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REPORT

INFLUENCE OF ECOSYSTEM CHANGES ON HARVESTABLE RESOURCES AT HIGH LATITUDES

Proceedings of the 18th Russian-Norwegian Symposium

Murmansk, 5–7 June 2018

Institute of Marine Research – IMR

Polar Research Institute of Marine
Fisheries and Oceanography – PINRO

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Murmansk, 5–7 June 2018

Edited by
Evgeny Shamray, Geir Huse, Alexander Trofimov, Svein Sundby,
Andrey Dolgov, Hein Rune Skjoldal, Konstantin Sokolov, Lis Lindal Jørgensen,
Anatoly Filin, Tore Haug and Vladimir Zabavnikov

Murmansk/Bergen/Tromsø
2019

Preface

The 18th Russian-Norwegian Symposium, entitled “Influence of ecosystem changes on harvestable resources at high latitudes”, was held in Murmansk, Russia on 5–7 June 2018. The Symposium was organized by the Polar Research Institute of Marine Fisheries and Oceanography (Russia) and the Institute of Marine Research (Norway) with the assistance of the Fishing Industry Union of the North (Russia). The theme of the Symposium attracted people from scientific institutions, people dealing with fisheries management and people from the fishing industry. In total, 77 persons attended the Symposium and 64 contributions were presented; 54 oral presentations and 10 posters.

Recent warming in the Arctic and in the Barents Sea has been continuing since the late 1990s. During this period, considerable changes have been observed in the Barents Sea ecosystem both in environmental conditions and in living organisms. Evidently, this period is long and enough to facilitate analyses of changes in marine organisms at different trophic levels. On this background, results from investigations of the Barents Sea environment were presented in Session 1 of the Symposium. Furthermore, presentations of impact of environmental changes on populations of plankton, benthos, fishes, sea birds and marine mammals were presented in Sessions 2–5. In general, increased water temperature results in increased abundance and extended northward distribution of boreal organisms (especially fish and marine mammals), while abundance and distribution area of Arctic species decreased. These changes are important for the biological state of marine harvestable resources, interspecific relations in the Barents Sea ecosystem, and national fisheries.

The oral and poster presentations given at the Symposium presented results related to all these important issues, and are valuable contributions to the evaluation of recent changes in the Barents Sea ecosystem and of possible impact on future fisheries in this region. The editors hope that the material from these Symposium Proceedings will be interesting for scientists (oceanographers and biologists) as well as for fishermen and managers.

The Proceedings contain contributions in a mixture of formats, chosen individually by the contributors. Some opted for an abstract or an extended abstract to be presented, others wrote a full paper to be included, and still others agreed to make their presentations available to the public, either as presented during the Symposium, or slightly edited by the authors after the Symposium. There has been no peer review process; the submitted contributions were included without any changes, apart from some modest language editing and uniform formatting. Only contributions from those who personally took part in the Symposium were included in the Proceedings.

Murmansk/Bergen/Tromsø, 15 February 2019

The editors

Individual papers in the Proceedings should be cited as:

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THEME SESSION I: OCEANOGRAPHY

Climate variability in the Barents Sea: Past, present, and future

Vidar S. Lien

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During the last few decades, the Arctic has experienced large climatic changes, reflected in its shrinking sea-ice cover. While the most spectacular sea-ice decline during summer has occurred on the Pacific side of the Arctic, the largest variability and decline in winter has occurred in the Barents Sea on the Atlantic side of the Arctic. The Atlantic Water transported poleward has been found to significantly influence the sea-ice cover in the Barents Sea, with climatic variability in temperature dominating on inter-annual and longer timescales and changes in volume transport dominating on shorter timescales. While global climate warming is causing a trend towards higher temperature, the Barents Sea climate also exhibits large variations between years and decades, superimposed onto the underlying trend. Currently, the climatic conditions in the Barents Sea are likely close to an intermediate temperature high and, thus, low sea-ice cover. These climatic changes and variability affect the ecosystem through changes in the thermal habitat, as well as the sea-ice cover, which acts as a barrier for some species while being a pre-requisite for others. Thus, the Atlantic Water flow to the Barents Sea plays an integral role in defining both the physical and biological border between the boreal and arctic realms. Indeed, the variability of the Atlantic Water flow to the Barents Sea has been found to move the position of the Polar Front, distinguishing the boreal from the arctic water masses, as well as the ice edge, thereby affecting the habitats of many species in the Barents Sea ecosystem.

Deep-water aeration as an indicator of changes in the Barents Sea ecosystem

Oleg Titov

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A historical series of observations of oxygen content in sea water along the Kola Section is one of the longest and data-rich oceanographic series in the world. Measurements of oxygen content in sea water on the Kola Section have been conducted for about a century. Since late 1950s, seawater from the Kola Section has been analysed for dissolved oxygen on the regular basis. More than 350 series of oxygen content measurements have been performed so far on the stretch of the Kola Section (stations 3–7, 70°30'–72°30'N, 33°30'E) crossing the main filament of the Atlantic Water, i.e. average frequency of measurements was 6 times annually. All seawater samples collected ca. 3–5 m above the seabed were analysed for dissolved oxygen in the vessel laboratory using the Winkler method immediately after the oceanographic station coverage. Oxygen saturation of near-bottom water on Kola Section (OSBW) was calculated based on the data on oxygen content, temperature and salinity of water samples. The input data were then mathematically processed to derive a continuous data series suitable for statistical analysis. It is applied similar methods for the procession of data on water temperature, salinity and OSBW. This information is available at the official website of PINRO (www.pinro.ru).

The distribution of water density and oxygen saturation of sea water suggests that in the near-bottom water layers at station 3–7 of the Kola Section, the lighter and oxygen-richer Atlantic Water from the western Barents Sea mix with heavier and less oxygen saturated Barents Sea Water located mostly east of the section location.

Large-scale changes in OSBW reflect the overall trends for the entire Barents Sea. Oxygen saturation of near-bottom water in the Barents Sea generally varied from 70 to 100%, with the largest variability in the east. However, the periods of higher- and lower-than-average oxygen saturation of near-bottom water in the entire Barents Sea can be clearly traced by the observation data from the Kola Section. It should also be noted that in the recent decades there have been signs of decreasing oxygen saturation of the near-bottom water of the Barents Sea. Simultaneously with warming-up of water, OSBW has declined by ca. 1% in comparison with the 1950s. This is in line with the general trend of poorer seawater aeration observed in the context of current climate changes.

No significant correlations between water temperature, salinity and OSBW have been revealed. The impact of the Atlantic Water flow on OSBW is clearly demonstrated by the comparison of OSBW with the data of instrumental observations of currents in the western Barents Sea performed by the Institute of Marine Research. There is a strong correlation on a medium-term scale, which means that the periods of stronger currents coincide with the periods of better aeration and vice versa. However, on the interdecadal scale the trends in current velocity and OSBW may be highly variable.

OSBW depends not only on horizontal advection, but also on vertical mixing. As known, the most important factor affecting the aeration of near-bottom layers of the Barents Sea is convective mixing in autumn and winter. This process, as well as near-bottom water dynamics, is difficult to measure instrumentally due to low velocity. In 2017–2018, PINRO experimented with measurements of age (time elapsed after the contact of water with atmosphere) of near-bottom water on the deep-sea troughs in the eastern Barents Sea based on the content of the radioactive isotope – tritium. The comparison of a surface water sample containing 1.2±0.4 tritium units and 100% oxygen saturation with 2 samples of bottom water from depths exceeding 300 m containing respectively 0.6±0.4 and 0.5±0.4 tritium units, 83 and 71% oxygen saturation allowed to estimate their approximate age as 12–16 years.

The correlation between OSBW and the recruitment of Northeast Arctic cod, one of the most abundant bottom species in the Barents Sea, was revealed quite a long time ago and has been used in scientific forecasting by the ICES Arctic Fisheries Working Group (AFWG). In general, better oxygen saturation of the Barents Sea near-bottom water provides favourable conditions for the survival of cod at early life stages (younger than 3 years old). In contrast to, e.g. the North Sea, where a similar natural correlation is observed, variations in oxygen saturation in the Barents Sea bottom water are relatively small and cannot directly affect the survival of juvenile cod.

There is another, previously unknown, specialty. Statistical analysis has shown that the strongest correlation between OSBW and the abundance of Northeast Arctic cod is observed when year-class strength is above average. As known, the strength of weak year-classes is closely correlated with water temperature. The obtained estimates of deep-water age allow the suggestion that strong year-classes of NEA cod can emerge when fresher, “younger” water newly advected from the Atlantic prevail near the bottom. Conversely, a wide distribution of “old”, stagnant Barents Sea Water on the Barents Sea shelf is the adverse biological factor affecting cod growth.

In most general terms, the above correlation can have the following explanation. Initially, cod spawn and live in the Atlantic Water, and, accordingly, during their downward migration to near-bottom layers, young cod experience a considerable stress as they move from their “native” Atlantic Water to strongly different Barents Sea Water. This stress may cause an increased mortality in juvenile cod.

There are many outstanding questions regarding both the causes of oxygen saturation variations in the near-bottom waters of the Barents Sea and the relationship between these changes and the strength of NEA cod year-classes. Why is the emergence of the most abundant cod year-classes related to good aeration, i.e. higher oxygen saturation of bottom water on the Kola Section? What is the difference between the properties of “fresh” Atlantic Water and “old” Barents Sea Water, and what is the impact of these properties on the survival of juvenile cod? How to explain the results of statistical analysis indicating that the correlation of OSBW and the abundance of cod year-classes is the strongest when the latter is above average? What is the impact of bottom water aeration on other demersal fauna in the Barents Sea? What is the environment resulting from the mixing of the Barents Sea and Atlantic Waters or the replacement of the Barents Sea Water by the Atlantic one? Our future research will seek answers to these and other questions.

Climate changes in the Barents Sea over the last half century

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Abstract

As a transition area between the North Atlantic and the Arctic Basin, the Barents Sea plays a key role in water exchange between these areas. Atlantic waters enter the Arctic Basin through the Barents Sea and the Fram Strait. Variations in volume flux, temperature and salinity of Atlantic waters influence hydrographic conditions in both the Barents Sea and the Arctic Ocean as a whole; and they are associated with the large-scale processes in the atmosphere. This paper analyses meteorological and hydrographic conditions in the Barents Sea over the past half century. An attempt was made to formulate integral indices for characterising thermohaline conditions in the Barents Sea as a whole. Based on these, long periods with different thermal (warm/cold) and haline (fresh/saline) conditions were identified since 1965. Since 2000, in the Barents Sea, a steady warm period was recorded. Since 2005, its waters were the warmest and saltiest over the entire period studied. Record high temperatures were recorded in the Barents Sea as a whole in 2016.

Keywords: Barents Sea, climate changes, climate index, haline index

Introduction

The Barents Sea is a shelf sea of the Arctic Ocean, located between northern Europe and the Spitsbergen, Frantz Josef Land and Novaya Zemlya Archipelagoes (Figure 1). Its climate is characterized by heterogeneity, which is determined by the spatial peculiarities of the mingling of warm and cold waters, the amount of solar radiation reaching the sea surface, conditions of ocean-atmosphere interactions, terrestrial influences and other factors (Boitsov, 2006). As a transition area between the North Atlantic and the Arctic Basin, the Barents Sea plays a key role in water exchange between these areas. Variations in volume flux, temperature and salinity of Atlantic waters affect hydrographic conditions in both the Barents Sea and the Arctic Ocean (Boitsov et al., 2012; González-Pola et al., 2018). In the Barents Sea, in the area of interaction of warm Atlantic and cold Arctic waters, water temperature, ice coverage, water circulation and frontal zone structure display extreme interannual variability, which is comparable to and, in some cases, exceeds seasonal variations in oceanic processes (Ozhigin et al., 2016).

The Barents Sea is highly productive and rich in many species of commercial marine species, mainly due to its geographical location between the Arctic and boreal oceanic systems. Hydrographic conditions of the Barents Sea play an important role in the formation of the year-class strength and commercial stocks of these marine organisms as well as influencing the conditions for their feeding, wintering, spawning and seasonal migrations (Trofimov, 2003, Jakobsen, Ozhigin, 2011, Manushin et al., 2014).

In the early 1990s, rising air and water temperatures and reduced ice coverage began in the Barents Sea. These three parameters are the main indicators of climate changes in high-latitude seas (Boitsov et al., 2012). The current warming, like the one in the 1930s – 1950s, a result of the increase in the transfer of warm Atlantic air from the North-East Atlantic and the increase in water advection by the Gulf Stream system and the North Atlantic Current (Karsakov, 2007, 2009). In the 2000s and 2010s, the annual mean temperature in the 0–200 m layer in the Kola Section (70°30'–72°30'N 33°30'E) exceeded the long-term mean every year (Boitsov et al., 2012; González-Pola et al., 2018). At the same time, 2006, 2007, 2012, 2013, 2015 and 2016 were anomalously warm, and, in 2012, the historical maximum annual mean temperature was observed in the Section, exceeding the long-term (1951–2010) mean by 1.3°C. In some months of 2006, 2012, 2015 and 2016, record-high temperatures were observed.

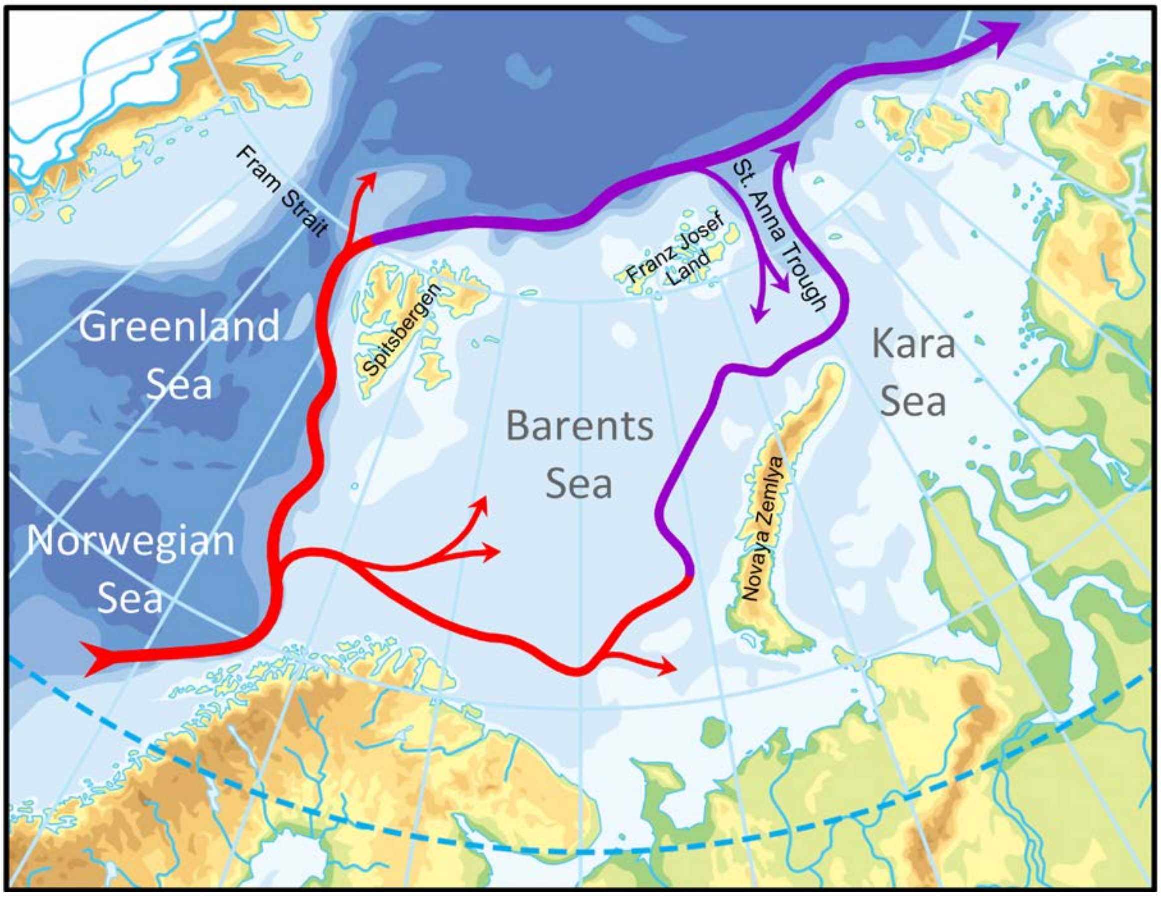

Figure 1. Main flows of Atlantic waters in the Barents Sea (after Boitsov et al., 2012).

The best indicator of climate in the marine part of the Arctic is its ice conditions (Ozhigin et al., 2016, Ozhigin et al., 2011). The analysis of satellite observations of ice conditions in the Arctic Ocean and its seas has shown a trend to reduction in the ice extent since the early 1980s. Over the past 30 years, the amount of ice has been halved in the Barents Sea – the ice-covered area has fallen by 360 000 square km. Since 2003, the extent of ice cover has decreased ever more rapidly (Boitsov et al., 2012).

Taking into account the impact of climate change in the Barents Sea on the functioning of its ecosystem, the association with climatic changes in the Arctic Ocean as well as the current ongoing warming of the Arctic, this paper has examined the patterns and features of changes in climate and its main indicators in the Barents Sea over the past half century.

Material and methods

We studied the following variables, meteorological and hydrographic series, to analyse the climate system of the Barents Sea:

- NAO – winter (December–March) North Atlantic Oscillation index for 1899–2017 (UCAR, 2018);
- TaW and TaE – annual mean air temperature (°C) averaged over the western (70–76°N 15–35°E) and eastern (69–77°N 35–55°E) Barents Sea for 1948–2017 (NOAA, 2018);

- Storms – storm activity (the number of days with wind > 15 m/s in a year, on the whole) in the central Barents Sea (68–80°N 30–40°E) for 1981–2017 (the data were obtained from the Murmansk Department for Hydrometeorology and Environmental Monitoring);
- WDFxSW, WDFxE – annual mean latitudinal (west-east orientation) wind-driven volume fluxes (Sv, 1 Sv = 10^6 m^3/s) in the south-western (through the section along 27°E, 71–75°N) and eastern (through the section along 48°E, 73–77°N) Barents Sea for 1960–2017, calculated with a hydrodynamic model (Trofimov, 2000);
- WDFySW, WDFyE – annual mean longitudinal (south-north orientation) wind-driven volume fluxes (Sv, 1 Sv = 10^6 m^3/s) in the south-western (through the section along 73°N, 20–34°E) and eastern (through the section along 75°N, 40–56°E) Barents Sea for 1960–2017, calculated with a hydrodynamic model (Trofimov, 2000);
- IceBS – annual mean ice coverage (%) of the Barents Sea for 1951–2017 (Shamray, 2018);
- IceAO – ice extent (10^6 km^2) in the Arctic for 1979–2017 (NSIDC, 2018);
- SSTSW and SSTSE – annual mean sea surface temperature (°C) averaged over the south-western (71–74°N 20–40°E) and south-eastern (69–73°N 42–55°E) Barents Sea for 1982–2017 (IRIDL, 2018);
- TwKS and SwKS – annual mean temperature (°C) and salinity in the top 200 m layer in the central part (70°30'–72°30' N) of the Kola Section (along 33°30'E) for 1951–2017 (ICES, 2018);
- AAT and AAS – area-averaged (71–79°N 25–55°E) temperature (°C) and salinity at 50, 100 m and near-bottom depths as well as in the 50–100 and 50–200 m layers in August–September 1965–2017 (the initial data on temperature and salinity were taken from the PINRO database);
- areas (10^3 km^2) covered by waters with different temperatures and salinities in the 50–100 m layer and near the bottom in the Barents Sea (71–79°N 25–55°E) in August–September 1965–2017: AreaArW – Arctic waters (T < 0°C) in the 50–100 m layer, AreaMW – mixed waters (0°C < T < 3°C) in the 50–100 m layer, AreaAW – Atlantic waters (T > 3°C) in the 50–100 m layer, AreaCBW – cold bottom waters (T < 0°C), AreaMBW – mixed bottom waters (0°C < T < 1°C), AreaWBW – warm bottom waters (T > 1°C), AreaFW – fresh waters (S < 34.7) in the 50–100 m layer, AreaMSW – waters with salinity of 34.7 to 34.9 in the 50–100 m layer, AreaSW – saline waters (S > 34.9) in the 50–100 m layer, AreaFBW – fresh bottom waters (S < 34.9), AreaMSBW – bottom waters with salinity of 34.9 to 35.0, AreaSBW – saline bottom waters (S > 35.0) (the areas were calculated on the basis of the data on temperature and salinity taken from the PINRO database).

Altogether, 36 variables were chosen. Their normalised anomalies were used for the analysis. The anomalies were calculated relative to the long-term (1981–2010) mean and normalised with respect to the standard deviation.

Descriptive statistics as well as comparative, correlation and principal component analyses (Eliseeva, Yuzbashev, 2004; Korosov, Gorbach, 2016) were used in the paper. Statistical processing used StatGraphics Centurion XVI and MS Excel 2013; the diagrams were prepared with MS Excel 2013.

Results and discussion

After the preliminary comparative and correlation analyses of the selected series, and taking into account their different lengths, the initial data set was reduced. The final data set included 20 variables for the period spanning 1965 to 2017:

- winter (December–March) North Atlantic Oscillation index (NAO);

- annual mean air temperature averaged over the western (70–76°N 15–35°E) and eastern (69–77°N 35–55°E) Barents Sea (TaW, TaE);
- annual mean latitudinal and longitudinal wind-driven volume fluxes in the south-western and eastern Barents Sea (WDFxSW, WDFxE, WDFySW, WDFyE);
- annual mean ice coverage of the Barents Sea (IceBS);
- annual mean temperature and salinity in the upper 200 m layer in the central part (70°30'–72°30'N) of the Kola Section (along 33°30'E) (TwKS, SwKS);
- area-averaged (71–79°N 25–55°E) temperature and salinity at 100 m in August–September (AAT, AAS);
- areas occupied by waters with different temperatures and salinities in the Barents Sea (71–79°N 25–55°E) in August–September: AreaArW, AreaAW, AreaCBW, AreaWBW, AreaFW, AreaSW, AreaFBW, AreaSBW.

First, let us consider the area-averaged temperatures and salinities. These variables are of particular interest, because they can be used as integral parameters that reflect the thermohaline conditions of the Barents Sea as a whole. The initial data set included area-averaged temperatures and salinities at three depths (50, 100 m, near-bottom) and in two layers (50–100 and 50–200 m). These series appeared to be intercorrelated very well: the correlation coefficients were 0.92–0.99 for temperature and 0.82–0.99 for salinity. The best correlation was observed between the variables at 100 m and in the 50–100 and 50–200 m layers: the correlation coefficient was 0.99 (practically functional connection) for temperature and 0.94–0.99 for salinity. In view of these results, the area-averaged temperature and salinity at 100 m were selected as characterizing the entire set of area-averaged variables for further analysis.

Figure 2 and Table 1 show the results of principal component analysis (PCA) of the selected variables. Relative weights (the percentage of explained variance of all variables) of the first three principal components were 53.5, 15.4 and 8.9%, respectively. It is clear that the first principal component (PC1) is responsible for thermal variables (water and air temperature, areas occupied by warm and cold waters, ice coverage). Both air and water temperature and the areas occupied by warm waters are directly interrelated and inversely with the ice coverage and the areas occupied by cold waters. The second principal component (PC2) is responsible for haline variables (water salinity and areas occupied by saline and fresh waters) and partly for dynamic variables (winter North Atlantic Oscillation index and wind-driven volume fluxes). The salinity and areas occupied by saline waters are directly interrelated and inversely with the dynamic variables and areas occupied by fresh waters. However, Table 1 shows that the wind-driven volume fluxes are more closely associated with the third principal component (PC3) than with the second one; their component weights in the third principal component are the largest (0.25–0.58).

The years 1966, 1968, 1969, 1978, 1979, 1981, 1982, 1987 and 1998, which occupy the extreme left position in Figure 2, were anomalously cold, with large ice coverage, large areas of cold waters, low water and air temperatures and small areas of warm water. The years 2006, 2007, 2012, 2013, 2015, 2016 and 2017, occupying the extreme right position in the diagram, on the other hand, were anomalously warm, with high water and air temperatures, large areas of warm waters, small ice coverage and small areas of cold waters. The years 1979, 1980, 1982, 1989 and 1996 were anomalously fresh, while 1965, 1970, 1973–1975, 2006–2008 and 2011–2016 were anomalously saline.

Figure 3 shows the normalised anomalies of the selected variables, sorted by correlation using the first principal component. There is a clear trend towards warming over the past 40 years. The period since 2005 is characterised by the highest temperatures, the largest areas occupied by warm and saline waters, low ice coverage and the smallest areas occupied by cold and fresh waters.

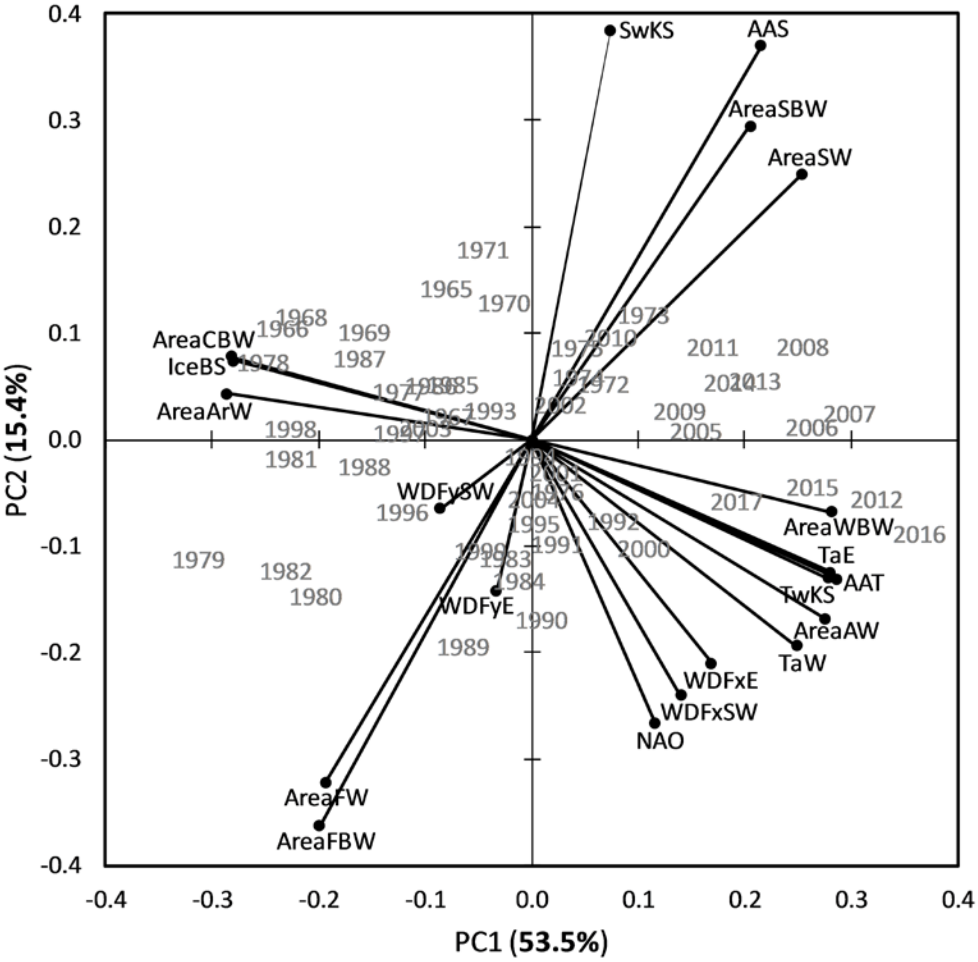

Figure 2. Distribution of meteorological and hydrographic variables for 1965–2017 in the coordinates of the first and second principal components (PC1 and PC2 respectively).

Table 1. Component weights of meteorological and hydrographic variables for the first three principal components (PC1, PC2 and PC3).

Variable	Principal component		
	PC1	PC2	PC3
AAT	0.29	–0.13	–0.07
TwKS	0.28	–0.13	–0.03
AreaAW	0.28	–0.17	–0.08
AreaWBW	0.28	–0.07	0.00
TaE	0.28	–0.12	–0.03
TaW	0.25	–0.19	0.17
AreaArW	–0.29	0.04	0.11
AreaCBW	–0.28	0.08	0.07
IceBS	–0.28	0.07	0.03
SwKS	0.07	0.38	0.32
AAS	0.22	0.37	0.09
AreaSBW	0.21	0.29	0.01
AreaSW	0.25	0.25	0.08
AreaFBW	–0.20	–0.36	0.01
AreaFW	–0.19	–0.32	–0.05
NAO	0.12	–0.27	–0.17
WDFxSW	0.14	–0.24	0.25
WDFxE	0.17	–0.21	0.34
WDFySW	–0.09	–0.06	0.58
WDFyE	–0.03	–0.14	0.53

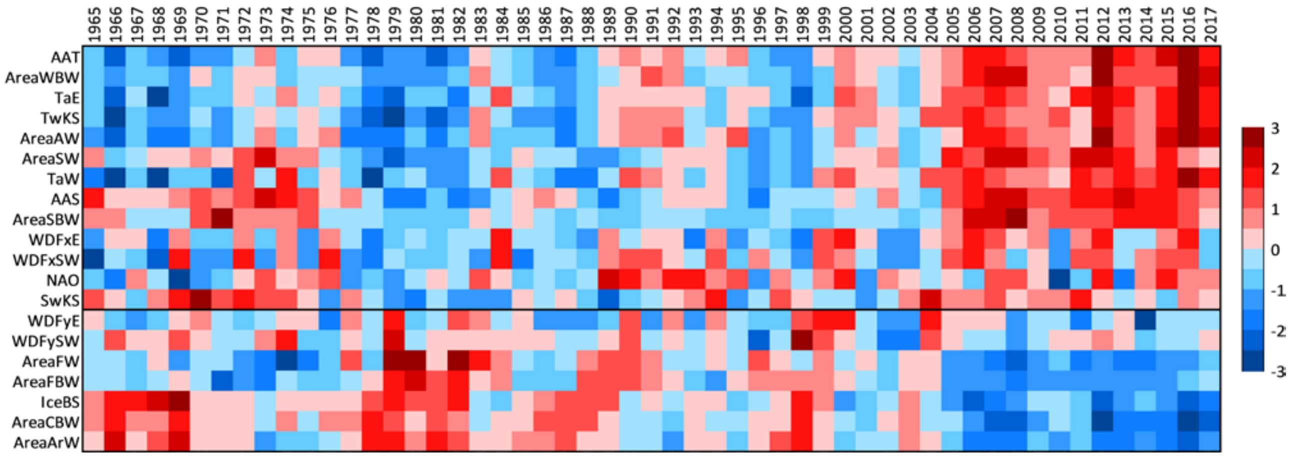

Figure 3. Normalized anomalies of meteorological and hydrographic variables for 1965–2017 (sorted by first principal component).

According to the PCA results, two groups of variables, thermal and haline, were distinguished in the analysed data set. The group of thermal variables includes air temperature in the western and eastern Barents Sea, water temperature in the Kola Section, area-averaged temperature at 100 m depth, areas occupied by warm and cold waters in the 50–100 m layer and near the bottom, as well as ice coverage. The group of haline variables includes water salinity in the Kola Section, area-averaged salinity at 100 m, areas occupied by saline and fresh waters in the 50–100 m layer and near the bottom. On the basis of these values, we searched for integral parameters, namely for thermal (or, in other words, climate) and haline indices, which would enable the thermohaline conditions of the Barents Sea as a whole to be estimated.

We first consider the thermal variables. Their PCA results are presented in Figure 4. It is known that ice coverage, air and water temperatures are indicators of marine climate (Boitsov et al., 2012). Therefore, we used these three key components to calculate the climate index of the Barents Sea. Taking into account the PCA results presented above (Figure 4), the annual mean ice coverage of the Barents Sea (here the ice-free area) was chosen as the first component of the climate index, the average of the annual mean air temperatures over the western and eastern parts of the sea as the second component, and the area-averaged temperature at 100 m depth in August–September as the third component. Here, the area-averaged temperature was chosen as a representative of all variables describing the thermal conditions of the Barents Sea waters (temperature in the Kola Section, areas occupied by warm and cold waters in the 50–100 m layer and near the bottom), because it correlates very well not only with each of these variables individually ($r = 0.91–0.97$), but also with their average ($r = 0.98$ – if the average is calculated without including the area-averaged temperature, $r = 0.99$ – if the average is calculated with including the area-averaged temperature). The area-averaged temperature at 100 m was therefore used to calculate the climate index instead of using the average of all variables describing the thermal conditions of the waters. As a result, the climate index of the Barents Sea was calculated as the average of normalized anomalies of these three variables chosen as its components (Figure 5).

The analysis of interannual variability of the climate index and its cumulative curve showed that there were two large climatic periods: a cold period from 1965 to 1989 and a warm period from 1990 to 2017 (Figure 5). To assess the thermal conditions of the Barents Sea in each year, all the years were classified by both the climate index and each of its three components (Figure 5). Seven intervals were suggested in the classification: anomalously cold years (normalised anomaly ($\Delta T/\sigma$) is less than –1.2), cold years ($-1.2 < \Delta T/\sigma < -0.6$), moderately cold years ($-0.6 < \Delta T/\sigma < -0.3$), normal years ($-0.3 < \Delta T/\sigma < 0.3$), moderately warm years ($0.3 < \Delta T/\sigma < 0.6$), warm years $0.6 < \Delta T/\sigma < 1.2$), and anomalously warm years ($\Delta T/\sigma > 1.2$). During the cold period, the coldest sub-periods became shorter and were interrupted by normal and moderately warm years. A stable warm period in the Barents Sea began in 2000 and was interrupted only in 2003 (a moderately cold year). According to the climate index, the warmest years were observed since 2005 and 2006, 2007, 2012, 2013 and 2015–2017 were anomalously warm, while 2016 was also record-warm since 1965. The years of 1966, 1968, 1969, 1978, 1979, 1981, 1982, 1987 and 1998 were anomalously cold.

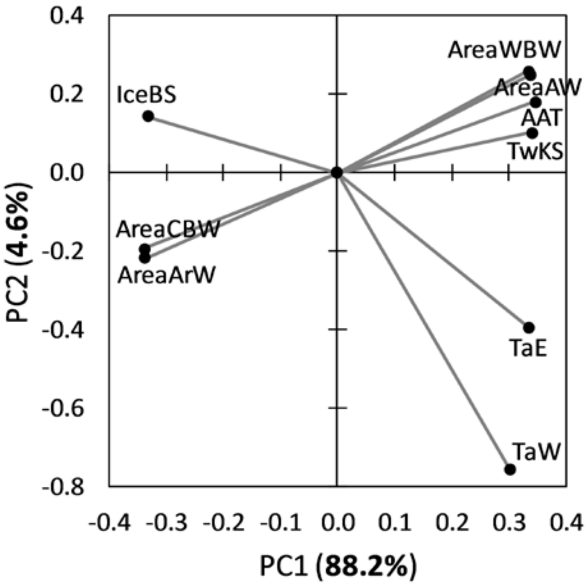

Figure 4. Distribution of thermal variables in the coordinates of the first and second principal components (PC1 and PC2 respectively).

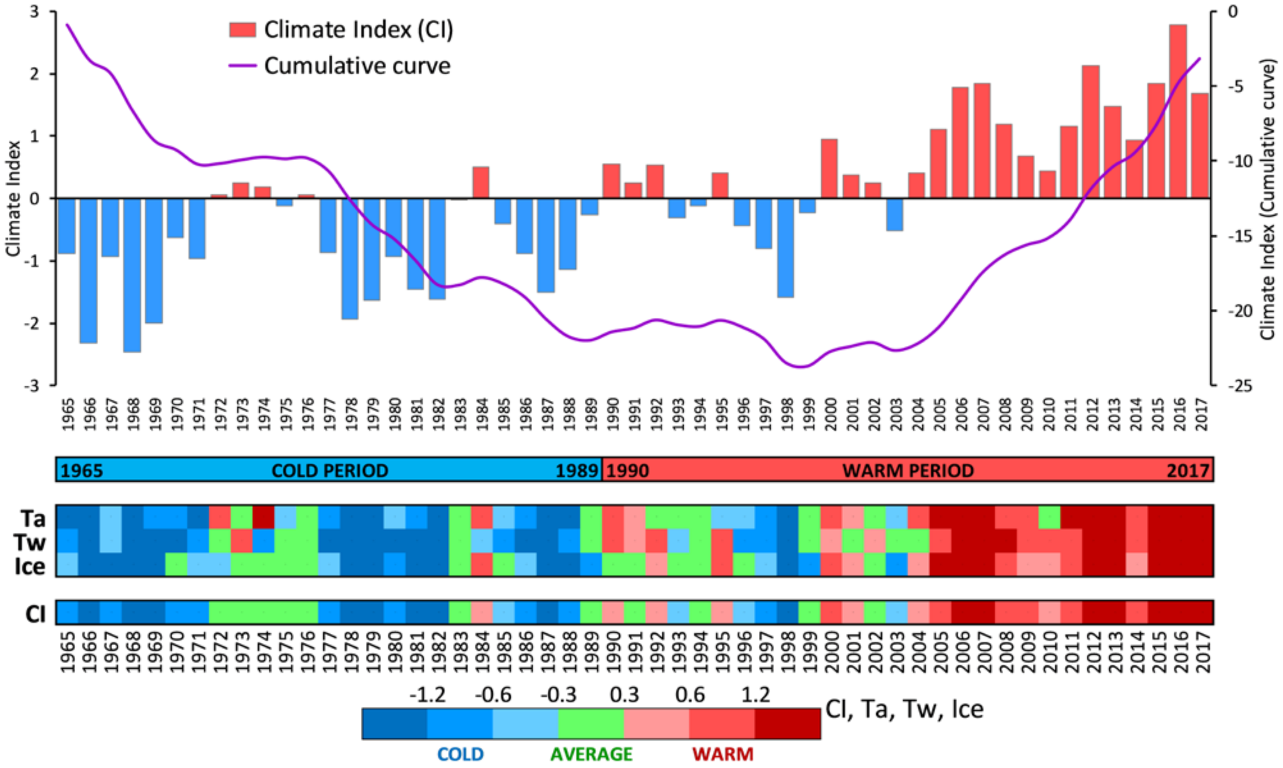

Figure 5. Climate index (CI) and its cumulative curve in 1965–2017 (top), main climatic periods (middle) and classification of years by the climate index and by its three components separately: Ta – normalized anomaly of air temperature, Tw – normalized anomaly of water temperature, Ice – normalized anomaly of ice-free area of the sea (bottom).

We now consider the haline variables. Taking into account their PCA results (Figure 6), in order to calculate the haline index of the Barents Sea, we first intended to use the annual mean salinity in the

Kola Section, the area-averaged salinity at 100 m in August–September and the average of the areas occupied by saline waters in the 50–100 m layer and near the bottom in August–September, as well as the average of the areas occupied by fresh waters in the 50–100 m layer and near the bottom in August–September. However, finally, only the area-averaged salinity was used for that purpose. It was chosen as a representative of all the listed haline variables, because it turned out to be the variable that correlated most highly with all the others (Table 2). The area-averaged salinity also showed a very good relationship with the average of the other haline variables (r = 0.97). Thus, the normalised anomaly of the area-averaged salinity at 100 m in August–September was adopted as a haline index of the Barents Sea to assess the haline conditions of its waters.

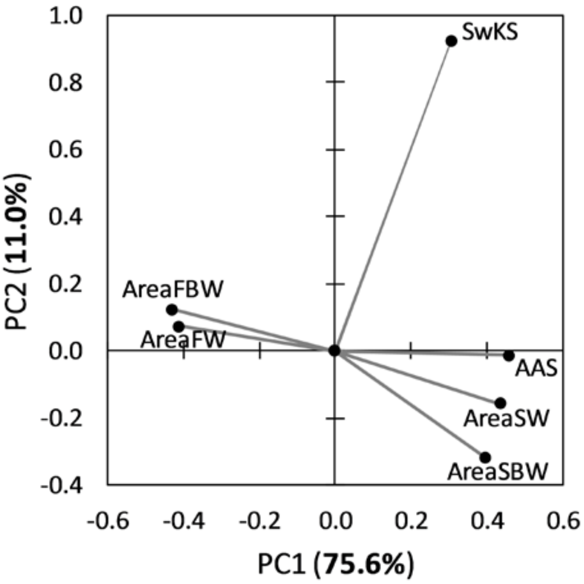

Figure 6. Distribution of haline variables in the coordinates of the first and second principal components (PC1 and PC2, respectively).

Table 2. Correlation matrix of haline variables.

Correlation coefficient	AAS	SwKS	AreaFW	AreaSW	AreaFBW	AreaSBW
AAS		0.61	–0.88	0.90	–0.86	0.78
SwKS	0.61		–0.49	0.50	–0.52	0.41
AreaFW	–0.88	–0.49		–0.76	0.77	–0.63
AreaSW	0.90	0.50	–0.76		–0.83	0.76
AreaFBW	–0.86	–0.52	0.77	–0.83		–0.75
AreaSBW	0.78	0.41	–0.63	0.76	–0.75	

The analysis of the interannual variability of the haline index (HI) and its cumulative curve showed that there were three long periods: two saline periods, from 1965 to 1977 and from 2000 to 2017, and one fresh period, from 1978 to 1999 (Figure 7). In order to assess the haline conditions of the Barents Sea from year to year, all the years were classified according to their haline index (Figure 7). By analogy with the climate index, seven intervals were used in the classification: anomalously fresh years (the haline index is less than –1.2), fresh years (–1.2 < HI < –0.6), moderately fresh years (–0.6 < HI < –0.3), normal years (–0.3 < HI < 0.3), moderately saline years (0.3 < HI < 0.6), saline years (0.6 < HI < 1.2), anomalously saline years (HI > 1.2). The fresh period was interrupted twice by normal and moderately saline years. The years 1979, 1980, 1982, 1989 and 1996 were anomalously fresh. The second saline period began in 2000 and was interrupted by a moderately fresh year in 2003 and a fresh year in 2004. A stable period of high salinity began in 2005. The years of 1965, 1970, 1973–1975, 2006–2008, 2011–2016 were anomalously saline. Since 2013, there has been a steady decrease in the haline index.

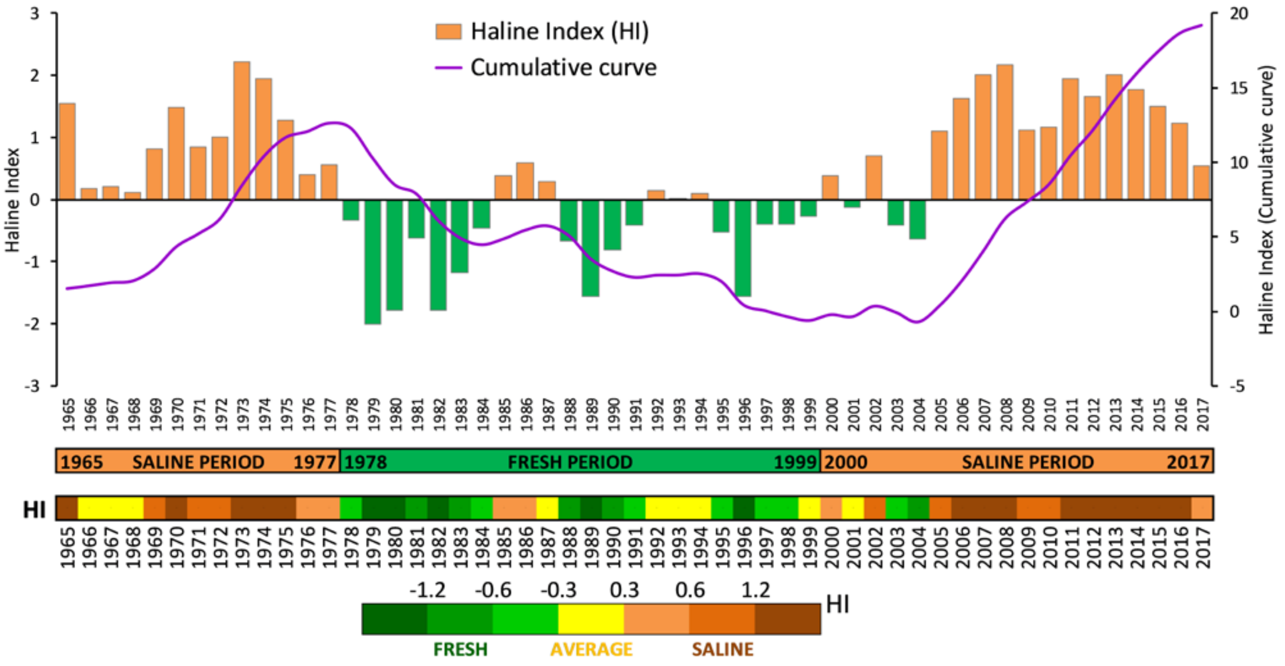

Figure 7. Haline index (HI) and its cumulative curve in 1965–2017 (top), main haline periods (middle) and classification of years by the haline index (bottom).

Comparisons of heat and freshwater contents in the Norwegian Sea with the climate and haline indices of the Barents Sea confirm that the variability of the thermohaline conditions of the Barents Sea is largely advective in nature. Changes in the heat content of the Norwegian Sea are in good agreement with changes in the climate index of the Barents Sea; in both cases, from 1965 to 2017, there are two long periods; a cold one with interruptions and a warm one (Figure 8). The correlation coefficient between these two series is 0.78 with a one-year lag.

Figure 8. Normalised heat content anomalies in the Norwegian Sea (upper) (ICES, 2018) and the climate index of the Barents Sea (lower) in 1965–2017.

As regards salinity, the freshwater content of the Norwegian Sea and the haline index of the Barents Sea are also in good agreement; in both cases, from 1965 to 2017, there are three long periods; two saline periods and one fresh period (Figure 9). The correlation coefficient between these two series is –0.74 with a one-year lag (the correlation coefficient is negative, because the freshwater content and salinity (i.e., the haline index) are inversely related.

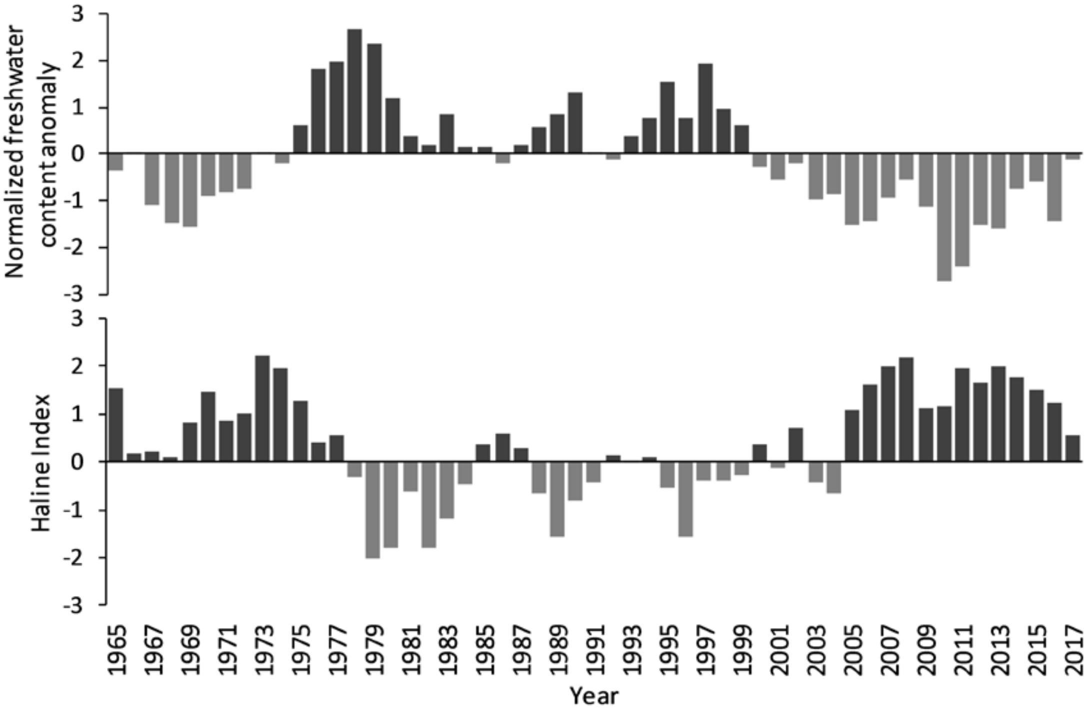

Figure 9. Normalised freshwater content anomalies in the Norwegian Sea (upper) (ICES, 2018) and the haline index of the Barents Sea (lower) in 1965–2017.

Conclusions

In our analyses of the meteorological and hydrographic conditions of the Barents Sea, we introduced climate and haline indices, which can be used as integral parameters for assessing the thermohaline conditions of the sea as a whole.

According to the indices, two long periods with distinct thermal conditions (cold – 1965–1989, warm – 1990–2017) and three long periods with different haline conditions (saline – 1965–1977 and 2000–2017, fresh – 1978–1999) have been identified in the Barents Sea since 1965.

The stable warm period began in the Barents Sea in 2000 and was interrupted only in 2003 (a moderately cold year). After 2005, the waters have been the warmest and saltiest since 1965. The year of 2016 was record-warm, with the climate index reaching its highest value for the entire period.

We noted that the variability of the thermohaline conditions of the Barents Sea is mainly due to advection.

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Possible impact of changing climate on marine conservation priority areas in the Barents and Kara Seas

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The network of marine conservation priority areas for the Russian Arctic was developed on the basis of the MARXAN support tool and extensive evaluation of the results by experts and application of the Convention on Biodiversity EBSA (Ecologically and Biologically Significant Areas) criteria (Solovyev et al., 2017). Ecological importance of these areas is largely driven by oceanographic factors (Spiridonov et al., 2017). In the Russian waters of the Barents and in the Kara Seas most of such areas (totaling 25 for these two marine basins) are currently marginally used by fisheries or are unfished. With few (but important) exceptions current anthropogenic impact on these areas is relatively low and most of threats are potential. However, the situation may change with changing climate. In these study we consider several regional climate scenarios on the basis of a review initiated by WWF Russia, most of them associated with a general trend to the warmer Arctic, increasing the Atlantic water input, and changing sea ice conditions in conservation priority areas and adjacent waters, "atlantization" or "borealization" of the biota (Fossheim et al., 2016), development of biological invasion (i.e. Zalota et al., in press), and possible changes in fisheries. Ongoing changes in the Arctic require development of a comprehensive balanced strategy of resources use and biodiversity protection.

Variability in the frontal zones of the Barents Sea in 1960–2017

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Abstract

The paper presents the research on interannual variability of the Barents Sea thermal frontal zones. The length index of the frontal zones and their mean temperature gradients at 50 m depth in August–September 1960–2017 were calculated for an area between 73–78°N, 15–30°E where the frontal zones are more evident. Thermal frontal zones were determined in areas where temperature gradients exceeded 0.04°C/km. Since the beginning of this century, the length index of the frontal zones has been decreasing and temperature gradients have been weakening. From the 1960s to the 2010s, decadal mean centroids of thermal frontal zones shifted northeast by 150 km.

Keywords: Barents Sea, Polar Front, thermal frontal zone, length index, temperature gradient, interannual variability, centroids

Introduction

The oceanographic conditions of the Barents Sea are largely determined by the interaction of Atlantic and Arctic waters that results in the occurrence of extended frontal zones (Agenorov, 1946; Izhevsky, 1958; Johannessen, Foster, 1978; Ozhigin, 1989; Loeng, 1991; Ozhigin et al., 2016). The Polar Frontal Zone is the most evident of them and it separates warm and saline Atlantic waters from cold and fresh Arctic waters. The position of frontal zones in the Barents Sea is closely related to the bottom topography (Ozhigin, 1989; Loeng, 1991; Parsons et al., 1996; Lien, 2010). In the area of the Spitsbergen and Great Banks, the thermal front position is trapped to an isobath of 250 m (Harris et al., 1998; Morozov et al. 2017; Harris, 1996). The areas with the sharpest temperature gradients are about 3 km wide (Morozov et al. 2017), and the total length of the Polar Front in the Barents Sea is about 1 500 km (Vage, 2010).

Given the fact that the frontal zones exist in areas where waters of different origins with widely varying properties interact, the main characteristic that defines frontal zones among other phenomena in the ocean is a sharp horizontal gradient of one or several hydrophysical parameters in a particular sea or ocean area (Fedorov, 1983; Gruzinov, 1986; Ozhigin et al., 2016). Despite the fact that a lot of research papers on the study of the Barents Sea frontal zones have been published, unfortunately, there is no clear understanding of their spatial pattern and interannual variability.

Using instrumental observations collected over a long period, this paper attempts to analyze and make a quantitative assessment of the spatial-temporal variability of the Barents Sea thermal frontal zones, namely the frontal zones identified in the water temperature field, over the period from 1960 to 2017.

Material and methods

Oceanographic data from the PINRO database for August–September 1960–2017 were used in the paper. These months were chosen because almost the entire Barents Sea is ice-free during this season, and the international ecosystem survey carried out in these months covers the sea sufficiently with oceanographic stations. To analyze the variability of thermal frontal zones in the Barents Sea, we chose an area between coordinates of 73–78°N and 15–43°E where the zones can be obviously observed (Ozhigin, 1989; Ozhigin et al., 2016).

The extent of the thermal frontal zones was estimated using the length index (Titov et al., 2007a; Titov et al., 2007b). To calculate the index for the selected area, water temperature fields were obtained at standard depths in grid nodes with spatial steps of 10' in latitude and 30' in longitude. The temperature fields obtained were used to calculate horizontal temperature gradients in every grid node. The length index of thermal frontal zones was defined as the number of grid nodes where temperature gradients (GradT) exceeded a critical value of 0.04°C/km that is used to identify thermal frontal zones (Titov et al., 2007a). The mean temperature gradient characterizing the "sharpness" of the frontal zones was calculated for those grid nodes as well.

To estimate the interannual variability in the position of thermal frontal zones, their geographical centroids were calculated taking into account weighting coefficients (horizontal temperature gradients). The centroids were calculated in ArcGis 10.2.2 for Desktop using the tool set "Spatial Statistics – Measuring Geographic Distribution – Mean Center" where the temperature gradient was used as a weight function.

Results and discussion

According to the above proposed method, the horizontal temperature gradients in the grid nodes and the length indices of thermal frontal zones within the study area in the Barents Sea (73–78°N and 15–43°E) were calculated. Table 1 shows that the largest area with high thermal gradients is observed at depths of 30–50 m in August–September, that corresponds to the previous studies (Ozhigin, 1989; Oziel et al. 2016). The seasonal cycle with a minimum in the winter months (February–April) is clearly visible at these depths. However, when studying seasonal variations, it is necessary to take into account the fact that different ice conditions occur in this area during the year: it is completely ice free in the summer months, partially ice free in winter, and as a result, the calculated fields and characteristics of the frontal zones will be different.

Table 1. Long-term (1960–2010) mean length indices of the thermal frontal zones in the Barents Sea at standard depths.

		Month											
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Depth, m	**0**	76	64	62	63	87	96	109	113	160	144	128	83
	10	69	61	60	59	81	87	106	116	137	126	119	77
	20	77	55	52	55	78	85	113	191	175	124	115	73
	30	75	54	52	55	77	84	113	242	232	129	112	71
	50	65	56	57	56	80	80	110	216	288	162	121	71
	75	57	55	48	52	65	70	86	165	193	134	92	61
	100	50	47	48	49	62	67	78	137	184	126	92	54
	150	37	35	36	39	47	50	54	84	100	86	72	43
	200	30	25	29	30	40	39	40	66	70	64	71	39

Further analysis of the variability in the thermal frontal zones was carried out for a depth of 50 m and the period from August to September. Figure 1 shows the distribution of probability of significant temperature gradients (more than 0.04°C/km) at 50 m depth for 1960–2017. Apparently, in the period under review significant gradients were observed more frequently in the western and central parts of the Barents Sea. The areas with the highest occurrence of frontal zones (more than 65%) drove round Bear Island from the west and south, spreading further to the northeast. Figure 1 confirms that the area between 73–78°N and 15–43°E was chosen correctly to assess the variability in thermal frontal zones: the sites where significant temperature gradients are observed the most frequently are entirely located within the marked area.

The long-term (1981–2010) mean distribution of significant (more than 0.04°C/km) temperature gradients at 50 m in August–September (Figure 2) is almost identical to the distribution of probability of such gradients (see Figure 1), while the areas with the highest values of both parameters coincide. The similarity in the distribution of these parameters indicates the quasi-stationarity of thermal frontal zones in the Barents Sea.

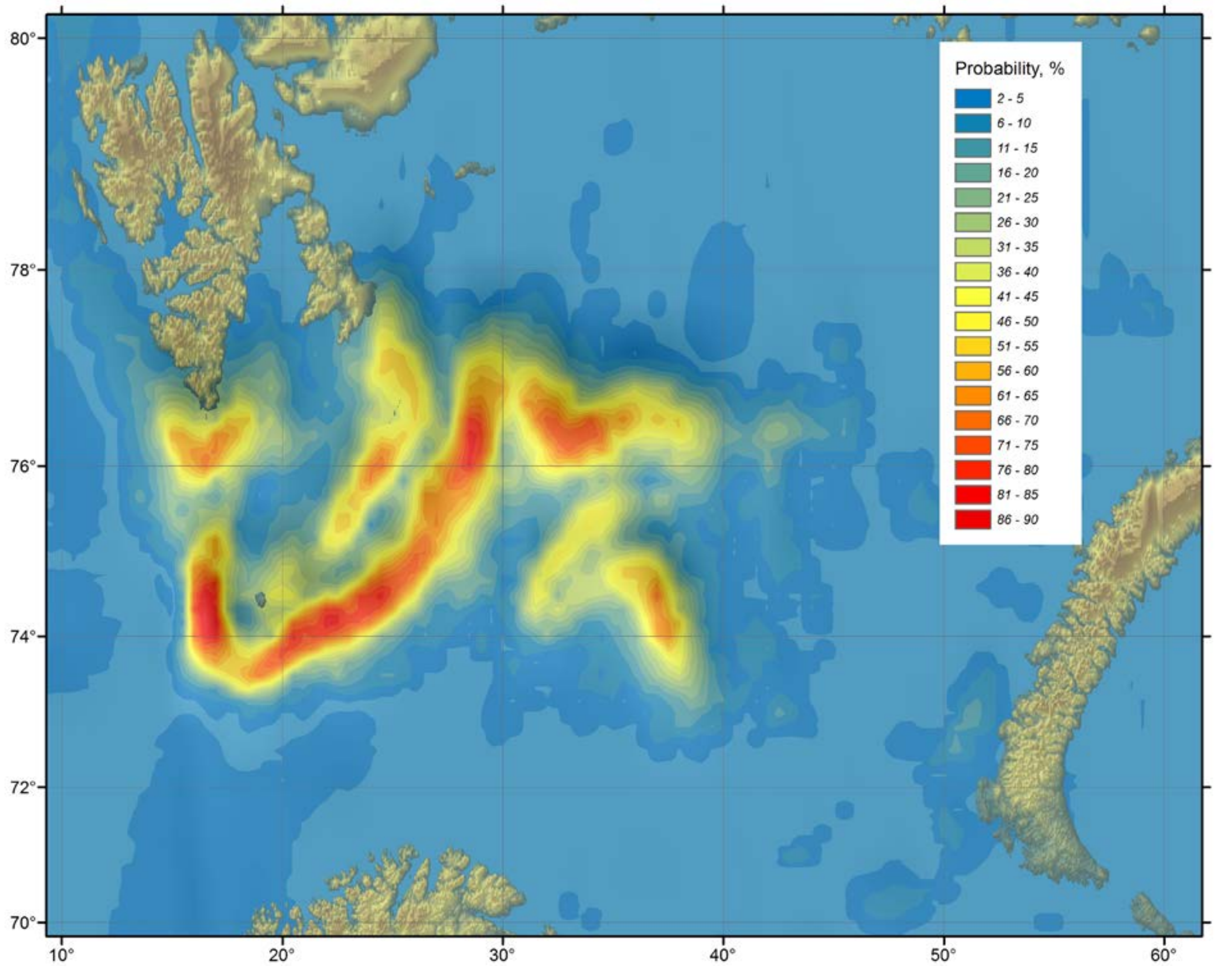

Figure 1. Probability (%) of relevant thermal frontal zones (GradT ≥ 0.04°C/km) in the Barents Sea at 50 m in August–September 1960–2017.

The highest temperature gradients (more than 0.08°C/km) within the marked frontal zones occur west of Bear Island (see Figure 2). Compared to other areas, the increased sharpness of gradients in this area is most likely the result of their more accurate calculation due to the occurrence of standard oceanographic section "Bear Island – West" (along 74°30'N, 9°50'–18°30'E), where the density of standard stations is high. The sharpness of the frontal zone is also observed east of Bear and Hope Islands, and it is probably determined by the close interaction of warm Atlantic waters and cold Arctic waters.

The interannual variations in the length index of the thermal frontal zones in the Barents Sea at 50 m depth in August–September have a high amplitude (from 100 to 600) for the period under consideration, while the long-term (1960–2010) mean value is 393 (Figure 3). There were significant interannual variations in this index before the mid-1970s that was probably caused by the different density of oceanographic observations. The period since the early 1980s shall be considered as the most "stable" period in the nature of variations in the index. By that time, a rather clear pattern of making observations during the ecosystem survey had been developed which included almost a regular network of oceanographic stations that may have resulted in decreased interannual variations in the index. It should be mentioned that the index gradually increased between the late 1980s and the early 2000s, thereafter it began to decrease to the absolute minimum in 2010. At the same time, the area of thermal frontal zones decreased five times between 2001 and

2010. After 2010, the index remained low, and only in 2011 and 2017, it was close to the long-term average.

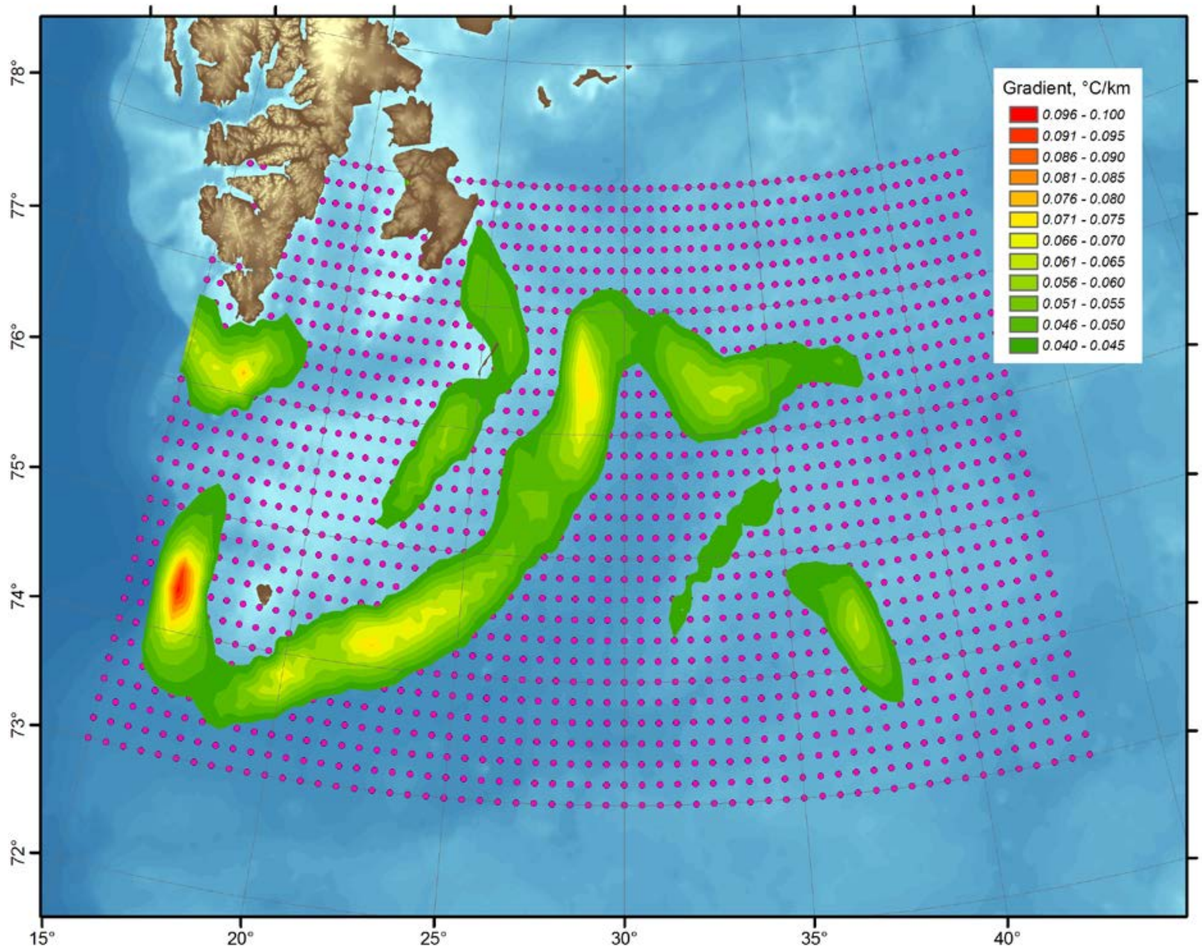

Figure 2. Long-term (1981–2010) mean temperature gradients in the Barents Sea at 50 m in August–September. Points indicate grid nodes.

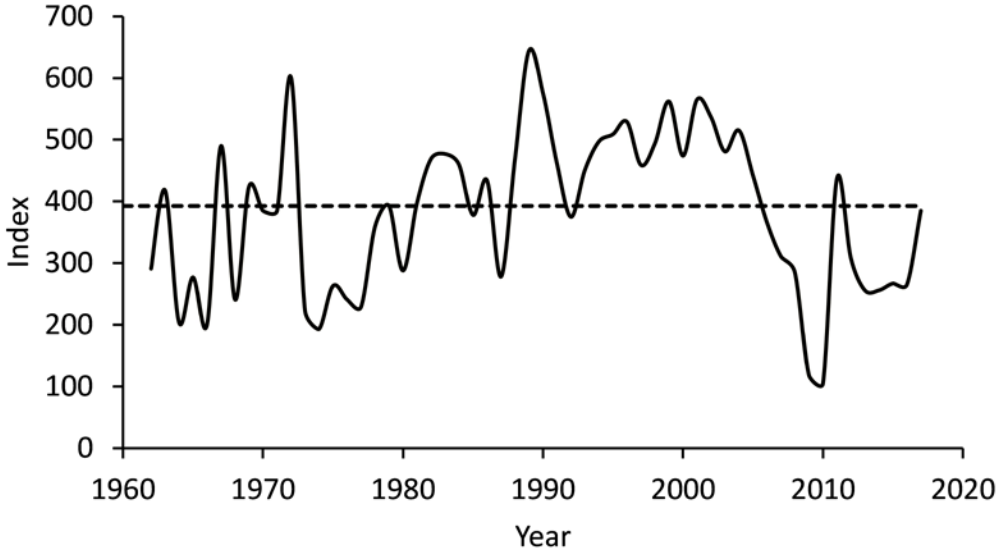

Figure 3. Interannual variability of the length index of the thermal frontal zones in the Barents Sea at 50 m in August–September. Dotted line shows a long-term (1960–2010) mean value.

The mean horizontal temperature gradient varied from 0.05 to 0.07°C/km in the marked frontal zones while the long-term (1960–2010) average was 0.061°C/km (Figure 4). Since the mid-1990s, its gradual decrease has been observed. In 2010, the index reached the absolute minimum, and after 2010, it remained at a low level (Table 2).

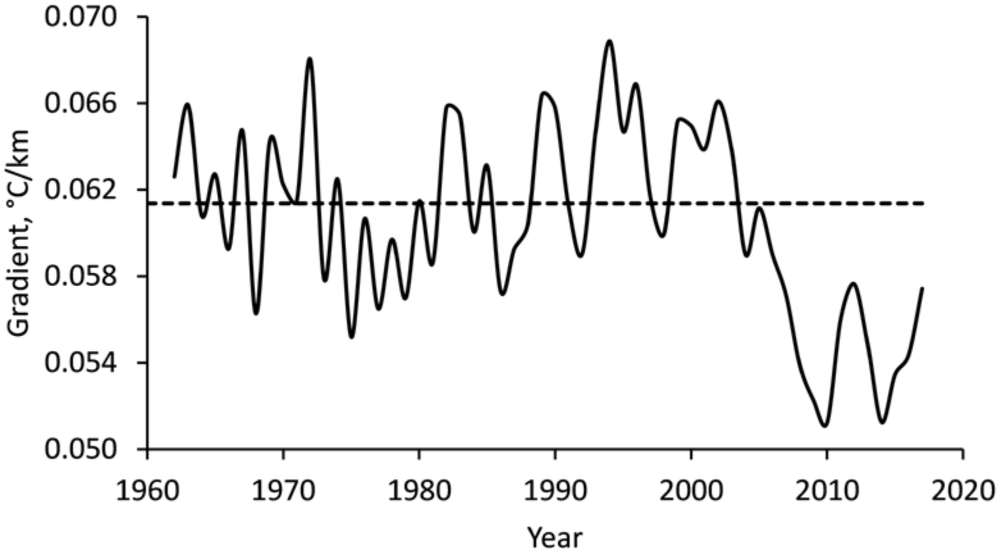

Figure 4. Interannual variability of the mean temperature gradient in the thermal frontal zones of the Barents Sea at 50 m in August–September. Dotted line shows a long-term (1960–2010) mean value.

Table 2. The length index of the thermal frontal zones in the Barents Sea and the mean horizontal temperature gradient (°C/km) in them at 50 m in August–September.

Year	Index	Gradient	**Year**	Index	Gradient	**Year**	Index	Gradient
1960	417	0.063	**1980**	288	0.061	**2000**	474	0.065
1961			**1981**	398	0.059	**2001**	565	0.064
1962	291	0.063	**1982**	469	0.066	**2002**	537	0.066
1963	418	0.066	**1983**	477	0.065	**2003**	481	0.064
1964	204	0.061	**1984**	460	0.060	**2004**	515	0.059
1965	277	0.063	**1985**	378	0.063	**2005**	442	0.061
1966	201	0.059	**1986**	434	0.057	**2006**	366	0.059
1967	490	0.065	**1987**	278	0.059	**2007**	311	0.057
1968	241	0.056	**1988**	468	0.060	**2008**	285	0.054
1969	424	0.064	**1989**	644	0.066	**2009**	118	0.052
1970	385	0.062	**1990**	575	0.066	**2010**	105	0.051
1971	385	0.061	**1991**	461	0.061	**2011**	437	0.056
1972	601	0.068	**1992**	375	0.059	**2012**	308	0.058
1973	223	0.058	**1993**	451	0.065	**2013**	256	0.055
1974	193	0.062	**1994**	497	0.069	**2014**	256	0.051
1975	263	0.055	**1995**	509	0.065	**2015**	267	0.053
1976	241	0.061	**1996**	529	0.067	**2016**	265	0.054
1977	229	0.056	**1997**	459	0.062	**2017**	385	0.057
1978	359	0.060	**1998**	494	0.060	**2018**		
1979	393	0.057	**1999**	562	0.065	**2019**		

Significant positive correlation was found between the length index and the mean temperature gradient of the Barents Sea frontal zones. The coefficient of determination was 0.52 (with series length n=58) (Figure 5). The plot shows the best relationship of these parameters (with less deviations from regression line) for the highest values. In years when frontal zones are widespread, the mean temperature gradient is usually rather large as well. The worse relationship is observed for weak frontogenesis (the length index varies in the range 200–300), when the mean temperature gradient can almost equiprobable be either large or small.

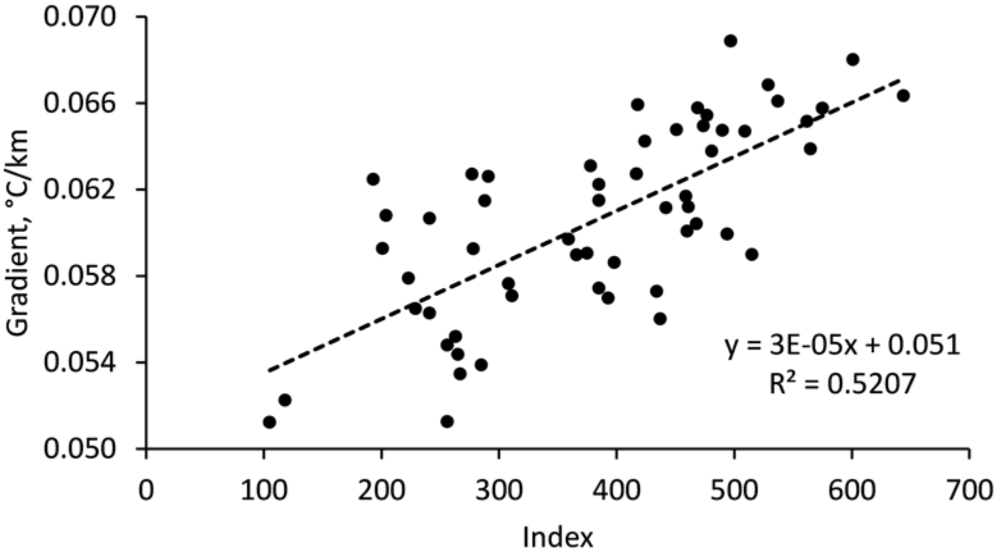

Figure 5. Correlation between the length index and mean temperature gradient (°C/km) in the thermal frontal zones of the Barents Sea at 50 m in August–September 1960–2017.

In order to estimate spatial shifts in thermal frontal zones from year to year, their centroids were calculated using the *ArcGIS* software. Weight functions of centroids are employed with the temperature gradient in frontal zones set as “weight”. The centroids calculated for each year from 1960 to 2017 are spread from southwest to northeast and located between the Spitsbergen Bank and Hopen Trench (Figure 6). The distance between the two outermost centroids (1962 and 1974) is about 290 km. Most centroids are concentrated within the small area (75–76°N and 26–28°E), that indicates relative stationary character of thermal frontal zones in the Barents Sea. Figure 6 shows that centroids had tended to be located southwest in the 1960s and shifted northeast in the 2010s.

Patterns in centroid shifting are more precise if we consider decadal mean centroids (Figure 7). For instance, in the 1960s, the centroids of the Barents Sea thermal frontal zones were located in the extreme southwest. The fact that these years' observations were mainly conducted along standard sections may have resulted in such a location of centroids. In the 1970s, the centroids shifted northeast by approximately 75 km, and during the next 40 years (1970s, 1980s, 1990s and 2000s), they were quasistationary and shifted within a tiny area (75.5–75.7°N and 26.8–27.4°E). Since the early 2010s, the centroids continued to shift northeast. As a result, from the 1960s to the 2010s, the centroids of the Barents Sea thermal frontal zones shifted northeast by approximately 150 km. L. Oziel et al. (2016) indicated that the front generally shifted northwards (from the 1970s to the 2010s) and they explained this shift by “atlantification” of the Barents Sea.

Conclusions

It was proved that thermal frontal zones of the Barents Sea are more evident in the 30–50 m layer in August–September. The length index of thermal frontal zones was used for quantitative assessment of their extent; the length index and mean temperature gradients in the zones were calculated for 1960–2017. It was noted that the length index of the thermal frontal zones had been decreasing since the early 2000s and their temperature gradients had been weakening; in 2010, the length index and the mean temperature gradient were record low since 1960. It was indicated that despite the quasistationary nature of the thermal frontal zones in the Barents Sea their decadal mean centroids shifted northeast by 150 km from the 1960s to the 2010s.

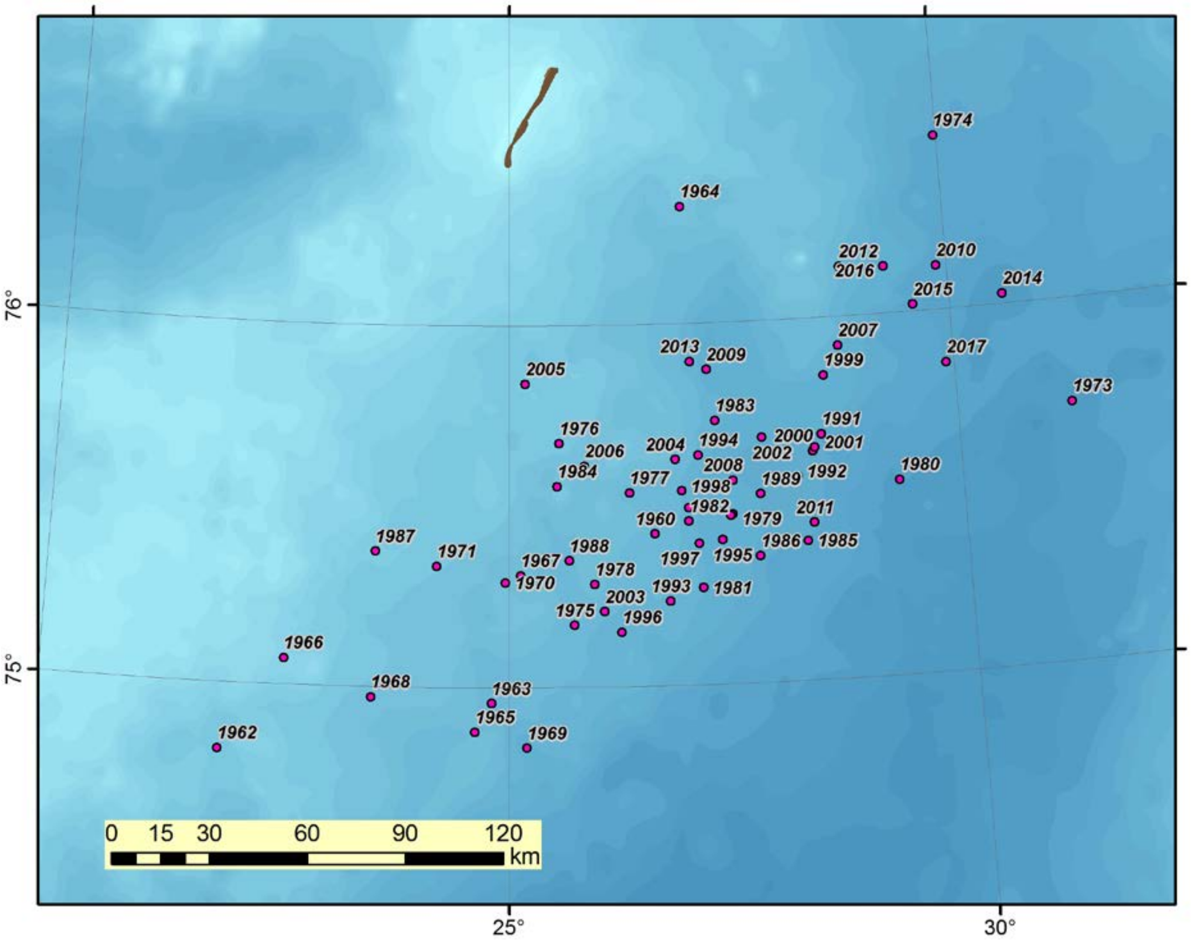

Figure 6. Centroids of the Barents Sea thermal frontal zones at 50 m in August–September 1960–2017.

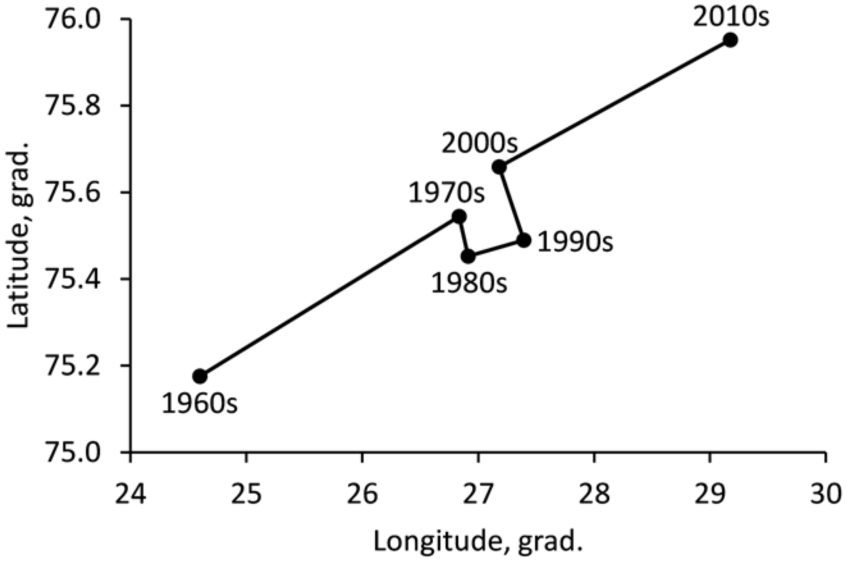

Figure 7. Decadal mean centroids of the Barents Sea thermal frontal zones at 50 m in August–September.

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Restoration of data on water temperature in the Kola Section in 2016–2017

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Abstract

The Kola Section is an oceanographic transect that is mainly located in the southern Barents Sea and crosses Atlantic waters flowing from the Norwegian Sea into the Barents Sea and further into the Arctic Basin. The Kola Section has been occupied since May 1900, and its time-series is one of the longest time-series in the world. Unfortunately, no observations were made in the Kola Section from June 2016 to May 2017 inclusive (during 12 months). This unique time-series has been interrupted. This paper presents methods and results of restoration of missing data on water temperature in the Kola Section in 2016–2017. The data have been restored using the following: (1) the internal structure of the time-series from the Kola Section; (2) multiple linear regressions and data from other nearby sections, namely Fugløya–Bear Island and Vardø–North Sections; and (3) modelled data from the Copernicus website. Eventually, the data on water temperature in the 0–50, 0–200, 50–200 and 150–200 m layers in the inner (Stations 1–3), central (Stations 3–7) and outer (Stations 8–10) parts of the Kola Section were restored for each month from June 2016 to May 2017.

Keywords: Barents Sea, Kola Section, water temperature, data restoration

Introduction

Long time-series from standard oceanographic stations are of an indisputable value in terms of studying regularities of seasonal and interannual variations in oceanographic parameters and finding out peculiarities in development of oceanographic processes. This gives a possibility to monitor a climate forcing and use the data for long-term temperature, sea ice and fisheries forecasts. The Kola Section is one of the longest oceanographic time-series in the world. Aside from going back about 120 years of sampling, it has relatively high temporal resolution. The observations along this section were first conducted in May 1900 during the cruise on board the research vessel "Andrey Pervozvanny" under the supervision of Nikolay M. Knipovich (Karsakov, 2009). Those observations initiated regular studies of the Barents Sea and provided the basis for studying regularities of climate fluctuations and impact of those fluctuations on dynamics of stocks and distribution of commercial fishes. In light of growing instability of current variations in climatic systems in the Northern hemisphere, the importance of observations in the Kola Section to find main regularities in the variability of natural processes increases largely.

In terms of duration, data quantity and spatial coverage, the Kola Section has been acclaimed unique and become widely known in scientific communities worldwide. As far back as in the early 1960s, G.K. Izhevsky (1961, 1964) noted that it would be fairly enough to conduct regular observations only in the Kola Section to study seasonal and long-term fluctuations in heat and salt contents, and other characteristics of water in the Barents Sea, and that processes taking place in the seas in the western Northern hemisphere could be analysed quite as much based on data from the Kola Section.

For a variety of reasons, from June 2016 to May 2017 (throughout the entire year) no observations were carried out in the Kola Section, and this jeopardised the entire multi-year research work on a long-term prediction of water temperature in this area. This paper aims at restoring missing data on water temperature in the Kola Section.

Challenges related to occupying the Kola Section

The Kola Section is located in the Barents Sea north of the Kola Bay along 33°30'E from 69°30'N to 77°00'N and comprised 16 stations. It is 450 miles long. The depth at the stations ranges from 150 to 310 m, with an average of 245 m (Table 1).

Table 1. Station coordinates and depths in the Kola Section.

Station number	Latitude, N	Longitude, E	Depth, m
1	69°30'	33°30'	260
2	70°00'	33°30'	150
3	70°30'	33°30'	250
4	71°00'	33°30'	225
5	71°30'	33°30'	275
6	72°00'	33°30'	260
7	72°30'	33°30'	280
8	73°00'	33°30'	220
9	73°30'	33°30'	290
10	74°00'	33°30'	310
11	74°30'	33°30'	260
12	75°00'	33°30'	170
13	75°30'	33°30'	225
14	76°00'	33°30'	300
15	76°30'	33°30'	250
16	77°00'	33°30'	175

The number of stations sampled in the Kola Section varied from year to year. Quite often, especially during the initial years of studies, only two or three stations were sampled. Other times, some individual stations located between 69°30'N and 73°00'N were done. In particular years, sampling in the northern Kola Section was largely limited due to sea ice conditions. The part of the section from 69°30'N to 74°00'N comprising the first ten stations has been sampled on a regular basis over the recent years (Figure 1). Those stations are located in the area of the Murman Current, Coastal Murman Current and Central branch of the North Cape Current, and are sampled most frequently (Boitsov et al, 2010).

PINRO and the Murmansk Department for Hydrometeorology and Environmental Monitoring made the largest contribution to the total number of observations along the Kola Section, and the main data array (99.7% of the total data) was formed by Russian institutions (Alekseev et al, 2005). Over the recent 25 years, the Kola Section have been mainly sampled by PINRO research vessels.

The oceanographic data collected from the Kola Section are not always equally distributed in time. Periods of rare observations (or no observations at all) are interchanged with periods of regular observations. As a result, the entire almost 120-year time-series in the Kola Section can be split into the following periods: 1) 1900–1906 – 7 years; 2) 1921–1941 – 21 years; 3) 1945–2016 – 72 years; 4) 2017 and up to now.

Thus, the total number of years when the Kola Section was indeed sampled is equal to 100 years. In total, the Kola Section was sampled 1209 times from 1900 to 2017 and water temperature was the main oceanographic parameter to be monitored (Karsakov, 2007; Karsakov, 2009) (Figure 2).

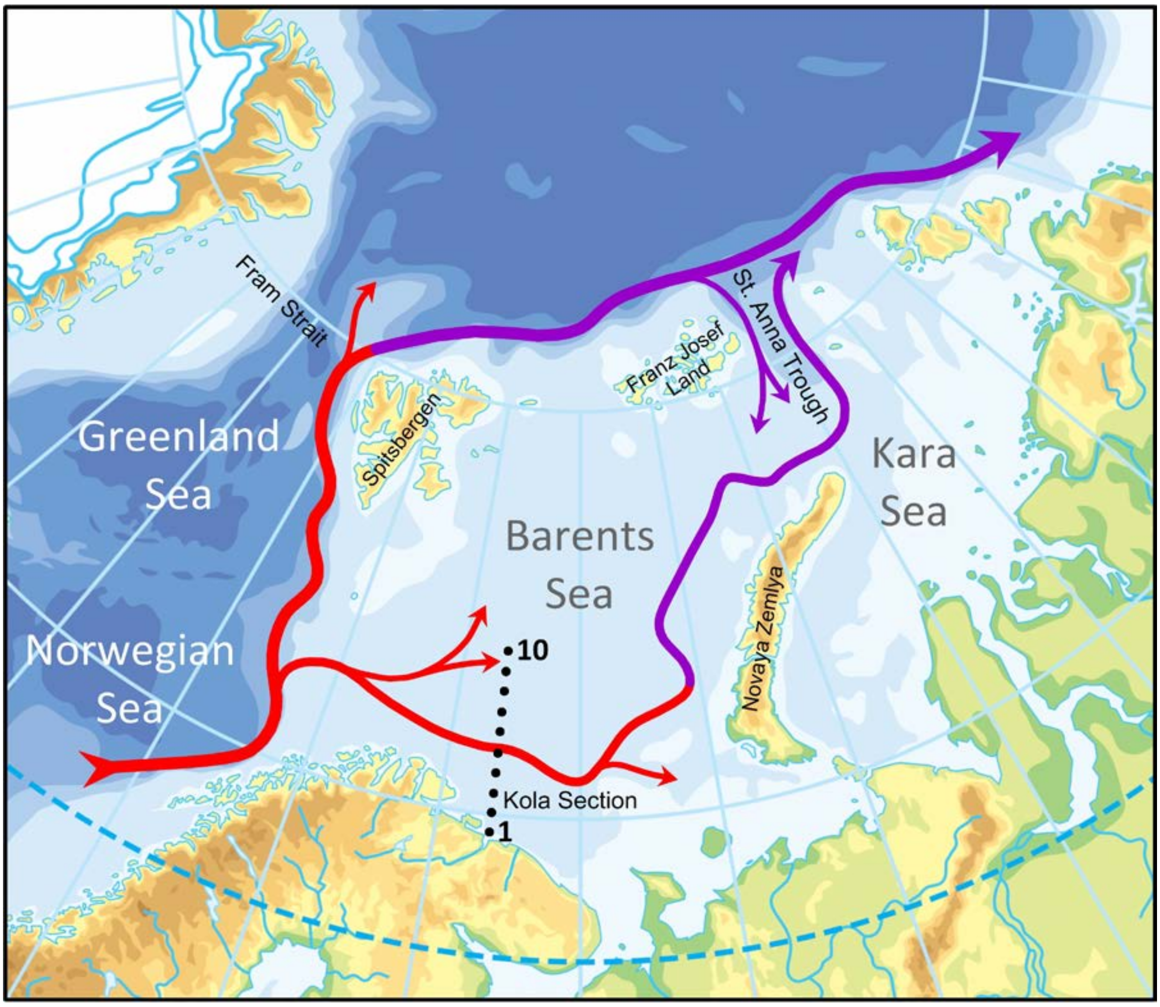

Figure 1. Location of the Kola Section in the Barents Sea (Stations 1–10) (after Boitsov et al, 2012).

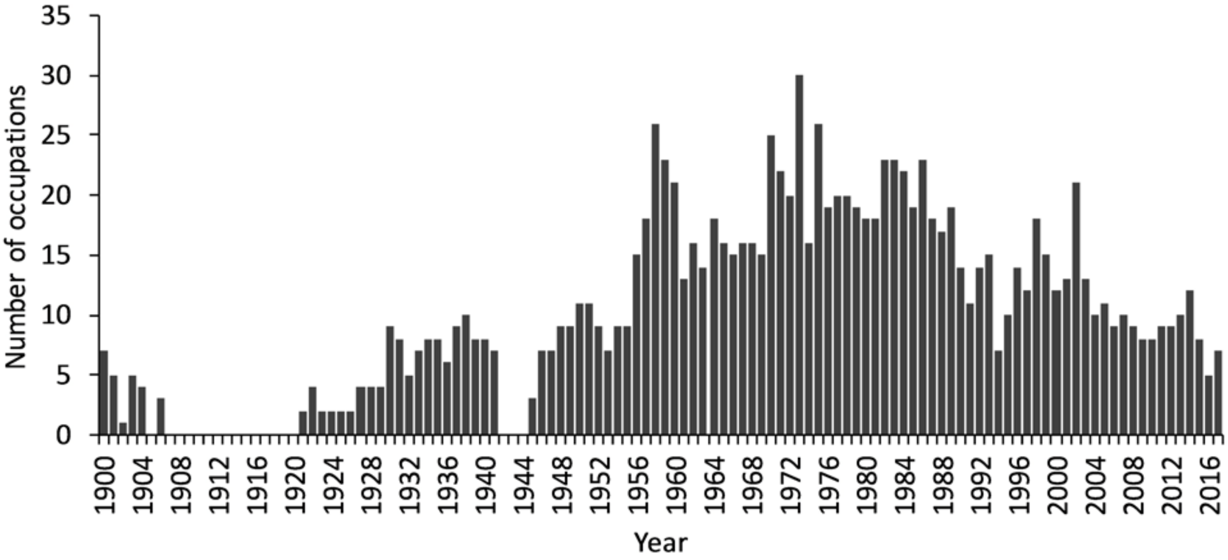

Figure 2. The number of water temperature observations in the Kola Section in 1900–2017.

The data gaps in time-series of depth-averaged temperature in the Kola Section were first restored by P.A. Gevorkyants in the late 1930s (Gevorkyants, 1945). Later, his data were verified by A.A. Zverev in 1952. A.A. Zverev formed monthly temperature series in various layers for the period from 1921 to 1952. Unfortunately, those data were not published. When restoring the data gaps, A.A. Zverev worked from the premise that there was a large inertia in temperature conditions in the

Kola Section, i.e. from the principle of maintaining temperature anomalies. A seasonal cycle of temperature was defined by him for the period of regular observations in the Kola Section (1921–1939). Afterwards, A.A. Zverev restored missing monthly data by a graphical method, plotting the seasonal cycle curve with depth-averaged temperatures. Despite the fact that this data restoration method was of relatively conditional nature, the monthly series of mean temperatures formed by him for the period from 1921 to 1941 have been used by some scientists to establish a general cycle of processes under study and to make qualitative correlations.

In the 1960s, the data by A.A. Zvervev were verified and ascertained by G.N. Zaycev (1967). The verification method applied was as follows: G.N. Zaycev used the data from Norwegian hydrometeorological stations and collated those data with the data from the Kola Section from the post-second world war time when observations had been already conducted on a regular basis to validate the pre-war data of a dubious nature using the mathematical relation derived. The study showed that there was a two-month delay in occurrence of peculiar features in the thermal conditions in the Kola Section compared to sea surface temperature by the Norwegian coast. Concurrently, G.N. Zaycev suggested that the nature of atmospheric circulation should be taken into account in such calculations, i.e. under stronger westerly winds the water temperature in the Kola Section increases relatively more rapidly compared to that at the sea surface by the Norwegian coast.

In 1982, Yu.A. Bochkov ascertained the data once more and recalculated the gaps in data on water temperature in the Kola Section (Bochkov, 1982). He derived seasonal (quarterly) and annual temperatures in the Kola Section for 1900–1920 and 1940–1944 by applying a group method of data handling. Seasonal and annual air temperatures in the Polyarny and Kola stations, the Barents Sea ice coverage in April–August, the number of deep cyclones in the Norwegian, Greenland and Barents Seas in winter (December–February) and annual temperatures in the Norwegian Sea upper layer in a number of the Norwegian coastal stations were used as predictors. Yu.A. Bochkov publicly released in his paper not only the restored data for 1900–1920 and 1940–1944 but also the entire time-series for 1945–1981.

From 1946 to 2016, the Kola Section was sampled almost on a monthly basis, and there were no data gaps. In the above period, the lowest number of observation series per year amounted to 7 (1946, 1947, 1953 and 1994), while the highest one was 30 (1973). In May 2016, the observations in the Kola Section were discontinued and were only resumed one year later in June 2017. Unfortunately, discontinuation of regular oceanographic observations in the Kola Section occurred simultaneously with the extremely high temperatures of the Barents Sea waters. This poses a challenge in restoring data gaps.

Material and methods

In this paper, an attempt was made to restore depth-averaged temperature in the 0–50, 0–200, 50–200 and 150–200 m layers in the inner (Stations 1–3), central (Stations 3–7) and outer (Stations 8–10) parts of the Kola Section for each month from June 2016 to May 2017. The following three methods of data restoration will be examined: (1) the use of internal structure of time-series from the Kola Section; (2) the use of multiple linear regressions and data from other standard sections; (3) the use of modelled data from the Copernicus website (NEMO ocean model).

1. The use of internal structure of time-series from the Kola Section. The method is as follows: first, the internal structure of the time-series is analysed by extracting quasi-periodic components using the Butterworth bandpass filter. Then, these components are extrapolated by statistical-probabilistic methods forward in time to obtain missing values.

The restoration of data gaps in the Kola Section by this method was carried out using “ASAPplus” and “PRIZMA” software packages (Averkiev et al., 1997), which implemented the above approach and were applied for long-term prediction of water temperature.

The premises for the use of predicting results to restore the gaps in time-series are the following: the validity of predictions of monthly mean temperature for 2008–2015 was as high as 91% in term of numerical values and 100% by sign. Therefore, the predictions were used for restoring the data gaps.

The prognostic values used for restoring the data gaps are calculated taking the interannual variability of time-series in the Kola Section into account and by no means they could disturb, distort or change it. The algorithm in detail is as follows:

1) Calculation of spectral function;
2) Division of the spectral structure of the initial series into separate components using bandpass filtering (tangent Butterworth filter);
3) Forecasting of each component using the most appropriate statistical method for this component (expected value method, inertial method, Bayesian method, dynamic-statistical method, dynamic-stochastic method, regression method, Fourier method, composite method of averages, composite regression method).
4) Evaluation of prediction quality based on a methodological prediction success rate of independent forecast of each component using each of the methods;
5) Derivation of the final prognostic value by summing-up the best prognostic values for each of the predicted components in the internal structure of the series.

Figure 3 shows an example of data restoration results in the Kola Section using the above method.

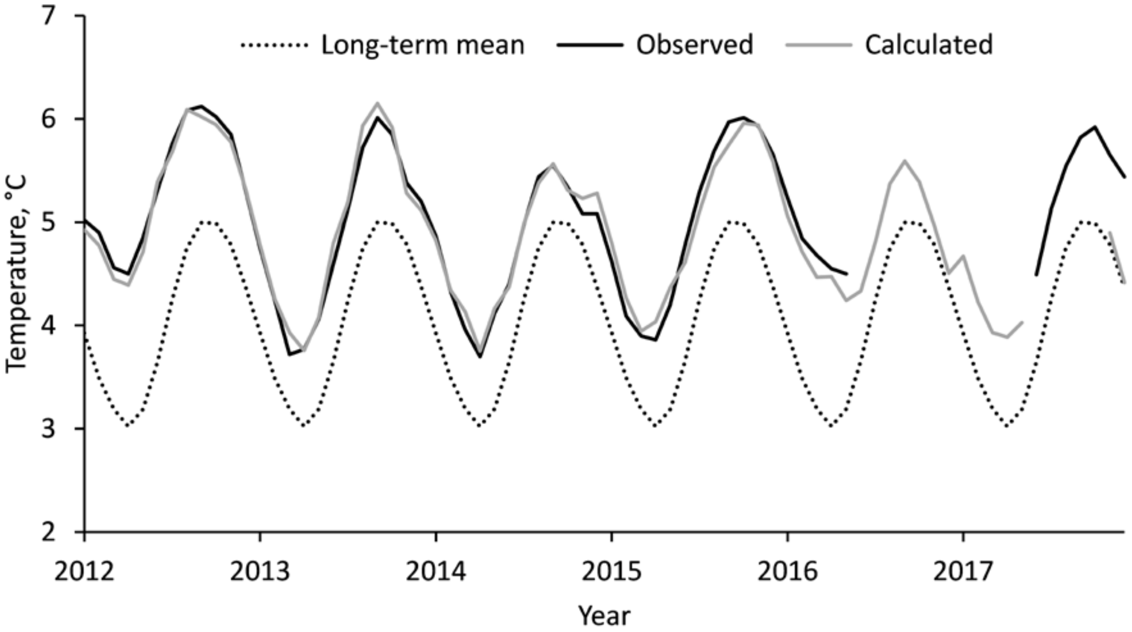

Figure 3. Long-term mean (dashed line), observed (black line) and calculated (grey line) water temperatures in the 0–200 m layer in the central Kola Section (Stations 3–7).

2. The use of multiple linear regressions and data from other standard sections. The principle of the method is to carry out a regression analysis of time-series from the Kola Section and from other nearby sections to develop regression models to calculate data from the Kola Section (predicant) using data from the neighboring sections (predictors).

The time-series from the Norwegian Fugløya–Bjørnøya and Vardø–North Sections from 1977 to 2017, kindly provided by the Institute of Marine Research, Bergen, Norway, were used as predictors. The time-series in January, March, April–May, August–September and October in the Fugløya–Bjørnøya Section and in January, March and August–September in the Vardø–North Section were used to develop regression models. Regression equations were developed in the Statistica 13.3 package by Stepwise regression Method: forward selection, P-to-enter: 0.05, P-to-remove: 0.05, separately for each month, i.e. the interannual variability was examined, so there was no need to exclude a seasonal cycle from the time-series. In total, 132 equations were formulated for 12 months, 3 (or 4) layers, and 3 parts of the Kola Section: 3 layers in the inner part of the section and 4 layers in the central and outer parts.

The coefficients of determination of the models developed are indicative of a rather high degree of correspondence of calculated and observed data for all the layers and parts of the Kola Section, excluding July–September in the 0–50 m layer in the outer part of the Kola Section (Stations 8–10) (Table 2). Thus, data calculated using the developed regression equations adequately describe interannual and seasonal variability of water temperature in the Kola Section.

Table 2. Coefficients of determination (R^2) for regression models of water temperature in the Kola Section.

A part of the Kola Section	Layer, m	Month											
		1	2	3	4	5	6	7	8	9	10	11	12
Stations 1–3	0–50	57.3	63.7	62.0	59.6	59.0	56.1	47.4	71.9	60.4	74.1		52.6
	0–200	61.9	64.7	63.0	63.6	64.1	84.2	77.2	85.2	74.0	71.8		53.9
	50–200	59.7	65.7	63.4	65.0	64.3	83.2	76.9	79.4	63.3	62.8		49.5
Stations 3–7	0–50	70.3	74.9	73.4	71.8	66.0	69.8	55.0	56.9	59.2	58.0	57.2	66.2
	0–200	70.3	74.2	73.2	69.3	67.0	84.6	78.1	83.7	83.0	81.2	68.8	68.9
	50–200	69.9	72.2	72.0	68.1	66.7	85.9	81.7	86.6	84.1	81.4	66.0	63.5
	150–200	72.7	69.0	68.7	66.3	64.3	77.2	80.5	83.3	80.4	80.0	71.4	69.7
Stations 8–10	0–50	76.2	74.1	67.6	52.9	55.4	66.7	20.3	37.4	28.4	59.0	69.7	73.3
	0–200	72.3	80.2	71.9	60.2	61.7	85.7	56.0	75.3	81.4	79.7	74.2	67.7
	50–200	69.0	80.8	71.7	56.5	56.4	79.8	66.8	87.0	91.7	83.5	76.3	67.5
	150–200	59.4	74.2	71.9	60.0	60.7	68.9	70.7	83.2	83.7	82.9	81.9	81.0

Figure 4 shows one of the best (R^2=84.6) and one of the worst (R^2=55.0) models for the central Kola Section as an example. Similar results of consistency between calculated and observed data were obtained for other layers and parts of the section. The best models were obtained for a summer-and-autumn period and deeper layers. The model quality deteriorates in wintertime as well as in the surface layer and in the inner Kola Section (Stations 1–3). This is most probably associated with a higher variability of temperature conditions here as well as with synoptic processes having an impact on deeper layers in wintertime.

Figure 5 shows an example of restored data in the Kola Section using the above approach. The largest discrepancies between observed and calculated temperatures were recorded for 2012 when record-high temperature anomalies were observed (González-Pola et al., 2018).

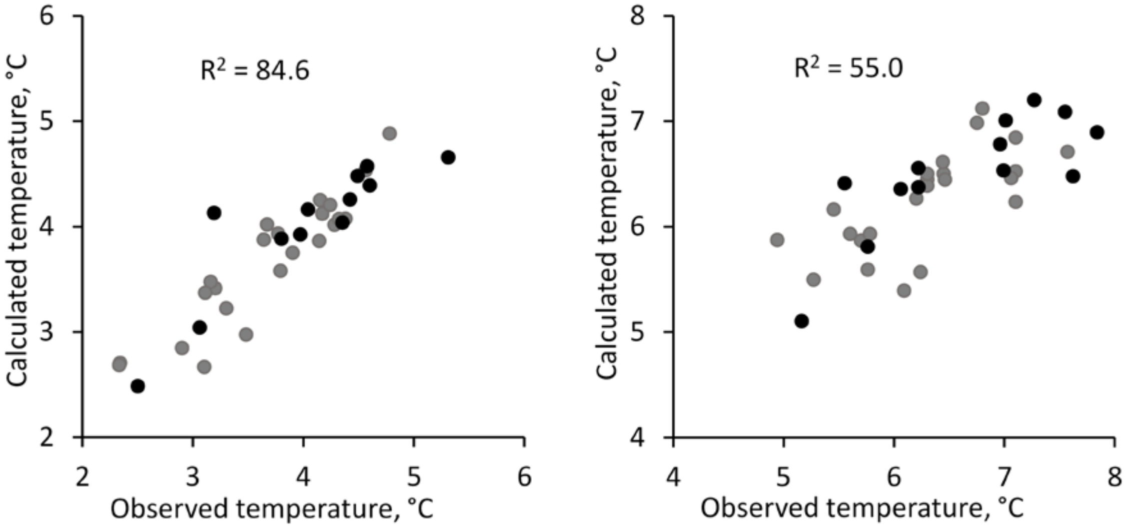

Figure 4. Distribution of observed and calculated temperatures in the central Kola Section (Stations 3–7) in the 0–200 m layer in June (left) and in the 0–50 m layer in July (right) from 1977 to 2017 (black circles show temperatures calculated using an independent data set).

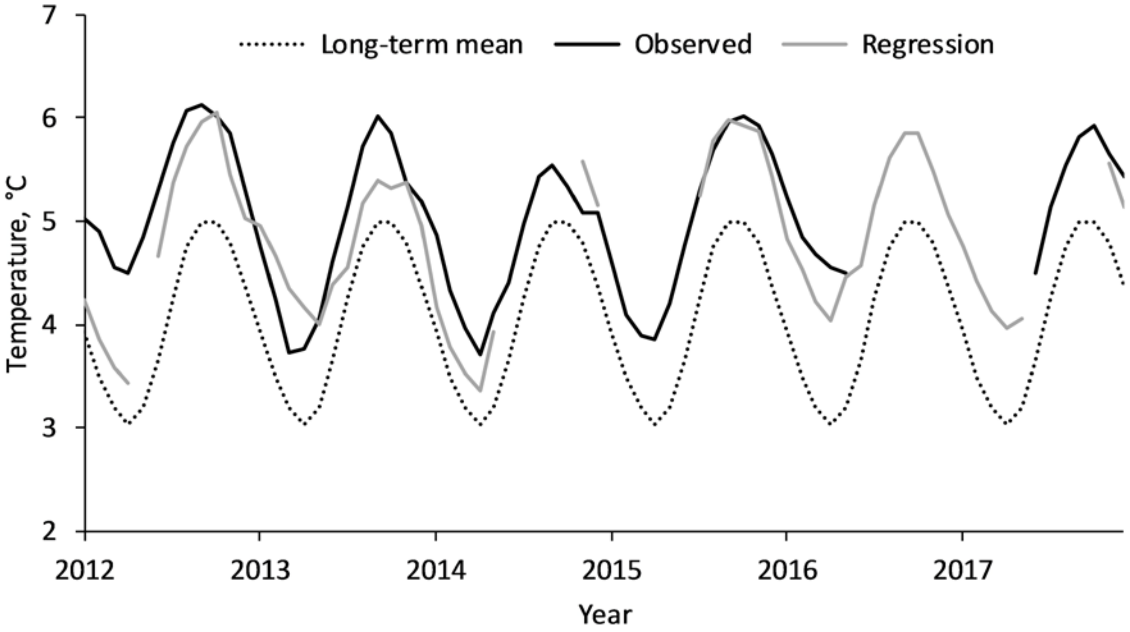

Figure 5. Long-term mean (dashed line), observed (black line) and calculated with regression equations (grey line) water temperatures in the 0–200 m layer in the central Kola Section (Stations 3–7).

3. The use of NEMO ocean model. Under this approach, modelled data from the multi-layer high resolution model NEMO (Madec et al., 2008) taken from the Copernicus website (http://marine.copernicus.eu) were used to restore data gaps.

The model has a 9 km horizontal resolution at the Equator, the 50-level vertical discretization, monthly and daily data. When restoring the data gaps, the monthly (from January 2007 to December 2017) modelled data on temperature at standard depths within the coordinates of standard stations in the Kola Section were used. The mean temperatures in the 0–50, 0–200, 50–200 and 150–200 m layers in the inner (Stations 1–3), central (Stations 3–7) and outer (Stations 8–10) parts of the Kola Section were calculated for each month based on the selected data. Then a regression analysis of modelled data obtained and the available observed data on water temperature was carried out. The regression equations between the modelled and observed data developed for each layer and part of the section were used to restore the gaps. Temperature anomalies were used in calculations to exclude a seasonal cycle.

As an example, Figure 6 shows the distribution of observed and modelled temperature anomalies in the 0–200 m layer in the central Kola Section (Stations 3–7). As can be seen in this figure, the relationship between these two series is statistically significant and rather close ($R^2 = 0.73$, n = 96). The highest deviations from the regression line are recorded in the area of large positive anomalies. Similar results of consistency between modelled and observed data were obtained for other layers and parts of the section (Table 3). Worst of all, the model describes the variability of temperature anomalies in the 50–200 m layer in the inner Kola Section (Stations 1–3) ($R^2 = 0.46$), although the relationship between modelled and observed data here remains to be statistically significant. This is most probably associated with a complex nature of hydrophysical and hydrodynamical processes in the coastal zone.

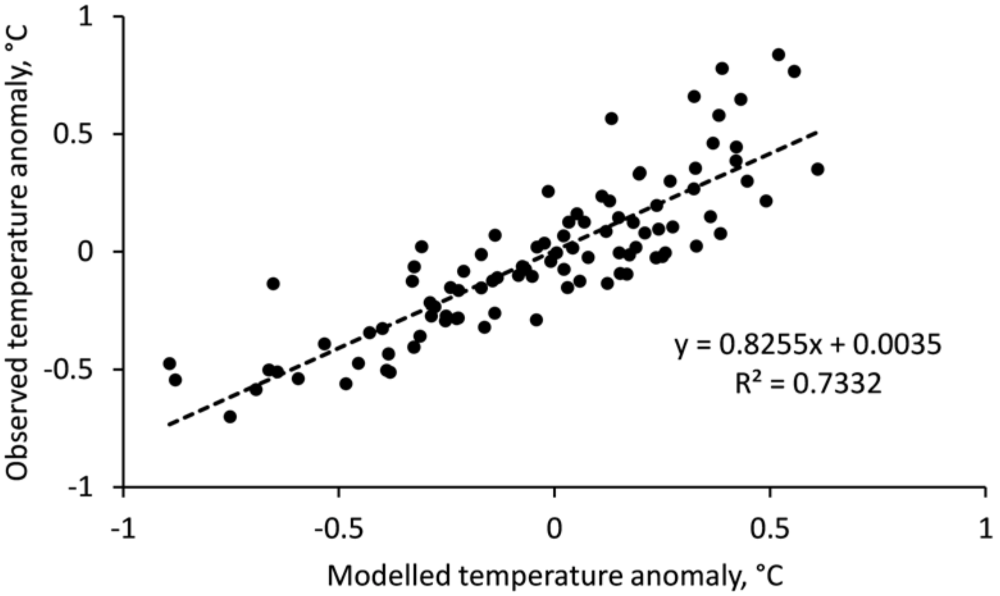

Figure 6. Distribution of observed and modelled water temperature anomalies in the 0–200 m layer in the central Kola Section (Stations 3–7) from January 2007 to December 2014 (dashed line shows a linear trend).

Table 3. Coefficients of determination (R^2) of regression equations used to calculate water temperature anomalies in the Kola Section.

A part of the Kola Section	Layer, m	R^2
Stations 1–3	0–50	0.74
	0–200	0.61
	50–200	0.46
Stations 3–7	0–50	0.78
	0–200	0.73
	50–200	0.72
	150–200	0.75
Stations 8–10	0–50	0.84
	0–200	0.78
	50–200	0.77
	150–200	0.72

Based on the temperature anomalies calculated using regression equations for the period of missing data, absolute values of temperature were calculated. Figure 7 shows an example of data restoration in the Kola Section using the above approach. Relatively large discrepancies between the observed and modelled temperatures were mainly recorded in 2012 when record-high temperatures were observed (González-Pola et al., 2018).

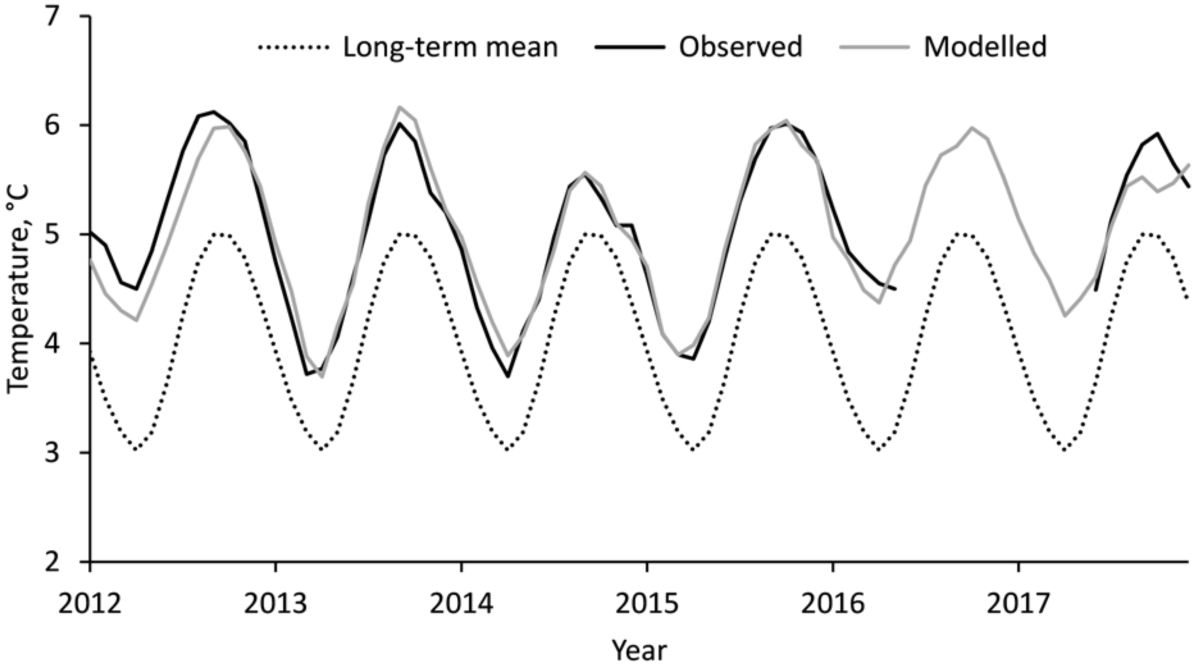

Figure 7. Long-term mean (dashed line), observed (black line) and calculated (grey line) with a model water temperatures in the 0–200 m layer in the central Kola Section (Stations 3–7).

In general, the model results closely describe interannual and seasonal variability of water temperature in the Kola Section and can be used for restoring gaps in time-series with a rather sufficient degree of reliability.

Results and discussion

To evaluate the quality of the proposed approaches for restoring data in the Kola Section and to select the most appropriate one, absolute errors were calculated, namely modules of differences between the observed and modelled temperatures. Then, mean absolute errors, maximum absolute errors and 2.5σ (σ – standard deviation) were calculated based on those values (Table 4). The 2.5σ means that about 99% of all the absolute errors are less than 2.5σ.

Table 4. Absolute error statistics for various approaches applied to restore data in the Kola Section by the example of the central Kola Section (Stations 3–7) and the 0–200 m layer from 2007 to 2017: 1 – the use of internal structure of time-series from the Kola Section; 2 – the use of multiple linear regressions and data from other standard sections; and 3 – the use of the NEMO model.

Absolute error statistics, °C	No. of approach		
	1	2	3
Mean absolute error	0.10	0.35	0.13
2.5σ (σ – standard deviation)	0.40	1.32	0.42
Maximum absolute error	1.02	2.54	0.54

Table 4 shows that the best results were obtained using modelled data from the Copernicus website (NEMO model). The highest absolute errors were recorded when using multiple linear regressions and data from other standard sections. As far as the first approach is concerned (the use of internal structure of time-series from the Kola Section), the mean absolute error was consistent with that for the third approach. The maximum absolute error, however, was twice as much. Moreover, the first approach provides good results on dependent data. However, when independent data were used (that is exactly what needed for data restoring), the error increases considerably (Figure 3). This is explained by the fact that when the series is being split into quasi-periodic components, they, in the aggregate, describe the series very well. However, when providing a prediction, i.e. when restoring data gaps, the results get worse, especially when there are abnormal situations like, for example, similar to that observed in 2016 when record-high temperatures were observed in the Barents Sea (González-Pola et al., 2018). The data restored with the first approach seem to be underestimated. Firstly, in August–September 2016 during the annual ecosystem survey in the Barents Sea, the temperature anomalies nearby the Kola Section were about two times higher than the restored data. Secondly, observations carried out in the Kola Section in November and December 2017 showed that observed temperature anomalies (0.70 and 0.90°C respectively) were well above the restored ones (–0.05°C and –0.12°C respectively).

Eventually, a decision was taken to use the third approach for restoring data on temperature in the Kola Section, namely using modelled data obtained with the NEMO ocean model. The restored data on temperature are given in Table 5.

Table 5. Mean water temperatures (°C) in the Kola Section in 2016 and 2017 (restored data are in bold).

Year	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
Stations 1–3 (Coastal Murman Current, 0–50 m layer												
2016	4.84	4.02	3.58	3.57	4.47	**5.39**	**7.19**	**8.37**	**8.74**	**8.13**	7.26	**6.03**
2017	**5.11**	**4.39**	**3.90**	**3.56**	**3.89**	4.82	6.71	8.35	8.55	7.62	6.79	5.87
Stations 1–3 (Coastal Murman Current), 0–200 m layer												
2016	5.06	4.26	3.80	3.68	4.13	**4.35**	**5.10**	**5.62**	**6.16**	**6.84**	7.00	**5.94**
2017	**5.07**	**4.37**	**3.92**	**3.53**	**3.68**	4.19	5.04	5.90	6.43	6.38	6.36	5.87
Stations 1–3 (Coastal Murman Current), 50–200 m layer												
2016	5.18	4.49	3.94	3.75	4.01	**3.86**	**4.17**	**4.42**	**5.08**	**6.37**	6.92	**5.91**
2017	**5.06**	**4.35**	**3.93**	**3.52**	**3.59**	3.96	4.25	4.81	5.53	5.87	6.26	5.87
Stations 3–7 (Murman Current), 0–50 m layer												
2016	4.91	4.40	4.33	4.39	4.85	**5.78**	**7.68**	**8.72**	**8.30**	**7.54**	**6.45**	**5.65**
2017	**5.09**	**4.68**	**4.40**	**4.14**	**4.40**	4.90	6.80	7.98	8.09	7.35	6.18	5.61
Stations 3–7 (Murman Current), 0–200 m layer												
2016	5.23	4.84	4.68	4.55	4.50	**5.05**	**5.56**	**5.83**	**5.92**	**6.08**	**5.98**	**5.64**
2017	**5.25**	**4.94**	**4.70**	**4.36**	**4.52**	4.49	5.13	5.54	5.82	5.92	5.65	5.44
Stations 3–7 (Murman Current), 50–200 m layer												
2016	5.33	4.99	4.80	4.62	4.36	**4.66**	**4.72**	**4.73**	**4.98**	**5.44**	**5.70**	**5.50**
2017	**5.17**	**4.87**	**4.66**	**4.30**	**4.42**	4.35	4.57	4.73	5.07	5.44	5.45	5.39
Stations 3–7 (Murman Current), 150–200 m layer												
2016	5.28	5.11	4.87	4.55	4.01	**4.55**	**4.60**	**4.46**	**4.56**	**4.85**	**5.00**	**5.09**
2017	**5.02**	**4.88**	**4.79**	**4.40**	**4.49**	4.17	4.24	4.36	4.53	4.80	4.94	5.13
Stations 8–10 (Central branch of the North Cape Current), 0–50 m layer												
2016	4.51	4.15	3.94	3.88	4.40	**5.33**	**6.97**	**8.12**	**7.59**	**6.93**	**5.68**	**4.93**
2017	**4.30**	**4.04**	**4.04**	**3.88**	**4.02**	4.48	5.84	7.04	7.19	6.53	5.37	4.75
Stations 8–10 (Central branch of the North Cape Current), 0–200 m layer												
2016	4.48	4.07	3.84	3.68	3.85	**4.28**	**4.92**	**5.38**	**5.62**	**5.73**	**5.26**	**4.74**
2017	**4.15**	**3.89**	**3.89**	**3.69**	**3.81**	3.85	4.48	4.89	5.19	5.13	5.15	4.54
Stations 8–10 (Central branch of the North Cape Current), 50–200 m layer												
2016	4.47	4.04	3.81	3.61	3.66	**3.98**	**4.25**	**4.46**	**4.96**	**5.34**	**5.12**	**4.69**
2017	**4.11**	**3.85**	**3.85**	**3.64**	**3.75**	3.63	4.02	4.17	4.51	4.66	5.05	4.48
Stations 8–10 (Central branch of the North Cape Current), 150–200 m layer												
2016	4.36	3.92	3.65	3.40	3.31	**3.56**	**3.78**	**3.89**	**4.18**	**4.67**	**4.47**	**4.43**
2017	**4.02**	**3.75**	**3.65**	**3.35**	**3.46**	3.28	3.51	3.64	3.82	3.84	4.51	4.20

Conclusions

Three approaches to restoring gaps in data on water temperature in the Kola Section were examined and implemented, based on the use of the following: (1) internal structure of time-series from the Kola Section; (2) multiple linear regressions and data from other standard sections; and (3) modelled data from the Copernicus website

The use of modelled data from the Copernicus website (NEMO ocean model) for restoring data gaps showed the best results and this approach was applied for the final restoration of missing data.

Mean water temperatures were restored for each month from June 2016 to May 2017 in the 0–50, 0–200, 50–200 and 150–200 m layers in the inner, central and outer parts of the Kola Section.

There is an intention to conduct similar exercise for restoring data on salinity.

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Long-term trends in the radioactive contamination of the Barents and Kara Seas

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Abstract

This publication summarizes long-term data on the radioactive contamination in the waters of the Barents and Kara Seas. It also describes current patterns in the distribution of radionuclides in the study area.

Keywords: Barents Sea, Kara Sea, radionuclides, ^{137}Cs, ^{90}Sr, long-term trend

The research interest in marine radioactivity decreased significantly in the first decade of the 21st century due to the general decrease of radionuclide levels after the cease of large-scale nuclear tests. Discovery of traces of Fukushima NPP discharges in high-latitude Arctic areas indicated the importance of regular monitoring of artificial radionuclide background in the environment.

Long-term trends in the radioactive contamination of the Barents-Kara region were reconstructed using a radioecological data base of the Murmansk Marine Biological Institute (MMBI), published information (AMAP 1997; Matishov, Matishov, 2004; Sivintsev et al., 2005; Matishov et al., 2009) and results of the latest marine studies of MMBI.

In 2015–2017 surface water samples were collected during cruises to the Barents and Kara seas using the research vessel *Dalnie Zelentsy* and other ships of opportunity *Talnakh, Nadezhda,* and *Norilskiy Nickel*. Radiological measurements were performed at MMBI. The activity of ^{137}Cs and ^{90}Sr were measured in the samples. The cellulose inorganic ANFEZH sorbent was used to concentrate ^{137}Cs from the sea water (Remez et al., 1998); the volume of each sample was not less than 100 L. The activity of ^{137}Cs was measured using the “InSpector-2000” γ-spectrometer and the multichannel “b13237” γ-spectrometer for measuring X-ray and gamma radiation with pure germanium detectors (“Canberra”, USA). The spectra were analyzed using the “Genie-2000” software. Each sample was measured for 24 hours and more. To determine the activity of ^{90}Sr we used the oxalate-radiochemical preparation method (Outola et al., 2009) followed by measuring the activity of equilibrium ^{90}Y in the multi-purpose scintillation counter “LS-6500” (“Beckman Instruments Inc.”, USA).

Barents Sea

In 2015–2017, no short-lived anthropogenic γ-nuclides associated with recent radioactive releases were registered. The activity of ^{137}Cs varied from 0.2 Bq·m^{-3} to 4.6 Bq·m^{-3}. The range of measured activities of ^{90}Sr was 0.05–13.5 Bq·m^{-3}.The waters of Atlantic origin have the greatest influence on the hydrological regime of the Barents Sea in comparison with other arctic seas. The Atlantic waters contribute the most part of the artificial radionuclides to the ecosystem. In 2017, the studies were carried out at two transects along the western boundary of the Barents Sea and at the Kola Meridian Transect. The comparison of average concentrations of ^{137}Cs in different parts of the Barents Sea makes it obvious that the Atlantic waters are still characterized by the highest concentration of radionuclides. The main flux of cesium enters the Barents Sea with the Atlantic waters through the North Cape–Bear Island border. The maximum concentration of this isotope was registered in the upper layers of the Atlantic water flow in all branches of the North Cape Current. At the Kola

Meridian Transect, in the central part of the Barents Sea the concentration of cesium is markedly reduced (1–1.5 Bq·m^{-3}).

Long-term dynamics of the activity of ^{137}Cs and ^{90}Sr in the waters of the Barents Sea are presented in Figure 1. By the period of 1979–1980, the increase in ^{137}Cs activity up to 45 Bq·m^{-3} (Kershaw, Baxter, 1995) was registered in the waters of the Barents Sea. Since that time, the long-term dynamics of the volumetric activity of ^{137}Cs has been showing the trend to decline exponentially: $y = 36.906e^{-0.099x}$, where x is the number of years elapsed after the maximum of contamination ($R^2 = 0.91$). The corresponding average environmental half-life ($T_{1/2}$) is about 7.0 years. The decrease in the volumetric activity of ^{90}Sr after the maximum of contamination is less pronounced: $y = 9.9354e^{-0.04x}$ ($R^2 = 0.58$). The environmental half-life ($T_{1/2}$) is about 17 years. The estimated environmental half-lives for ^{137}Cs and ^{90}Sr are much less than the physical half-lives of these radionuclides. This fact can be well-explained for a dynamic marine environment where radionuclide redistribution occurs under the influence of hydrological conditions, water exchange with adjacent seas, geochemical processes in the water column, and at the 'water-bottom sediment' boundary.

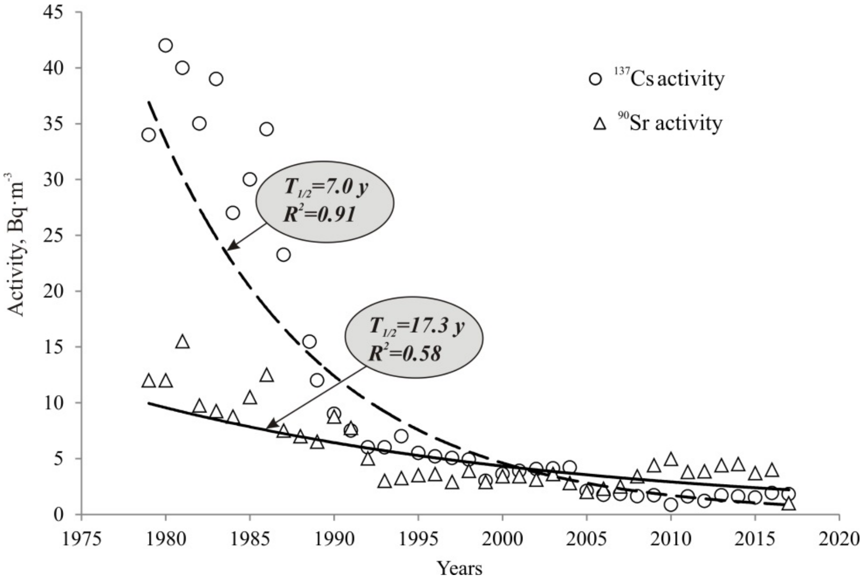

Figure 1. Long-term dynamics of ^{137}Cs and ^{90}Sr activities in water of the Barents Sea in 1979–2017.

Kara Sea

In 2015–2017, the activity of ^{137}Cs varied from 0.4 Bq·m^{-3} to 4.3 Bq·m^{-3}. Spatial differences in ^{137}Cs concentrations in the Kara Sea waters are hard to be determined because of the unavailability of data. Reduction of the ^{137}Cs content in seawater was registered at low depths. The area of the lowest ^{137}Cs concentrations is allocated in the southern part of the sea, near the estuary zones of the Yenisei and Ob rivers. The range of ^{90}Sr activity varied from 0.5 to 11.6 Bq·m^{-3}. The distribution of ^{90}Sr activity in the Kara Sea is significantly affected by the river runoff. The highest concentrations of the radionuclide were observed in the shallow parts of the sea most affected by the runoffs of the Ob and Yenisei rivers.

A comparative analysis of the long-term dynamics of ^{137}Cs and ^{90}Sr activity in the waters of the Kara Sea showed a sharp decrease in the ^{137}Cs activity compared to the 1990s. The concentration of ^{90}Sr in the water varied in a relatively wide range and there were no obvious decrease compared to ^{137}Cs. Long-term tendencies for decreasing of ^{137}Cs and ^{90}Sr concentrations in the Kara Sea water can also be described by the exponential curves but the degree of reliability is lower than in the Barents Sea.

Comparative analysis of water contamination on the continental shelf and in the coastal zone of the Barents and Kara seas suggests that due to the natural oceanological processes and isotope decay the concentration of artificial radionuclides has multiply decreased over 60 years. At present, the influence of regional and local contamination sources (such as discharges from West-European radiochemical plants, Russian nuclear industrial enterprises Mayak and Tomsk-7, nuclear fleet bases, burials at the Novaya Zemlya), which were active in the past, has become almost indistinguishable from the background.

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Carbonate chemistry dynamics around the Svalbard Archipelago: impacts of melting sea ice, biological production and deep water inputs

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The Arctic Ocean and surrounding seas are vulnerable to climatic changes, however impacts to the ecosystem and biogeochemical cycling remain poorly understood. The aim of this study was to investigate the dynamics of carbonate chemistry in the oceanic waters around the Svalbard archipelago. The key objectives were: (1) determine seasonal macronutrient changes and biological carbon uptake to infer rates of primary production; (2) investigate the impacts of melting sea ice on upper ocean carbonate chemistry; (3) describe the state of ocean acidification and identify key driving processes.

Seawater samples for analyses of total dissolved inorganic carbon (C_T), alkalinity (A_T), macronutrients and meltwater tracer $\delta^{18}O$ were taken in summer 2015, 2016 and 2017 during SI_Arctic cruises for the Institute of Marine Research. Surface, shelf and deep waters were sampled from Fram Strait to north of the Svalbard archipelago, including within the seasonal pack ice. Oceanographic data and satellite-derived sea ice cover were used to identify regions of recent ice melt and to trace the path of Atlantic waters around Svalbard. Seasonal and year-to-year variability in carbon cycling are discussed in relation to Atlantic and polar water masses, biological production and melting sea ice.

This study revealed large spatio-temporal variability in oceanic carbonate chemistry and biological carbon uptake around Svalbard. High concentrations of C_T found in eastern Fram Strait and along the shelf reflect the imprint of Atlantic waters transporting inorganic carbon and nutrients northwards into the region, fueling biological production. Intense biological carbon uptake occurred in the surface ocean influenced by polar water masses flowing into the region. During retreat of the ice pack, meltwater freshened the surface ocean to reduce C_T and lower $A_{T,}$ suppressing saturation states of important calcium carbonate bio-minerals. Melting sea ice enhances the vulnerability of polar waters to ocean acidification upon atmospheric carbon dioxide uptake.

Maps of sea zones vulnerability to human impact – an important element of sea bioresources management

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Abstract

Maps the sensitivity/vulnerability of sea-coastal zones to oil are of great importance in OSR activities, offshore project EIA preparation and integrated management of marine natural resources. However, there are some issues related to the mapping method development. Virtually every method in current uses rank values for calculations, although these cannot be used for arithmetical operations. A vulnerability mapping approach that eliminates the need for ordinal values is presented here.

Keywords: Sea zone vulnerability maps, human impact, oil, suspended matter, underwater noise, ordinal values, ranks, maps of Kola Bay vulnerability to oil

Introduction

Long-term sustainable management of biological resources of seas and open oceanic areas requires a focus on human impacts on marine ecosystems, first of all, from the offshore petroleum sector. All human impacts affect biota and bioresources, which means that bioresources cannot be properly managed if this impact is ignored.

Today, maps of vulnerability to oil are more often developed and are used for human impact. For example, the international organizations IMO, IPIECA and OGP have prepared a number of reports that not only address individual aspects of oil effects on marine environment and biota but also contain recommendations on mapping sensitivity/vulnerability to oil. These reports date back to 1994 and 2012 (IMO …, 1994; IPIECA …, 2012). For example, the Report (IPIECA …, 2000) on oil spill response says: “Making and updating maps of vulnerable zones is a key aspect of the planning process. Spill responders will use these maps as a source of important information on the locations of various coastal resources and sensitive environments”.

Maps of vulnerability to various human impacts (oil, suspended matter, noise) and underlying databases are needed: for oil spill response (OSR) plans and activities – to minimize damage from spills and implications of their responses; for environmental support of various offshore projects – to choose the best project option in terms of conservation of nature and bioresources; for environmental monitoring and planning at various levels (state and production); for human impact consideration, control and mitigation – in the management of marine bioresources. Thus, vulnerability maps ought to form the basis of the entire environmental protection policy in the Barents Sea region.

This paper addresses problems of existing vulnerability mapping methods, discusses the possibility of developing a common mapping method for various types of human impact and outlines the MMBI method of oil impact mapping based on metric instead of rank values.

Seasonal maps of the vulnerability to oil and other impacts of maritime zones, based on the common method must be an important element of marine bioresources management plans. In Norway, such a management plan has been developed for the western part of the Barents Sea (Integrated …, 2006). The updated plan was presented in 2011 (First …, 2011). Similar planning activities for the eastern part of the sea are under way in Russia (Integrated …, 2011).

Although the Norwegian Plan describes the most sensitive areas of the sea and biota species maps, it still lacks seasonal maps of vulnerability to certain impacts. As a general principle, such maps must show areas with different vulnerability to various impacts. This will help us to plan certain activities in certain regions in such a way as to minimize potential impacts and avoid causing significant harm to biological resources. They must take into account the abundance of the biota in the area being mapped, and its vulnerability in different seasons of the year. Abiotic components of the marine ecosystem must also be considered.

1. Methods and issues of mapping vulnerability to oil

The global and Russian experience in mapping oil-vulnerable zones takes two complementary approaches. *The first* is based on mapping coastline sensitivity by the environmental sensitivity index, ESI. Broadly speaking, ESI's are based on coastal features and how oil's potentially interacts with them. In the US, such maps were developed in the 1970–80s for the entire coast and are still in active use today. Other countries, including Russia, have introduced similar developments. This paper addresses *the second* approach – mapping vulnerability of offshore zones to oil.

For example, the public administrations of all *Norwegian* counties possess vulnerability maps based on the unified method (SFT …, 2004). These maps show areas of priority protection in the event of oil spills. All the vulnerable resources considered are assessed in terms of four factors, each scored as 1, 2 or 0, 1, 2, 3. The adjusted numerical scores are not metric values but are actually ranks. Next, factors for each resource are multiplied together to obtain its priority protection rankings. The higher the priority ranking, the more important is the resource and the more protection it needs in the event of an oil spill. One factor is bigger than the other, but the actual difference (even if scored) is ignored.

BRISK project. Vulnerability maps for the entire Baltic Sea were created as part of the BRISK project (2009–2012), which included all Baltic countries as participants (Sub-regional …, 2012). Seventeen different abiotic components were considered, including several biota habitats. The vulnerability of these components was ranked from 1 to 4 in different seasons. The resulting maps were added together to obtain seasonal vulnerability maps. The latter was used to assess the risk (damage) of oil spills. Vulnerability maps are also based on rank values.

A similar approach based on rank values has been employed in other methods (Depellegrin et al., 2010; Offringa, Låhr, 2007).

Russia has similar developments too. Many offshore projects for OSR plans use the vulnerability maps developed by the expert team of JSC "Ecoproject" headed by V. B. Pogrebov (Pogrebov, 2010). Briefly, the method is based on the following algorithm: ranked biota abundance maps are created and multiplied by rank coefficients of biota vulnerability to oil. Next, all the maps for a given season are added together to produce seasonal vulnerability maps. In 2012, an expert team under the auspices of WWF prepared a more detailed method (WWF …, 2012), but the algorithm remained the same. It is based on rank value calculations.

MMBI experts also created vulnerability maps for the Barents Sea, White Sea and other seas based on the rank approach and method of Pogrebov. However,we have introduced major improvements – vulnerability maps were calculated in the vulnerability range of the entire year (absolute vulnerability maps) and in the vulnerability range for individual seasons (relative vulnerability maps). However, the calculation was based on rank (ordinal) value operations (Shavykin, Ilyin, 2010).

Refusal to use ranks leads to certain problems in the creation of vulnerability maps. These include *choice of biota abundance units of measurements*, *justification of biota vulnerability coefficients,* *summation of vulnerability of various objects* (consideration of biotic and abiotic components of ecosystem). There are also some other issues of methodology not related to the use of ordinal values: the scale of vulnerability maps; choice and justification of seasonal boundaries; connecting/overlapping maps of neighbouring regions for the same season; classification issues in the final presentation of vulnerability.

In our opinion, solutions for some of these problems (choice of biota abundance units of measurement for source maps and justification of biota vulnerability coefficients) have already been found and have been presented in patents and publications (Shavykin et al., 2017; Shavykin, Karnatov, 2017, 2018) and in the monograph "Kola Bay and Oil: Biota, Vulnerability Maps, Pollution" that will soon be published in Russian.

2. The problem of using ordinal (rank) values for map calculations

In all the above and many other methods, rank values (rankings or scores where the relation between scores or ranks does not reflect relationships on a metric ratio scale) are used for vulnerability map calculations. However, arithmetical operations cannot be performed on ordinal values (Zax, 1976; Khovanov, 1996; Orlov, 2011), as they would lead to incorrect results unless ranks have been subjected to prior arithmetisation. However, such a process is not envisaged in the above methods.

We can provide examples that show why rank operations are inappropriate. *Example 1.* Let us assume that one value is known to be greater than others (A > B > C > D) and we rank them 1, 2, 3, 4 (Figure 1). We do not know the range of variation of these values although, in fact, they have certain limits, as Figure 1 shows. As a result, the sum of values 1 and 2 (A+B) will not yield the rank typical of value B ranked 3: the actual unknown amount will anyhow be more than 210 units, i.e. even more than rank 4.

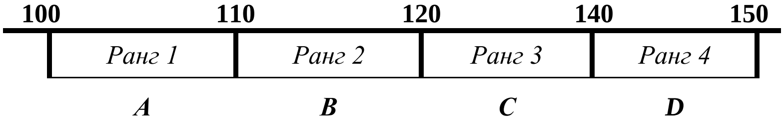


Figure 1. Illustration of example 1. All rank-matching intervals are approximately equal, but this correlation of class limits is unknown to experts who assess the relevant values and assign them ranks.

Example 2. Two tables (1 and 2) show possible products of real metric values of two numbers (X_m and Y_m) and the same numbers as rank values (X_r and Y_r). This yields a vital difference in the arrangement of their products when calculations are performed using ranks and real metric values.

Table 1. Base values of numbers X and Y on the metric (m) and rank (r) scales.

X	X_m	X_r	Y	Y_m	Y_r
A	50	1	P	60	5
B	60	2	Q	40	4
C	70	3	R	30	3
D	110	4	S	10	2
E	120	5	T	4	1

Table 2. Product calculation results as metric ($X_m \cdot Y_m$) and as rank ($X_r \cdot Y_r$) values.

$X \cdot Y$	$X_m \cdot Y_m$	$X_r \cdot Y_r$
$A \cdot P$	50·60 = 3000	1·5 = 5
$C \cdot Q$	70·40 = 2800	3·4 = 12
$A \cdot Q$	50·40 = 2000	1·4 = 4
$E \cdot S$	120·10 = 1200	5·2 = 10
$B \cdot S$	60·10 = 600	2·2 = 4
$E \cdot T$	120·4 = 480	5·1 = 5

It is therefore not possible to use values (estimates) in arithmetical operations, including calculations of maps of sea-coastal zones vulnerability to oil when all or even some of these values (biota distribution density, vulnerability coefficients, etc.) are scores or rank values on an ordinal scale. This approach yields incorrect results including incorrect vulnerability maps. Score and rank values may only be used in arithmetic calculations following arithmetisation. Scores may be used if their correlations reflect actual quantitative relations between values on a metric ratio scale.

3. Common methods of building vulnerability maps for various types of human impact

Long-term sustainable management of marine biological resources requires focusing on various human impacts on both individual ecosystem components and marine ecosystem as a whole.

The offshore petroleum sector produces the most significant human impacts on marine resources. These include: *effects of oil* in the event of oil spills; *effect of suspended matter* when accidental kicks and blowouts of mineral-rich oil occur, dredging and damping during field development; *acoustical action* (seismic surveys) during field development, offshore pipeline laying, oil and gas transportation by heavy-tonnage vessels and acoustic measurements (from air guns).

The main elements of methods of mapping vulnerability to various impacts are as follows. *First*, gathering initial data on 1) seasonal biota abundance distribution – the most numerous biota and endangered species; 2) the location of relevant abiotic components – social and economic areas and protected areas. *Second*, calculation of biota vulnerability coefficients and coefficients of priority protection of abiotic components. According to Offringa and Låhr (2007), biota vulnerability coefficients depend on: a) biota sensitivity (S) to the relevant impact type, b) its recoverability (R) after impact; c) the potential biota effect (E) of the relevant factor. It is possible that area vulnerability depends both on biota abundance and the presence of especially significant objects and their vulnerability coefficients that are calculated with regard to parameters S, R and E ($V=E \cdot R/S$) for biota and for abiotic components, which are chosen on the metric ratio scale. In this case, the algorithm of calculating maps of vulnerability to oil, suspended matter, and underwater noise only differs in the use of different vulnerability coefficients. These coefficients, in their turn, are determined by the values of biota sensitivity to impacts and the magnitudes of the potential impacts of various factors, while biota recoverability will be identical for different impact types.

4. MMBI developments for the method of mapping vulnerability to oil

Let us briefly discuss the main elements of the MMBI method of mapping the vulnerability of marine areas to petroleum. We do not claim that this is the only correct approach and we believe that all developments, including our own, need to be discussed in detail to arrive at the best correct approach.

In order to consider the potential environmental impact of oil spills, a suitable spill model should take into account the spill location, representative conditions, and the properties of the spill – primarily, its density and viscosity (light, middle and heavy oils have very different properties).

The list of biota groups/subgroups/species – important biota components (IBC), especially significant social-economic objects (ESO) and protected areas (PA) considered – is determined.

Primary distribution maps of IBC groups/subgroups/species *are created* for individual seasons using a certain algorithm in the units of measurements accepted for these groups. Since values may be incompatible due to different units of measurement, they need to be converted to the same units of measurement to add them up later on. To this end, the average annual abundance of a range of biota groups is determined within marine region boundaries (in terms of distribution density and area). Next, density values are normalized by each group's annual average abundance (each group has its own value). This results in primary biota distributions in the same units of measurement – shares of the annual average abundance of groups/subgroups/species per unit area. Everything is easier for abiotic components – ESO and PA. If there is an object, a range is ranked 1, if there is none – zero.

Next, distribution maps of the objects under study are “multiplied” by coefficients of vulnerability to oil (*V*) for IBC and by priority protection coefficients for ESO and PA. As pointed out above, vulnerability coefficients *V* are calculated based on *E, R and S*. However, if parameters *E and R* are given in the same units (percentage for potential impact and years for recoverability), biota sensitivity is assessed in different ways. For biota in the water column (ichthyoplankton, fish) exposed to dissolved and dispersed oil, these values *S* are assessed by LC50 concentrations or lethal load LL50 (mg/L). For biota that mostly lives on the water surface (sea and water birds) and is affected by the oil film thickness, sensitivity is assessed by lethal film thickness LT50 (similar to LC50) measured in µm. In order to handle values in the same units of measurement, water object sensitivity can be normalised to the maximum allowable concentration of oil in water (MAC, mg/L) and wetland object sensitivity to the maximum allowable oil film thickness (MAT, µm), similar to MAC. In this case, sensitivity values *S* will be dimensionless and the issue of different units of measurement eliminated. Vulnerability coefficients for the Kola Bay biota (Table 3) have been developed based on this approach.

Table 3. Assessment of vulnerability parameters (S_b^g, E_b^g, R_b^g) in metric scale values and resulting vulnerability coefficients V_b^g of Kola Bay biota groups (subgroups)

Biota	LC$_{50}$, mg/L	LT$_{50}$, µm	S_b^g	E_b^g, %	R_b^g, year	V_b^g
MAC = 0.05 mg/L						
Macrophytobenthos	550 (100–1000)		11 000	70	5	3.2
Macrozoobenthos:	290		5 800	40	4	2.8
polychaetes	(10–100)					
bivalves	(50–500)					
gastropods	(100–1000)					
Megazoobenthos nonmobile:	410		8 200	60	4	2.9
bivalves	(50–500)					
gastropods	(100–1000)					
Megazoobenthos mobile – crustaceans	55 (10–100)		1 100	10	3.5	3.2
MAT = 0.04 µm						
Water birds		25	625	90	2	28.8
Periwater birds:						
gulls		25	625	35	3	16.8
sandpipers		25	625	35	3	16.8

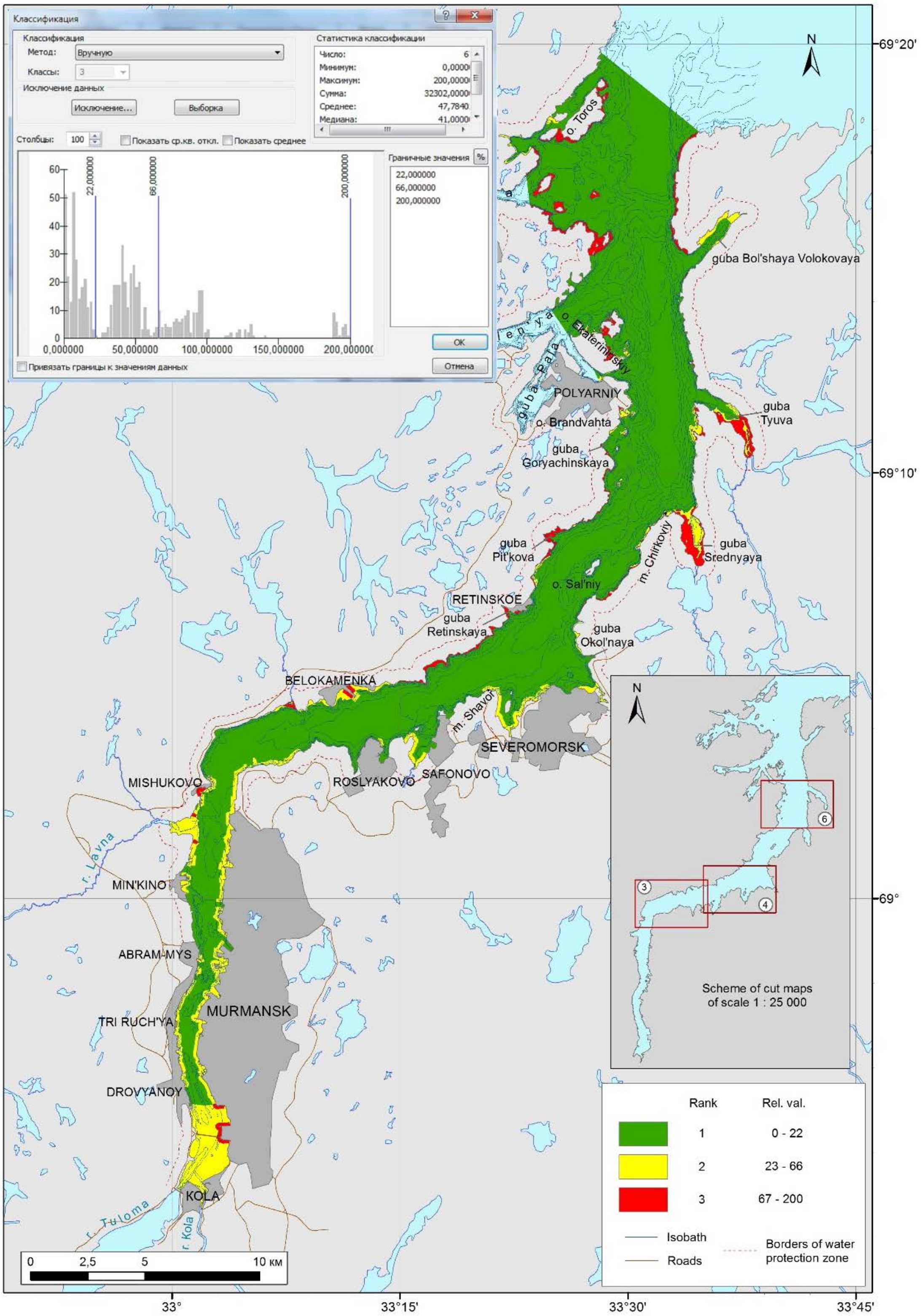
Note. Numbers without brackets show average values, bracketed numbers show ranges of values;
S_b^g= LC$_{50}$/MAC – for benthos;
S_b^g= LT$_{50}$/MAT – for birds;
$V_b^g = (E_b^g \cdot R_b^g / S_b^g) \cdot 100.$

These operations result in maps of IBC vulnerability and ESO and PA priority protection. We performed a series of normalisations of resulting maps. Summing these gave us relative integral vulnerability maps separately for each season (areas of ranges with different vulnerability values) (range: min÷max for the season, different for different seasons) and absolute integral vulnerability maps (range: min÷max for the year, the same for all seasons).

The integral vulnerability range on maps was then divided into either three or five subranges, ranked from 1 to 3 or to 5, where areas with maximum values (ranks 3 or 5) are the most vulnerable ones in need of priority protection.

For a more detailed description of the proposed algorithm of the vulnerability map calculation, see (Shavykin et al., 2017).

The method we propose has been used to create Kola Bay seasonal vulnerability maps on two scales: *tactical* – 1:150 000 for the entire bay and *object* – 1:25 000 for its three individual regions. For examples, see Figures 2 and 3 posted on the "Murmansk Region Geoinformation Portal" website (URL: http://portal.kgilc.ru/mmbi/), which also contains publications that describe the primary distributions of biota abundance and mapping method.



Метод: Вручную

Классы: 3

Число: 6

Минимум: 0,0000

Максимум: 200,0000

Сумма: 32302,0000

Среднее: 47,7840

Медиана: 41,0000

Столбцы: 100

☐ Показать ср.кв. откл. ☐ Показать среднее

Граничные значения:
22,000000
66,000000
200,000000

☐ Привязать границы к значениям данных

	Rank	Rel. val.
🟩	1	0 - 22
🟨	2	23 - 66
🟥	3	67 - 200

Figure 2. Example of the tactical map of Kola Bay relative vulnerability, summer, scale 1:150 000.

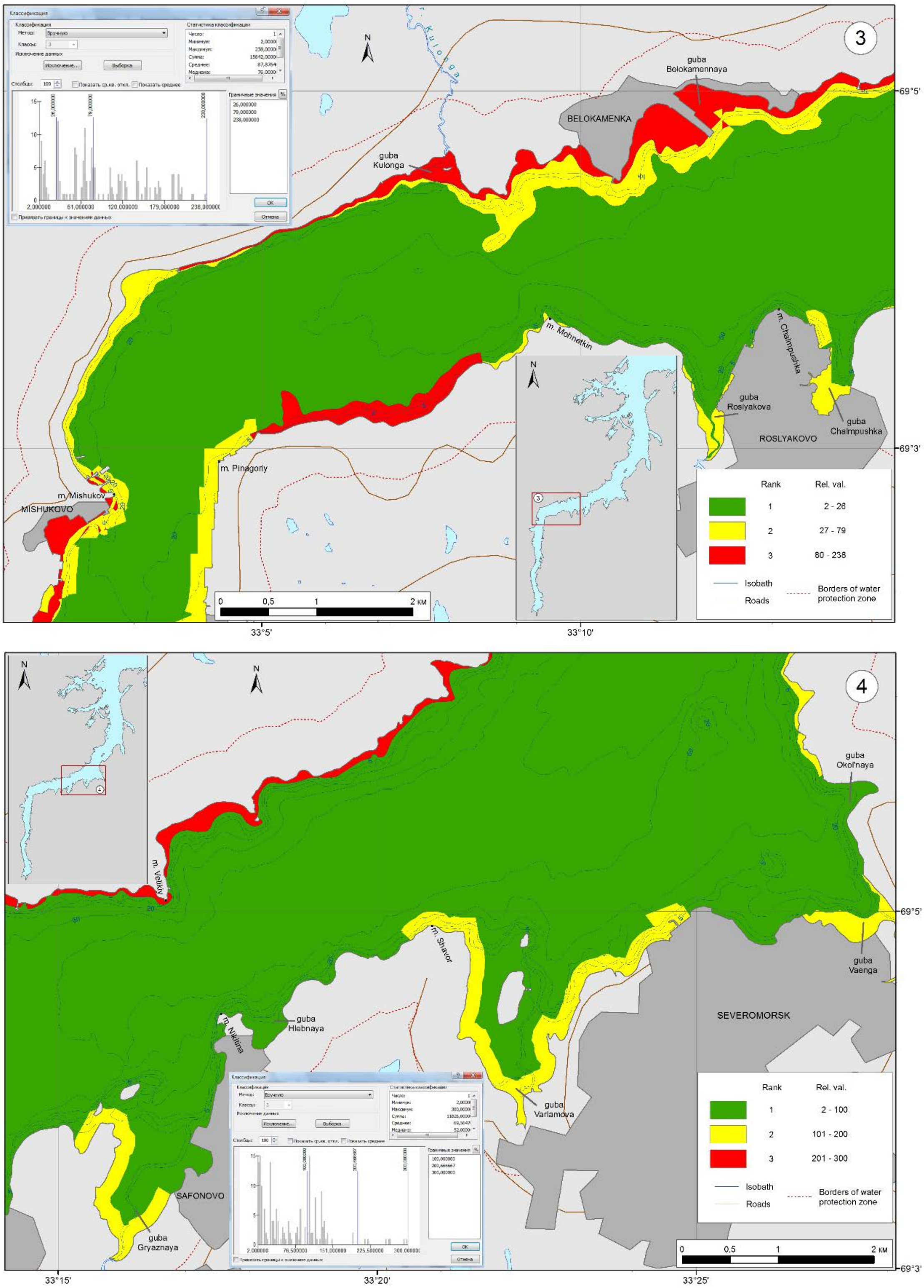


Figure 3. Example of the object maps of Kola Bay relative vulnerability, regions No. 3 and 4, summer, scale 1:25 000.

The approach described above is only the beginning of the development of the vulnerability mapping method based on metric values. For example, the determination of vulnerability coefficients of benthos might require consideration of not only its sensitivity to a particular concentration of dissolved oil but also its concentration in bottom sediments and/or oil layer thickness on the seabed. There is also an open question of how biota and oil interact in the littoral zone, where oil can also have two types of impacts: depending on its concentration and film thickness.

Conclusions

Vulnerability maps of sea-coastal zones are an important element of oil spill contingency plans, environmental support of offshore projects, EIA preparation and integrated management of marine natural resources. These maps help us to plan various activities in certain regions so as to mitigate the potential impact of spills and avoid significant harm to biological resources.

Our review of publications on vulnerability maps permit us to conclude that many existing vulnerability mapping methods do not permit proper maps and their use to be created to correctly assess the degree of vulnerability of individual areas; i.e. the total vulnerability of biota (various biological resources) and abiotic components. Rank/score values must be abandoned at all mapping stages that include arithmetic operations, as arithmetic operations with these values cannot yield correct results. The approach that involves the use of metric values on the ratio scale should be used.

Vulnerability maps must be used as the basis to assess the impact area of oil spills, underwater noise and suspended matter, etc. Maps showing these impact types must be based on a common method and should consider the following: 1) seasonal distribution of biota abundance; 2) location of relevant abiotic components; 3) biota vulnerability coefficients and priority protection coefficients of abiotic components.

We have briefly discussed the results of the development of the MMBI method of mapping vulnerability to oil, described the main stages of the vulnerability mapping algorithm and suggested solutions to certain problems such as the choice of units of biota abundance measurement, and the justification of biota vulnerability coefficients. Although some problems addressed in this paper have been solved in full or in part, quite a few open issues require further elaboration, understanding and proper justification. The main issues include justification and specification of vulnerability coefficients of benthos, fish, ichthyoplankton and marine mammals; summed values of the vulnerability of objects of various natures; i.e. joint consideration of biotic and abiotic ecosystem components; representation of the final vulnerability of a water area, i.e. choice of a data classification method for mapping and other purposes.

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Experience of using of combined acoustic-temperature vertical transects in the pelagic surveys

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Abstract

The results of the analysis of vertical profiles of the acoustic values of herring and blue whiting and temperature distribution are presented in paper. The combined data were obtained on transects during summer pelagic surveys in 2011–2017. The accumulated experience of such an analysis has made it possible to compare the spatial and vertical distribution of pelagic fish under different oceanographic conditions. Some climatic and inter-annual features of fish concentration of different age groups are revealed.

Keywords: temperature, acoustic values, transects, Norwegian Sea, herring, blue whiting

Introduction

International investigations of pelagic fish stocks have been carried out in the Norwegian Sea for more than 20 years. They are part of the international ecosystem survey in the Nordic Seas (IESNS). Consideration of the main commercial fish of the Norwegian Sea, such as the Norwegian spring-spawning herring, the blue whiting of the North-East Atlantic, are performed in these trawl-acoustic surveys (ICES, 2015).

As a rule, after completing the surveys, the distribution of joined acoustic records for various species of fish are integrated throughout the water column for farther estimate of stocks. To understand the fuller pattern of the fish distribution depending on the environmental conditions, the author of present work suggested a joint express analysis of the vertical distribution of both the acoustic records of pelagic fish and the temperature at the transects performed in ecosystem surveys.

The novelty of the presented approach is in the possibility of considering the quasi-3D distribution of fish acoustic records, in contrast to the traditional estimation of the spatial distribution of summarized acoustic values over the water column.

Material and methods

Oceanographic data collected on board RV ”G.O. Sars” and “Johan Hjort” (Institute of Marine Research/Havforskningsinstituttet, Norway) on transects in the Norwegian Sea during the ecosystem surveys of pelagic fish (May–June) 2011–2017 (ICES, 2011, 2013, 2014, 2015a, 2016, 2017) were used in the work. The collection of oceanographic information was carried out using a SBE 9Plus CTD profiler. Data of the water temperature from the surface to a depth of 500 m were used in the described work. The temperature at standard horizons was transformed by a Surfer package into grid nodes with a horizontal step of 0.5° in longitude and vertical step of 10 m in depth for plotting distribution graphs on transects.

The acoustic observation data obtained with the echosounders EK60, EK80 and expertly processed were divided into acoustic records for herring and blue whiting in the form of nautical area scattering coefficients (NASC, S_A, m^2/nm^2, acoustic values) (ICES, 2015) in 1 nautical mile horizontally and 10 m in depth. The data obtained separately for herring and blue whiting were also included in grid nodes using a Surfer package.

Individual profiles of vertical temperature distribution, acoustic values for herring and blue whiting were combined on a general scale for each transect, spatially directed from west to east. As a result, from 8 to 10 combined transects were obtained for each survey in 2011–2017 (in which the author of the work participated).

Results and discussion

The obtained combined profiles of the vertical distribution of acoustic values for herring and blue whiting in relation to temperature made it possible to reveal some general patterns and features for each specific year.

The clearest inter-annual deviations in the distribution of pelagic fish and temperature were obtained on transects which were carried out in different years in close coordinates. The transect along 64°15' N in the southeastern part of the sea (Figure 1) has the most frequent repetition.

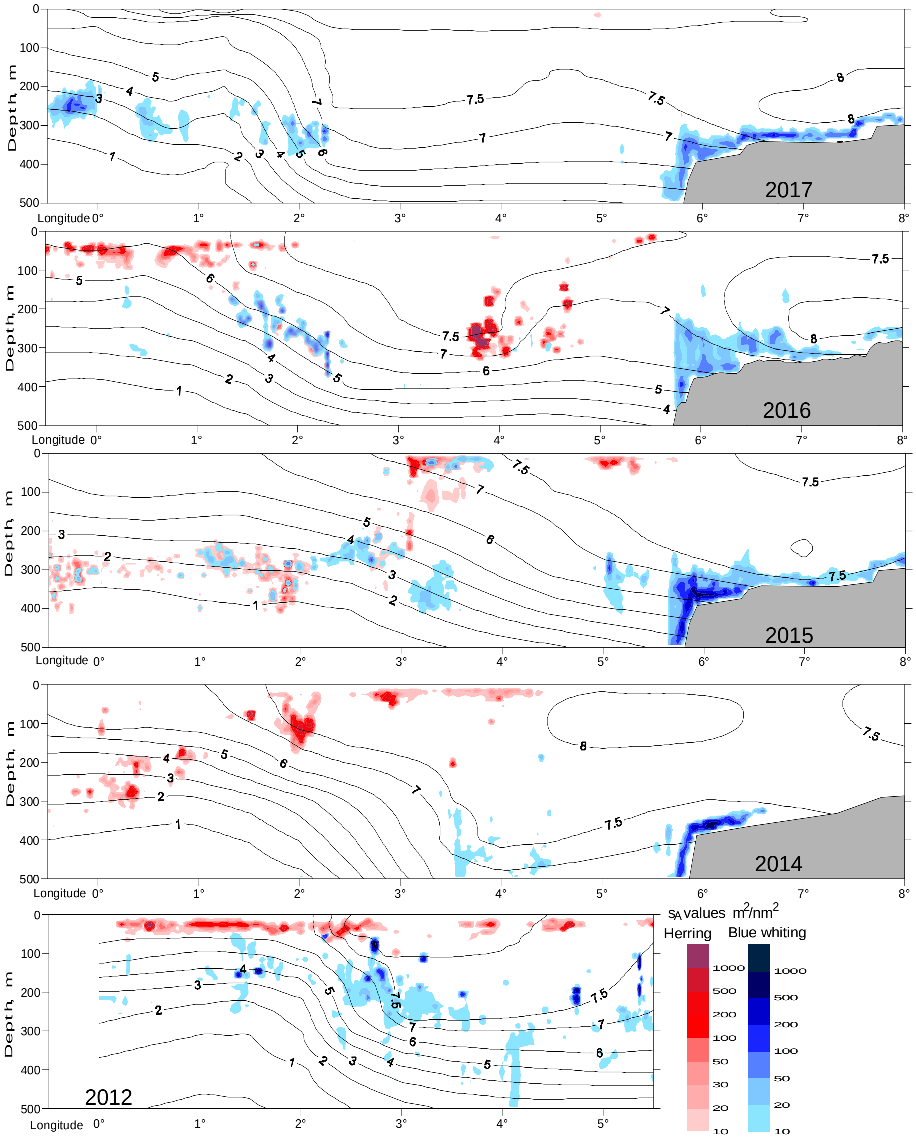

Figure 1. Vertical distribution of water temperature (°C) in 0–500 m layer and acoustic values (S_A, m^2/nm^2) for herring (red) and blue whiting (blue) in May 2012, 2014–2017 on the transect along 64°15' N.

Two rows of transects across the Norwegian Sea (between Iceland and Norway, carried out since 2015) were the most informative from the point of view of the distribution of fish in different parts of the sea in both warm and cold water masses with frontal zones between them (Figures 2 and 3).

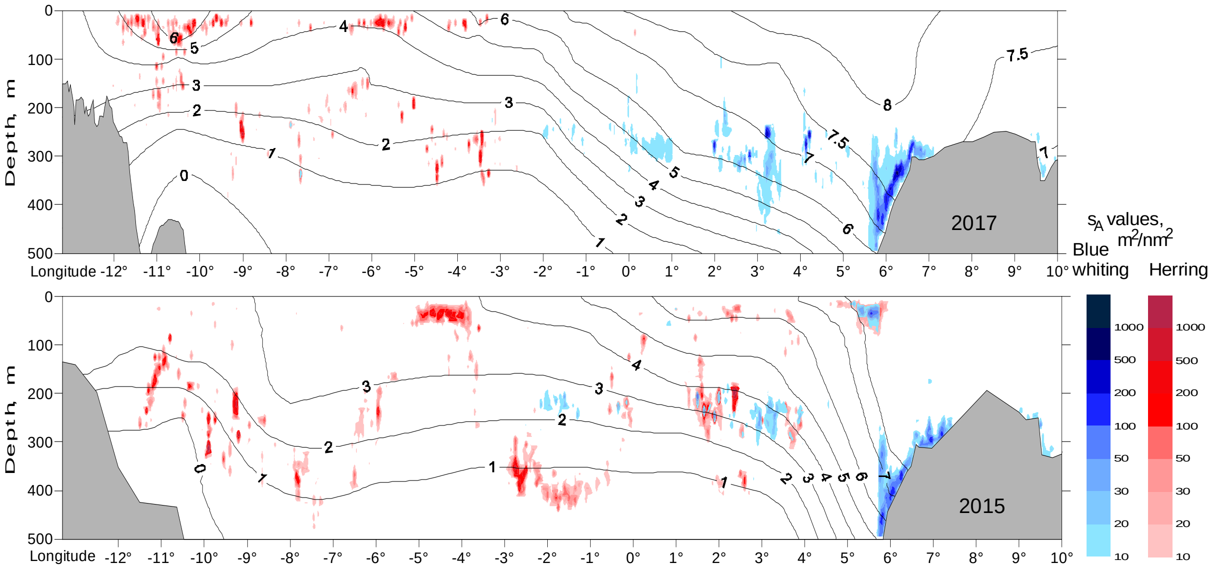

Figure 2. Vertical distribution of water temperature (°C) in 0–500 m layer and acoustic values (S_A, m^2/nm^2) for herring (red) and blue whiting (blue) in May 2015 and 2017 on the transect along 64°50'–65°00' N.

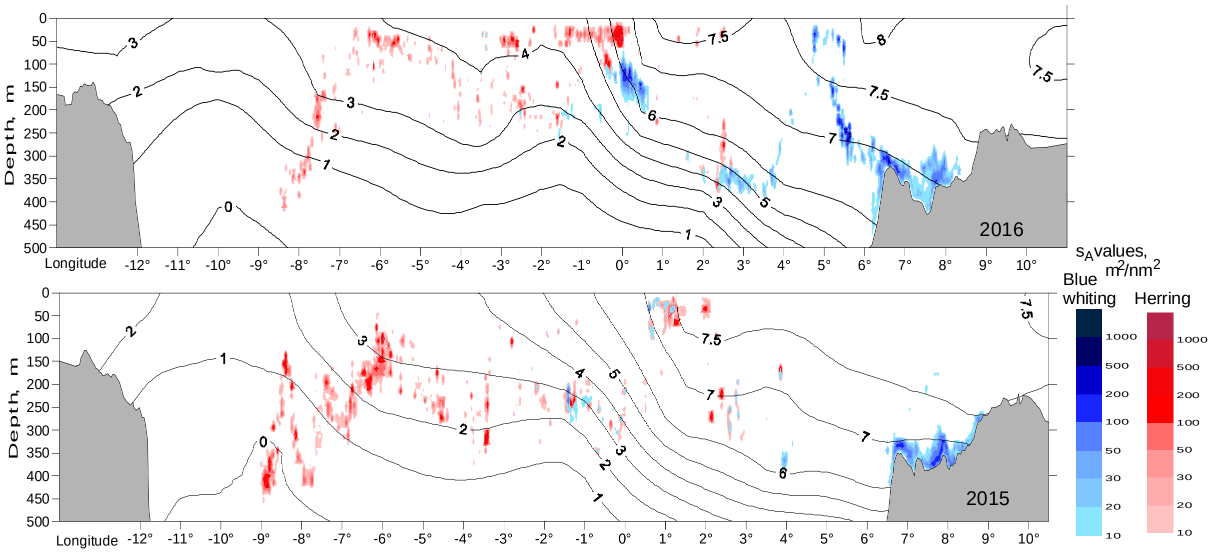

Figure 3. Vertical distribution of water temperature (°C) in 0–500 m layer and acoustic values (S_A, m^2/nm^2) for herring (red) and blue whiting (blue) in May 2015 and 2017 on the transect along 66°00'–66°15' N.

General pattern

It is shown that during the acoustic survey in May, the Atlantic-Scandinavian herring concentrates mainly in the western part of the investigated area over a wide range of depths and temperatures, reaching in some years in the west of the sea to depth of 450 m at a temperature below 0°C (Figure 3). Results of age analysis of the samples showed that the fish of the older age groups of the generation of 2004, 2006, 2009 prevails in the western part of the sea. Part of the fish, mostly younger (4–5 years old), is distributed in the eastern and northeastern parts of the sea in the upper 50-meter layer at a temperature of 6–8° C (Figures 1–3).

As well, it was revealed that during the whole observation period, the mass concentrations of blue whiting are always located in the eastern part of the sea above the Scandinavian shelf slope in layer 200–400 m under temperature 4–7°C. Also, blue whiting is often observed in the intermediate layer (200–300 m) in the warm side of the frontal zone between the Atlantic and subarctic waters under a temperature from 2 to 6°C sometimes under herring schools (Figures 1–3). More often, blue whiting in the spring-summer feeding period is generally observed mainly to the east of the zero meridian. Schools of herring are often detected over the cold side of this frontal zone, preferring highly gradient areas. Relatively young herring, as mentioned earlier, is kept in the upper layer under a temperature above 7°C.

Inter-annual features
The series of observations, conducted in different years on transects in close positions, made it possible to find a number of features in the distribution of pelagic fish, depending on oceanographic conditions. From year to year, the frontal zone between warm and cold waters shifted in the east or west direction, and sharpness of this zone at different sites and in different layers was observed (see Figure 1). Most strongly, these differences in the frontal zone influent to the distribution of blue whiting, which is concentrated on the warm side of the front. Its distribution depends not only on the temperature conditions in the frontal area, but also on the slope angle of the zone.

The described features are not so important for the distribution of herring, as large-scale processes associated with environmental conditions, age structure and the availability of food. These processes mainly form herring migrating paths. So, for example, if in the summer 2015–2016 herring was distributed in the southern and central parts of the Norwegian Sea in large numbers, but in 2017 this fish was not found in these areas at all excluding only colder western sector (see Figures 1 and 2).

When a collapse of the blue whiting stock happened (2010–2011), fish recordings were concentrated only over the shelf slope in very small quantities. In some years (2012, 2015, 2016), on the contrary, blue whiting has been mixed with herring schools and has also extended in relatively cold waters in the central part of the sea. These schools are very difficult to differentiate and identify. This is probably due to close preferences in the environment and food. During the last 2 years, such mixing has not been observed. Fish is distributed in exactly bounded areas, differing in space and depth.

Last survey, carried out in spring 2018, confirmed obtained results on distribution of herring and blue whiting in depend from thermal conditions (Figure 4). Just like in all previous years, blue whiting was concentrated in the eastern part of the sea mainly over the continental slope and within the high-gradient temperature zone in the 200–300 m layer. Herring was distributed west of the zero meridian in a wide range of depths and temperatures, creating the largest concentrations in the upper layer over cold East-Icelandic waters at a temperature of 1 to 5–6°C. As in the past year, a pronounced separation of herring schools and blue whiting has been noted. In 2018 this boundary was located perpendicular to the frontal zone between 4°W and 1°E.

Summary

Based on the analysis of combined vertical profiles of water temperature and acoustic values, a number of general regularities and inter-annual features of the distribution of such pelagic species of the Norwegian Sea as blue whiting and Norwegian spring-spawning herring have been revealed.

The obtained combined vertical transects are currently used only in the express analysis of scientific surveys for scrutinizing of the distribution of fish in a given area in depend from environmental conditions. In the future, it is possible to use such combined transects in 3D distribution models not only in the Norwegian Sea, but also in other seas including high latitudes.

Acknowledgements

The author expresses great gratitude to Terje Haugland, Åge Høines and Are Salthaug (IMR) for their long-term tremendous assistance in the scrutinizing and interpretation of obtained acoustic data.

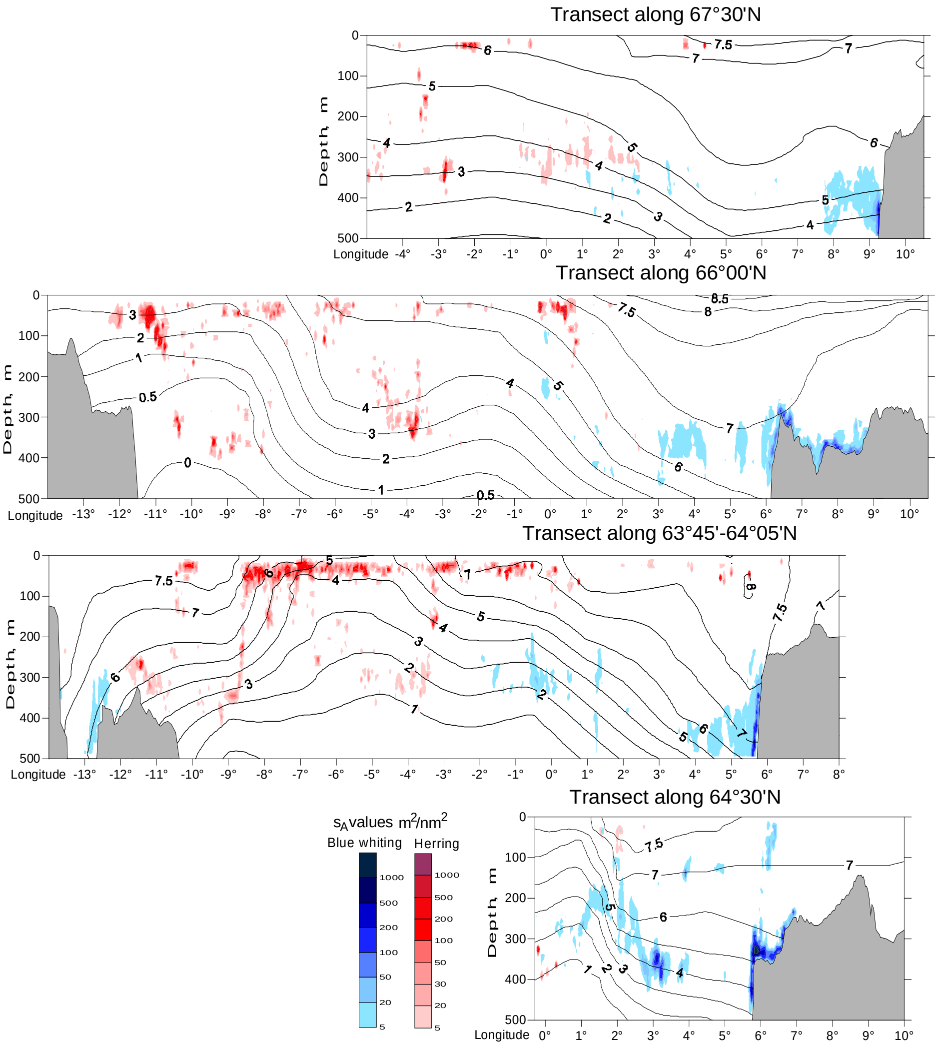

Figure 4. Vertical distribution of water temperature (°C) in 0–500 m layer and acoustic values (S_A, m^2/nm^2) for herring (red) and blue whiting (blue) on some transect in May 2018.

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Spatial-temporal changes of the Barents Sea organic matter in modern conditions

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The Barents Sea is one of the richest trade areas of the World Ocean. The Barents Sea has experienced significant changes over the last few decades with expansion of relatively warm Atlantic waters and reduction in the sea ice, leading to an increase in the net primary production (NPP) by phytoplankton within the Arctic Ocean and, in particular, a 28% increase in the Barents Sea (Arrigo and Van Dijken, 2011).

The analysis of the changes in the spatial-temporal distribution of dissolved organic matter (DOM) over this period is particularly relevant, as it will allow assessing the variability in the productivity of the sea and food supply for the heterotrophs.

The biohydrochemical data, obtained during September–October 1998, August–September 2004, June–July 2013, August–September 2016, July–August 2017 was analyzed for the different parts of the Barents Sea. These parameters were defined: concentration of the DOM, its elemental (organic carbon-Corg, nitrogen-Norg and phosphorus-Porg) and biochemical composition (carbohydrates, proteins, lipids). The results reflect high spatio-temporal variability of dissolved and particulate organic carbon concentrations of in the area explored, especially in high latitudes. The significant decrease of sea ice coverage area led to corresponding increase in dissolved organic carbon concentrations in September of 2016 up to 350 µM/l. In 2016, the spatial variability amplitude significantly increased too: oncentrations varied from 87–245 µM/l in 2004 for the photic layer with an average value of 156 µM/l to 83–664 µM/l in 2016, and the average concentration increased to 211 µM/l Corg. At the same time, a significant increase of areas of high concentrations of Corg occurred in the Barents Sea.

However, in 2017 due to high seasonal and interannual variability of these parameters such high C_{org} concentrations were not observed. At the same time smaller concentration of organic nitrogen and organic phosphorus have been registered in the high latitudes in 2016 compared to 1998.

The Barents Sea is characterized by a considerable variability in concentrations of Norg and Porg. The maximum Norg concentrations were observed on the shores of Novaya Zemlya in 2004 and in 2016 both in the surface and in the bottom layers, but it is not associated with the production processes, and it is caused by an anthropogenic impact. The non-uniformity of the Norg distribution over the sea area causes a large heterogeneity in the values of the C/N molar ratios. The lowest C/N (3–7) were obtained in the Novaya Zemlya.

During this period Porg concentrations have changed noticeably (by more than 2 orders). In 2004, the Porg content varied in the range of 0.001–1.02 µM/l, and in 2016, 0.001–0.4 µM/l. This determined the high values of the C/P ratio, which largely exceeds the molar ratios of these elements according to Redfeld, which is typical for the waters of the Barents Sea.

Smaller concentration of Norg and Porg have been found in the high latitudes of the sea in 2016 compared to the data from 1998. Not only the elemental, but also the biochemical composition of OM has changed during this time: both in dissolved and in the particulate fractions the amount of protein has increased, probably, due to the biomass of heterotrophs.

During the same time not only did the supply of trade hydrobionts change considerably, but so did the ratio of boreal and arctic fish species have considerably changed (Eriksen et al., 2016).

In recent times, there is no definite idea by which scenario the further distribution of the spatial fishery clusters will change by due to the warming of the climate, as shown in the example of the North Atlantic (Lenoir et al., 2011).

Keywords: Barents Sea, organic matter, elemental and biochemical composition, primary production, dissolved organic carbon, nitrogen and phosphor, spatial distribution

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Background levels of heavy metal content in the Barents Sea

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Abstract

The presence of heavy metals in high concentrations in the seawater is a threat to the normal life of commercial organisms. The problem of determining the background levels of a number of heavy metals in the water of the Barents Sea is considered. The ultimate goal of estimating the background levels (metal concentrations) is to identify subsequently water areas where they are exceeding, i.e. the areas of contamination. The data on the content of heavy metals in the water of 655 stations made by PINRO in the Barents Sea in the period from 1999 to 2015 were processed. To determine the level of the natural background of the content of trace elements, we used the mathematical statistics and geostatistical methods. Using the database, the background values of the Cd, Co, Cu, Ni, Hg, Zn, Pb and Cr contents in the water of the Barents Sea (in μg/L) were calculated. We compared the obtained values with the available analogues from the other sources. Based on the calculated background metal concentrations in the GIS application ArcGIS 10, we made a map of the distribution of the anthropogenic pollution in the Barents Sea. Values of concentrations of toxic metals (Pb, Hg, Cd) exceeding the background were recorded in the Atlantic water mass in the southern and central parts of the Barents Sea, and in the Norwegian and Murmansk coastal water mass – mainly, in a narrow coastal strip. One should consider these areas as permanently polluted waters. We estimate the contamination level as low.

Keywords: heavy metals, Barents Sea, water masses, pollution

Previous studies have shown that the level of trace elements in the surface layer of the Barents Sea water is generally typical of natural geochemical background values (Novikov and Draganov, 2017b). Given that background values of heavy metals (HM) in the Barents Sea water published in several scientific papers (Ivanov et al., 1997, 1999; Ocean Chemistry 1977; Bakke et al., 2007) are not sufficiently accurate and informative and are based on certain methodological flaws (Novikov and Draganov, 2017a), we have attempted to calculate the background values their contents based on a statistical approach. A prerequisite for our work was the availability of our own extensive database (DB) on the pollution of waters of the Barents Sea, which has been realized in the form of an electronic "Atlas of pollution of water masses in the Barents Sea", published by PINRO.

This study attempted to determine the regional background levels of a number of heavy metals in the Barents Sea, based on the PINRO data, using geographic and statistical analyses and, based on the background values, to construct an integrated map of the distribution of metals in quantities that exceeded background levels.

The material for the studies was a large number of samples of seawater from the surface layer (0–2 m), collected by PINRO staff in the course of marine expeditions. Between 1999 and 2015 inclusive, samples from 655 stations were analysed for cadmium, cobalt, copper, nickel, lead, zinc, chromium and mercury content in unfiltered seawater. Either one or two samples were taken at each station, so the total number of measurements of HM concentrations was 946. The samples were taken during different seasons of the year, but mainly in February–March and August–September. The levels of metals were determined in PINRO's Laboratory of applied ecology and toxicology. The values of the concentrations are shown below in μg/l.

The data were analysed using the R applied statistics package, version 3.01[https://www.r-project.org/]. In addition to the basic statistical procedures, a correlation analysis to evaluate the relationship of the contents of various HMs in the Barents Sea water for the period from 1999 to 2015, inclusive, was performed. Mapping, including geostatistical analysis, was performed using the ArcGIS 10 application of the GIS application package.

The first stage of performing the main task of our study involved a preliminary effort to sort the entire database of the content of HM in the Barents Sea, in order to group information on water masses (WM). Delimiting individual WM is bases on the gradients of oceanographic characteristics, primarily temperature and salinity. In some seas, such as the Barents Sea, the seabed relief and the prevailing large-scale currents have a significant influence on the separation of WM. In earlier studies, we noted significant differences in the microelement composition and level of pollution of individual Barents Sea WM (Novikov and Draganov, 2017b). To do so in the present context, we mapped the presumed boundaries of five types of water masses in the Barents Sea: Atlantic (AB), Arctic (ArB), two types of coastal waters (CW1 and CW2) and the waters of the frontal zone – the mixing areas of the Atlantic and Arctic water masses (Polar Front), based on known data and the information of the PINRO specialists to isolate the WM (Ozhigin, Ivshin, 1999). Due to the small number of stations in the frontal zone, this zone was eliminated from the subsequent calculations of the background levels of HM content.

During the statistical processing of the data, the probability distribution of random variables was estimated, and the arithmetic mean values of the concentrations of the HM, the standard deviation (SD) and the standard error of the arithmetical mean (SEM), as well as the 95th percentile were calculated in order to obtain estimates statistical values for the four main Barents Sea WM (without the frontal zone).

In order to derive the background value, we used: 1) the value of the upper bound of the confidence interval (CI) for the main entity, i.e. the sum of the arithmetic mean and twice the SEM value, which corresponded to the 95% significance level (95% CI), 2) the 95th percentile value. The background values for each WM are shown in Table 1. To enable the background levels proposed by us to be compared, the table also provides information on background characteristics from known scientific publications. As the table shows, the background levels recommended by the Norwegian Pollution Control Authority (SFT) (Bakke et al., 2007) are very low and sometimes almost an order of magnitude lower than the 95th percentile level. The values of the background for metals given in the work of the All-Russian Research Institute of Oceanology, which are derived as mean values of the measured concentrations (Ivanov et al., 1997), are of the same low order. The known values of average compositions from the monograph (Chemistry of the Ocean, 1979) are several time larger than the values from the sources cited above, and they are probably more suitable for describing the background characteristics of HM in the northern seas.

The map of the distribution of the HM concentrations above the value of the upper boundary of the CI, which was the first made by us, appeared to be less informative. The number of values exceeding background levels was quite large, and were relatively evenly distributed all over the sea. This follows logically from the estimate of the upper arithmetic mean of the main entity. Statistical analysis of correlations showed that in the Arctic WM a high correlation level was noted for the Co-Cd pair (Spearman’s rank correlation coefficient r = 0.81) and the Ni-Cd pair (r = 0.64). However, on the map, only a few such combinations occurred. The combinations of Ni-Cu and Ni-Co were much more frequent. The latter combinations indicate that the amount of data exceeding the proposed background level is large enough, which led to the mapping of coincidences in HM localization with relatively low correlation coefficients: r = 0.33 for a Ni-Cu pair and r = 0.53 for a Ni-Co pair. It is obvious that the pairs of these metals are more highly correlated in the case of higher values than the small ones. Similar regularities were obtained for the other metals studied.

Table 1. Calculated background values of heavy metal content in water masses of the Barents Sea (for water mass designations, see text).

Metal	Background levels: based on the upper confidence interval (upper) and 95th percentile below (in parentheses), µg/l				Background level proposed by SFT (Bakke et al., 2007), µg/l	Average composition of elements in sea water by (Ivanov et al., 1997), µg /l	Average composition of elements in sea water by (Chemistry of Ocean, 1977), µg/l
	АрВ	АВ	ПВ 1	ПВ 2			
Cd	0.09 (0.3)	0.20 (0.6)	0.22 (0.7)	0.18 (0.5)	< 0.03	0.02	0.07
Co	0.14 (0.43)	0.18 (0.57)	0.13 (0.43)	0.04 (0.23)	-	0.01	0.03
Cu	1.16 (2.0)	1.47 (3.3)	2.38 (3.8)	1.96 (3.3)	< 0.3	0.1	1.4
Ni	0.63 (1.2)	1.23 (4.3)	1.42 (3.6)	0.87 (2.8)	< 0.5	0.04	0.5
Hg	0.015 (0.05)	0.019 (0.07)	0.036 (0.08)	0.024 (0.06)	< 0.001	-	0.03
Zn	13.8 (24)	15.9 (40)	32 (93)	19.8 (45)	< 1.5	1.1	5
Pb	0.16 (0.5)	0.21 (0.7)	0.29 (1.2)	0.54 (2.3)	-	0.3	0.03
Cr	2.54 (5.6)	2.78 (5.1)	3.0 (5.8)	2.73 (4.6)	< 0.2	-	0.25

Similar problems arose when we compared the cartographic data with the results of the correlation analysis for the remaining three WM.

The statistic analysis also showed that the distribution of the concentrations of HM in all the Barents Sea WM was very different from the normal one. On the one hand, this complicates the use of parametric criteria, which, by the way, are the arithmetic mean, SD, SEM and CI, and the interpretation of the results. On the other hand, it is in favour of the fact that the definition of the background level is additionally complicated by the influence of the random variable of strong external factors on the distribution. These include impact anthropogenic pollution, seasonal and inter-annual variability associated, *inter alia*, with the flow of pollution from various global and regional sources (current flow, atmospheric precipitation, ice melting), etc.

In order to assess the influence of the factors shown above on the distribution of HM concentrations in the Barents Sea, we calculated their mean values for elementary water areas – trapezoids of a regular grid. The calculation of average concentrations was performed in the ArcGIS 10 application environment with a step of 2 degrees of longitude and 1 degree of latitude. Each trapezium was assigned an average value of the measured concentrations at the sampling stations it covered. If the samples were not selected on any given elementary water area (section), then the calculated value for it is absent. The mean values should have leveled out inter-annual and inter-seasonal differences in the content of HM in the waters of the Barents Sea and thus accentuate the areas of sustained elevated HM content.

The classification of the data on the maps of mean values was carried out by the method of natural boundaries (Jenks natural breaks optimization) built in the ArcGIS 10 environment, which enables variations in the data within each class to be minimized. Here it is important to note that the resulting lower bounds for the 5th class of values were close to the 95th percentile values given in Table 1.

Analysing the maps of the average concentrations of HM, which were made by us, we noted that the average content of Cu in the water of the elementary sections at the level of the upper boundary of CI is distributed randomly within the Barents Sea. The situation with other HM looks similar, with some reservations. Thus, the factors listed above that affect the variability of the content of HM in water (seasonal, inter-annual, etc.) do occur, and their effect is leveled out by averaging the data on elementary water areas for the entire observation period. It turns out that the levels of HM concentrations above the upper boundary of CI for different WM in many respects characterize not a permanent (stable) pollution, but rather a regional geochemical component that takes into account the seasonal and inter-annual dynamics of the pollution input (variability).

The picture of the distribution of the average content of HM at a level close to the 95th percentile concentration is much more informative. Here, for example, two areas of the pollution can be shown on the Cd distribution map: the first in the zone of the Kola section (33°30' E), and the second in the area of the North Kanin Bank. On the Kola section, Cg is accompanies by Hg, and at the North-Kanin Bank by Pb.

This indicates that only the transfer of the background value to the level of the 95th percentile makes it possible to separate the significant (stable) anthropogenic pollution from unstable anthropogenic varying background levels. Figure 1 shows the distribution of the pollution of Barents Sea waters by the most toxic heavy metals in terms of the 95th percentile concentration.

Figure 1 clearly identifies the areas with higher heavy metal content. First, in the northern part of the map, the boundary waters of the Atlantic and Arctic water masses, adjacent to the frontal zone on both sides, are evident. Secondly, in the southern part of the map, the pollution of the coastal zone of the Kola Peninsula is clearly indicated. Pollution in the south-eastern part of the Barents Sea is minimal. Perhaps this is local impact pollution. Thirdly, within the Atlantic WM, there is an extensive water area subject to stable pollution. This is the area of the Central Trench and its adjacent waters. Fourthly, there is an area of complex water pollution in the area of the Kola section. In recent years, in this section, the stations were sampled repeatedly, in the same period (February). Obviously, the pollution of this area is stable and reflects the actual situation of pollution transfer from the Norwegian Sea to the Barents Sea by the eastern current around the end of the European winter.

The map of HM distribution in concentrations above the 95th percentile, as shown in Figure 1, adequately reflects the most important ideas regarding how anthropogenic pollution enters the Barents Sea. This is the main pollution from the Western Europe and the North Atlantic. We should also note the accumulation of pollution in the margins of the shallow-water areas, including the southern and eastern slopes of the Bear Island Bank, the northern slopes of the North Kanin Bank and the Goose Bank. This is probably due to the presence of hydrological frontal zones here.

The 95th percentile of the concentration can therefore be regarded as a reliable criterion for the levels of pollution above the regional anthropogenic background. The concentrations of HM in seawater, above these values (Table 1) for some WM, should be considered as anomalous, and as a reliable sign of the occurrence of anthropogenic pollution.

The concentration of HM and trace elements at levels beyond the 95th percentile should be used as a reliable criterion for the presence of appreciable anthropogenic contamination. We recommend that concentrations of HM between the 95th percentile and the upper limit of the confidence interval should be regarded as belonging to the regional geochemical background, including the anthropogenic one, which characterizes insignificant, unstable pollution. The waters of the Barents Sea contain HM at such concentrations, can be conditionally considered to be unpolluted.

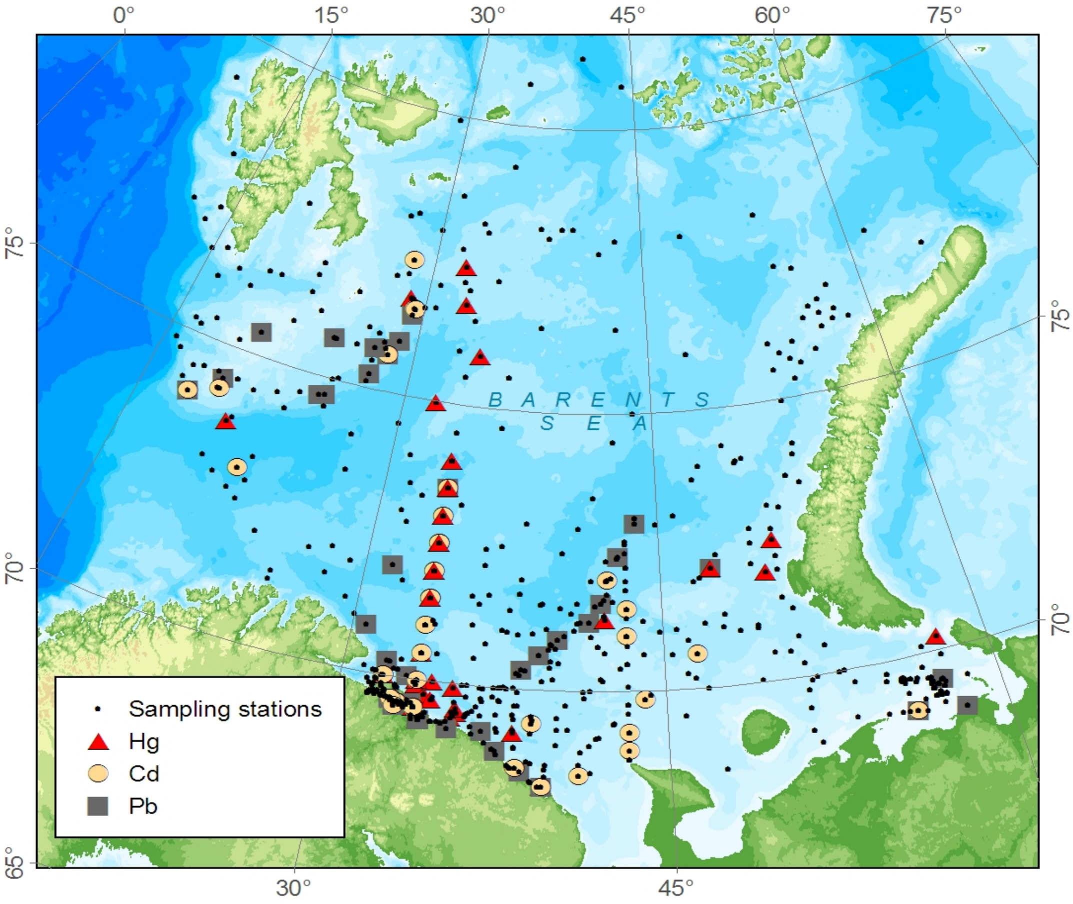

Figure 1. Sampled sites of heavy metal pollution at a levels above the regional background values (95th percentile).

As Figure 1 indicates, values that exceed the background levels of highly toxic HM, which have a predominantly anthropogenic origin, is localized in the Atlantic waters, in the southern and central parts of the Barents Sea, and in the Norwegian and Murmansk coastal waters, mainly within a narrow coastal strip. The listed water areas should be regarded as polluted. The level of the pollution can be considered as low, except for the coastal waters of the west Murman (west of the Kola Bay). The Arctic and eastern coastal waters can be regarded as clean, because here the values exceeding the background of the concentrations of HM have a characteristically random distribution.

The main area of application of the background values is the possibility of both assessing the current state of pollution of the Barents Sea and the inter-annual dynamics of pollution levels. The normative indicators, such as MPLs (maximum permissible level), can only ascertain the presence of anthropogenic pollution at a critical level for the health of the ecosystem. Exceeding background indicators enables us to monitor pollution earlier, at a lower level, and to identify the sources of the pollution and trends in habitat changes, and thus opens up important opportunities for forecasting and preventing critical situations (exceeding MPLs and, as a consequence, damaging marine bioresources, etc.).

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THEME SESSION II: PLANKTON

Zooplankton investigations in the Barents Sea by IMR, 1979–2017: rationale, methods, and some results

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The Institute of Marine Research (IMR) in Norway started zooplankton investigations in the Barents Sea in 1979 as part of integrated ecological studies with the project ‘Summer feeding of capelin’. This project was followed by the national *Norwegian Research Programme for Marine Arctic Research* (Pro Mare), 1984-1989. The research activities in the 1980s focused on the spring and summer period including the spring bloom of phytoplankton, reproduction and development of zooplankton, and feeding and growth of capelin. Beginning in 1986, zooplankton sampling was included in the joint IMR-PINRO 0-group and capelin autumn surveys which subsequently became the autumn ecosystem survey.

IMR has used two zooplankton sampling nets in combination: vertical tows with WP-2 net to obtain horizontal zooplankton distribution, and obliquely towed MOCNESS (Multiple Opening and Closing Net and Environmental Sampling System) to obtain vertical distribution and better and more representative samples of large zooplankton. Both nets have been used with 180 um mesh nets. From 1983, a standard method has been used where each net sample is split in two halves: one for determination of dry weight biomass in three size fractions (<1 mm, 1-2 mm, and >2 mm screen size), and the other fixed with buffered formalin and stored for later taxonomic species counts. All biomass samples are worked up and provide a comprehensive description of spatial and temporal changes in zooplankton over the time period.

1979 was in the coldest period since the beginning of the twentieth century. Since then, the Barents Sea has been on an oscillating warming trend with temperature of the Atlantic water now being about 2^{o}C warmer than around 1980. The effects of this warming are now being addressed i.e. in the IMR project TIBIA (Trophic Interactions in the Barents Sea: steps towards Integrated Ecosystem Assessment). Among the changes in mesozooplankton are declines in biomass on the Central Bank and Great Bank, which are important feeding areas for capelin, and a recent increase in *Calanus finmarchicus* in the Atlantic water in the southwestern Barents Sea. An important research question is whether the Arctic species *Calanus glacialis* is declining in response to the on-going warming.

Regional patterns of biomass distribution and zooplankton productivity in the Arctic Ocean

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A review of the state-of-the-art knowledge on the structure and productivity of zooplankton communities of the Arctic Ocean is presented based on zooplankton collections from over 200 locations visited by expeditions of the research ice-breakers during the past two decades. The modern quantitative sampling techniques applied in all the four deep basins of the Arctic Ocean (Nansen, Amundsen, Makarov and Canada Basins) along with consistent and standardized zooplankton processing methods allowed for a pan-arctic comparison of regional structure and productivity of the zooplankton communities. The results indicate that two major components contribute to the zooplankton biomass and productivity in the deep Arctic basins: an autochthonous community, consisting of arctic residents, i.e. locally reproducing species, and an allochthonous community, consisting of expatriate species advected from the North Atlantic with Atlantic inflow, and expatriate species advected with Pacific water from the North Pacific. A strong link between regional variability of the zooplankton biomass in the Arctic Ocean and water circulation pattern, bottom topography, and life cycle traits of species from both the autochthonous and allochthonous communities is demonstrated.

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Occurrence of high productive zones in the Barents Sea: drivers and impact

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The Barents Sea is a vital nursery area for several commercially and ecologically important fish stocks. Aggregations of meso-, macro- and ichthyoplankton and small pelagic fishes in the pelagic layer attract predators such as larger fish, marine mammals and seabirds. The Joint Norwegian-Russian ecosystem survey (BESS) samples the pelagic habitat by use of plankton nets and small-meshed pelagic trawl, while also collecting associated data on environmental conditions. In the present study we link abundance data on mesozooplankton, macroplankton (jellyfish) and 0-group of 8 fish-species with environmental conditions (temperature and salinity in the 0-50m layer). Additionally, we examine spatial relationships between abundance of jellyfish versus abundances and lengths of 0-group fish. To achieve this, we divided the Barents Sea into grid-cells of 60 x 60 nm, and for each grid-cell the average values for the different variable were estimated for subsequent statistical analyses. We chose to include only 2016 in this study, as this year displayed high amounts of both 0-group fish and jellyfish, as well as larger fish. Our results suggest that that 2016 represents a year with very good environmental conditions for most of the 0-group fish species included in the study.

Figure 1 shows CCA results, which indicated that the northern area (green dots) with lower water temperatures, salinities and plankton was mainly less productive with respect to 0-group fish species, and dominated mainly by polar cod, long rough dab and wolfish. Both western (red dots) and eastern (blue dots) areas at lower latitudes were highly productive zones with high abundances of 0-group fish (western area: redfish and haddock, and eastern area: cod and herring) and moderate to high biomasses of mesozooplankton (especially in the southwestern area) and *C. capillata* (highest biomass in the eastern area). These three predictors explained 30% of total variation in response.

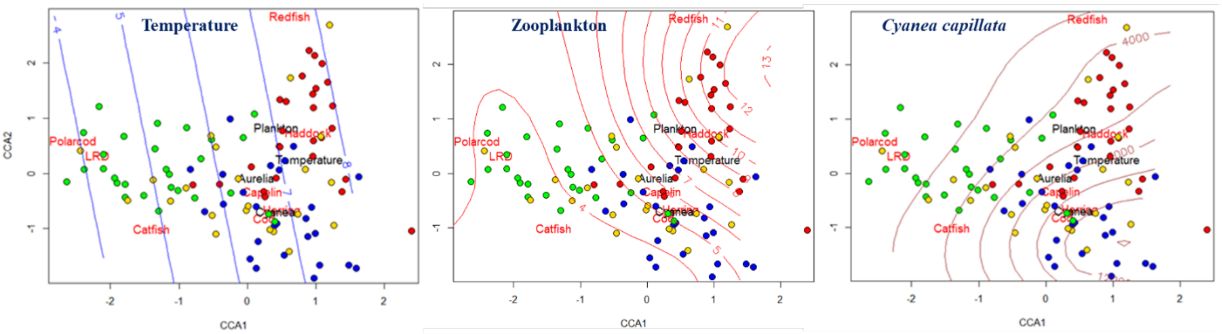

Figure 1. Triplots for canonical correspondence analysis with abundance of 0-group fish species - herring, capelin, cod, haddock, polar cod, long rough dab (LRD), and wolffish (log millions of individuals per nautical mile) as response and temperature average 50-0m and biomasses of zooplankton and *Cyanea capillata* as significant predictor-variables. Response variables are shown in red, and predictor variables in black. In the subpanels, smoothed surfaces for the predictor variables are superimposed – one at the time – to ease interpretation (upper panel - temperature, mid-panel – zooplankton biomass, lower panel – biomass of *Cyanea capillata*).

Atlantic water masses, rich with plankton, were distributed over a large area, providing good feeding conditions for the 0-group fishes. Our interpretation of feeding success was further supported by juvenile fish being relatively large. Aggregations of zooplankton and 0-group fish seem to be driven by a large inflow of Atlantic water, providing suitable living conditions over larger areas.

Keywords: 0-group fish, environmental conditions, fish length, feeding success

Pelagic and near-bottom zooplankton communities in the Kara Sea under recent warm period

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The Kara Sea was poorly investigated shelf sea due to hard ice conditions until warming in North Atlantic and Arctic in 2000s. It resulted in relatively weak knowledges on biota including zooplankton. Most investigations of zooplankton were conducted in 1920-1940s and later only in 1980-1990s. Since 2000s zooplankton investigations became more intensive and conducted by various Russian institutes (Institute of Oceanology, Murmansk Marine Biological institute and others). PINRO had also conducted some scientific surveys in the Kara Sea in 2007-2008 and 2014 as well as investigations in the northern Kara Sea in 2009-2013. The main objectives of the paper were to consider recent state of zooplankton in the Kara Sea, to investigate zooplankton and copepods communities in the pelagic layers and to investigate copepods and euphausiids communities in the near-bottom layers.

Based on the data of several research surveys, conducted by PINRO in August-November 2009-2014, the state of zooplankton communities in the Kara Sea in present warm period was investigated. Juday net and the trawl-attached plankton net were used as sampling gears. In total 78 taxa were registered in plankton samples in the Kara Sea, including both boreal and arctic species.

Pelagic zooplankton

Total abundance and biomass of zooplankton in pelagic layers of the Kara Sea in 2007-2014 consisted of 1398 ind. $\cdot$ m^{-3} and 167.7 mg $\cdot$ m^{-3} in average. Copepods were the dominant group of zooplankton (1330 ind. $\cdot$ m^{3} и 106.9 mg $\cdot$ m^{3}) and consisted 95.1% and 64.5% of total abundance and biomass respectively. Abundance of heteropods and jellyfish comprised 38.1 and 12.2 ind. $\cdot$ m^{-3} correspondingly, but their portion did not exceed 2.7% and 0.9% of the total zooplankton abundance. Considering zooplankton biomass, only chaetognaths (23.0 mg $\cdot$ m^{-3}), hyperiids (21.0 mg $\cdot$ m^{-3}) and euphausiids (8.4 mg $\cdot$m^{-3}) were important among other groups, and their portion made up 13.9, 12.7 and 5.1% respectively.

Among copepods *Pseudocalanus* sp. and *Oithona similis* dominated in terms of abundance (48.0 and 33.0% respectively), while *Calanus glacialis*, *Pseudocalanus* sp. and *Calanus finmarchicus* dominated in terms of biomass (40.4, 21.30 and 11.9% respectively). In addition, higher biomass of *Metridia longa* were observed in the northern Kara Sea (up to 21.2%) and of *Limnocalanus grimaldii* in the southeastern Kara Sea (up to 17%).

Three groups of zooplankton communities were clearly separated – in the southeastern, central and northern Kara Sea. These groups differed by total abundance and biomass of zooplankton as well as dominant groups or species.

Total zooplankton abundance was the lowest in the northern Kara Sea (760.9 ind. $\cdot$ m^{-3}) and much higher in the central and southeastern parts (2115 and 2044 ind. $\cdot$ m^{-3} respectively). The highest total zooplankton biomass was observed in the southeastern part (263.2 mg$\cdot$ m^{-3}), while their values was lower in the central and northern parts – 173.4 and 135.8 mg $\cdot$ m^{-3}.

Copepods were the dominant group in all three areas. Despite their abundance varied from 726 ind. $\cdot$ m^{-3} in the north to 1989-1991 ind. $\cdot$ m^{-3} in the south-east and the center, their portion was similar in these areas (94-97%). Copepod biomass varied from 94.6-97.1 mg · m^{-3} in the central and northern parts to 177.7 mg · m^{-3} in the south-east, and their portion decreased from 71.5% in the north to 67.5% in the southeast and only 54.5% in the central part.

The subdominant groups in terms of abundance were appendicularians and heteropods in the northern Kara Sea (1.9 and 1.5%), heteropods and jellyfish in the central part (4.4 and 1.0%), jellyfish in the southeast (1.7%). Considerable portion of zooplankton biomass in the northern Kara Sea was formed by chaetognaths (21.6%) and to a lesser degree by hyperiids, heteropods and ctenophores (2.8, 1.3 and 1.1% respectively), while hyperiids and euphausiids were the subdominant groups in the central part (25.6 and 13.5%) and chaetognaths and hyperiids in the southeast (19.8 and 10.6%).

Near-bottom zooplankton

Total abundance and biomass of zooplankton in the near-bottom layer of the Kara Sea in summer 2013 comprised 95.7 ind. · m^{-3} and 80.8 mg · m^{-3}. Copepods were the dominant group in the near-bottom layer both in terms of abundance (94.6 ind. · m^{-3} or 98.8%) and biomass (57.3 mg · m^{-3} or 70.8%). Despite of low abundance, biomass of large euphausiids and chaetognaths was rather high (10.7 and 6.3 mg · m^{-3}; 13.2% and 7.8% respectively).

Copepods community in the near-bottom layer was presented by only 9 taxa compared to 30 taxa in pelagic layer. *C. finmarchicus* and *M. longa* were the dominant and subdominant species by abundance and biomass (77.1% and 65.2; 17.5% and 21.0% respectively). *C. glacialis* was important copepod species in total zooplankton biomass only in the central Kara Sea (up to 17-42%). Total abundance of copepods in 2013 (200 ind. · m^{-3}) was almost 1.5 times lower than in 2007-2008 (335 ind. · m^{-3}).

Three euphausiids species were identified in the samples– *T. raschii*, *T. inermis* and *M. norvegica*. Coldwater species *T. raschii* dominated in euphausiids community (70.1% by abundance and 64.9% by weight). *T. inermis* was subdominant species (29.7% by abundance and 34.8% by weight). Warmwater species *M. norvegica*, which is drifted from the Norwegian Sea, rarely observed in the Kara Sea, and its abundance and biomass did not exceeded 0.3%. In addition, larvae (megalopa stage) of new invasive species snow crab *Chionocoetes opilio* were found in the Kara Sea. Totally 39 individuals were registered on 8 of 20 stations. Abundance of snow crab larvae ranged from 2 to 40 ind. · 1000 m^{-3}. Presence of *C. opilio* larvae confirmed recent reproduction of this species in the Kara Sea.

Acknowledges

This work was supported by the Russian Science Foundation Project “Structure and functioning of plankton and fish communities in the Kara Sea in recent warming period” (Grant No. № 14-14-00808)

Keywords: zooplankton, Kara Sea, abundance, biomass, copepods, euphausiids, hyperiids, chaetognaths, snow crab

Statistical distribution and variance structure of size-fractioned zooplankton biomass in the Barents Sea based on monitoring data from 1989–2016

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A large data set of mesozooplankton dry weight biomass has been collected by IMR with WP-2 net and MOCNESS sampler during joint autumn surveys from 1989 to 2016 (ca. 4.000 and 1.000 stations, respectively). The zooplankton biomass follows a log-normal-like distribution for each of the three size fractions (<1 mm, 1-2 mm, and >2 mm screen size) as well as their sum total. WP-2 and MOCNESS produced very similar frequency distributions, suggesting that they sample the same statistical populations. The Barents Sea has been subdivided into 15 subareas according to topography and oceanography, and mean zooplankton biomass has been estimated for each of the subareas for each survey-year. The total variance of each of the WP-2 and MOCNESS data sets has been broken down into spatial (subareas) and temporal (years) components plus their interactions in order to characterize the variance structure of the mesozooplankton biomass in the Barents Sea. The biomass is dominated by *Calanus finmarchicus* in the Atlantic water of the southern part and *Calanus glacialis* in the Arctic water of the northern Barents Sea.

Inter-annual dynamics of zooplankton in the Kola Section during the recent warming period

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The Kola Section is one of the standard oceanographic sections in the Barents Sea. This section is unique as it is one of the longest time-series in the world and has been sampled since the beginning of the last century. The Kola Section covers warm Atlantic waters flowing from the Norwegian Sea into the Barents Sea. Fluctuations in Atlantic water properties and seasonal warming rates influence zooplankton communities of the southern Barents Sea by triggering phytoplankton bloom and zooplankton reproduction, accelerating or reducing developmental rates of plankton organisms.

The objectives of the investigations were to examine species and stage composition of zooplankton as well as interannual dynamics of zooplankton abundance and biomass, and to estimate influence of environment factors on quantitative parameters of zooplankton.

Total 243 zooplankton samples were collected in the Kola Section in May-June 2009-2017. Juday net was used as a sampling gear. The samples were processed according to a standard PINRO procedure. Zooplankton abundance, biomass and frequency of occurrence were analysed. To estimate the diversity of the zooplankton community, we used the Shannon index based on the abundance of taxa.

The following environmental variables were used to estimate their influence on zooplankton: winter North Atlantic Oscillation index, temperature in the upper 50 and 200 m layers in the central part of the Kola Section, area covered by Atlantic waters, latitudinal wind-driven and total volume fluxes in the western Barents Sea.

In the period investigated, 77 taxa of 9 phyla were identified in zooplankton in the Kola Section. Copepods were the most diverse zooplankton group and included 25 taxa. The biodiversity index varied considerably in different years. Its lowest mean value was observed in 2010, while the highest one was in 2017. A stable tendency of increasing the index since the beginning of studied period was found.

Total abundance and biomass of zooplankton varied considerably in different years. The highest values of these parameters were noted in 2010, and the lowest ones – in 2013. In 2017, the zooplankton abundance and biomass decreased compare to the previous three years.

Copepods were the dominant zooplankton group comprising on average 73-96 % of the total zooplankton abundance and 81-96 % of the total zooplankton biomass. *Calanus finmarchicus* was the most important copepod species, which made on average 70 % of copepods abundance and up to 94 % of their biomass. Among the other copepods, only *Oithona similis* comprised on average about 10 % of copepods abundance, but due to its small size it made only 0,5 % of copepods biomass. In the population of *C. finmarchicus*, I-III copepodites dominated. However, in 2013 and 2015, survey was conducted later than in the other years, and individuals have already reached III-V stages. At the same time, *C. finmarchicus* biomass was formed by III-V copepodites in all the years.

The last decade covering the period of our investigation was characterized by very high water temperatures in the Barents Sea. However, in many years of the previous century, there were cold conditions in the sea. There was statistically significant correlation between zooplankton biomasses and abiotic variables, namely thermal variables such as temperature in the Kola Section and area of

Atlantic waters, as well as dynamic variables such as winter North Atlantic Oscillation index and volume fluxes through the Barents Sea Opening. Therefore, zooplankton biomasses were higher in years with higher temperatures and stronger water inflow. A positive significant correlation was found between abundance of *C. finmarchicus* of older (IV-V) copepodite stages and abundance of immature herring, that can indicate favourable feeding conditions for herring.

The results of principal component analysis showed that herring abundance and biomass, abundance of *C. finmarchicus* older copepodites, North Atlantic Oscillation index and water temperature in the Kola Section appeared to be intercorrelated. The direct relationship was also found between volume fluxes and total biomass of zooplankton and biomass of *C. finmarchicus* as well as between total abundance of zooplankton and abundances of copepods and *C. finmarchicus* younger (I-III) copepodites.

Isfjorden Marine Observatory Svalbard – IMOS

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Isfjorden Marine Observatory Svalbard (IMOS) is a long-term plankton time series that aims at capturing seasonal, annual and decadal changes in Arctic plankton communities. The presences of permanent research infrastructure in Isfjorden (the Marine Research Station in Barentsburg, the University Centre in Longyearbyen) and the frequency of visiting research vessels make regular, year round sampling feasible – a prerequisites for maintaining long time series. Isfjorden is the largest fjord system in Svalbard.The outer Isfjorden resembles the southern Barents Sea with warmer Atlantic water and no sea ice, while the innermost parts are characterized by cold water masses and a seasonal ice cover. Almost 20 years of plankton data exist from Isfjorden, and bi-weekly to monthly plankton data have been collected at selected sites since 2011. High seasonal sampling resolution allows us to differentiate between natural variability and persistent changes in plankton communities. Isfjorden zooplankton community consists of a mix of boreal and Arctic species with a dominance of boreal species in the outer part and Arctic species in the inner part. The seasonal variability in the community composition is stronger than the interannual with the zooplankton community resetting to a more Arctic one over the winter even in the outer part of the fjord. This suggests that the Atlantification of the zooplankton community in Isfjorden is slowed down by the long dark and unproductive winter.

Direct and indirect effects of climate on major zooplankton groups in the Barents Sea

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We analysed long-term observation series of key zooplankton groups in the Barents Sea together with key abiotic and biotic variables using statistical state-space modelling in order to investigate effects of climate and fish predation on zooplankton species composition.

Higher temperatures lead to a poleward displacement of species globally and altered species compositions regionally. In the Barents Sea, there are indications that Atlantic species have increased in distribution and abundance while arctic species have decreased. The drivers of these changes remain incompletely understood. In particular, for sustainable multi-species management under climate change, we need to understand better the role of altered species interactions in the driving the observed changes. We here analysed long-term observation series of key zooplankton groups and planktivorous fishes in the central and northern Barents Sea together with key driving variables using statistical state-space modelling (Figure 1). Results contribute to disentangle the relative roles of sea ice and predation in driving the changes in zooplankton species composition, and to separate the direct and indirect effects of climate.

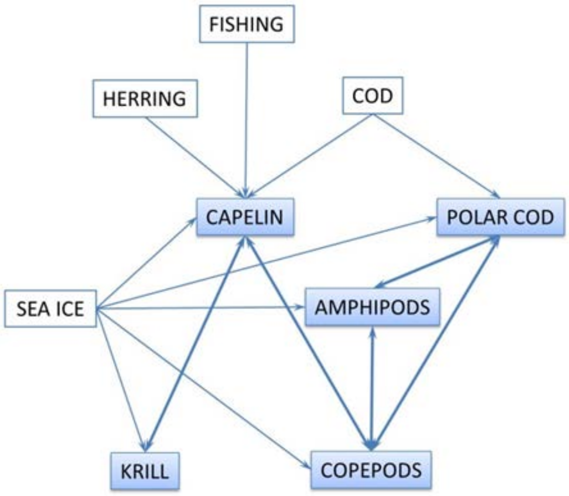

Figure 1. Schematic presentation of the analysed multi-species dynamics in the central and northern Barents Sea. Blue boxes represent focal species or species groups, among which strengths of both bottom-up and top-down effects were estimated (arrows). White boxes represent other key abiotic or biotic variables that influence dynamics.

Keywords: Copepods, krill, amphipods, capelin, polar cod, multi-species dynamics

Dynamics of macro-plankton communities of the Barents Sea

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Abstract

The most abundant macroplankton groups in the Barents Sea are Chaetognatha, Euphausiacea, Hyperiidea and Pteropoda. The paper considers distribution, species structure and abundance of the taxa, as well as impact of the main factors: water temperature and predation in 2000s. The researched period in the Barents Sea was warm and anomalously warm, which affected the distribution and abundance of macrozooplankton. Abundance of predatory chaetognaths (predominant species Sagitta elegans) increased throughout the researched period and had an adverse impact on the communities of mesoplankton. Species structure of euphausiids was typical for warm years, Thysanoessa. Inermis predominated. Portion, abundance and distribution area of the brought species T. longicaudata and Meganyctiphanes norvegica also increased. Abundance of hyperiids decreased due to the reduction of abundance and distribution area of Arctic T. libellula. Abundance decrease of pteropods was also revealed, they are mainly represented by cold-water Clione limacine.

Keywords: macrozooplankton, Chaetognatha, Euphausiids, Hyperiidea, Pteropoda, distribution, abundance, biomass, Barents Sea

Introduction

Chaetognatha, *Euphausiacea*, *Hyperiidea* and *Pteropoda* are the most abundant macroplankton groups in the Barents Sea. Distribution, species structure, abundance of these taxa, and influence of water temperature in 2000s as the main factor were studied under the present research. In the Barents Sea, the investigated period conditions were characterized as warm and abnormally warm, this factor had impacted the abundance and distribution of macrozooplankton.

Material and methods

Data obtained during the annual macroplankton assessment survey conducted in October-December 2001-2015 within the survey of demersal fish were used in the research. Samples were collected using a bottom trawl net (mesh size 564 micron, 50 cm mouth opening diameter) which was attached to the middle of the bottom trawl headline and captured euphausiids in the near-bottom layer (6-10 meters above the bottom). Abundance of various species and groups was expressed as number of individuals per 1000 m^3 and biomass was expressed as g wet weight per 1000 m^3.

Results and discussion

Chaetognatha

Average abundance of predatory chaetognaths with *Sagitta elegans* dominating was generally tending towards increase during the investigated period, impacting negatively the mezoplankton community. Long-term average abundance in 2001-2015 was 940 ind./1000 m^3. The lowest average abundance was in 2004 (369 ind./1000 m^3) and the highest was in 2010 (1601 ind./1000 m^3). We have noted a trend of decrease in average abundance at temperature fluctuations and of its increase at stable temperatures (when the heat content of waters was at the “warm years” level) (Figures 1 and 2).

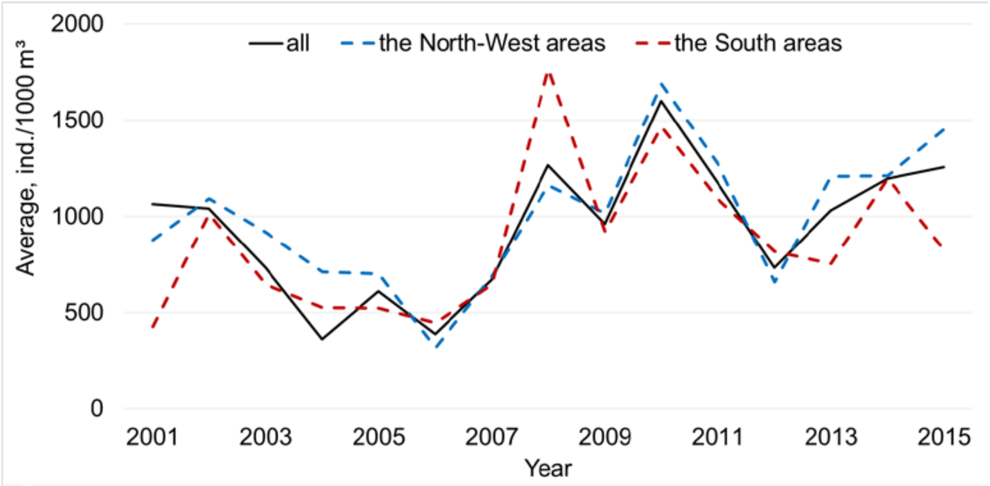

Figure 1. Average abundance of *Chaetognata* in the Barents Sea in 2001-2015.

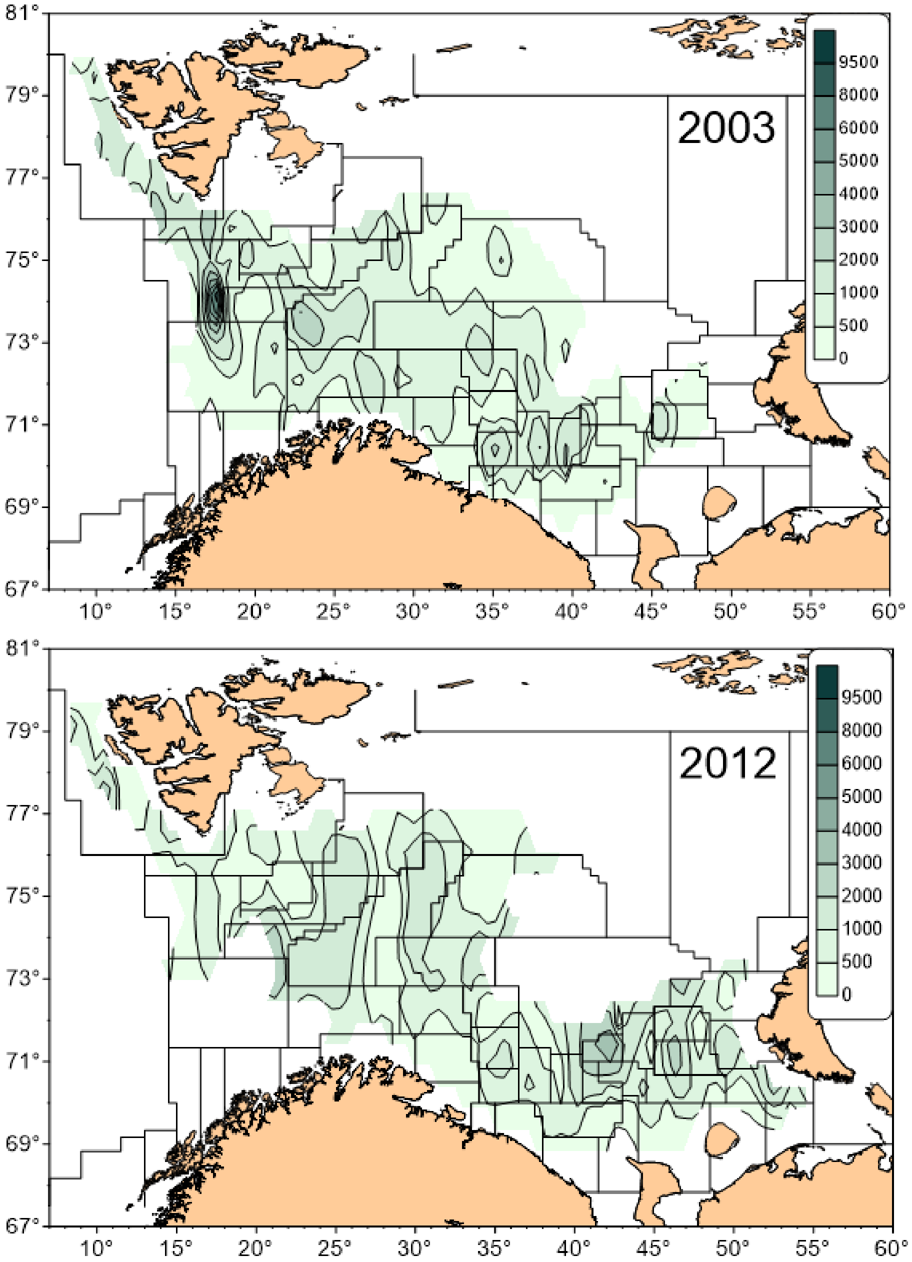

Figure 2. Distribution of *Chaetognata* aggregations in the Barents Sea in “normal” year (2003) and “abnormally warm” year (2012).

Euphausiacea

Structure of euphausiids species was typical for warm years with local Barents Sea species dominating, particularly *Thysanoessa inermis*. Average abundance of this species amounted to 1061 ind./1000 m^3 in the assessment period with 59% mean portion (Figures 3, 4, and 5). Moreover, distribution of euphausiids was typical for warm years with significant increase in distribution of dense euphausiids aggregations in abnormally warm years (Figure 6).

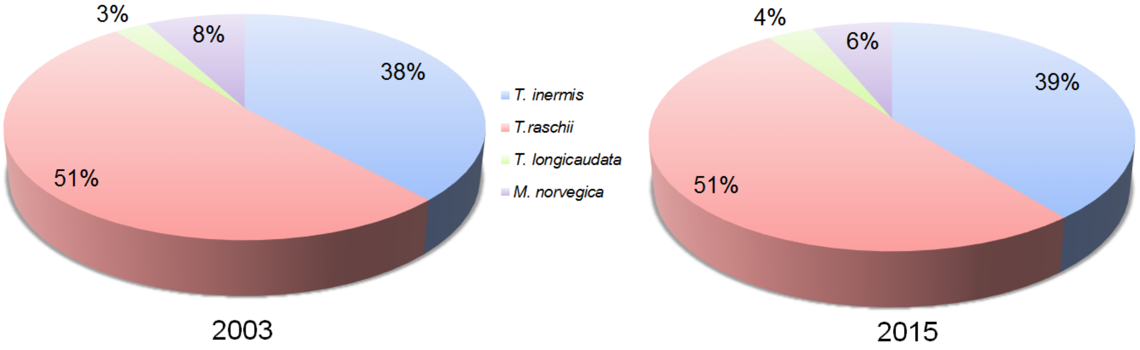

Figure 3. Proportion of average abundance of different euphausiids species in the Barents Sea in "normal" year (2003) and "abnormally warm" year (2015).

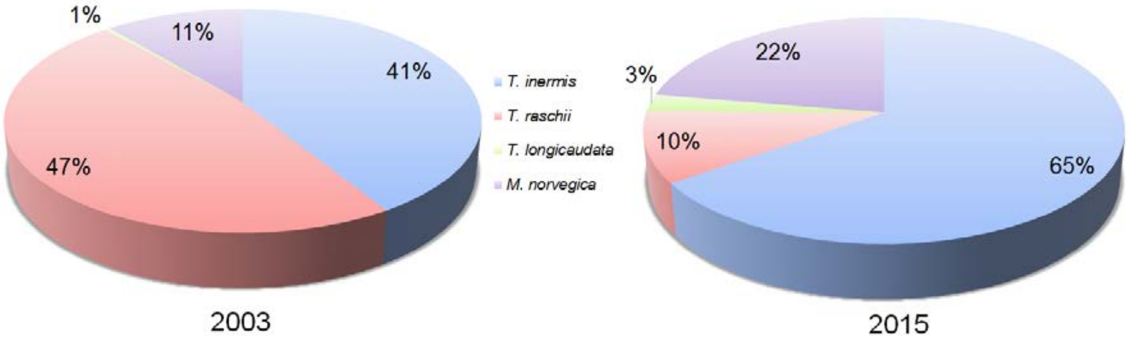

Figure 4. Proportion of average biomass of different euphausiids species in the Barents Sea in "normal" year (2003) and "abnormally warm" year (2015).

At the same time, we noted an increase of abundance, portion and distribution of transferred species *T. longicaudata* and *Meganyctiphanes norvegica* (Figures 5, 7, and 8). As *M. norvegica* is the largest species among euphausiids (up to 44 mm), its increased transfer in the area of research was essential. In 2015 the *M. norvegica* biomass comprised 9.73 g/1000 m^3 (22 % from total biomass), despite the fact that average abundance of this species was only 114 ind./1000 m^3 (6% from total euphausiids abundance in the Barents Sea).

Distribution of different euphausiids species followed the consistent pattern (Figures 7 and 8). Despite the fact that *T. inermis* was widespread, its main aggregations were found in the north-western areas of the Barents Sea. The densest aggregations of *T. raschii* traditionally spread in the eastern areas. Transferred species *T. longicaudata* and *M. norvegica* were found within the whole area, however their aggregations were recorded in the south-eastern Barents Sea (at the Norwegian coast of and in the western areas), along the cost of Norway and the Kola Peninsula and in certain years due to its accumulation in the remoted border areas of the Barents Sea (the eastern part and areas around Spitsbergen).

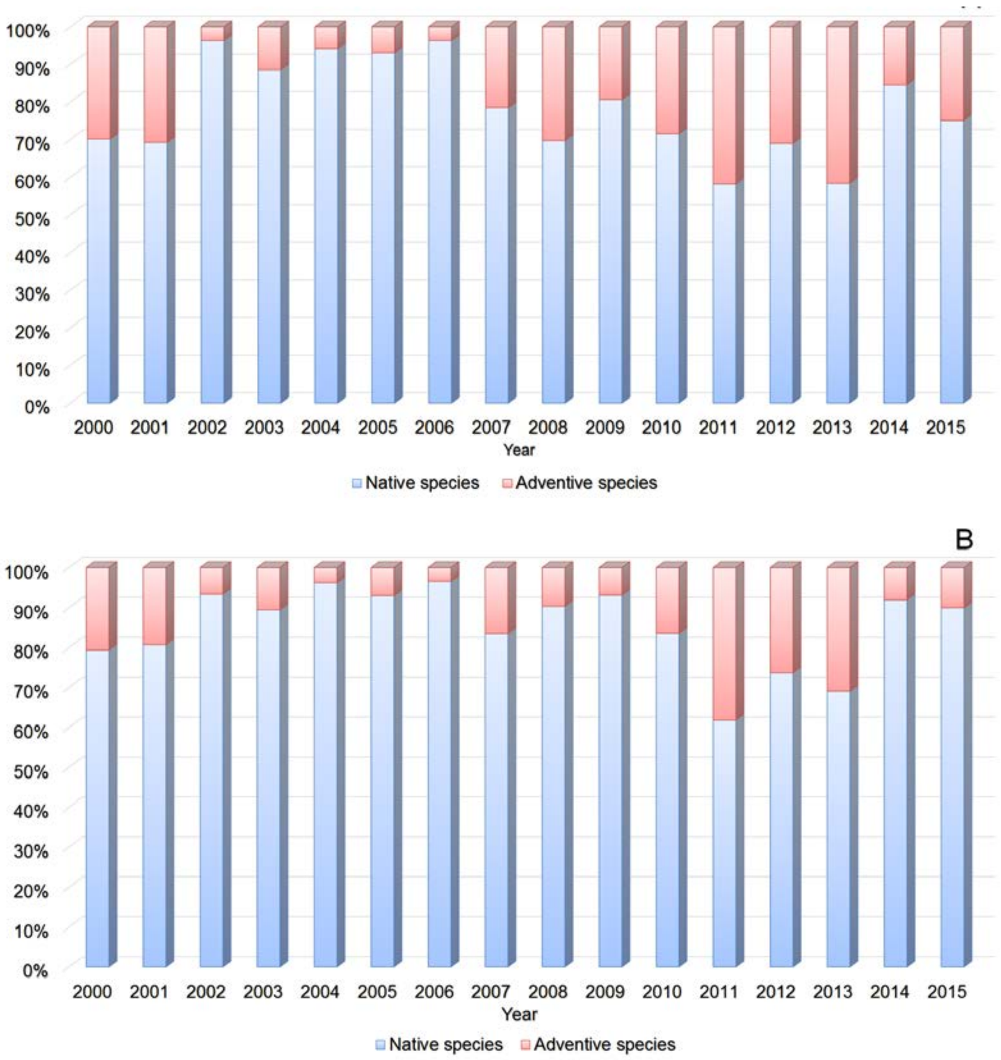

Figure 5. Abundance (A) and biomass (Б) proportions of local and transferred euphausiids species in the Barents Sea in 2001-2015 (blue color is for local species, orange is for transferred species).

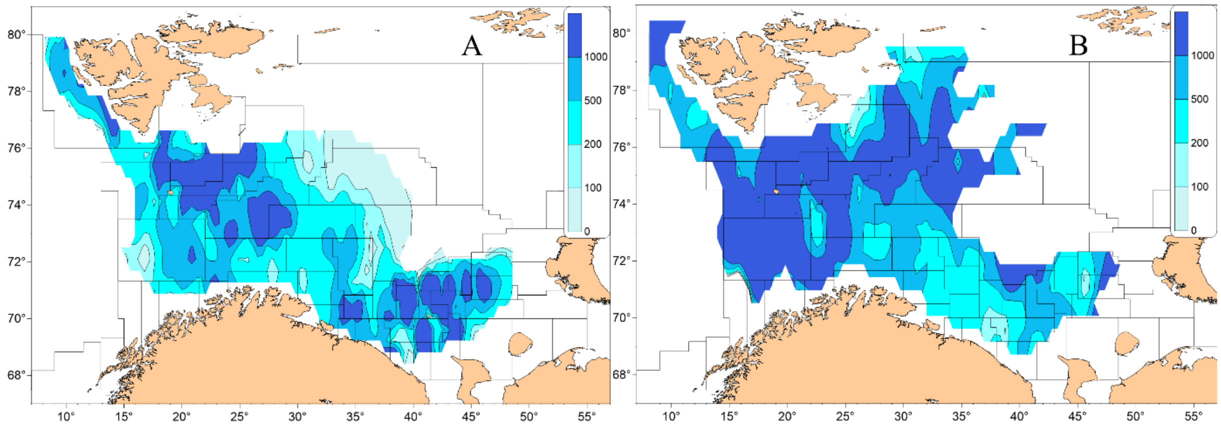

Figure 6. Distribution of euphausiids aggregations in the Barents Sea in “normal” year (2003) and “abnormally warm” year (2015).

Hyperiidea

Abundance of hyperiids had been decreased in 2000s and only in 2015 its growth was recorded (Figure 9). Average abundance of arctic *T. libellula* in 2004-2015 comprised 4.6 ind./1000 m^3 in the north-western Barents Sea and 0.6 ind./1000 m^3 in the southern part. The highest abundance of this species was recorded in the north-western part in 2015 and comprised 34 ind./1000 m^3, density of its aggregations reached 934 ind./1000 m^3 on the Great Bank.

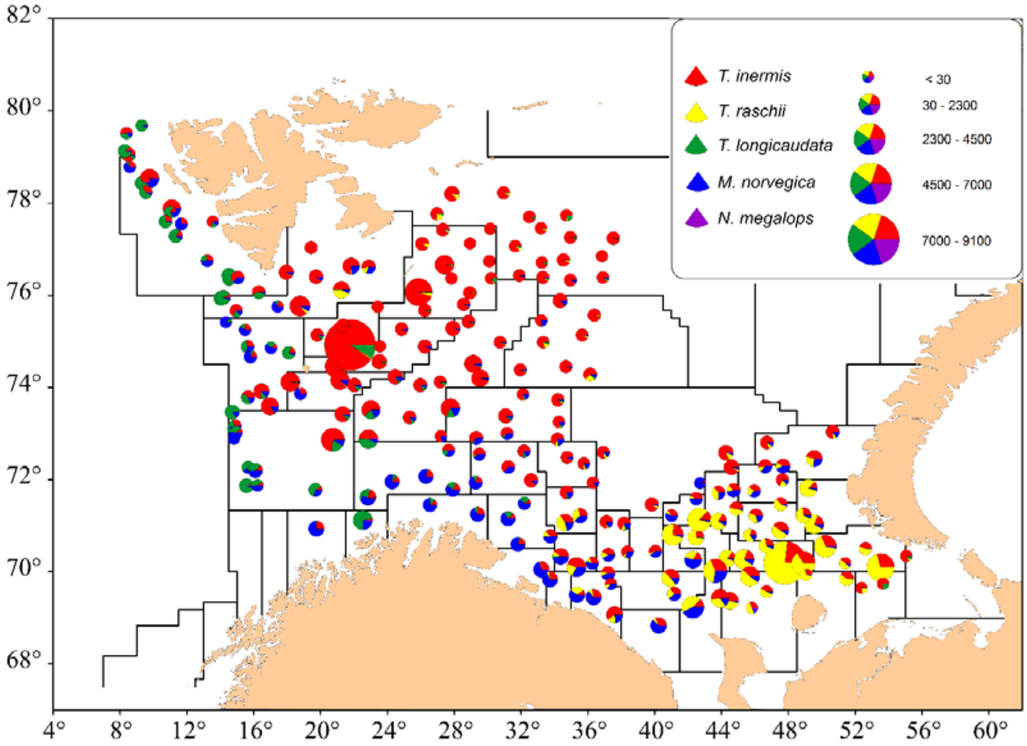

Figure 7. Distribution of average abundance of different euphausiids species in 2012 (abnormally warm year), ind./1000 m^3.

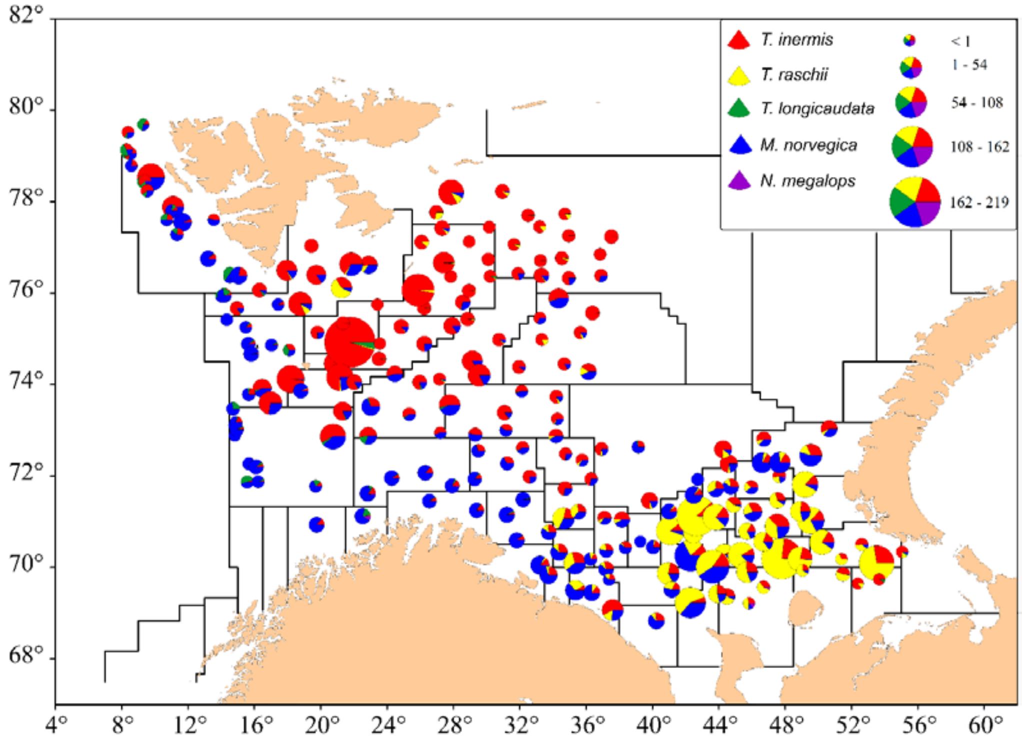

Figure 8. Distribution of average biomass of different euphausiids species in 2012 (abnormally warm year), g/1000 m^3.

Average abundance of boreal *T. abyssorum* was higher than of *T. libellula* and comprised 34.4 ind./1000 m^3 in the north-western Barents Sea and 10.4 ind./1000 m^3 in the southern part. *T. abyssorum* spread within almost the whole Barents Sea area and *T. libellula* was found mainly in the northern part (Figure 10).

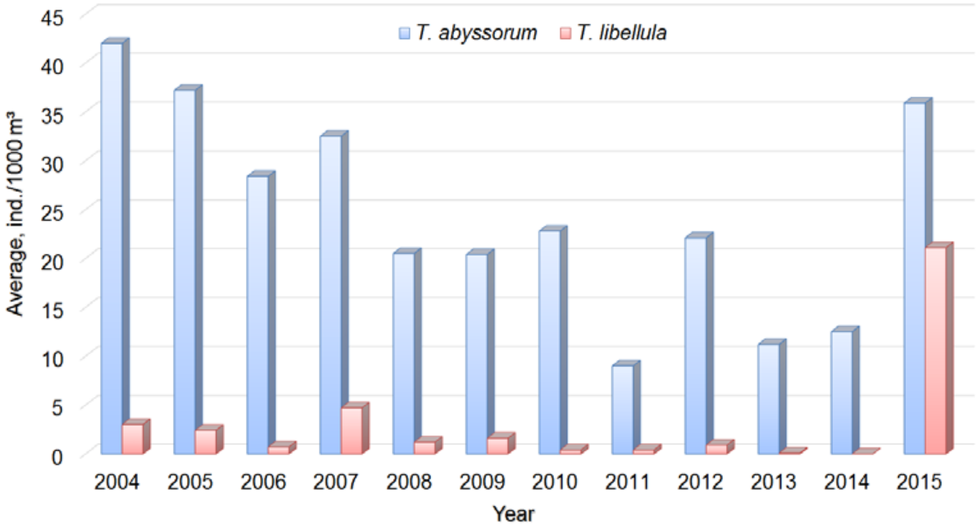

Figure 9. Average abundance of *T. abyssorum* and *T. libellula* in the Barents Sea in October-December 2004-2015; ind./1000 m^3.

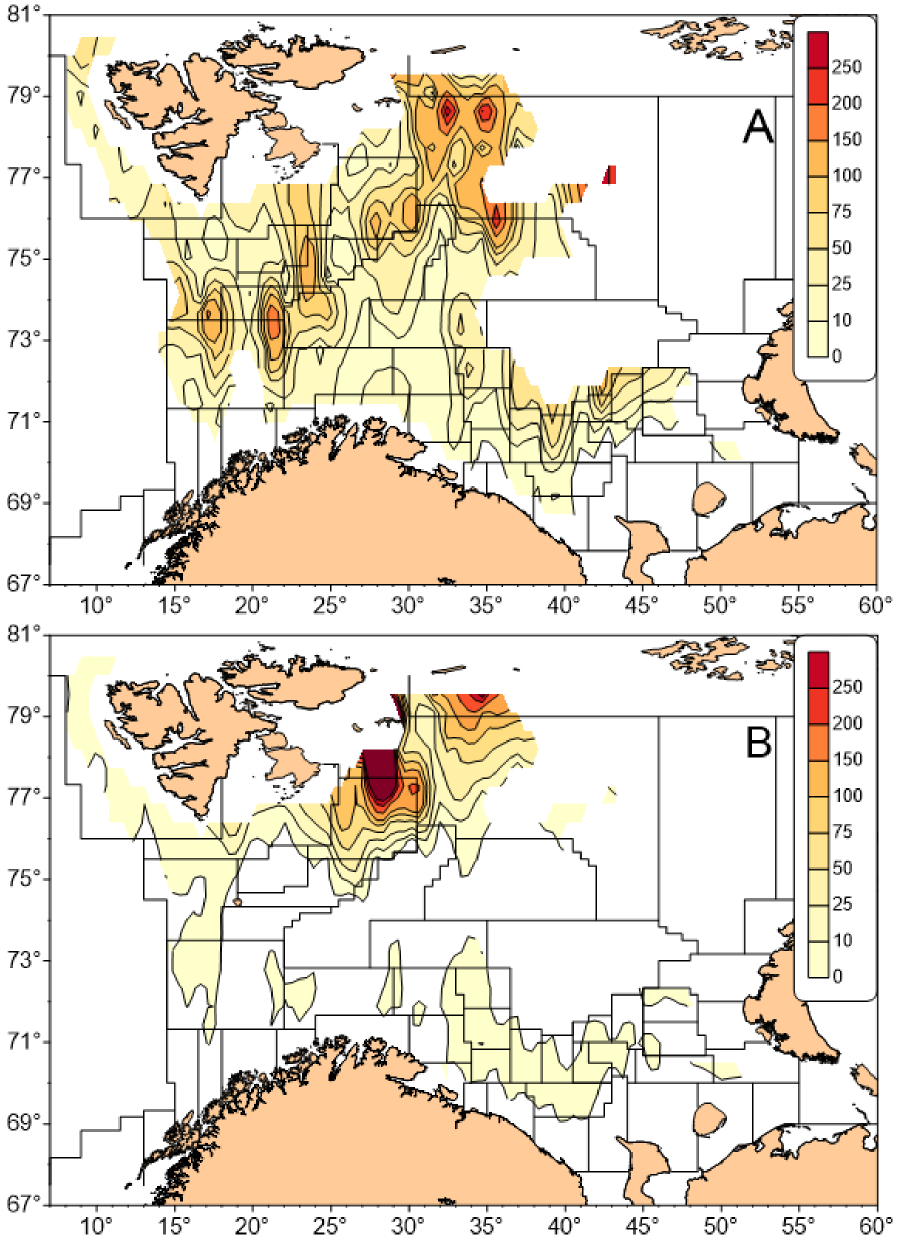

Figure 10. Distribution of *T. abyssorum* (A) and *T. libellula* (B) in the Barents Sea in October-December 2015; ind./1000 m^3.

Pteropoda

Aggregations of the most abundant pteropods species *Clione limacina* were not dense. In 2013, this species was smoothly distributed in the southern part Barents Sea and only in 2014-2015 some dense aggregations of *C. limacina* were recorded in several areas (Figure 11). Average abundance of this species was low and varied from 1 ind./1000 m^3 in 2015 to 4 ind./1000 m^3 in 2013 (Figure 12). Dense concentration of *C. limacina* in the Kopytov area (up to 302 ind./1000 m^3) resulted in high average abundance of this species in north-western areas in 2014.

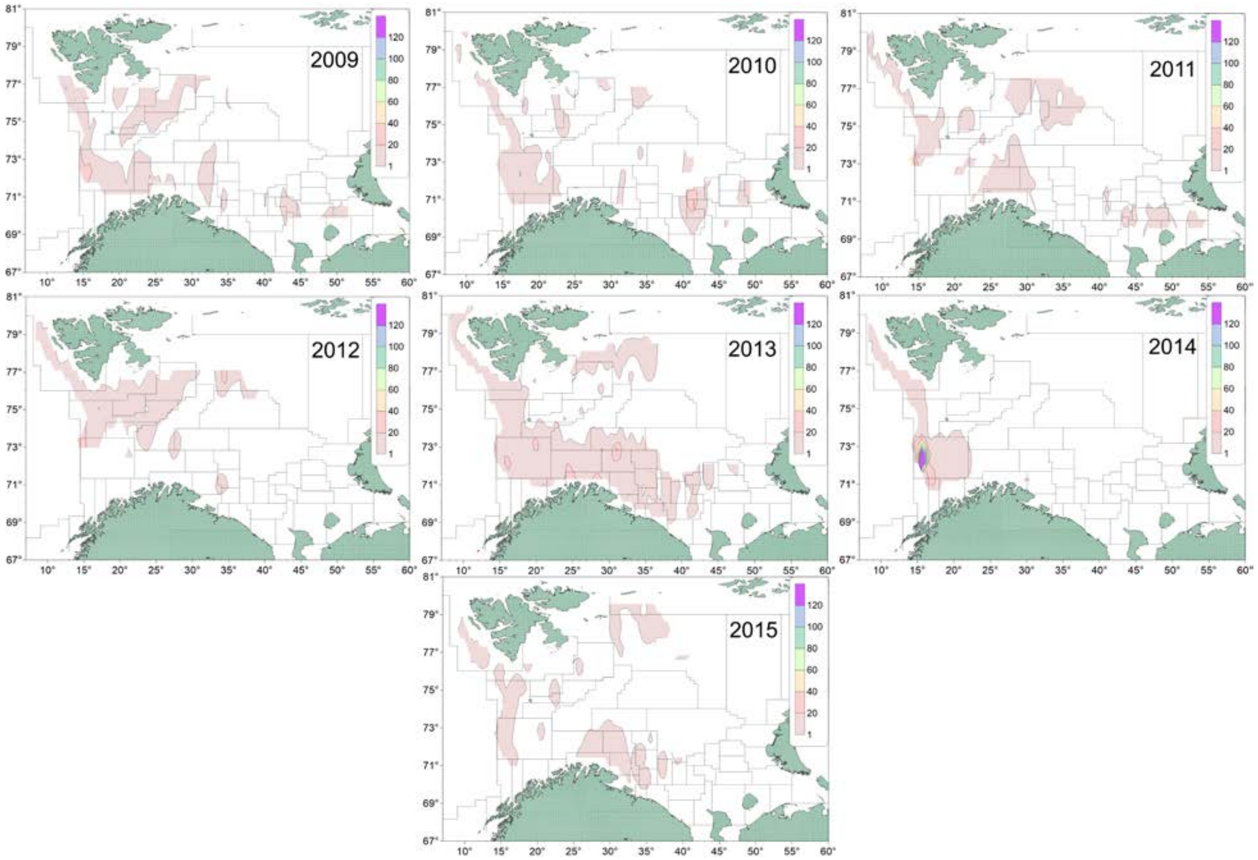

Figure 11. Distribution of *C. limacina* in the Barents Sea in October-December 2009-2015, ind./1000 m^3.

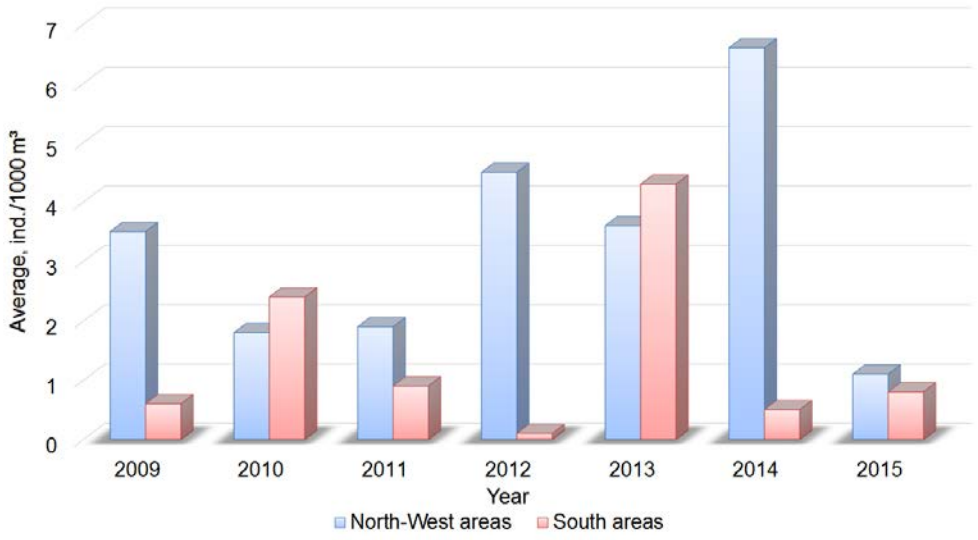

Figure 12. Average abundance of *C. limacina* in the Barents Sea in October-December 2009-2015, ind./1000 m^3.

Conclusions

To sum up, during the current warm period in the Barents Sea (2000-2015) conditions for the warm-water macroplankton species were characterized as good, particularly for euphausiids, the abundance of which had been close to the long-term average level (since 1950s) or higher. Abundance of predatory chaetognaths had increased during the assessment period as well. However, distribution area and abundance of hyperiids and pteropods in the Barents Sea had decreased.

Phytoplankton distribution, abundance and biomass in the south-western and central part of the Kara Sea in the autumn

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Abstract

The research was done in the south-western and central Kara Sea during 91-st cruise of R/V “Fridtjof Nansen” (Polar Research Institute of Fisheries and Oceanography, PINRO) in late October 2013. Phytoplankton taxonomic composition and distribution, abundance and biomass, ratio and role of autotrophic and heterotrophic species in the community were studied. Phytoplankton community was represented mainly by marine neritic arcto-boreal species with a small part of cosmopolitan forms and fresh-water microalgae. Totally 68 species of phytoplankton were found. Diatoms predominated in the species composition. Phytoplankton abundance ranged from 352 to 3857 X 10^3cell/m^3, biomass varied from 1,77 to 20.05 mg/m^3. Bacillariophyceae, Dinophyceae and Prasinophyceae had great contribution to the phytoplankton abundance, with small size autotrophic diatoms prevailing. Biomass was mainly formed by Prasinophyceae and Dinophyceae. Phytoplankton was at the autumn stage of succession with typical seasonal transformation to the resting stage: taxonomic restructuring and a significant decrease in abundance and biomass.

Keywords: Kara Sea, phytoplankton , species composition, abundance, biomass

Introduction

In recent decades, interest in the Kara Sea study has increased significantly due to the high economic activity in the continental shelf waters. The Kara Sea has an important role in the river runoff transformation of the Arctic basin, as it brings more than 40% of the total river flow to the Arctic region. Over the last years there has been an ice area shrinking in summer and ice-free waters area extension as well as increase an open water period duration, affecting the marine ecosystem functioning.

The study of the structural and physiological characteristics of marine ecosystems in the Russian Arctic is becoming one of the priority areas of the environmental research, in connection with increasing anthropogenic effect on the region and the climate change. Phytoplankton communities of the arctic seas are the most important component of marine ecosystem and the basis of the biological productivity. This paper presents data on species composition, abundance and biomass of phytoplankton in the South-West and Central part of the Kara Sea in October 2013. Regular collecting of biological data provides an opportunity to development of conservation, preservation and rehabilitation methods of the Arctic marine environment.

Material and methods

The research was done in the south-western and central Kara Sea during 91-st cruise of R/V “Fridtjof Nansen” (Polar Research Institute of Fisheries and Oceanography) in late October 2013 (Figure 1).

Figure 1. R/V "Fridtjof Nansen" (Polar Research Institute of Fisheries and Oceanography).

The material was collected at stations located to the East of the Novaya Zemlya archipelago to 65° E, between 70° N and 76° N (Figure 2).

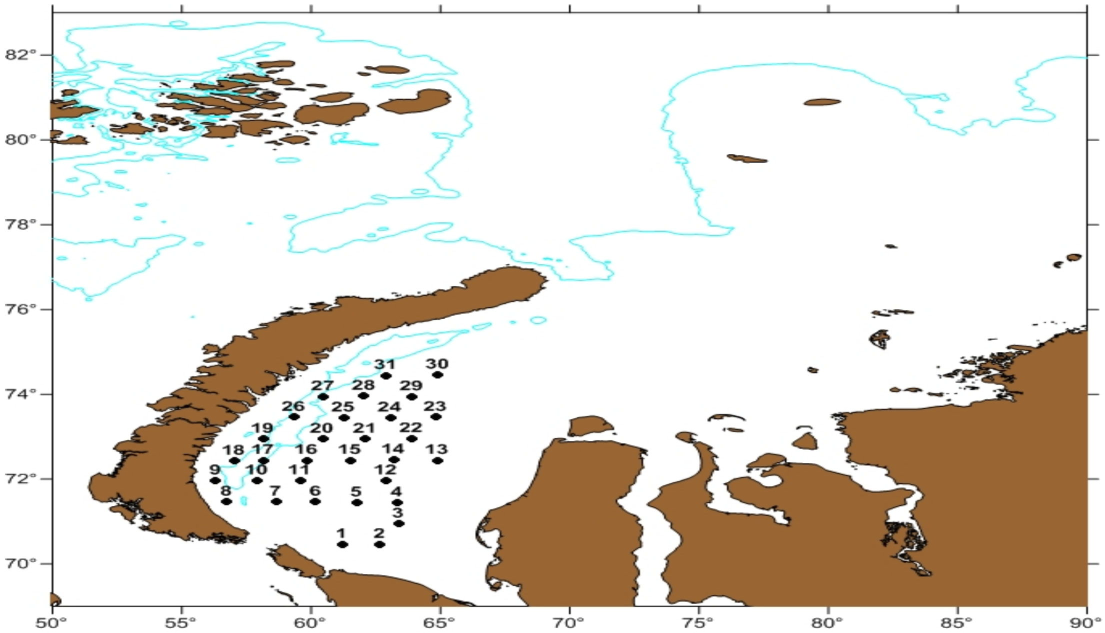

Figure 2. Map-scheme of phytoplankton sampling in the Kara Sea, the cruise R / V "Fridtjof Nansen" in October 2013.

Phytoplankton taxonomic composition and distribution, abundance and biomass, ratio and role of autotrophic and heterotrophic species in the community were studied.

Totally 31 integral samples for microphytoplankton (cell sizes 15 - 200 μm) taxonomic composition and quantitative parameters analysis were collected. The phytoplankton samples were concentrated by the standard method of reverse filtration and then preserved with 40% neutral formalin to a final concentration of 2% on the shipboard. Phytoplankton taxonomic analysis, microphotography and quantification was done in the PINRO laboratory with light biological microscopes MBS-9 and XS-402 (magnification X40-800) The obtained data on abundance and biomass were recalculated by volume 1 m^3 (Figure 3).

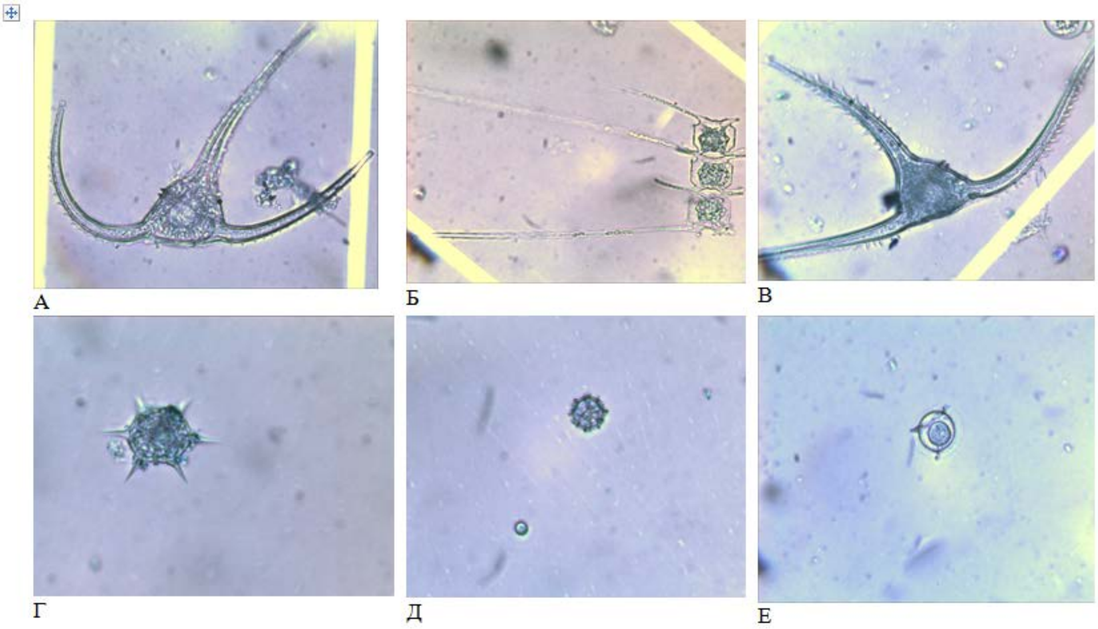

Figure 3. Representatives of the Kara Sea phytoplankton community in the samples of October 2013: А – *Ceratium longipes*; Б – *Chaetoceros danicus*; В – *Ceratium arcticum*; Г – *Dictyocha speculum*; Д – *Pterosperma polygonum*; Е – *Pterosperma marginatum* (micrography and taxonomic analysis by O. S. Tyukina).

Results

Phytoplankton community was represented mainly by marine neritic arcto-boreal species with a small part of cosmopolitan forms and fresh-water microalgae. Totally 68 species of phytoplankton were found. Diatoms predominated in the species composition (Figure 4).

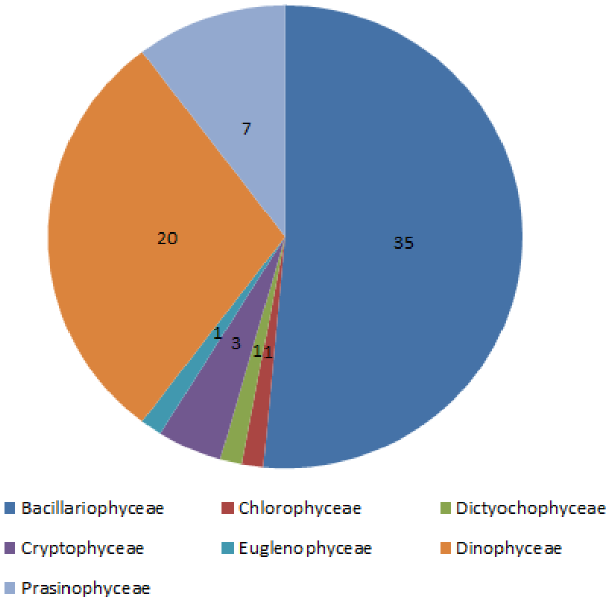

Figure 4. The ratio of the species number in different taxonomical groups of the Kara Sea phytoplankton community in October 2013.

Phytoplankton abundance ranged from 352 to 3857 X10^3 cell/m^3 (average 1006 X10^3 cell/m^3) (Figure 5).

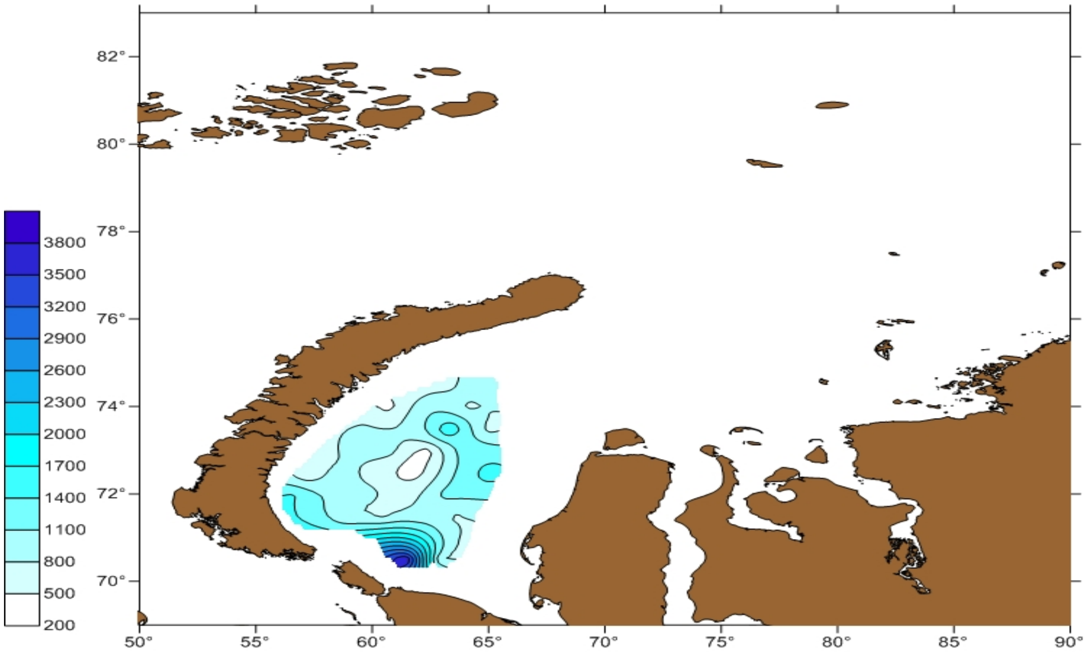

Figure 5. Distribution of phytoplankton abundance (N, 103 cell/m3) in the Kara Sea in October 2013.

Bacillariophyceae, *Dinophyceae* and *Prasinophyceae* had great contribution to the phytoplankton abundance, with small size autotrophic diatoms prevailing. The maximum abundance values were observed in the Barents Sea water masses, the lowest in the mixing zone of the Barents Sea and the Arctic surface waters.

Biomass varied from 1,77 to 20.05 mg/m^3 (average - 6.52 mg/m^3). Biomass was mainly formed by *Prasinophyceae* and *Dinophyceae* (Figure 6).

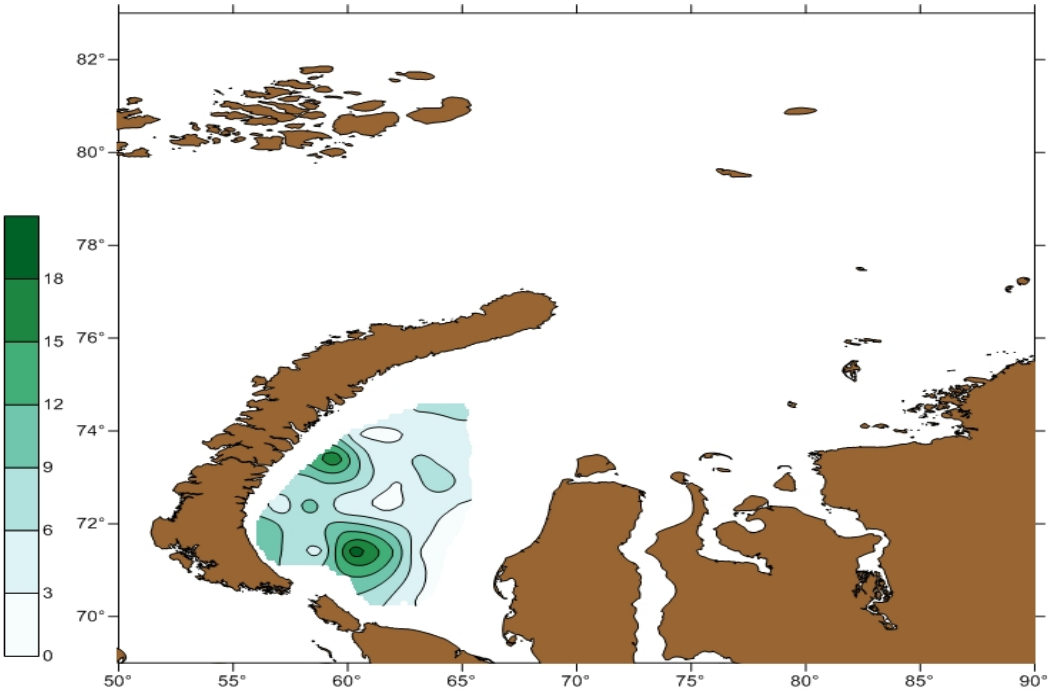

Figure 6. Distribution of phytoplankton biomass (mg/m3) in the Kara Sea in October 2013.

Conclusions

Phytoplankton was at the autumn stage of succession with typical seasonal transformation to the resting stage: taxonomic restructuring and a significant decrease in abundance and biomass. The obtained data is well correlated with seasonal phytoplankton characteristics in this area. In October 2013 the phytoplankton community of the Kara Sea was predominated by diatoms, which is typical for the arctic seas and the Kara Sea in particular. Phytoplankton consisted mainly of neritic marine arcto-boreal algae complex with a small proportion of cosmopolitan forms. The percentage of freshwater species in the phytoplankton community was insignificant even in the coastal stations, probably due to standoff distance of sampling stations from the shore and minimal river flow at this season. Phytoplankton activity depends on the seasonal insolation and the water column cooling, which leads to disintegration of the community species structure and decrease of abundance and biomass. In biomass, the phytoplankton was predominated by a small size fraction of autotrophic diatoms, flagellates, *Chaetoceros* and *Ceratium* genera and *Dinophyta* algae, mainly *Protoperidinium* and *Dinophysis.* The change of the main dominants in the community took place in accordance with the season and was expressed in the progressive replacement of autotrophic forms with heterotrophic and mixo-heterotrophic. The study area included the southernmost shallow part of the basin, the central and deep western part of the sea. A significant impact on the Kara Sea ecosystem is provided by continental runoff, due to which the Kara Sea is characterized by a pronounced zoning in the distribution of marine ecosystem biotic components, including phytoplankton. The southern and central regions of the sea are influenced by the Ob' and the Yenisei river flow. In the western part of the sea convective mixing of waters extends approximately to a depth of 50 m. The particular feature of phytoplankton biomass distribution in this area is circumferential concentration in the coastal areas. The maximum biomass was recorded at the eastern coast of the Novaya Zemlya archipelago. The relatively high local biomass values were observed at stations with depths of more than 150 m. Spatial differences in the abundance and biomass distribution have been associated with the hydro physical and hydro chemical parameters of the environment, particularly the Barents Sea waters penetration and the influence of the coastal currents along the Yamal Peninsula. The Kara Sea phytoplankton status in autumn 2013 substantially similar to the seasonal stage of development representative of arctic microalgae communities.

Acknowledges

This work was supported by the Russian Science Foundation Project “Structure and functioning of plankton and fish communities in the Kara Sea in recent warming period” (Grant No. № 14-14-00808).

THEME SESSION III: BENTHOS

Benthic distribution and production

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Benthos plays a significant role as food for a wide variety of fish and benthic species (Planque et al 2014), as substrate and as refuge from predation for species of all life stages. As increasing temperature and ice melting open for a northward expanding industrial trawling (Jørgensen 2017, Jørgensen et al 2017, Jørgensen et al 2015) and into areas with vulnerable benthic fauna (Jørgensen et al 2015, Certain et al 2015), long term monitoring becomes more important. On the Ecosystem Survey a time and cost efficient method has been developed where benthic experts are analyzing the fish trawl catch of megabenthos. This means no extra ship time or use of equipment need to be used to obtain data from benthos. Benthos from almost than 5000 trawl catches, used in annual assessments of commercial fish stocks, has been identified and measured on-board the join IMR-PINRO Ecosystem surveys from 2005 and ongoing. Results from benthic communities in a 1.5 million km2 large area are derived for more than 1000 taxa whereas 650 identified to species level. More than 70 tonnes of biomass and more than 15 million individuals has been processed. The mean megafaunal biomass trawl catch per nml varied from ~23 to ~38 kg between 2005-2017 (Figure 1) with the highest biomass in north east and southwest.

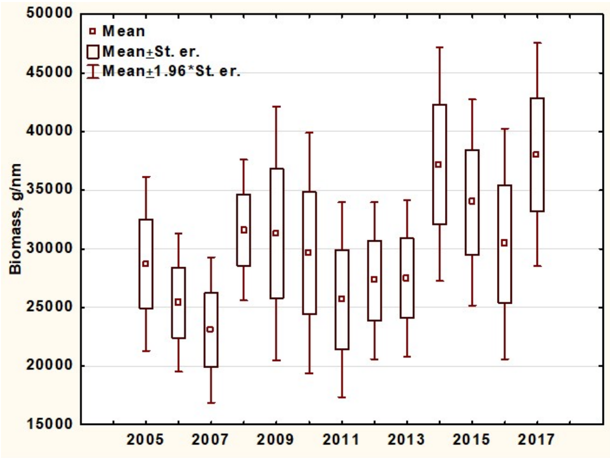

Figure 1. The mean biomass per trawl-catch per year from 2005-2017.

The production in the Barents Sea megafauna varies from 0.015 - 105 mg C m^{-2} y^{-1} depended on area, with the highest production in the northeast. Megafaunal productivity are at the highest in the central part of the Sea (Degen et al 2016). Average megabenthic production per station are calculated to be 3-6 kg/nm/year (Manushin in prep). Sea water temperature fluctuations are shown as changing of the proportional distribution of Boreal and Arctic species (Manushin et al., 2012**)**. Warming pushes the border toward the east while cooling toward the west in the southeastern part of the Barents Sea, and a possible time-lag of seven years of benthic response to temperature changes might be shown. Not only temperature, but also trawling can change the benthic faunal distribution by removal/destruction of large upraised species being caught or entangled by the trawl (Jørgensen 2017) and the peripheral areas of the Barents Sea are inhabited by such species (Jørgensen et al in review). It is also excepted that the snow crab might have an impact on prey species in areas with high populations of the snow crab. This predator consumes up to 4.6 g benthos per m^2 (Manushin, 2016) and are found in highest numbers in areas with high biomass of benthic prey (Zakharov et al., 2018).

Benthic faunal regions have been identified in the southwest, on banks/slopes in southeast and west, in the northwest, and in the northeast. These regions are significantly related to depth, temperature, salinity, and number of ice-days (Jørgensen et al 2014). In the seasonally ice-covered northeastern part of the Barents Sea dominated by plankton-feeding brittle stars and an increasing snow crab population. The permanently ice-free southwest areas with less production were dominated by filter-feeders (sponges) in the inflow area of warm Atlantic water while the deeper trenches had a detritivorous fauna (echinoderms) (Anisimova et al 2011). The long-term investigation of the benthos from the ecosystem surveys indicates a spatially change in the faunal composition and a possible change in function, and multiple stressors can be the cause of this change. This has led to an international brought awareness and networks trying to develop PanArctic methods to detect changes in a rapidly changing Arctic (Jørgensen et al 2018).

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Chemical ecology of benthic invertebrates yields important clues for marine bioprospecting

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Honourable colleagues,

The great American poet Thomas Alan Waits acknowledged the complexity and potential of our common language when he proclaimed that; *fishing for a good time starts by throwing in your line*.

I will throw in a few lines, since I have been given the opportunity to present views regarding new approaches in bioprospecting, and hopefully my lines will be short and concise. I have printed copies of what I will talk about as I attempt to outline the present efforts of Norwegian bioprospecting, and draw ecologically based perspectives towards some developing possibilities.

In short, the present efforts at isolating attractive bioactive chemical compounds from marine organisms, are being conducted along the main strategy which was founded more than a decade back in time; biological material is collected by trawling, dredging or diving in annual cruises along the Norwegian coast and in deeper waters within the Norwegian territories. In the laboratory ashore, the biological material is freeze dried and extracted. The extracts are tested in a range of cell-lines, – malignant human cells, normal human cells, various microorganisms and amongst those, such strains which demonstrate the most vicious antibiotic resistance. When effect is indicated through such simple screening, subsequent detailed analysis of isolate fractions and singular compounds will contribute to isolation of a potential pharmaceutical. But, as you surely understand, this is a simplified version of the story.

An alternative and more targeted approach in marine bioprospecting can be based in the ecological context of specific marine organisms, or of tissues, organ systems or body fluids in which biochemical mechanisms or compounds are either known or can be expected. Such a functional approach might identify the biochemical mechanisms responsible for certain observed abilities, such as the well-known anti-fouling properties of alcyonarian corals or the rapid and clean wound-healing and skin-repair of demersal fish.

Somewhat naïvely, the initial expectations were to harvest biochemical from the sea much in the same manner as we have for centuries harvested biochemical pharmaceutical ingredients from the botanical diversity of our planet. Researchers and representatives of marine-biopharma have presented politicians and investors with golden prospects of potential cures to grave diseases, including cancer. However, to date only a handful of functional pharmaceuticals have been developed from marine organisms.

Furthermore, after more than a decade of intensive bio-prospecting in the marine environment, we face new fundamental realisations. Importantly, we have recently reached an understanding of the importance of microbial symbionts, – the so-called microbiomes of various host organisms. Organisms such as marine-sponges, fish and humans have specific societies of bacteria and other microorganism living in specific tissues or organ systems, – these are the vitally important microbiomes which aid in what we might describe as numerous micro-ecosystem-services; defence against potential pathogens, digestion of specific compounds, holobiont regulation and possibly some services which are rather difficult to explain, – it has even been suggested that in *Homo sapiens* the functionality of microbiomes is important for not only overall health, but mood and mental function as well. Although difficult to accept, such indications are being investigated at present.

Thus, we return to chemical ecology as a strategy to search for compounds. Chemical ecology is what helps organisms obtaining lunch without becoming lunch, and there are numerous important biochemical interactions in which marine organisms use chemical means to signal, attract mates, deter enemies and incapacitate predators. What we know at present is impressive, but even more astonishing is the realisation that in this subject, as in so many other subjects, our understanding is shallow and barely breaks the surface of that specific biological complexity.

Recently we understand that the trophic level supplied by such sponge reefs (sponge grounds) of species in the genus *Geodia* and others, has high ecological importance as an ecosystem service beyond the simple conversion of biomass from dissolved organic carbon or microbial origin. We also suspect that complex dialogue is taking place within the sponge holobiont of such species, as sophisticated prime line of immune system defences, antipredatory measures and cultivated tissues analogues of vegetable gardens. The medical qualities which ancient Chinese, Indian and Greek attributed to marine sponges are undoubtedly products of this biochemical complexity. Previously, when bioprospecting marine porifera, we have homogenized the entire holobiont and performed extraction from this. However, we have now begun stratifying the holobiont and testing distinct strata, – such as the exterior – or dermal – layers separate from the interior layers. Whether such simple differentiation will lead to anything but frustration, is still an open question.

In order to do groundbreaking research, move our field forward and truly solve the grand scientific enigmas, we must be able to acknowledge several aspects which we at present ignore at best, or which we at worst even counteract and oppose. Several of our fundamental assumptions must be revised, and we must be honest regarding potential and possibility of novel research fields.

In the near future marine microorganisms undoubdedly will be recognized for their enigmatic complexity and fundamental ecological importance. Microorganisms constitute a large part of global biomass, quoting a recent figure, an estimated 1.3 Gt marine carbon is contributed by bacteria. This is roughly the double of the global biomass of fish, which is estimated at 0.7 Gt (700 megaton).

Marine bacteria – as bacteria in general – are highly adaptable and the present efforts at developing strains which can utilize and degrade plastic waste is a reflection of that quality. From before we know that marine bacteria in the core microbiome of the deep water coral *Lophelia pertusa* include strains which can degrade and utilize hydrocarbons. Also, my own recent research presents soil bacteria adaptation to agriculture toxins as an important ecological driver for development of functional genes. Thus, it must be expected that as we speak, the galactic complexity of marine microbiology is evolving and adapting in response to changes in water chemistry, evolving mechanisms to deal with industrial effluents, residues of pharmaceuticals and other man-made pollutants.

I will spend a few minutes of this talk in accentuating my strong belief, that only diversity of academic background can help us form research-teams which can solve the present big challenges of natural science research. In several disciplines – such as genetics – we have worked ourselves into blind alleys and we need new ideas. As an example, we have recently initiated a project which will investigate analogue occurrence of semi-identical code in distantly related organism, speculating on new fundamental principles in heredity. One of the main problems with the academic socialisation, homogenisation and indoctrination which is performed at present, is the intolerance it poses to alternatives proposed by academic dissidents. Such dissidents must be allowed to contribute, even if their messages may be unpleasantly blunt, as in the situations when they correctly observe that the emperor has no clothes.

The previous time I gave a talk at an international conference, the subject was coral reef ecology and my presentation was entitled “the interval of biological normality”, – it was in 1995, in Newcastle, and it was well received. A Russian researcher was also there, Boris Preobrazhensky from the *Pacific Institute of Geography* in Vladivostok (maybe it has another name when translated from Russian now). I had the great privilege to spend some enlightening moments with professor Preobrazhensky, – we walked along the British coastline, observed natural phenomena and talked of various subjects. Although this is more than two decades back in time, I must say that these were important moments in my development as a scientist. To me – who had recently completed my masters of biology – professor Preobrazhensky stood out as an impressive academic capacity and a truly trans-disciplinary researcher. He had written a book on biological complexity of underwater landscapes and had interesting reflections on many of the issues, which I had previously strived to understand. And, like me, he was an active diver.

As an example, he taught me some new things on chemistry of marine waters. Also, some of his reflections made me understand that several widely accepted explanations and scientific dogma, are simply not correct. In a certain way, that introduced me to epistemology and – notably – *agnotology*.

However, we shall not talk of epistemology and agnotology here, although these subjects are so very important in all scientific work. This realization, though, is one which practitioners of the noble arts of natural sciences have to reach by themselves.

Many – if not most – are satisfied with the narrow focus of numbers and statistics, with little need to neither penetrate mentally into neighbouring academic fields nor to challenge themselves intellectually. And such professional decisions must be respected, – colleagues should be allowed to go about in their daily business and not be forced to fill their stressed minds with all sorts of adjacent disciplines, new complexities and revolutionary ideas.

I must say that our basic understanding of microorganisms will surely change dramatically within the coming decade. We will reach such realisations which today are nearly unspeakable. One might thus say that I should keep my tongue and not speak of purely hypothetical concepts – which I even admit are mostly based on little evidence other than own conclusions. However, being in the country which fostered such minds as Boris Mikhaylovich Kozo-Polansky who lived from 1890 to 1957, I feel that such comments are justified. Kozo-Polansky investigated cells living within other cells as symbionts and fathered the only much later accepted theories of symbiogenesis, theories which notably inspired the work of Lynn Margulis, who had to endure more than ten rejections of her manuscript on symbiogenesis, before those revolutionary ideas were recognized and received standing ovations in academic circles.

I will dare to say that a few aspects of microbiology are rapidly approaching realizations so clear to us at present, that we as a community simply have to acknowledge the coming advances. Here, I specifically think of two subjects, microbial taxonomy and microbial genetics. In a few years those subjects can become revolutionized by new realizations, primarily the concept of microbiomes as generators and providers of genomic elements and sorely needed code for metabolic processes needed to solve ecological challenges, – such as the presence of persistent or regularly inflowing pollutants and chemical disruptors.

The other issue, which might emerge relating to microbes and their taxonomy, will mean a complete revision of the concept of separate and distinct species as units of biological and genetic integrity. In the future we will see a new phylogenetic tree emerging, accentuating the importance of horizontal transfer of genes and supplementing and enhancing the present realization that most living diversity, is within the worlds of microbes. The idea which I hereby will attempt conveying to you, speculates that microbes have an infinite number of species. The term “infinite” is so very absolute and heretic in the language of science, but here it must be used with some justification. You can imagine the stems of the phylogenetic tree, as these stems and trunks are constantly subdividing into trillions-gazillions separate small branches. Recent estimates on the number of marine bacteria speculate at 1029 individual cells, but no researchers have dared to present estimates of species numbers. Possibly, because we cannot speak of traditional concepts such as species when it comes to bacteria. Possibly, we must acknowledge that the correct terms to use in microbial taxonomy are that of strains, and operational taxonomical units, the so-called OTUs.

The parent mother microbe exchanges her genetic code with not only close relatives, but with other microbes and higher organisms as well. This constant exchange of genes, through the well-established process of lateral or horizontal – gene transfer, is a main driving force in creating such diversity. But, also the mutability of the prokaryote plasmids, providing the adaptability which microbes demonstrate, be it towards antibiotics, agricultural pesticides or marine oil-spills.

For *marine bioprospecting*, the simple and primary goal is ecological approaches aimed at identifying ecological interactions in candidate holobionts, for subsequent harvesting and testing, but also with a wider perspective, such as employing microbial generators based on hosts modified via transgenesis. Simple expressions of such candidate genes for example coding for antimicrobial peptides are already routinely performed in model microbes such as E. coli, and surely the future will bring numerous advances there as well.

And here we reach conclusion regarding the ecological changes to our northern seas and the future of the harvestable marine resources which these seas will provide: we must realize that changes in water-chemistry, temperature and human activity, may profoundly affect the diversity of marine microorganisms. The sad fact of this matter is, that we have only limited reference knowledge of this diversity and these complex microbial ecosystems, and thus no benchmark to measure changes against.

Finally, I must say that I am excited to be here, as a representative of the small neighbour at the western shores. Although the recent statistics from the United Nations assessments of the Global Ocean Survey find that amongst the nations of this world, Norwegian marine research has the highest number of employees per hundred-thousand inhabitants, – still I find that numerous challenges to the marine ecosystems are neglected at present. Notably, this concerns marine microbiology, a subject where we have only limited understanding of the ecosystem services performed by bacteria.

Hopefully this will change. In the IMR the understanding of these things is developing rapidly, and it pleases me to notice the attention which many researchers are now giving to this important complexity.

I thank you for your attention and if any of you wish to discuss any of these things, I will be happy to enter into conversation. (final comments out of script on 1) diving, and 2) this, the authors first visit to Russia, 50 years after Russia visited him in Prague, Czechoslovakia).

Perspectives of snow crab *Chionoecetes opilio* fishery in the Russian Exclusive Economic Zone in the Barents Sea

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Abstract

The paper describes the current state of the snow crab stock in the Barents Sea. The main factors affecting the acclimatization in the new area are examined. Based on the spatial distribution modeling, the potential area and probable future commercial concentrations of the snow crab after the complete naturalization are estimated. Commercial stock biomass of snow crab in the Russian waters of the Barents Sea at present is estimated at 400 thousand tons with the possibility of annual catch of 40–80 thousand tons.

Keywords: Barents Sea, snow crab, fishery

Introduction

The first captures of the snow crab *Chiloecetes opilio* in the Barents Sea were registered in the mid-1990s (Kuzmin et al., 1998). Following 20 years the crab-invader actively reproduced itself, occupying new waters where sometimes forming there commercial densities. Since 2013, the unregulated snow crab fishery began in the open part of the Barents Sea (the “Loophole”). In 2013–2016 the total international snow crab catch in these waters exceeded 50 thousand tons. In 2016 the fishery for snow crab was started also in the Exclusive Economic Zone of the Russian Federation (Russian EEZ).

The aim of the work is to assess the perspectives for the Russian snow crab fishery in the Russian EEZ in the Barents Sea. The analysis of data on the modern state of the crab population was used in achieving of the aim. A probability model of species distribution (species distribution model (SDM): Elith, Leathwick, 2009) application was used to investigate the influence of some environmental factors on the snow crab present spatial distribution as well as the possibility of further area expanding. The complex results, obtained by the SDM model and the Leslie depletion model, were used to extrapolate and estimate the total and commercial stocks biomass of snow crab in the Barents Sea.

Material and methods

The PINRO’s data of the snow crab catches in the Barents Sea, collected in the Russian-Norwegian ecosystem survey in 2005–2017 were used. These annual surveys were carried out according to the standard methods during the summer-autumn and covered major part of the Barents Sea on an area about 1,500 thousand km² each year (Eriksen, 2012).

The snow crab stock condition in the Barents Sea was assessed by some indicators: the occurrence of the crab in space, number and the biomass of the commercial stock. To assess the snow crab spatial distribution in the Barents Sea and to analyze the environmental factors determining the acclimatization success, a family of SDM distribution cartographic models implemented in the Biomod2 library of the statistical environment R were used. The choice of the probability model to analyze the snow crab distribution, model diagnostics, and also the evaluation of the variables influence on the simulation results were performed by the functions of the “biomod2” library. The method essence is in the correlation relationship analysis between the predicted values of two variants modeled: with the standard set of independent variables and when the analyzed variable is replaced by randomized analogue. The lower the correlation, the higher the influence of the variable analyzed (Mielke, Berry, 2001). The index of the snow crab stock number was calculated as the arithmetic mean catch (spec. per 1 n. mile of trawling) in the surveyed area of the Russian EEZ in 2005–2017. To assess the stock in the fishery area, the Leslie model of depletion with a time step of one quarter was used (Bakanev, 2015a).

To obtain the minimum value of the snow crab commercial stock biomass in the Russian EEZ, the density of crabs obtained in the “Loophole” in 2014 (before the fishery in the Russian EEZ) was extrapolated to the area of commercial sized crabs distribution in the Russian EEZ estimated in ecosystem surveys 2012-2017.

Results and discussion

From the first captures of the snow crab in 1996 up to the start of commercial fishery (2013), an explosive-like population growth, active spreading to the eastern part of the Barents Sea, forming of commercial concentrations and new rich generations were observed (Bakanev, 2015b). Currently, the area of this specie is about 900 thousand km², close to 30% of the total Barents Sea area. The snow crab becomes one of the most wide-spread creature of the bottom fauna in the eastern and northeastern parts of the Barents Sea.

According to the results of analysis of the some factors influencing the crab distribution, the only variable – the distance from the core of initial crab settlement is most significant. Climatic and landscape factors currently do not significantly affect the crab distribution. The bottom sediments on the major part of the Barents Sea is optimal for the snow crab and does not limit its spreading. Almost the total bottom surface of the Barents Sea is covered by sandy mud (64%) and muddy sand (22%), where the majority of snow crabs were observed. The near bottom water temperature is a one of main factor limiting the further dispersal of the crab to the areas with rather high water temperatures (Bakanev, 2015b). Crab is currently found in the near bottom waters temperatures from –1.9°C to 6.5°C. One of the factors possibly limiting the crab penetration to the coastal areas is the near bottom waters salinity, which are often rather low (Anger, 2003). At the same time, it is known that crab often forms concentrations of rather high densities at low salinity even about 32 (Slizkin, 1982). Based on the assumption that 2/3 of the Barents Sea area is under the Atlantic waters influence where the salinity exceeds 34, while in the rest of the sea the salinity varies between 32 and 34 (Dobrovolsky , Zalogin, 1982), the salinity factor will not play a significant role in the further snow crab distribution. The role of nitrates, phosphates and oxygen is rather high. Such a significant contribution of these factors is primarily due to the distribution of the species in relation to the distribution of the Barents Sea water masses types. At present crab is almost not found in the Atlantic waters of the western part of the Barents Sea (west of 35 ° E) (Ozhigin et al., 2016). Thus, the main environmental factors in the Barents Sea, influencing the snow crab spatial distribution, do not prevent its successful acclimatization, colonization of new areas and formation of high densities concentrations.

Analyzing the factors affecting the snow crab distribution, some authors are pointing out such biotic features as the feed benthos and predators (Kobyakova, 1958; Slizkin, 1982; Galkin, 1985). The absence of cannibalism and numerous predators, which could decrease the population number on the early life stages, is essential. The inclusion of benthic by-catch data collected during ecosystem surveys (benthos distribution density) in modeling of the snow crab distribution shows that the influence of such variable is currently insignificant compared to natural factors. Based on the index of population number dynamics, there were three periods in the crab stock history: low number in 2005–2008, active growth in 2009–2010 and high number in 2011–2016. Changes in the size composition in crab catches show that some rich generations periodically appear in the crab population. This could affect the population dynamics, as well as the commercial stock biomass. Thus, the high uncertainty in the population indices of the Barents Sea snow crab does not allow using them as confident indicators of stock status in a certain year of assessment. Therefore, such results of trawl surveys as changes in the size composition of catches, the distribution area and general trends in the stock number dynamics in recent years could only indirectly be used to estimate the status of the crab stock. The basis for future commercial stock estimates and the forecast of the snow crab total allowable catch (TAC) could be the data obtained during the fishery. In case of poor information, the crab stock assessment could be performed by one of the most promising analytical methods - regression models of the productivity reducing during the fishery season, based on the accumulated catch, i.e. depletion models (Bakanev, 2015a).

The commercial snow crab fishery in the Barents Sea began in mid-2013 in the central region of the Barents Sea outside of the national economic zones. Since the beginning of the unregulated snow crab fishery in the “Loophole”, the total Russian catch to the end of 2016 exceeded 20 thousand tons, while the foreign catch reached 35 thousand tones. Upon the intensive and rather large-scaled new established fishery, the productivity decline was observed, indicating a significant overfishing these areas. In this regard, targeting to protect the stock, in mid-2016 the Russian Federation and the Kingdom of Norway in frames of the Joint Russian-Norwegian Fishery Commission agreed to regulate the snow crab fishery in the “Loophole” jointly. In 2016, the snow crab fishery started in the Russian EEZ of the Barents Sea. First results of the fishery in 2016 showed that the density of crab concentrations allows to harvest the new stock at the same stable productivity, as in the Pacific. To estimate the snow crab commercial stock biomass in the Russian EEZ of the Barents Sea, the values of the crab’s commercial stock density in the “Loophole” before the fishery opening (774 t / thousand km^2) were extrapolated to the area of commercial-sized snow crab distribution in the Russian EEZ obtained by modelling the probability of spatial distribution. The commercial stock biomass of snow crab in the Russian waters of the Barents Sea is currently estimated at a median level of 400 thousand tons.

Conclusions

The snow crab commercial stock biomass dynamics has no clear trends in the Barents Sea. Last two years the area of the snow crab is not increase. Despite that, the potential for further distribution of snow crab in the Barents Sea remains rather high. The previous optimistic estimates of the commercial stock of snow crab in the Russian EEZ in the Barents Sea, resulted from ecosystem surveys, confirmed by the fishery statistics. The snow crab commercial stock in the Russian part of the Barents Sea is currently estimated of about 400 thousand tons. There are some clear evidences of rich yearclasses of the snow crab in the Barents Sea periodically appearing. It is a sign of rather stable future recruitment to the commercial stock. The level of exploitation for stable and high commercial stocks may constitute about 10–20% of the commercial biomass. Under the current condition, the biologically grounded annual TAC of snow crab in the Russian EEZ in the Barents Sea could vary from 40 to 80 thousand tons.

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Towed video module recordings – rapid, non-invasive method of assessing *Chionoecetes opilio* (Decapoda, Brachyura) population expansion in the Barents and Kara Seas

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Snow crabs, *Chionoecetes opilio*, have probably invaded waters of the Barents Sea in 1980s and Kara Sea in early 2000s [Kuzmin et al. 1998; Pavlov, 2006; Zimina, 2014; Zalota et al., in press]. Since then they have undergone rapid expansion across the north-east Barents Sea and western Kara Sea. This is a large predatory, commercially valuable species, whose population level and distribution is of interest to both fishery industry and environmentalists concerned with the health of these seas' ecosystems. Moreover, this species is highly unwelcome in marine protected areas, where it can undermine the main objective to protect local biodiversity.

Main method of snow crab expansion monitoring is performed using trawls, which is damaging to the environment and require high man power. This method is often unacceptable in marine protected areas. During the 2016 and 2017 Institute of Oceanology (IO RAS) expeditions to the Kara Sea an underwater towed video module (designed and created in the Sonar ocean bottom surveying laboratory of IO RAS) has been used to survey sea bottom in different localities of the Kara Sea. This method allows detecting presence/absence of non cryptic species and approximating their population size in a non invasive way. This method can be used to survey protected regions, such as MPA Russian Arctic (Russkaya Arktika), where constant up to date monitoring data is essential to achieve nature protection goals.

Data obtained from the 2016 and 2017 IO RAS filming shows that snow crabs' presence is still undetectable in the eastern part of the Kara Sea, Laptev and East Siberian Seas. It seems that the population has not expanded east of its margins observed in 2014 [Zalota et al. in press]. The video module has been used to select specific transects for trawling and the two methods have been combined to complement each other in population density approximation.

The research has been done with the support of the RSF grant No. 145000095.

Keywords: Barents Sea, Kara Sea, snow crab, expansion

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Interspecific competition and the abundance of Fucaceae on the Murmansk coast of the Barents Sea

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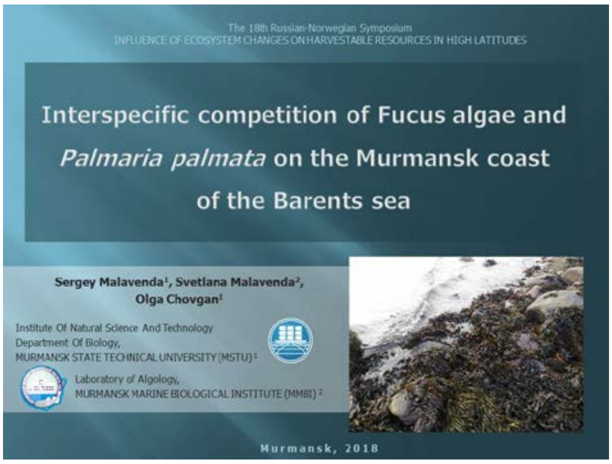
[2]Murmansk Marine Biological Institute, Murmansk, Russia

Fucus algae can be used for the pharmaceutical, cosmetics and to food. It is a perennial species, dominant at the intertidal communities on Murman and forming the essential stocks. Competition between Fucoid species the study has been ongoing for some time, but data in a polar region is extremely small, though it is under on the brink of tolerance changes in benthic communities is influenced by climatic shifts or anthropogenic disasters can be the greatest. The basis of this work was the results of experiments on the interaction of commercial species of seaweeds *Ascophyllum nodosum*, *Fucus distichus*, *Fucus serratus*, *Fucus vesiculosus* (Fucaceae, Phaeophyceae) and *Palmaria palmata* (Palmariaceae, Rhodophyta), mass species in Fucus communities. Experimental study of the growth rate when sharing content Fucus in aquariums in thermostatic conditions showed the suppression of growth of *A. nodosum*, up to necrosis of the tissues. The most stable in co-culture of fucoid was *F. distichus* and *F. vesiculosus*. *P. palmata* was an increase in the growth rate and concentration of chlorophyll a in the presence of *F. serratus* and *F. distichus*. In experiments conducted over the plants directly in the intertidal zone, removal of *P. palmata* and *F. vesiculosus* resulted in an increase in density of another species, and the biomass grown in conjunction with them to control the ranges of *F. distichus* did not change. Thus, there are significant interspecific interactions. Density analysis of the studied species in natural communities is consistent with the results obtained.

Keywords: Barents Sea, algae, Fucus, interspecific competition



The 18th Russian-Norwegian Symposium
INFLUENCE OF ECOSYSTEM CHANGES ON HARVESTABLE RESOURCES IN HIGH LATITUDES

Interspecific competition of Fucus algae and *Palmaria palmata* on the Murmansk coast of the Barents sea

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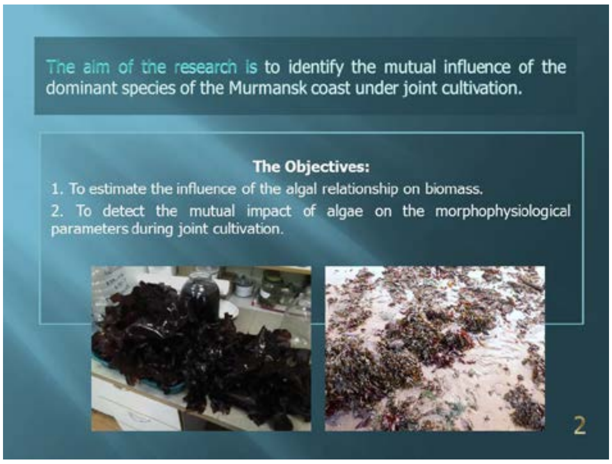
Murmansk, 2018

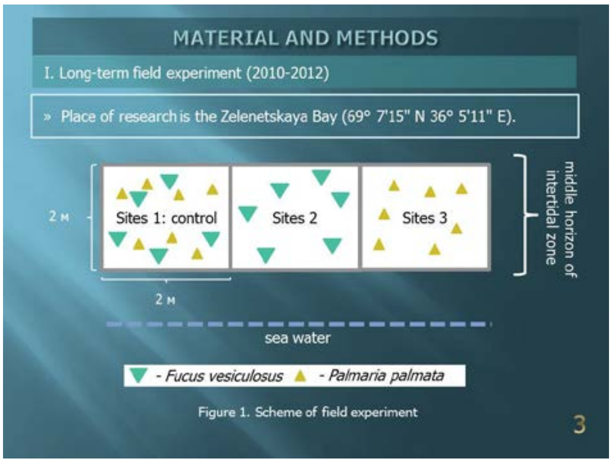


The aim of the research is to identify the mutual influence of the dominant species of the Murmansk coast under joint cultivation.

The Objectives:

1. To estimate the influence of the algal relationship on biomass.
2. To detect the mutual impact of algae on the morphophysiological parameters during joint cultivation.

2

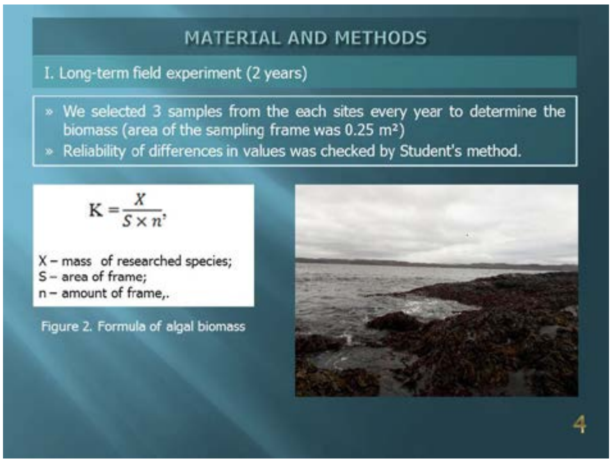


MATERIAL AND METHODS

I. Long-term field experiment (2010-2012)

- Place of research is the Zelenetskaya Bay (69° 7'15" N 36° 5'11" E).

Figure 1. Scheme of field experiment



MATERIAL AND METHODS

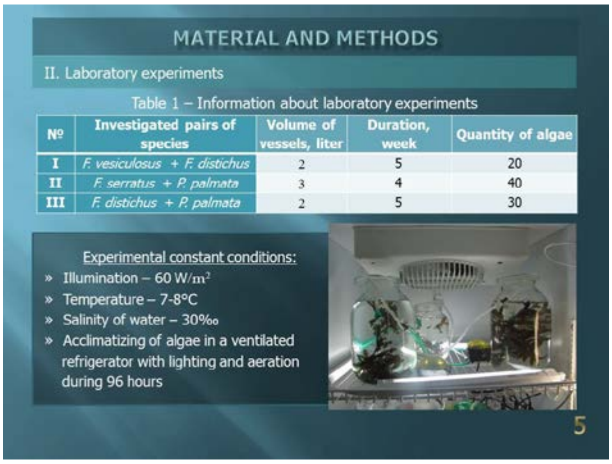
I. Long-term field experiment (2 years)

- We selected 3 samples from the each sites every year to determine the biomass (area of the sampling frame was 0.25 m²)
- Reliability of differences in values was checked by Student's method.

$$K = \frac{X}{S \times n},$$

X – mass of researched species;
S – area of frame;
n – amount of frame,.

Figure 2. Formula of algal biomass



MATERIAL AND METHODS

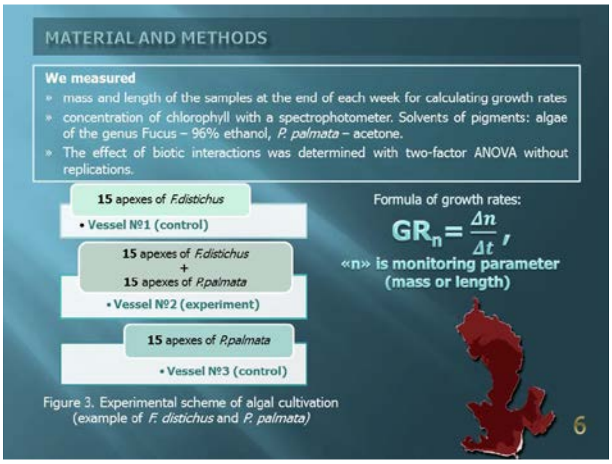
II. Laboratory experiments

Table 1 – Information about laboratory experiments

№	Investigated pairs of species	Volume of vessels, liter	Duration, week	Quantity of algae
I	*F. vesiculosus* + *F. distichus*	2	5	20
II	*F. serratus* + *P. palmata*	3	4	40
III	*F. distichus* + *P. palmata*	2	5	30

Experimental constant conditions:

- Illumination – 60 W/m²
- Temperature – 7-8°C
- Salinity of water – 30‰
- Acclimatizing of algae in a ventilated refrigerator with lighting and aeration during 96 hours



MATERIAL AND METHODS

We measured

- mass and length of the samples at the end of each week for calculating growth rates
- concentration of chlorophyll with a spectrophotometer. Solvents of pigments: algae of the genus Fucus – 96% ethanol, *P. palmata* – acetone.
- The effect of biotic interactions was determined with two-factor ANOVA without replications.

15 apexes of *F.distichus*
- Vessel №1 (control)

15 apexes of *F.distichus*
+
15 apexes of *P.palmata*
- Vessel №2 (experiment)

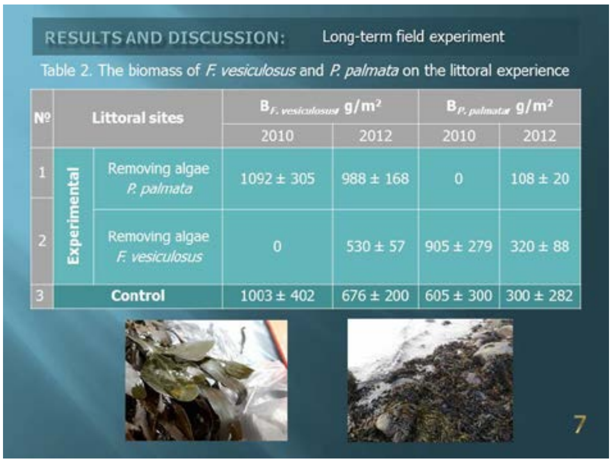
15 apexes of *P.palmata*
- Vessel №3 (control)

Figure 3. Experimental scheme of algal cultivation (example of *F. distichus* and *P. palmata*)

Formula of growth rates:

$$GR_n = \frac{\Delta n}{\Delta t},$$

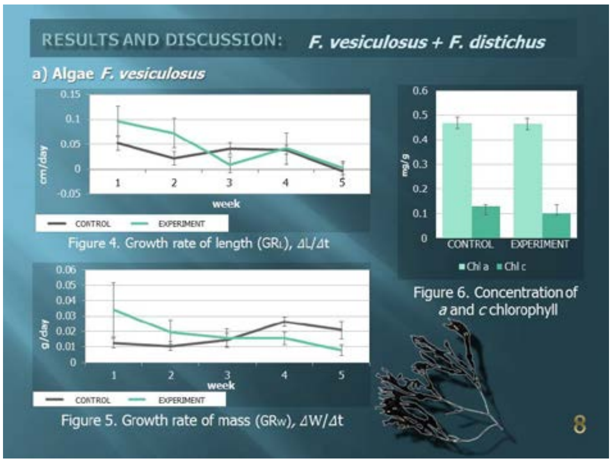
«n» is monitoring parameter (mass or length)



RESULTS AND DISCUSSION: Long-term field experiment

Table 2. The biomass of *F. vesiculosus* and *P. palmata* on the littoral experience

№	Littoral sites		$B_{F. vesiculosus}$, g/m²		$B_{P. palmata}$, g/m²	
			2010	2012	2010	2012
1	Experimental	Removing algae *P. palmata*	1092 ± 305	988 ± 168	0	108 ± 20
2		Removing algae *F. vesiculosus*	0	530 ± 57	905 ± 279	320 ± 88
3	Control		1003 ± 402	676 ± 200	605 ± 300	300 ± 282



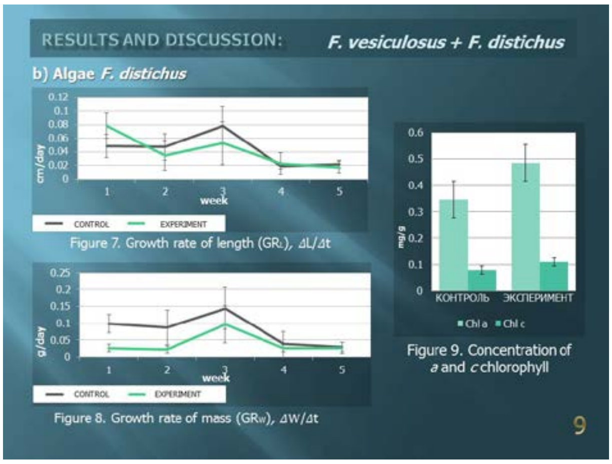
RESULTS AND DISCUSSION: *F. vesiculosus + F. distichus*

a) Algae *F. vesiculosus*

Figure 4. Growth rate of length (GR_L), ΔL/Δt

Figure 5. Growth rate of mass (GR_W), ΔW/Δt

Figure 6. Concentration of *a* and *c* chlorophyll



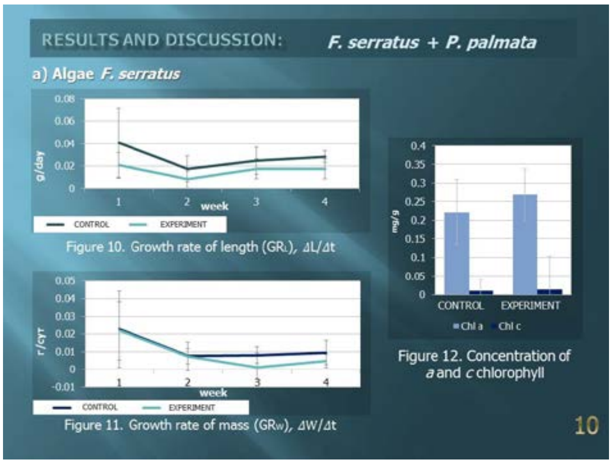
RESULTS AND DISCUSSION: *F. vesiculosus + F. distichus*

b) Algae *F. distichus*

Figure 7. Growth rate of length (GR_L), ΔL/Δt

Figure 8. Growth rate of mass (GR_W), ΔW/Δt

Figure 9. Concentration of *a* and *c* chlorophyll



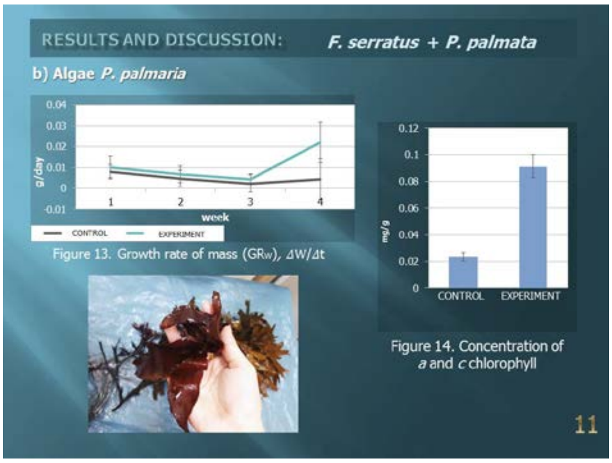
RESULTS AND DISCUSSION: *F. serratus + P. palmata*

a) Algae *F. serratus*

Figure 10. Growth rate of length (GR_L), ΔL/Δt

Figure 11. Growth rate of mass (GR_W), ΔW/Δt

Figure 12. Concentration of *a* and *c* chlorophyll

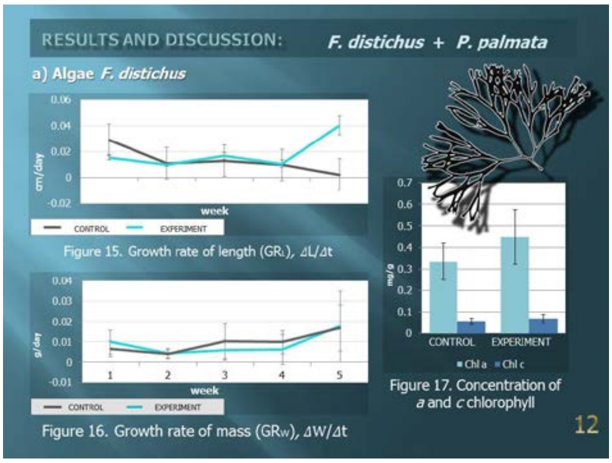


RESULTS AND DISCUSSION: *F. serratus + P. palmata*

b) Algae *P. palmaria*

Figure 13. Growth rate of mass (GRw), ΔW/Δt

Figure 14. Concentration of *a* and *c* chlorophyll



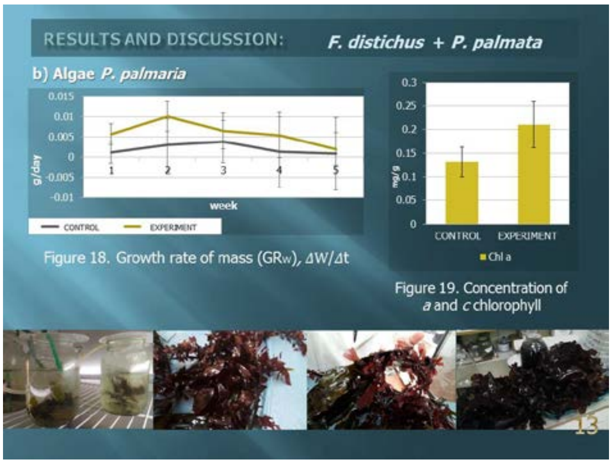
RESULTS AND DISCUSSION: *F. distichus + P. palmata*

a) Algae *F. distichus*

Figure 15. Growth rate of length (GRL), ΔL/Δt

Figure 16. Growth rate of mass (GRw), ΔW/Δt

Figure 17. Concentration of *a* and *c* chlorophyll

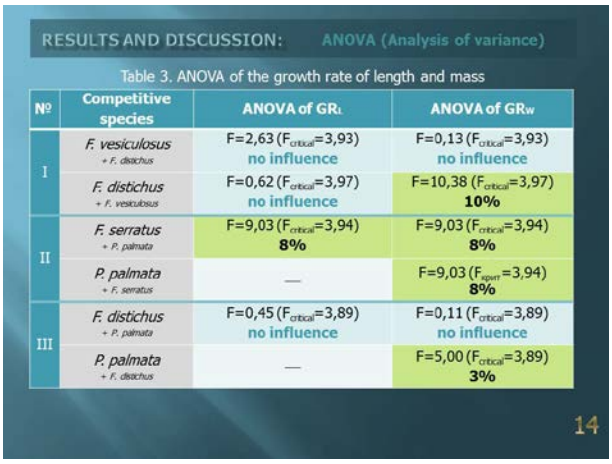


RESULTS AND DISCUSSION: *F. distichus + P. palmata*

b) Algae *P. palmaria*

Figure 18. Growth rate of mass (GRw), ΔW/Δt

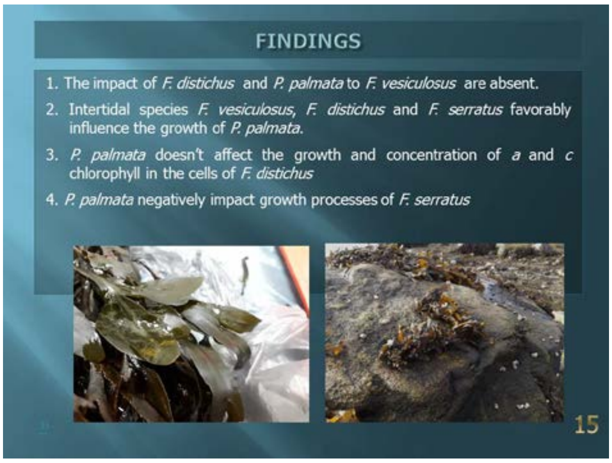
Figure 19. Concentration of *a* and *c* chlorophyll



RESULTS AND DISCUSSION: ANOVA (Analysis of variance)

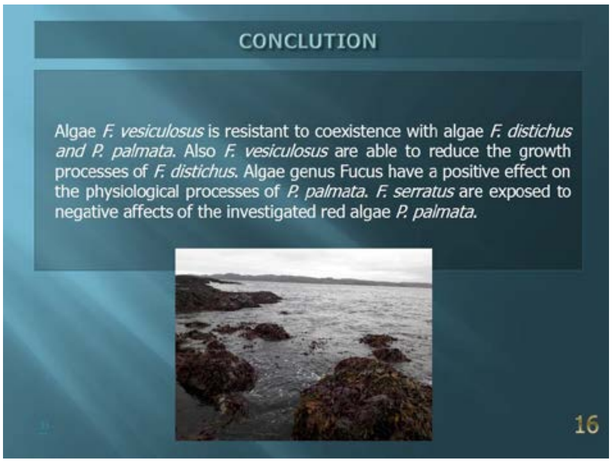
Table 3. ANOVA of the growth rate of length and mass

№	Competitive species	ANOVA of GRL	ANOVA of GRw
I	*F. vesiculosus* *+ F. distichus*	F=2,63 ($F_{critical}$=3,93) **no influence**	F=0,13 ($F_{critical}$=3,93) **no influence**
	F. distichus *+ F. vesiculosus*	F=0,62 ($F_{critical}$=3,97) **no influence**	F=10,38 ($F_{critical}$=3,97) **10%**
II	*F. serratus* *+ P. palmata*	F=9,03 ($F_{critical}$=3,94) **8%**	F=9,03 ($F_{critical}$=3,94) **8%**
	P. palmata *+ F. serratus*	—	F=9,03 ($F_{\text{крит}}$=3,94) **8%**
III	*F. distichus* *+ P. palmata*	F=0,45 ($F_{critical}$=3,89) **no influence**	F=0,11 ($F_{critical}$=3,89) **no influence**
	P. palmata *+ F. distichus*	—	F=5,00 ($F_{critical}$=3,89) **3%**



FINDINGS

1. The impact of *F. distichus* and *P. palmata* to *F. vesiculosus* are absent.
2. Intertidal species *F. vesiculosus, F. distichus* and *F. serratus* favorably influence the growth of *P. palmata*.
3. *P. palmata* doesn't affect the growth and concentration of *a* and *c* chlorophyll in the cells of *F. distichus*
4. *P. palmata* negatively impact growth processes of *F. serratus*



CONCLUTION

Algae *F. vesiculosus* is resistant to coexistence with algae *F. distichus and P. palmata*. Also *F. vesiculosus* are able to reduce the growth processes of *F. distichus*. Algae genus Fucus have a positive effect on the physiological processes of *P. palmata*. *F. serratus* are exposed to negative affects of the investigated red algae *P. palmata*.

Thank you for attention!

Stocks of kelp in Grønfjorden, Spitsbergen

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Abstract

Grønfjorden is part of system of fjords of the Western coast of the Spitsbergen. The growth and production of kelp as the basis of plant communities is of particular interest, especially in connection with climate change. Stock assessment of Laminariales of Spitsbergen was carried out by PINRO in the beginning of the century. The aim of this work was to assess the distribution and species composition of kelp in Grønfjorden. Algae was test in Grønfjorden of the island of Spitsbergen. In the period 16.06-06.07.2013 5 sublittoral sections 9-27.07.2014 -5 treated, respectively, 30 and 30 samples of macrophytes. The classical method of vertical transects was used, stations were performed at depths of 5, 10 and 15 m. Sampling in the sublittoral was completed by diving specialist. Total stocks of algae-macrophytes in the Grønfjorden is about 20 thousand tons, mainly formed by *Saccharina latissima,* less – *Laminaria digitata*. The increase in biomass and algae stocks may be associated with an increase in coastal water temperature for 25 years.

Keywords: Spitsbergen, Grønfjorden, brown kelps, stocks

Introduction

Grønfjorden is part of system of fjords of the Western coast of the Spitsbergen. The growth and production of kelp as the basis of plant communities is of particular interest, especially in connection with climate change. Stock assessment of Laminariales of the Spitsbergen was carried out by PINRO in 1987.

There is a large body of evidence on the impact of climate change on biota, including the Spitsbergen archipelago (Adey, 2008; Cheung et al., 2009; Weslawski et al., 2010, etc.). There is reason to believe that the Arctic archipelagos are most sensitive to climate change, as they are located on the border of the Arctic and Arctic-boreal zones. Data on the increase in temperature from Hornsund fjord to Is and Grønfjorden in 2003 and 2008, the increase in the flow of Atlantic waters to the Is fjord in the specified period of time, and large variations in temperature and salinity in the relatively deep-sea is fjord (Moiseev, Gromov, 2009) allow us to expect changes in biodiversity in this Bay of West Spitsbergen. Earlier in West Spitsbergen, an increase in species diversity of littoral phytocenoses was found in the southern part of the island, in the Horsund fjord and on Cape Sorkappland after a number of warm years (Weslawski et al., 2010). In general, the biota of the Spitsbergen fjords plays a role of indicator of climate change in the Arctic (Hop et al., 2012).

The aim of this work was to assess the distribution and species composition of kelp in Grønfjorden.

Material and methods

Material for research was collected in Grønfjorden of the island of Spitsbergen. In the period 16.06-06.07.2013 5 sublittoral sections 9-27.07.2014 -5 treated, respectively, 30 and 30 samples of macrophytes respectively. The classical method of vertical transects was used, stations were performed at depths of 5, 10 and 15 m. Sampling in the sublittoral was completed by diving specialist. The calculation of kelp reserves was performed by multiplying the average biomass by the area of the site with homogeneous vegetation. Average biomass was calculated as arithmetic mean with confidence interval. The area was determined in the MapViewer 8.

Results

There are five species of Laminariacea in Grønfjorden (Ochrophyta, Phaeophyceae, Laminariales).

Saccharina latissima (L.) Lane, Mayes, Druehl et Saunder 2006. Common in boulder silty-sand with individual boulders and pebbles soils.

Laminaria digitata (Hudson) Lamouroux 1813 was identified on boulder soils at the mouth of the fjord (5 m) and in the middle part on the Eastern shore (mostly 5 m and one copy at 15 m, probably demolition).

Saccorhyza dermatodea (Bachelot de la Pylaie) J. Agardh 1868:31 there are noted isolated thalli at depths of 5 m of rubbly soils in the estuary of the West Bank and in the middle part of the Eastern shore.

Laminaria solidungula J. Agardh 1868:3 single specimens at the mouth of the fjord (5 m on the West Bank and 10 and 15 m on the East) and in the middle part of the fjord on the East Bank at 10 m. Timed to the communities of *S. latissima* on boulder soils.

Alaria esculenta (L.) Greville 1830 common in boulder silty-sand with individual boulders and pebbles soils.

Kelp grows at depths of 5-15 m, except for the mouth part of the East coast (Figure 1, transect 9) where kelp observed at depths of 0-3 m. *S. latissima* biomass at an average of 3.6 kg/m². Maximum biomass of 19.3 kg/m² is at transect 4. At the top of the fjord soils at these depths with a predominance of silt and clay, which prevents the growth of macrophytes. In the sublittoral of northern part of the fjord vegetation is developed, projective cover ranges from 5 to 100%. In the mouth of the Grønfjorden macrophytes form very dense thickets, with average biomass of 32.4 kg/m².

The main stocks of macrophytes are concentrated at depths of 0-5 m. Length consider the shallows of Cape Festningen to the plot, where the slope of the bottom 40% 6.5 km, width shoals varies from 100 to 700 m, increasing towards the mouth (selected by polygon at fig.). The shoals area is approximately 2.6 km^2. Total biomass of macrophytobenthos in the shallows is about 17 900 tons.

In the top of the Grønfjorden and on littoral biomass macrofitobenthos close to zero. Determination of total biomass is difficult because of the extremely uneven and sporadic distribution of algae. Stocks in most parts of the bottom of the fjord can be taken equal to zero.

Thus, the total stocks of algae-macrophytes in Grønfjorden is about 20 thousand tons, mainly formed by *Saccharina latissima (80%),* less – by *Laminaria digitata*. Most part of stock is on the rocky shoal of west coast (18 thousand tons).

The commercial stock biomass of snow crab in the Russian waters of the Barents Sea is currently estimated at a median level of 400 thousand tons.

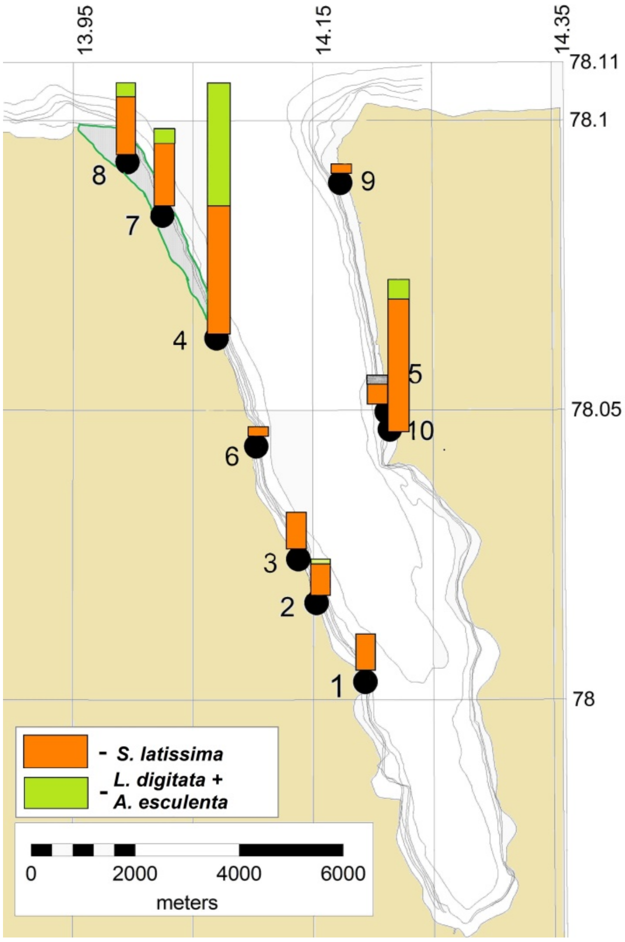

Figure 1. The biomass of algae in Grønfjorden in 2013-2014. The height of the bar indicates biomass, kg/m^2.

Discussion

Previously when determining the distribution of the biomass of algae-macrophytes in the study area, it was shown that only soils with large boulders and rock outcrops and boulder-pebble soils provide the necessary substrate for the attachment of seaweed (mostly *S. latissima*, *L. digitata* and *Desmarestia aculeata*) (Matishov et al., 2004). Boulder-pebble soils are most characteristic of the Northern part of the Gulf of Grønfjorden, and are located almost throughout it. The distribution of algae depends on the number of boulders per square meter. In the Gulf of Grønfjorden minimum quantity - 1 boulder with a diameter of 20-25 cm per 4-5 m^2, which grows a Bush 1 in 15-20 or more plants. Due to the large area of the plates with a significant wave load, such a substrate can be transferred from one place to another, rubbing algae and breaking old plants due to their greater fragility (up to 10 dying stems of older plants fall on a Bush of 20 young plants). Algae in such clusters are mainly biennial. Biomass on average - 0.5-1 kg / m^2, the number - 4-5 plants/m^2. The maximum amount of substrate on boulder-pebble soils - 4-5 boulders per square meter. In this case, there is a more uniform projective cover of the bottom with algae - 50-80 %. Basically, there are one-year-old plants *S. latissima* or *L. digitata* at the age of 6 years (the presence of a particular type of algae depends on the depth) and the largest number of plants is observed - 50-60 plats/m^2, biomass is 2.5-3 kg/m^2. In the estuary of Grønfjorden and is the largest well-defined bottom cover of vegetation peculiar only to the upper sublittoral, at depths of (0)1-23(25) m (Wozzhinskaja, 1992; Matishov et al., 2004).

PINRO explored the kelp of is-fjord in 1987. According to them in Grønfjorden, dwelt *Saccharina latissima*, *S. nigripes*, *Laminaria digitata* and *Alaria esculenta*, the average biomass in the most productive North-Western sector of the bottom was 12 kg/m (PINRO, 1988). Stocks of laminariales field was estimated at 12 thousand tons. Our data is slightly higher. The increase in biomass and algae stocks may be associated with an increase in coastal water temperature. The last decades there is a significant increase in heat inflow by the Atlantic waters to the West Spitsbergen (Pavlov et al., 2013).

Conclusions

Kelp stocks in Grønfjorden in 2013-2014 constituted up to 20 thousand tons. For the last 25 years kelp stocks increased, possibly due to climate warming.

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Functional groupings and connectivity in the Barents Sea ecosystem determined by stable isotope analysis

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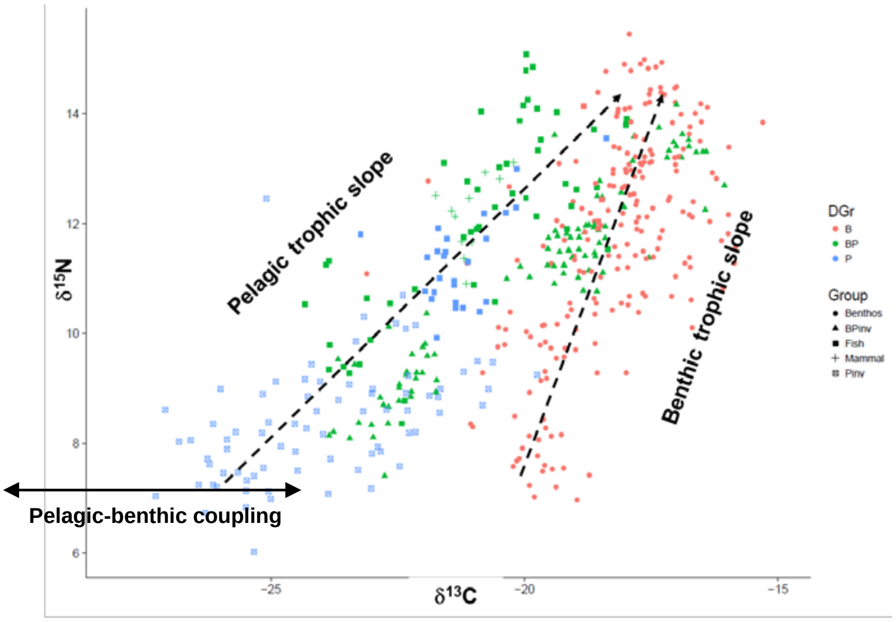
The aim of this study is to measure the strength of pelagic-benthic coupling, and to gain a more holistic understanding of the food web structure and functioning in the Barents Sea ecosystem, from the surface to the seafloor, as part of the SI_ARCTIC and TIBIA research projects at IMR. The benthic component, despite its high biomass, remains under-represented in ecosystem research, in part due to its inaccessibility and the difficulties associated with in-situ studies. To clarify the role of the benthos, we used stable isotopes of carbon and nitrogen in pelagic (P), pelagic-benthic (BP), and benthic (B) organisms (defined by feeding location), including fish, mammals, and invertebrates, to measure and compare trophic behaviour.

Animals were captured between 2014 and 2016, during the TIBIA and SI_ARCTIC cruises for the Institute of Marine Research. These cruises sampled the faunal communityfrom the epipelagic to the epibenthic at 12 Barents Sea case study locations: off the north Norwegian coast, around the polar front, and to the east, north, and west of Svalbard. Organic tissues from key species by biomass or ecological importance were analysed for ^{13}C and ^{15}N composition.

We report stable isotope data from western Barents Sea ecosystems, and within all case study sites, spanning a broad range of latitudes and oceanographic conditions. We show patterns in functional groups within the pelagic-, pelagic-benthic-, and benthic-feeding organisms, and use these to demonstrate the diversity of function in the benthos. The range of connectivity between pelagic and benthic feeding areas is discussed in relation to the main water masses in each area.

We find that benthic invertebrates and fishes occupy overlapping groups within the food web based on their functional behaviour, and should be managed together. We show how benthic organisms fit into the overall functioning of the ecosystem, and discuss the strong connectivity throughout the functional depth classes of the ecosystem.



Keywords: Barents Sea, ecosystem, functional structure, stable isotopes of ^{13}C and ^{15}N, pelagic-benthic coupling.

Vulnerability of some groups of megabenthos to bottom trawling in the Barents Sea

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Abstract

Barents Sea is the area of extremely active bottom trawl fishery. Large sessile and slow-moving edificator species are the most vulnerable to bottom trawling. According to the classification of NAFO and NEAFC, abundant population of certain species of colonial corals, sponges and some other groups of benthos refer to indicators of the VME. The paper provides information about potential indicators of VME in the Barents Sea based on analysis of the distribution of by-catches. As in North Atlantic, in the Barents Sea the most vulnerable group will be sponges. Their dense catches were observed is south-western part of the sea. However, unlike the North Atlantic, where the second largest group is coral polyps, in the Barents Sea second largest group is echinoderms, mainly represented by basket star of the genus *Gorgonocephalus*. Other groups of megabenthos are not likely to be present in commercial trawls.

Keywords: Barents Sea, bottom trawlings, vulnerable species

Introduction

Negative influence of trawl fishery on bottom ecosystems primarily consists of physical impact of fishing gear on benthic communities and of by-catching the benthic organisms. Large sessile and slow-moving edificator species are the most vulnerable to bottom trawling; sponges and corals are considered the most vulnerable to bottom trawling. In some fishery areas of North Atlantic, around continental slopes and seamounts, there are rules established to protect the bottom fauna. One of these rules is the restriction of bottom fishing in areas where the bycatch of vulnerable fauna is bigger than the allowed level. The Barents Sea is the area of extremely active bottom trawl fishery and the discussion about protecting the benthic communities from the negative impact of fishing trawling in this area is becoming stronger year to year. However, the use of experience from the North Atlantic in the Barents Sea without adapting it remains unjustified due to significant differences between fauna of the shelf and atlantic deep-sea areas. The purpose of this study is to show the groups of megabenthos most vulnerable to trawling in the Barents Sea and its adjacent waters.

Material and methods

As the material for this work, there have been used benthos samples from catches of bottom trawls made during the annual Russian-Norwegian ecosystem surveys of the Barents Sea 2005-2017. Samples were collected on the research vessels of PINRO (“Fridtjof Nansen”, “Smolensk”, “Vilnius”) and IMR (“G.O. Sars”, “Jan Mayen” (since 2011 “Helmer Hansen”), “Johan Hjort”, “Christina E”). The studies have been conducted in the period 2005-2017 covering the entire area of the Barents Sea, the northwestern part of the Kara Sea, the eastern regions of the Norwegian and Greenland Seas, as well as the adjacent parts of the Arctic Ocean (Figure 1).

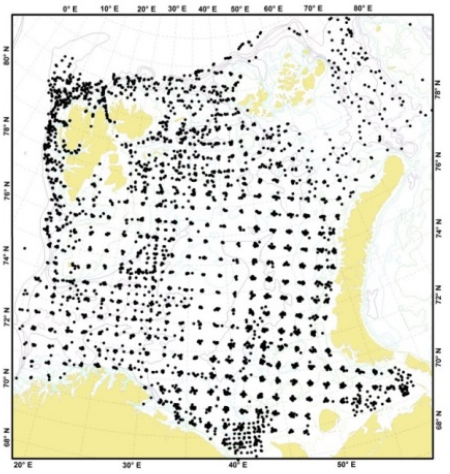


Figure 1. The location of the 4992 stations sampled during 2005-2017 by the joint Russian-Norwegian Ecosystem Survey.

The sampling equipment was a Campelen 1800 bottom trawl, rigged with 40 cm rockhopper bottom gear, towed on double warps, and standardized to a fixed sampling effort (equivalent to a towing distance of 0.75 nautical miles or 1.4 km). The horizontal opening was 15 m, and the vertical opening was 5 m. The mesh size was 22 mm in the cod end, allowing the capture and retention of vertebrates (fish and sharks) and the largest invertebrates (benthic megafauna) from the seabed. The standard trawling time was 15 minutes, the average trawling speed was 3.20±0.01 knots. Taking into account the size of the horizontal opening of the trawl and the distance covered by it, the approximate coverage was about 20-25 thousand m^2.

A total of 4992 stations were sampled during 2005-2017. The total sampled biomass of benthic megafauna was nearly 137.8 tons, encompassing over 15.9 million individuals. Some animals were identified to genus or higher taxonomic levels because their species identification was uncertain. The final list included 1058 taxa identified, including 667 species.

Due to the complexity of using the linear parameters of organisms related to different systematic groups in this work, their average mass was used as a criterion for the size of individuals.

Results and discussion

At present, information on the species and size composition of the invertebrate by-catch of the bottom trawl fisheries in the Barents Sea is practically absent. We attempted to use the calculated selectivity for the Campelen trawl to estimate the potential invertebrate by-catch in the commercial fishery. It has been assumed that the coefficient of catchability of the commercial trawls and Campelen trawl are equal, and their selectivity is proportional to the mesh size. According to investigation of P.A. Luybin (2010), selectivity of Campelen trawl with mesh size 22 mm in the cod end for megabenthos is 100 % when mass of animals equals to 1 g or more. That is, an animal with mass of 1 g or more and minimum size of 22 mm, being captured by the Campelen trawl, is 100% likely to be found in its catch.

According to the Fishery Rules, the use of net fishing gear with a mesh size of not less than 130 mm is allowed for bottom trawl fishery in the Barents Sea (Состояние…, 2018). “Square–cube law” was used to calculate the possible mass of animals that will remain 100% in trawls with mesh size 130 mm. Described in 1638 by Galileo Galilei, the law can be stated as follows: when an object undergoes a proportional increase in size, its new surface area is proportional to the square of the multiplier and its new volume is proportional to the cube of the multiplier. According to this law and assuming the preservation of the body shape and density in the ontogenesis, mass of animals that with 100 % chance will remaining in commercial trawl can be calculated using the formula:

$$M_2 = M_1\left(\frac{L_2}{L_1}\right)^3$$

where M_2 – mass of animals that with 100 % chance will remaining in commercial trawl if caught, M_1 – mass of animals that with 100 % chance will remaining in Campelen trawl if caught (1 g), L_2 – minimum mesh size of commercial trawl (130 mm), L_1 – minimum mesh size of Campelen trawl (22 mm).

Calculations using the above formula show that the possible individual mass of benthos organisms (that with 100 % chance will remain in commercial trawl) is approximately 206 g. Thus, having data on the invertebrates' by-catch by the Campelen trawl and excluding animals with an individual mass below the specified level from the analysis, we can get modelled information of the by-catch of benthic organisms during commercial trawling.

Biomass of megabentos by-catch in ecosystem surveys (Campelen trawl) formed by sponges is 45 %, by crustaceans – 25 % and by echinoderms – 23 %; the share of other groups does not exceed 7 %. If we exclude animals with average weight less than 206 g from analysis we will get another picture with by-catches. Estimated values show, that modelled by-catches for commercial trawls will be formed by sponges – 78.9 % and echinoderms – 21 % of the total biomass. (Figure 2).

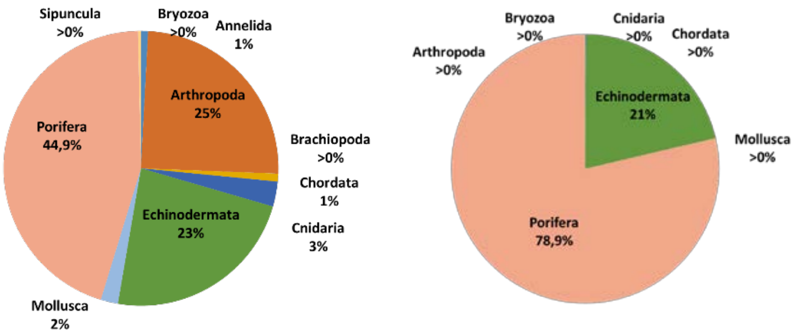


Figure 2. The biomass ratio of the main phylums in ecosystem survey and modeled ratio in commercial trawls.

As in the regions of the North Atlantic, in the Barents Sea in the modeled catches of commercial trawls, the main group of invertebrate by-catch is sponges. However, unlike the North Atlantic, where the second largest group is coral polyps, in the Barents Sea the second largest group is echinoderms, mainly represented by basket star of the genus *Gorgonocephalus*. Portion of other groups, including species of the Anthozoa, is negligible.

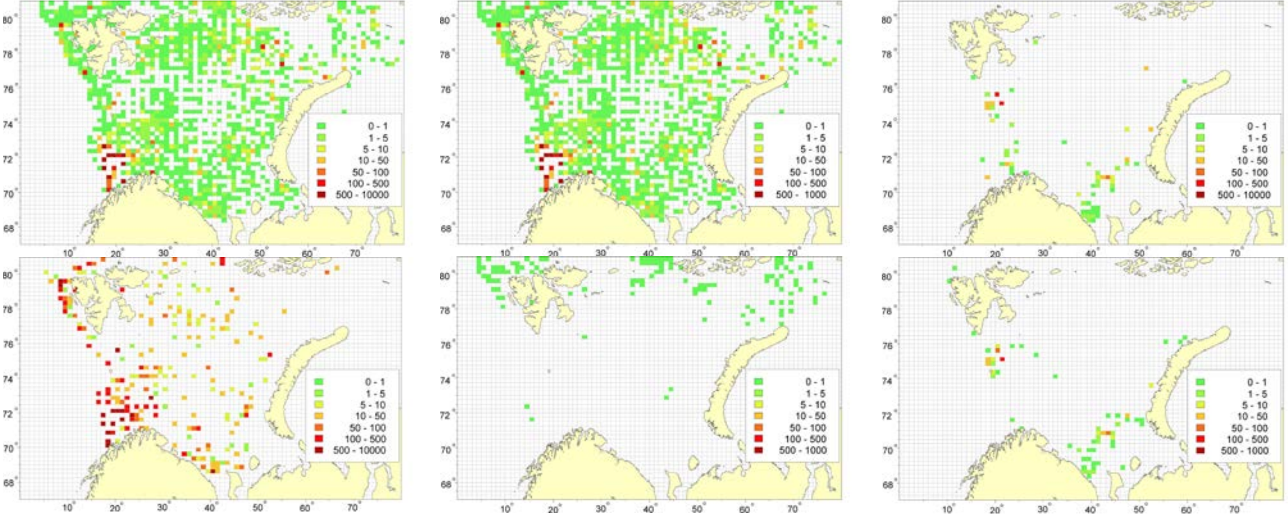
There is no single list of "vulnerable marine ecosystems" (VME) indicators. In each specific case, a set of such species should be selected in accordance with regional characteristics (FAO, 2009). Modelled data of by-catch in the commercial trawls shows that sponges and echinoderms will be the most common objects of by-catch, but some specialists think that the list of indicator species in the Barents Sea would be much bigger. Some authors include to this category all species of Porifera, corals (Pennatulacea, Alcyonacea, Scleractinia), echinoderms (Ophiuroidea, Holothuroidea (*Cucumaria frondosa, Parastichopus tremulus*), Crinoidea), Bryozoa, Chordata and *Chlamys islandica* (Bivalvia) (Detailed list of…, 2012; Vozdeystviye…, 2013; Jorgensen et al., 2015; Spiridonov, 2018).

Modelled distribution of the by-catch in commercial trawls was made for all these groups (Figure 3).

Porifera

Anthozoa (Pennatulacea, Alcyonacea, Scleractinia)

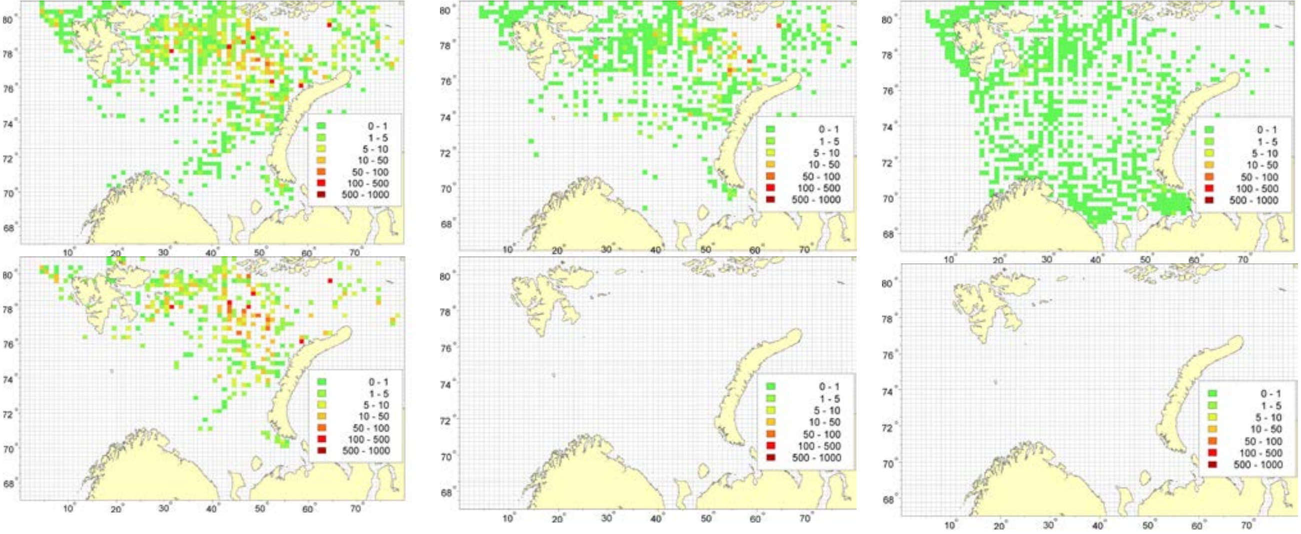
Holothuroidea (*C. frondosa*, *P. tremulus*)



Gorgonocephalus

Crinoidea

Bryozoa



Chordata

Chlamys islandica

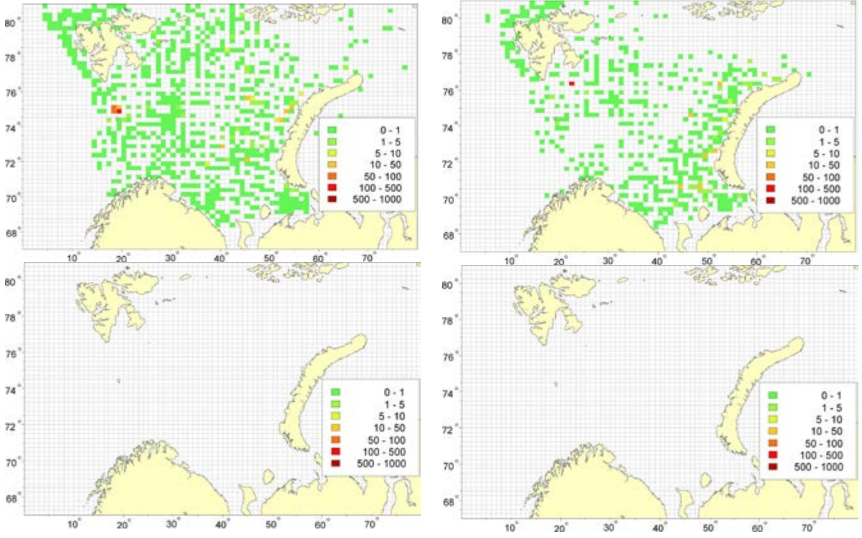


Figure 3. By-catches of the megabenthos in ecosystem survey and modelled by-catches in commercial trawls.

Modelled distribution of sponges shows that the largest by-catches of this group are supposed to distribute in southwestern part of the sea, around continental slope to the north and to the west from

Spitsbergen and in coastal waters of Kola Peninsula. Mostly it is large sized species of genus *Geodia*, family Axinellidae and other.

Large by-catches of corals will be caught by commercial trawls only in the northern part of the Barents Sea Shelf. The most common species in this area is likely to be sea pen *Umbellula encrinus*.

There are no significant differences between the by-catch of holothurians in commercial trawl and Campelen trawl. The biggest part of the population is localized on the seamounts and will rarely be encountered in the by-catches.

Modelled map of distribution of basket star of the genus *Gorgonocephalus* almost has not changed. This group of benthic organisms can be considered as the most vulnerable one for bottom trawling.

Other groups like sea lilies (Crinoidea), bryozoans (Bryozoa), ascidian (Chordata) и icelandic scallop (*Chlamys islandica*) have shown the total absence of by-catches in the modelled catches of commercial trawls. Results for these groups should be interpreted very carefully, because sessile and slow-moving species are also destroyed from the traumatic effect of the parts of trawl like rockhopper or cod end.

Conclusions

Ecosystem surveys provide a complete picture of the distribution of vulnerable habitats. Information about by-caches from fishery vessels will be very useful in investigation of distribution of vulnerable biotopes. It is necessary to collect information about megabenthos bycatch on fishery vessels and compare it with the data from ecosystem surveys. As in North Atlantic, in the Barents Sea the most vulnerable group will be sponges. Their dense catches were observed is south-western part of the sea. However, unlike the North Atlantic, where the second largest group is coral polyps, in the Barents Sea second largest group is echinoderms, mainly represented by basket star of the genus Gorgonocephalus. Other groups of megabenthos are not likely to be present in commercial trawls.

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Changes in the fauna of the Barents Sea Hydrozoa in the course of 1899–2017

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Abstract

The Barents Sea has a rich fauna of Hydrozoa, which undergoes constant changes in its composition, largely due to the influence of the warm waters of the Atlantic. Comparing the state of the fauna over the years, we can say the processes occurred in the Barents Sea over a long period of time. Recent decades, have witnessed the maximum species diversity and activity (the presence of gonothecs) of warm-water species which indicates the increase in the influence of warm waters on the Barents Sea. Such a marked influence was last observed about 100 years ago.

Keywords: Fauna of Hydrozoa, warm-water Atlantic flow, Barents Sea, fauna change

Introduction

Nothing happens in nature unchanged. The fauna of the hydroponics of the Barents Sea is no exception, as it constantly undergoes transformation. Some species replace others, changes occur within species. Part of this is due to real changes in the environment and within the group, and part to changes in the interests of researchers in their area of research. In recent years, interest in the study of the Barents Sea has increased again, which, in turn has affected the results of the studies themselves. We learn more and more and look back, trying to analyze what has happened earlier, what is happening now and estimate what will happen in the future. hydropolypes are a very convenient object for this sort of analysis, since they lead an attached life after pelagic larval settlement, and many other groups are associated with this group at different stages of their life cycles.

It is well known that the Barents Sea has the greatest faunal diversity of Eurasian arctic seas. Studies of the biology of the Barents Sea began towards the end of the nineteenth century. Although it is the most thoroughly studied water area of the Arctic, every new study adds to the list of species inhabiting its depths. In this study, we have used the data from the polypoid stages of Hydrozoa.

As long a century ago, the penetration of Arctic species into the area of eastern Murman and even into the waters of the Kola Bay was noted (Deryugin, 1915, 1925). Deryugin linked their appearance with the weakening influence of the warm waters of the Atlantic. He believed that the Barents Sea fauna, which (unlike the other Arctic seas of Russia) has in its composition both cold-water species of animals and elements of the warm-water fauna, which reflects its hydrological state by its movements. He demonstrated the cyclicity of the intensification and weakening of the action of the Atlantic waters in the Barents Sea, and described the penetration of warm-water species of some groups of invertebrates (in the years of the most intensive influence of warm waters) far to the east beyond the Kola meridian, while the appearance of cold-water Arctic species in the south of the Barents Sea can be explained by a retreat to the west of the current, which carries warm water masses.

Material and methods

We collected our material in areas covering almost the all the waters of the Barents Sea (Figure 1), and partly entering (in some areas) the waters of the Norwegian and Greenland Seas and the Arctic Ocean. The materials were obtained the expeditions of the Polar Scientific Research Institute of

Marine Fisheries and Oceanography (PINRO), 2003-2008 (including the contributions of the Norwegian research vessel "G.O. Sars"), 2017, available materials from the collection of the Zoological Institute of the Russian Academy of Sciences (ZIN RAS) of various charges for the period 1861-2017 and the collections of the Institute of Marine Research (IMR, Norway) 2010, 2014 and 2015. PINRO expeditions used the vessels "Romuald Muklevich", "Smolensk", "Vilnius" and "Fridtjof Nansen". IMR expeditions used material collected by the author during her participation in ecosystem cruises on "Helmer Hansen" (formerly known as "Jan Mayen") and "Johan Hjort".

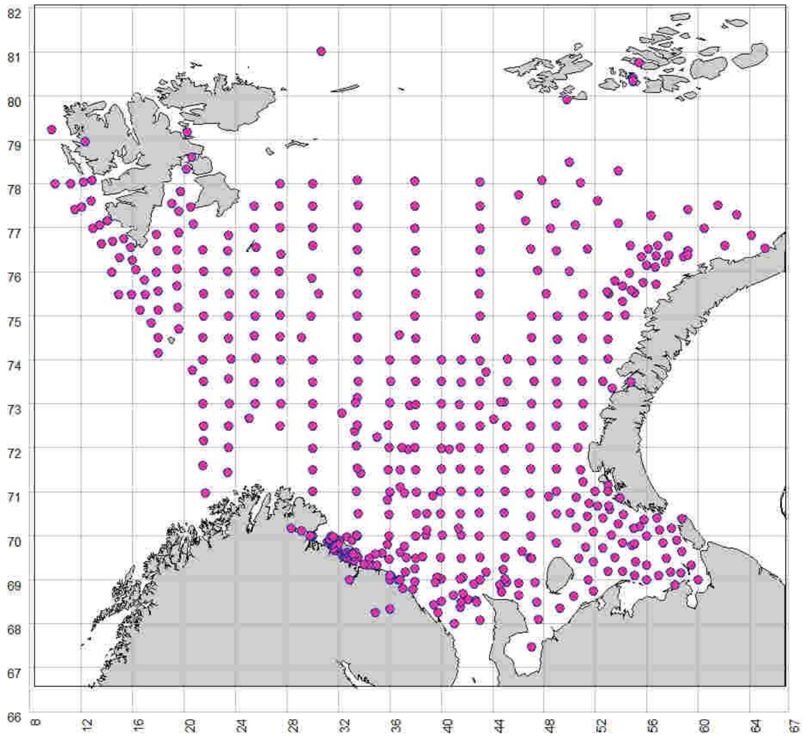

Figure 1. Area of research.

Five hundred and eight samples of Hydrozoa were processed, of which 169 were collected by the Sigsbee middle trawl with a frame size of 1x0.35 m and an inner shirt with a mesh size of of a 10 mm. The lowest part of the inner shirt was lined with a woven insert with a mesh size of 5 mm. Trawl catches were flushed out on a special washing table through a system of two metal screens with mesh sizes of 10 mm and 3 mm.

Material from the by catch of bottom ichthyological trawls of the Campelen type, with a mesh size of 135 mm was also analyzed. Of these catches, 54 samples were used. In total, 2,173 items of the above collections were analyzed.

From the collections of the Zoological Institute of the Russian Academy of Science, 2609 items from expeditions were analyzed: Danilevsky's collections (1861); collections Merezhkovsky (1876, 1877); The Murmansk expeditions of S. Gertsenstein (1880, 1887, 1898–1900); the collections of N.M. Knipovich "Ermak", "Rider" (1891, 1893, 1894, 1895, 1901, 1908); ENPIM "Pomor" (1898), RV "Andrew Pervozvanny", "Fisherman" (1899-1907); "Pakhtusov" (1902, 1909, 1913); expedition PMNI "Malygin", "Murman" (1898, 1921–1928); Russian polar expedition (1900–1903); "Alexander Kovalevsky" (1908–1909); The Kara expedition "Taimyr" (1921); Perseus (1923); Expedition to the Novaya Zemlya "Dolphin", "Zarnitsa", "Elding" (1924, 1925, 1927, 1929, 1935); "Sedov" (1925, 1929, 1930); PINRO – 1935; Sadko (1935, 1936); MBS (1936, 1949, 1950); "Deryugin" (1953); MBI (1967); expeditions of ZIN (1970, 1976, 1981, 1982, 1983); "Polarstern" (1991, 1996, 1998); RV "Dalnye Zelentsy" (1990, 1993); expedition of the Norwegian Polar

Institute (1996, 1998); collections N.N. Panteleeva (1999, 2000); Norwegian expedition on the vessel “Ivan Petrov” (1999, 2003).

The drawings were made using an RA-4 drawing machine. The photos were obtained by the Canon Power Shot A70 camera and MBS-9 binoculars, and a Top Cam 5.0 camera and LOMO binoculars.

In the taxonomic analysis of hydroid polyps, the taxonomic system for Hydrozoa, proposed by Bouillon (1985), was used.

MapViewer7 was used to build the maps. Excel 2013 was used to generate charts and graphs.

Results and discussion

With the materials of expeditions from different years, we were able to compile lists of the species found in each of the expeditions. Comparing the composition of species of hydroid polyps in these expeditions showed that some species were collected on almost every expedition, while others were rarely detected. This is understandable. It is well known, that there are species that adapt to environmental changes, and have a fairly wide range of tolerance to various factors, while there are other for which the slightest deviation from their normal habitat conditions is intolerable, and the species cannot survive locally. Another role is played by the morphology of the animal. Species with a strong exoskeleton are easier to detect during collection than those without one.

Studies did not take place evenly (there is no constant grid of stations) and contributions from a given sampling station from year to year were also irregular, so there is no point in considering each year of research. But considering the various combined periods it turned out that the change in the number of species encountered since the beginning of research expeditions until our days, if we combine the time periods of eight years, is rather obvious. (Figure 2).

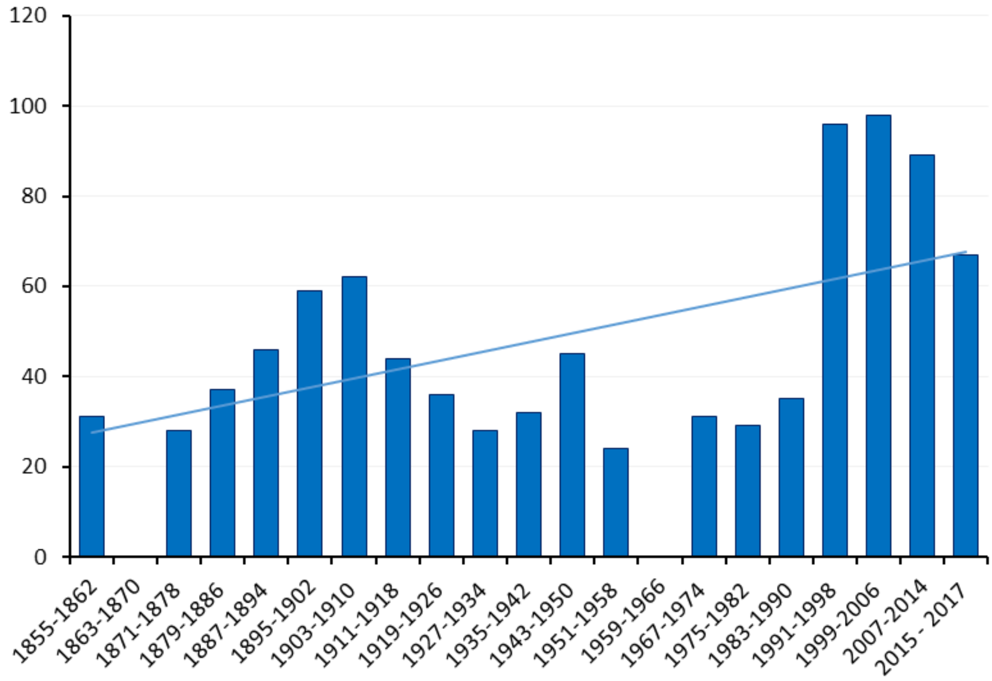

Figure 2. The Number of species of Hydrozoa found in the Barents Sea in different time periods.

The histogram shows the number of species noted in each eight-year time period since the beginning of studies of the the Barents Sea. Since 1898, extensive material on the entire sea has been collected, apart from 1959-1966, when I was unable to find data on hydropolypes in the area under study. Materials from earlier years (until 1898) are very limited, although they make it possible to compile a certain picture of the state of fauna for those periods. The number of species detected during each period never exceeded 100, and the total list of species currently includes123 species. Each period included three to four expeditions. The maximum of Hydrozoan species in the Barents Sea we can see with the range almost at 100 years.

It must be taken into account that at the very beginning of scientific interest in the Barents Sea, the taxonomic system was different from the current model, and it developed over time as new material was received and new species were described. These processes are inextricably linked. As the number of expeditions increased, so did the amount of collected material and the number of sites studied. Meanwhile, new species were described and many old species synonyms were reduced to a smaller number of more recent synonyms. It is difficult to cover all the internal changes in the study of the Hydrozoa group within one publication, but if we examine the fauna classification that existed in each of the study periods, it is obvious that regardless of the number of species detected in each period (Figure 2) the total number of species of hydropolyps in the Barents Sea gradually increased (Figure 3).This is not surprising, as the conditions of existence in the Barents Sea allow us to find our place for life to species representing various biogeographical groups. The lower species diversity factor for the last three years is associated with the changes in systematic standing of some Hydrozoa species.

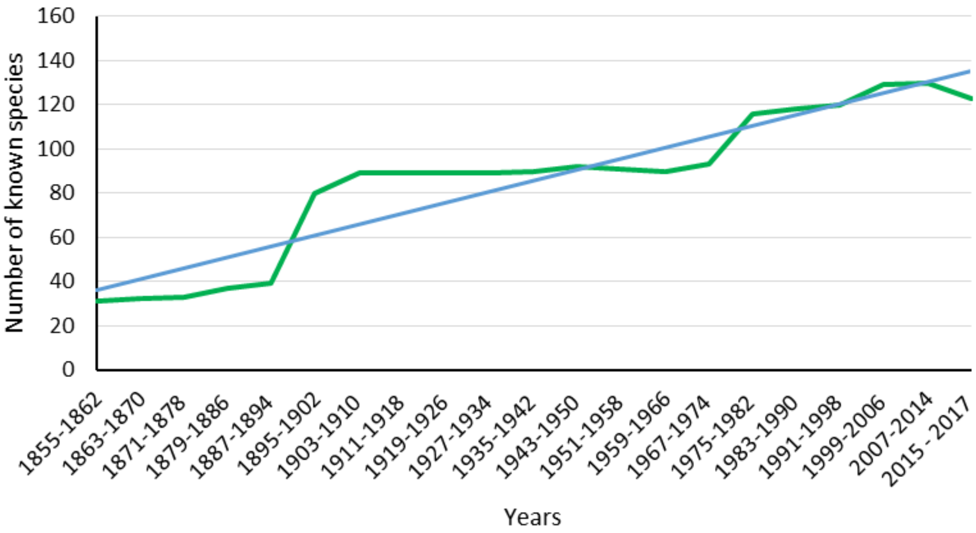

Figure 3. The extent of studies of the hydropolyps of the Barents Sea in 1855–2017.

To the system of biogeographical regionalization proposed in 2004 (ed. by Sirenko, 2004), extends to 19 biogeographical groups: arctic circumpolar (4 species), arctic (1), arctic Eurasian (3), endemic (3), widespread boreal-arctic circumpolar (20), widespread boreal (1), highly boreal arctic (1), highly boreal-arctic circumpolar (13), Atlantic widely distributed boreal-arctic (7), Atlantic high-boreal-arctic circumpolar (3), Atlantic widespread boreal (6), Atlantic high-boreal (9), amphiboreal (22), Pacific high-boreal (1), East Atlantic widespread boreal (1), subtropical-arctic (12), Atlantic subtropical-boreal (2 species), Atlantic tropical widespread boreal (1) panoceanic (13 species). Such a wide variety of biogeographical groups is another confirmation of the uniqueness of the area as a research ground. The origin of species represented in the Barents Sea is different. There are species of supposedly Atlantic and Pacific origin, warm water and cold water, rare and endemic, and, widespread. Examination of each of the above groups separately is not very convenient for perception, therefore, using the already mentioned system of biogeographical zoning (ed. by Sirenko, 2004), it is more useful to combine them into composite groups of higher ranks (Figure 4).

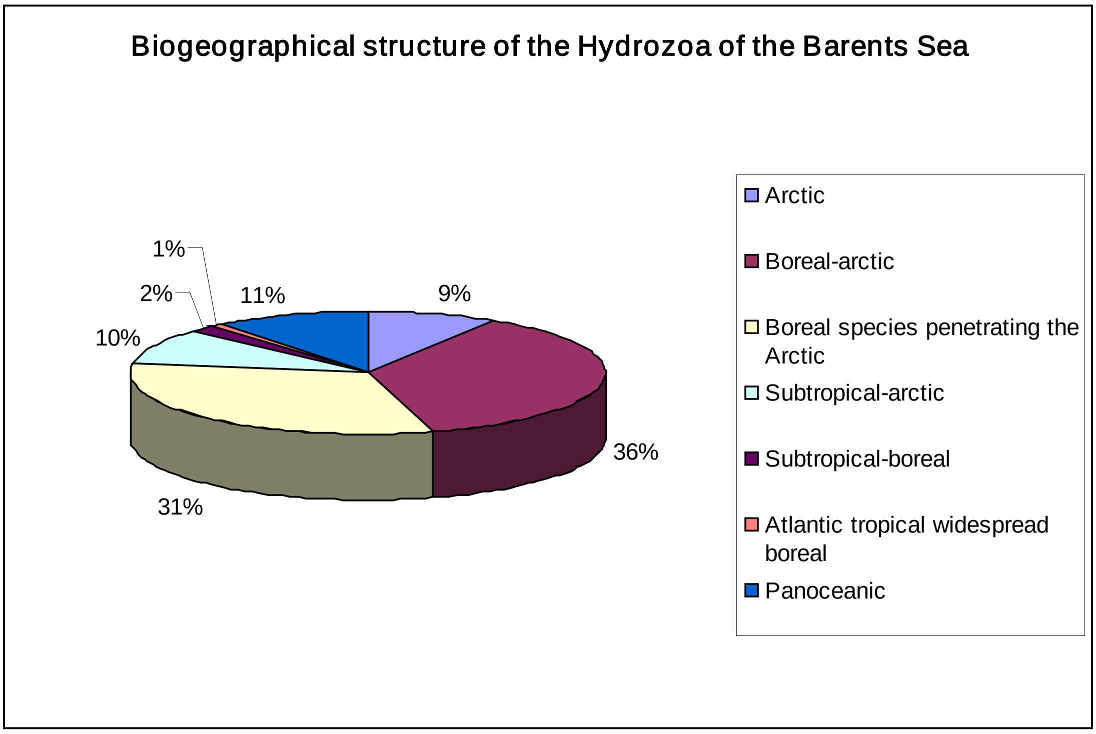

Figure 4. Simplified biogeographical structure of the Hydrozoa of the Barents Sea.

This division enables us to see the fauna structure more clearly. It is based on boreal arctic species and boreal species entering the Arctic, which together make up 67% of the total number of species recorded in the study area. Most of the species in this group are concentrated in the southern and southwestern parts of the Barents Sea, and only five species penetrate to the northern part of the area. Representatives of these two groups invariably form the basis of the fauna recorded in all the periods of research. The biogeographical structure of hydropolyps described above was compiled for all available collections from the region, which means that it is an artificial, generalized model of the structure. An analysis of the literature on the area (Ronowicz, Schuchert, 2007, Sars, 1874 and other), available in the collection of the Zoological Institute of the Russian Academy of Sciences material and its own collections, showed that the structure undergoes some changes from time to time. They occur not evenly throughout the entire water area, since they are related, for the most part, to changes in the influence of warm Atlantic waters, which have a certain regularity. In cold periods, some of the warm-water species apparently pass to a state of rest, awaiting better conditions for life, while species that can tolerate lower water temperatures continue to occupy biotopes that would threaten less resistant species. During periods of increasing influence of the warm waters of the Atlantic, larvae of more warmth-tolerant occupy these waters, and the fauna gradually changes again. The gradual shift is explained by the fact that the hydropolyps lead an attached way of life and can not change their habitat when they do not enjoy a favorable temperature regime. The periods marked by the discovery of a large number of species appear to be those of fauna change, which are the consequences of the hydrological changes. And the dependence of the number of species recorded on water temperature is well documented (Figure 5).

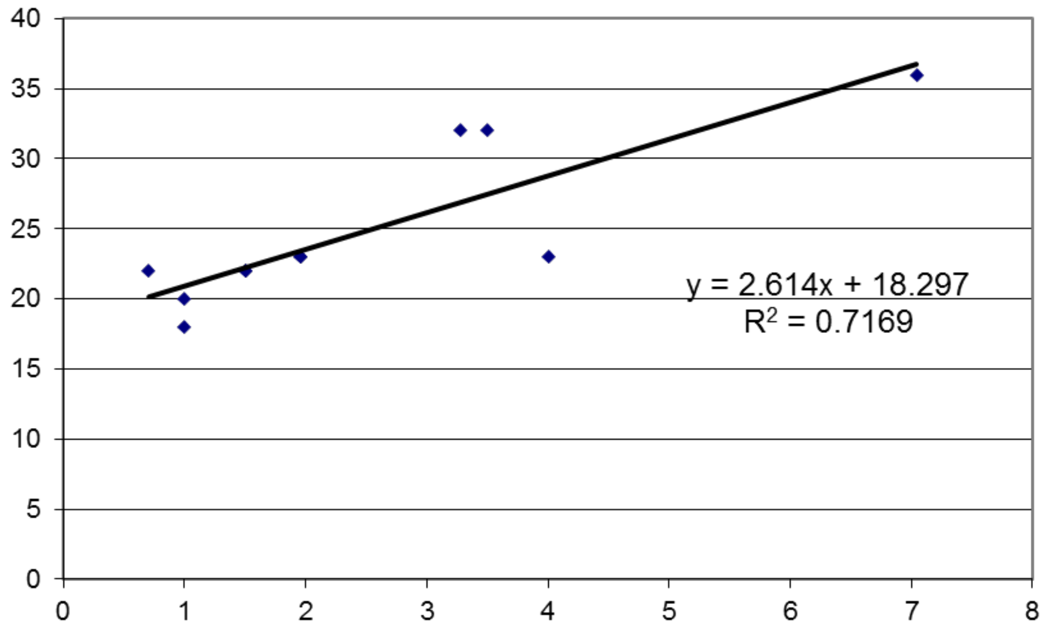

Figure 5. Simplified biogeographical structure of the Hydrozoa of the Barents Sea.

It is most convenient to focus on warm-water species, which in unfavorable cold years do not have gonothecs. Therefore, if a representative of a warm water species with gonotecs is found in the collections, then the conditions of existence for that species are favorable. In the period from 1861 to 1902, representatives of the Atlantic boreal fauna in the fertile state were recorded as far as 35 degrees east longitude. In subsequent years, these groups are represented by small and usually non-fertile specimens. The next advance to the east of representatives of these groups occurred between 1936 and 1953. Thereafter, until 1996 there were virtually no changes in the distribution of boreal groups, although there were few fertile colonies, while in the collections from 2003-2006, fertile colonies of representatives of these groups are no longer a rarity, and some types of groups penetrate far to the east. Such oscillations in the movements of more warm-water species are probably associated with changes in the water temperature during different periods.

Over the past 150 years, the influence of the warm current seems to have been the strongest, which affects the life and distribution of the warm-water species of Hydrozoa. Incomplete extinctions of many of these species in colder years are associated with their typically attached lifestyle and the presence of a chitinous outer skeleton, which researchers observe even in years when the colony is experiencing difficulties. Now it is not surprising that the Bonnevie described in 1898 *Gymnogonos crassicornis* (Figure 6) (lacking dense formations: perisark and tecs) disappeared from samples for more than 100 years but suddenly turned up in two Barents Sea expeditions in 2003 at about 40 and 50 degrees East (Stepanjants & Svoboda, 2001).

Ronowicz and Schuchert (2007) described a new species of the genus Halecium (*Halecium arcticum*) from the southeast of the Spitsbergen archipelago, which I encountered near southwestern Greenland, indicating that it belongs to the western boreal-arctic group species and does not exclude the penetration of this species from the west with the waters of the Atlantic.

In 2017 two more species: *Neoturris abyssi* (G.O.Sars, 1874) and *Eutonina indicans* (Romanes, 1876) hydropolyps were discovered in the Pechora Sea (Figure 7). The latter was had never previously been recorded in the Barents Sea.

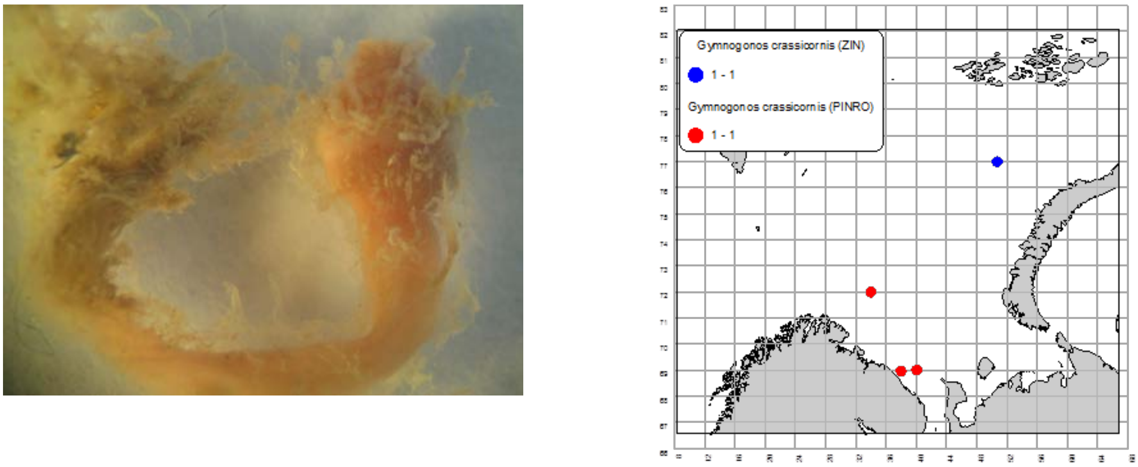

Figure 6. *Gymnogognos crassicornis* Bonnevie, 1898 (left) and location of the findings in 2003 (right).

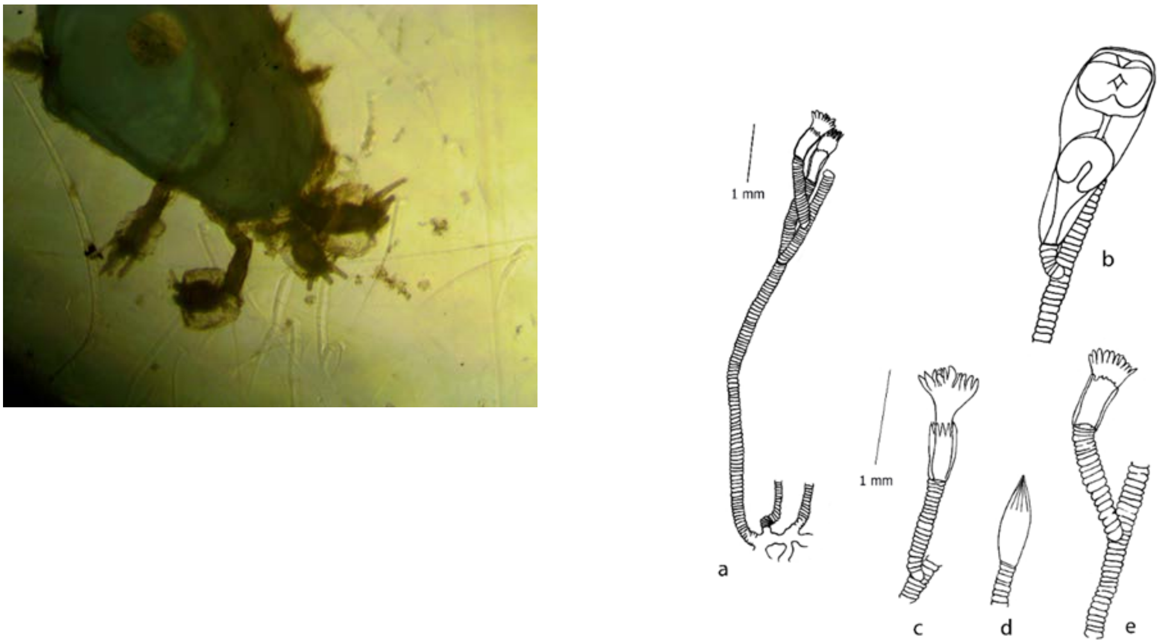

Figure 7. *Neoturris abyssi (*G.O.Sars, 1874)(left) and *Eutonina indicans* (Romanes, 1876 (right).

Conclusions

The biogeographic species structure of the Hydrozoa of the Barents Sea is fairly stable throughout the entire period of the survey. In spite of this, the faunistic composition of the hydropolyps of the Barents Sea is constantly changing, a phenomenon that is associated with changes in the temperature of the water, which in turn is directly dependent on the influence of the warm-water Nordkapp current. In recent years, elements of the warm-water fauna have penetrated to the eastern part of the sea, something that had not happened for more than 100 years, and which may be a consequence of the stronger influence of the Nordkapp current in recent years. This is evidenced by the great species diversity that occurs during the periods, when a change in the distribution of some hydopolyps takes place. The presence of two periods with great faunal diversity indicates a certain regularity of the processes that occur, with a repetition interval of about 100 years. In the future, then the process of reducing the number of species noted in collections due to the retreat of warm waters will probably soon begin again, the result of a deterioration in the life conditions of warm-water species. However, the appearance of new species in the area we studied is also possible since, in spite of the high level of interest in the Barents Sea, its Hydrozoan fauna is still not fully understood.

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Growth of *Stegophiura nodosa* (Lütken, 1854) in the Pechora Sea

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This publication presents the results of growth rate and lifespan evaluations for the Arctic brittle stars *Stegophiura nodosa* (Lütken, 1855) from the Pechora Sea (the south-eastern part of the Barents Sea).

The material was collected during the summer expedition in the Pechora Sea (August, 2017). 228 specimens of *S. nodosa* were collected on the station near the Vaigach Island, of which 53 specimens with different disk sizes were selected for growth analysis. The individual age of brittle stars was determined by counting of growth marks on the animal's ossicle by the method developed and described in detail by several researchers (Gage, 1990a; Gage, 1990b; Dahm, 1993; Dahm, 1999; Dahm and Brey, 1998). Each visible ring was considered as an annual growth mark. The Gompertz equation was applied as the basic mathematical model describing the growth.

The Gompertz equation was applied in the following form: $\boldsymbol{R_t = R_\infty \cdot e^{ln(R_0/R_\infty)\cdot e^{-gt}}}$, where $\boldsymbol{R_t}$ is the distance (μ) from the center of the arm (vertebral ossicle) to the age mark (ring) at a particular time t (years), $\boldsymbol{R_o}$ – radius of the vertebral ossicle at $\boldsymbol{t = 0}$, $\boldsymbol{R_\infty}$ – theoretical maximum radius of vertebral ossicle, $\boldsymbol{g}$ – speed of exponential deceleration of the specific growth rate.

All the equation parameters were found by analyzing the recurrent regression of $\boldsymbol{ln(R_{t+1})}$ on $\boldsymbol{ln(R_t)}$ by analogy with the Ford-Walford method (Sparre and Venema, 1998). The final value of $\boldsymbol{R_0}$ was optimized by the target function in Microsoft Excel using the SOLVER.XLAM add-in.

The theoretical maximum radius of vertebral ossicle ($\boldsymbol{R_\infty}$) averaged 318±17.92 μ, the exponential deceleration of the specific growth rate ($\boldsymbol{g}$) was 0.46±0.023. The parameters of the Gompertz equation for group growth, found from the general recurrent regression, were as follows: $\boldsymbol{R_\infty}$ = 395±7.89 μ, $\boldsymbol{g}$ = 0.32±0.012.

The number of visible growth rings in the studied sample ranged from 3 to 10, with averaged 6.

The maximum lifespan expectation was calculated from the minimum value of the second derivative for the found growth equations (Gompertz equation were used), in accordance with the proposal of A. Alimov and T. Kazantseva (Alimov and Kazantseva, 2004).

The calculations were performed using the parameters $\boldsymbol{R_\infty}$ and $\boldsymbol{g}$ averaged for the studied sample and separately for the values of the parameters calculated for the group growth. At the result of analysis, it was found that the individuals in the studied population of *S. nodosa* from the Pechora Sea can live up to 9-12 years, which almost completely coincides with the data of similar studies made for representatives of this genus Stegophiura from the Pacific Ocean (Quiroga and Sellanes, 2009) and other species of ophiuroids from the North Atlantic and the Antarctic (Gage, 1990a; Gage, 1990b; Dahm, 1993; Dahm and Brey, 1998; Dahm, 1999), as well as with the results of growth study for the Arctic species *Ophiura sarsii* (Anisimova, 2000).

Keywords: growth analysis, vertebral ossicle, growth marks, individual growth, group growth, lifespan

Distribution of bivalves in the Barents Sea in the different environmental conditions

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Abstract

This research presents data on the distribution of key species of bivalves in the cold and warm periods in the Barents Sea. The analysis of the available data on water temperature, depth and biomass of mollusks was conducted to reveal the relationships between the distribution and the environment parameters. The estimation of varieties of species reactions under climate changes for key species of bivalve mollusks is given.

Keywords: Barents Sea, bivalves, environment, climate changes

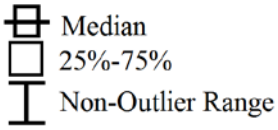
Introduction

In the modern period of climatic changes, especially well visible in the Arctic, attempts are being made to predict the distribution of species under different scenarios of temperature fluctuations. As a source for modeling probable species distribution, it is necessary to have a sufficient amount of data based on a long-term observation series. PINRO hydrobiological studies, started as early as the 20s of the 20th century, can provide a large amount of data of the distribution of specific species for various environmental factors. Previous studies have shown that total biomass of benthos has lower values during cold periods and higher values during warm periods (Manushin et al., 2013). However, changes in the biomass of individual taxa may differ from this pattern.

Material and methods

The biomass data of bivalve mollusks from bottom grab samples from 1924 to 2017 were used. For this period, four climatic periods were noted in the Barents Sea (Boytsov, 2012; Trofimov, Karsakov, Ivshin, 2018): cold (I) started before 1900 and ended in 1929 (benthic samples were taken of 1924-1929) warm (II) - 1930-1961 (samples of 1930-1935, 1937, 1939, 1945, 1947-1950 and 1955-1956), cold (III) - 1962-1987 (samples of 1968-1972, 1975, 1976, 1978) and continuing warm (IV) - from 1988 (samples of 2003-2017) (Table 1). Ecological characteristics at any periods were considered for 15 species of bivalve mollusks: *Astarte elliptica, Bathyarca glacialis, Bathyarca pectunculoides, Chlamys islandica, Ciliatocardium ciliatum, Crenella decussate, Macoma calcarea, Mya truncata, Nuculana pernula, Serripes groenlandicus, Similipecten greenlandicus, Yoldia hyperborea, Yoldiella intermedia, Yoldiella lenticula, Yoldiella lucida*. These species could be reliably determined and frequently occurred in the Barents Sea.

The “Statistica 10” software package was used to visualize the ranges of the ecological characteristics of bivalves, where:



And also to calculate the average values:

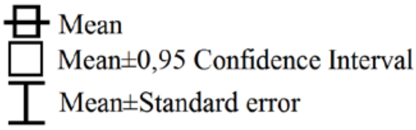


Table 1. Number of measurements of the near bottom temperature (T), habitat depth (D) and biomass (B) of mollusks in 4 climatic periods.

Periods	I			II			III			IV		
Parameter	T	D	B	T	D	B	T	D	B	T	D	B
Astarte elliptica	7	12	12	19	66	67	16	18	18	19	29	29
Bathyarca glacialis	43	55	55	25	75	76	41	42	42	238	268	268
Bathyarca pectunculoides	12	13	13	11	48	48	15	16	16	38	48	48
Chlamys islandica	5	7	7	14	61	62	9	11	12	23	34	34
Ciliatocardium ciliatum	41	72	72	14	60	59	68	69	69	107	136	135
Crenella decussata	42	67	67	14	61	61	14	15	15	113	154	154
Macoma calcarea	79	131	131	52	200	207	111	113	113	243	316	236
Mya truncata	27	42	42	23	48	48	17	17	17	33	46	46
Nuculana pernula	92	146	146	43	177	182	88	90	90	202	243	243
Serripes groenlandicus	24	36	35	2	14	14	21	21	21	36	48	48
Similipecten greenlandicus	24	33	33	12	49	49	6	6	6	249	313	184
Yoldia hyperborea	37	58	58	5	34	36	56	58	58	54	80	80
Yoldiella intermedia	76	103	103	65	181	187	41	43	43	259	320	201
Yoldiella lenticula	232	341	76	191	749	144	346	368	47	476	591	302
Yoldiella lucida	29	38	38	20	137	140	10	11	11	140	181	181
Total:	**232**	**341**	**341**	**191**	**749**	**771**	**346**	**368**	**369**	**528**	**591**	**591**
Total stations:	**341**			**771**			**369**			**591**		

At different periods, the station positions differed significantly, therefore, for comparison, the average values of macrozoobenthos biomass in the water area under consideration were calculated in two ways:

1 – The average biomass was calculated from actual station data (341 stations for the period 1924-1929, 771 stations for 1930-1950, 369 stations for 1968-1970, and 591 stations for 2003-2017; stations were taken into account located only on the studied area with accounting).

2 – The average biomass was calculated using an interpolation method: the station data was converted into the metadata of the regular grid nodes (100x100) using the “Inverse Distance to Power” method (98 stations over the period 1924-1929, 234 stations over 1930-1950, 141 stations per 1968-1970 and 218 stations from 2003-2017; in this case, for greater accuracy, the influence of stations located not only on the studied water area, but also near its borders was taken into account using the Surfer Version 11.1.719 program. Nodes not related to the area under consideration were not counted. The average biomass in the studied area was calculated as the average biomass in the remaining nodes of the interpolation lattice; in total, extrapolated data of 7049, 6780, 7125 and 7174 nodes were used in the calculations, respectively.

In this paper, the weight of the mollusks is given for alcoholized specimens without conversion to live (wet) weight.

Results and discussion

For the period 1924-2017 the distribution of the total biomass of bivalve mollusks in the Barents Sea was changed only slightly: large biomass was recorded along the coast of the Novaya Zemlya archipelago and southeast of the Spitsbergen archipelago (Figure 1). From one climatic period to another, only the values of biomass changed. In the first period, the largest biomass were noted in the southeast of the sea, where they reached 618.3 g/m2 in the Pechora Sea. The second period was warmer and the mollusk biomass values were higher. This is indicated by the maximum values, which reached 1200 g/m2 in the area of Cape Kanin Nos, 900 g/m2 in the Rybach'ya Bank, 600 g/m2 in the area of the Sukhoy Nos and the Melkovod'ye Gusinoy Zemli. It is assumed that the true values of the biomass of mollusks were higher, because bottom grading works in the southeast of the Barents Sea, where traditionally high values of the biomass of mollusks are noted, were practically not carried out. This was followed by a cold period in which there was a significant decrease in biomass. As before, the highest values were observed in the southeast of the sea, where they reached 510 g/m2. In the last, the warmest period, the Spitsbergen bank and the Pechora Sea have become areas with maximum biomass, with maximum values of 1200 and 1100 g/m2, respectively. The data obtained for the last two periods can be considered the most accurate, since the grid of stations covers almost the entire sea.

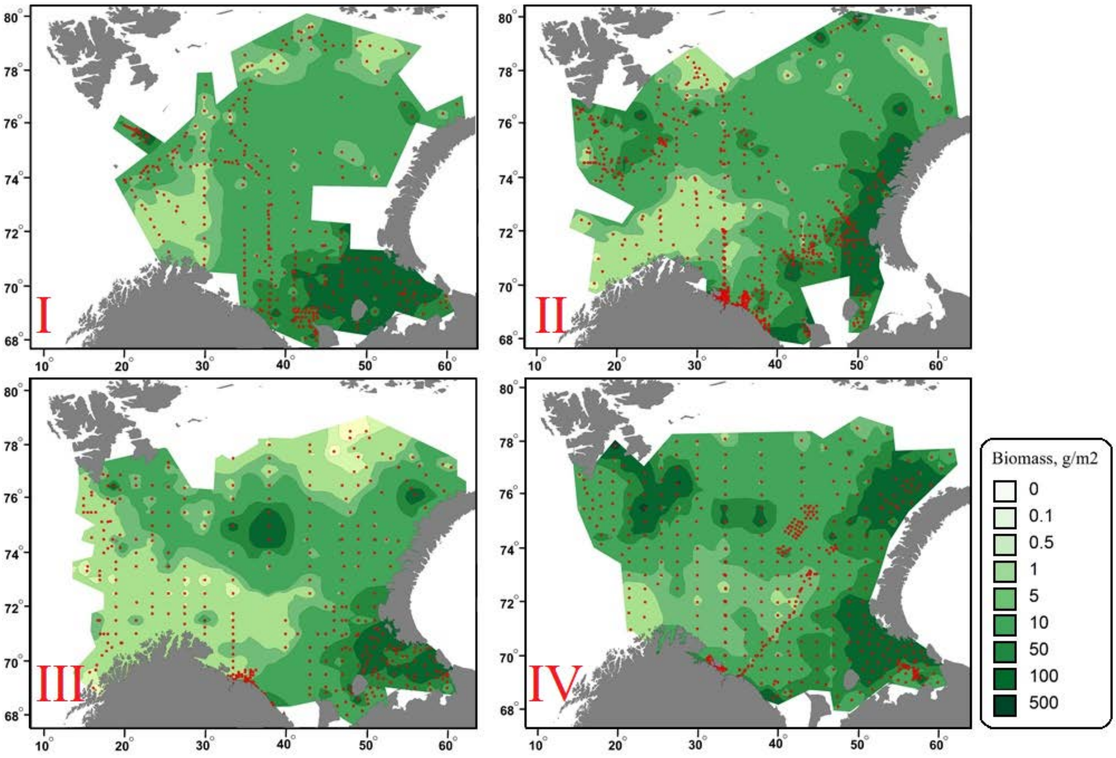


Figure 1. Bivalve mollusks biomass distribution in the Barents Sea in different climatic periods.

The maximum average biomass of bivalve mollusks, according to both actual and model data, was recorded in the Barents Sea in I and IV climatic periods (Figure 2). Thus, the Bivalvia communities show high biomass in both cold and warm periods. This means that parameters such as temperature and sea ice extent themselves do not play a significant role for biomass values, and other, possibly internal, factors play a decisive role. Therefore, changes in the biomass of individual species were considered.

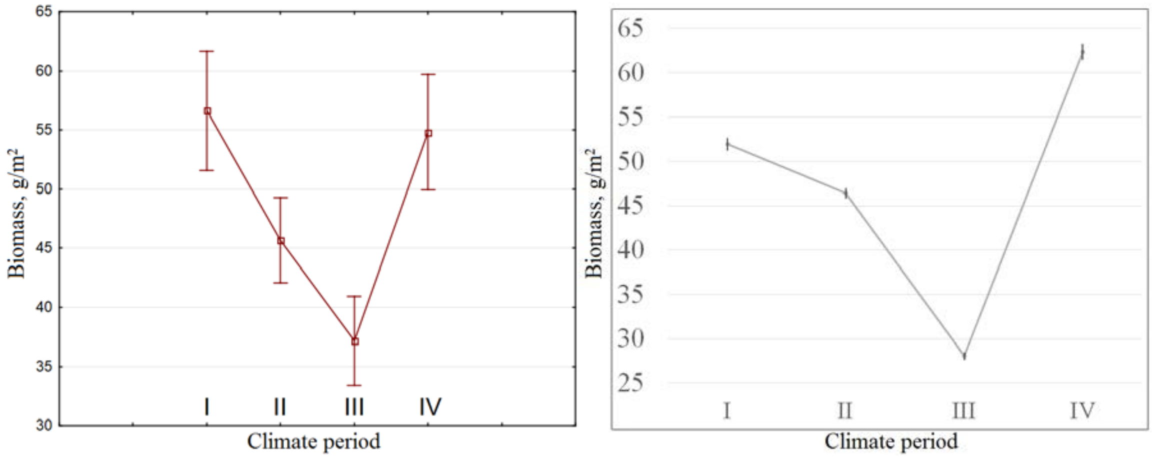


Figure 2. Average biomass values (g / m^2) of bivalve mollusks according to actual (left) and model data (right) with the standard error in the studied area.

The ecology and biomass dynamics of 15 species, which are well identified even at an early age and constitute a significant part of the total biomass of bivalve mollusks, were considered. Of the selected species, 9 were identified, whose trends in biomass changes were the same as the changes characteristic of the whole group of bivalve mollusks. These are *Ciliatocardium ciliatum*, *Serripes groenlandicus*, *Crenella decussata*, *Macoma calcarea*, *Nuculana pernula*, *Similipecten greenlandicus*, *Yoldia hyperborea*, *Yoldiella intermedia*, *Yoldiella lenticula*.

The other 5 species (*Chlamys islandica*, *Bathyarca glacialis*, *Mya truncata*, *Astarte elliptica*, *Yoldiella lucida*) react to changes in the environment in the same way as most benthic organisms: biomass increases in warm periods and decreases in cold ones. The exception is *Bathyarca pectunculoides*, which biomass changes does not allow to attribute it to any of the groups.

For each species, graphs of changes in the depths and temperatures of the occurrence of mollusks in each of the periods were compiled. As a result of the analysis, individual characteristics of the reaction to climate change in each species were noted. We consider a few examples (*Ciliatocardium ciliatum* from the first group, *Chlamys islandica* from the second and *Bathyarca pectunculoides*).

In the second half of the 20s, the species *Ciliatocardium ciliatum* was distributed mainly in the southeastern and central parts of the Barents Sea (Figure 3). With climate changes, the distribution of this species did not change significantly, only the frequency of occurrence of mollusks in the central part of the sea from the Spitsbergen archipelago to Novaya Zemlya increased. Throughout the entire period of studies of this species, a slight increase in its median values of temperature was noted; the depth of the mollusks increased only in the second period (Figure 4).

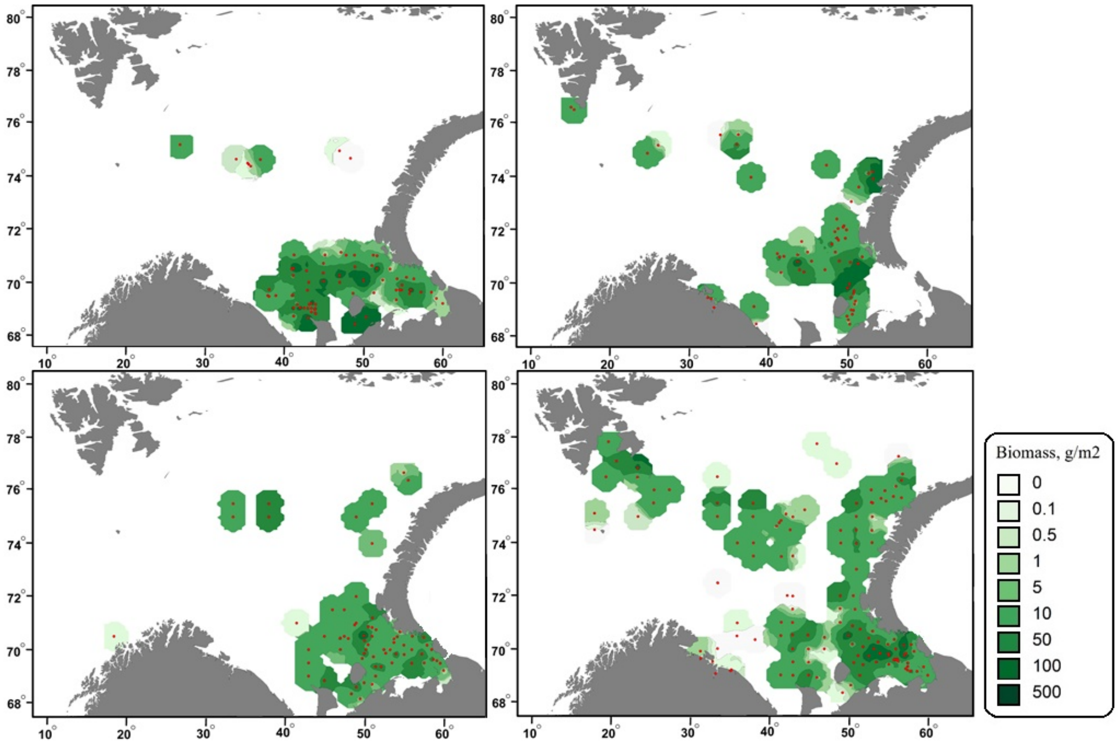


Figure 3. Biomass distribution of *Ciliatocardium ciliatum* in the Barents Sea.

A typical representative of the second group is the Icelandic scallop *Chlamys islandica*. In warm periods, the species occupies a larger water area than in cold ones, both in traditional habitats and in new ones (shallow waters along the Novaya Zemlya archipelago) (Figure 5). The average biomass at the stations is also greater in warm years than in cold ones (Figure 6). The median depth of habitat gradually decreases over the entire observation period, while the temperature of the presence of representatives of the species in the first three periods remains unchanged, and only in the last period increases.

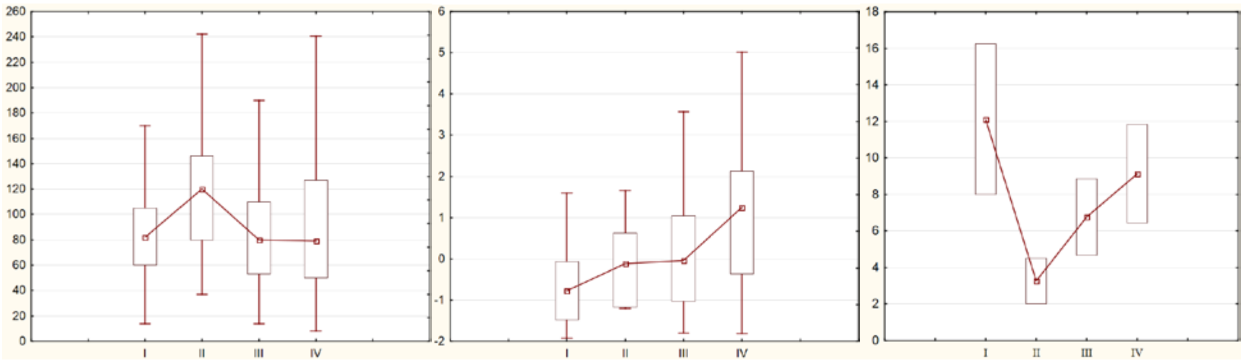


Figure 4. From left to right: Median depth (m) and temperature (°C) of *Ciliatocardium ciliatum* occurence, as well as their average biomass values (g/m^2).

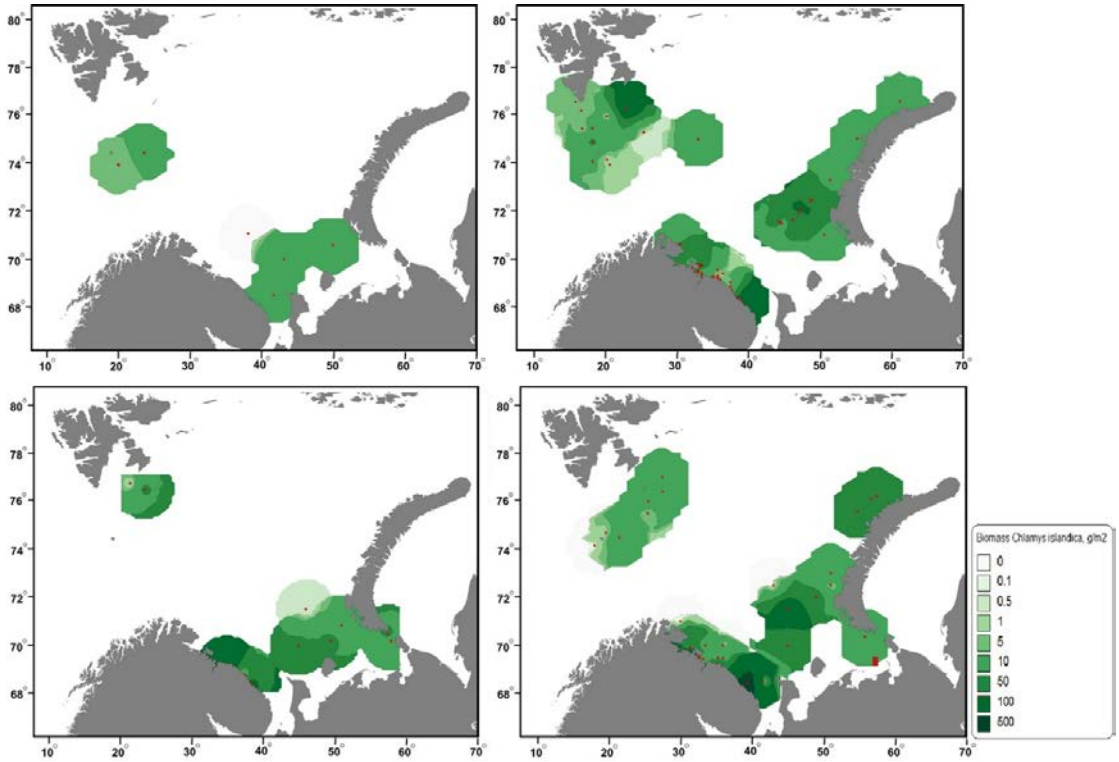


Figure 5. Biomass distribution of *Chlamys islandica* in the Barents Sea.

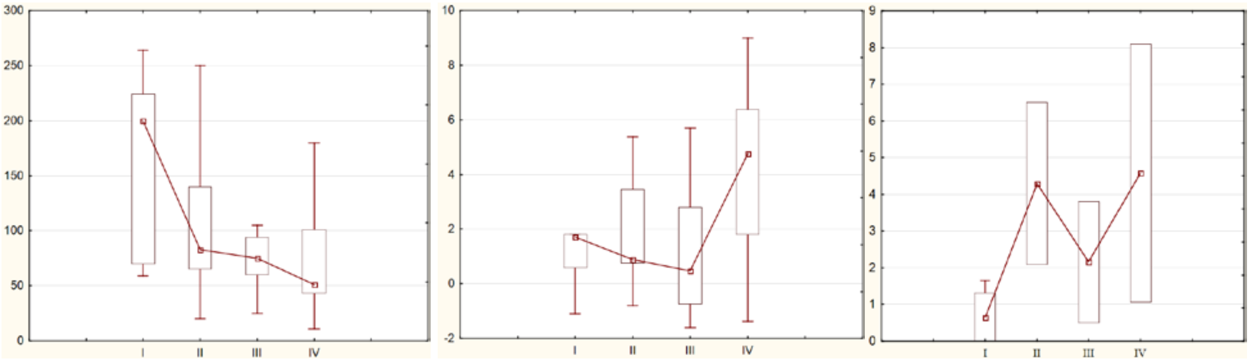


Figure 6. From left to right: median depth (m) and temperature (°C) of *Chlamys islandica* occurence, as well as their average biomass values (g/m^2) in the studied area.

Individuals of the warm-water Bathyarca pectunculoides react to climate change quite differently. This species was found mainly in the southwestern part of the sea, where the bottom temperature has positive values and was single encountered north of 76º (Figure 7). Its biomass is higher, although not significantly, in cold periods than in warm periods (Figure 8). In cold periods, this species is found in deeper parts of the sea than in warm. The habitat temperature of the species in the Barents Sea is about the same for the first three climatic periods and significantly higher in present.

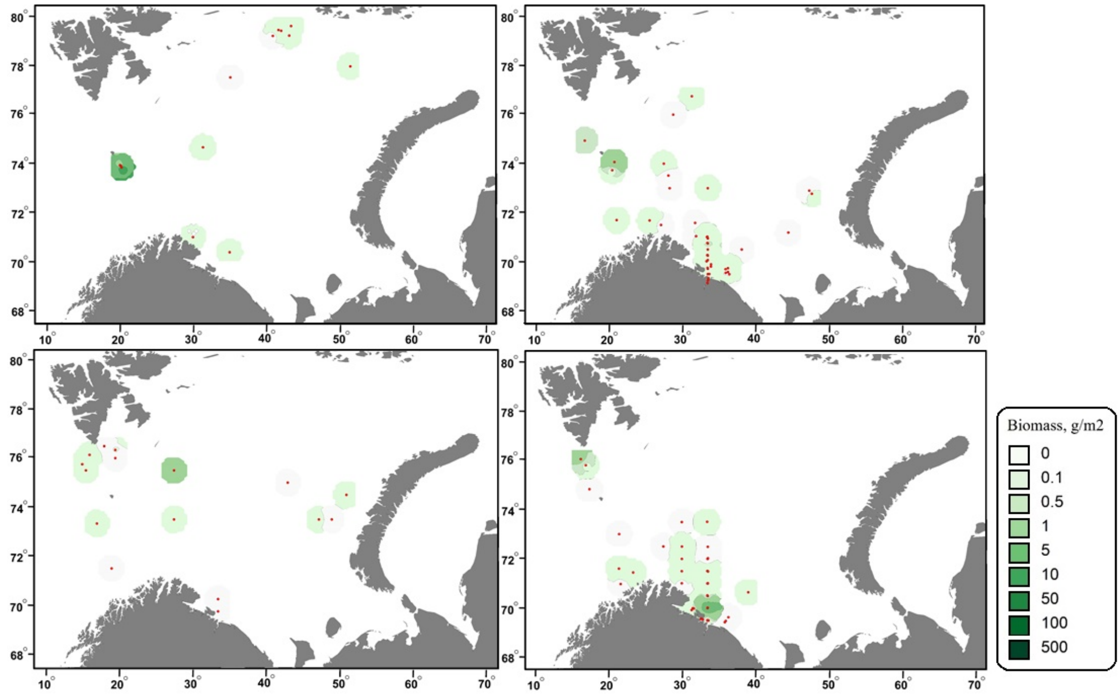


Figure 7. Biomass distribution of *Bathyarca pectunculoides* in the Barents Sea.

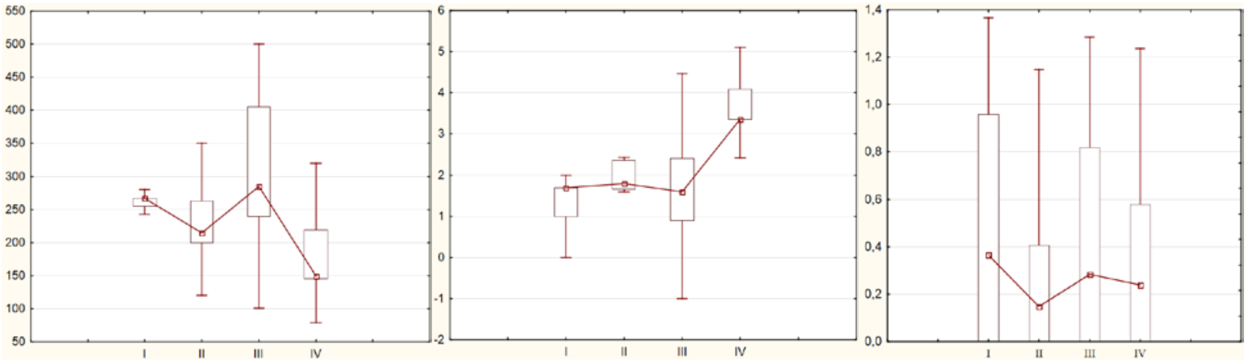


Figure 8. From left to right: median depth (m) and temperature (°C) of *Bathyarca pectunculoides*, as well as their average biomass values (g/m^2) in the studied area.

Changes in biomass and habitat conditions of certain species of bivalve mollusks in different climatic periods in large areas show that the characteristics of their distribution and the dynamics of biomass depend both on a complex set of factors (temperature, depth, ice cover, soil, amount of food, etc.) and on ecological plasticity of the species. For example, a species under the influence of changes in temperature can either disappear in a given area, or change its depth. Moreover, this reaction will depend not only on the ecological plasticity of the species, but also on the duration and impact force - large individuals of bivalve mollusks living for 10–20 years and making the main contribution to biomass can safely survive several years of adverse conditions. Thus, in order to predict the reaction of a species to climate change, it is necessary to know its “history” of habitat in the studied area as much as possible and for a longer period.

Conclusions

Long-term forecasting of the distribution and biomass of certain species of bivalve mollusks is impossible without long-term (of several generations) and detailed studies of their reactions to the external environment.

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Comparative analysis of snow crab *Chionoecetes opilio* diet in the Barents and Kara Seas

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Abstract

Snow crab *Chionoecetes opilio* from the Barents Sea is known as an object of fishery and an important diet component for some fish species at the same time. In the Kara Sea, the population of this species has not yet reached commercial significance, but, in recent years, its rapid growth indicates an increase in its importance in the sea ecosystem. By this reason, the investigations of the crab feeding are important, since feeding is one of the possible causes of the pattern of abundance dynamics and the character of the distribution area. Based on the analysis of 228 crab stomachs, collected in autumn 2014-2016, the differences in the diet of crab in the Barents and Kara Seas were revealed. Comparing of diet peculiarities showed that, in the Kara Sea, males with the carapace width (CW) less than 60 mm preferred to prey on ophiurans, while the individuals with a CW greater than 60 mm – on crustacean *Hyas araneus*. In the Barents Sea, *S. typicus* polychaetes dominated in the diet of males from all size groups. In the Kara Sea, females of two size groups (40 <CW <40 mm) fed mainly on ophiurans and bivalves, and, in the Barents Sea, – on polychaetes *S. typicus* and sea urchins. The cluster analysis of the data showed that, in the Barents and Kara Seas, the greatest similarity was found among males with CW less than 60 mm and females with CW greater than 40 mm.

Keywords: Barents Sea, Kara Sea, snow crab, feeding

Introduction

Snow crab *Chionoecetes opilio* from the Barents Sea is known as an object of fishery and an important diet component for some fish species at the same time. In the Kara Sea, the population of this species has not yet reached commercial significance, but, in recent years, its rapid growth indicates an increase in its importance in the sea ecosystem. The study of the pattern of crab feeding is important, since it is one of the possible factors determining the population dynamics and area.

Material and methods

The material for the study was crab specimens captured in the Barents (136 stomachs) and Kara (92 stomachs) Seas during the trawl surveys of PINRO in autumn 2014-2016 (Figures 1, 2).

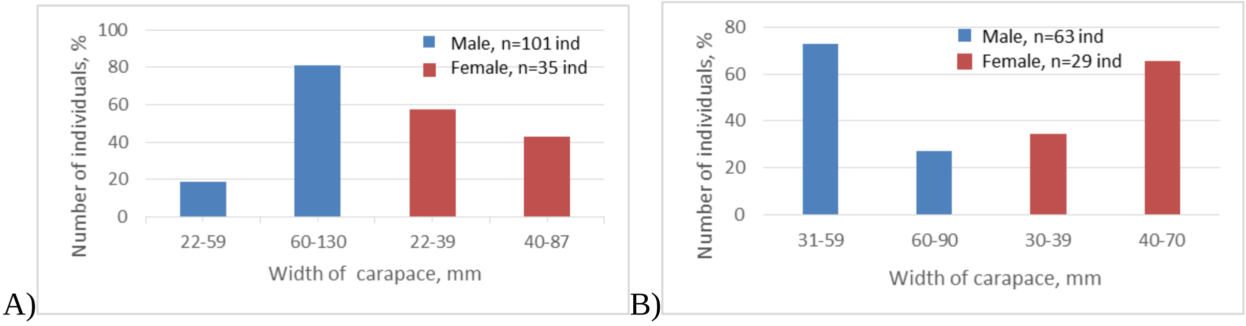

Figure 1. Biological characteristics of the investigated snow crab in the Barents (A) and Kara (B) Seas in September-October 2014-2016.

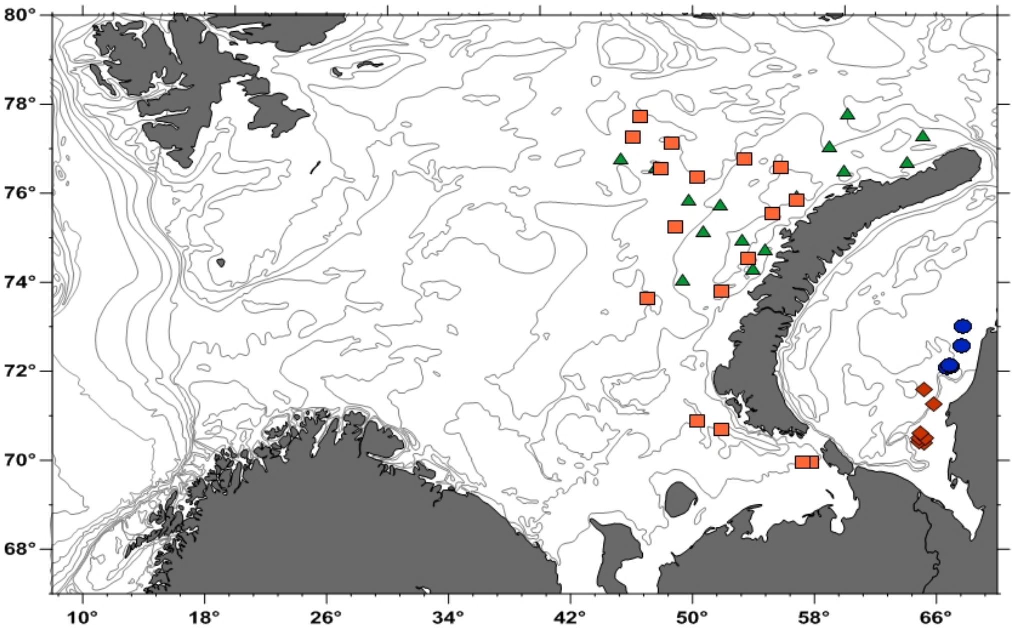

Figure 2. Location of stations for collecting snow crab feeding samples in the Barents Sea: ■ - 2015, ▲ - 2016; in the Kara Sea: ● – 2014, ◆ – 2016.

To obtain the minimum value of the snow crab commercial stock biomass in the Russian EEZ, the density of crabs obtained in the “Loophole” in 2014 (before the fishery in the Russian EEZ) was extrapolated to the area of commercial sized crabs distribution in the Russian EEZ estimated in ecosystem surveys 2012-2017.

The results of feeding studies were summarized for the following groups:
Females:
Group I - immature juveniles with a carapace width (CW) of up to 40 mm
Group II - mature adults with a CW of more than 40 mm.
Males:
Group I - immature juveniles with a CW of up to 60 mm;
Group II - mature adults with a CW of greater than 60 mm.

Results and discussion

Characteristics of snow crab feeding based on the occurrence of food items

The Barents Sea. In 2015-2016, in the Barents Sea, in the diet of the crab 63 taxa of marine organisms were recorded (Figure 3A). The most frequently occurred diet item were polychaetes and bivalve mollusks in the stomachs (more than 50% of the stomachs). On the second place of occurrence were crustaceans, ophiuroids, gastropods and sea urchins (from 10 to 20%), on the third - barnacles of genus Balanus and Foraminifera (<4%). Fish remains were registered in 4% of cases. Other components of the diet (foraminifera, hydroids, priapulid worms and sipunculids) were met in less than 2% of the stomach. Also, in the stomachs of large males (≤ 100 mm), the individuals of snow crab (4%) was recorded.

The Kara Sea. The food composition of snow crab in the Kara Sea was less diverse (Figure 3B). In the stomachs of crabs, there were 45 taxa of marine organisms. The most frequently recorded items were bivalves (<50% of stomachs); polychaetes, crustaceans and ophiurans met in stomachs seldom (40%). Other components (hydroids, gastropods, barnacles and foraminifers) were found in less than 5% of the stomachs, and fish – in 3%.

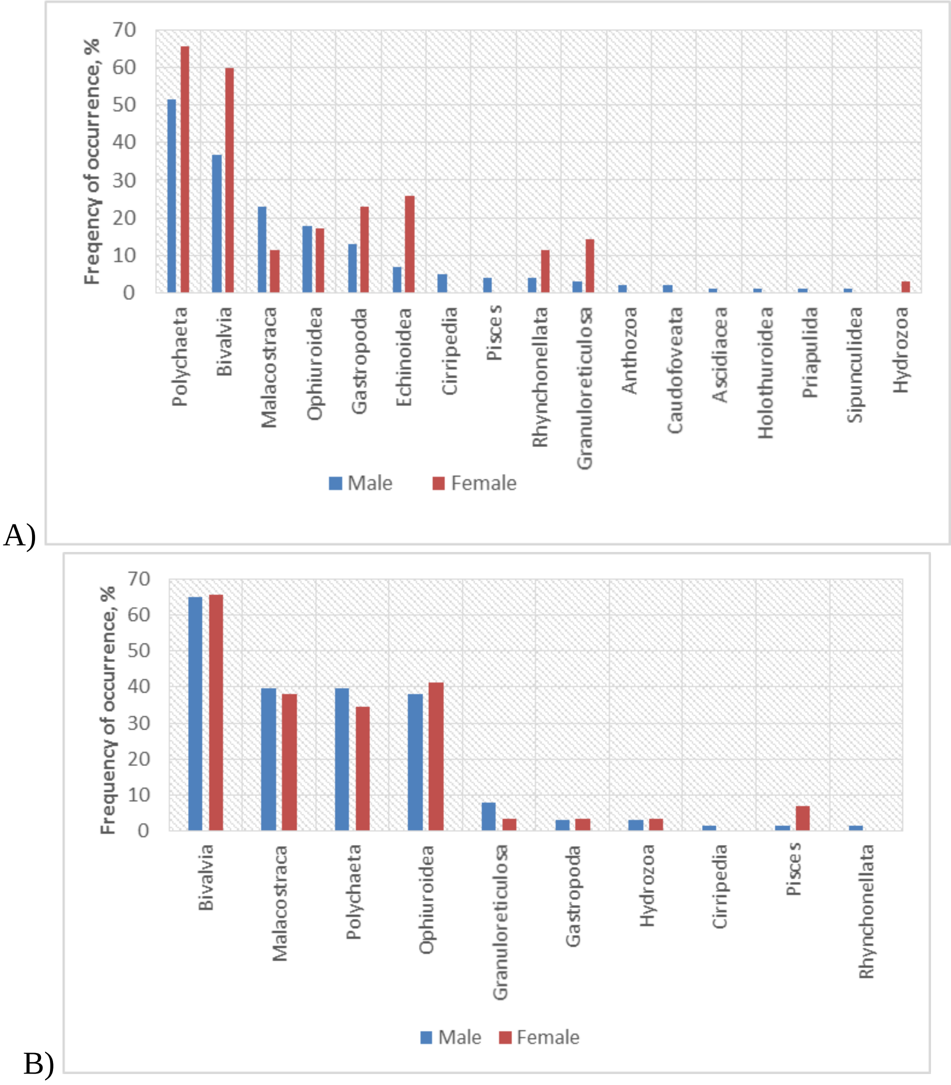

Figure 3. The frequency of prey occurrence (in% of the total number of stomachs) in the stomachs of snow crab in the Barents (A) and Kara (B) Seas in 2014-2016.

Feeding of different size and sex groups of the crab

The analysis of the materials revealed significant differences in the intensity and change of the dominant groups of benthic organisms in feeding of the different size sex groups of the crab in the two seas (Figure 4).

The Barents Sea. Female juveniles consume mainly bivalves, *S. typicus* polychaetes and the sea urchin *Strongylocentrotus pallidus*. For mature females, the importance of mollusks and sea urchins was much lower than immature, polychaetes (in particular, *S. typicus*) have main importance. The significance of other groups (hydroids, foraminifera) in female’s diet of both groups was lower. In the feeding of immature males, the dominant role played also polychaete *S. typicus*, secondary role played ophiurans and bivalves, third-rate - sea urchins, barnacles, gastropods, shrimps and amphipods. For mature males, an important food item, except *S. typicus*, was *Pectinaria hyperborea*, the second place have shrimp *Pandalus borealis* and ophiurans. Less important in the diet of mature males have bivalves, fish, gastropods and worms Sipuncula. Own juveniles of Snow crab were noted only in the stomachs of males with width of carapace over > 100 mm and did not play a significant role in diet. The most intensively consume mature females and juvenile males.

The Kara Sea. In the Kara Sea, ophiurans were an important component of consumption of both groups of females, secondary importance have bivalves (*Serripes groenlandicus* and *Yoldia* *hyperborea*). In juveniles of females, the value of crustaceans (in particular, the crab *Hyas araneus*) was much higher than that of the mature individuals. The importance of polychaetes was higher for females, they did not play a significant role in consumption of young crabs. The fish remains were noted only in the stomachs of immature females. In the feeding of young males, ophiuroids played a significant role, and for adults the most important were the Hyas sp. In juveniles and sexually mature males, bivalves (*Yoldia hyperborea*) have secondary importance, and polychaetes from the family Maldanidae and Spiochaetopterus typicus were less significant. Intensity of food consumption was higher for juvenile males and females.

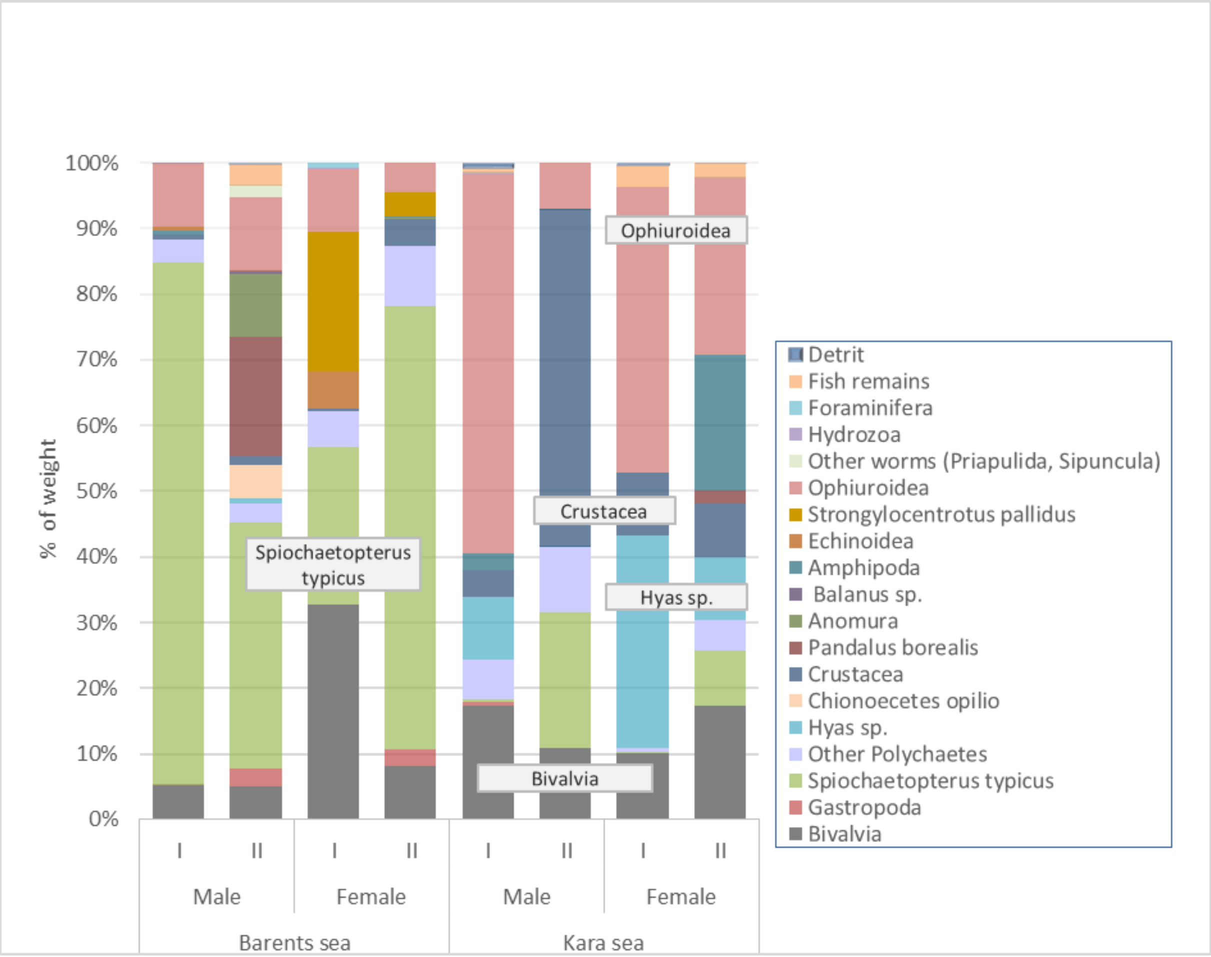

Figure 4. Weight percentage (% of the food bolus weight) of snow crab food items according to data on the Barents and Kara Seas in 2014-2016.

Analysis of similarity of the crab food composition in the Barents and Kara Seas

Cluster analysis of data by the weight percentage of the prey organisms found in crab stomachs revealed a similarity in the food composition between the different size groups of females and males (Figure 5).

To assess the degree of similarity of the food spectrum, the index of the faunistic similarity Chekanovsky-Serensen was used.

In the Barents Sea, immature males (group I) and mature females (group II) have the most similar composition of food due to dominance in their diet of polychaetes *S. typicus* and ophiurans. In the Kara Sea, the greatest similarity of food was noted between the immature females and males, in the diet of which the ophiuroids, bivalves and various crustaceans predominated.

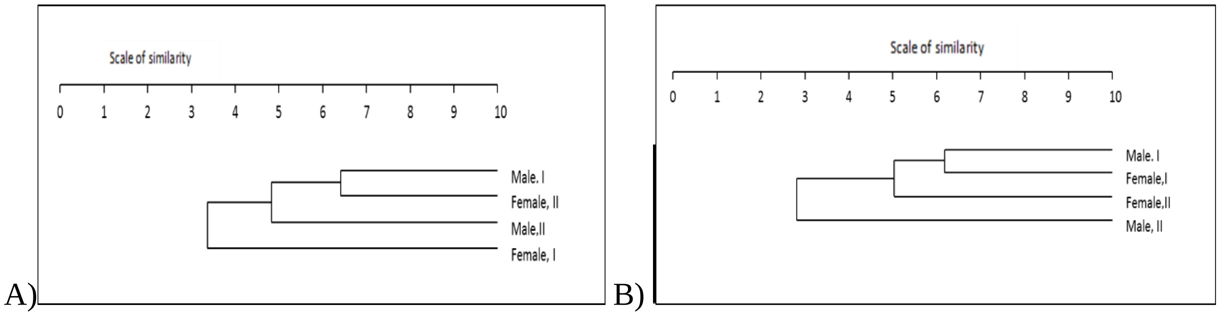

Figure 5. Cluster analysis of similarity of different size groups of snow crab (in terms of the weight percentage of prey) in the Barents (A) and Kara (B) Seas.

Conclusions

In the Barents Sea, the widespread sedentary polychaete *Spiochaetopterus typicus* predominated by weight in the diet of males of all size groups. In the Kara Sea, adult males fed mainly on crustaceans, while juveniles - on ophiurans and bivalves. In the Kara Sea, young and adult females mainly fed on ophiurans and crustaceans (Hyas sp, Gammaridae g.sp), and, in the Barents Sea, - on polychaetes *S. typicus* and bivalves. A special feature of the food composition of crabs in the Kara Sea is the complete absence of sea urchins.

High values of the average total stomach fullness index of crabs in the Barents (12 o/ooo under 93% of stomachs with food) and the Kara Seas (16 o/ooo under 96% of stomachs with food) indicated a good supply of crabs with food. Cannibalism was noted only in 4% of the stomachs in large males (CW > 100 mm) in the Barents Sea.

Adult mature males of the Barents and Kara Seas were more likely to eat mobile forms of benthos (crabs, shrimps) compared to young males and females. Detection of fish remains in the stomachs of immature females and males gives reason to guess that young snow crabs eat only dead fish, because the relatively small claws and the slow mobility do not allow young crabs to hunt actively to live fish.

The greatest similarity of the food composition of adult males and young females was found in the Barents Sea, while juvenile males and females - in the Kara Sea.

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Red king crab’s distribution on the east of the Barents Sea and the “Gorlo” of the White Sea as its adaptive capabilities

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Abstract

The paper presents new data of red king crab distribution in the Barents Sea and the White Sea as the results of trap surveys 2015-2017. King crab was observed at depths of 44-54 meters at the bottom salinity of 29.2 ‰ and the bottom temperature of 6.7°C in the White Sea and in eastern part of the Barents Sea at the temperature 0.06°C. According to the trap research, the red king crab is distributed in the “Gorlo” of the White Sea up to 66°37.40'N. The catches of the crab with a research drag (the Sigsby trawl) were registered at 66°37.30`N.

Keywords: Barents Sea, White Sea, red king crab, distribution, biology, salinity and temperature, traps, Sigsby trawl

Introduction

The red king crab was introduced into the Barents Sea for economic use by the fishing industry. Today it is distributed in the Russian Economic Zone from the borders with the Kingdom of Norway in the west to the Vaigachsky district in Novaya Zemlya in the east and the “Gorlo” of the White Sea in the south. The crab is developing new water areas, the conditions in which may be even unfavorable. The given paper presents new data on the distribution of the red king crab in the Barents and White Seas.

In summer, in the “Gorlo” of the White Sea, salinity is the main limiting abiotic factor. Crabs were only caught only at a salinity of 28 ‰ and above. The “Gorlo” (throat) is characterized by strong tidal currents and a complex hydrological regime, which reduces the intensity of development of this area by the red king crab. Most likely, the crab makes regular migrations there from the north of the “Voronka” of the White Sea. Also in the “Gorlo” there are settlements of the Iceland scallop and, perhaps, this is one of the factors that leads to the migrations of the crab in search of food to the areas with unfavorable conditions.

Further research on the distribution of the red king crab in the “Gorlo” of the White Sea and towards the Kara Sea will help to determine the crab adaptive capabilities more accurately.

Material and methods

The paper uses materials obtained from the results of work during the integrated survey for the red king crab in the territorial waters of Russia in 2015-2017, the drag survey for Iceland scallop in 2017, as well as from the data on the joint Russian-Norwegian Ecosystem Survey in 2017.

In the caught crabs, sex, the intermolt category in males and the stage of maturity of the female roe were determined, the width of the carapace was measured, missing or regenerated legs and other injuries were recorded.

Also, the data on bottom temperature and salinity at the crab capture areas obtained during the surveys were used.

Results and discussion

In the Vaigachsky district (70°11 N 55°28 E), the red king crabs were caught as single specimens. The depth of fishing was 154 m, the bottom salinity - 34.7 ‰, the temperature - 0.06 °C (Figure 1).

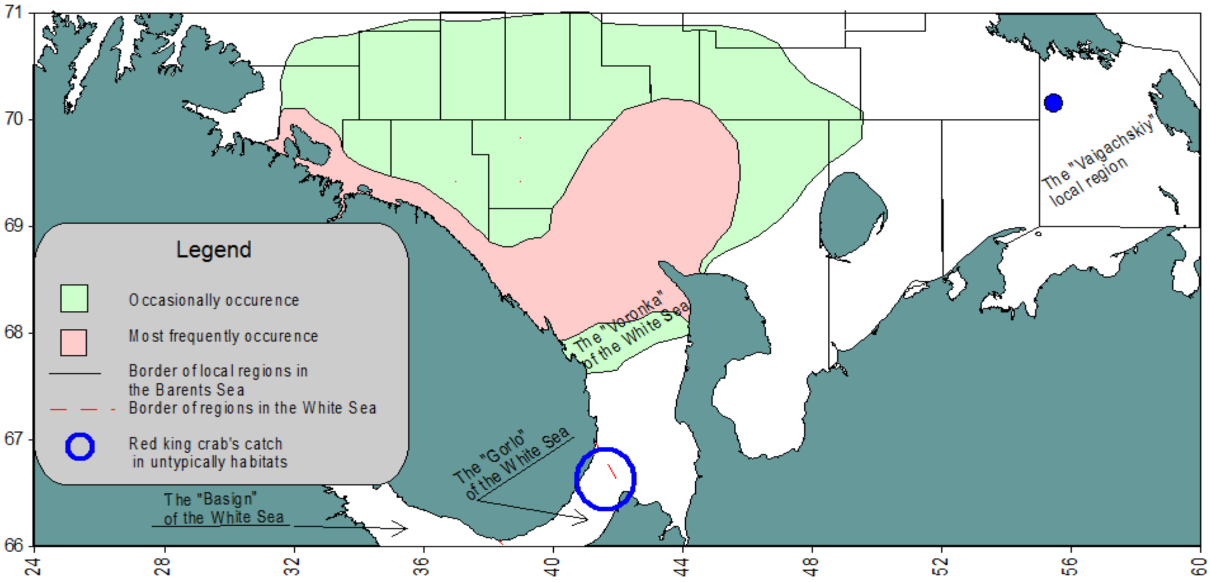

Figure 1. Current distribution of the red king crab in the Russian Economic Zone and areas of its capture in atypical habitats.

In 2015-2016, in the “Gorlo” of the White Sea, the crabs were caught by traps up to 66°37.40`N at a bottom temperature of 6.7 °C and a salinity of 29.2 ‰ and more. The depth of fishing was 44-54 m (Figure 2).

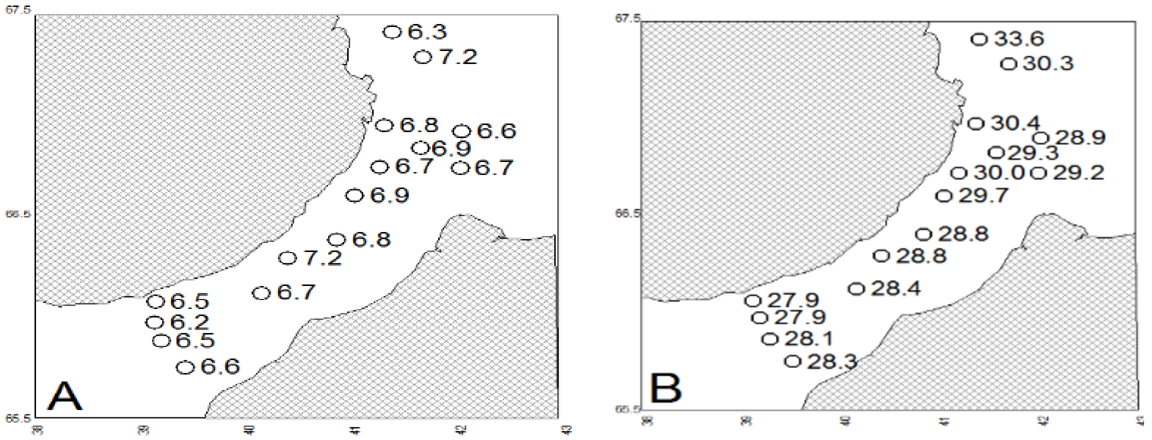

Figure 2. Bottom temperature (A) and salinity (B) in the “Gorlo” of the White Sea and adjacent areas in July 2015.

The specimens were predominantly represented by males and females with a carapace width of 90-120 mm. Catches of crab in the Gorlo of the White Sea were to 8.7 ind. / trap. Males of commercial size with a carapace width greater than 150 mm were observed as single individuals. All females were immature or non-breeding, individuals with external roe were not found (Figure 3).

The biological analysis did not reveal any pathologies in the caught crabs. In animals, encrusting of carapace was minimal.

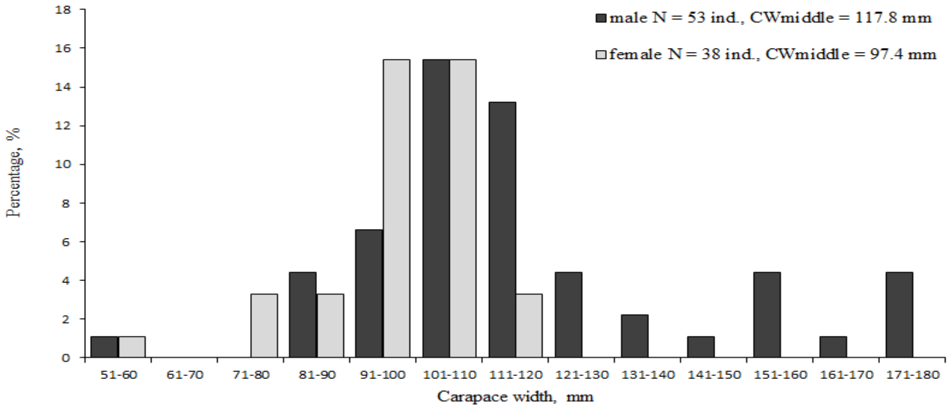

Figure 3. The size composition of the red king crab in the trap catches in the “Gorlo” of the White Sea in 2015-2016.

In 2017, in the same area, the similar studies did not yield results. Fishing by Sigsby trawl conducted simultaneously with using traps also showed a zero crab capture. In the fishing area the bottom temperature was 5.18 ° C, and the salinity was 27.5 ‰. In the autumn of 2017, slightly southward of the area where fishing was carried out in the summer (66 ° 37.30`N), a non-breeding female of the red king crab with a carapace width of 106 mm was caught. At the site of the crab capture, the bottom salinity was 28.1 ‰, and the temperature - 7.7 °C.

The temperature optimum for the red king crab varies within 2-7 °C. Females with external roe are more warm-requiring. Unfavorable temperature and salinity are 0 °C and lower, and 30 ‰ and lower, respectively. Adult individuals can survive at a temperature of -1.7 °C and a salinity of 28-35 ‰. In the aquarium, for a short period (month), the crab lives at the salinity of 20 ‰. The red king crab larvae survive with a short-term salinity up to 25 ‰.

In the Vaigachsky region, bottom salinity does not go beyond the optimum for the red king crab, hence, its further distribution can be limited by temperature. In winter, this area is covered with ice, in addition, when moving to the “Gates” of the Kara Sea, the depth of the sea decreases and the freshening of the water area increases.

Conclusions

According to the trap research, the red king crab is distributed in the “Gorlo” of the White Sea up to 66°37.40'N.

The catches of the crab by a research drag (the Sigsby trawl) were registered at 66°37.30`N.

The red king crab in catches from the “Gorlo” of the White Sea is represented mainly by males and females with a 90-120 mm carapace width. The commercial crab males were occasionally recorded. Females with external roe were not observed.

In the areas of the red king crab capture, the minimum salinity was 28.1 ‰.

Acknowledgement

The author is grateful to “Kovda” Ltd. for assistance in the collection of primary material in the autumn of 2017.

THEME SESSION IV: FISHES

Past natural climate variability and future anthropogenic climate change in the Northeast Atlantic – responses of marine organisms

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The Northeast Atlantic, and particularly the Barents Sea, has the longest time series of ocean physics and biotic data of the world oceans. Such time series enabled the ICES scientific community already at the end of the 1940s to focus on how the long-term warming of the North Atlantic from the 1920s to the 1940s influenced marine organisms by shifting distributions poleward and increasing the abundance of many boreal species. During the 1960s and 1970s Russian oceanographers pointed of that this warming was part of longer-term oscillatory patterns of the climate influencing marine organisms in similar ways. Today, the early Russian findings have been confirmed by the new recent warming from the 1980s, but also by analyzing extension of climate data back to 1860s, and proxy climate data back to the 16th century. The present northward displacement of boreal species in the Barents Sea was also observed during previous warming of the mid-20th century. However, the present warming has now exceeded that of the mid-20th century indicating that the anthropogenic climate change adds to the multidecadal natural variability. The continued and accelerating anthropogenic warming through the 21st century indicates that the temperature of the Barents Sea will become higher than ever observed by instrumental data. However, there are important processes that constrain poleward migration and increase in biomass of marine species. Such constraints will be outlined and analyzed in this presentation.

Trophic level of cod in the Barents Sea – estimates from stomach data, stable isotope data and an ecosystem model

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The abundance, individual size and age, and distribution area of Northeast Arctic (NEA) cod (*Gadus morhua*) in the Barents Sea has increased during the last two decades. NEA cod is a key species in the food web of the Barents Sea, and along with the recent population changes, we observe changes in the trophic interactions in which this stock is involved. Trophic level is an important variable in the studies of food webs, holding information about the predatory impact of the predator in question, as well as the potential carrying capacity for the predator population.

The objectives of this presentation are to demonstrate how the trophic level of NEA cod can be estimated based on different data sources, and how the trophic interactions vary in time and space, and with cod size.

The trophic level of NEA cod will be estimated based on four different sources; stomach data from routine surveys covering the Barents Sea in winter and autumn, detailed stomach data from a targeted sampling in the TIBIA and SI_Arctic projects, carbon and nitrogen stable isotope analysis of muscle samples from the Norwegian part of the Barents Sea from TIBIA, SI_Arctic, and the autumn ecosystem cruises, and diet information from the NoBa end-to-end ecosystem model.

We will provide new knowledge about the trophic role of NEA cod as a key species in the Barents Sea ecosystem, including its trophic level, how this varies, and possible sources for this variation. We will also demonstrate the applicability of different approaches and data for estimating trophic level. We will discuss causes of variation and trends in the role of NEA cod in the food web, its trophic niche, and how this predator impacts its food base. The discussion will also include methodological issues based on the output from the different methods used.

The role of cod in decline of arctic demersal fishes in the northern Barents Sea

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Cod (*Gadus morhua*) is the main piscivore predator in the Barents Sea. Since 2004 cod biomass has increased and cod distribution during seasonal feeding migrations has expanded northwards. This has co-occurred with a change in overall species composition of demersal fishes. The northern Barents Sea has become “borealized”; cod and other boreal species has expanded into regions that previously were dominated by arctic fishes. A decline in true arctic species has also been noted in the same period. Here we explore the trophic impact of the cod expansion and to what extent cod has contributed to the decline of the arctic fishes. In previous work the borealization has solely been attributed to climate. However, the increase of the cod stock biomass and cod expansion cannot alone be explained by climate, as fishing and food competition also could play a role. Furthermore, since cod is a dominant predator it is likely to have an impact on the smaller arctic fishes. Here we use cod stomach data to estimate consumption rates of small demersal fishes and compare these to biomass estimates of small demersals in the northern Barents Sea. We calculate potential mortality rates caused by cod predation by varying catchabilities of small demersals and resident times of cod in the northern Barents Sea and combine these with cod abundance estimates. We also investigate possible food competition between cod and arctic fishes as cod can prey on the same plankton organisms (hyperiids, euphausiids etc) as some small demersal fish (e.g. *Liparis fabricii*, *Triglops nybelini*, *Eumicrotremus spp.*). Although the biology of arctic demersals is relatively poorly known, we discuss the potential role of cod predation and competition relative to direct effects of climate on the demographic parameters of arctic fishes based on the present knowledge and provide an outline for further work.

Diet and trophic relations in the Barents Sea fish communities: spatial and seasonal variability of diet and trophic relations

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Despite a long history of investigations, trophic structure of fish communities in the Barents Sea remains a rather poorly studied. Commercially important fish and their food consumption have been mainly focusing in previous investigations, while diet and interactions of other fishes were sporadically (both on time and space) studied. In 2015, a large-scale program on stomach sampling of all fish species in various surveys was conducted by IMR and PINRO. Totally, 27658 stomachs of 76 fish species were sampled and investigated. Such approach allows to evaluate spatial and seasonal variability of diet and trophic relations patterns in fish communities throughout the Barents Sea. This presentation will present data on general food composition for these species and their ontogenetic, spatial and seasonal variability. Intra- and interspecies similarity of their diet will be also evaluated. Finally, trophic groups/guilds will be recognized based on diet data.

Interannual dynamics in diet of the most abundant demersal fishes of the Barents Sea

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Since mid-1980s PINRO and IMR started the joint program on investigations of cod diet in the Barents Sea. Later PINRO extended such program to other abundant fish species. This presentation will show data on general diet composition and their interannual dynamics for the most abundant fishes of commercial importance (cod, haddock, Greenland halibut, saithe, redfishes, long rough dab, plaice, catfishes and others). Role of commercially important prey (capelin, herring, polar cod, gadids etc.) is analyzed related to predator and prey stock dynamics and climatic changes. Possible changes in fish diet under continued warming and northward expanding of boreal fishes distributuion as well as a role of arctic fish species in their diet are also discussed.

Fish predation on capelin larvae in the Barents Sea: myth or reality?

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Abstract

Status of the Barents Sea capelin stock depend on various factors. Some researchers consider predation of Atlantic herring on capelin eggs and larvae during spring season as one of the crucial reasons of capelin recruitment success. Using data on diet of herring and capelin and zooplankton samples, we tried to evaluate a predation press of fish on capelin larvae in the southern Barents Sea during May-June 2015-2017. Our data show that occurrence of capelin larvae in herring and capelin stomachs was quite low and such predation does not seem to have a considerable impact on capelin recruitment dynamics.

Keywords: capelin, herring, predation, diet, larvae, Barents Sea

Introduction

Capelin *Mallotus villosus* and Atlantic herring *Clupea harengus* have a great importance in the Barents Sea ecosystem as commercially important species and as prey mainly for cod, sea birds and marine mammals. Capelin inhabit the Barents Sea and migrate from Murman and Norwegian coast (spawning grounds) to the northern areas (feeding grounds). Herring drifted to the Barents Sea as larvae, live there 2-4 years in the southern areas and migrate back to the Norwegian Sea after maturation.

Interrelations between these species include not only trophic competition mainly for zooplankton, but also predation on capelin by herring. Some scientists, mainly from Norway (Gjøsæter, 1998; Huse and Toresen, 2000; etc), consider that immature herring prey on capelin larvae in the Barents Sea and the predation is a key factor of capelin recruitment success.

“This hypothesis, now frequently called ‘Hamre’s hypothesis’ because it was first suggested and later on elaborated by him (Hamre, 1985, 1988, 1991, 1994), is that the young herring, when they appear in the Barents Sea, will graze down the capelin larvae and thereby cause failure of recruitment to the capelin stock. This hypothesis has gained general acceptance after the mechanism behind this hypothesis was verified in the field (Huse, 1994; Huse and Toresen, 1995).” (Gjøsæter, 1998).

“The herring (*Clupea harengus*) occur as juveniles in the Barents Sea, and while there, consume considerable amounts of capelin larvae (Huse and Toresen, 1995). The resulting mortality of capelin larvae is thought to be a major cause of the recruitment failure of capelin associated with years when abundant herring year classes are growing up in the area (Hamre, 1988, 1991; Huse, 1994; Gjøsæter, 1995; Gjøsæter and Bogstad, 1998).” (Gjøsæter, 1998).

The conclusions on high importance of herring predation on capelin recruitment were based on the data only from two years – 1992 and 1993, provided by Huse and Toresen (1996, 2000). Later Gjøsæter and Bogstad (1998) and Mikkelsen and Pedersen (2004) also showed that the modified Beverton–Holt model with a term for juvenile herring fit capelin recruitment data well and that young herring was found to have a negative influence on the capelin recruitment.

We would like to re-analyse predation level on capelin in recent years. The main goals of our paper were to consider role of capelin larvae in fish diet in spring-early summer period in 2000s, to compare occurrence of capelin larvae in plankton and fish diet and to try to reveal other possible reasons of predation on capelin recruitment.

Material and methods

Capelin and herring for stomach analysis as well as zooplankton were sampled in the course of the International ecosystem surveys in the Nordic seas in May-June 2015-2017. The location of trawling stations for capelin and herring collected for stomach analysis is shown on Figure 1. In total, 169 stomachs of Atlantic herring and 303 stomachs of capelin were analysed in the PINRO laboratory. In addition, data of capelin and herring stomach content (10 343 capelin stomachs and 3 293 herring stomachs) examined on-board in May-June 2002-2017 were used. 99 zooplankton samples were collected in May-June 2017, were used to analyse the occurrence of fish eggs and larvae.

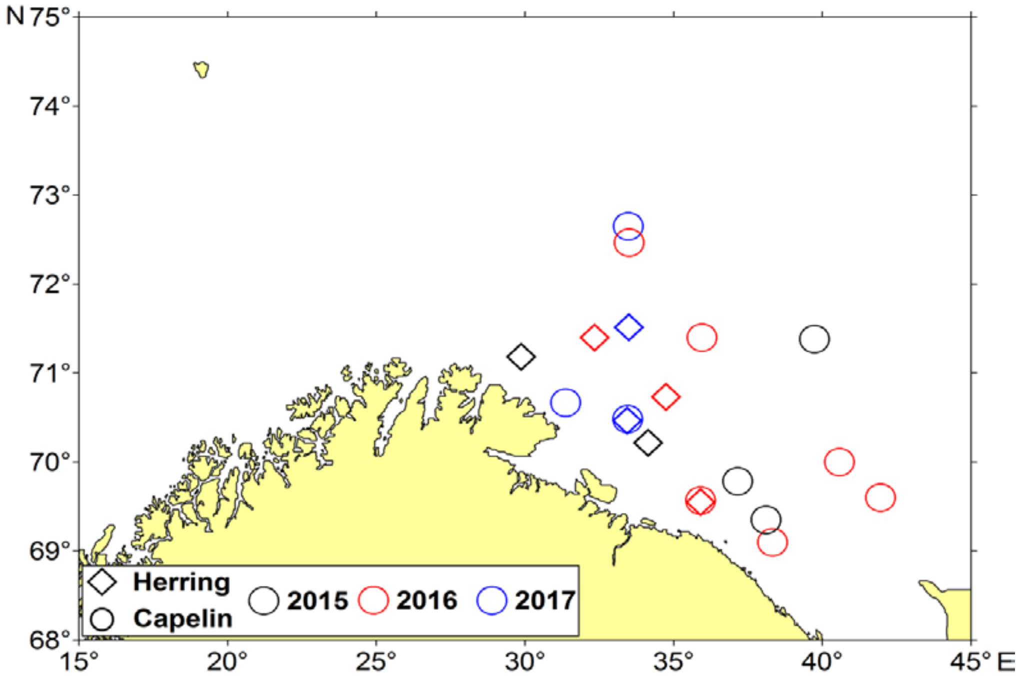


Figure 1. The location of capelin and herring stomachs sampling stations in May-June 2015-2017.

Results and discussion

Data from previous publications

The conclusions on high importance of herring predation on capelin recruitment were based on the data only from two years – 1992 and 1993, provided by Huse and Toresen (1996, 2000). Detailed analysis of these data showed that the data were quite limited and could not represent high predation level on capelin by herring.

Based on 236 herring stomachs collected at 9 stations and 238 capelin collected at 9 stations, frequency of occurrence of capelin larvae was 5.6% in herring diet and only 0.5% in capelin diet in May-June 1992 (Huse and Toresen, 1996). The main conclusion was the following : “Capelin larvae were the only fish larvae consumed and were only observed in a modest amount of the herring stomachs analyzed.” (Huse and Toresen, 1996).

Later Huse and Toresen (2000) provided additional information on herring predation on capelin in May-June 1992 and 1993. The number of stomachs collected for diet analysis in 1992 (799 herring stomachs at 18 stations) were higher compared to previous research, thought capelin larvae was found in 45 herring stomachs (5.6%) only at 6 stations (33%). In addition, intensive consumption of capelin larvae was observed only on 1 station, where 28 herring (from 30 ind. per sample) consumed capelin larvae. At the other stations only 2-4 herring (of 4-100 ind. per sample) preyed on capelin larvae. In May-June 1993, 2 590 stomachs of herring collected at 49 stations were analysed. Capelin larvae were found in 77 herring stomachs (3.0%) sampled at 19 stations (39.0%). Intensive predation on capelin larvae was observed only at two stations, where 17 and 22 herring (from 80 and 60 ind. per sample) consumed capelin larvae. At the other stations only 1-5 fish (of 5-80 ind. per sample) fed on capelin larvae. The main conclusion was the following : “We found that juvenile herring eat larval capelin, thus showing that such predation actually takes place in the sea. The observed predation rates correspond to herring encounter rates in areas of low larval density, and were not high enough to explain the poor recruitment of the capelin cohorts.” (Huse and Toresen, 2000).

Other authors also investigated effect of herring and other fishes predation on capelin recruitment in the Barents Sea. During investigations of herring diet in the Barents and the Norwegian Seas, Prokopchuk (2006) found out that in June 2001 (98 stomachs at 4 stations) frequency of occurrence of fish larvae (probably capelin larvae) was 11.3%, while its weight portion was very low and did not exceeded 0,8%.

Based on the data from June-July 2003 Godiksen et al. (2006) observed higher herring predation on capelin larvae than reported in earlier studies, and the authors also reported predation of sandeel on capelin larvae. In total, 110 sandeel stomachs at 1 station and 330 herring stomachs at 3 stations were investigated, capelin larvae were found in 22 sandeel stomachs (20%) and in 131 herring stomachs (39.7%).

Our data

Zooplankton

Capelin larvae were found at 16 of 90 stations (17.8%) in May-June 2017 (Figure 2). Totally 111 capelin larvae were observed in zooplankton samples or 6.9 larvae per stations with capelin larvae. Moreover, larvae of other fish species were registered in zooplankton samples, but their occurrence and numbers were much lower compare to capelin larvae. 29 gadids larvae were found at 13 stations, 7 larvae of long rough dab were observed at 6 stations, and 1 larva of herring and 1 sandeel larva were found per 1 station. Fish eggs were also observed in zooplankton samples, notably, 14 eggs unidentified eggs at 6 stations and 6 eggs of long rough dab at 5 stations and.

Data on the diet of herring in May-June 2015-2017, preserved in formalin and analysed in laboratory on-land, showed rather low occurrence of capelin larvae in herring stomachs. In 2015 (49 stomachs at 2 stations were analysed), unidentified fish eggs were found only in 2 stomachs (4.1%), unidentified fish larvae – in 2 stomachs (4.1%) and capelin larvae – in 1 stomach (2.0%). In 2016 (70 stomachs at 3 stations), unidentified fish eggs were found only in 3 stomachs (4.1%), unidentified fish larvae – in 1 stomach (1.4%) and none capelin larvae were observed. In 2017 (50 stomachs at 2 stations), unidentified fish larvae were found in 3 stomachs (6.0%) and capelin larvae – in 2 stomachs (4.0%, 1 and 7 larvae per stomach respectively).

In addition, the results of herring diet analysis carried out on-board during the cruises in May-June 2002-2017 also showed low importance of capelin larvae in herring diet (Figure 3). Capelin larvae occurred in herring diet only in 3 years. In 2011 capelin larvae was found in 1 stomach at 1 station

(1 stomach was analysed), in 2012 – in 1 stomach at 1 station (3 stomachs) and in 2017 – in 11 stomachs at 1 station (76 stomachs). Weight percent of capelin larvae consisted of 0.07, 10.44 and 3.96% in these years. However, it should be mentioned that other unidentified fish larvae had high weight percent in 2011-2013 (10-46% by weight), and probably some of this fish larvae could be capelin larvae.

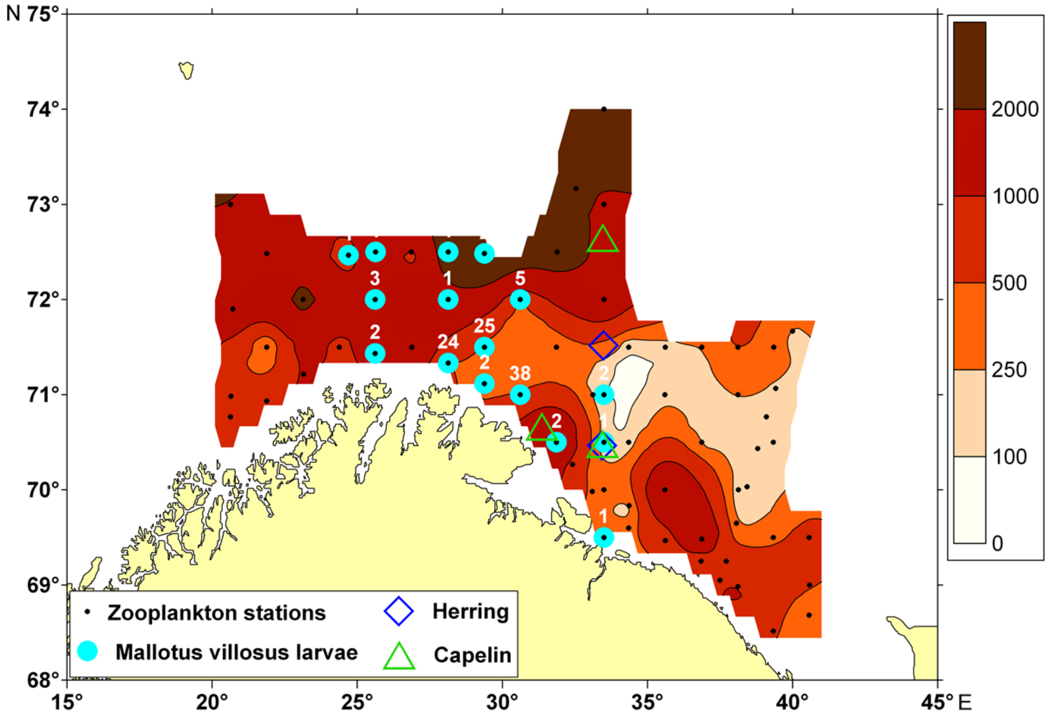
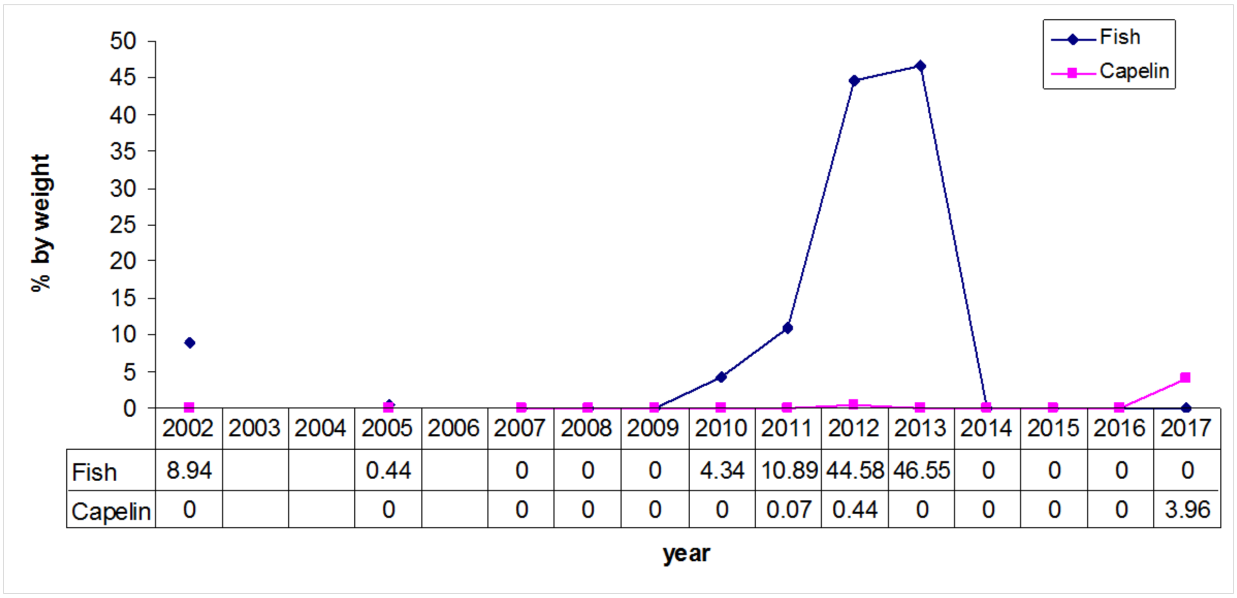


Figure 2. Zooplankton biomass (wet weight, mg · m^{-3}), capelin larvae distribution and location of capelin and herring stomachs sampling stations in 2017.

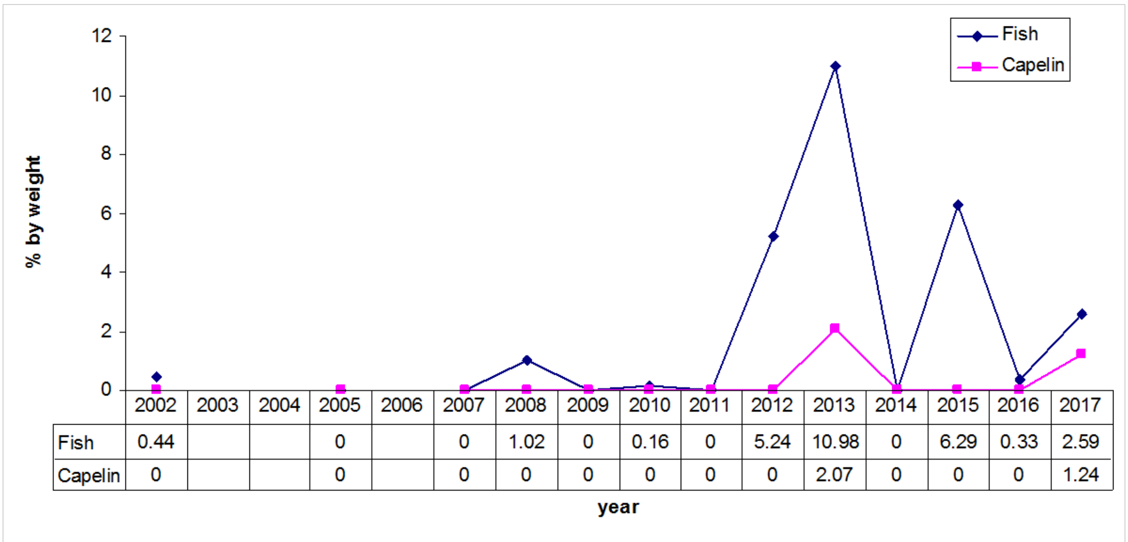


	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Fish	8.94			0.44		0	0	0	4.34	10.89	44.58	46.55	0	0	0	0
Capelin	0			0		0	0	0	0	0.07	0.44	0	0	0	0	3.96

Figure 3. Weight portion of capelin larvae and unidentified fish larvae in herring diet based on on-board stomachs analysis in the southern Barents Sea in May-June 2002-2017.

Analysis of capelin stomachs collected in May-June and analyzed in laboratory on-land showed that there were none capelin or other fish larvae in capelin diet in 2015 (74 stomachs at 3 stations were analysed) and in 2017 (77 stomachs at 3 stations). In 2016 (152 stomachs at 6 stations) 4 fish larvae (probably sandeel *Ammodytes* sp.) were found in 4 stomachs (2.6% of stomachs investigated).

In addition, diet of capelin field data, analysed on-board in May-June 2002-2017, also showed very low cannibalism level (Figure 4). Capelin larvae were observed in capelin diet only in 2 years. In 2013 capelin larvae was found in 4 stomach at 1 station (50 stomachs were analysed), and in 2017 they were observed in 2 stomachs at 1 station (50 stomachs). Weight percent of capelin larvae was 2.07 and 1.24% correspondingly. Other unidentified fish larvae had quite high weight percent in 2012-2013 and 2015 (5-10% by weight) and some lesser in 2002, 2008, 2010, 2016-2017 (0.4-2.5%), and probably some of this fish larvae could be capelin larvae.



	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Fish	0.44			0		0	1.02	0	0.16	0	5.24	10.98	0	6.29	0.33	2.59
Capelin	0			0		0	0	0	0	0	0	2.07	0	0	0	1.24

Figure 4. Weight portion of capelin larvae and unidentified fish larvae in capelin diet based on on-board stomachs analysis in the southern Barents Sea in May-June 2002-2017.

Other possible factors

Capelin recruitment success/failure can be affected not only by predation, but also influenced by other reasons as well. Despite low level of capelin cannibalism in spring period (Huse and Toresen, 1996, our data), can be very high in other seasons.

Juvenile capelin (total length 30-70 mm) was rather important prey for mature capelin (14-16 cm) (Figure 5) in the western and central areas of the Barents Sea in January-March 2008-2013 (Orlova et al. 2014). Based on large number of capelin stomachs Orlova et al. (2014) showed that frequency of occurrence (2-16%) and weight percent (1.6-100%) of capelin juveniles in capelin stomach in winter-spring pre-spawning period in the western and the central areas of the Barents Sea was very high (Table 1). Such predation can have high impact on capelin recruitment.

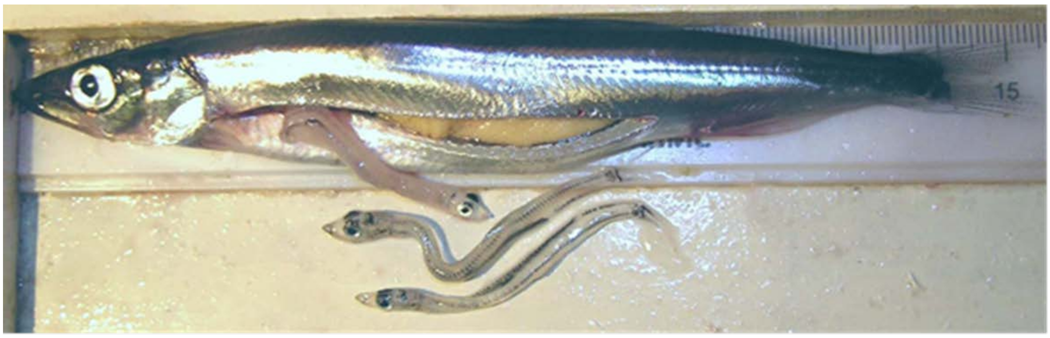


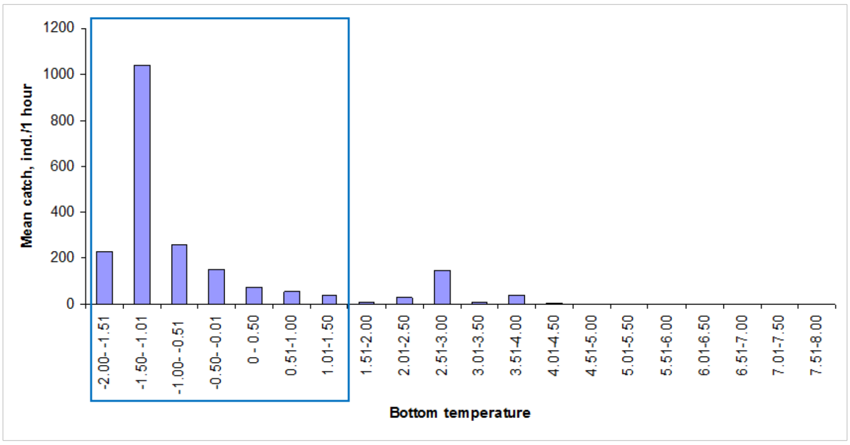
Figure 5. Occurrence of juvenile capelin in stomach of adult capelin, February 2010 (from Orlova et al., 2014).

Other possible reason of opposite trends in abundance dynamics of capelin and herring can be differences in favorable temperature conditions for these species. Capelin usually prefer water with lower temperature compared to herring. Higher catches of capelin in August-September observed at water temperature from -2.0 to 1.5ºC, while herring preferred temperature range from 1.51 to 5.0ºC

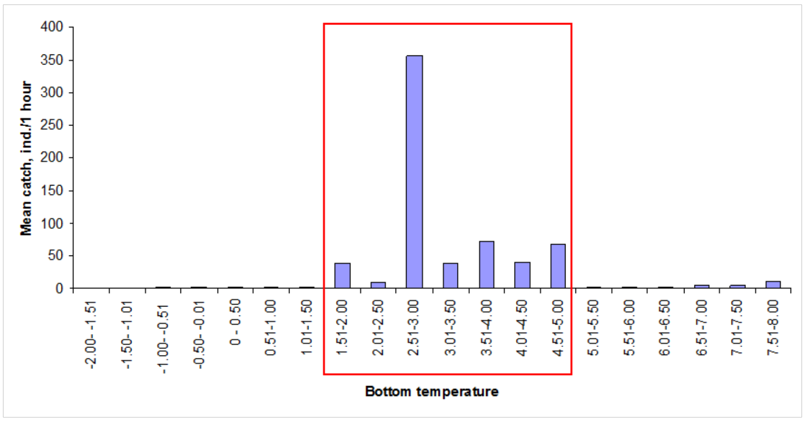
(Figure 6). Mean water temperature weighted by abundance (catch per 1 hour trawling) of capelin and herring was very different and differed to 1-2ºC. Based on the data from winter, ecosystem and autumn-winter surveys in the Barents Sea, mean temperature for capelin was 1.4, 2.5 and 1.1 compared to 2.3, 3.6 and 3.0 for herring in February, August-September and October-December respectively. It means that warming of the Barents Sea can provide more favorable conditions for herring and at the same time adverse conditions for capelin.

Table 1. Frequency of occurrence (% FO) and weight percent (% W) of own juveniles in capelin diet in some local areas in January-March 2008-2013.

Year	Local area	No of stomachs	% FO	% W
2008	The Central Deep	50	16.0	97.3
	The western slope of the Goose bank	150	2.7	0.6
2009	The northern slope of the Murman Shoal	100	6.0	16.2
	The southern slope of the Goose bank	50	8.0	45.6
	The Central Deep	78	1.3	6.7
2010	The western slope of the Goose bank	50	2.0	36.7
	The Central Deep	150	4.7	21.1
	The Central Plateau	50	2.0	1.6
	The northern slope of the Murman Shoal	50	2.0	3.3
2011	The Norwegian Deep	25	8.5	100.0
2013	The Central Elevation	200	14.5	30.0
	The Central Deep	260	6.9	32.3
	The north-eastern slope of the Murman bank	50	14.0	32.2



Capelin



Herring

Figure 6. Mean catches of capelin and herring at different water temperature based on data from the ecosystem survey in August-September 2004-2013.

Conclusions

No considerable predation on capelin larvae was observed in 2010s. It is possible, that importance of herring predation on capelin larvae in 1990-early 2000th was overestimated on the one hand, or different patterns of herring predation on capelin larvae was observed in 1990-early 2000th and in 2010th on the other hand. Another possible reason of recruitment success/failure can be considerable cannibalism of capelin during their pre-spawning migrations in January-March 2008-2013 and different preferable temperature conditions for herring and capelin.

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Diet and growth of capelin and polar cod in the Barents Sea

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In the Barents Sea, stomachs of the commercially important stocks capelin (*Mallotus villosus*) and polar cod (*Boreogadus saida*), were collected for diet analysis during the Joint Norwegian-Russian ecosystem survey in August-September during the periods 2006-2016 and 2007-2016, respectively. These two stocks are the dominant pelagic stocks in the northern and eastern Barents Sea. In general, copepods and euphausiids are the main prey of capelin and polar cod. However, hyperiids are also major prey for polar cod in the northernmost areas. Furthermore, large polar cod prey on fish. The annual diet composition and stomach fullness for capelin is shown in Figure 1 and for polar cod in Figure 2. Inter-annual variability in stomach fullness and growth (weight at age) correspond well for capelin but not for polar cod. An inverse relationship between zooplankton and capelin biomass was observed, especially on the Central Bank.

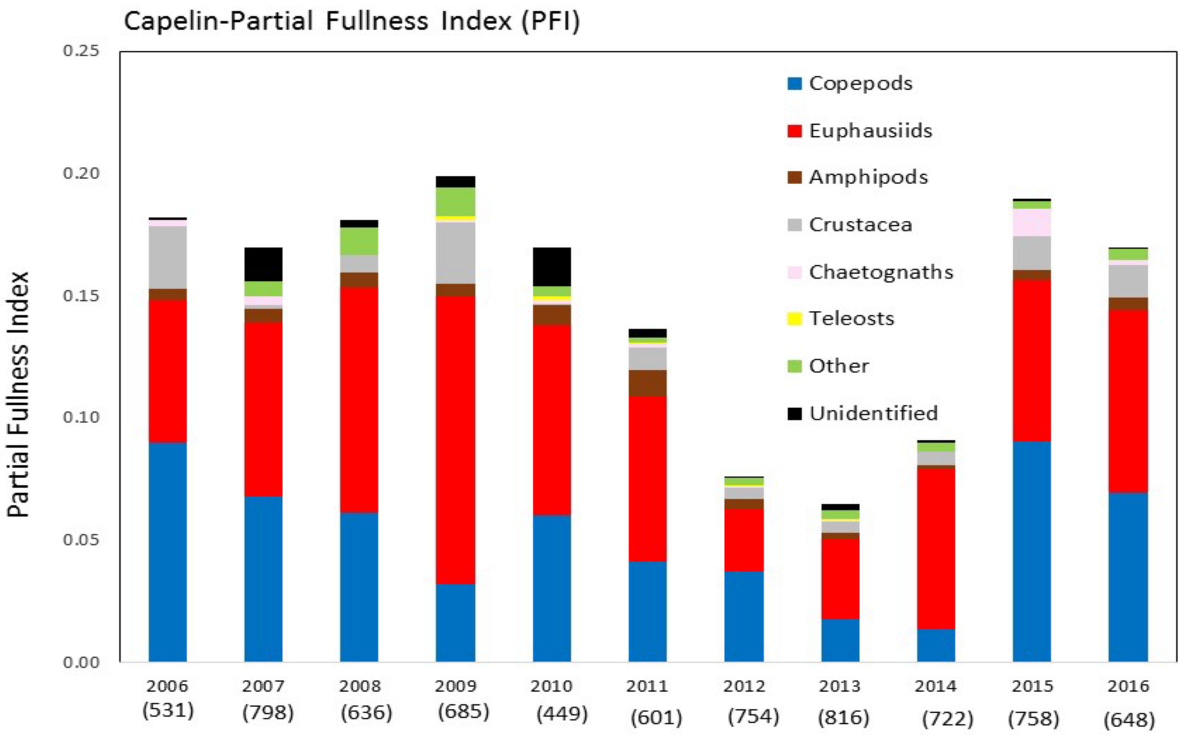

Figure 1. Diet composition and partial fullness index (Lilly and Fleming, 1981) in 2006-2016 for capelin in the Barents Sea. The numbers in brackets indicate number of stomachs sampled annually. The PFI is based on dry weight. Russian data were initially registered in wet weight, while Norwegian data were registered in dry weight. A conversion factor of 5.0 between dry and wet weight has been used.

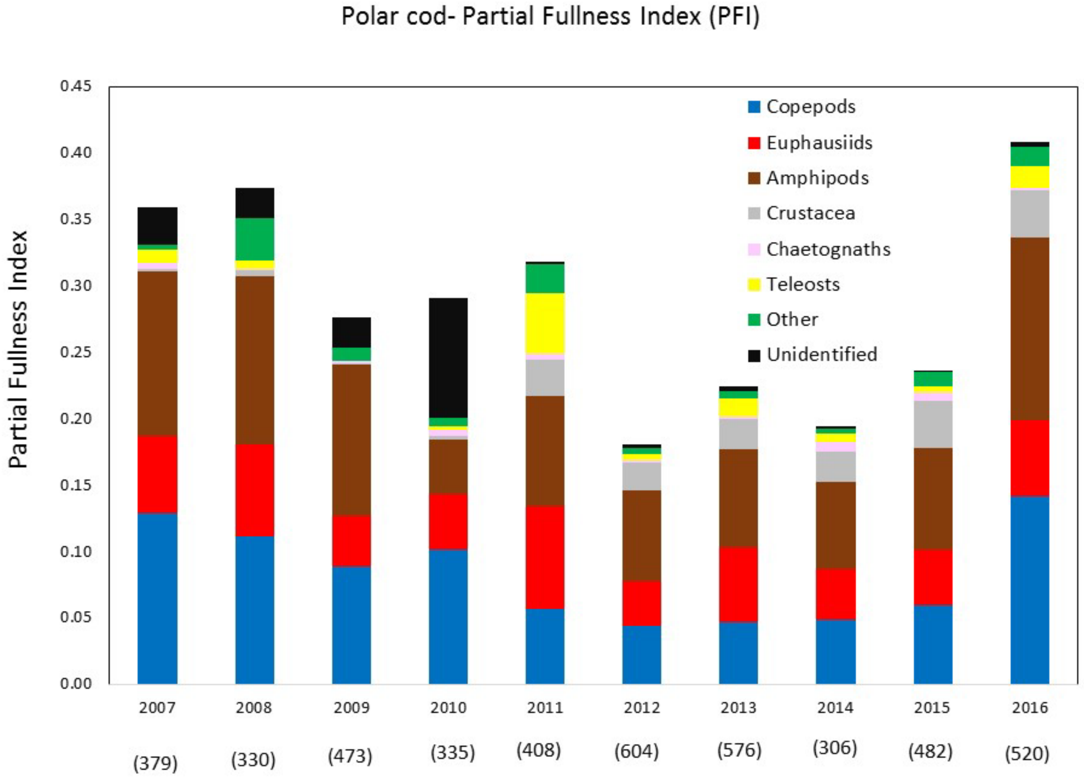

Figure 2. Diet composition and partial fullness index (Lilly and Fleming, 1981) in 2007-2016 for polar cod in the Barents Sea. The numbers in brackets indicate number of stomachs sampled annually. The PFI is in dry weight. Russian data were initially registered in wet weight, while Norwegian data were registered in dry weight. A conversion factor of 5.0 between dry and wet weight has been used.

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Feeding ecology of immature herring *Clupea harengus* in the Barents Sea

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Abstract

The diet of immature herring *Clupea harengus* was analysed based on the samples collected in several cruises conducted by PINRO in the southern Barents Sea in different seasons in 1999-2017. In total 808 individuals of immature herring were analysed. 54 different taxa were identified in the diet of immature herring during the period of investigation. The most diverse diet of herring was observed in May-June, while its food spectrum in November-December was very scant. Though most of the fish contained food in the stomachs, the mean stomach fullness was rather low, and generally did not exceed 100‱. The dominant herring prey in terms of weight were copepods, followed by euphausiids. Copepods were the most important prey group comprising up to 60-80% of the total bolus weight in May-September. Some variability in feeding intensity and prey composition of different age groups of herring was revealed, probably related to the features of seasonal development and distribution of their prey, as well as dietary habits of herring at different stages of their ontogeny.

Keywords: immature herring, feeding ecology, *Calanus finmarchicus*, euphausiids, Barents Sea

Introduction

Norwegian spring-spawning herring (*Clupea harengus* L.) are an important commercial fish in the Northern basin. Herring are distributed from the North Sea to the Novaya Zemlya Archipelago. They spawn along the coast of Norway in February-March. Their larvae and fries drift to the Barents Sea with the Norwegian current waters. The Barents Sea is inhabited by immature herring, which can live there until the age of 3 to 6 years depending on their abundance and rates of development, as well as on water inflow (Marti, 1956, Shutova-Korzh, 1958, Pashkova, Seliverstova, 1988, Hamre, 1990).

A clearly marked seasonal feeding activity is inherent for herring. In the Barents Sea, after winter feeding decline, herring start to feed on zooplankters of spring generation in March-April (Boldovskiy, 1941, Shutova-Korzh, 1966). Herring reach maximal feeding intensity in May-June, while in August-September their index of fullness gradually declines coming to minimal values in December-January (Boldovskiy, 1941, Prokopchuk, Prokhorova, 2010). The main prey of herring year-round are copepods (mainly *Calanus finmarchicus*) and euphausiids (Boldovskiy, 1941, Manteyfel, 1941, Orlova et al., 2001; Орлова и др., 2006; Prokopchuk, Prokhorova, 2010). In spring and summer herring shoals are concentrated in the upper layer with maximal zooplankton biomass, where herring fatten on *Calanus*. In August-September, when zooplankton starts diel migrations, herring also start vertical movements. Increased herring condition results in reducing their feeding activity, developing herring dense aggregations and their descending into lower layers for wintering, while gradual condition decrease leads to herring feeding activation and their ascent to upper layers.

The main objectives of the present study were to examine prey composition of immature herring as well as to investigate seasonal and spatial differences in the immature herring diet in the Barents Sea during the current warm period (1999-2017).

Material and methods

The diet of immature herring was analyzed based on the samples collected in several cruises conducted by PINRO in the southern Barents Sea in 1999-2017. Samples were collected in February in the course of the Joint Barents Sea winter surveys, in May-June during the International ecosystem surveys in the Nordic seas, in August-September in the course of the Joint Russian-Norwegian ecosystem surveys and in November-December in the course of Russian bottom trawl and acoustic surveys.

A standard sample for stomach analysis consisted of 25 individuals (May-September). However, in other seasons, due to low herring abundance, all intact individuals were collected, and the number of fish varied from 1 to 30 specimens per sample. Herring was preserved whole in 10% formalin for the detailed analysis in the laboratory on-shore. In total, 808 individuals of immature herring were examined (Table 1). The location of herring stomach sampling stations is shown in Figure 1.

Table 1. The number of immature herring for stomach analysis in the Barents Sea in 1999-2017.

Year	The number of immature herring, ind.			
	February	May-June	August-September	November-December
1999		24		
2001		97		
2003			20	
2005		106		
2007		128	165	
2010	6			46
2012		20		
2015		50		
2016	37	73		
2017		50		
Total:	43	524	185	46
Stomachs with food, %	79.2	96.4	95.6	8.7

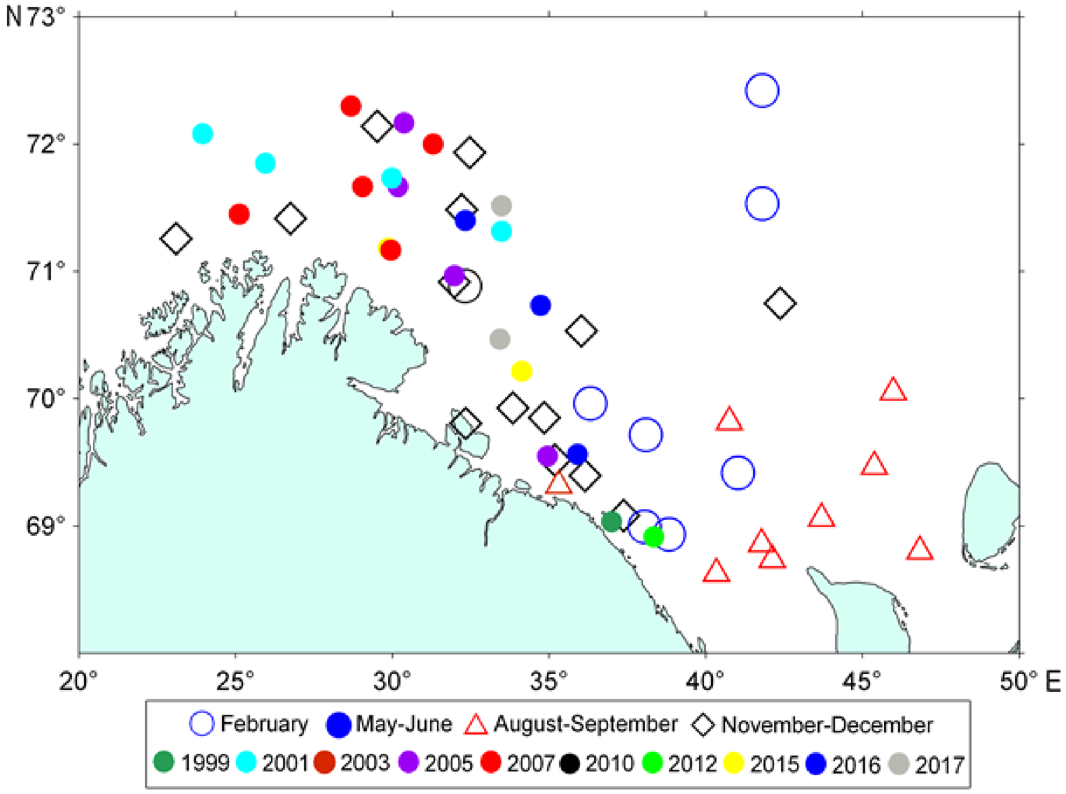

Figure 1. Location of stations for immature herring stomach analysis in the Barents Sea if 1999-2017.

Each fish was weighed (with the accuracy to 0.1 g) and measured (with the accuracy to 1 mm), its sex, maturation, condition and stomach fullness were determined. The content of each stomach was emptied into a Petri dish and examined by means of a binocular microscope. Prey were identified to the lowest possible taxonomic level, counted and weighed. Well-preserved organisms were measured. The weight of small organisms was calculated on the basis of individual weight of plankton organisms (Kanaeva, 1962, Pertsova, 1967; Prokopchuk, unpublished) considering the degree of digestion. Copepods were sorted out according to developmental stages and the abundance of each stage or stage group was estimated. Stomach samples were collected and processed using standard PINRO methods (Anon, 1974).

To determine herring feeding intensity the total (ratio of total stomach content weight to total weight of fish multiplied by 10^4, ‱) and partial (ratio of prey weight to total weight of fish multiplied by 10^4, ‱) stomach fullness indices were calculated. The importance of different prey was calculated based on the frequency of occurrence (FO, % of the total number of fish analyzed), the prey’ share by weight (W, % of the bolus total weight) and the index of relative importance (IRI, %).

$$IRI = (F*(N+W))*100$$

where, F – frequency of occurrence, %, N – number of prey, %, W – weight of prey, %) (Pinkas et al., 1971; Cortés, 1997).

Results

Herring collected for stomach analysis in February were the smallest (the mean length of 110.2 mm, the mean weight of 7.5 g), while in May-June the largest herring were examined (the mean length of 164.4 mm, the mean weight of 33.6 g). The mean length and the mean weight of herring in August-September and November-December were 133.3 mm and 15.5 g, and 154.8 mm and 23.3 g, respectively. Herring condition was low and in different seasons varied from 0.8 (May-June) to 1.3 (August-September). Of the 808 herring stomachs analysed, 728 (90.1%) were found to contain food. The highest portion of empty stomachs was found in November-December (93.1%), and the lowest one in May-June (3.6%).

In total, 54 different taxa of 7 phyla were observed in the diet of herring. The most various prey spectrum was observed in the diet of herring in May-June and included 45 items (Table 2). In August-September the list of prey reduced to 34 items. In February 10 different prey items were consumed, while in November-December only 4 items were found.

Copepods and euphausiids were the most frequently occurred prey groups in herring diet (Table 2). *C. finmarchicus* was the most often observed copepod in herring stomachs, and its FO was higher in May-June (81.3%) than in August-September (41.7%). At the same time, FO of small copepods *Pseudocalanus* sp. and *Temora longicornis* considerably increased from May-June to August-September (from 18.1 to 54.3% for *Pseudocalanus* sp. and from 5.1 to 53.7% for *T. longicornis*) (Table 2). Euphausiids larvae were more often found in herring stomachs in May-June than in August-September (70.0 and 45.7% correspondingly). FO of cirripeds larvae (from 18.1 to 56.6%) and cladocera (from 11.6 to 67.4% for *Evadne nordmanni* and from 0.4 to 12.0% for *Podon leuckartii*) appreciably increased from May-June to August-September (Table 2). Adult euphausiids were more often found in herring stomachs in autumn-winter (Table 2).

Weight portion of different prey items varied in different seasons. Copepods were the most important prey in terms of weight from May to September coming to 80.4% (*C. finmarchicus* 79.2%) in May-June and 63.9% (*C. finmarchicus* 24.2%) in August-September (Table 2).

Euphausiids dominated in the herring diet in February (94.1% by weigh) and November-December (98.4%), while in other seasons they were less important (8.7% in May-June and 16.7% in August-September) (Table 2).

Table 2. Frequency of occurrence (*F*), weight portion (*W*) and Index of Relative Importance (*IRI*) of herring prey in the Barents Sea in 1999-2017. F – February; M – May-June; A – August-September; D – November-December.

Taxon	*F*, %					*W*, %				*IRI*, %			
	Total	F	M	A	D	F	M	A	D	F	M	A	D
Polychaeta larvae/juv.	6.0		6.9	5.1			<0.1	<0.1			<0.1	<0.1	
Pectinaria sp.	0.1		0.2				<0.1				<0.1		
Evadne nordmanni	24.0		11.6	67.4			<0.1	4.2			<0.1	21.7	
Podon leuckarti	3.1		0.4	12.0			<0.1	<0.1			<0.1	<0.1	
Copepoda ova	6.8			28.6				0.1				2.1	
Copepoda nauplii	0.1			0.6				<0.1				<0.1	
Acartia sp.	5.8		1.0	21.7			<0.1	0.4			<0.1	0.3	
Calanus finmarchicus	66.8	15.4	81.3	41.7		1.2	79.2	24.2		2.0	90.2	12.1	
Calanus glacialis	0.1			0.6				<0.1				<0.1	
Calanus hyperboreus	0.3			1.1				<0.1				<0.1	
Centopages sp.	0.7		1.0				<0.1				<0.1		
Metridia sp. juv.	1.2		1.8				<0.1				<0.1		
Metridia longa	4.6	13.5	4.5	2.3		0.2	0.3	<0.1		0.6	<0.1	<0.1	
Metridia lucens	2.2	23.1	0.6	0.6		2.3	<0.1	<0.1		22.4	<0.1	<0.1	
Microcalanus sp.	0.5		0.6				<0.1				<0.1		
Pseudocalanus sp.	25.3		18.1	54.3			0.3	28.5			0.1	34.4	
Temora longicornis	16.3		5.1	53.7			<0.1	10.4			<0.1	19.0	
Oithona similis	6.5		1.8	22.3			<0.1	0.1			<0.1	0.5	
Oithona atlantica	0.4		0.4	0.6			<0.1	<0.1			<0.1	<0.1	
Harpacticoida g. sp.	0.1		0.2				<0.1				<0.1		
Microsetella norvegica	1.8		0.8				<0.1				<0.1		
Cirripedia g. sp. larvae	25.9		18.1	56.6			<0.1	1.5			<0.1	1.6	
Euphausiacea g. sp. larvae	58.9		70.0	45.7			7.7	4.9			8.6	3.0	
Euphausiacea g. sp.	13.1	44.2	9.9	12.6	25.0	13.6	3.0	7.3	<0.1	14.7	0.2	1.0	21.5
Meganyctiphanes norvegica	1.2		1.0	2.3			2.6	4.1			<0.1	0.1	
Thysanoessa inermis	3.8	36.5	1.6		50.0	57.7	2.4		98.4	46.0	<0.1		74.7
Thysanoessa longicaudata	0.1	1.9				2.5				0.2			
Thysanoessa raschii	2.3	28.8	0.2	0.6		20.3	0.7	0.5		14.0	<0.1	<0.1	
Decapoda g. sp. larvae	0.4		0.6				<0.1				<0.1		
Hyas sp. larvae	1.1		0.8	2.3			<0.1	<0.1			<0.1	<0.1	
Pagurus sp. larvae	4.6		0.8	17.1			<0.1	5.2			<0.1	1.0	
Caridea g. sp. larvae	1.6		1.4	2.9			<0.1	<0.1			<0.1	<0.1	
Munnida sp. larvae	0.1		0.2				<0.1				<0.1		
Themisto sp.	0.1		0.2				<0.1				<0.1		
Themisto abyssorum	1.1		1.2	1.1			<0.1	0.1			<0.1	<0.1	
Gastropoda g. sp. juv.	0.8			3.4				1.1				0.1	
Limacina helicina	0.1				25.0				<0.1				1.6
Limacina retroversa	1.2	3.8	0.6	2.3		<0.1	<0.1	<0.1		<0.1	<0.1	<0.1	
Bivalvia larvae	11.4		0.2	47.4			<0.1	0.3			<0.1	2.1	
Cephalopoda g. sp.	0.1		0.2				<0.1				<0.1		
Bryozoa larvae	0.1			0.6				<0.1				<0.1	
Chaetognatha g. sp.	5.8		1.4	20.0	25.0		0.1	4.4	1,6		<0.1	0.9	2.2
Parasagitta elegans	0.3		0.4				<0.1				<0.1		
Echinoidea larvae	0.9		1.4				<0.1				<0.1		
Holothuroidea larvae	0.5		0.8				<0.1				<0.1		
Ophiuroidea larvae/juv.	6.1		8.5	1.1			<0.1	<0.1			<0.1	<0.1	
Fritillaria borealis	2.2		3.2				<0.1				<0.1		
Oikopleura sp.	10.4		15.0	0.6			2.0	<0.1			0.5	<0.1	
Pisces g. spp. ova	3.4		4.1	2.3			<0.1	<0.1			<0.1	<0.1	
Pisces g. spp. larvae	8.7	1.9	11.8	1.7		<0.1	0.8	1.7		<0.1	<0.1	<0.1	
Pisces g. spp.	0.3	1.9		0.6		2.2		0.9		0.1		<0.1	
Clupea harengus larvae	0.1		0.2				<0.1				<0.1		
Mallotus villosus larvae	0.5		0.8				<0.1				<0.1		
Undetermined	0.7		1.0				0.4				<0.1		

Concerning the Index of Relative Importance, *C. finmarchicus* was the most important prey of herring in May-June (90.2%) (Table 2). However, in August-September IRI of *C. finmarchicus* considerably decreased (up to 12.1%), but the IRI of small copepods *Pseudocalanus* sp. and *T. longicornis* had a multifold increase (from 0.1 to 34.4% for the former and from <0.1 to 19.0% for the latter).

Considerable individual variability of the herring stomach fullness index (SFI) was observed in the investigated period; however, its mean SIF was quite low and did not exceed 100‰. The highest mean value of herring SFI was found in February (134.9‰), while the lowest value was found in November-December (33.3‰). In May-June the herring mean SFI was 81.9‰, and in August-September it was 53.6‰.

Substantial interannual differences of mean herring SFI were also found (Figure 2). In February 2010, the herring SFI was 34.0‰, while in 2016 it reached 176.9‰. In August-September 2003, the SFI was very low (10.9‰), and in 2007 it was 58.2‰. In May-June, its value varied from 34.5 to 136.7‰ (Figure 2). In May 2012, the herring SFI reached the maximum value of 408.8‰ that, however, could not indicate a real situation due to a low number (20 specimens) of analysed herring stomachs. For all those variations in herring SFI, copepods and, to a lesser degree, euphausiids larvae were the main prey consumed from May to September, while adult euphausiids dominated in herring diet in February and November-December (Figure 2).

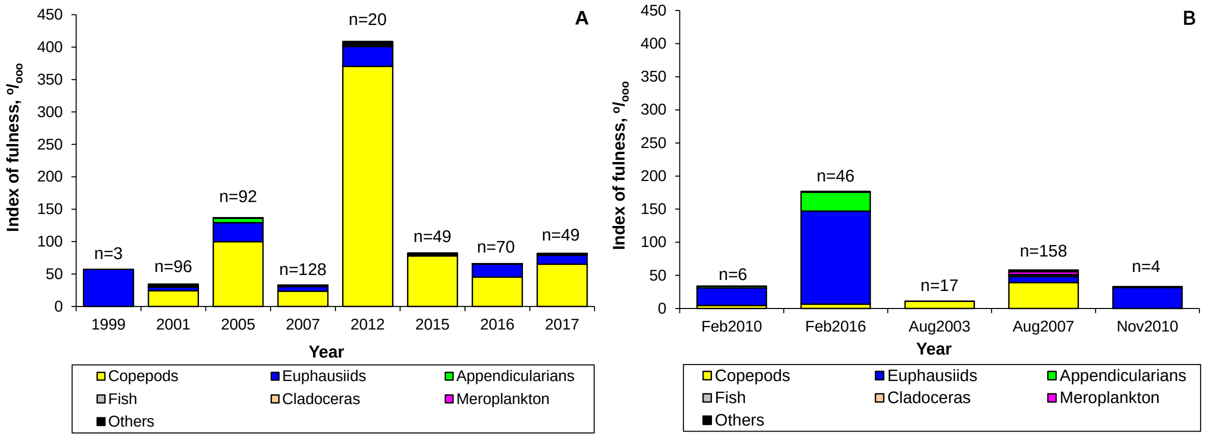

Figure 2. Feeding intensity and the diet of immature herring in the Barents Sea in different seasons 1999-2017. Number above the bars are the number of stomachs with food.

In spite of spatial differences in herring feeding intensity, *C. finmarchicus* was the principal prey for herring in May-June at most of the stations, while larvae and adult euphausiids were important at a few stations (Figure 3). Copepods were also the dominant prey for herring at most locations in August-September, and euphausiids, chaetognaths, cladocera and larvae of bottom invertebrates were significant at some stations (Figure 4). In February, herring preyed on euphausiids, and in November-December, euphausiids, chaetognaths and heteropods (group “Others”) were present in herring stomachs (Figure 5).

Since copepods dominated in herring diet, *C. finmarchicus* was the most important prey for herring, especially in May-June, coming up to 99% of the total bolus weight. Stage composition of *C. finmarchicus* differs in different seasons (Figure 6A). In May-June, mainly copepodite stages II-IV were consumed by herring, while in August-September copepodites IV-V prevailed (Figure 6A). The number of *C. finmarchicus* individuals eaten by herring in May-June was much higher compared to August-September (867 and 31 ind. per stomach respectively). In addition, interannual variations in the number of *C. finmarchicus* consumed as well as in its stage composition in May-

June were observed (Figure 6B). Herring preyed on *C. finmarchicus* most intensively in 2012 and 2015 (3000-3837 ind. per stomach), while in 2007 and 2017 only 601-721 ind. of *C. finmarchicus* per stomach were consumed. In May-June 2001-2007, herring fed on III-V copepodites of *C. finmarchicus*, in 2012 mainly individuals CII-III were found in the stomachs, in 2015 herring preyed on II-V copepodites of *C. finmarchicus*, and in 2016-2017 individuals of II-IV copepodite stages dominated in their stomachs (Figure 6B).

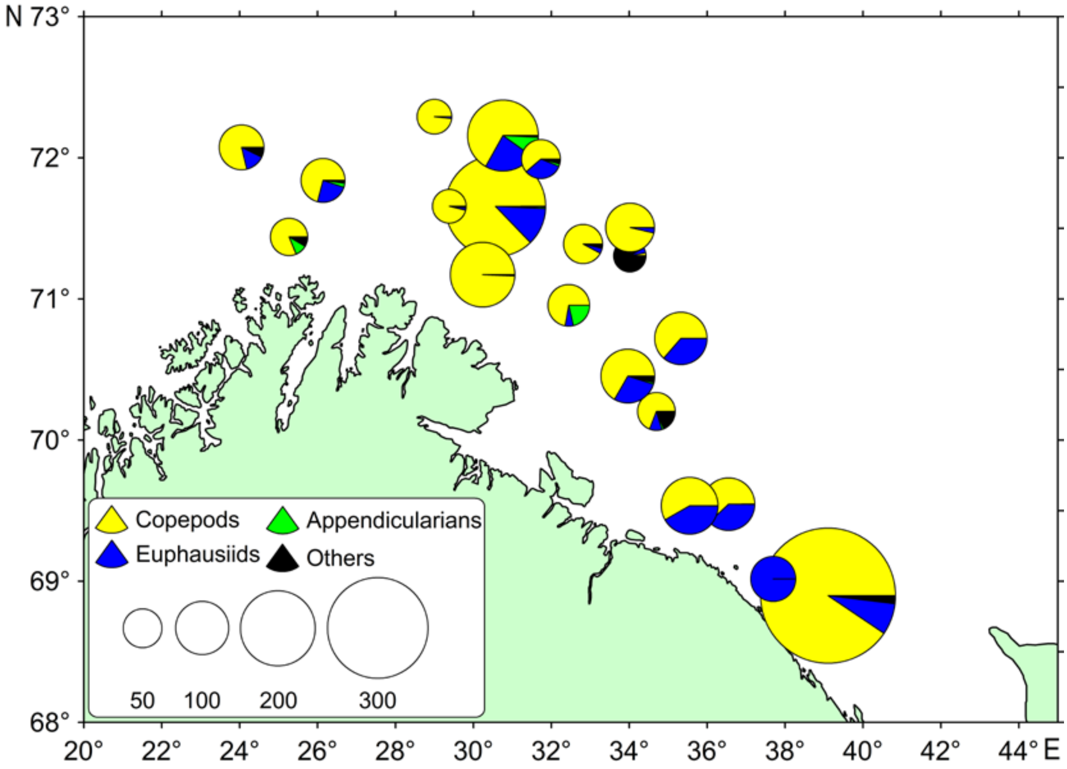

Figure 3. Diet of immature herring in the Barents Sea in May-June.

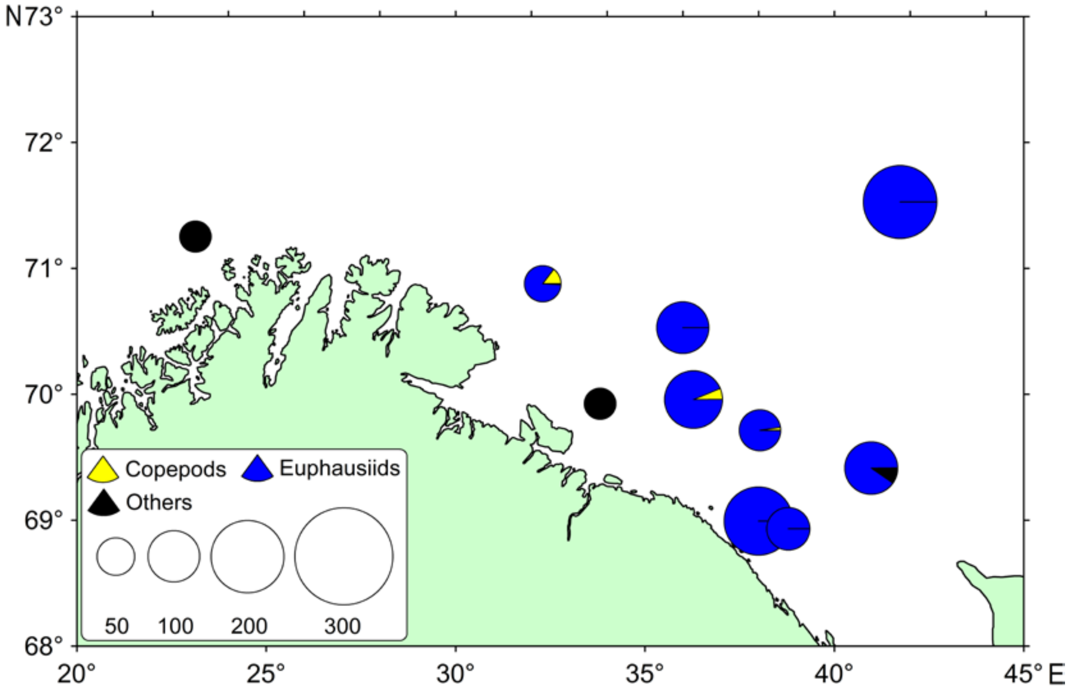

Figure 4. Diet of immature herring in the Barents Sea in August-September

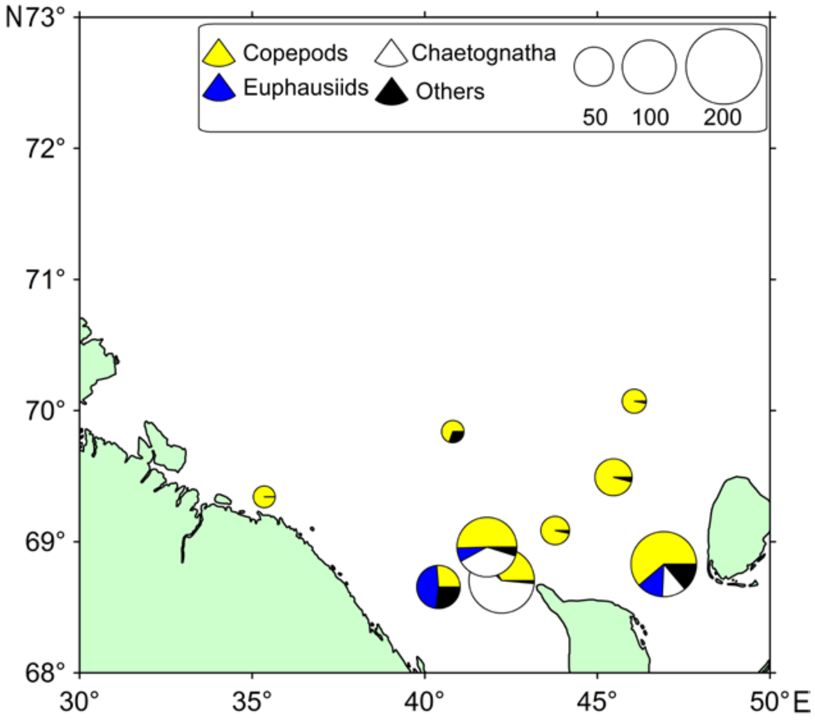

Figure 5. Diet of immature herring in the Barents Sea in February and in November-December.

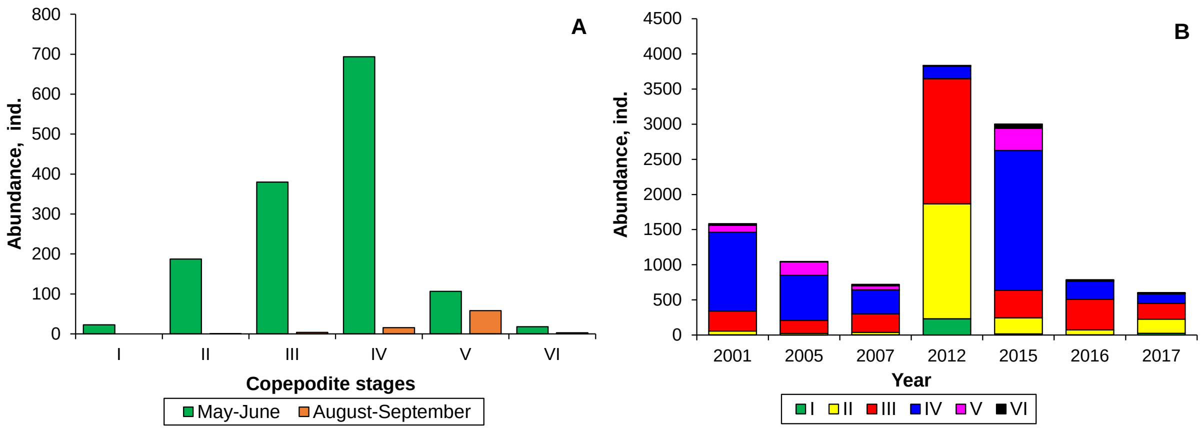

Figure 6. Seasonal and interannual changes of *C. finmarchicus* stage composition in the diet of immature herring in the Barents Sea. A – in May-June and in August-September, B – in May-June of different years.

Discussion

The results of present investigations of herring diet in the Barents Sea confirmed previous studies that copepods and euphausiids are the main prey for herring (Boldovskiy, 1941, Manteyfel, 1941, Huse, Toresen, 1996, Orlova et al., 2001). In other areas, for example, in the North Sea, herring consumed euphausiids, copepods and hyperiids, as well as fish eggs (Last, 1989). Last (1989) also discovered seasonal differences in herring diet, notably, he found, that in February *C. finmarchicus* was the most numerous prey (50.4%), in May *T. longicornis* comprised 93.4%, and in August *C. finmarchicus* (48.1%) dominated again. Probably, the changes in herring diet showed seasonal changes in zooplankton communities of the North Sea. Dominant role of *C. finmarchicus* in herring diet in the North Sea was also observed by Ogilvie (1934). In August, euphausiid *M. norvegica* and *Calanus* sp. were found in the stomachs of 8-12-cm herring in the Irish Sea (Rice, 1963).

In the annual cycle of herring diet in the Barents Sea copepods (mainly *C. finmarchicus*) comprised about 50% by weight (Prokopchuk, Prokhorova, 2010). Differences in amount and the stage structure of *C. finmarchicus* consumed by herring in May-June and August-September can reflect the population structure of *C. finmarchicus* in different seasons, as well as indicate herring selective feeding. In May-June, mass development of *C. finmarchcicus* was observed in the southern Barents Sea, and zooplankton biomass was high in that period, favouring good feeding conditions for planktivorous fishes and other plankton feeders. In August-September in the south-eastern Barents Sea plankton biomass was low due to development of numerous but small copepods (*Oithona similis, Microsetella norvegica, Acartia* sp., *Temora longicornis*) and cladocera (Manteyfel, 1941). The abundance of *C. finmarchcicus* in that period was by several orders of magnitude lower than in May-June and mainly copepodites IV-V (which formed wintering stock) were present in its population. Moreover, some zooplankters and *C. finmarchicus* and euphausiids in particular, started active diel vertical migrations and preparation for overwintering. In autumn, herring also descended into the bottom layer for wintering (Shutova-Korzh, 1960). Herring feeding activity gradually decreased and the number of its prey reduced as plankton in autumn-winter months was quite scarce and the main prey for herring (*Calanus* spp., euphausiids, *Themisto* spp., *Paraeuchaeta norvegica* и *Metridia longa*) were wintering in bottom layers (Manteyfel, 1941). In winter, predation, by herring included, seems to be an important factor regulating loss in zooplankters populations and *Calanus* spp. in particular (Manteyfel, 1941, Espinasse et al., 2018). Thereby, seasonal change of zooplankton species composition and changes in accessibility of prey in different time of the year have an influence on herring diet and their fattening success.

As a planktivorous fish, herring depend on zooplankton community structure. *C. finmarchicus* is the dominant zooplankton species in the southern Barents Sea and its mass development takes place in May-July (Jashnov, 1939). The southern Barents Sea (the area of immature herring distribution) is influenced by warm Atlantic waters penetrating along with the North Cape Current from the Norwegian Sea. Zooplankton, and *C. finmarchicus* first of all, is drifting into the Barents Sea with the Atlantic waters, thereby recruiting local population. Plankton biomass depends on water temperature and in summer it makes up 200 mg · m^{-3}, while at a low predation level it increased up to 500-700 mg · m^{-3} (Drobysheva, Nesterova, 2005). A substantial temperature increase in the southern Barents Sea has been observed since the beginning of 1999, and the temperature has remained above the average value (González-Pola et al., 2018). It was found that zooplankton biomass is higher in the years with high water temperature and strong water inflow from the Norwegian Sea (Prokopchuk, Trofimov, unpublished results). However, high water temperature can negatively affect *C. finmarchicus* population because high temperature accelerates its development rate, reduces the period of its pelagic life and promotes *C. finmarchicus* earlier descent for wintering into the bottom layer, thus reducing its availability for herring.

Trophic relationships of herring in the Barents Sea are quite complicated. Herring have few competitors during its foraging season, especially in the eastern area, as capelin and polar cod are distributed farther to the north of the main herring habitat. In the area of herring and capelin overlap they do not enter into competition in spite of the similar diet as their vertical distribution is different (Huse, Toresen, 1996). Adult cod prey on herring and young cod up to 3 years old can compete with herring consuming euphausiids (Zatsepin, Petrova, 1930; Dolgov, 2016), however, due to spatial and temporal dissociation of their foraging strong competition between them is not observed. Young individuals of commercial fishes such as cod, haddock, capelin, herring etc., are strong competitors for herring on the one hand, and can be herring prey in some seasons, on the other hand (Manteyfel, 1941, Huse, Toresen, 2000). In our study, fish larvae were occasionally observed in the herring diet but they were not of any importance. Strong herring competitors can be jelly-fishes and ctenophores in the period of their mass development (Manteyfel, 1941). According to our investigations, in August-September 2007, in the eastern Barents Sea, namely, westwards 50° N (the area of herring distribution) a high number of ctenophores was observed that probably affected quantitative and qualitative composition of zooplankton and herewith the herring diet as well.

Summary

Thereby, in spite of high variety of different prey in the immature herring diet in the Barents Sea, their main prey were copepods, with the dominance of *C. finmarchicus*, and euphausiids. Copepods were important in herring diet in spring-summer, while in autumn-winter euphausiids dominated. Feeding intensity of herring was the highest in February and the lowest in November-December. However, as the number of herring stomachs was quite low in February and November-December, and the percentage of empty stomachs was high in November-December, it is necessary to continue investigations of herring diet in these seasons.

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New spatial 0-group fish abundance indices: step towards a better understanding of fish recruitment

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The Barents Sea has experienced substantial warming over the last few decades with expansion of relatively warm Atlantic water, polar ward shift of fish and decreased of arctic species. Based on a WGIBAR division of the Barents Sea in to 15 subareas we estimated a new spatial abundance indices of 0-group fish species (capelin, cod, haddock, herring, redfish and polar cod) and fish length for each sub area for the period 1980-2017. We studied temporal and spatial fluctuations of 0-group abundance indices and how spawning stock biomass and climate driven changes in the ecosystem influence recruitment success. Warming were linked to increased of pelagic biomasses, including 0-group fish. If warming is an important controlling factor for juvenile's abundance and distribution, then we expected that importance of spawning stock biomass could be reduced due to higher survival of fish larvae and juveniles during the first summer. Additionally, we studied similarity of occurrence of strong or weak year classes and if that changes during the recent warming.

Ecosystem impact on formation of the year-classes strength of haddock (*Melanogrammus aeglefinus*) in the Barents Sea

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The study is devoted to investigation of ecosystem impact on dynamics of the haddock recruitment in the Barents Sea. This problem of the great interest in connection with climate change. Haddock *Melanogrammus aeglefinus* is a valuable fishery resource and one of the most important species in the demersal communities in the Barents Sea ecosystem. Large annual changes in stock size of haddock are caused by very strong differences in recruitment. Rich year classes at age 3 can exceed an abundance of poor year-classes more than 100 times. Water temperature strongly affects the recruitment of haddock mainly through a high natural mortality of juveniles during the first wintering in the cold years.

Data on abundance and distribution in 1980-2017 of haddock at age from 6 months (0-group) to 3 year old were used in the study. Spatial distribution of the haddock juveniles was evaluated using data from the Russian multispecies trawl-acoustic survey in November-December. Abundance indices of 0-group of haddock and numbers of recruits at age 3, as well as the estimations of consumption of haddock by cod, were taken from the report of the ICES Arctic fisheries working group (ICES, 2017). PINRO data on annual water temperature on the Kola section in depth of 0-200 m were used as an indicator of temperature conditions.

It was concluded that the current warming of the Barents Sea changes the mechanism driving recruitment of the haddock. Mortality during the first wintering, induced by unfavorable temperature conditions, has lost as a dominant importance for year-class formation. This leads to increase a link between abundance indices of haddock at the stage of 0-group and its number at age 3. This means that contribution of survival rate of haddock at stages of larvae and pelagic juveniles into the formation of its year-classes strength has been increased since the end of the last century. The extremely strong year-classes of haddock 2004-2006 was extremely abundant at the 0-group stage.

However, the high abundance of 0-group of haddock is only a necessary but not sufficient factor leading to appearance of numerous recruitment at age 3. Mortality due to cod predation may significantly reduce survival after the 0 -group stage. Thus, the relatively high number of 0-group of haddock in 2009-2010 did not lead to the strong recruitment to the stock. These year classes recruited into fishery in a period when the cod stock was at the level of historical maximum and was characterized by a large proportion of fish of older age groups. Accordingly, the consumption of haddock juveniles in those years was also very high, which affected survival until juveniles were reaching the fishing size.The regulatory role of cod in formation of year-classes strength of haddock depends on not only the cod stock size and age composition. It also varies depending on cod's food supply (especially on capelin availability) as well as the overlap between the cod and juvenile haddock distributions.

Annual changes in growth rate of haddock (*Melanogrammus aeglefinus*) in the Barents Sea

Alexey Russkikh

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The study is devoted to analysis of complex influence of environmental as well as density of population on growth rate of haddock in the Barents Sea during the first 7 years of its life. The water temperature and density of population being the principal factors that determine a haddock individual growth rate. Increase in population density can be induced both by a reduction in the distribution caused by unfavorable temperature conditions, and by increasing the abundance. According to the literature, a decrease in the rate of individual growth of haddock leads to a later maturation and lower fecundity.

Dependence of the rate of haddock growth on water temperature and population density was considered for the generations of 1993-2009. It has been revealed that population density affects the rate of haddock growth in the larger extent than the warming of the Barents Sea. Super-abundant generations of 2004-2006 had the lowest rate of growth, although they grew in anomalous warm years. The recruitments produced by them were estimated as weak. The obtained results show that in the conditions of warming of the Barents Sea observed in the recent decades, the role of the population density factor as a regulator of the rate of haddock growth increases, despite the expansion of area of its distribution.

Tropho-spatial variability in Barents Sea fishes determined by stable isotope analysis

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The overall aim of this study was to improve understanding of the trophic interactions, and food web structure and functioning in the Barents Sea ecosystem, as part of the TIBIA and SI_Arctic research projects at IMR. Fishes were captured by campelen, harstad and åkra trawls during the TIBIA, SI_Arctic, and Ecosystem Survey cruises for the Institute of Marine Research, between 2014 and 2016. These cruises covered the entire area of the Norwegian Barents Sea from northwest of Svalbard to the Norwegian coast and the central Barents Sea. Over 1600 fish muscle samples were analysed for carbon and nitrogen stable isotope composition, with over 1500 of these originating from the Ecosystem Survey cruise of 2015.

Here we report stable isotope data for a total of 57 fish species. We demonstrate patterns in relative trophic position and specialism both geographically and by size. We relate patterns to those seen in stomach content data from the same fishes to compare short-term, high resolution diet data with longer-term, integrated stable isotope measurements. We show how the Barents Sea fishes fit into the overall functioning of the ecosystems by species and by size, demonstrating how we can observe the connectivity between pelagic and benthic feeding areas.

Shifts in functional trait distribution and ecosystem functioning in the Barents Sea marine fish communities affected by climate change

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Climate change affects species distribution and diversity across the globe. Marine fish species are particularly prone to show early signs of climate-driven changes in distribution because the barriers to their movement are often environmental (e.g., temperature, salinity) instead of physical as for many terrestrial organisms. In the Barents Sea, marine fish show a zoogeographic divide between Atlantic and Arctic waters. There, demersal fish species have shown a poleward shift in distribution following the increase in warmer waters from the North Atlantic. We assessed 15 functional traits of 52 demersal fish species, totalizing 3600 sampling stations over nine years of survey covering the entire Barents Sea and assessed whether the recent period of warming (from 2004 to 2012) has caused a shift in the functional composition of the marine fish communities. We found that the Arctic communities are rapidly converging into boreal communities and the niche width of the Arctic communities has expanded even more quickly, indicating that the majority of traits typical of boreal communities is already present within the Arctic communities. Traits related to large body-size, generalist consumption, and higher development rate are becoming more common in the Arctic, with strong implications to ecosystem functioning in the region.

Evaluation of potential sources of error leading to an underestimation of the capelin stock in 2016

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Abstract

A rapid decline in stock size of Barents Sea capelin was recorded from 2014 onwards, and in 2016 the lowest biomass of capelin since 2005 was estimated from the joint Russian-Norwegian autumn Barents Sea Ecosystem Survey (BESS). The capelin estimate from 2017, however, was so much higher that the results from 2016 and 2017 were incompatible when comparing cohorts. For several reasons, the assessment group concluded that the 2017 survey was the more reliable of the two. Here, we try to look deeper into the possible reasons for the incompatible survey results in 2016 and 2017, taking also the 2018 survey results into account. Various possible reasons for the discrepancy are sought for. We consider survey coverage and geographical distribution of capelin, possible bias caused by wrong interpretation of echograms and hence wrong allocation of acoustic backscatter, potential influence of the vertical distribution of capelin, possible bias due to capelin migrations during the surveys, as well as errors from biological sampling. Definite conclusions cannot be reached, but error in interpretation of the acoustic backscattering (echogram scrutiny) is evaluated to be the single candidate with the highest potential to explain an underestimation of capelin in the 2016 survey.

Keywords: Barents Sea capelin, Acoustic survey, Underestimation

Background

The Barents Sea capelin stock has been monitored acoustically in the autumn since the early 1970s, most of the period as a joint venture between PINRO, Murmansk and IMR, Bergen (Gjøsæter, 2011). Since a TAC-based management of capelin began in the late 1970s, these annual surveys have been key events underpinning the stock assessment and management advisory process. This is one of a few cases where an acoustic stock size estimate is considered an absolute estimate of stock size, and the maturing part of the stock forms basic input to the population model used for advisory work (Gjøsæter et al., 2012). Consequently, the TAC advice given for capelin is totally dependent of this autumn investigation. The history of stock estimates obtained (Figure 1) shows that the stock abundance of capelin has fluctuated considerably, and therefore an annual update of stock size is a prerequisite for good management advice.

A rapid decline in stock size of Barents Sea capelin was recorded from 2014 onwards, and in 2016 the lowest biomass of capelin since 2005 was estimated from the survey. This resulted in a zero-catch advice. However, the survey result from 2017 was so much higher that the results from 2016 and 2017 were incompatible when comparing cohorts. For several reasons, the assessment group considered the 2017 survey to be more reliable than the 2016 survey, and ICES advised a TAC of 205 000 tonnes for the winter fishery in 2018. The quota was set equal to the advice, and almost the entire quota (195 000 tonnes out of 205 000 tonnes) was taken. The view that capelin abundance was underestimated in 2016 gained support by observations during the fishing season of 2018, and in particular when the results from the 2018 survey showed good consistency with the 2017 results. There are several examples from the time series of capelin monitoring where a negative survey mortality has been estimated, in particular between age-1 and age-2 fish demonstrating inconsistencies in survey results. However, discrepancies between consecutive survey years have never been as large as observed between 2016 and 2017 (Figure 2). In the present work we explore and revisit some of the survey results to seek for possible explanations to the inconsistencies.

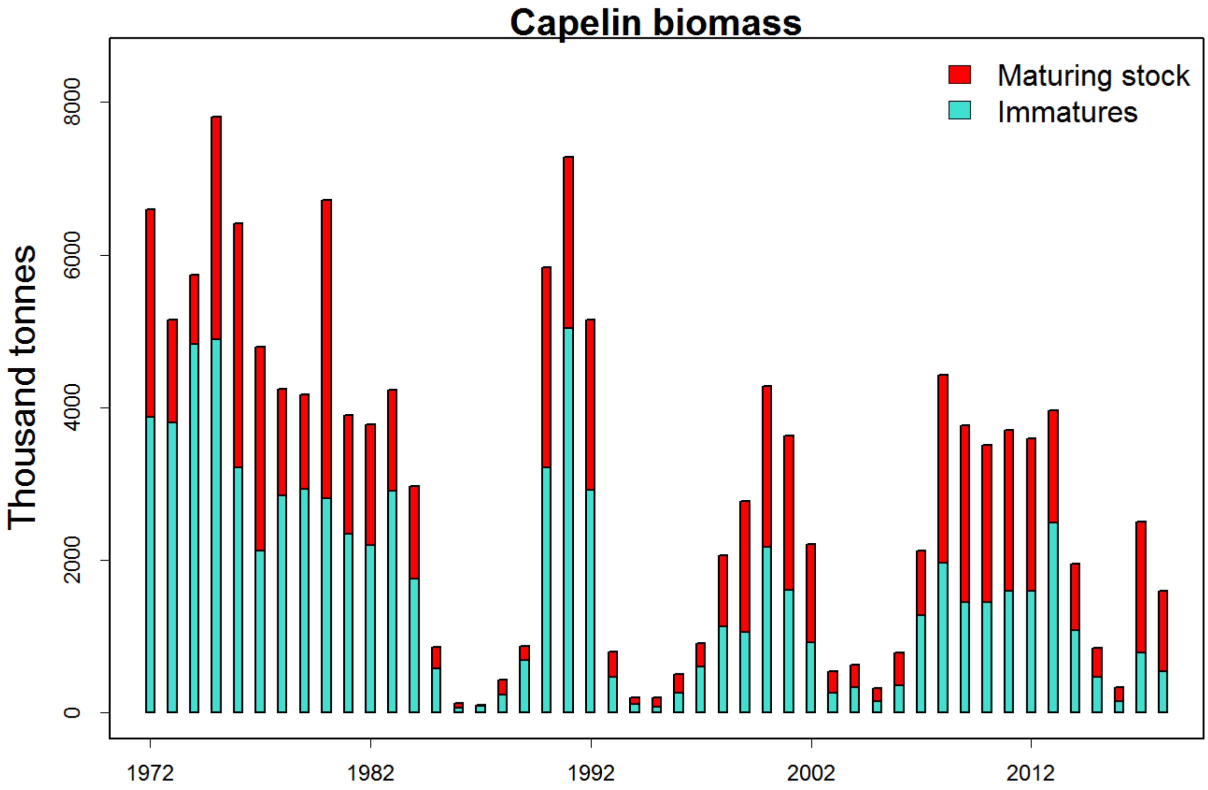

Figure 1. Historical capelin stock size separated in immature and maturing stock components.

Review of some potential methodological issues

Reliability of survey estimate at different stock levels

We first reviewed historical survey mortality (number of individuals at age 2 in present year divided by number of individuals at age 1 in previous year). This was done to assess how well the survey reflects abundance of different age classes at different stock levels.

Figure 2 shows that there is a huge variability in survey mortality when the estimated number of 1-year-olds is low. In part, this could reflect that mortality rates actually are variable at low abundances, but some of the values are obviously not realistic (negative mortality values can not occur in nature and must be due to monitoring issues). This result indicates that biomass estimates are uncertain when biomass is low. Most likely this is due to bias in the estimation of 1-year-olds, which are difficult to detect acoustically, but the estimation of 2-year-olds could also be biased when biomass is low. The main point is that the estimate seems less reliable when abundance is low, and this is also reflected in a higher survey sampling variance.

Survey coverage

We then evaluated the survey coverage, to assess whether important capelin concentrations might have been missed during monitoring. Normally the survey coverage is good, but there are exceptions, like in 2008 when the survey ran out of time before reaching the northern distribution border, or in 2014 when ice coverage limited access to some historically important capelin areas.

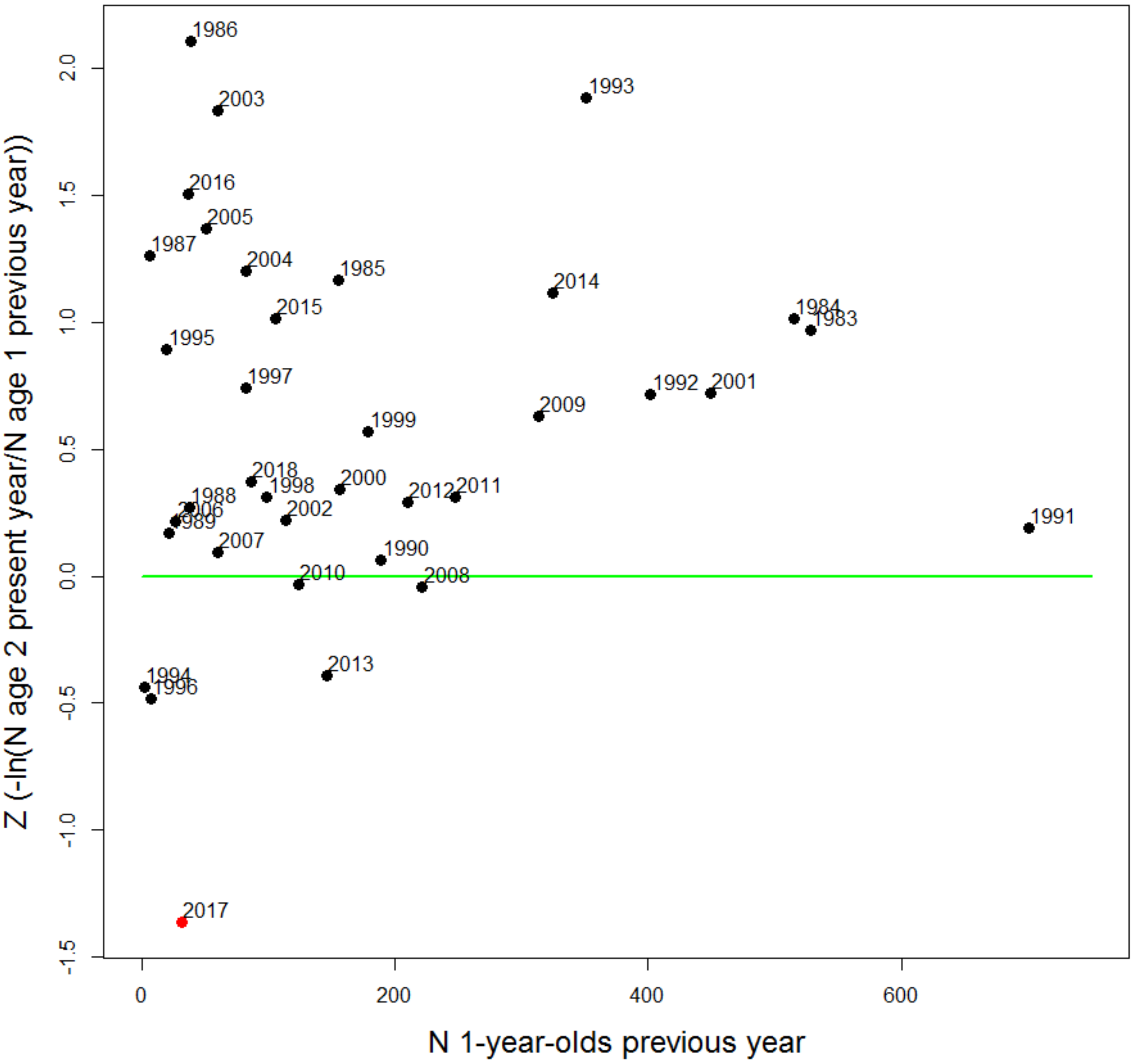

Figure 2. Barents Sea capelin survey mortality from age 1 to age 2 as a function of abundance at age 1, for the period 1983 to 2018 (cohorts of 1-year-olds from 1982-2017 and 2-year-olds from 1981-2016). Red dot marks the survey mortality from 2016 to 2017.

Figure 3 indicates that the survey covered most of the distribution area for capelin. Although the recordings indicate that some capelin may have been distributed outside the covered area in the north-east, there are no recordings of high capelin concentrations here or at any of the borders of the covered area. In theory, capelin may have had an abnormal distribution compared to previous years, for instance with high concentrations in Hinlopen or Storfjord. If this were the case, the survey may have missed out on high concentration areas. However, it seems unlikely given that the survey time series, and hence knowledge of capelin distribution used for survey planning stretches back to 1972. It must be noted that the evaluation of coverage here is assuming that the allocation of acoustic backscatter (echogram scrutiny) is done correctly, and is not necessarily valid if not (see section below).

Interpretation of the acoustic data

Interpretation or scrutiny of acoustic data, i.e. discrimination of acoustic targets and allocation of acoustic backscattering (normally stated in units of Nautical Area Scattering Coefficient; NASC; m^2/nmi^2) to target groups, can be challenging if the echogram appearance of different targets is similar. In challenging cases it is crucial to have frequent biological sampling (typically by trawling) to validate the interpretation of the acoustic recordings. In 2016, as stated in the capelin section of the Arctic Fisheries Working Group report (ICES, 2016), the interpretation was considered particularly challenging. We evaluated the scrutiny to assess potential impact on the biomass estimate.

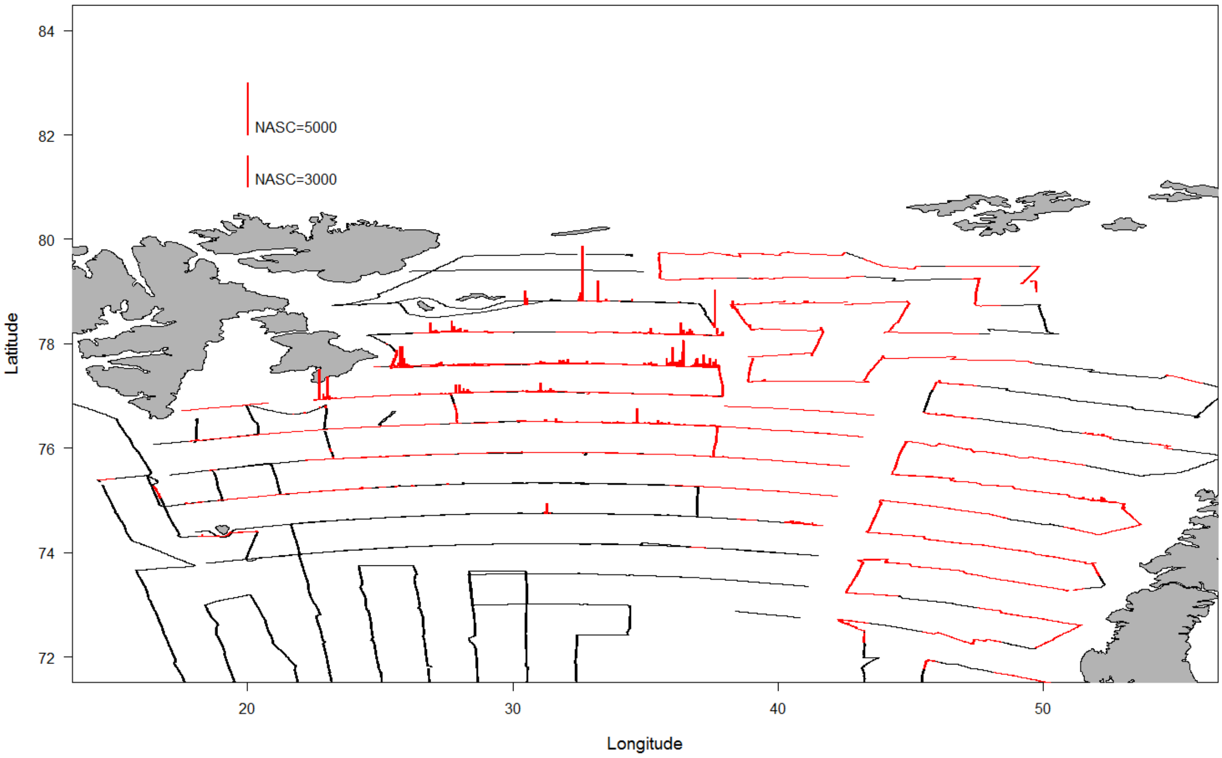

Figure 3. Survey transect lines from 2016 with capelin recordings by 1 nautical mile marked in red. The height of each bar is proportional to the nautical area scattering coefficient (NASC; nmi^2/m^2) by 1 nmi.

Figure 4 shows the acoustic abundance of capelin in proportion to abundance of targets with similar acoustic features as capelin. Only nautical miles with some acoustic backscattering allocated to capelin have been included since these are considered main candidates for misinterpretation during scrutiny. In general, capelin dominates in proportion (between 54 and 83 % of 'capelin-like' acoustic abundance), so for a typical year there is not potential for a huge increase in the capelin estimate even if all capelin-like recordings are interpreted as capelin. There are exceptions to this when the capelin abundance is estimated to be low, like in 2004 and 2005 when the proportion of capelin was 19 and 26 % respectively. However, the biggest exception was in 2016, when the capelin proportion was 18 % and polar cod proportion totally dominated with 72 %.

In the abundance estimate, the backscattering from one polar cod does not translate directly into one capelin. For capelin the relation between fish length (L) and acoustic Target Strength (TS) which is applied is given as TS=19.1*log10(L)-74.0. For polar cod the relation is TS=21.8*log10(L)-72.7. At 15 cm length the TS of a capelin is -51.54 dB re 1m^2 while for polar cod it is -47.06 dB re 1m^2, which is a ratio of 2.8 when converted to the linear domain. In other words, if all capelin and polar cod are 15 cm long and equal weight at this length, acoustic backscatter corresponding to 1 kg of polar cod would correspond to 2.8 kg of capelin. Based on the 2016 survey, capelin were on average a little bit longer than polar cod while polar cod were heavier at a given length so the biomass ratio given the same amount of echo was 1.92.

It is well known that the BESS survey does normally not cover the entire polar cod distribution. A BESS polar cod biomass estimate for a typical year must therefore be considered an underestimate, but the degree of bias due to incomplete coverage likely varies from year to year. However, even taking this into consideration, the dramatic increase measured in polar cod abundance from 2015 to 2016 (large negative survey Z both from age 1-2 and from age 2-3), and dramatic decrease measured from 2016-2017 (among the highest survey Z observed for age 1-2 and from age 2-3) seem highly unlikely to be real. An overestimation of polar cod in 2016 compared to neighbouring years seem likely to have occurred, which is also supported by the further decrease in the polar cod abundance from 2017 to 2018.

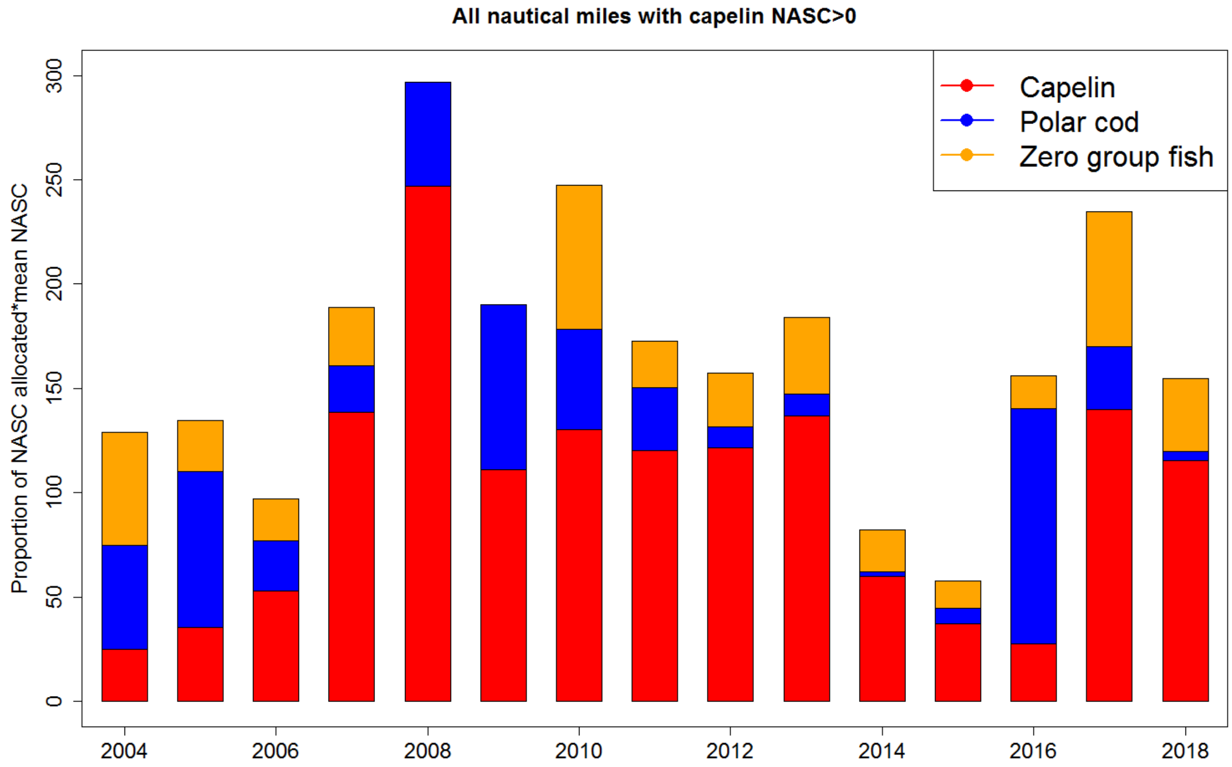

Figure 4. Overview of the estimated occurrence of targets with similar acoustic appearance as capelin during BESS 2004-2018. Occurrence is shown as proportion of acoustic backscatter (NASC; m^2/nmi^2) times the mean NASC. The scrutinized data are exported with 1 nautical mile resolution, and only miles with capelin NASC>0 according to the scrutiny are included in the figure.

Figure 5 indicates the acoustic recordings superposed by the location of target trawl stations. The figure indicates a low frequency of target trawls in the north-east. These target hauls in the north-east supported high abundance of polar cod (See Eriksen, E. (Ed.) 2017 and two examples in appendix), but the number of target trawls is too low to get a good validation of the scrutiny of acoustic data in this area with the highest NASC registrations.

Potential effect of vertical distribution

Capelin has a physostomous swimbladder, and there are indications that the acoustic backscatter from single fish (Target Strength; TS) is influenced by swimming depth (Jørgensen and Olsen, 2004) like it is for the physostomous herring (Ona, 2003). If there are inter-annual variability in depth distribution, this could influence the biomass estimation. We assessed the depth distribution to provide a qualitative assessment of this.

Figure 6 shows that the depth distribution of capelin is typically bimodal with an upper mode centered around 50 m depth and a lower mode centered around 150 to 200 m. However, the significance of the lower mode is very variable from year to year, for instance in 2015 it is dominating while in 2007 it is very weak. The implication of this is that if the depth distribution influences target strength and therefore the biomass estimate, there will be a clear inter-annual variability in impact. The potential effect of depth on the swimbladder of physostomous fish is a compression with increasing depth. If such an effect is present, the target strength will decrease with increasing depth, with the risk of an underestimation when capelin is distributed deep, and vice versa an overestimation when distributed shallow. From Figure 6 it seems like the depth distribution is deeper at low stock levels, in which case a tendency towards underestimation will be more pertinent in low capelin years like in 2016 than in high years like in 2008. However, there are many uncertain points here, and this warrants further studies.

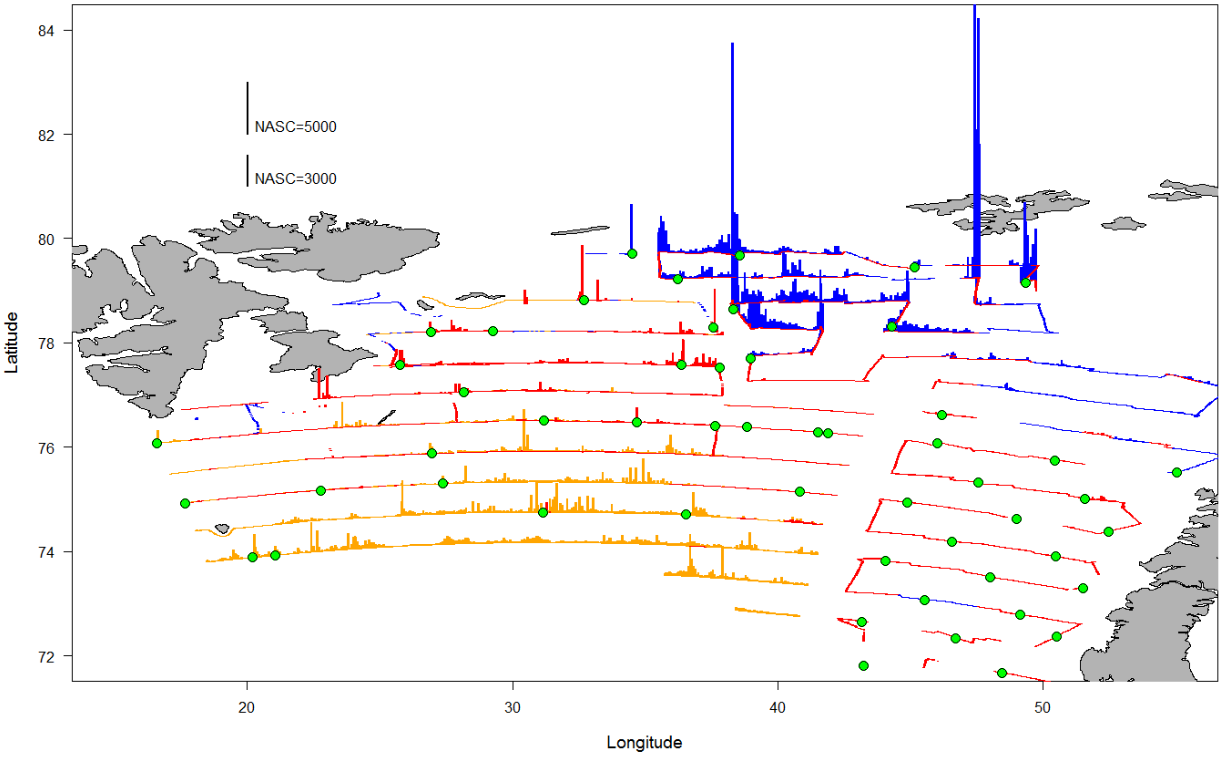

Figure 5. Acoustic recordings from 2016 scrutinized to capelin (red), polar cod (blue) and zero-group fish (yellow). The height of each bar is proportional to the nautical area scattering coefficient (NASC; nmi^2/m^2) by 1 nmi. Target trawl hauls are marked as green dots.

Brief evaluation of other factors which may have influenced the 2016 estimate

Impact of the timing and direction of the survey

In 2016, BESS was carried out from north to south and consequently surveyed the main capelin area a month earlier than in a standard year. Young capelin, including 1-group capelin, may be less available to acoustic detection at this time than later in the year due to a shallower distribution. However, the consequences of earlier survey timing are in general uncertain.

Bias due to systematic capelin migration

If the surveyed fish population moves systematically along with or against the survey direction, the estimate will be biased up or down, respectively. In the case of the capelin survey, it is assumed that there is no systematic migration during the survey. Some data from sonar tracking on board Johan Hjort in 2017 indicate that this assumption may be erroneous (Figure 7), and that the migration direction of capelin in this period is non-random. However, whether the migration pattern is consistent between years is not known, and sonar data were not recorded in 2016.

Potential errors from the biological sampling

There are several potential sources of errors related to how the biological samples are weighted when converting acoustic data to biomass estimates. While these potential errors can alter the quota advice for instance by changing the ratio of immature to maturing capelin, they cannot explain general underestimates across age groups. Separation between 0-group and 1-group capelin is also prone to error in the lab, as their lengths and visual appearance can overlap. 0-group capelin is not included in the estimate and potentially length separation between 0-group and 1-group was set too high placing 1-year-olds erroneously together with 0-year-olds. However, even a 2 cm reduction in separation length between 0 and 1-group (which can occur in some years but is much more than what is supported by the samples), only increases abundance of 1-year-olds by ca. 30 %.

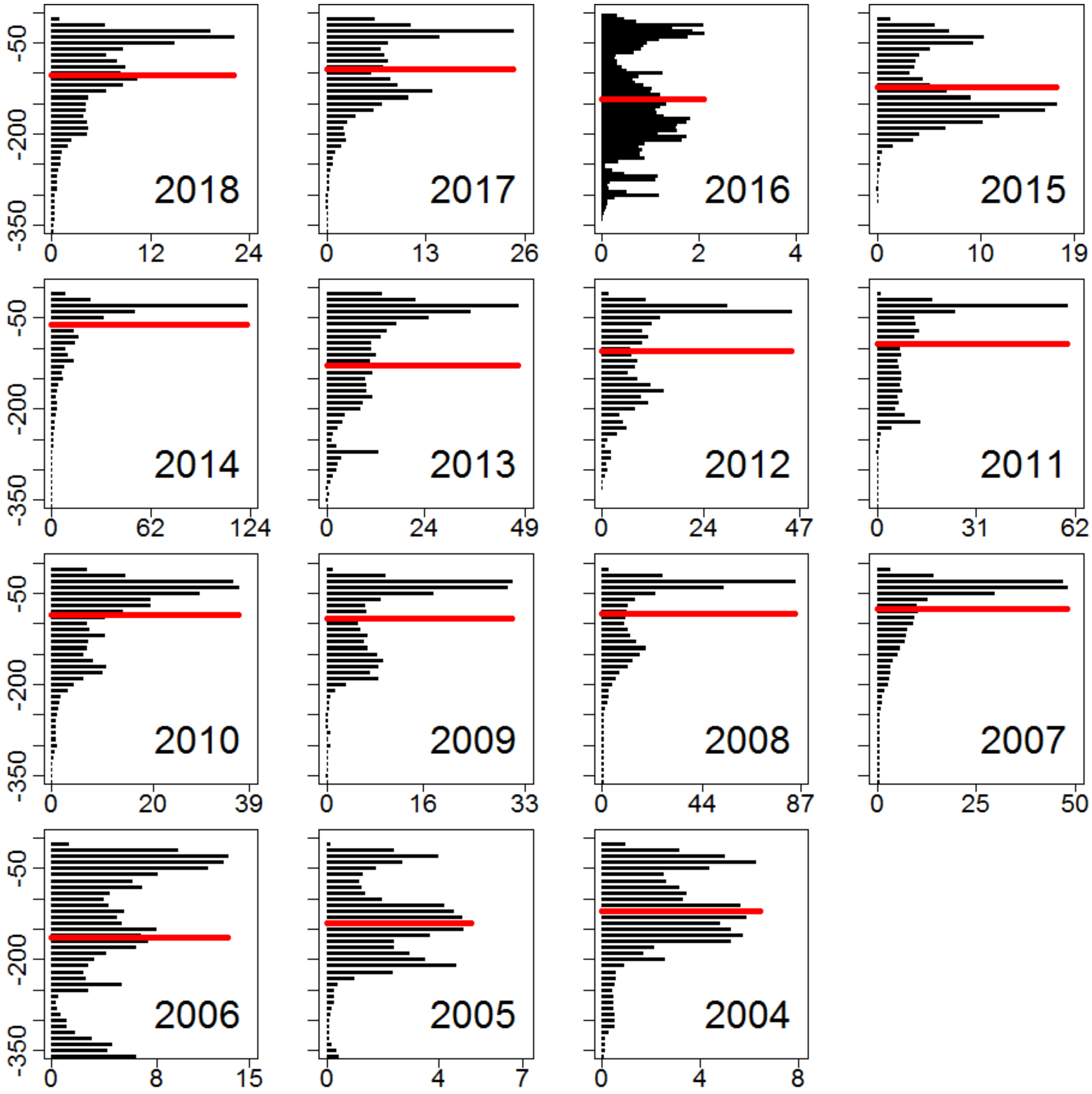

Figure 6. Vertical distribution of capelin NASC in 2004-2018. Vertical resolution is 10 m for all years except 2016 where it is 5 m. Only results from the surveys in which the data are vertically resolved have been used here. The red line marks mean depth of the acoustic recordings. Note that the scaling of the x-axis differs between the panels.

Errors in instruments or instrument settings

Errors in instrument or instrument settings like for instance a partly defect transducer or the use of erroneous calibration settings may obviously have huge consequences for abundance estimates. No such errors have been detected.

Calibration error

Wrong calibration can have huge impact on biomass estimates, but the calibration followed standard procedures by experienced personal, the calibration sheets have been checked and errors are not suspected.

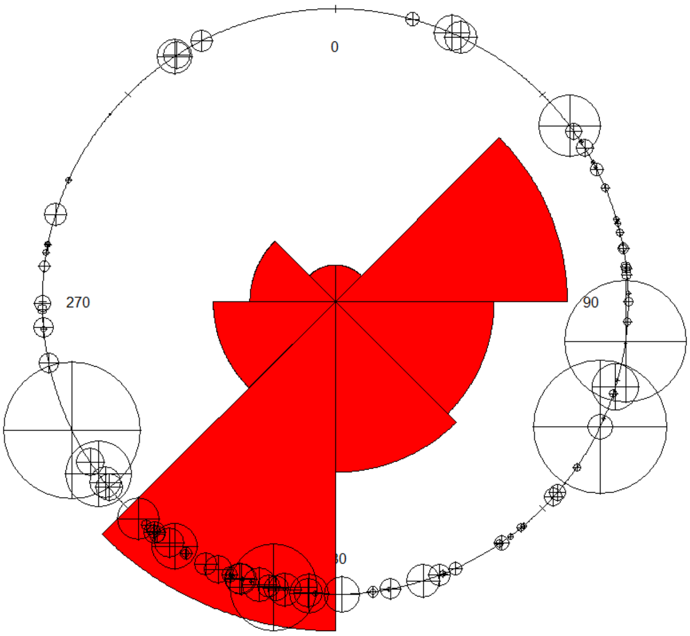

Figure 7. Rose plot indicating main swimming direction of the capelin schools tracked with sonar in 2017 (N=96). The size of the small circles bordering the large circle are proportional to the estimated swim speed of a school (range 0.02-1.94 knots, mean 0.53 knots).

Estimation error

2016 was the first year when the software StoX was replacing BEAM for the biomass estimation. There are differences in the estimation procedure between the softwares, but a BEAM estimation done for comparison showed a discrepancy in results of only 6 percent in total estimated biomass between BEAM and Stox (ICES, 2016).

Conclusions

The acoustic estimates obtained in 2016 and 2017 are incompatible. Viewed in light of the way the surveys in these two years were conducted, the reported methodological issues in 2016 and results from the 2018 survey, we consider it much more likely that the 2016 estimate was an underestimate than 2017 an overestimate. We cannot conclude that any clear factor(s) caused an underestimation in 2016, but we consider wrong allocation of acoustic backscatter - echogram interpretation error, as the most likely single candidate to cause important underestimation. Of other potential factors, we consider annual variability in vertical capelin distribution and timing of the survey to have the largest potential to influence.

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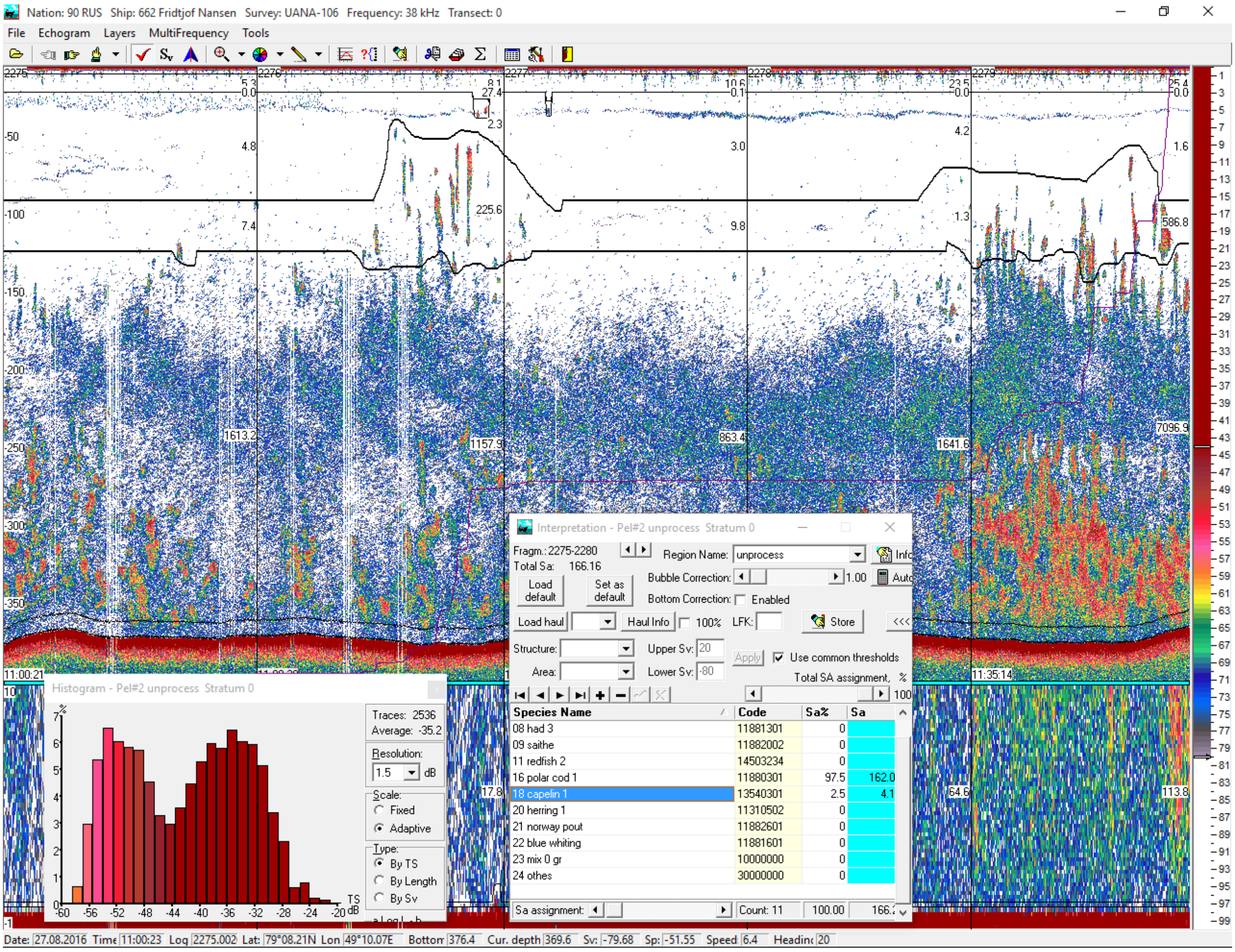
Appendix

Echogram examples and catch composition in the north-eastern part of the survey area



Nation: 90 RUS Ship: 662 Fridtjof Nansen Survey: UANA-106 Frequency: 38 kHz Transect: 0

Interpretation - Pel#2 unprocess Stratum 0

Fragm.: 2275-2280

Total Sa: 166.16

Region Name: unprocess

Bubble Correction: 1.00

Bottom Correction: ☐ Enabled

☐ 100%

LFK:

Structure:

Area:

Upper Sv: 20

Lower Sv: -80

☑ Use common thresholds

Total SA assignment, % 100

Species Name	Code	Sa%	Sa
08 had 3	11881301	0	
09 saithe	11882002	0	
11 redfish 2	14503234	0	
16 polar cod 1	11880301	97.5	162.0
18 capelin 1	13540301	2.5	4.1
20 herring 1	11310502	0	
21 norway pout	11882601	0	
22 blue whiting	11881601	0	
23 mix 0 gr	10000000	0	
24 othes	30000000	0	
Sa assignment:	Count: 11	100.00	166.2

Histogram - Pel#2 unprocess Stratum 0

Traces: 2536

Average: -35.2

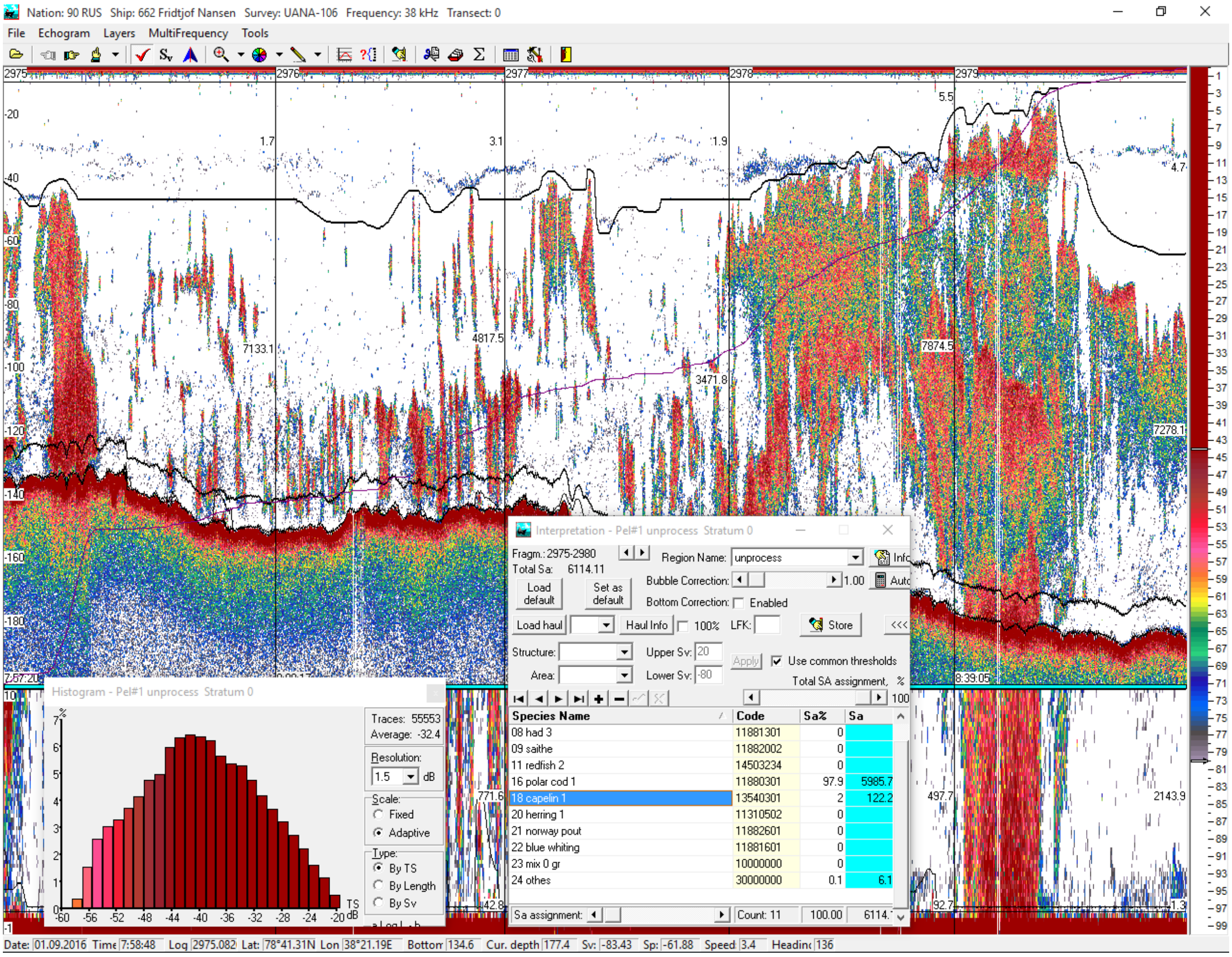
Resolution: 1.5 dB

Scale: ○ Fixed ● Adaptive

Type: ● By TS ○ By Length ○ By Sv

Date: 27.08.2016 Time 11:00:23 Log 2275.002 Lat: 79°08.21N Lon 49°10.07E Bottom 376.4 Cur. depth 369.6 Sv: -79.68 Sp: -51.55 Speed 6.4 Heading 20

Figure 1. Echo recording at 79°08N 49°10E:
Trawl №86 (fishing depth 120 m). Catch composition: polar cod 1696 ind., capelin 99 ind. NASC distribution: polar cod 97.5%, capelin 2.5 %.



Nation: 90 RUS Ship: 662 Fridtjof Nansen Survey: UANA-106 Frequency: 38 kHz Transect: 0

Histogram - Pel#1 unprocess Stratum 0

Traces: 55553
Average: -32.4
Resolution: 1.5 dB
Scale: ○ Fixed ● Adaptive
Type: ● By TS ○ By Length ○ By Sv

Interpretation - Pel#1 unprocess Stratum 0

Fragm.: 2975-2980
Total Sa: 6114.11
Region Name: unprocess
Bubble Correction: 1.00
Bottom Correction: ☐ Enabled
☐ 100%
LFK:
Structure:
Area:
Upper Sv: 20
Lower Sv: -80
☑ Use common thresholds
Total SA assignment, % 100

Species Name	Code	Sa%	Sa
08 had 3	11881301	0	
09 saithe	11882002	0	
11 redfish 2	14503234	0	
16 polar cod 1	11880301	97.9	5985.7
18 capelin 1	13540301	2	122.2
20 herring 1	11310502	0	
21 norway pout	11882601	0	
22 blue whiting	11881601	0	
23 mix 0 gr	10000000	0	
24 othes	30000000	0.1	6.1

Sa assignment: Count: 11 100.00 6114.

Date: 01.09.2016 Time 7:58:48 Log 2975.082 Lat: 78°41.31N Lon 38°21.19E Bottom 134.6 Cur. depth 177.4 Sv: -83.43 Sp: -61.88 Speed 3.4 Heading 136

Figure 2. Echo recording at 78°41N 38°21E
Trawl №110 (fishing depth 115 m). Catch composition: polar cod 34477 ind. (ml=10.5), capelin 851 ind. (ml=14). NASC distribution: polar cod 97.9%, capelin 2 %.

Ecosystem Based Fisheries Management: progress on the other side of the Atlantic

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There has been a large amount of work on multispecies and ecosystem management in the United States in recent years. Most of this is still theoretical, but some of it is coming close to being operational. This presentation will give a brief overview of some of the recent work being conducted in the United States towards a goal of implementing Ecosystem Based Fisheries Management.

Parasites and the topology of the Barents Sea food web

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Studies of food webs topology can be a powerful tool for improving our understanding of the dynamics of ecosystems. For example, studies of the topology of the Barents Sea food web have suggested that changes in geographical distribution of fish communities caused by increasing temperatures, have changed food web topology in the Arctic part of the ecosystem in a direction where perturbations may spread more easily throughout the ecosystem. While these analyses have been done using extensive data on trophic interactions of free living species collected over several decades by Russian and Norwegian scientists, they have so far not included data on parasites. Because adding parasite data to food web analyses can reveal novel patterns of topology, undertaking such an exercise can further improve our understanding of the dynamics of the Barents Sea ecosystem. Using the wealth of data on fish parasites that have been collected through several decades fish in the Barents Sea by Russian scientists (Polyanski, Karasev and Bakay) and more recently on fish, benthos, zooplankton and marine mammals by a Norwegian led team through the TIBIA project, the influence of parasites on the topology of the Barents Sea food web is being assessed. Results from these analyses will be presented as well as outlines for future work in this area.

Feeding habits of demersal juvenile cod and haddock of the 2015 year-class during their first wintering

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Abstract

The success of young fish feeding in the first year of life is extremely important for the abundance dynamics of the commercial bottom fish species in the Barents Sea. The knowledge of the feeding pattern of fingerlings during this period makes it possible to predict the survival of the year-class and the abundance of the commercial stock recruitment.

Based on the quantitative analysis of feeding of 257 cod and 271 haddock collected in November-December 2015 and February-March 2016, the feeding conditions and peculiarities of cod and haddock fingerlings from 2015 year-class were studied. To estimate feeding conditions, their biological characteristics (average length and weight, fatness and condition) were also used.

The differences in the feeding intensity and food composition of fingerlings at the beginning and end of wintering were revealed. Euphausiids predominated in the diet of cod and haddock. The second most important feeding item of cod fingerlings was fish (capelin, sand lance, redfish, eel-blenny), of the haddock ones - hyperiids and polychaetes. From the beginning to the end of wintering, feeding intensity of both species increased, while fatness and condition decreased. Moreover, feeding peculiarities of the 2015 year-class and the year-classes of the past were compared.

Keywords: cod, haddock, juveniles, diet, prey, biological parameters, Barents Sea

Introduction

Fattening conditions of cod and haddock – the main commercial fish species in the Barents Sea – during the first years of their lifecycle are important factors for the further development of their populations. Variations in feeding habits during the first wintering related to the adaptation to new environmental conditions have a significant impact on the survival of a year class and its abundance in older age groups. Long-term observations over the interannual variations in the diet of juvenile cod and haddock in the Barents Sea provide precise predictions of the size of their stocks and correct estimates of their abundance.

Materials and methods

The samples for study were demersal juvenile cod and haddock collected on board PINRO’s research vessels “Fridtjof Nansen” and “Vilnus” in winter (in November-December 2015 and in February-March 2016). Using the quantitative-weight analysis method, the total number of examined specimens of cod and haddock was 257 and 271, respectively. Additionally, basic biological parameters including fat content and fish condition were studied as well.

Results and discussion

General diet composition

Twenty seven prey species from 15 large taxa were identified in the diet of juvenile cod and haddock. Species from nine taxonomic groups were found in the stomachs of cod in early and late winter, however, these taxa slightly varied in the beginning and the end of the season (Figure 1). At the beginning of wintering, the diet of juvenile haddock included prey species from ten taxonomic groups and in February-March – from thirteen taxonomic groups (Figure 2).

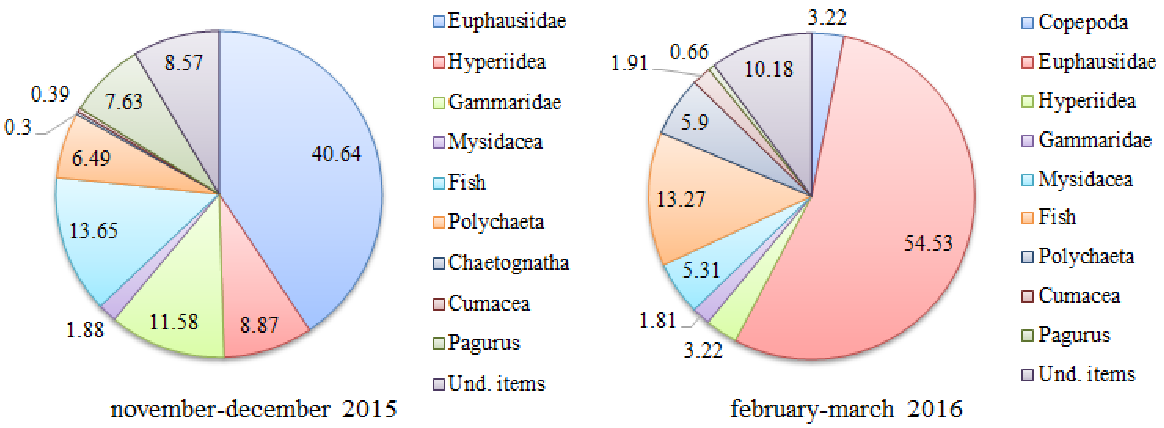


Figure 1. Food composition of juvenile cod in November-December 2015 and February-March 2016.

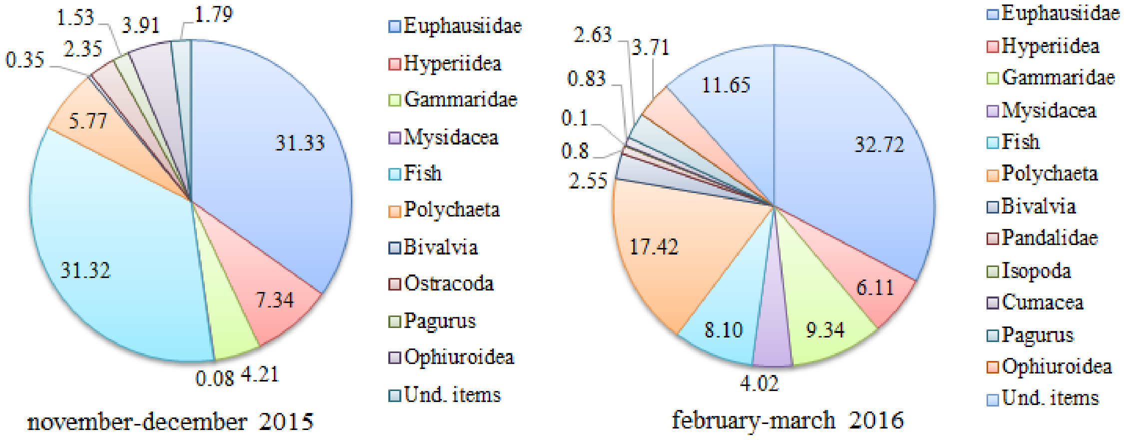


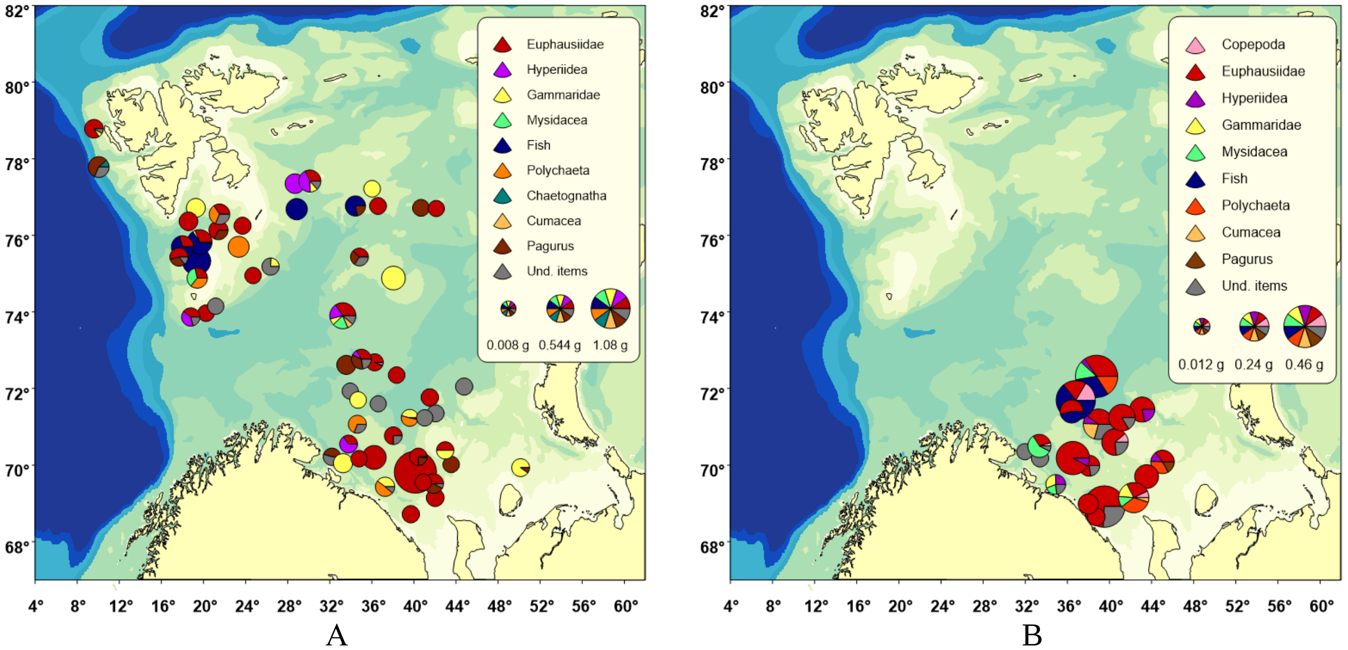
Figure 2. Food composition of juvenile haddock in November-December 2015 and February-March 2016.

The spatial distribution of feeding intensity and food composition of juvenile cod and haddock is shown in Figures 3 and 4.

Cod

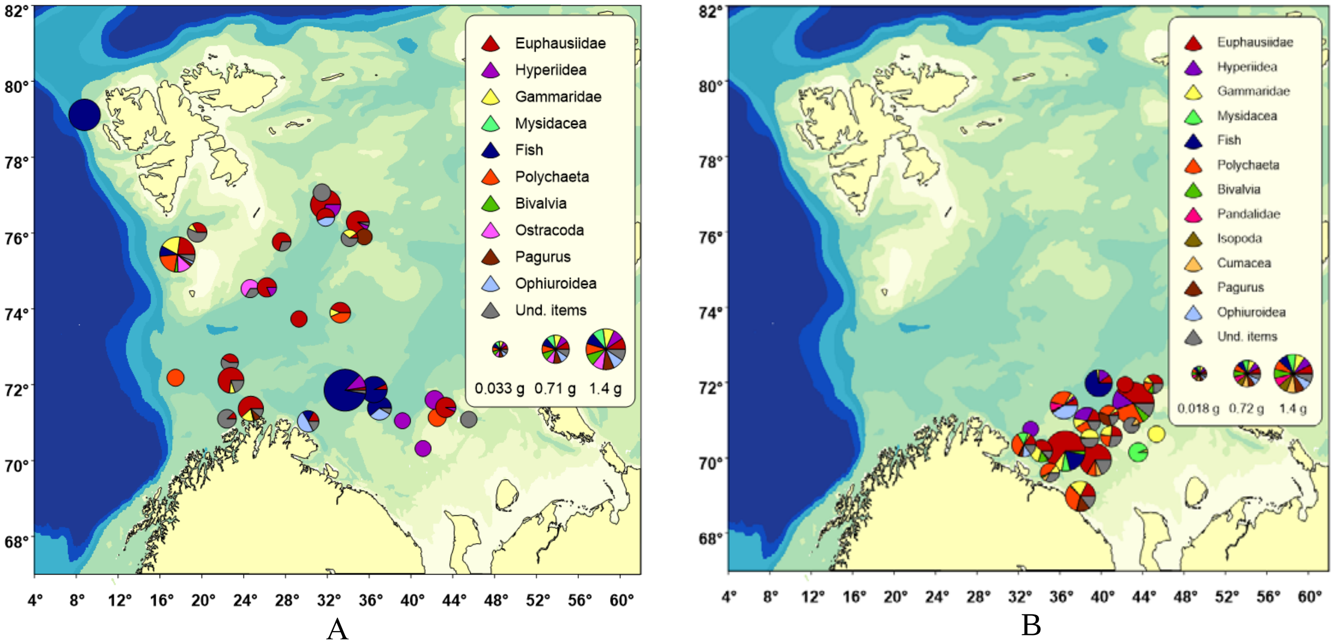
In November and December 2015, euphausiids (*Euphausiidae*) prevailed in the diet of cod by frequency of occurrence and weight. They comprised 33.6 % and 42.5 %, respectively. The frequency of occurrence of freshwater shrimp (*Gammaridae*) and hermit crabs (*Pagurus*) was low (10.9 %) and their weight percentage was 10 % and 6.61 %, respectively. Moreover, polychaetes (*Polychaeta*) (6.9 % by weight), hyperiids (*Hyperiidea*) (8.4 %), fish (11.1 %), as well as chaetognaths (*Chaetognatha*), mysids (*Mysidacea*) and cumaceans (*Cumacea*) (0.3-2.7 %) were observed in the stomachs of cod. The feeding intensity was relatively low. The average stomach fullness index (SFI) was only 63.3%oo whereas the portion of fish with empty stomachs did not exceed 13.0 %.

The diet of juvenile cod in February 2016 varied from the food composition in late 2015. Euphausiids remained the main food items (78.9 % by weight), however, the frequency of their occurrence was low (5.4 %). In addition, hyperiids and copepodas (*Copepoda*) were relatively abundant in the stomachs of cod (7.2 % and 5.4 %, respectively), however, their weight ratio was low (3.2 %, for both prey species). Mysids, polychaetes and fish (1.9 -5.6 %) were important food items as well. The feeding of cod was more intensive, the average stomach fullness index (SFI) increased to 100.1 %oo and the portion of fish with empty stomachs decreased to 8.1 %.



A B

Figure 3. Spatial-temporal dynamics in the diet of juvenile cod in November-December 2015 (A) and February-March 2016 (B).



A B

Figure 4. Spatial-temporal dynamics in the diet of juvenile haddock in November-December 2015 (A) and February-March 2016 (B).

Haddock

In November and December 2015, the diet of haddock included predominantly euphausiids as well. Their weight percentage was 35.7 % with a frequency of occurrence of 28.5 %. The second important food items were fish including capelin, leptoclinus and redfish (31.3 % by weight and 6.3 % by frequency of occurrence) and hyperiids (7.3 % by weight and 25.2 % by frequency of occurrence). The rest of the food was benthos (including freshwater shrimp, polychaetes, brittle stars (*Ophiuroidea*), ostracodes (*Ostracoda*), hermit crab, bivalved mollusks (*Bivalvia*) and mysids). The weight percentage of benthos comprised 0.05-6.1 %. The feeding intensity was relatively low. The average stomach fullness index (SFI) was 68.1%oo whereas the portion of fish with empty stomachs did not exceed 11.0 %.

In February 2016, euphausiids predominated in the diet of juvenile haddock (55.9 % by weight and 24 % by frequency of occurrence). The second important food items were polychaetes and freshwater shrimp (15 % and 7.7 % by weight, respectively) while the frequency of their occurrence was high (25 % and 22 % of the weight of food bolus, respectively). The other bottom-dwelling species (bivalved mollusks, cumaceans, mysids, hermit crab, brittle stars and isopoda (*Isopoda*)) and plankton (hyperiids), as well as fish species were far less abundant (0.03-2.7 %) regardless of their high occurrence (up to 6-8 %). The feeding of haddock was more active, the average stomach fullness index (SFI) increased to 75.7 %oo whereas the percentage of fish with empty stomachs was almost twice as high as in late 2015 (24.3 %).

The diet of juvenile cod and haddock. Comparative analysis

Euphausiids were prevalent in the diet of juvenile cod and haddock during their wintering in the entire Barents Sea (Figures 3, 4). An active consumption of euphausiids by cod and haddock gradually increased (from 32-41 % to 33-55 % by weight). Prey fish was the second important food item in the diet of juvenile cod and haddock. In early winter cod actively fed on prey fish in the northwestern Barents Sea and haddock – in the central areas. However, while the consumption of prey fish by cod eventually remained stable (13-14 %), the portion of prey fish in the diet of haddock decreased from 31 % to 8 %. At the beginning of wintering, in the diet of cod and haddock pelagic hyperiids (8.9 % and 7.3 %, respectively) dominated over polychaetes (6.5 % and 5.8 %, respectively). By February and March 2016, the weight percentage of polychaetes was higher than that of hyperiids (5.9 % versus 3.2 % for cod and 17.4 % versus 6.1 % for haddock).

The food spectrum of haddock was wider than that of cod. The diet of haddock included bivalved mollusks, brittle stars, ostracodes, isopoda and shrimps that did not occur in the diet of cod. Nevertheless, copepoda were found in the stomachs of cod at the end of wintering. A relatively high occurrence of benthos in the diet of juvenile haddock may indicate the species' earlier adaptation to the benthic mode of life and more accelerated development.

Biological parameters

At the beginning and the end of the first wintering, biological parameters of juvenile cod and haddock varied widely. These variations were caused by changes in their diets. Thus, fat content in fish of both species was higher by early winter (3.1 % for cod and 3.2 % for haddock) and it decreased when the wintering was over (up to 2.3 % and 2.2 %, respectively) (Tables 1, 2). Fish condition, as a more permanent indicator of fattening conditions than fat content, decreased in a similar way from November to March. At the beginning and the end of wintering, the condition of cod varied between 0.67 and 0.66, respectively, and the condition of haddock varied between 0.79 and 0.73, respectively. Low fat content and poor condition indicate that cod and haddock fed less actively and they consumed less food in early winter. However, the feeding of cod and haddock was more active by February, the average stomach fullness index (SFI) increased from 63.3 to 100.1 for cod and from 68.1 to 75.0 for haddock. Moreover, the percentage of cod with empty stomachs decreased (from 13.0 % to 8.1 %), whereas the percentage of haddock with empty stomachs was almost twice as high as in early winter (from 11.0 % to 24.3 %).

Table 1. Biological parameters of juvenile cod of the 2015 year-class.

Average data	November-December 2015	February-March 2016
Empty stomachs, %	13.01	8.11
Length, cm	11.31	11.38
Weight, g	10.34	10.07
Fat content, %	3.14	2.28
SFI, $\%_{oo}$	63.32	100.09
Fulton's condition factor	0.67	0.66

Table 2. Biological parameters of juvenile haddock of the 2015 year-class.

Average data	November-December 2015	February-March 2016
Empty stomachs, %	11.02	24.31
Length, cm	13.88	14.34
Weight, g	21.57	21.96
Fat content, %	3.17	2.33
SFI, $\%_{oo}$	68.12	75.73
Fulton's condition factor	0.79	0.73

Conclusions

The feeding intensity of cod and haddock increased by the end of wintering. The food spectrum of haddock was wider than in early winter. The number of prey species consumed by cod remained virtually unchanged, however, the food composition in the diet of cod varied.
From November to March, euphausiids prevailed in the diet of juvenile cod and haddock. Additionally, prey fish were important food items for cod and polychaetes and gammaridae – for haddock. Species diversity in the diet of haddock was higher than in the diet of cod. A variety of prey species consumed by haddock was wider in early 2016. The occurrence of benthic organisms in the stomachs indicated that juvenile haddock had successfully adapted to the benthic mode of life.

Despite the fact that juvenile cod and haddock fed more actively, their biological parameters (i.e. fat content and fish condition) gradually decreased between November-December and March.

From November to March, stomach fullness of juvenile cod gradually increased whereas stomach fullness of juvenile haddock decreased. Nevertheless, the diet of juvenile haddock included a wider variety of prey species than that of juvenile cod.

Feeding of Greenland halibut in various areas of the Barents and Kara Seas

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The paper analyzes feeding habits of Greenland halibut, an important commercial species in the Barents and Kara Seas. Feeding intensity and general food composition, its spatial, ontogenetic and interannual variability were studied based on the 2001-2017 data (over 42 thousand stomachs in total). A comparative analysis of Greenland halibut feeding in the Barents and Kara Seas was conducted. The links between halibut feeding of different food items and their abundance were analyzed. The importance of the Northern area of the Barents and Kara Seas as feeding and nursery grounds for juvenile Greenland halibut was shown. It was revealed that food resources of these areas were getting insufficient for larger Greenland halibut individuals, which is one of the possible reasons for the return migration to the west of the Barents Sea.

Practical prospects of the electronic Barents and Norwegian Seas fish species identification atlas

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Knipovich Polar Research Institute of Marine Fisheries and Oceanography, Murmansk, Russia

Based on the information from the trawl-acoustic surveys (TAS) conducted by PINRO in the Barents Sea and adjacent waters, an electronic fish species identification atlas (AVIR 1.0) was compiled. The Atlas presents a multi-year selection of specific echograms of major commercial species in different time periods. The Atlas will provide precise identification of size and species composition of the objects while reading echograms and monitoring dynamics in distribution and migration of aggregations. The Atlas may be used by both fishermen and scientists when identifying echograms. It may also be used as a teaching tool in echo-traces identification. Currently, database update for recent years is being done.

Materials and methodology

The Atlas database comprises a set of echograms presented in pictures for major commercial species by seasons in 2001-2014. Seasons correspond to periods of the basic TAS. The database comprises descriptions to the selected echograms (depth, range, same-species and/or mixed-species aggregations, and information about a trawl catch if a trawl was present on the point). Echograms were selected for the Atlas by visual estimation of aggregations; duration and type of echo-trace were also taken into account.

Results

Some problems have emerged when analyzing acoustic images due to the lack of relevant information or inadequate trawls number. During the 2017 multi-species TAS, there were some dense fish aggregations registered on the north Kanin Bank on the segment between points of bottom trawlings (Figure 1). It was not possible to take them with a pelagic trawl because of strong headwind (12-15 m/sec). In the Atlas database there are echograms related to this area (Figure 2). The description reads that those are juvenile herring echo-traces. Thus, one can firmly identify the size and species composition of the detected fish aggregations.

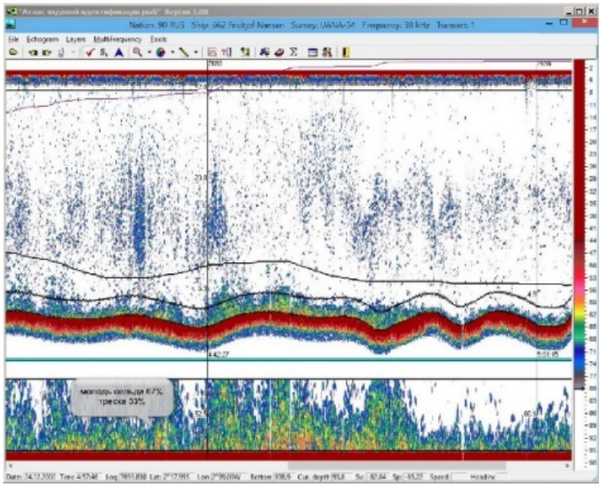


Figure 1. Aggregations on the north Kanin Bank during a 2017 cruise.

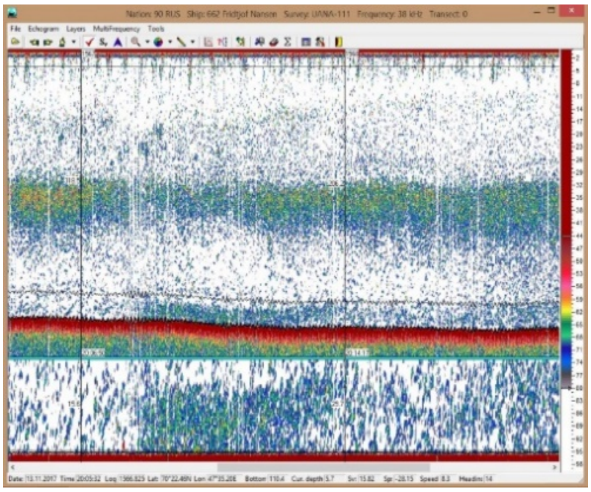
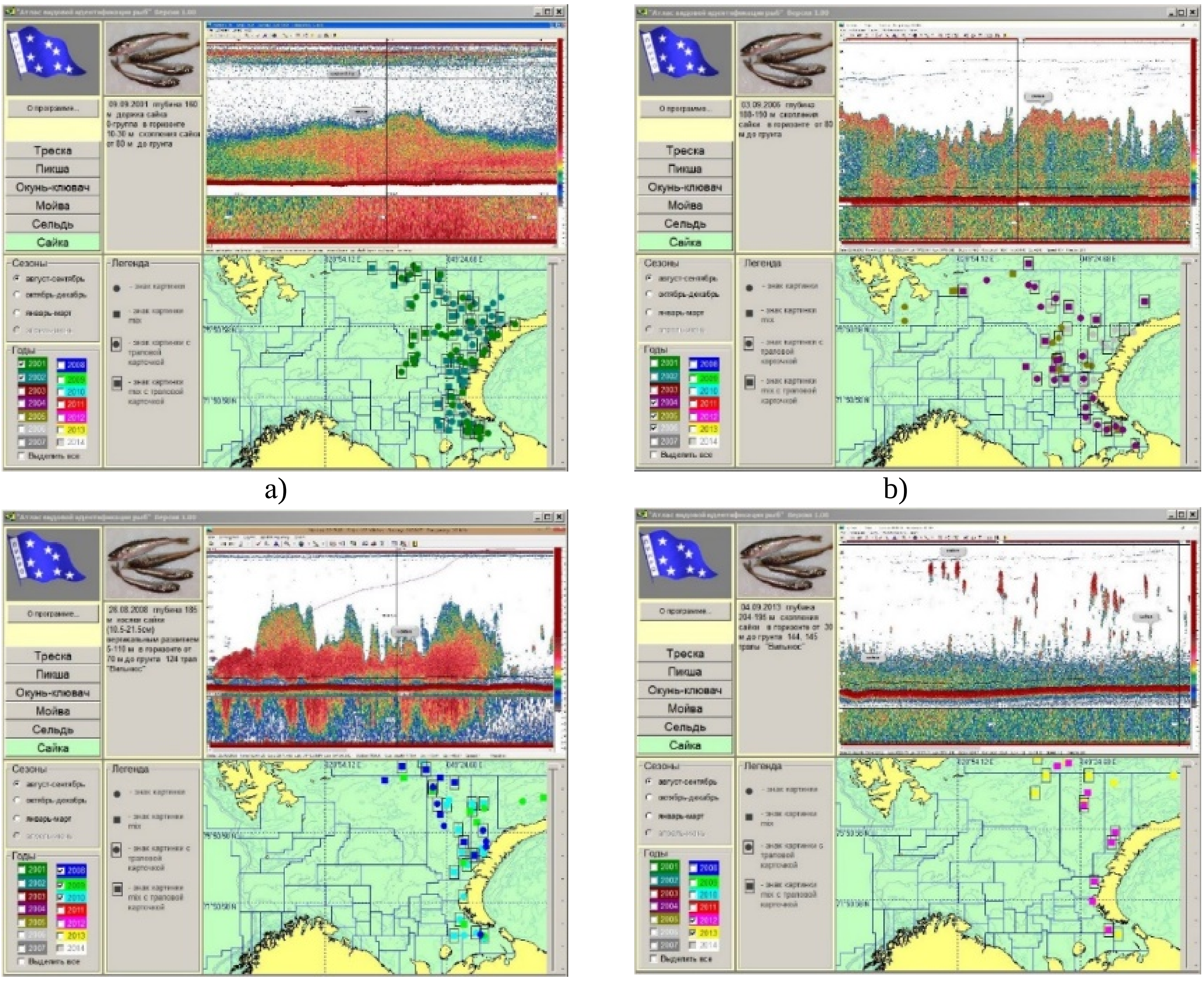


Figure 2. Juvenile herring aggregations on the north Kanin Bank from the atlas.

The Atlas provides clear monitoring of not only seasonal but also many year dynamics of distribution and migration of aggregations. Polar cod data provides an example of dynamics in aggregations shifts and changes in their densities in summer over the last 14 years – large aggregations decreased in the south of Novaya Zemlya during recent years, and aggregations moved to areas of Franz Josef Land and Victoria Island (Figure 3).



a)

b)

c)

d)

Figure 3. Examples of polar cod aggregations distribution and their densities. a) 2001-2002; b) 2004-2006; c) 2007-2010; d) 2012-2014.

There are currently extremely few illustrated reference materials on the type of fish aggregations echo-traces in this or that area on fishing vessels. Misidentification of an object, its size composition and density may result in inefficient trawling (e.g., when trawling juveniles aggregations). Use of the Atlas to compare the echo-traces in fishing areas may prevent such mistakes. Due to the information obtained by the echo sounder and precise identification of acoustic images, an experienced navigator will be able to determine commercial value of fish aggregations.

Collected and processed data will provide to prepare employees to successfully carry out tasks of the oncoming survey. Continuous many-year and seasonal selection of the Atlas database may be used for scientific papers and research. Short instructions and trawl cards will help train employees and other specialists to read echograms.

Conclusion

The Atlas contributes to the quality of fish objects identification, precise estimation of commercial fish stocks and monitoring the dynamics of distribution and migration of aggregations. It may be used as a training program for echograms identification.

“PINRO” received a certificate of state registration of computer program “AVIR 1.0” (Figure 4).

РОССИЙСКАЯ ФЕДЕРАЦИЯ

СВИДЕТЕЛЬСТВО

о государственной регистрации программы для ЭВМ

№ 2017612310

«АВИР 1.0»

Правообладатель: ***Федеральное государственное бюджетное научное учреждение «Полярный научно-исследовательский институт морского рыбного хозяйства и океанографии им. Н.М. Книповича» (ФГБНУ «ПИНРО») (RU)***

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Руководитель Федеральной службы
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Г.П. Ивлиев

Figure 4. A certificate of state registration of computer program “AVIR 1.0”.

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Authors would like to thank Sergeeva T.M. and Zhurbyk T.V. for taking part in development and testing of the program.

THEME SESSION V: TOP PREDATORS

Marine mammal consumption and fisheries removals in the Nordic and Barents Seas

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In terms of biomass and consumption, marine mammals are significant players in the northeast Atlantic. Sigurjónsson and Víkingsson (1997) estimated the total annual consumption by 12 cetacean species occurring around Iceland to 6 million tons, corresponding to around four times the total Icelandic fishery landings at the time. Further, Bogstad et al. (2000) estimated that the two most abundant marine mammal species in the Barents Sea, the harp seals *Pagophilus groenlandicus* and the minke whales *Balaenoptera acutorostrata*, consumed around 1.8 and 3.4 million tons per year, and were the second and third most important predators in this system in terms of biomass consumed, only surpassed by the Northeast Atlantic cod (*Gadus morhua*). With diverse diets, also including commercial species such as herring, capelin and cod, marine mammals may interact both directly and indirectly with fisheries. For example, Lindstrøm et al. (2009) found that more minke whales in the Barents Sea resulted in more capelin available for fisheries, due to strong indirect effects on minke whale predation on cod reducing cod predation on capelin. Also, while marine mammals may not deplete prey stocks to critical levels they may impede recovery of fish stocks collapsed due to e.g. overfishing (e.g. Bundy et al., 2009; O'Boyle, Sinclair, 2012). Furthermore, marine mammals can be sensitive to fluctuations in the marine ecosystems, including climate change related changes in prey or habitat availability, potentially increasing their vulnerability to impact from fisheries (e.g. Nilssen et al., 1998; Trites et al., 2007; Bogstad et al., 2015). However, these interactions are system specific, and the potential for direct competitive interactions between marine mammals and fisheries is both related to harvesting intensity, the trophic levels targeted by the fisheries (e.g., large predatory fish, forage fish, zooplankton), the diets and dietary breadth of the mammals, the functional form of marine mammal – prey interactions, and simplicity of ecosystem in terms of number of species and trophic links (e.g. Mackinson et al., 2003; Kaschner, Pauly, 2005, Morissette et al., 2012).

In this study, which is based on a ms (Skern-Mauritzen et al. in prep.), we estimate the prey consumption by 21 marine mammal species (7 seal species, 8 toothed- and 6 baleen whale species) in three areas in the northeast Atlantic: 1. the Iceland shelf, Denmark Strait and Iceland Sea (ICE), 2. the Greenland and Norwegian Seas (GN) and 3. the Barents Sea (BS). A well-established modelling framework (Leaper, Lavigne, 2007; Smith et al., 2015) is used to estimate the prey consumption. Further, the potential competition between marine mammals and fisheries in these areas is assessed in this study using three different properties: 1. Trophic level overlap, 2. Morisita's overlap index (Krebs, 1999) and 3. Overlap in the Cumulative biomass - TL relationship (Link et al., 2015).

The preliminary results from this study suggest that marine mammals consume ca. 17 mill. ton food annually, which is ca. twice as much food as the average fishery catches in the northeast Atlantic in 2013/2014. The total prey consumption by marine mammals in the ICE, GN and BS areas sums up to ca. 7.5, 4.5 and 5 million tons, respectively. The prey consumption by the marine mammals varies between areas and groups due to differences in prey preferences and prey availability; baleen whales are by far the most conspicuous predator group in the ICE (~5.2 mill. tons) and GN (~2.2 mill. tons) areas whereas seals dominate the prey consumption in the BS (~3 mill. tons) area. Krill, cephalopods and amphipods are the overall most important prey for baleen whales, toothed whales and seals, respectively. Krill, herring and polar cod are the single most import prey species in the ICE, GN and BS areas, respectively.

Except for herring in the ICE and GN areas and capelin in the BS area the fishery catches exceed the prey consumption by marine mammals. The marine mammal-fishery competition analysis suggests weak and variable competition; there is a significant competition between marine mammals and the fishery in the GN area but not in the other areas. The degree of marine mammal-fishery competition varies between marine mammal groups; the competition between toothed whales and the fishery is strongest. The Cumulative Biomass-TL relationship indicate that the exploitation pattern of marine mammals and the fishery differ.

The preliminary conclusions from this study are: 1. the total prey consumption by the marine mammals varies much between both areas and groups due to differences in prey preferences and prey availability; baleen whales are by far the most conspicuous predator group in the ICE and GN areas whereas seals dominate the prey consumption in the BS area, 2. Krill, cephalopods and amphipods are the overall most important prey species for baleen whales, toothed whales and seals, however, herring and polar cod are the overall most import prey in GN and BS, respectively, 3. Marine mammals in the northeast Atlantic consume twice as much food as the fishery removes, however, except for herring in the ICE and GN areas and capelin in the BS area the fishery catches exceed the prey consumption by marine mammals, 4. the overall marine mammal-fishery competition analysis, i.e. all marine mammal included, suggest there is a significant competition between marine mammals and the fishery in the GN area, driven by the predation on herring, but not in the other areas, 5. the degree of marine mammal-fishery competition varies between marine mammals; the competition between toothed whale and the fishery appears to be significant in all areas except, perhaps in the Barents Sea, depending on the property used to assess the competition, 6. The three properties display similar competitive picture which is that the exploitation pattern of the marine mammals and fishery catches differ, particularly in the ICE and BS areas.

Finally, to explore the dynamical consequences of various harvesting scenarios on the dynamics of marine mammals and vice versa, we need to include these marine mammal species in ecosystem or multispecies models and run scenarios. The Norwegian-Barents Sea Atlantis model (Hansen et al., 2016), which presently contains nine marine mammal species, will be used to run such scenarios.

Keywords: Nordic and Barents Seas, marine mammals, consumption, fishery interactions

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Supplementary

Table 1. Marine mammal species regularly occurring in the Nordic and Barents Seas, categorized as all year residents (Residents) or summer migrants (Migrants).

	Species	Resident/ Migrant	Body mass, kg	Habitat
Pinnipeds	Harbour seals	Resident	90	Coastal
	Grey seals	Resident	200	Coastal
	Ringed seals	Resident	75	High Arctic
	Bearded seals	Resident	250	High Arctic
	Harp seals	Resident	120	Arctoboreal
	Hooded seals	Resident	250	Arctoboreal
	Atlantic walrus	Resident	1 200	High Arctic
Odontocetes	White whales	Resident	1 350	High Arctic
	Narwhal	Resident	1 300	High Arctic
	Killer whale	Resident	4 400	Arctoboreal
	Sperm whale	Migrant	40 000	Arctoboreal
	Lagenorhyncus dolph.	Resident	210	Arctoboreal
	Pilot whales	Migrant	1 700	Arctoboreal//Temperate
	Harbour porpoise	Resident	55	Coastal
	Bottlenose whales	Migrant	6 000	Arctoboreal
Mysicetes	Minke whales	Migrant	6 600	Arctoboreal
	Fin whales	Migrant	55 500	Arctoboreal
	Humpback whales	Migrant	30 400	Arctoboreal
	Blue whales	Migrant	100 000	Arctoboreal
	Sei whales	Migrant	17 000	Arctoboreal/Temperate
	Bowhead whales	Resident	80 000	High Arctic

Marine mammals research as top predators in the Barents Sea ecosystem by PINRO in modern stage

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Research objectives

PINRO specialists have long time experience on marine mammals research in the Barents Sea. The main purpose it is study and understanding of marine mammals (*Cetacean* and *Pinnipeds*) role and place in the Barents Sea ecosystem including as top predators here.

Methods

For above use difference information about marine mammals distribution and number, so named, about meeting. This information during complex vessel surveys, including trawl-acoustic and ecosystem, and also coastal observations and aerial surveys are collected. It carries out on basis of principles that used in carrying out of the Trans North Atlantic Sighting Survey in 2007 (T-NASS) and multispectral aerial survey. Last method in PINRO was devised.

Main findings

Carrying out of considerable research is very important during last ten years when in the Barents Sea great warmer was recorded. This reason this paper marine mammals meeting in the Barents Sea during last years was presented including how their distribution and number with fish aggregations is connected. Also as it is known that harp seal of the White Sea/Barents Sea population is the most numerous species as marine mammals as *Pinnipeds* in the Barents Sea. This reason this paper his distribution and number during whelping time for difference ice conditions was presented. Also in modern stage marine mammals meeting in the Barents Sea coastal zone has special interest. In our opinion it is very important for aquaculture in the first.

Conclusions

This paper all above aspects of PINRO research in modern stage including main results it will be summarized and considered here.

Marine Mammals Research as Top Predators in the Barents Sea Ecosystem in Modern Stage

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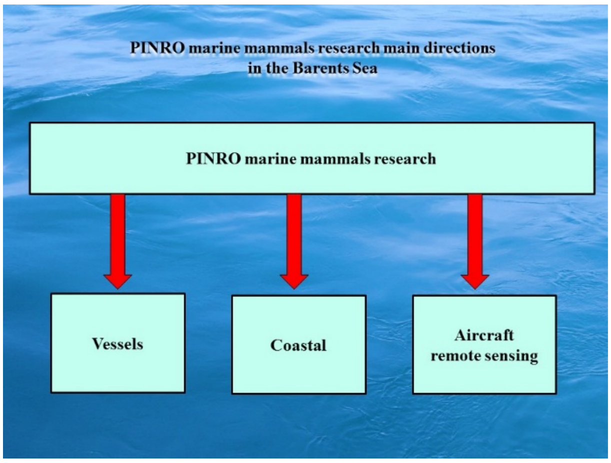
The 18th Russian-Norwegian Symposium



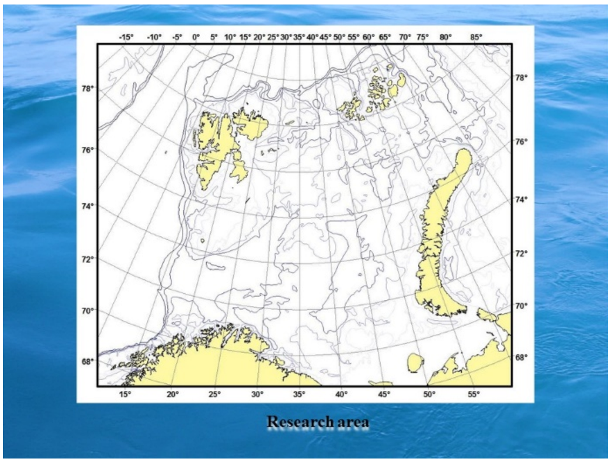
PINRO marine mammals research main directions in the Barents Sea

PINRO marine mammals research

Vessels

Coastal

Aircraft remote sensing

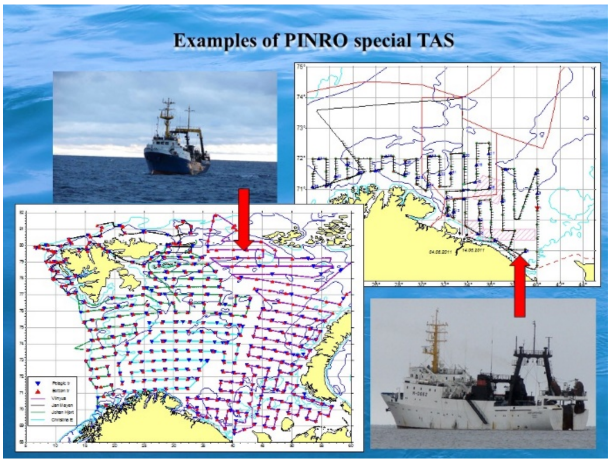


Research area

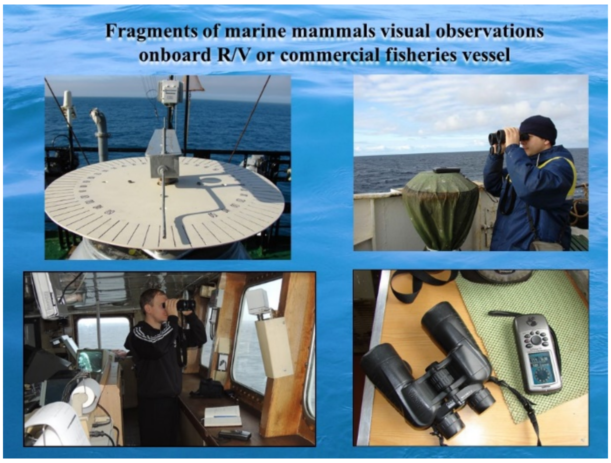
PINRO total numbers of marine mammals research in the Barents Sea by vessel observations

Now we have data from 136 cruises (among them)

- 48 cruises as special surveys (beginning from 2004)
- 74 cruises as commercial fisheries by PINRO observers and others (beginning from 2002)
- 14 cruises during special ecological researches from Russian oil and gas industry (beginning from 2008)

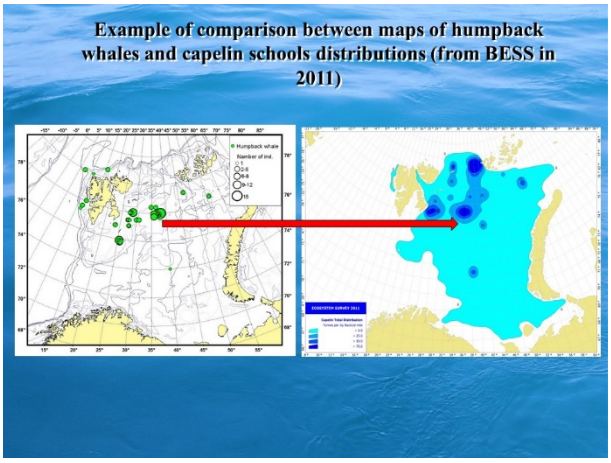


Examples of PINRO special TAS



Fragments of marine mammals visual observations onboard R/V or commercial fisheries vessel

Example of food objects definition in place where humpback whales were observed

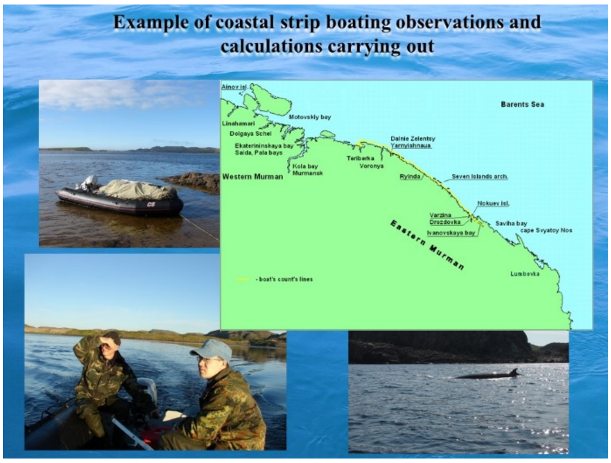


Example of comparison between maps of humpback whales and capelin schools distributions (from BESS in 2011)

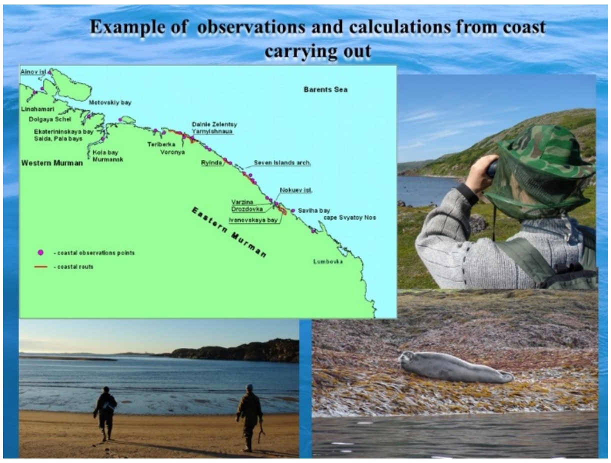
PINRO coastal expeditions along the Barents Sea Kola Peninsula coastal line

From 2002 to current time 16 expeditions were carried out which included

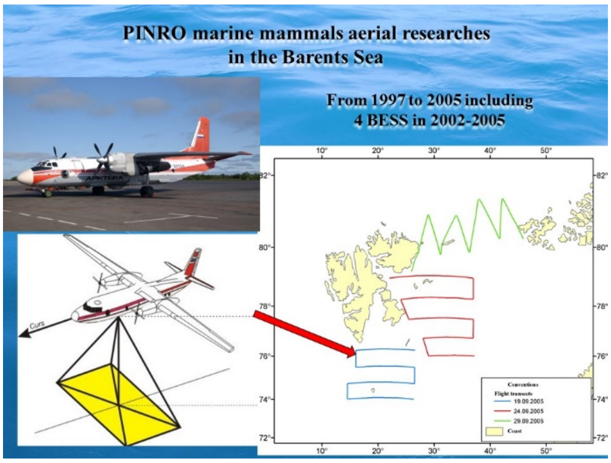
- Coastal strip boating observations and calculations
- Observations and calculation from coast
- Sightings from coastal observation post



Example of coastal strip boating observations and calculations carrying out



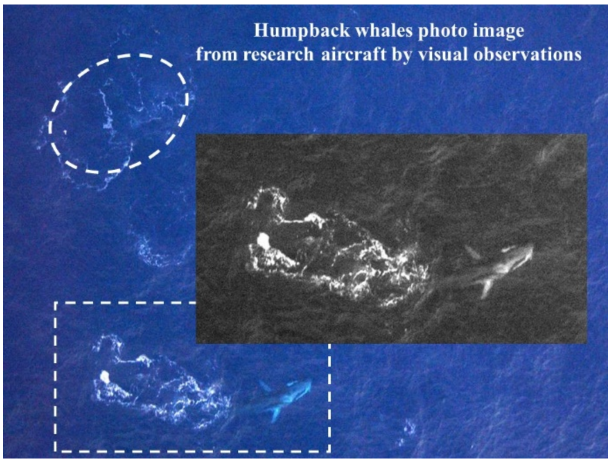
Example of observations and calculations from coast carrying out



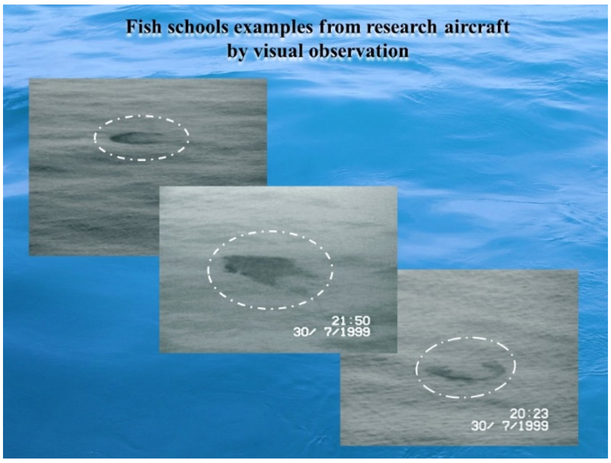
PINRO marine mammals aerial researches in the Barents Sea

From 1997 to 2005 including
4 BESS in 2002-2005

Working fragments onboard research aircraft



Humpback whales photo image from research aircraft by visual observations



Fish schools examples from research aircraft by visual observation

THANK YOU VERY MUCH FOR YOUR ATTENTION!
PLEASE, ANY QUESTIONS?

Distribution of rorquals and predatory fish in relation to prey in the Norwegian high Arctic

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Recent warming in the Barents Sea has led to changes in spatial distribution of both zooplankton and fish, with boreal communities expanding northwards. A similar northward expansion is observed in several rorqual species that migrate into the northern waters to take advantage of high summer production and hence feeding opportunities. Based on ecosystem surveys performed in August-September in 2014-2017, we investigated the spatial associations between the three rorqual species blue, fin and minke whales, the predatory fish cod, and their prey in the Arctic Ocean waters to the west and north of Svalbard. Using existing knowledge about dive habits of the rorquals involved, attention was particularly paid to prey in the upper 200 m of the water column, but we also did some analyses of prey down to 500 m. During the surveys, whales were observed from the bridge of the vessel by dedicated whale observers, whereas the distribution and abundance of cod and potential prey species were assessed using trawling and acoustic methods. We used a logistic regression model to investigate the association between the rorquals and location (latitude/longitude), zooplankton, and fishes, respectively. Furthermore, we applied a linear regression model to analyse the association between cod and zooplankton. And finally, we used a spatial overlapping analysis to assess the spatial associations between the rorquals and their prey.

The acoustic data of zooplankton and fish, with 10 m vertical and 1 nautical mile horizontal resolution, were obtained by Simrad EK60 echo sounders from around 10 m below the sea surface and down to around 1000 m depth. Rorquals were observed and recorded systematically along the cruise tracks. Prior to the analyses, we organized the data by corresponding whale sighting data to trawl/acoustic data with respect to time and location along the cruise tracks. Subsequently, data were pooled to grids with nodes respectively 25 km and 50 km apart which enabled comparisons under different grid resolutions. The recorded acoustic data were integrated for each 100 m depth layer and all zero values were transformed into sufficiently small random numbers to avoid numerical problems for the computational procedure. For the whale sighting data, we transferred the counted number for rorquals into zero as absence and one as presence.

First, in the logistic regression model, the absence/presence data for each rorqual was set as the objective variable, for which the covariates were set as zooplankton and fishes. We observed consistent significant p-values (< 0.05) for both 25km and 50km grid resolutions, indicating significant associations between cod and minke whales at 100-200 m depth, and between zooplankton and fin whales at 300 – 500 m depth. No associations were detected, neither for blue whales in general nor between the rorquals and location (latitude/longitude).

Secondary, a linear regression model was applied to investigate possible associations between zooplankton as prey and cod as predator. As objective variable was set the acoustic data of cod occurring in layers from 10 m to 500 m depth, and as covariate was set the data on location (latitude/longitude) and the acoustic data of zooplankton occurring in the same depth layers in each survey year. We observed consistent significant p-values (< 0.05) for both 25 km and 50 km grid resolutions, indicating significant association between locations (latitude/longitude) and zooplankton occurring at around 300-500 m depth on one hand, and cod occurring at around 300-500 m depth on the other in 2015-2017. In 2014, zooplankton occurring between 100-200 m was

associated with cod at the same depths, whereas locations (latitude/longitude) associated with cod only when using the 25 km grid resolution.

Finally, we analyzed the spatial overlap between whales and their prey using a one-dimensional direction distance from 2 to 50 km along the cruise track, centered on the whale sighting to align with the presence of fish. Significant spatial overlap was observed between minke whales and zooplankton occurring in the upper 100 m. This is somewhat in contrast to the results from the logistic regression model. On the other hand, observed significant overlap between fin whales and zooplankton occurring around 200-300 m depth is consistent with outputs from the logistic regression analysis. Furthermore, overlap between minke whales and cod in the upper 100 m around 15 km from the sighting area was significant, and the overlap between fin whales and cod occurring in 300-400 m depth was significant as well.

Keywords: Spatial association; minke whale; fin whale; blue whale; zooplankton; fish

The distribution of marine mammals in the Barents Sea in recent years based on PINRO vessel research

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Abstract

We present data on the distribution of marine mammals (primarily cetaceans), in the waters of the Barents Sea, obtained in the course of PINRO marine research activities in recent years. The article focuses on the results of observations made in the course of trawl-acoustic and ecosystem surveys (TAS and ES respectively) onboard PINRO research vessels during different seasons of the year. In February-March during Joint Russian-Norwegian multispecies TAS for demersal fish, we carried out research in the southeastern Barents Sea. This time low cetacean numbers were recorded, and although these were higher in the western part of the survey area. Marine mammals were sighted in May-June during the International ES of the northern seas (IES) in the south Barents Sea. This time the number of cetaceans encounters was significantly higher, while their abundance also increased and their distribution was wide. Marine mammals observations were made in August-October during the annual joint Russian-Norwegian Barents Sea ecosystem survey (BESS) in all areas of the Russian zone. This time, the widest cetacean distribution was registered. The next PINRO marine mammals sightings were registered during the multispecies TAS for estimation of juvenile fishes and stock assessment of demersal fishes in the Barents Sea and adjacent waters in October-December, when low numbers of marine mammals were registered. Research covered almost the entire surface of the Barents Sea. On the basis of these studies, we determined that the distribution of the main species of cetaceans was usually closely associated with pelagic fish aggregations obtained from trawl-acoustic data.

Keywords: marine mammals, distribution, encounters, Barents Sea, vessel observations

Introduction

The main PINRO research area in the Barents Sea is a region of intensive fishing activity, in which almost all the main fish stocks encountered in high numbers are exploited. For their rational use, it is necessary to take into account all potential influences, including the presence of predatory marine mammals. For this, we need information about the composition of marine mammals species; seasonal distributions, the time that they remain in given areas, migration routes, numbers, diet specialisation and so on.

Currently, research on the distribution and numbers of marine mammals in the Barents Sea area is performed on board PINRO research vessels and during coastal expeditions. Previously, from 1997 until 2005, aircraft were usually employed for this purpose.

Nowadays, PINRO research cruises in the Barents Sea enable us to collect data on marine mammals throughout the year. At present almost all PINRO marine research cruises are trawl-acoustic based and ecosystem oriented, which enables to determine why marine mammals occupy particular areas of the Barents Sea.

Data on marine mammals distribution, encounters and numbers, besides evaluating their role in the Barents Sea ecosystem and their impact on commercial fish species, can also be used as an indicator of aggregations of fishery target species, including the state of the environment as a whole. Marine mammals are also a huge potential commercial resource that only Norway is currently developing in the Barents Sea.

Materials and methods

PINRO marine mammals research in the open area of the Barents Sea takes two forms:
1. Marine mammal observations during specialized trawl-acoustic and ecosystem surveys (TAS and ES respectively);
2. Marine mammal data collected during fisheries on board fishing vessels and from other cruises.

PINRO currently performs regular annual specialised studies of marine mammals in the Barents Sea during:

- The Joint Russian-Norwegian multispecies TAS for demersal fish in the Barents Sea in February-March;
- The International ES of the northern seas in May-June;
- The Joint Russian-Norwegian Ecosystem Survey in the Barents Sea (BESS) in August-October;
- Multispecies TAS for estimation of juvenile fishes and stock assessment of demersal fishes in the Barents Sea and adjacent waters in October-December.

Vessel-based naked-eye transect surveys of marine mammals are performed when the vessel is under way, either from the navigation deck or from the ship’s bridge. We use 7x50 binoculars (only to determine the species), a special protractor, ship or portable GPS system, digital camera, portable personal computer for data processing. All the marine mammals observed are identified to species level, and if this is impossible, recorded as “unidentified” (unid.), for example, unid. whale, unid. dolphin, unid. seal. During the observations, the date, time, position, type, numbers, size of the group, distance from vessel, behaviour and weather conditions are recorded in a working log. The distance to the observed object is measured using a binocular grid or a special measuring ruler. Every 60 minutes during the transect, coordinates are recorded, including the transect's starting and finishing coordinates. Any marine mammals opportunistically observed outside the transect are also recorded. Observations are also made when setting and hauling the trawl, when the vessel is actually trawling, or drifting, including under adverse weather conditions (Zyryanov, 2004).

During TAS, when the research vessel is following the planned tacks with its acoustic equipment active, it is possible to view the relationship between marine mammal encounters and distribution with the presence of other marine organisms. Simultaneously with the acoustic survey, control trawls are carried out at predetermined points. When marine mammals are registered, the echo sounder recordings are analysed, as are individuals from any trawl catches . With these results in hand, it is possible to define and characterize with some accuracy the prey of marine mammals in the area (Klepikovskiy, Nosov, 2013).

In addition to its specialised marine research projects, PINRO collects information about marine mammals on board fishing vessels and from other cruises that involve PINRO staff, who collect available data regarding commercial fish species, and wherever possible make marine mammal observations.

Results

This article presents the results of specialized observations of marine mammals during TAS and ES surveys carried out on board PINRO research vessels.

During the Joint Russian-Norwegian multispecies TAS for demersal fishes in the Barents Sea in February-March, observations by PINRO of marine mammals were performed in 2004, 2011, and every year since 2012. During the survey, PINRO research vessels explored the southeastern part of the Barents Sea (Figure 1).

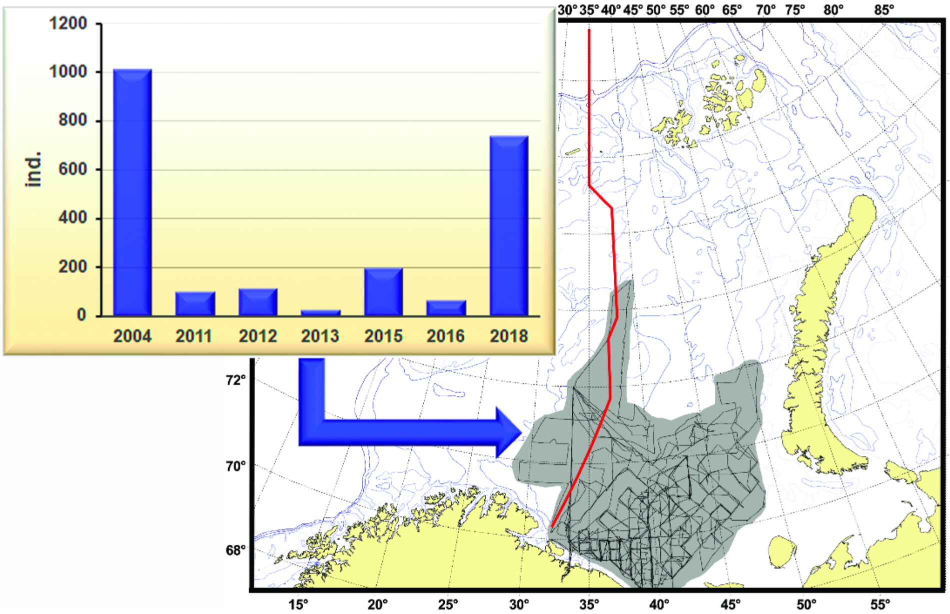

Figure 1. PINRO research area with research vessel routes and total numbers of cetaceans counted during Russian-Norwegian multispecies TAS for demersal fish in the Barents Sea, February-March.

The main results of the observations made during this period in the PINRO research area show low marine mammals (mostly cetaceans) encounters in the eastern part of survey. Most of the marine mammals encounters take place in the western part of the survey area (Figure 2).

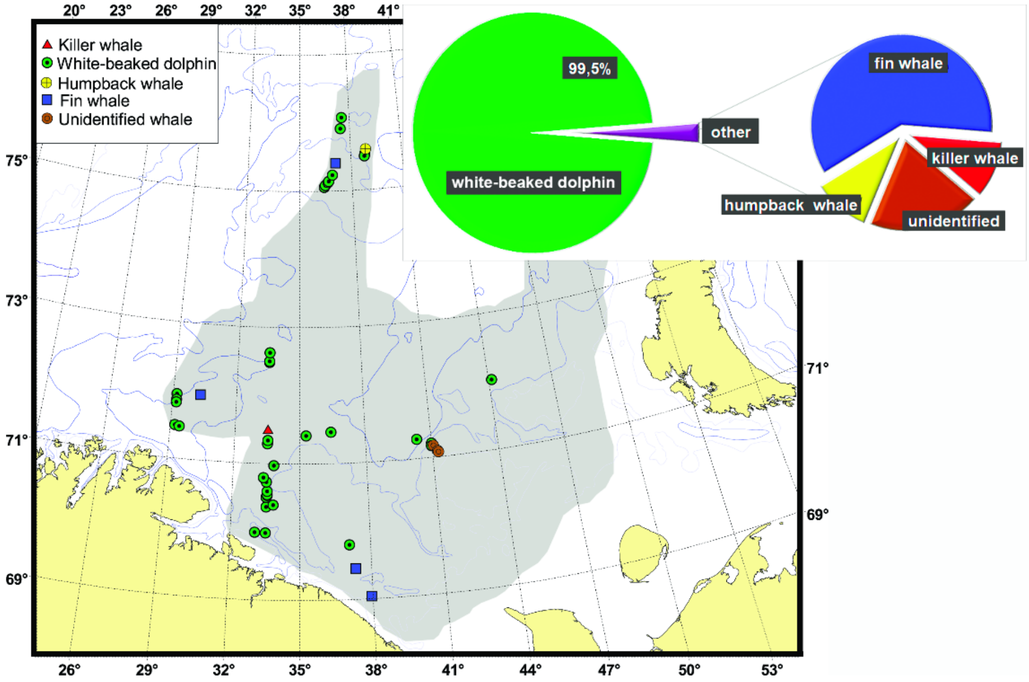

Figure 2. Species composition, distribution and percentage of cetaceans counted during Russian-Norwegian multispecies TAS for demersal fishes in the Barents Sea, February-March.

In the area centred on 71º56´N/29º08´E, mixed concentrations of capelin (*Mallotus villosus*) and herring (*Clupea harengus*) and wintering groups of white-beaked dolphin (*Lagenorhynchus albirostris*) numbering 100-500 individuals were observed, and in the area centred on 71º12´N/40º59´E, close to capelin aggregations, group of some 1000 dolphin were seen. Likewise, close to capelin aggregations in the northern and southern parts of the research areas, small numbers of humpback (*Megaptera novaeangliae*) and fin (*Balaenoptera physalus*) whales (mostly individuals) were observed, apparently remaining for the winter in the Barents Sea or having already returned there. Minke whales (*Balaenoptera acutorostrata*) were not observed.

Marine mammal observations have been performed by PINRO during the International ES of the northern seas in May-June since 2008. Our research covers the southern part of the Barents Sea from east to west (Figure 3).

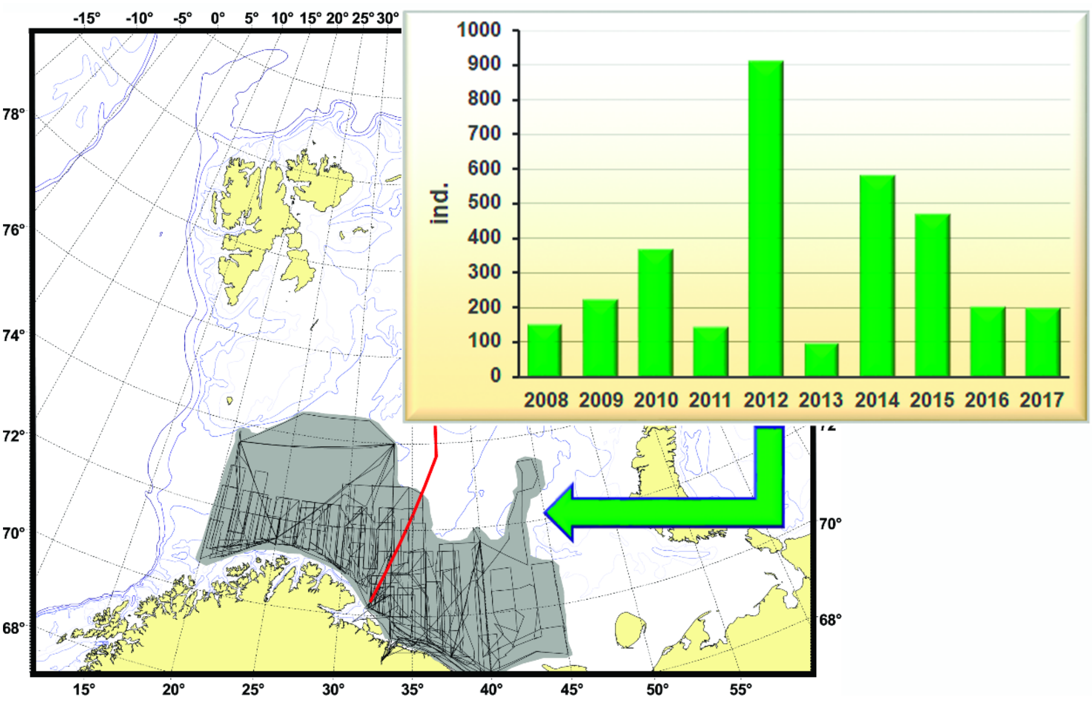

Figure 3. PINRO research area with research vessel routes and numbers of cetaceans recorded in the Barents Sea during the annual International ES of the northern seas, May-June.

Compared to the previous survey (February-March) there is a significant increase in encounters of marine mammals and a wider distribution within PINRO's research area (Figure 4).

The species found here in largest numbers were white-beaked dolphin, minke whale, fin whale and humpback whale. The white-beaked dolphin was recorded both singly and in groups of from 2-8 to 15-20 individuals in almost all over the research area. These species concentrated on capelin and herring aggregations. Most minke whale were observed singly in the eastern and central parts of the research area, where they were recorded close to herring and cod (*Gadidae*) aggregations. Fin whales were the most numerous species of the *balaenopteridae*. During the observations fin whales were recorded singly and in groups of up to five individuals. Most of these animals were observed in the western part of research area between 20ºE and 27ºE close to macroplankton, capelin and herring aggregations. Humpback whales were recorded singly and in groups of up to four individuals, and most were observed west of 27ºE. Humpbacks were sometimes recorded together with white-beaked dolphin, actively feeding on herring and capelin aggregations. Among the toothed whales in some years we also observed harbour porpoises (*Phocoena phocoena*), killer whales (*Orcinus orca*), northern bottlenose whales (*Hyperoodon ampullatus*) and sperm whales (*Physeter macrocephalus*).

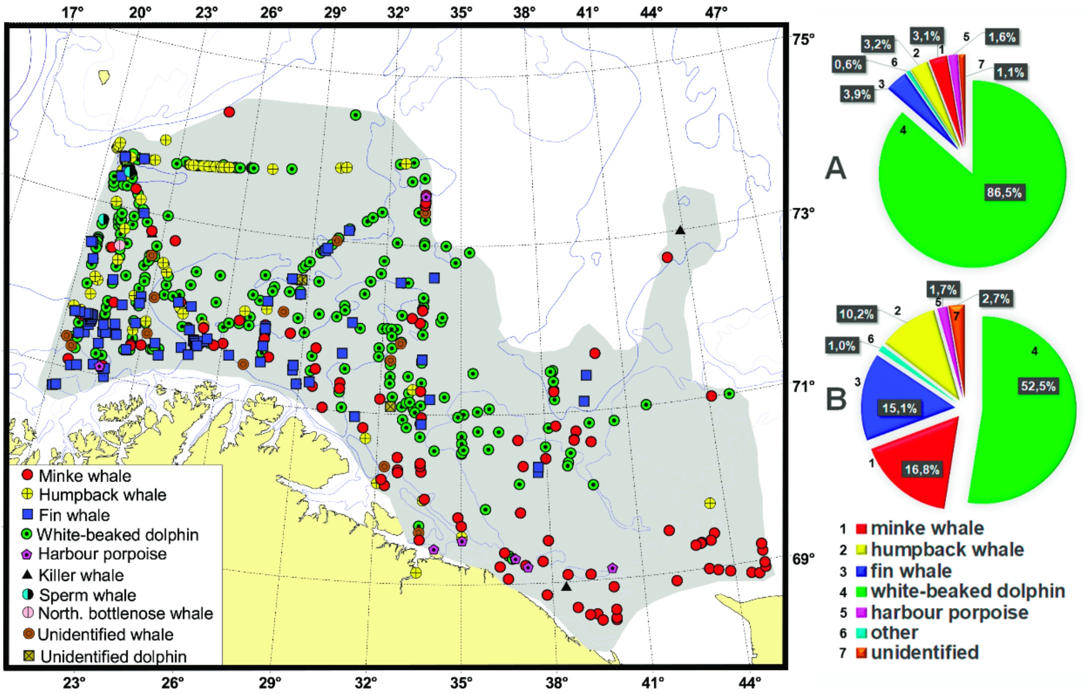

Figure 4. Species composition, distribution, percentages of numbers (A) and encounters (B) of cetaceans counted in the Barents Sea during the International ES of northern seas, May-June.

PINRO has been studying marine mammals during BESS cruises in August-October since 2004. In 2004-2007, our studies covered the western regions of the Barents Sea, but since 2008 only the Russian zone has been explored (Figure 5).

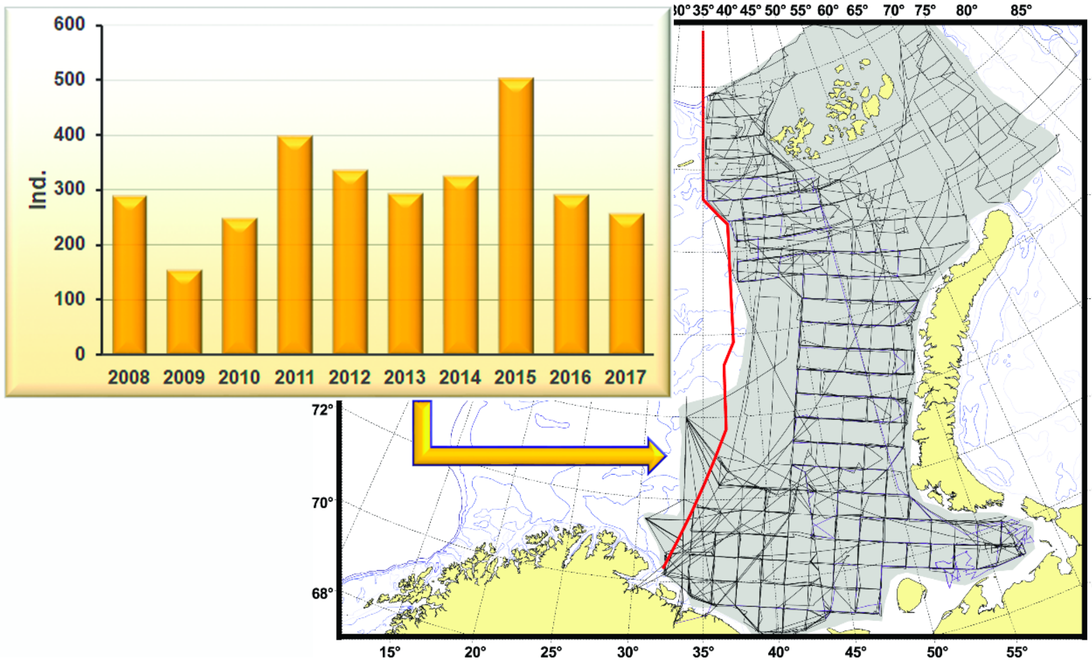

Figure 5. PINRO research area with research vessel routes and marine mammals total numbers recorded during BESS in August-October.

We recorded the widest distribution of cetaceans in August-October (Figure 6). The most frequently species observed were white-beaked dolphin, harbour porpoise, minke whale, humpback whale and fin whale. The white-beaked dolphin was most widely distributed in the research area, except for the Pechora Sea. Long-term observations have shown that this species does not enter the Pechora Sea at all. It was recorded mainly in groups of 5–20, but sometimes as many as 40–70 individuals.

Encounters of white-beaked dolphins were co-located with aggregations of polar cod (*Boreogadus saida*), capelin, herring, and cod. Harbour porpoises were observed in small groups. According to observations of recent years, the largest numbers of this species in August-September are located in the southern and southeastern parts of the PINRO research area. Animals were recorded on herring, sand eel (*Ammodytes marinus*), juvenile capelin and cod. Minke whale were recorded mostly as individuals throughout almost the entire PINRO research area, except its western deep-water seas. In the northern areas, they were registered close to aggregations of capelin and juvenile polar cod, in southern areas minke whales were observed close to herring, juvenile cod and other fish, and in the southeastern they accompanied polar cod, herring and sand eel aggregations. The largest numbers of humpback whales were observed at 76ºN, close to capelin aggregations. During BESS in the PINRO research area, fin whales were observed everywhere except in the Pechora Sea and some western areas. Sperm whales were seen only once around 71º05 N 35º56´E. Killer whales were seldom seen, and then mostly north 75ºN.

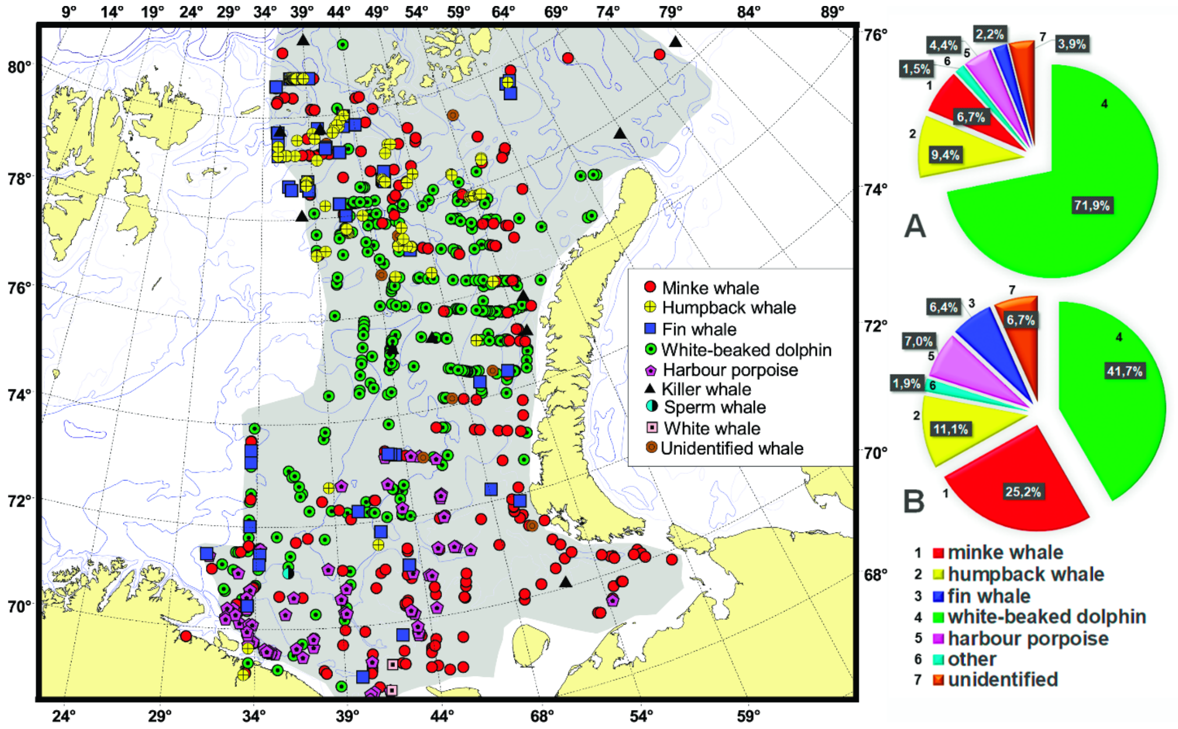

Figure 6. Species composition, distribution, percentage of numbers (A) and encounters (B) cetaceans counted during BESS in August-October.

In October-December, during the multispecies TAS for estimates of juvenile fish and stock assessment of demersal fishes in the Barents Sea and adjacent waters, our research covered almost the entire Barents Sea, except for the eastern and northeastern regions (Figure 7).

The main results for this period and research area are presented below. First, there were few encounters with marine mammals, due to the migration of most cetaceans from the Barents Sea and poor observation conditions (short period of daylight, adverse weather). In the northern and eastern parts of the Sea where capelin aggregations were recorded, wintering groups of up to 100 white-beaked dolphins were recorded. In the western parts, mostly in deep waters, northern bottlenose whale and sperm whales were encountered. Killer whales were observed in the east and west, closely associated with herring aggregations. Baleen whales were registered, mostly singly, rarely as pairs. Humpback whales were recorded in the north, close to capelin aggregations, and in the west, accompanying herring. Fin whales and minke whales were observed only in areas west of 30ºE (Figure 8).

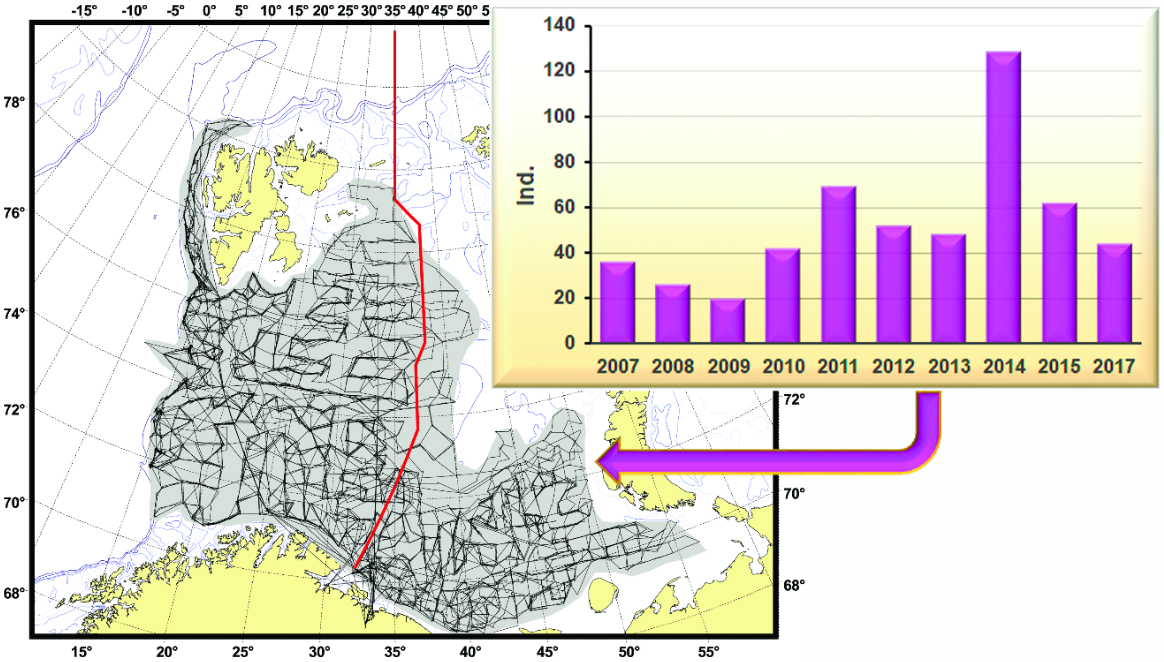

Figure 7. Area of research cruises, showing research vessel routes and numbers of cetaceans recorded during multispecies TAS of juvenile fish and stock assessments of demersal fish in the Barents Sea, October-December.

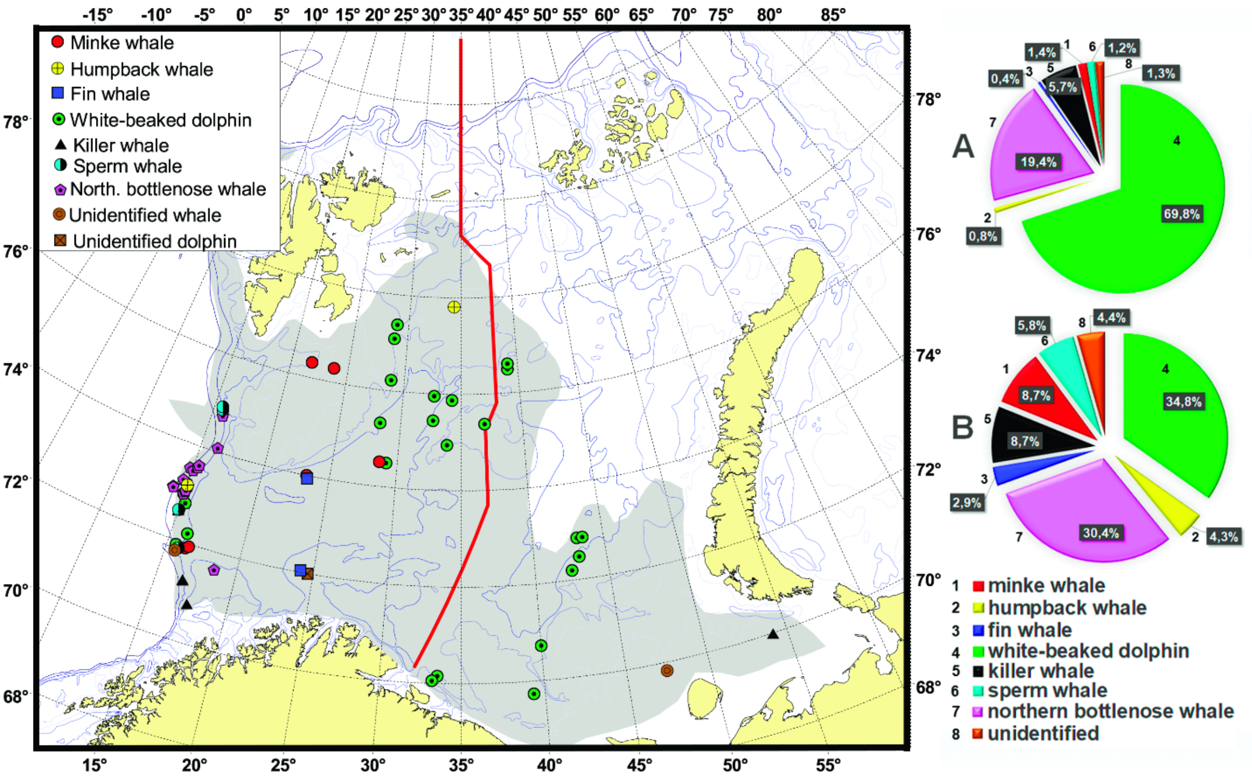

Figure 8. Species composition, distribution and percentage of cetacean numbers (A) and encounters (B) of species counted during multispecies TAS of juvenile fishes and stock assessments of demersal fishes in the Barents Sea, October-December.

Besides cetaceans, pinnipeds and polar bears (*Ursus maritimus*) were recorded in the trawl-acoustic surveys described here. Most of the material on them was collected during BESS in August-October. The harp seal (*Pagophilus groenlandicus*) was the most heavily represented pinniped species. The main meeting places for seals and polar bears were the northern regions with ice patches near Franz Josef Land and Novaya Zemlya.

Conclusions

Specialised observations of marine mammals during TAS and ES in the Barents Sea obtained the following main results:

- in February-March, in the southeastern Barents Sea, low numbers of marine mammals, primarily cetaceans, were observed. Only white-beaked dolphins, killer whales, fin whales and humpback whales were recorded. These animals were observed closely following capelin and herring aggregations;

- in May-June in the southern part of the Barents Sea increases in species diversity and in encounters with marine mammals were observed. Eight cetacean species were recorded. Their most dense aggregations, primarily of white-beaked dolphins, were observed in areas of capelin and herring aggregations;

- in August-October, the most extensive distribution of cetaceans in the entire open water area of the Barents Sea was recorded in the Russian zone. Seven species were registered, the most numerous and frequently encountered being white-beaked dolphin, harbour porpoise, minke whale, fin whale and humpback whale. Groups of these species were always found in close association with concentrations of capelin, polar cod, herring, cod and other fish species, at various densities;

- in October-December, low numbers of cetaceans were observed throughout the Barents Sea. Seven species were registered , most of them in the western regions.

The PINRO research presented this paper enables us to continuously monitor marine mammals in the Barents Sea throughout the year, collecting material to study the distribution patterns of animals and their relationships with aquatic organisms, primarily with commercially relevant fish species.

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Growth and condition parameters of early maturing female hooded seals from the Northwest Atlantic and late maturing females from the Greenland Sea stock

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Morphometric parameters of female hooded seals (*Cystophora cristata*) from the Northwest Atlantic (NWA) and Greenland Sea (GS) stocks were analysed to explore underlying causes for higher mean age at primiparity in the severely depleted GS stock. The two stocks have so far not been proven to be genetically differentiated, but are considered demographically independent based on available tagging data and differences in abundance trends. Hooded seals on both sides of Greenland haul out on sea ice during breeding in early March and moulting in June-July.

All morphometric and reproductive data used in this study are derived from hooded seals sampled by Norwegian scientists during commercial and scientific sealing expeditions to breeding and moulting patches over the period 1956-2010. The most consistently measured morphometric parameter was standard length, but a subset of samples also had data on blubber thickness and total weight. The seals were aged based on numbers of dentinal annuli in transverse sections of a lower canine tooth. Reproductive status was determined from presence or absence of ovarian corpora
Only moulting samples comprise significant numbers of immature seals. Due to prolonged fasting, moulting seals are generally also leaner than breeding seals. Separate analyses were therefore run for breeding and moulting females.

GAM analyses of length-at-age data for moulting NWA females showed an increase in intercept between the sampling periods 1956-60 and 1964-76 ($p<0.01$). This was supported by a significant increase in growth rate estimated from Richards growth models ($p<0.001$). For the GS stock, moulting patch data were only available for 1990 and 2008-10. In both cases very few older females were available and comparisons of asymptotic lengths were therefore inconclusive. For 1-4 year-old females, however, both of the GS samples showed significantly shorter length-at-age than the corresponding NWA samples ($p<0.01$) and GS females from 1990 were significantly shorter than GS females from 2008-10 ($p<0.01$).

GAM analyses of length-at-age of breeding NWA females showed interannual homogeneity over the sampling period 1965-72. In contrast length-at-age of GS females showed a significant decrease between the period 1958-75 and 1980-99. After correction for seasonal effects, length-at-age of parous GS females in the 2008-10 moulting sample, however, suggests a return to levels observed before 1980. All GS samples, however, showed significantly shorter length-at-age than for parous NWA females. Average length at primiparity of GS females was similar to NWA females before 1980, but significantly reduced during the period 1980-99 ($p<0.01$). During the entire study period, however, mean age at primiparity remained constant in GS females and ~ 0.5 year higher than for available samples of NWA females over the period 1967-72.

GAMs correcting for length, age and sampling date, generally showed lower blubber levels for breeding GS females than for breeding NWA females and also lower total mass.

Blubber thickness of moulting females was highest in NWA samples from the 1950s, but later estimates were similar between stocks. In contrast, total mass of GS females sampled 2008-10 was significantly reduced compared to 1990 and reference data from the NWA ($p<0.01$). This suggests low protein stores, which could affect early pregnancy rates.
In combination with high values of MAP, reduced length-at-age in GS hooded seals strongly suggest that females from this stock had a poorer balance between energetic costs and gains

compared to reference data for the NWA hooded sea stock. Poor conditions appear to have been particularly pronounced during the period 1980-99 as also supported by the reduction in average length at primiparity. Estimated abundance of NWA hooded seals was rather constant during the study period, while the GS stock declined by about 75 % from 1960 to 1980. The observed changes in morphometric parameters in the GS stock and to a lesser extent also in the NWA stock therefore most likely represent density-independent responses.

Keywords: Cystophora cristata, length-at-age, body condition, age at primiparity, length at primiparity, core mass, density dependence, North Atlantic

Role of marine mammals in the Barents Sea food web

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Predator-prey interactions are one of the main regulators of ecosystem dynamics. By addressing these interactions explicitly and collectively, food webs provide a useful framework for studying ecosystem structure, functioning and vulnerability. The role of species or groups of species in maintaining ecosystem functioning depends at least partly on their direct links to the other species (both prey and predators) and their topological position. Central and functionally unique species might propagate perturbations through trophic cascades and radically affect food web structure, whereas species that are more peripheral might be less influential on the network characteristics. Identification of key players and understanding of species' role in a food web are therefore of paramount importance for conservation measures and management decisions. In this respect, changes in top predator species such as marine mammals are known to affect intermediate consumers through direct predation links and risk-mediated effects. These effects can also ripple through the food chains and affect lower trophic levels through trophic cascades and top-down effects. Our objectives were to describe the role of marine mammals in the Barents Sea food web based on their position in this ecological network and to assess commonalities and differences among marine mammals from a food web perspective.

We updated an existing, highly resolved Barents Sea food web by including all the most commonly observed marine mammals and their prey. This food web consists of a list of species or trophospecies (TS) that are defined as set of species that share the same predators and prey. In total, 239 species were included, belonging to five groups: plankton (53), benthic invertebrates (81), fish (77), seabirds (9) and marine mammals (19). They connected through 2464 links yielding a link density of 10.3 links per species. As a group, marine mammals consumed 134 available trophospecies of the Barents Sea food web, which represents 56% of the available species. Prey species of marine mammals belonged to 60 different families of zooplankton, benthos, fish and other marine mammals. The number of direct interactions between marine mammals and the rest of the food web ranged from four for the sperm whale (*Physeter microcephalus)* to 52 for the harbour porpoise *(Phocoena phocoena)*, with a certain heterogeneity between phylogenetic groups. Pinnipeds consumed a larger number of prey items compared to odontocetes (39 vs. 21 on average). Mysticetes as a group were more planktivorous, whereas odontocetes and pinnipeds consumed mostly fish. However, one odontocete, the killer whale *(Orcinus orca)* and two pinniped species, the walrus *(Odobenus rosmarus)* and the bearded seal *(Erignathus barbatus)* had a more specific diet consuming marine mammals and benthic prey, respectively. Odontocetes' diets overlapped mostly with pinnipeds', and the highest percentage of diet overlap occurred within the Mysticetes. The dietary niche of the fin *(Balaenoptera physalus)*, bowhead *(Balaena mysticetus)* and blue whales *(Balaenoptera musculus)* are included within the humpback's *(Megaptera novaeangliae)*, whereas the minke whale *(Balaenoptera acutorostrata)* overlaps the least with other species in its phylogenetic group. The diet of pinnipeds is included within the diet of several odontocetes with the exception of the killer whale that consumes pinnipeds. Based on the clustering of two different diet overlap indices, some species were consistently grouped together: ringed *(Pusa hispida)*, harp *(Pagophilus groenlandicus)* and hooded seal *(Cystophora cristata)*; white beaked dolphin *(Lagenorhynchus albirostris)* and beluga whale *(Delphinapterus leucas)*; and the baleen whales with the exception of the minke whale.

As a group, marine mammals are characterized by high trophic levels, a high number of prey and a low number of predators. They are connected to all of the basal species (species that do not have any prey such as primary producers and detritivores) and to the most central species (species with the most direct links or on the most numerous paths) in the food web. In that sense, they are similar to seabirds and some predatory fish. Although marine mammal species share some commonalities in terms of position within the food web, some inter-specific and inter-phylogenetic group differences are apparent. Pinnipeds are the most homogenous group associated with a high degree of omnivory and high number of prey which themselves are well connected to the rest of the network. We note the exception of the walrus, which has a lower degree of omnivory and a lower number of prey compared to the other pinnipeds. Mysticetes are split between well-connected species with a high degree of omnivory and peripheral specialist species such as the blue and the bowhead whale. The 19 marine mammal species split between two distinct modules of species with tighter links with each other than with the rest of the network. The majority of their feeding links is located within their own module. However, three pinnipeds species act as module connectors: the grey seal *(Halichoerus grypus)*, the bearded seal and the walrus. Topological similarity indices reflecting the position of each species within the network showed that pinnipeds were associated with the harbour porpoise and the minke whale while all the other odontocetes and mysticetes clustered together.

Marine mammals in the Barents Sea share a number of characteristics associated with top predators in ecosystems. However, within this top predator group, there is an important heterogeneity across species. Based on their trophic links and those of their immediate neighbours, some species, the sperm and the bowhead whales are more peripheral to the network whereas others, such as the harbour porpoise or the grey seal, are more central. The latter may mediate perturbations via several paths to the lowest levels of the Barents Sea food web and across modules. Some species, such as the ringed, hooded and harp seals were also similar in terms of network positioning, potentially indicating some redundancy with regard to contribution to ecosystem functioning.

The present food web study encompasses the entire Barents Sea without taking into account species’ spatial distributions. Some species have very strict habitat requirements and although they may be similar to other species from a network perspective, they might not overlap spatially. Nonetheless, changes in climate and environmental conditions in the Barents Sea might affect species distributions, causing some boreal marine mammal species to expand northwards, with consequences for the regional structure of food webs in the Barents Sea.

Computer detection of seals on ice using digital photos

Ilias Shafikov

Knipovich Polar Research Institute of Marine Fisheries and Oceanography, Murmansk, Russia

The visual method of counting seals in digital photographs of aerial survey significantly increases the time of obtaining the result. There is a need for computer automation of this process.

In the paper, some approaches to computer counting of seals in digital photographs are determined. The main task is to develop an algorithm for singling out images of seals that are on ice during the period of whelping and moulting patches.

To process, one chooses an array of photos made under relatively similar conditions (camera settings, survey height, weather conditions). To configure the recognition parameters in the photographs, we selected samples of seal images in separate files. The following parameters are used:

- the overall brightness of the image,
- the saturation of the RGB color component,
- the form factor (the ratio of area to perimeter).

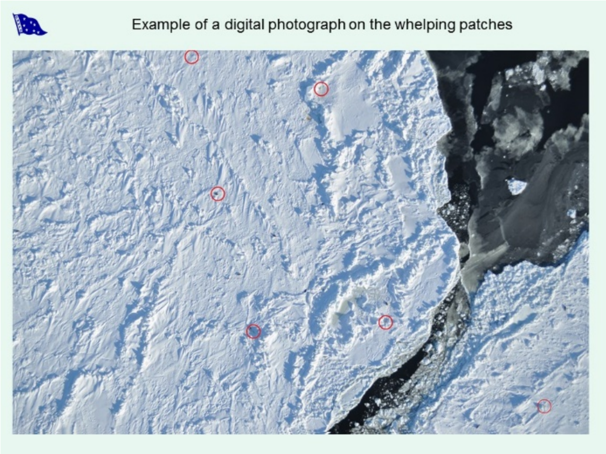
When setting up the counting program, the operator using the derived histograms of the brightness of the constituent colors (RGB) and the form factor determines the boundaries of the values of the seal image parameters that distinguish it from the background of ice and water. There is a recording of the parameters of the seal images determined in this way with a given deviation of the values in a file for the subsequent counting of the seals.

When processing original digital photos, presented as an array of pixels, the software selects objects according to the set parameters corresponding to the specified parameters of the seal images. For visual control, one displays a digital photo with seals marked by the program. After converting a color image to a binary view, there is a counting of seals.

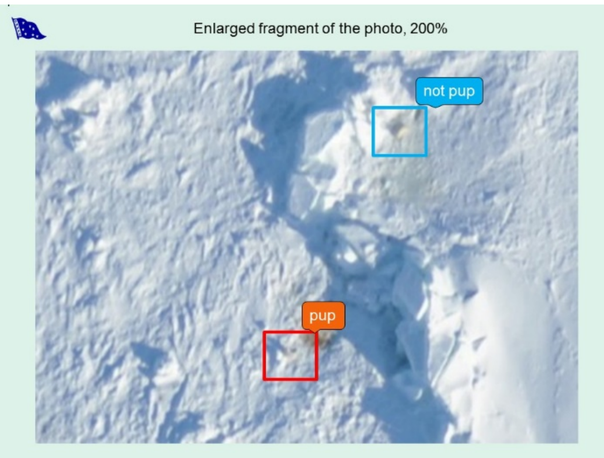
The author realized in a software the described approaches to computer counting of seals in digital photographs. One can use presentations on computer recognition of seals on digital photographs in order to organize a neural network.

Knipovich Polar Research Institute of Marine Fisheries and Oceanography (PINRO)

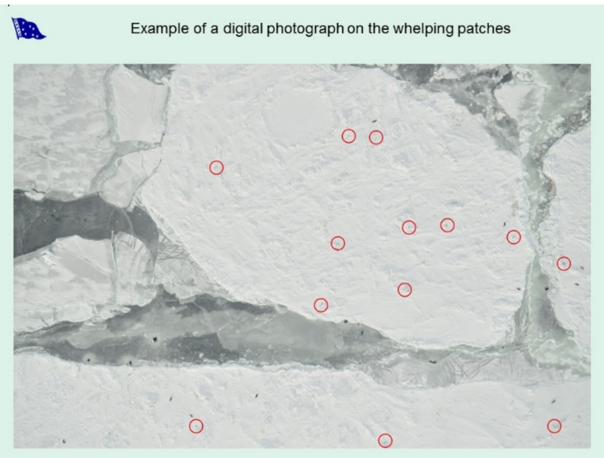
Computer detection of seals on ice using digital photos



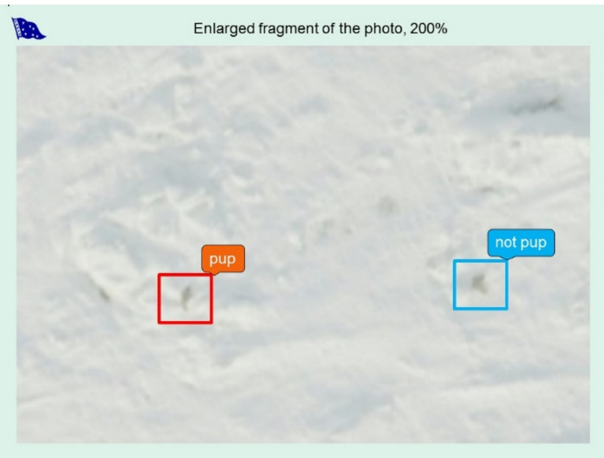
Example of a digital photograph on the whelping patches



Enlarged fragment of the photo, 200%



Example of a digital photograph on the whelping patches



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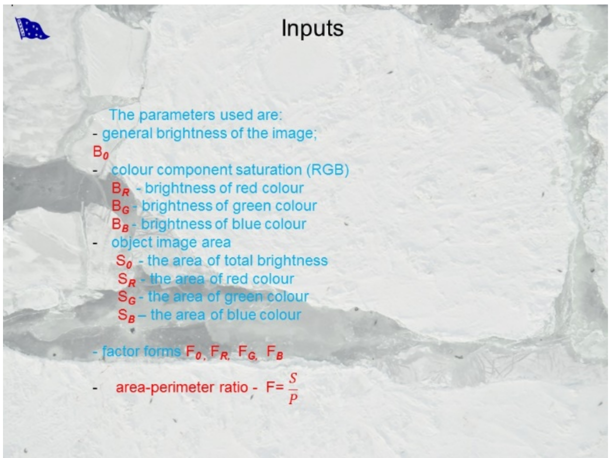


Inputs

The parameters used are:

- general brightness of the image;

B_0

- colour component saturation (RGB)

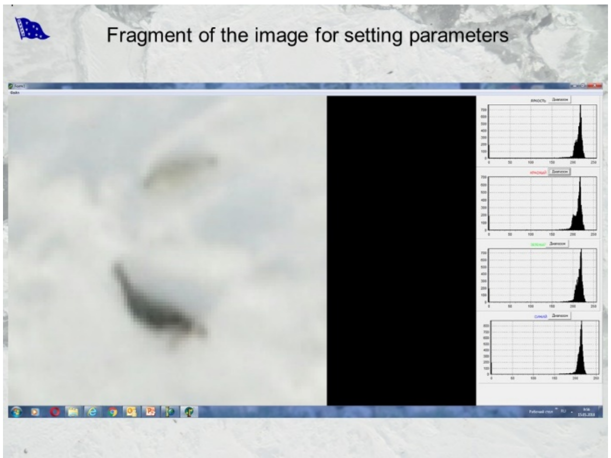
B_R - brightness of red colour
B_G - brightness of green colour
B_B - brightness of blue colour

- object image area

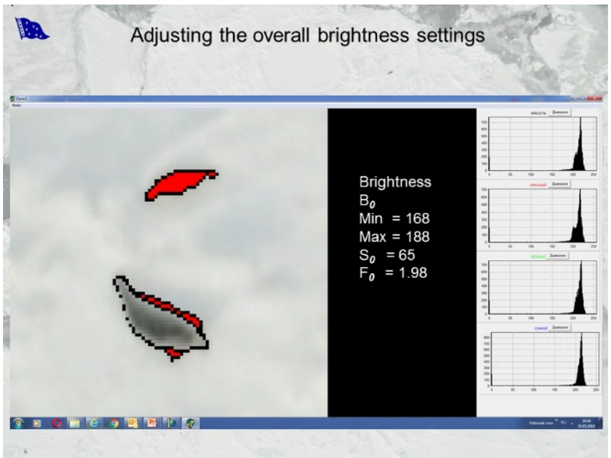
S_0 - the area of total brightness
S_R - the area of red colour
S_G - the area of green colour
S_B – the area of blue colour

- factor forms F_0, F_R, F_G, F_B

- area-perimeter ratio - $F=\frac{S}{P}$

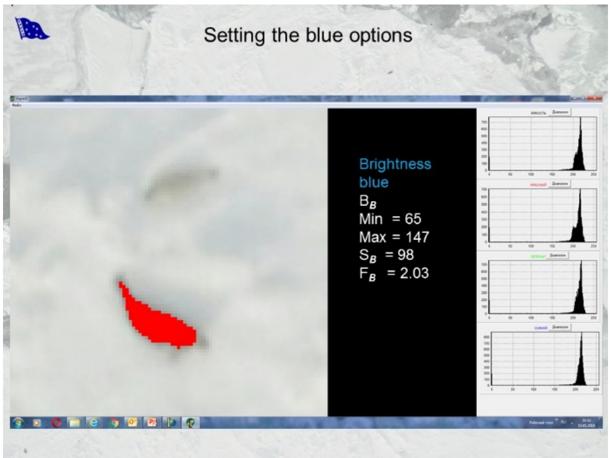


Fragment of the image for setting parameters



Adjusting the overall brightness settings

Brightness
B_0
Min = 168
Max = 188
S_0 = 65
F_0 = 1.98



Setting the blue options

Brightness
blue
B_B
Min = 65
Max = 147
S_B = 98
F_B = 2.03

Adjusting the red colour settings

Brightness
red
B_R
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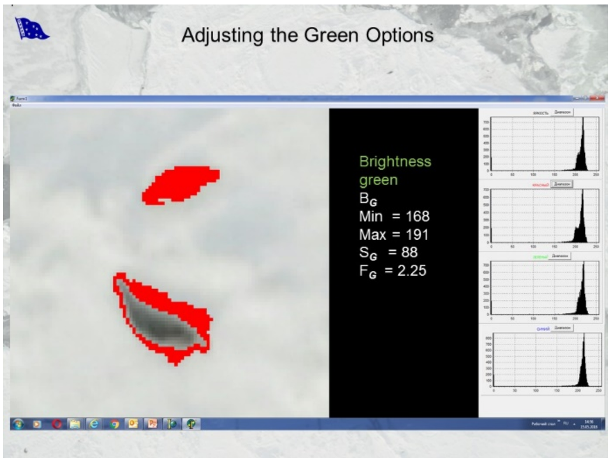
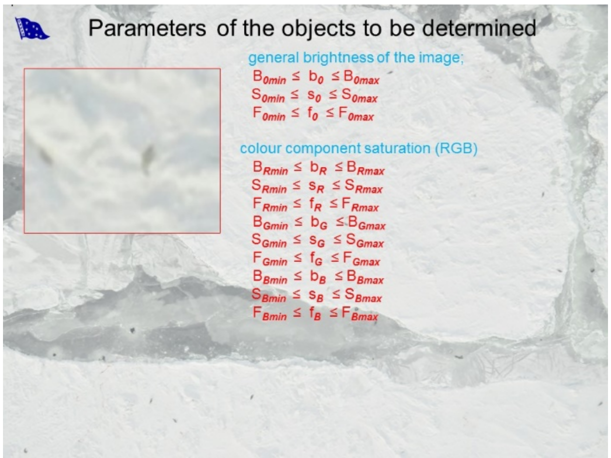
Max = 191
S_R = 75
F_R = 2.14



Adjusting the Green Options

Brightness green
B_G
Min = 168
Max = 191
S_G = 88
F_G = 2.25



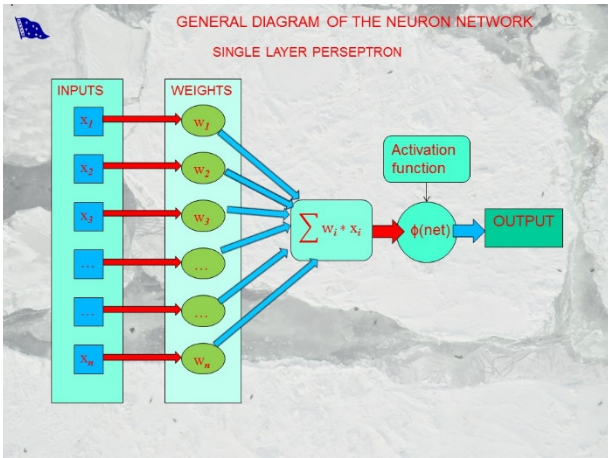
Parameters of the objects to be determined

general brightness of the image;

$B_{0min} \le b_0 \le B_{0max}$
$S_{0min} \le s_0 \le S_{0max}$
$F_{0min} \le f_0 \le F_{0max}$

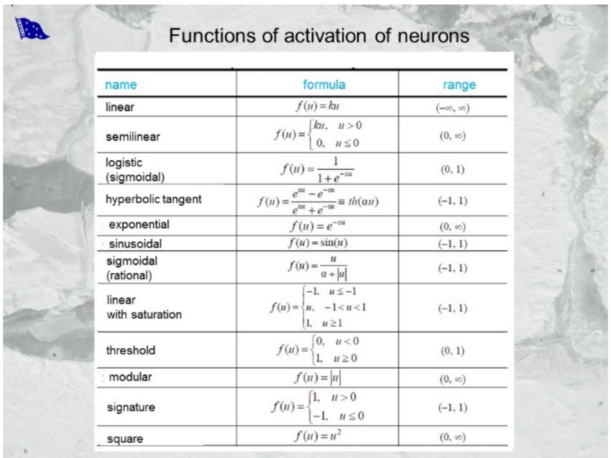
colour component saturation (RGB)

$B_{Rmin} \le b_R \le B_{Rmax}$
$S_{Rmin} \le s_R \le S_{Rmax}$
$F_{Rmin} \le f_R \le F_{Rmax}$
$B_{Gmin} \le b_G \le B_{Gmax}$
$S_{Gmin} \le s_G \le S_{Gmax}$
$F_{Gmin} \le f_G \le F_{Gmax}$
$B_{Bmin} \le b_B \le B_{Bmax}$
$S_{Bmin} \le s_B \le S_{Bmax}$
$F_{Bmin} \le f_B \le F_{Bmax}$



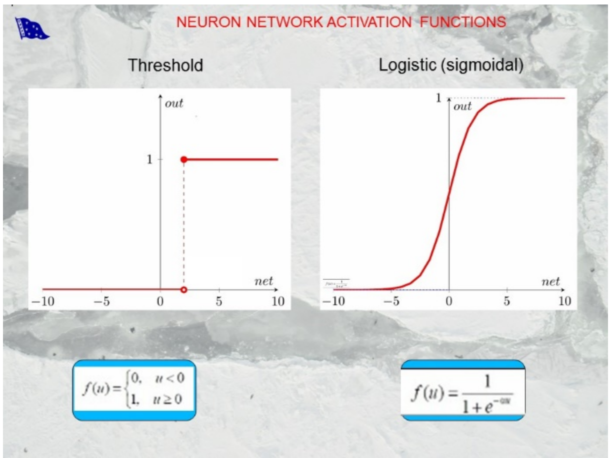
GENERAL DIAGRAM OF THE NEURON NETWORK

SINGLE LAYER PERSEPTRON



Functions of activation of neurons

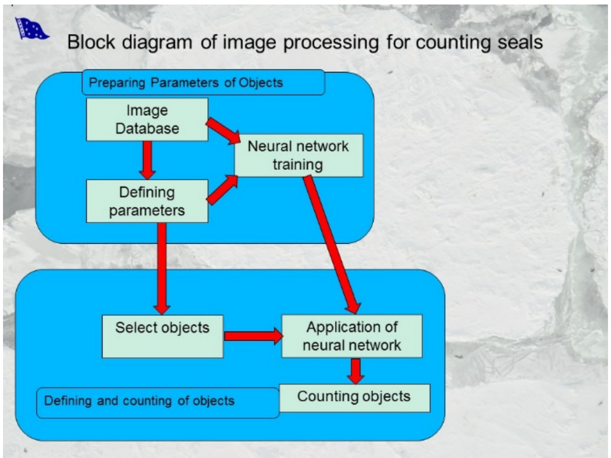
name	formula	range
linear	$f(u)=ku$	$(-\infty, \infty)$
semilinear	$f(u)=\begin{cases} ku, & u>0 \\ 0, & u\le 0 \end{cases}$	$(0, \infty)$
logistic (sigmoidal)	$f(u)=\dfrac{1}{1+e^{-\alpha u}}$	$(0, 1)$
hyperbolic tangent	$f(u)=\dfrac{e^{\alpha u}-e^{-\alpha u}}{e^{\alpha u}+e^{-\alpha u}}\equiv th(\alpha u)$	$(-1, 1)$
exponential	$f(u)=e^{-\alpha u}$	$(0, \infty)$
sinusoidal	$f(u)=\sin(u)$	$(-1, 1)$
sigmoidal (rational)	$f(u)=\dfrac{u}{\alpha+\lvert u\rvert}$	$(-1, 1)$
linear with saturation	$f(u)=\begin{cases} -1, & u\le -1 \\ u, & -1<u<1 \\ 1, & u\ge 1 \end{cases}$	$(-1, 1)$
threshold	$f(u)=\begin{cases} 0, & u<0 \\ 1, & u\ge 0 \end{cases}$	$(0, 1)$
modular	$f(u)=\lvert u\rvert$	$(0, \infty)$
signature	$f(u)=\begin{cases} 1, & u>0 \\ -1, & u\le 0 \end{cases}$	$(-1, 1)$
square	$f(u)=u^2$	$(0, \infty)$



NEURON NETWORK ACTIVATION FUNCTIONS

$$f(u)=\begin{cases} 0, & u<0 \\ 1, & u\ge 0 \end{cases}$$

$$f(u)=\frac{1}{1+e^{-\alpha u}}$$



Block diagram of image processing for counting seals

THANK YOU FOR ATTENTION!

The role of harbour porpoise in Norwegian coastal marine communities

Ulf Lindstrøm[1,2], Kirsteen MacKenzie[1], Inkeri Lehtinen[2], Lotta Lindblom[1], Torstein Pedersen[2]

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[2]*Department of Arctic and Marine Biology, Tromsø, Norway*

Coastal ecosystems (fjords and coastal waters) are very productive and complex systems, both in terms of species diversity and topography, which provides large variety of habitats both for resident and for transient species. Coastal systems in central and northern Norway have experienced major changes in structure, functioning and, not the least, commercial value the past four decades. The most conspicuous is the large-scale outbreak of the green sea urchin in the 1970s and the major decline in coastal cod populations in the 1980s. Additionally, coastal waters in northern Norway was invaded by harp seals and red king crabs in the 1980s and 1990s, respectively (Haug et al., 1991; Jørgensen, Nilssen, 2011). Beside the invasion of king crab, and to some extent harp seals, the mechanisms underlying these events are poorly understood but they are likely a combined effect of overfishing, predatory interactions and climate change.

Knowledge of the structural and functional characteristics of ecosystem's is crucial for understanding its dynamics and responses to natural and anthropogenic perturbations. Predation is a pervasive feature of coastal ecosystems, and in some ecosystems, the predation mortality constitutes the major fraction of the total mortality (Pedersen et al., 2008). Thus, analyzing the ecological role of key predators in coastal communities may shed light into the underlying mechanisms behind observed changes in these systems. The last HP feeding ecological study in Norwegian waters, which was conducted in the late 1980s, suggest that HP are opportunistic piscivorous predators (Aarefjord, Bjørge, 1995); their diet varies much in time and space due to variation in prey availability. Pelagic fish (capelin, herring) dominates the HP diets along the Barents Sea coast of Norway followed by mesopelagic and demersal fish (e.g., cod, haddock, whiting). Further south, on the Atlantic coast of Mid-Norway and North Sea/Skagerrak, pelagic shoaling fish (e.g., herring, capelin, sandeel) and demersal fish (e.g., cod, saithe, whiting), respectively, become more important. These diet data are likely not representative today because, as mentioned above, the Norwegian coastal ecosystems have changed the past three decades.

The objective of this study was, therefore, to explore the feeding ecology and ecological role of HP in Norwegian coastal waters. To do this we collected stomach contents and stable isotopes from 134 HPs, incidentally by-caught in gillnets in 2016 and 2017. To explore the potential role of HPs in coastal ecosystems we constructed an Ecopath with Ecosim (EwE) model (Christensen, Pauly, 1992; Christensen, Walters, 2004) and explored various fishery scenarios.

In this study, the feeding ecology and the potential interactions between the harbour porpoise (HP) and the fisheries was assessed in Norwegian coastal waters. Stomach contents and stable isotopes (SI) data from 134 HP, incidentally caught in gillnets, were used to make inference of their feeding ecology. An Ecopath with Ecosim (EwE) food web model (Pedersen et al., 2016) was used to explore the potential HP-fishery interactions in a selected area (Vestfjorden).

The preliminary results of the stomach content analysis show that the HP feed mainly on juvenile or small cod fish; saithe was the overall most important HP prey (33-90%). Both the diet and stable isotope analysis suggests that there is little spatio-temporal variation in diet composition. However, the observed spatial variability in the δ^{15}N-δ^{13}C relationship may suggest that the diet niche width of HP varies between areas. The HP does not display ontogenetic trends in δ^{15}N suggesting that the trophic level at which the HP feed on is independent on body size. However, the fact that there was a positive significant relationship between body size and δ^{13}C and, a negative significant relationship between latitude and $\delta^{13}C$ may suggest a southwards migration with body size or increased demersal feeding as the grow or both. There was no relationship between trophic level in the diet and $\delta^{15}N$ suggesting that the short- and long-term diet composition differ in terms of trophic level.

The model simulations indicate that a reduced fishing effort may have a significant effect on the HP mortality. A 50% reduction in fishing effort on the fish stocks that are caught in the gillnet fishery resulted in a 20-25% increase in the HP biomass. The EwE model is under development and, therefore, these results must be interpreted cautiously.

To sum up, the preliminary conclusions of this study are: 1. HPs feed mainly on juvenile cod fish and primarily on saithe, 2. Diet and stable isotope analysis suggests little variation in prey use in both time and space, 3. HP does not display ontogenetic trends in $\delta^{15}N$ suggesting that the trophic level, at which the HP feed on, is independent of body size, 4. HP does display ontogentic trends in $\delta^{13}C$ which may suggest a southwards migration with body size or, perhaps, more increased preference for demersal prey as they grow or both, 5. There is no relationship between trophic level of the prey composition in the stomachs and the $\delta^{15}N$ suggesting that the short- and long-term diet composition differ in terms of trophic level and, 6. Reduced fishing effort appears to have a significant effect on the HP mortality; a 50% reduction in fishing effort on the fish stocks caught in the gillnet fishery resulted in a 20-25% increase in the HP biomass.

Keywords: Harbour porpoise, feeding ecology, stable isotopes, fishery interaction

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Spring observation the White Sea population of harp seal

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Since 1998 PINRO has been conducting regular multispectral surveys of harp seals in the White Sea from board of plane An-26.

Air surveys were carried out in the period from spring 1998 to spring 2010 by the multispectral technology developed in PINRO and approved by the WGHARP. The air surveyed area was the White Sea and the Cheshskaya Inlet of the Barents Sea. The airport of deployment is Arkhangelsk. The main task of the given flights was obtaining of materials on the distribution and abundance of the White Sea population of harp seal. Simultaneously with these works the visual observations of the other sea mammals species, white whale (*Delphinapteras leucas*), were performed.

Assessing multispectral aerial surveys of harp seal pups were carried out according to the methods developed and approved by PINRO using IR, photo and video equipment. Immediately before the beginning of the assessing survey the ice and meteorological conditions were monitored every day in the White Sea and neighbouring territories and seas.

Specially trained observes, 2 persons from each side, monitored visually the sea surface. Observations were carried out through the convex windows (blisters). A vertical viewing angle constituted on average 45 degrees and could somewhat change in dependence on the conditions of observations (visibility, altitude of the sun above the horizon etc.).

Air surveys were carried out by the parallel tacks oriented in the longitudinal directions with a step of 10’-20’. Duration of tacks depended mainly on the ice conditions, i.e. the tacks were laid above the ice surface to the edge, and the turn of the aircraft was carried out on the open water. A flight speed constituted 300 km/hr, on average, and the survey altitude was 150-250 m.

Spring observation
the White Sea
population
of harp seal

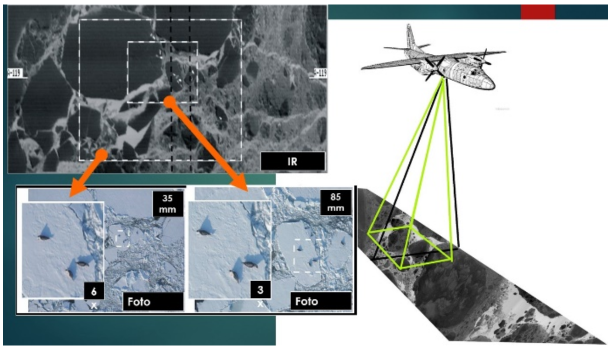
REGULAR MULTISPECTRAL SURVEYS OF HARP SEALS IN THE WHITE SEA

1998-2013

Selecting aircraft for installation
survey equipment set

An-26,
1998-2005

L-410,
2008-2013



Russian Research Aircraft
Remote Sensing Equipment using during 1998-2013

Aerial Photography Device TK10/18, Digital Fotocamera «Nikon D1X», «Nikon D90», «Nikon D100»

IR-scanner “Malakhit”

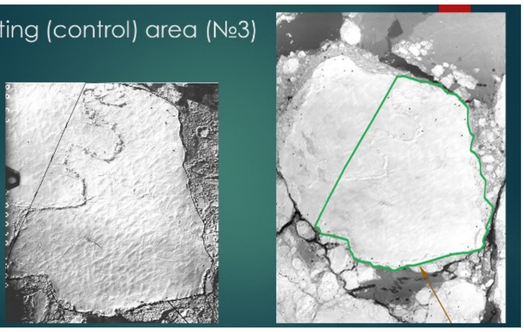
Analog Video System , Digital Video System «Panasonic»

The number of female and pups, accounted for in the control areas in the White Sea. March, 1998

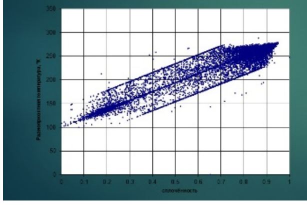
№ area	Date	Coordinates		Количество, шт.		
		Lat	Long	Female	Pups	Лунки
1	07.03	65° 48,9'	39° 38,0'	6	7	?
2	08.03	65° 45,0'	39° 32,5'	18/21	24/24	?
3	12.03	65° 38,2'	39° 11,5'	38/32	43/43	8
4	16.03	66° 00,0'	39° 58,5'	23/18	29/28	7

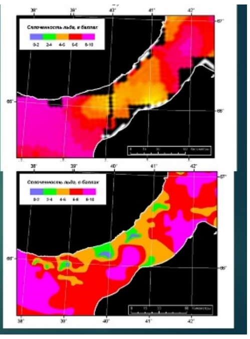
One of the most important indicators when taking into account the number of harp seal on the swarms is the evaluation of the accuracy of displaying and recording adult animals and pups on ice by various types of survey. The most representative way is to compare the results of direct recording of animals in control areas with the results of simultaneous registration by the method of multi-species aerial survey.

Testing (control) area (№3)



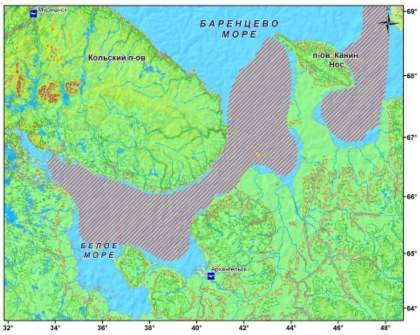
In 2001 and 2002 an experimental verification of the possibility of determining the cohesion from the results of radiometric measurements was performed. Synchronous recording of the radio brightness and radiation temperature profile was performed, according to the readings of the microwave and infrared radiometers, as well as the recording of photos and video images of the ice cover sections with different degree of cohesion. To monitor the sea surface and ice cover, the IR-radiometer "AIR-2" and the microwave radiometer "Fish" were used.





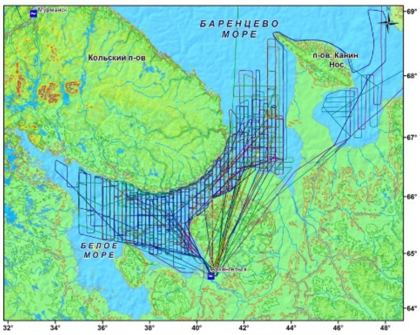
Transect accounting for the Harp Seals 1998-2013

The area covered by surveys



Transect accounting for the Harp Seals 1998-2013

Routes of aerial surveys for the whole period of work



Whelping Grounds

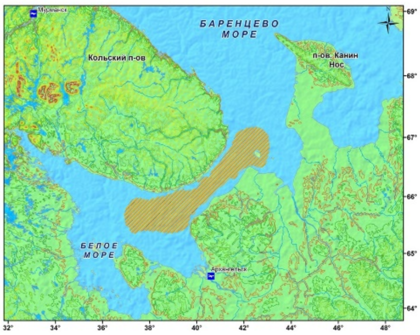
Survey during 1998

Whelping Grounds

Survey during 2000

Whelping Grounds

Survey during 2002



Whelping Grounds

Survey during 2003

Whelping Grounds

Survey during 2004

Whelping Grounds

Survey during 2005

Whelping Grounds

Survey during 2008

Whelping Grounds

Survey during 2009

Whelping Grounds

Survey during 2010

Whelping Grounds

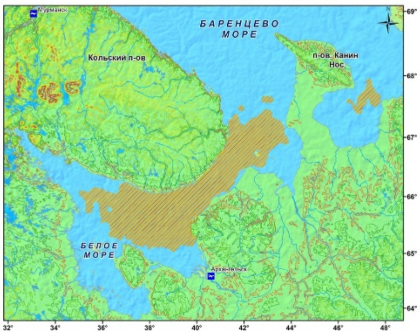
Survey during 2013

The total area of whelping grounds by according

Aerial survey

during

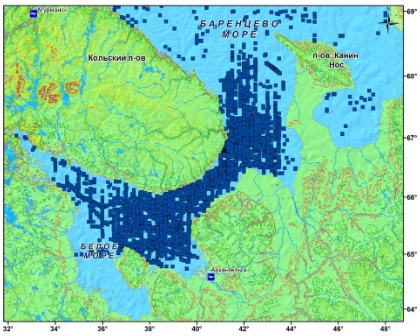
1998 -2013 years



The marks of visual observations of the harp seal (10 in groups or more)

In the period: End of February-Beginning of April

1998 -2013



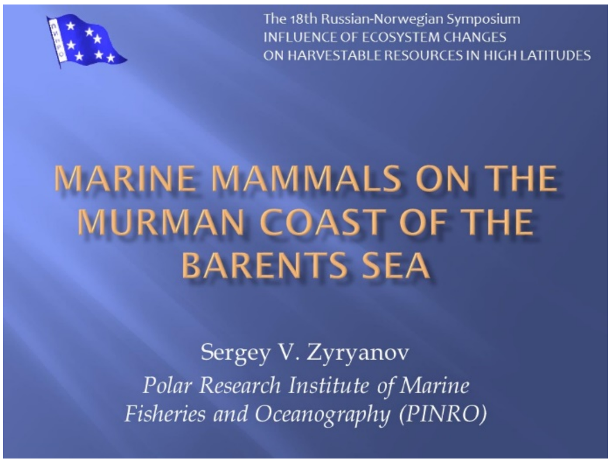
THE WHITE/BARENTS SEAS HARP SEAL POPULATION PUP PRODUCTION ESTIMATED NUMBERS (UNDER "KINGSLY METHOD")

Year	Harp seal pup production numbers including commercial catches / error (pieces)
1998	*286 260 / 43 000*
2000	*339 710 / 30 000*
2002	*330 000 / 45 000*
2003	*327 000 / 41 000*
2004	*239 000 / 36 000*
2005	*122 658 / 19 900*
2008	*123 104 / 28 341*
2009	*157 000 / 17 000*
2010	*163 032 / 32 280*
2013	*128 790 / 25 500*
2018	*??? (ROUGH DATA ARE IN PROCESSING)*

Marine mammals of Murman coast of the Barents Sea

Sergey Ziryanov

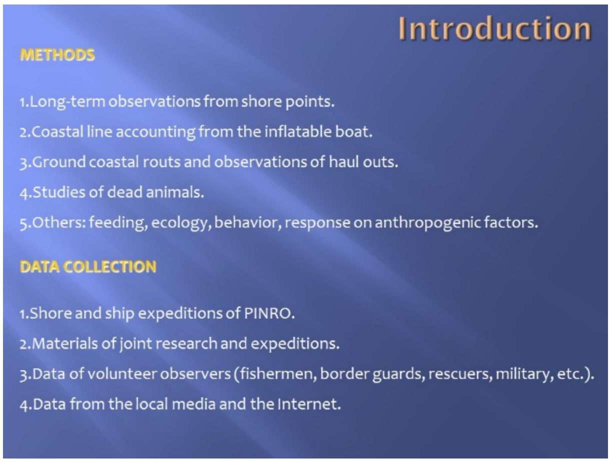
Knipovich Polar Research Institute of Marine Fisheries and Oceanography, Murmansk, Russia



The 18th Russian-Norwegian Symposium
INFLUENCE OF ECOSYSTEM CHANGES
ON HARVESTABLE RESOURCES IN HIGH LATITUDES

MARINE MAMMALS ON THE MURMAN COAST OF THE BARENTS SEA

Sergey V. Zyryanov
Polar Research Institute of Marine Fisheries and Oceanography (PINRO)



Introduction

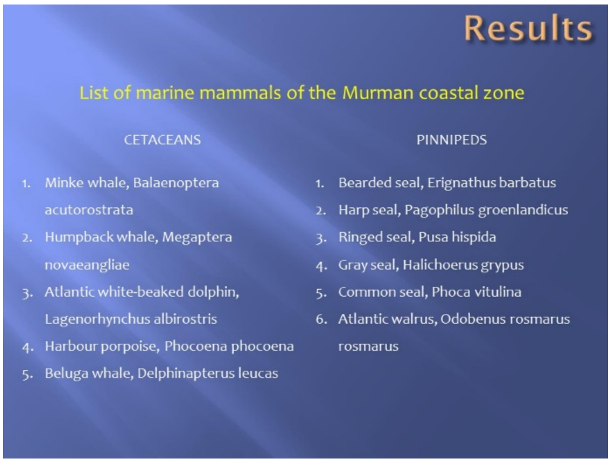
METHODS

1. Long-term observations from shore points.
2. Coastal line accounting from the inflatable boat.
3. Ground coastal routs and observations of haul outs.
4. Studies of dead animals.
5. Others: feeding, ecology, behavior, response on anthropogenic factors.

DATA COLLECTION

1. Shore and ship expeditions of PINRO.
2. Materials of joint research and expeditions.
3. Data of volunteer observers (fishermen, border guards, rescuers, military, etc.).
4. Data from the local media and the Internet.

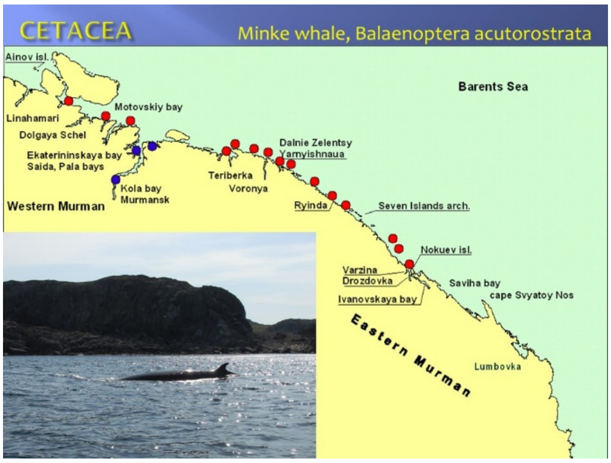
Research area



Results

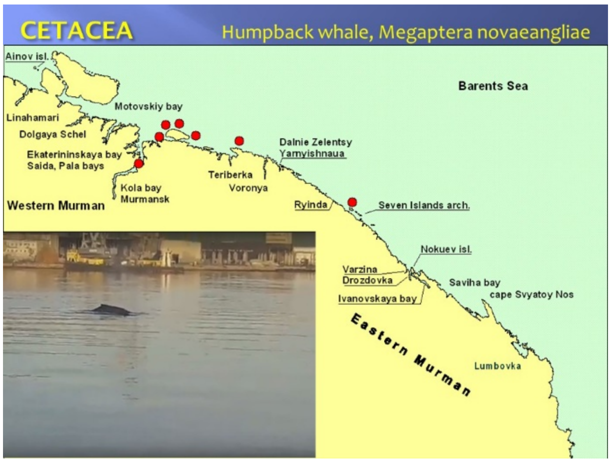
List of marine mammals of the Murman coastal zone

CETACEANS	PINNIPEDS
1. Minke whale, Balaenoptera acutorostrata	1. Bearded seal, Erignathus barbatus
2. Humpback whale, Megaptera novaeangliae	2. Harp seal, Pagophilus groenlandicus
3. Atlantic white-beaked dolphin, Lagenorhynchus albirostris	3. Ringed seal, Pusa hispida
4. Harbour porpoise, Phocoena phocoena	4. Gray seal, Halichoerus grypus
5. Beluga whale, Delphinapterus leucas	5. Common seal, Phoca vitulina
	6. Atlantic walrus, Odobenus rosmarus rosmarus



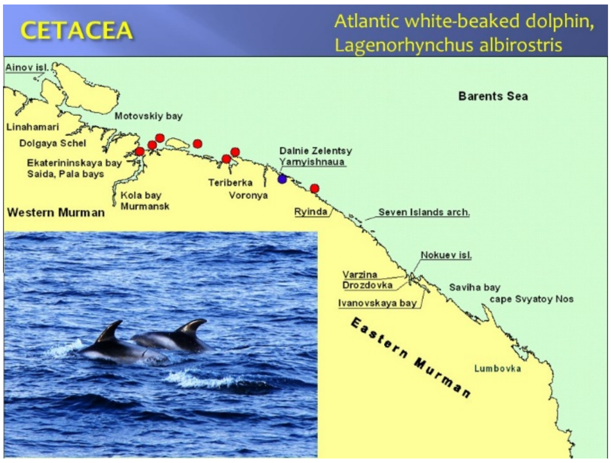
CETACEA

Minke whale, Balaenoptera acutorostrata



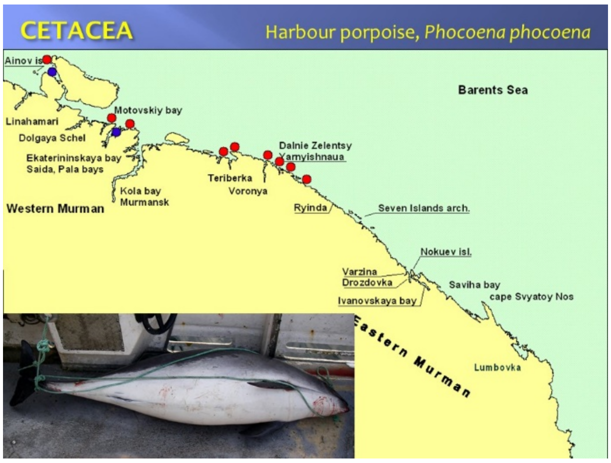
CETACEA

Humpback whale, Megaptera novaeangliae



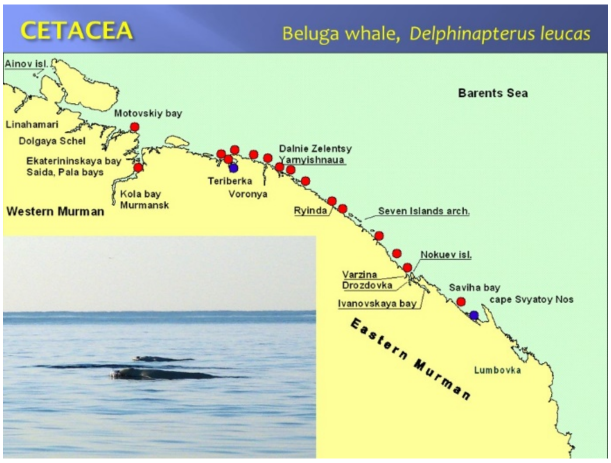
CETACEA

Atlantic white-beaked dolphin, Lagenorhynchus albirostris



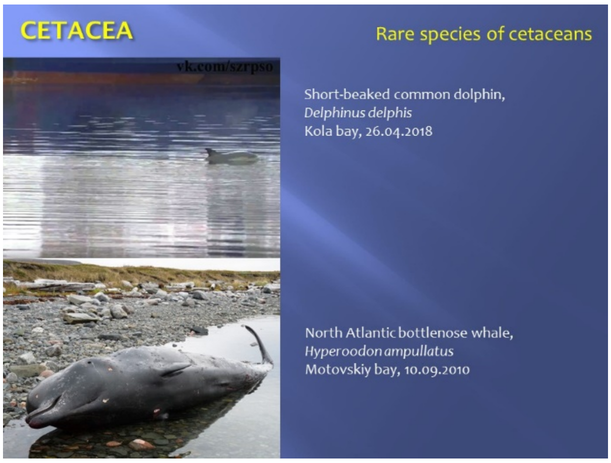
CETACEA

Harbour porpoise, *Phocoena phocoena*



CETACEA

Beluga whale, *Delphinapterus leucas*

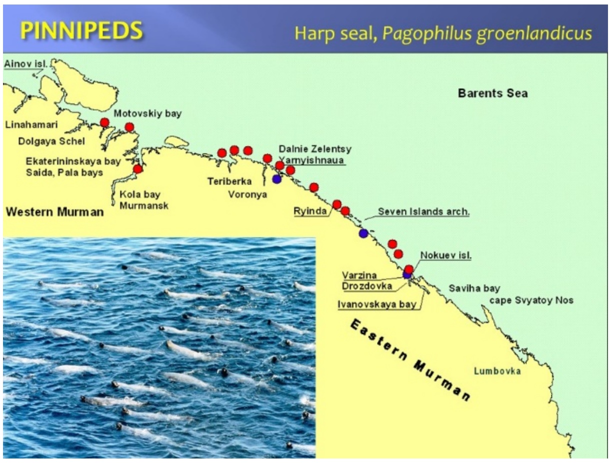


CETACEA

Rare species of cetaceans

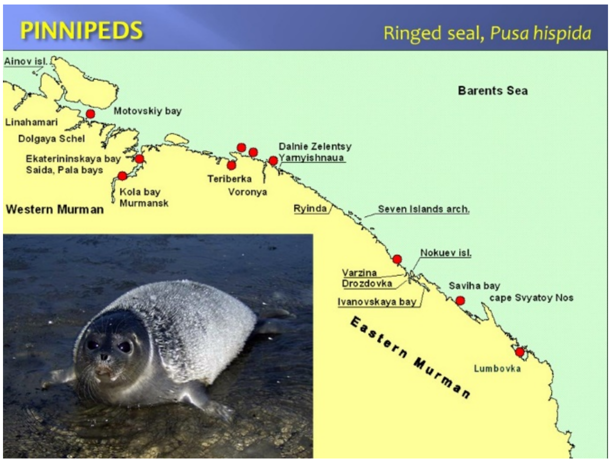
Short-beaked common dolphin, *Delphinus delphis*
Kola bay, 26.04.2018

North Atlantic bottlenose whale, *Hyperoodon ampullatus*
Motovskiy bay, 10.09.2010



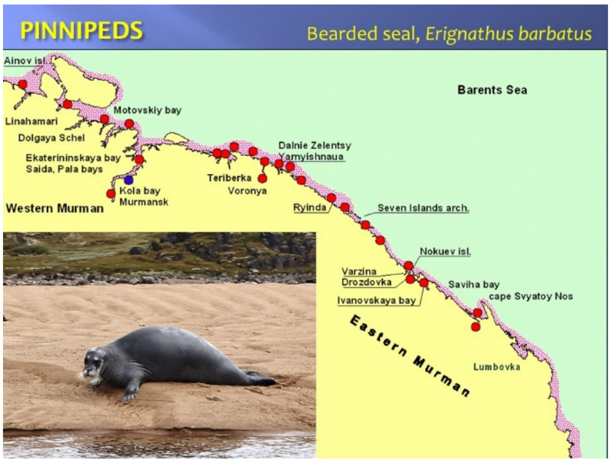
PINNIPEDS

Harp seal, *Pagophilus groenlandicus*



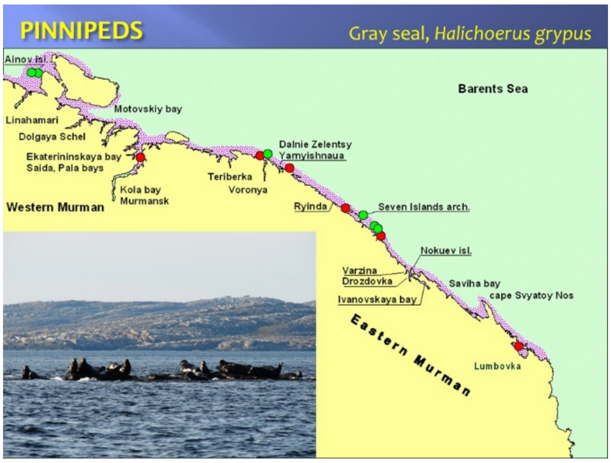
PINNIPEDS

Ringed seal, *Pusa hispida*



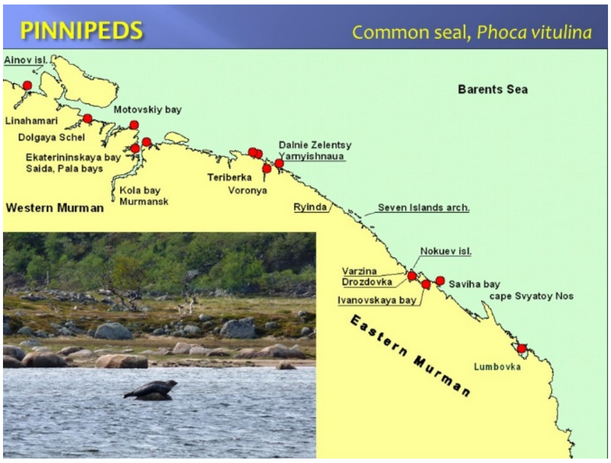
PINNIPEDS

Bearded seal, *Erignathus barbatus*



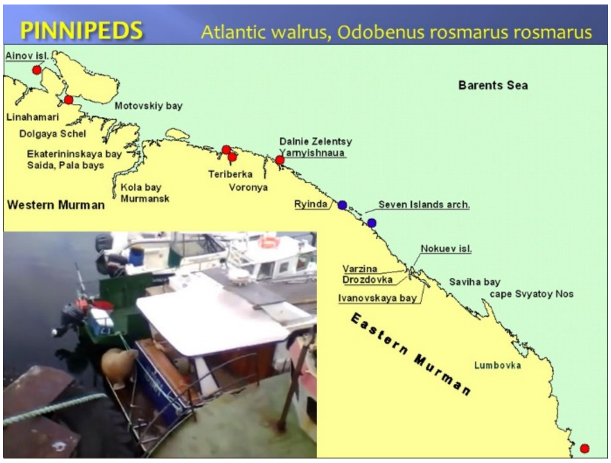
PINNIPEDS

Gray seal, *Halichoerus grypus*



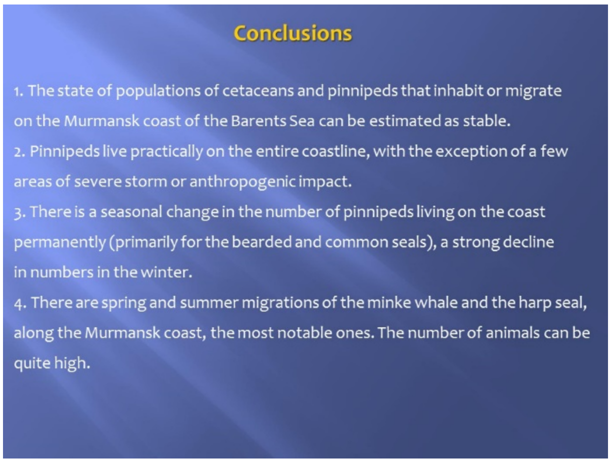
PINNIPEDS

Common seal, *Phoca vitulina*



PINNIPEDS

Atlantic walrus, Odobenus rosmarus rosmarus



Conclusions

1. The state of populations of cetaceans and pinnipeds that inhabit or migrate on the Murmansk coast of the Barents Sea can be estimated as stable.
2. Pinnipeds live practically on the entire coastline, with the exception of a few areas of severe storm or anthropogenic impact.
3. There is a seasonal change in the number of pinnipeds living on the coast permanently (primarily for the bearded and common seals), a strong decline in numbers in the winter.
4. There are spring and summer migrations of the minke whale and the harp seal, along the Murmansk coast, the most notable ones. The number of animals can be quite high.

Institute of Marine Research – IMR

Polar Research Institute of Marine
Fisheries and Oceanography – PINRO