv	100	188	125	C
OITHONA SIMILIS Cop	100	106	103	D
OITHONA SIMILIS FemaleCop 6	100	90	115	B
OITHONA SIMILIS Juv	100	189	148	C
OITHONA SIMILIS MaleCop 6	100	89	129	B
OITHONA SIMILIS Naup	100	251	90	A
ONCAEA BOREALIS Cop	100	193	79	A
ONCAEA BOREALIS FemaleCop 6	100	121	83	A
ONCAEA BOREALIS MaleCop 6	100	231	79	A
PARAFAVELLA DENTICULATA	100	143	250	C
PODON LEUCKARTI	100	117	129	C
POLYCHAETA Larvae	100	106	158	C
PSEUDOCALANUS MINUTUS Cop 1	100	103	183	C
PSEUDOCALANUS MINUTUS Cop 2	100	95	156	
PSEUDOCALANUS MINUTUS Cop 3	100	75	141	B
PSEUDOCALANUS MINUTUS Cop 4	100	87	115	B
PSEUDOCALANUS MINUTUS Cop 5	100	80	100	
PSEUDOCALANUS MINUTUS FemaleCop 6	100	95	114	D
PSEUDOCALANUS MINUTUS MaleCop 6	100	145	142	C
PSEUDOCALANUS MINUTUS Naup	100	144	98	
SAGITTA ELEGANS	100	95	134	
TEMORA LONGICORNIS Cop	100	107	141	C
TEMORA LONGICORNIS FemaleCop 6	100	86	141	B
TEMORA LONGICORNIS Juv	100	148	93	A
TEMORA LONGICORNIS MaleCop 6	100	105	119	
TEMORA LONGICORNIS Naup	100	201	85	A

Figure 9 shows the diagrams of the abundance dynamics for those zooplankton species that considerably change their mean annual abundances with temperature and salinity deviation from the long-term mean. As seen, temperature and salinity variations cause a 10- to 12-fold and 1.5- to 4.3-fold change, respectively, in zooplankton abundance. This leads us to the conclusion that in the White Sea region under consideration, zooplankton is more sensitive to temperature rather than salinity variations. Zooplankton species *CALANUS GLACIALIS Naup.* is most sensitive to changes both in temperature and salinity.

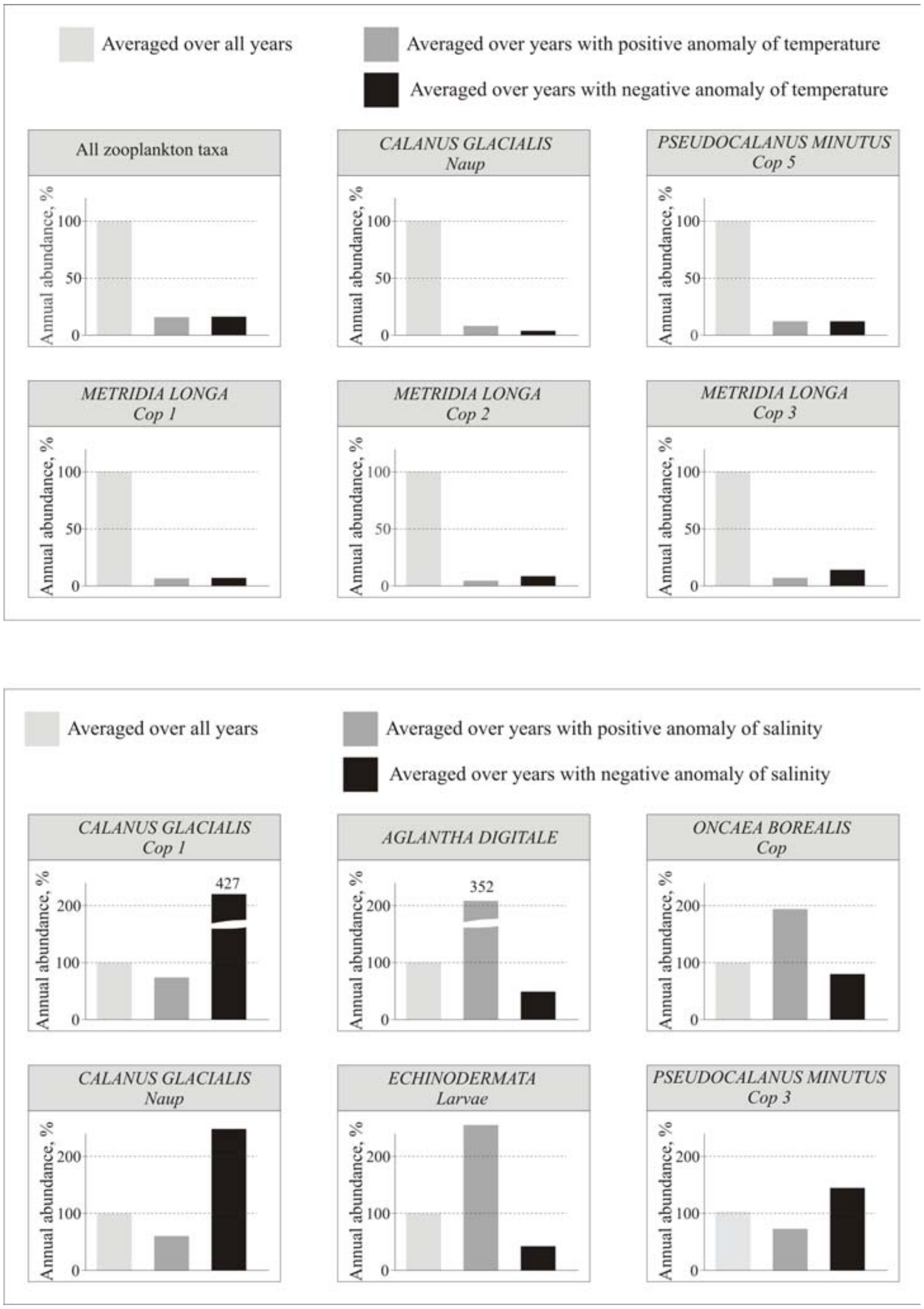

Figure 9. The effect of temperature and salinity variations on zooplankton abundance.

6. CD-ROM Contents

The accompanying CD-ROM contains original data in comma separated value (CSV) format along with auxiliary tables, figures, and text of the Atlas in PDF format.

Documentation: This section contains the text of the *36-Year Time Series (1963-1998) of Zooplankton, Temperature, and Salinity in the White Sea.*

Database: There are two categories in this section: "Taxa" and "Primary Data". Under "Primary Data," there are three subsections: Temperature, Salinity; Zooplankton; and All Data. The Taxa subsection will permit the user to see an Excel spreadsheet containing Group, Species, and Ontogenetic stages of zooplankton in the White Sea. The "Temperature, Salinity" and "Zooplankton" subsections provide an inventory of these parameters by year and the number of measurements per ten-day period. Clicking on any year will result in an Excel spreadsheet of the primary data for that year. Clicking on the "All Data" subsection simply produces a pop-up window indicating that the user can find all data in the Atlas/Data folder on the CD-ROM.

Environment: This section provides graphs depicting the analyses of temperature and salinity. Within the "Temperature" and "Salinity" categories, the user will find two subsections on the "Annual Cycle" and "Time Series" of these parameters. The "Annual Cycle" subsection for both "Temperature" and "Salinity" is further broken down into "All Years (climatology)," "Years with anomaly T>0 (or S>0)," and "Years with anomaly T<0 (or S<0)."

Zooplankton: This section has four categories: "Annual Cycle," "Zooplankton vs. T," "Zooplankton *vs*. S," and a "Read me" pop-up window. Clicking on "Annual Cycle" produces a pop-up window of all the zooplankton species measured at three different levels. The user can check as many boxes as desired with the option to display the graphs on the screen (click on the "okay" button) or to send the graphs to a printer. By going to the Window section, the user can choose to display the graphs onscreen in a variety of formats: Cascade, Tile Horizontal, or Tile Vertical. However, the last two formats can only display a maximum of 12 graphs on the screen.

Summary: This section provides the graphical results of the zooplankton species most sensitive to the variability of temperature and salinity, averaged over all years and for positive and negative anomalies.

White Sea Publications: A list of publications by the personnel of the White Sea Biological Station and a full manuscript version of four selected articles are provided in this section.

Photo Gallery: This section contains a selection of pictures of the ship, various experiments, and scenery on and around the White Sea.

About: E-mail addresses and phone numbers for the authors of this product can be found in this section.

7. Conclusion and Future Studies

The time series of salinity variations points to two time intervals with clearly differing values of salinity anomalies. The period 1961-1978 is characterized by positive salinity anomalies for the surface-to-bottom water layer. The period 1979-1995 is characterized by negative salinity anomalies.

The development for every zooplankton species given in the database can be described according to its climatic annual cycle. This result can be applied to other biological data in the Arctic Seas as a criterion for quality control.

The zooplankton species most sensitive to variations in temperature and salinity have been identified. These relationships can be a useful tool as applied to other regions of the White and Barents Seas. In future studies, priority will be given to the development of the methods for quality control of biological data as well as the documentation of changes in the conditions of the marine environment and to zooplankton.

8. References

Babkov A.I., A.N. Golikov, 1984: *Hydrobiocomplexes of the White Sea*. Leningrad: Zoological Institute, AS USSR, 102 pp. (in Russian).

Berger, V. Ja., A.D. Naumov, A.A Sukhotin, 1995: Conclusion, in *The White Sea: Biological resources and problems of their rational exploitations, Part 1: Exploration of the fauna of seas*, 42(50). St. Petersburg: Zoological Institute, RAS, pp. 207-214 (in Russian).

Berger, V. Ja., S. Dahle, K. Galaktionov, X. Kosobokova, A. Naumov, T. Rat'kova, V. Savinov, T. Savinova, 2001: *The White Sea Ecology and Environment* (ed. by V. Ja. Berger and S. Dahle), St. Petersburg – Tomsø: Derzavets, 157 pp.

Bogorov, V.G., M.E. Vinogradov, N.M. Voronina, I.P. Kanaeva and I.A. Suetova, 1968: Distribution of zooplankton biomass in surface layer of World Ocean. *Reports of the AS USSR (Doklady Akademii nauk SSSR),* 182(5), pp. 1205-1207 (in Russian).

Bondarenko, M.V., 1994: Features of zooplankton distribution of the White Sea in the beginning of summer 1991, in *Complex Research of the White Sea Ecosystem*. Moscow, pp. 92-94 (in Russian).

Epstein, L.M., 1963: Zooplankton of the White Sea and its importance in feeding of herring, in *Problems of Utilization of Commercial Resources of the White Sea and Inland Reservoirs of Karelia* (Problemy ispol'zovaniya promyslovych resursov Belogo morya i vnutrennich vodoemov Karelii). Moscow-Leningrad, 1, pp. 98-104 (in Russian).

Kuznetsov, V.V., 1960: *The White Sea and Biological Features of its Flora and Fauna*. Moscow-Leningrad: Russian Academy of Sciences, 322 pp. (in Russian).

Marshall, S.M., A.P. Orr, 1955: On the biology of Calanus finmarchicus, VIII: Food uptake, assimilation and excretion in adult and stage V Calanus. *J. Mar. Biol. Assoc. UK,* 34(3), pp. 495-529.

Moiseev, P.A., 1969: *Biological resources of the World Ocean*. Moscow. 339 pp. (in Russian).

Naumov A.D., V.V. Fedyakov, and S.J. Cochrane, in press: Some seasonal and long-term observations of intertidal benthic biomass in two small bays in the inner part of the White Sea. *Sarsia*.

Pertzova, N.M. and R.V. Prygunkova, 1995: Zooplankton, in *The White Sea: Biological Resources and Problems of their Rational Exploitations, Part 1: Exploration of the fauna of seas*, (Beloe more: Biologicheskie resursy i problemy ih ratsional'nogo ispol'zovaniya), Vol 42(50), St. Petersburg: Zoological Institute RAS, pp. 115-141 (in Russian).

Prygunkova, R.V., 1974: Some features of seasonal zooplankton development in Chupa Inlet of the White Sea, in *The Seasonal Phenomena of Life in the White and Barents seas: Exploration of the fauna of seas* (Sezonnye yavleniya v zhizni Belogo i Barentseva morei), 13(21). Leningrad: Zoological Institute AS USSR, pp. 4-55 (in Russian).

Troshkov, V.A., 1998: On the characterization of zooplankton in the Gorlo Strait of the White Sea, in *Proc. of the Study of the Problems of Rational Exploration and Conservation of Natural Resources of the White Sea* (Problemy izucheniya, ratsional'nogo ispol'zovaniya i ochrany prirodnych resursov Belogo morya). Arkhangelsk. pp. 130-131 (in Russian).

Sushin V.A., 1978: The problem of dependence of marine Copepod metamorphose duration on ambient temperature, in *Oceanological Investigations in the Atlantic Ocean (Okeanologicheskie issledovanija v Atlanticheskom okeane),* Proceedings of AtlantNIRO*,* Issue 76, pp. 94-98 (in Russian).

Vinogradov, M.E., 1955: Vertical migrations of zooplankton and their role in feeding of deep-water pelagic fauna. *Proc. of IO AS USSR* (Trudy IOAN SSSR), 13, pp. 71-76 (in Russian).

Waterman, T.H. (ed.), 1960: *The Physiology of Crustacea*, Vol. 1. New York-London: Academic Press, 670 pp.

Zatichnoi, B.M. and D.E. Gershanovich (eds.), 1991: *Hydrometeorology and Hydrochemistry of the Seas of the USSR, Vol. II: The White Sea*, Leningrad: Hydrometeozdat, 193 pp.

Zenkevich, L.A. 1947: *Fauna and biological productivity of the sea*. Moscow, 558 pp. (in Russian).